Assistant Life Support Technician

Course Manual

TRAUMA TRAINING

PREFACE

The Assistant Life Support Technician (A.L.S.T.) is an intensive 10-day programme aimed at providing candidates with the skills and knowledge to begin a career supporting commercial saturation divers within a hyperbaric environment. .

The programme adopts an adult learning approach with an emphasis on the practical application of underlying knowledge within the confines of the candidate's professional role. To that end, the programme aims to be both interactive and practical in its delivery.

Teaching will draw upon the evidence based, nationally and internationally agreed guidelines and expert consensus opinion where such evidence exists.

Teaching is provided using clinical lectures, practical skills stations and homework.

Knowledge and skills are assessed by means of continual assessment, written examinations and daily knowledge confirmation sessions.

Those candidates who reach the required standard are awarded an A.L.S.T. certificate, which is accredited by International Marine Contractors Association (IMCA).

Lectures and small group teaching sessions are delivered by: Life Support Technicians, Commercial Divers, Chamber Supervisors and Doctors who are highly experienced.

This manual is designed to accompany the 10-day course. The aim is to reinforce all of the elements covered.

Website: **www.trauma-training.org**

E-mail: **info@trauma-training.org**

TABLE OF CONTENTS

TRAUMA TRAINING

Contents

Section 1

Diving Physics

INTRODUCTION 1

Whatever your role in the diving operation, whether diver or surface support, it is essential that you are familiar with the changing physical factors which affect the diver and influence the techniques and procedures used.

All diving is similarly affected by the following Laws of Physics:

- Boyle's Law — Gas Law
- Charles' Law — Gas Law
- Dalton's Law — Gas Law
- Henry's Law — Law of Solubility

Before we continue with the Laws of Physics we must understand the units of measurement employed, and the conversion factors linking the different systems.

UNITS OF MEASURMENT 1.2

There are two systems commonly used in the diving industry:

- The Metric or SI System (System International).
- The Imperial System.

Most companies conducting diving operations now use the metric system, but some American companies continue to use the imperial system. Of the two, the metric system is the easier, but diving personnel must be conversant with both systems.

	THE METRIC SYSTEM	THE IMPERIAL SYSTEM
LENGTH	Metre (m)	Foot (ft) and inch (in)
DEPTH	Metres of Sea water (msw)	Feet of sea water (fsw)
AREA	Square metres (m^2)	Square feet (ft^2)
VOLUME	Litres (l) or Cubic metres (m^3) 1000 l = 1 m^3	Cubic feet (ft^3) or gallons (gal)
WEIGHT	Kilograms (kg) or Tonnes (t) 1000 kg = 1 t	Pounds (lb) or Tons (ton) 2240 lb = 1 ton
PRESSURE	Millibar (mbar) or bars (bar) 1,000 mbar = 1 bar 10 msw = 1 bar	Pounds per Square Inch (psi) or Atmospheres (atm) 14.7 psi = 1 atm 33 fsw = 1 atm

The following abbreviations are used throughout this manual:

Name	Abbreviation
Absolute pressure	AP
Atmosphere	atm
Atmospheres absolute	ata
Bar	bar
Cubic feet	ft^3
Cubic metre	m^3
Feet of sea water	fsw
Gauge Pressure	GP
Litres	l
Metres of sea water	msw
Millibar	mbar
Partial pressure	p
Parts per million	ppml
Percentage	%

Conversion Factors 1.2.1

The following tables give an accurate means of converting between the metric and the imperial systems.

For common usage offshore, and for use in IMCA exam calculations.

The following are taken as being (approximately) equal:

$$1 \text{ atm} \cong 1 \text{ bar} \cong 14.7 \text{ psi} \cong 1 \text{ kg/cm}^2 \cong 760 \text{ mmHg}$$

also

$$10\text{msw} \cong 1 \text{ bar} \cong 1 \text{ atm} \cong 33 \text{ fsw}$$

Length 1.2.2

TO CONVERT	INTO	MULTIPLY BY
Centimetres	feet	0.033
	inches	0.394
	metres	0.001
Feet	cm	30.480
Inches	cm	2.540
	metres	0.0254
Kilometres	feet	3280.84
	inches	39370.1
	miles	0.621
	nautical miles	0.540
Metres	feet	3.281
	inches	39.370

Volume 1.2.3

TO CONVERT	INTO	MULTIPLY BY
Cubic centimetres (cc)	cubic inches	0.061
Cubic feet (ft^3)	cc	28317
	cubic inches	1728
	m^3	0.028
	Litres	28.3
Cubic inches	cc	16.3
	litres	0.016
Cubic metres (m^3)	ft^3	35.3
	cubic inches	61023.7
	litres	1000
Litres	ft^3	0.035

Pressure 1.2.4

TO CONVERT	INTO	MULTIPLY BY
Atmospheres	bar	1.013
	feet of sea water (fsw)	33.000
	kg sq/cm	1.033
	metres of sea water (msw)	10.060
	millimetres of mercury (mmHg)	760
	pounds per square inch (psi)	14.696
Bar	atmospheres	0.987
	fsw	32.570
	kg/sq cm	1.020
	msw	9.928
	mmHg	750.062
	psi	14.504
Feet of sea water	atmospheres	0.0303
	bar	0.0307
	kg/sq cm	0.0313
	mmHg	23.031
	psi	0.4453
	msw	0.305
Kilograms per square centimetre	atmospheres	0.968
	bar	0.981
	fsw	31.940
	msw	9.736
	mmHg	735.560
	psi	14.223
Metre of seawater	atmospheres	0.099
	bar	0.101
	fsw	3.280
	kg sq/cm	0.103
	mmHg	75.529
	psi	1.461

*Remember for exam purpose:

$$1 \text{ atm} \cong 1 \text{ bar} \cong 14.7 \text{ psi} \cong 1 \text{ kg/cm}^2 \cong 760 \text{ mmHg}$$

also

$$10\text{msw} \cong 1 \text{ bar} \cong 1 \text{ atm} \cong 33 \text{ fsw}$$

THE EFFECTS OF PRESSURE 1.3

On the surface of the earth we are all exposed to the pressure exerted by the weight or mass of the atmosphere above us. This is called atmospheric or barometric pressure. If we alter our position within the atmosphere the pressure will be altered accordingly, e.g. if we move upward through the atmosphere the pressure will decrease. If we ascend to a level of some 18,000 feet the pressure at that point will be equal to approximately half of the pressure at sea level. If we descended into a mineshaft, for example, the additional depth of the atmosphere will increase the barometric pressure.

Because of the relative lightness of air, the pressure differences in such moves are small. In diving, the massive weight difference between air and water means that small depth changes in water result in significant pressure differences.

Pressure is measured in a variety of units from either of two reference points;

- It can be expressed relative to a vacuum (zero pressure). This is called **absolute** pressure (AP).
- It can be measured relative to atmospheric pressure. This is called **relative** or **gauge** pressure (GP).

thus at sea level the gauge pressure is 0 and the absolute pressure is 1 atmosphere.

More common units for measuring pressure and approximate conversion factors are:

1 Atmosphere	=	14.7 pounds per square inch
	=	1 bar (actually 14.5 psi)
	=	1 kilogram per square centimetre
	=	760 mm of mercury (symbol Hg)

If you had an imaginary tube with a bore area equalling one square inch, extending from sea level to the edge of the atmosphere (some 60 miles), the weight of the atmosphere measured at sea level would be 14.7 lb.

Because of the weight difference between water and air, a depth increase in water of only 10msw or 33fsw will increase the pressure by 1 atmosphere. Each additional 10msw or 33fsw increase will add 1 atmosphere.

Thus at a depth of 60m in sea water, the gauge pressure will equal 6 bar but the absolute pressure will equal 7 bar.

Pressure Conversion Table 1.3.1

For exact conversion figures see the table on page 7. But for common usage offshore, and for use in IMCA exam calculations.

The following are taken as being (approximately) equal:

1 atmosphere	=	10 metres of sea water
	=	33 feet of sea water
	=	34 feet of freshwater
	=	1kg/cm^2
	=	14.7 psi
	=	1 bar
	=	760 mmHg
	=	760 Torr
	=	1 atm

NOTE: A pressure of 1 atm on a chamber door, will exert 14.7 psi on that door. Therefore if the door diameter equals 24" the area (πr^2) is 452 square inches. Thus the total pressure on the chamber door is 6,644 lb., i.e. 2.9 tons.

The Effects of Pressure on a Divers Body 1.3.2

Many people have difficulty in understanding why the substantial pressure increases experienced underwater do not crush the diver.

The answer can be considered in two ways. The body largely comprises liquid and solid parts in different ratios for different tissues. These liquid and solid parts are virtually incompressible so a pressure applied to them does not alter their volume. The water pressure, i.e. hydrostatic pressure, is transmitted through them. After immersion the increase in pressure relative to depth pushes against the skin, which pushes against the adjoining tissue and so on until the skin on the other side of the body is pushed against the water pressure. Thus the system remains in balance.

The effects of pressure on the gas spaces within the body are more complex. The basic fact is that the applied pressure does not constitute a problem so long as the pressure within the gas space is equal to the external pressure. Only if pressure differentials exist between the gas space and the surrounding water, will the potential for physical damage be present. If the pressure within the lung was greater than the pressure outside the body by a value equivalent to a depth of only 2 metres, then the lung would be structurally damaged.

Thus, it can be seen that pressure itself will not hurt the diver but that an **imbalance** of pressure between the diver and his environment can.

Before we progress onto the gas laws, we need a short explanation of some frequently occurring problems:

Transposing of Formulas, i.e. the adjustment of the formula to suit our needs

Example:

If we use the Boyle's Law formula $P_1V_1 = P_2V_2$ and require to find V_2 then:

- We must know the other 3 values, and
- We must adjust the formula to isolate V_2 on one side.

To isolate V[2] we do the following:

Take the other factor on the same side as V_2 across and underneath the two factors on the other side, i.e.

$$V_2 = \frac{P_1V_1}{P_2}$$

To confirm this or refresh yourselves if you have the right formula, simple values can be substituted for the factors:

$P_1 = 2$

$V_1 = 6$ $\qquad P_1V_1 = P_2V_2$

$P_2 = 3$

$V_2 = 4$ $\qquad 2\,x\,6 = 3\,x\,4$

This is obviously true.

Now to confirm if the V_2 formula is correct.

$$V_2 = \frac{P_1V_1}{P_2}$$

$$4 = \frac{2\,x\,6}{3}$$

This confirms that the formula has been transposed correctly.

In the case of the Charles Law formula:-

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

It is preferable to get the formula into one line by cross multiplying to give:-

$$P_1T_2 = P_2T_1$$

Once again, this can be confirmed using numbers instead of letters, e.g.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \qquad \Rightarrow \qquad \frac{6}{3} = \frac{4}{2}$$

Then cross multiply:

$$P_1T_2 = P_2T_1$$

$$\Rightarrow \qquad 6\,x\,2 = 4\,x\,3$$

Again, the transposition is confirmed.

Rounding Up of Decimals 1.3.3

Normally in equations the numbers are rounded up or down to one decimal place.

To achieve this look at the **second** number after the decimal point. If this second number is less than 5, then the preceding number stays as it is, e.g. 2.3**4** becomes 2.3.

If the second number after the decimal point is equal to, or greater than 5 then the preceding number goes to the next greater number, e.g. 2.3**6** becomes 2.4.

Percent (%) and Parts Per Million (ppm) 1.3.4

Both these describe proportionally the amount of, for example, a gas in a total volume.

10% oxygen in a heliox mix means that 10% of the total volume is oxygen and the remainder, i.e. 90%, is helium. This is often written as 10/90 heliox.

That indicates that 10 parts of every hundred is oxygen with the remaining 90 parts in helium.

Some gases are measured in such small quantities that parts per hundred is too coarse a measurement. In this case, parts per million (ppm) is used.

For instance Carbon Dioxide and Carbon Monoxide are most often measured in PPM. Most CO2 analysers read in ppm but some are in %.

To Convert ppm To Percentage And Vice Versa:

$$\% = \frac{ppm}{10{,}000}$$

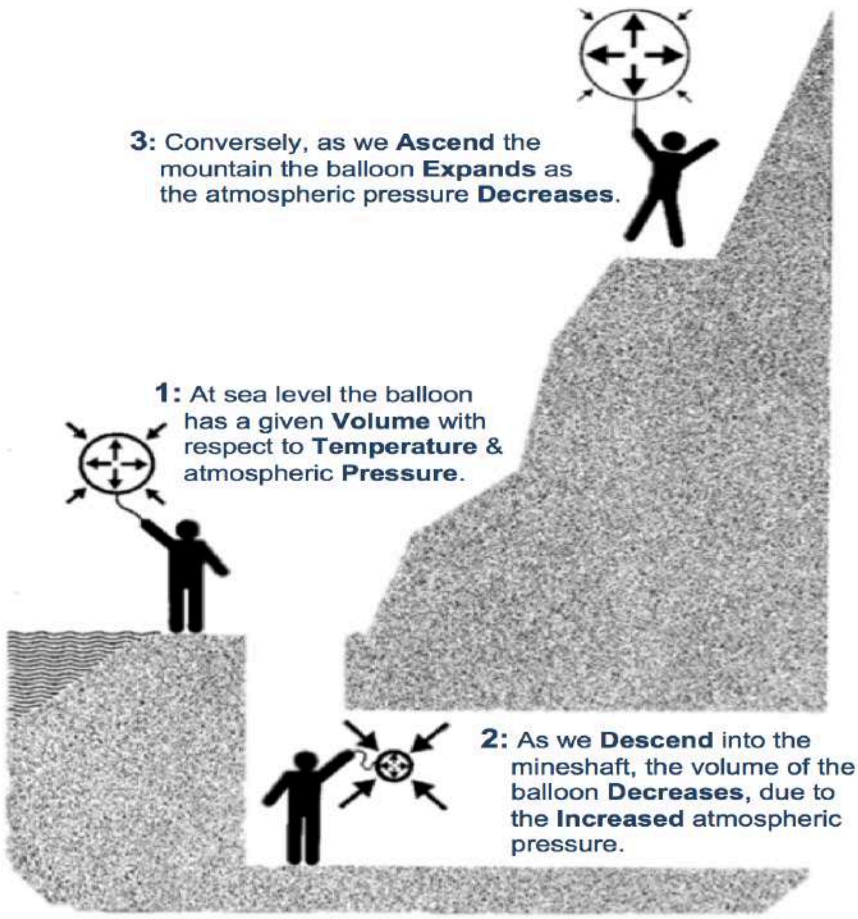
$$ppm = \% \; x \; 10{,}000$$

Therefore, 0.1% is equal to 1,000 ppm.

ATMOSPHERIC PRESSURE 1.4

Atmospheric pressure is the force per unit area exerted on a surface by the weight of air above that surface in the atmosphere of Earth. In most circumstances atmospheric pressure is closely approximated by the hydrostatic pressure caused by the weight of air above the measurement point.

On a given plane, low-pressure areas have less atmospheric mass above their location, whereas high-pressure areas have more atmospheric mass above their location. Likewise, as elevation increases, there is less overlying atmospheric mass, so that atmospheric pressure decreases with increasing elevation. On average, a column of air one square centimeter in cross-section, measured from sea level to the top of the atmosphere, has a mass of about 1.03 kg and weight of about 10.1 N.



GAS LAWS 1.5

The early gas laws were developed at the end of the 18th century, when scientists began to realize that relationships between the pressure, volume and temperature of a sample of gas could be obtained which would hold for all gases. Gases behave in a similar way over a wide variety of conditions because to a good approximation they all have molecules, which are widely spaced, and nowadays the equation of state for an ideal gas is derived from kinetic theory. The earlier gas laws are now considered as special cases of the ideal gas equation, with one or more of the variables held constant.

Boyle's Law (The Pressure / Volume Relationship) 1.5.1

Boyle's Law describes the relationship between changes in volume of a gas and the pressure applied to it (if the temperature is kept constant). It is an inversely proportional relationship (while one doubles, the other halves) at a constant temperature.

$$P_1V_1 = P_2V_2$$

It Can Also Be Written As:

$$PV = C$$

Where V is volume, P is absolute pressure and C is a constant.

Boyle's Law
"At a constant temperature the volume of a fixed mass of gas is inversely proportional to the absolute pressure"

For Example:

10 litres of gas at sea level pressure will be compressed to 5 litres at 2 ata (10m) and 1 litre at 10 ata (90m).

$P_1V_1 = P_2V_2$ 1 bar(A) x 10L = 2 bar(A) x 5L

Or If Preferred:

PV = C 1 x 10 = 10 and 2 x 5 = 10

Thus during descent the increase in pressure around the body results in a volume reduction of gas in the gas spaces within the body. Unless pressure within these spaces is equalised with the external pressure then a squeeze will result. Gas (or air) must enter these cavities during periods of increasing pressure in order to maintain pressure balance. Failure to do so will result in barotrauma that may lead to tissue distortion or damage.

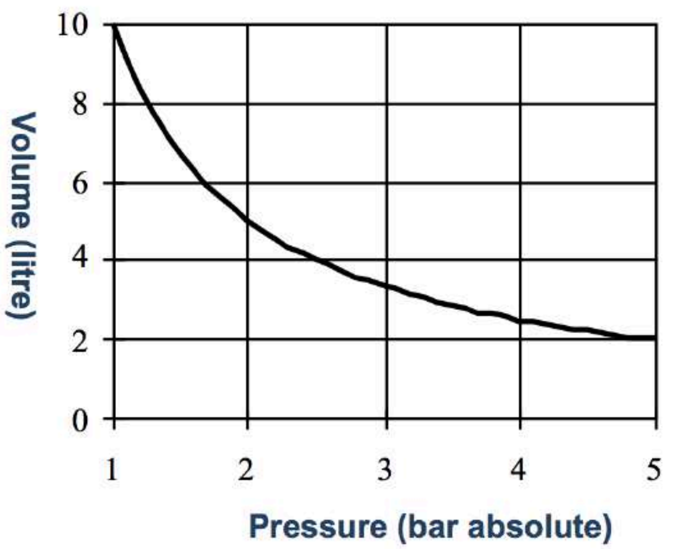
Conversely during ascent the gas within these spaces will expand with decreasing pressure. If there is a restriction to this expansion then barotrauma of ascent may occur.

Boyle's Law is also important in decompression. Already we have spoken about barotrauma of ascent but we must also mention the effects of Boyle's Law on bubble formation during decompression.

Ideally, bubble formation is minimised during decompression but obviously any bubbles formed are influenced by Boyle's Law whilst pressure is reduced.

The chart above shows that volume pressure changes are more pronounced at shallower depths. For example, a 10 metre or 1 bar pressure reduction at 40 metres gives a volume increase of 25%. The same pressure drop, i.e. 10 metres or 1 bar, at 10 metres means a volume increase of 100%.

This partly explains why some diving practices, e.g. upwards excursions are restricted to deeper water.



Examples Using Boyle's Law Formula:

Pressure:	1 atmosphere	=	760 mmHg	=	14.7 psi
	1 bar	=	750 mmHg	=	14.5 psi

For Calculation Purposes Only:

1 atm is said to be equal to 1 bar
1 atm = 33fsw = 14.7 psi = 1 bar = 10msw

Volume: Metric system - cubic metres are commonly used.
$1m^3 = 1{,}000$ L

Imperial system - cubic feet are used.
$1m^3 = 35.32\ ft^3$

Boyle's Law Formula

$$P_1V_1 = P_2V_2$$

If three of the values are known then the fourth, the unknown, can be found. To transpose the formula to find the unknown, do the following. Take the value on the same side as the unknown across and below the two values on the opposite side.

If you require to find P_2, move V_2 across and under the P_1V_1

$$P_2 = \frac{P_1V_1}{V_2}$$

Simple Example:

If a balloon has a volume of 6 litres on the surface, what will its volume be at 30 metres?

$P_1 =$	Pressure at surface	= 1 bar
$V_1 =$	Volume at surface	= 6 litres
$P_2 =$	Pressure at 30 metres	= 4 bar (absolute)
$V_2 =$	Unknown	

$$V_2 = \frac{P_1V_1}{P_2}$$

$$V_2 = \frac{1\ bar\ x\ 6\ litres}{4\ bar}$$

$$V_2 = \mathbf{1.5\ litres}$$

Some people prefer to use the formulae ***PV = C***. Where V is volume, P is absolute pressure and C is a constant.

So 1 bar x 6L = 6 therefore 4 bar x *1.5 L* = 6

i.e. the pressure has been increased 4 times and the volume has been decreased to a ¼ of its original volume.

Simple Example (Expanded):

If the pressure is reduced the volume will increase proportionally. e.g. if the same balloon is raised to 20 metres what will be the new volume?

$$V_2 = \frac{P_1V_1}{P_2}$$

$$V_2 = \frac{4\ bar\ x\ 1.5\ litres}{3\ bar}$$

$$V_2 = \mathbf{2\ litres}$$

Again using the formulae *PV* = *C*

4 bar x 1.5L = 6 therefore 3 bar x *2L* = **6**

While breathing underwater the divers respiratory volume remains about the same, as it would be doing equivalent work on the surface. Because of the increase in density of his breathing gas under the increased pressure, he must move a greater mass with each breath.

Therefore if he breathes at a rate of 35 litres per minute on the surface, then he must move an equivalent of 70 litres/minute doing similar work at a depth of 10 msw. Using Boyle's Law it is apparent that if diving at 90 msw, i.e. an absolute pressure of 10 bar, then 10 times the amount of gas must be utilised to occupy the **same** volume as on the surface.

Therefore for working out diver consumption (or breathing usage) the formula to use is:-

Surface consumption rate *x* Absolute Pressure = Actual consumption rate

For working out gas used in pressurising or available from cylinders it must be remembered that you start with and always will have atmospheric pressure in the cylinder,

Floodable Volume *x* Gauge Pressure = Free Gas Volume

i.e. if you blow down a 20 litre BOB (Bailout Bottle) to 200 bar, the gas used is:

FV *x* GP = 20L *x* 200 bar = 400L

For available gas use gauge or relative pressure, but for diver consumption use absolute pressure.

Calculating Gas Consumption 1.5.2

One of the most fundamental tasks of a Live Support Technician is actually calculating the divers consumption of breathing gas at the relevant depth they are working at.

Normally used consumption rates are: (at surface pressure)

For UK			
Open Circuit Diving	35 l/min	Or	1.25 ft^3/min
Closed Circuit Systems	5 l/min	Or	0.18 ft^3/min
Bailout	40 l/min	Or	1.5 ft^3/min
Built in Breathing Systems (BIBS / Therapeutic gas)	20 l/min	Or	0.70 ft^3/min

For Norway	
Bailout	62.5 l/min for 10 mins
Bell on Board Gas	62.5 l/min for 20 mins

To Work Out Diver Consumption Rate

Surface Consumption Rate *x* Absolute Pressure = **Actual Consumption Rate**

Example:

How much gas does a diver at 32 msw use for 30 minutes?

35L *x* 30 minutes *x* 4.2 bar (A) = 4410L

To Calculate Gas Available From A Bank Or Cylinder

Depth of dive in pressure absolute must be subtracted, as must the regulator working pressure, which is normally taken as 10 bar.

Therefore if you have a 50L bottle, pressurised to 200 bar to be used for a dive to 84 metres, the volume of gas available for use is:-

GP x FV = FGV **1.5.2**

Calculating Cylinder Volume

GP *x* FV = FGV

Example:

200 bar - 10 bar (working pressure) - 9.4 bar (pressure absolute)

= 180.6 bar *x* 50 L

= 9030 L

= 9.03 m^3

How long will this gas last 2 divers on open circuit?

Consumption rate = 35L *x* 9.4 bar a *x* 2 divers = 658 L/min

Duration = Available Gas / Consumption Rate = 9030 litres / 658 litres

= 13.7 minutes

To get the seconds it is 0.7 of 1 minute: 0.7 x 60 secs = 42 secs

= **13 min 42 seconds**

To Work Out Duration Of Bailout Bottles

Find out the amount of gas that is available to the diver

Remembering to subtract his dive pressure and his hat working pressure from his total bailout pressure.

Example:

If a bailout with a volume of 12L is pressurised to 300bar, how much time will it give a diver at 162 msw?

Gas available = 12L *x* (300bar - 17.2bar (AP) - 10bar(HP))
= 12L *x* 272.8b
= 3273.6L of gas

Gas consumption = 40L *x* 17.2 bar (AP)
= 688 L/min

Duration = $\frac{3273.6}{688}$

= 4.76 minutes or **4 min 45 seconds**

Compressor Capabilities

Compressor output = 70 m^3 per hour at 11 bar outlet pressure
Diver consumption = 35 L/min

Example:

In theory - How many divers will the compressor support at 40 msw?

Ignore the 11 bar as irrelevant (unless the outlet pressure is less than working pressure).

Gas required per diver = 35L *x* 5 bars absolute
= 175 L/min

No of divers = $\frac{\text{Compressor output (in L/min)}}{\text{Gas required}}$

= $\frac{1167 \text{ L/min}}{175 \text{ L/min}}$

= **6.67**

Therefore, 6 divers can be supported.

Example:

In theory - How deep could the same compressor supply one diver?

Gas required for the diver = 35 L *x* 5 bars absolute
= 175 L/min

No of divers = $\frac{\text{Compressor output (in L/min)}}{\text{Gas required}}$

= $\frac{1167 \text{ L/min}}{175 \text{ L/min}}$

= 6.67 bar absolute
 - 1 bar

= 5.67 bar gauge
x 10

= 56.7 msw

To Calculate Blowdown Gas

Because you are adding gas to a volume of gas already present, i.e. 1 ata at the surface, gauge or relative pressure is used to calculate blowdown gas. The gas used is also known as the **Free Gas Volume**; that is the volume the gas would take up if at 1 atmosphere.

The floodable volume is the volume of the container at 1 atmosphere, and every time one atm (or bar) is added, or taken away, this changes the volume by one floodable volume. ie an 11 m^3 is pressurised to 10 msw that means that another 11 m^3 has been added. If it is pressurised to 62 msw, that is 6.2 FV's have been added: 6.2 bar g x 11 m^3 = 68.2 m^3 has been added to the chamber

Floodable Volume (FV) *x* Gauge Pressure (GP_R) = Free Gas Volume (FGV)

Example:

To pressurise an 670ft^3 chamber to 495 fsw

FV = 670 ft^3 P_R = 15 atm

Therefore 670 *x* 15 = **10050ft^3**

Calculating Blowdown Gas

FV *x* GP_R = FGV

To Find The Volume Of DDC From Gas Used In Blowdown

$$FV = \frac{\text{Gas Used}}{GP_R}$$

Example:

If gas used equals 243 m^3 to pressure a system to 42 msw then to calculate the system volume:

$$= \frac{243\ m^3}{4.2}$$

= **57.9 m^3** = system floodable volume

To Find Out Pressure Drop In A Quad After Blowdown:

$$P_R = \frac{\text{Gas Used}}{\text{FV of quad}}$$

Example:

Find the pressure drop in a quad if you pressurise a 15m^3 chamber to 80 msw from a 64 bottle quad. (Each cylinder or bottle in a quad has a given value of 50 litres)

Gas Used = 15 m^3 *x* 8 bar = **120 m^3**

FV of quad = 64 *x* 50 = 3200 l = **3.2 m^3**

Pressure drop from quad $\frac{120\ m^3}{3.2\ m^3}$ = **37.5 b**

Example:

If you have a 15 m^3 chamber at a depth of 120 msw with a pO_2 of 0.6 bar, and a 28 m^3 chamber at a depth of 60 msw with a pO_2 of 0.4 bar, how do you find the depth at which they will equalise?

NB:- This calculation uses **Bars Gauge**, ie 120 msw = 12 bar

Gas Present

Chamber 1	=	15 m^3 *x* 12 bar	=	180 m^3
Chamber 2	=	28 m^3 *x* 6 bar	=	168 m^3
Total Gas	=	348 m^3		
Total Volume of System	=	15 m^3 + 28 m^3	=	43 m^3
Depth of Equalisation	=	$\frac{348}{43}$		
	=	8.09 bar(G)		
	=	8.09 x 10 = msw		
	=	**80.9 msw**		

Eventually, given time, the partial pressures (see Dalton's law) in the chamber equalisation in would find equilibrium.

To find out what partial pressure of Oxygen (pO_2) they will equalise at we need to first find out how much O_2 volume is present in the chambers; the formula for this is

Floodable Volume (FV) *x* Partial Pressure (GP) = Gas Volume

Volume of Oxygen in Chamber 1 is 15 m^3 x 0.6 bar = 9 m^3
Volume of Oxygen in Chamber 2 is 28 m^3 x 0.4 bar = 11.2 m^3

Total Volume of Oxygen in the system = 20.2 m^3
Total Volume of System = 43 m^3

$$pO_2 = \frac{\text{Oxygen Volume}}{\text{Floodable Volume}}$$

$$\frac{20.2\ m^3}{43\ m^3} = 0.47\ \text{bar}$$

This scenario would not be done as it would in manned chambers, but **in theory** if the chambers were unmanned.

Metabolic Oxygen Consumption

The Oxygen volume formula is useful for working out how long Oxygen will last in metabolic usage. Metabolic usage is how much O_2 the body burns to maintain the chemical reactions to sustain life.
It is a constant figure and is not variable with depth changes.

Metabolic oxygen consumption is **0.5 litres a minute per diver** (30 l/hour = 0.72 m^3/24 hours)

Example:

How long will it take 6 divers in a 24 m chamber to breathe the pO_2 from 400 millibar to 160 millibar?

Floodable Volume (FV) *x* Partial Pressure (GP) = Gas Volume

The pO_2 is being breathed from 400mb to 160mb, so 240mb is being consumed, therefore the volume of O_2 consumed is:

24 m^3 x 240 millibar = 5760 litres (note the answer is in litres if mbars are used, but in cubic metres if bars are used)

Oxygen consumption rate:

6 divers x 30 litres/hour = 180L/hr

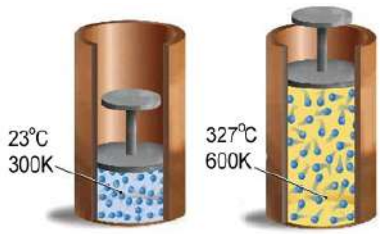
$$\frac{5760\ \text{litres}}{180\ \text{litres}} = 32\ \text{hrs}$$

Calculating Gas Volume
FV *x* Partial Pressure (GP)
= Gas Volume

Charle's Law (Temperature Effect on the Pressure / Volume) 1.5.3

Temperature changes in a gas alter the pressure or volume in a uniform way. This is described in **Charles Law,** which states:

"If pressure is constant, the volume of a fixed mass of gas is proportional to its absolute temperature"



It can equally be stated:

"If the volume is constant, the pressure of a fixed mass of gas is proportional to its absolute temperature"

Absolute Temperature

The temperature of a body is a measure of the intensity of its heat, and is produced by the average kinetic energy or speed of its molecules.

Zero degrees absolute is the theoretical temperature at which there is a complete absence of molecular activity (i.e. everything stops) thus no heat energy is evolved.

The temperature at which the kinetic energy is absent is given as **-273^{O}C** in the Celsius scale and **-460^{O}F** in the Fahrenheit scale.

- 273^{O}C = 0 K (Kelvin)
- 460^{O}F = 0^{O}R (Rankine)

Therefore if we look at the three states of matter, in this example of water, and convert to absolute temperature:

Unit	Absolute zero	SOLID ice	→	LIQUID water	→	GAS steam
°C	-273		0		100	
K	0		273		373	
°F	-460		32		212	
°R	0		492		672	

Therefore when using absolute temperature in the Celsius scale 273 is added to the Celsius Value:

17^{O}C becomes 290 K

Similarly, when using the Fahrenheit scale the addition of 460 to the Fahrenheit reading will convert to absolute scale:.

52^{O}F becomes 512^{O}R

Charles Law can be written:

At Constant Volume

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$(\textbf{OR } P_1 \, x \, T_2 = P_2 \, x \, T_1)$$

P_1 is the pressure of a mass of gas at temperature T_1 absolute
P_2 is its pressure after the temperature has changed to T_2 absolute.

Charles's Law Formula
Constant Volume

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Or at Constant Pressure

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$(\textbf{OR } V_1 \, x \, T_2 = V_2 \, x \, T_1)$$

V_1 is the volume of a mass of gas at temperature T_1 absolute
V_2 is its volume after the temperature has changed to T_2 absolute.

Charles's Law Formula
Constant Pressure

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Combined Gas Equation

Boyle's and Charles Law may be combined to give the combined gas equation.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Combined Gas Equation

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Charles's law has much less relevance to diving physiology than **Boyle's Law,** however, it should be remembered when considering gas volumes and how they are affected by temperature.

Its relevance is in realising the effects of temperature fluctuation on gas pressures in quads, chambers, etc. Therefore when using the formula you will find that the volume isn't changing in the rigid metal of a chamber or cylinder, it is the depth & pressure that changes with absolute temperature.
It is for this reason that the formula most used in Charles law is:

$$P_1 \, T_2 = P_2 \, T_1$$

USING CHARLES LAW FORMULAE

Remember – **you must always use Absolute Temperature**.

To convert °C to absolute: ^{O}C + 273 = Kelvin

To convert °F to absolute: ^{O}F + 460 = ^{O}Rankine

Example:

If the temperature drops following the pressurisation or blowdown of a fixed volume vessel, then the pressure will drop:

A 10 litre cylinder is charged to 200 bar. The temperature rose to 38^{O}C before dropping back to 18^{O}C. Find the (new) pressure. **(Cylinder volume is irrelevant.)**

$T_1 =$ 38°C + 273 = 311K
$T_2 =$ 18°C + 273 = 291K
$P_1 =$ 200 bar
$P_2 =$?

$$P_2 = \frac{P_1 T_2}{T_1}$$

NB :-
When working with **H.P. bottles** You can work in **gauge pressure**

$$P_2 = \frac{200 \ x \ 291}{311}$$

$$P_2 = \mathbf{187 \ bar}$$

Example:

To find a new chamber depth after cooling the depth in metres or feet of seawater should be converted to **absolute pressure**.

A bell was rapidly blown down to a depth of 70m. On arrival at that depth the temperature was 36.5°C. Theoretically what would the bell depth be if the temperature dropped to 21°C?

$T_1 =$ 36.5°C + 273 = 309.5K
$T_2 =$ 21 °C + 273 = 294K
$P_1 =$ 70 m = 8 bar absolute
$P_2 =$?

NB :-
When working with **Chambers** You **must** work in **Absolute Pressure**

$$P_2 = \frac{P_1 T_2}{T_1}$$

$$P_2 = \frac{8 \ x \ 294}{309.5}$$

$$P_2 = \mathbf{7.6 \ bar \ a = 66 \ msw}$$

Therefore if the bell depth were not adjusted after cooling the pressure decrease would result in the water level rising in the trunking until the temperature had stabilised.

Example:

If a quad arrived onboard at a pressure of 190bar and a temperature of 16°C, what would happen if it was positioned below a flare stack and the temperature rose to 34°C?

$T_1 =$ 16°C + 273 = 289K
$T_2 =$ 34°C + 273 = 307K
$P_1 =$ 190 bar
$P_2 =$?

$$P_2 = \frac{P_1 T_2}{T_1}$$

$$P_2 = \frac{190 \ x \ 307}{289}$$

$$P_2 = 202 \ \mathbf{bar}$$

Therefore, the pressure has risen by 12 bar.

Temperature Conversion

To convert ^{O}Celsius to ^{O}Fahrenheit:

(^{O}C x 1.8) + 32 = ^{O}F

To convert ^{O}Fahrenheit to ^{O}Celsius:

(^{O}F – 32) ÷ 1.8 = ^{O}C

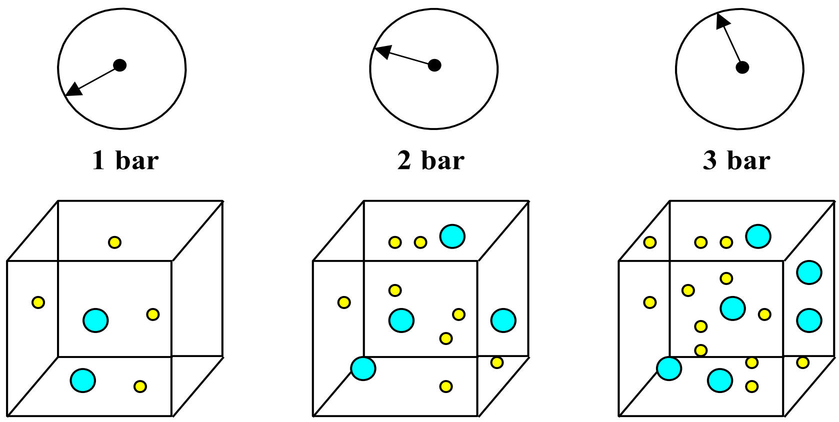
If you can remember that the conversion has the figures of 1.8 and 32 in the calculation, try to remember that 16 ^{O}C = 61 ^{O}F. This may help you to remember and work out the calculation.

Dalton's Law (Partial Pressure) 1.5.4

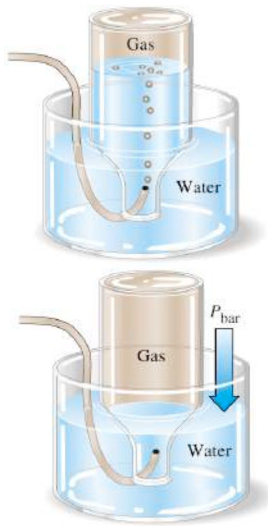
The term Partial Pressure is used commonly in the diving industry. Partial pressure is simply that part of the total pressure contributed by each individual gas in a mixture. If air at an absolute pressure of 3 bar had an O_2 concentration of 21% then the partial pressure of O_2 is 21% of 3 bar.

It States:-

"The total pressure exerted by a mixture of gases is equal to the sum of the partial pressures that would be exerted by each of the constituent gases if it alone occupied the total volume."



pO_2 = 0.21	pO_2 = 0.42	pO_2 = 0.63
pN_2 = 0.79	pN_2 = 1.58	pN_2 = 2.37
Total = 1.00 bar	Total = 2.00 bar	Total = 3.00 bar



The initial formula is:

Partial pressure (bar) x 100 = percentage x absolute pressure

i.e p x 100 = % x AP

By transposition the formula can be adjusted to find any of the values.

To find partial pressure $$p = \frac{\% \; x \; AP}{100}$$

To find percentage $$\% = \frac{p \; x \; 100}{AP}$$

To find absolute pressure $$AP = \frac{p \; x \; 100}{\%}$$

The above formulae all use absolute pressure. If adding gas to a quantity of gas already there and you wish to find partial pressures of gases added, then gauge pressure is used. If you then require to find the partial pressure at the new depth then you must add the partial pressure added to the initial partial pressure and use the absolute pressure formula to find percentage.

It is important to remember that, in most cases, absolute pressure is used and that if you are looking for a depth where a known percentage will give a known partial pressure then the answer is in absolute pressure which must be converted to a depth.

The partial pressure of breathing mixes can be manipulated to the divers advantage. For example, the composition of the gas breathed by a diver may be modified, perhaps to reduce the chance of decompression sickness by reducing the amount of inert gas, or perhaps by adjusting oxygen levels to avoid oxygen toxicity. The effects of increased partial pressures or carbon dioxide or carbon monoxide on the surface can become toxic as the pressure increases.

In air at 1 Atmosphere, the pressure contributed by oxygen = 21% of 1 atm = 0.21 atm.

In air at 1 Atmosphere, the pressure contributed by nitrogen = 79% of 1 atm = 0.79 atm.

i.e.	ppO_2	=	21% of 1 atm	=	0.21 ata
	ppN_2	=	79% of 1 atm	=	0.79 ata
	TOTAL	=	**1.0 ata**		

To transpose Daltons Formula:

Whichever value you require, take the other value on the same side across and below the values on the other side.

$$p = \frac{\% \, x \, ap}{100}$$

$$\% = \frac{p \, x \, 100}{ap}$$

$$ap = \frac{p \, x \, 100}{\%}$$

Dalton's Law Formula
(PARTIAL PRESSURE) *p x 100 = % x AP*

Example:

What is the pO_2 when a diver breathes an 8/92 mix at 68 msw?

$$p = \frac{\% \, x \, ap}{100}$$

$$p = \frac{8 \, x \, 7.8}{100}$$

$$pO2 = \boldsymbol{0.62 \text{ bar OR } 624 \text{ mbar}}$$

Example:

What gas will give a pO_2 of 0.6 at a depth of 123 msw?

$$\% = \frac{pO2 \, x \, 100}{ap}$$

$$\% = \frac{0.6 \, x \, 100}{13.3}$$

$$= \boldsymbol{4.5\%}$$

Therefore, gas used is 4.5% O_2 and 95.5% He.

Example:

If the maximum pO_2 for a bounce dive is 1.5bar, what is the maximum depth for using an 8% mix?

$$ap = \frac{pO2\ x\ 100}{\%}$$

$$= \frac{1.5\ x\ 100}{8}$$

= 18.75 *bar absolute* = 17.75 *bar gauge*

= 177.5 msw

If pressuring a system from the surface or increasing a living depth, you must take into account the partial pressures of the gases already present.

e.g. If you pressurise a system to 40 msw using 5% oxygen, then:

pO_2 initial	**+**	**pO_2 added**	**=**	**pO_2 total**
ppO_2 initial	=	21% of 1 bar	=	0.21bar or 210 mbar
ppO_2 added	=	5% of 4 bar	=	0.2bar or 200 mbar
Therefore pO_2 total	=	0.41 bar or **410 mbar**		

Example:

To find the percentage of the gas at 40msw use absolute pressure.

$$\% = \frac{pO2\ x\ 100}{ap}$$

$$\% = \frac{0.41\ x\ 100}{5}$$

$$= \mathbf{8.2\%}$$

Example expansion:

Now if we increase the living depth to 110 msw using 2/98.

Then the pO_2 total = pO_2 initial + pO_2 added.

pO_2 added = $\frac{2\%\ x\ 7\ bar\ g}{100}$ = 0.14 bar = **140 mbar**

The pO_2 already there = 410 mbar

Therefore pO_2 at 110 msw = 410 + 140 = **550 mbar**

The new oxygen percentage is: (First convert 550 mbars to bar)

= $\frac{550}{1000}$ = 0.55 bar

= $\frac{0.55\ bar\ x\ 100}{12\ bar\ a}$ = **4.6%**

If we increase the living depth using pure helium, then the pO_2 will not change as no more oxygen has been added. The percentage though, will decrease as it now constitutes a smaller proportion of the total.

In most offshore work sites pure helium has been replaced by a 2% oxygen in helium mix. However where saturation depths are in excess of 200msw, pressurisation may result in an undesirable high partial pressure of oxygen, therefore a lower O_2 may be required i.e. 1%. Similarly when saturation depths are shallow, for example, 50msw, a higher % may be required.

The reason for using 2% instead of pure Helium is to allow a diver, who has been given this gas accidentally, to survive. When blowing down a system using 2% and another gas, the formula to calculate the initial blowdown on the high gas is:-

$$\text{Depth in msw using high mix} = \frac{(\text{Final } pO_2 - 210) - (\text{Msw x } O_2 \text{ low mix})}{(O2 \text{ high mix} - O2 \text{ low mix})}$$

Example:

Pressure a system to 97 msw using 2% and 6% to give a O_2 of 0.6 bar.

$$\frac{(600 - 210) - (97 \times 2)}{(6 - 2)}$$

$$= \frac{390 - 194}{4}$$

$$= \frac{196}{4}$$

= 49 msw gauge

> **NB :-**
> 210 is the 210 mbars in the atmosphere at the surface when the door is closed.
> This is **ALWAYS** applied.

Thus initial blow down will be to 49 msw using 6% then onto 97 msw using 2%.

To confirm the results, add up the partial pressures.

e.g.	pO_2 initial	=	0.21 bar
	pO_2 added using 6% to 49 msw	=	0.294 bar
	pO_2 added using 2% to 97 msw	=	0.096 ba
	Total	**=**	**0.6 bar**

Conversely, if we vent gas from a chamber or bell, the ratio of each gas in the mixture will remain unchanged, i.e. if you vent from a bell containing 5% O_2 from 90 msw, the mixture of gases will be the same all the way to the surface. The very important difference is that the partial pressures of the gases will drop significantly.

At 90 msw	pO2 = 5% of 10 bar	=	0.5 bar
On the surface	pO2 = 5% of 1 bar	=	0.05 bar (or 50mbar)

Thus you can see that the 5% oxygen at 90 msw was more than enough to support life whereas the same 5% at the surface will not.

This is important to remember, not only when surfacing a bell or chamber, but also when operating a split level saturation, the oxygen level must be checked when moving the bell or transfer chamber from one depth to the other.

Dalton's Law and Carbon Dioxide

Dalton's law and CO_2 can cause some confusion for some people. This is because we can end up dealing with very small numbers with lots of zero's and there are other systems used by some dive companies that require a different approach. There is also the "complication" of readings taken at depth and on surface.

The main unit used in measuring CO_2 is parts per million (ppm), but occasionally you will find percentage (%) readings. As with any gas the proportion of it within the container is not as important as the actual amount which with CO_2 is calculated best in millibar (mbar or mb). Companies have differing maximum levels of CO_2 allowed, but most companies allow up to 5 mbar in their living chambers. Let's use Dalton's law to work out what proportion this would be at a two different depths:

To use Dalton's law we need the pCO_2 in bar 5mb ÷ 1000 = 0.005 bar

On surface: $\frac{0.005 \times 100}{1} = 0.5\ \% \times 10000 = 5000$ ppm

At 90 msw: $\frac{0.005 \times 100}{10} = 0.05\ \% \times 10000 = 500$ ppm

You can see that a short cut to finding the maximum ppm for a given depth is to divide the maximum 1 atmosphere reading 5000 ppm by the absolute depth ie at 120 msw: $\frac{5000}{13}$ = 384 ppm

That covers readings taken on the surface but what about at depth? Readings at depth are normally taken by draeger tubes and the reading is a direct reading of partial pressure, although not in bar or millibar.

The units are in ppm or %, and to convert to bar or millibar then it is the reading:

ppm (at depth) ÷ 1000 = partial pressure in mbar

or

If draeger tube reads in % then % (at depth) x 10 = partial pressure in mbar

As stated some people use surface equivalent percentage or values (SEP or SEV) and a reading at depth is the SEV ie if the draeger tube reads 0.5 % or 5000 ppm these are SEV readings and some company's make these amounts their maximum level. Some companies have 20 mbar (2% or 20000 ppm SEV) as a maximum level in the bell.

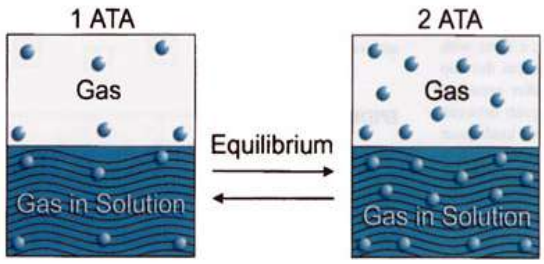
Henry's Law (Solubility of Gas) 1.5.5

Henry's Law States

"At a constant temperature the amount of gas that will dissolve in a liquid is proportional to the partial pressure of that gas in contact with the liquid."

This law implies an equilibrium in which equal amounts of each gas are passing into and out of any solution in contact with it.

At sea level (1 atm), a man's body tissues contain about 1 litre of nitrogen in solution. If he dived to 33 fsw and breathed air at 2 ata, he would eventually reach a new equilibrium and have twice as much nitrogen in solution in his tissues. If he increased depth to 132 fsw he would eventually have 5 litres of nitrogen and so on. The time taken to reach a new equilibrium depends on the solubility of the gas in the tissue and the rate at which the gas is supplied to each tissue.



The two inert gases commonly encountered in diving are **nitrogen** and **helium**. When combined with suitable oxygen content they comprise most breathing mediums, i.e. either air/nitrox or heliox.

Nitrogen and helium differ in both diffusion rate and solubility. Helium is less soluble in the tissue than nitrogen is, but it will diffuse into the tissues much faster.

There are differences in the rate of diffusion and solubility of gases in different tissues. Fatty tissues will hold significantly more Nitrogen than watery tissues (5 times more) thus will take longer to absorb or eliminate excess inert gas.

The carrier of increased gas pressures to the tissue is the blood system, therefore tissues that are highly vascularised, i.e. those that have a good blood supply, will exchange gases more quickly than tissues with a poor blood supply. Similarly, the rate of gas elimination is affected by perfusion in the tissues.

Gas movement is not instantaneous. Equilibrium can take hours. Gas molecules dissolve in the tissue and move from one area to another until the partial pressure of the gas is the same at each point.

NB: Gas pressures tend to equilibrate, **not** the number of gas molecules. If a gas is twice as soluble in one tissue compared to another, then there will be twice as many of its molecules in the first tissue to produce the same partial pressure. This information can be calculated from the solubility coefficients of the gas in the components of the tissue.

Thus at sea level a body is saturated with nitrogen. If we increase the pressure a corresponding amount of nitrogen will then dissolve into the body until it reaches a new saturation level. If we then decrease the pressure the tissues will have to off load the excess inert gas to the level accepted at the new depth. This is a major principle of diving and will be discussed in decompression.

GASSES ENCOUTED IN DIVING 1.6

A diver is totally dependent on a supply of breathing gas whilst underwater. This gas is supplied either via a surface umbilical or from a self-contained supply carried by the diver.

Air & Nitrox (Enriched Air) 1.6.1

Air is a mixture of gases (and vapours) containing oxygen (20.946%), nitrogen (78.084%), carbon dioxide (0.033%), argon (0.934%) and 0.003% other rare gases. Air is the most commonly used breathing gas used in diving.

If ordered in cylinders from a dive gas supplier then the supplier will actually mix Air from O_2 and N_2. This is how they also mix Nitrox which is a mixture of O_2/ N_2 in proportions to suite the partial pressure requirements of the dive mix, ie 40/60 means that there is 40% O_2 and 60% N_2

Colour Code

Air that is pumped from the atmosphere by compressors must meet the guidelines in BS EN 12021.

Colour code - diving quality Black cylinder with white collar/shoulder.

Oxygen 1.6.2

Molecular Formula	O_2
Molecular Weight	32.00
Boiling Point	-183ºC
Melting Point	-218.4oC
Specific Gravity (Air = 1)	1.053
Density	1.331 gm/l

Oxygen is a colourless, odourless, tasteless gas which is slightly soluble in water. It is slightly more dense than air at equal temperatures.

One volume of liquid oxygen gives 860 volumes of gas at ambient temperatures.

Solubility in water at 10oC and 1 atm = 0.055 (wt/%.)

Oxygen is the only life supporting gas used by the body. The other gases breathed from the atmosphere or by the diver in his breathing mix, serve only as a vehicle and dilutent for the oxygen. The body consumes O_2 at a rate given as 0.5 litres per minute (independent of ambient pressure).

If breathed at high partial pressures it can cause oxygen toxicity.

It is an oxidant and although not flammable it supports and is consumed in both respiration and combustion. It is highly reactive and great care is required in it's handling to guard against explosion/fire, indeed any gas mixture containing more than 25% O_2 must be treated as if pure Oxygen.

Colour Code

Oxygen is produced industrially by the fractional distillation of liquid air

Colour code - diving quality Black cylinder with white collar/shoulder

Nitrogen 1.6.3

Molecular Formula	N_2
Molecular Weight	28.016
Boiling Point	-195.8oC
Melting Point	-209.9oC
Specific Gravity (Air = 1)	0.967
Density	1.16 gm/l

Nitrogen is a colourless, odourless, tasteless gas. It is chemically inert and is incapable of supporting life. Its main function is as a dilutent or carrier of oxygen in a breathing mixture, but when used in a diving gas mixture it has several disadvantages.

When nitrogen is breathed at partial pressure in excess of 3.2 bar, i.e. air beyond 30 metres, it has a distinct anaesthetic effect on the body producing "nitrogen narcosis", a condition characterised by loss of judgement and disorientation.

Because of the high density of the gas compared to helium, more energy is used in the work of breathing during deeper diving.

Nitrogen is produced industrially by the fractional distillation of liquid air

Solubility in water at 10oC and 1 atm = 0.0024 (wt %).

Solubility in fat is much greater - around five times the quantity.

Nitrogen can cause hypoxic problems if the O_2 level is flushed to below critical level. Therefore, care must be taken when discarding or emptying N_2 cylinders.

Colour code - Grey cylinder with black collar/shoulder

Colour Code

Helium (& Heliox) 1.6.4

Chemical Symbol	He
Atomic Weight	4.003
Boiling Point	-268.96oC
Melting Point	-271.24oC
Specific Gravity (Air = 1)	0.138
Density	0.166 gm/l

Helium is colourless, odourless and tasteless. It is the second lightest gas known (hydrogen being the lightest) with a density of one seventh of air at equal temperature and pressure.

It has the lowest boiling point of any known substance. Helium is not flammable, is chemically inert and non-toxic. It is normally present in the dry atmosphere in trace quantities - 5 ppm by volume. It is normally extracted as a byproduct of natural gas, the major producers being the USA and Algeria. Helium does not support life and is used in deep diving as a carrier of oxygen. It is then known as Heliox, and the O_2/He mixes vary according to use, such as 2/98 for most pressurisation uses deeper than 40 msw, and 50/50 for DCI treatments between 18 to 40 msw. Care must be taken when using pure helium that oxygen levels are not reduced to dangerous levels, causing Anoxia or Hypoxia. Current IMCA guidelines recommend the base gas should contain 2% Oxygen in Helium, and not pure Helium for this reason.

Breathing heliox causes speech distortion, which hinders communication especially in very deep diving.
Helium also has a high thermal conductivity, 6 times greater than Air, which can result in rapid loss of body heat.

Apart from these two disadvantages, it still has greater advantages over nitrogen, namely because of its lower density and lack of toxic effect.

Solubility in water at 10oC and 1 atm = 0.000161 (wt/%).

Colour Code - Brown Bottle (Heliox Brown, white collar/shoulder).

Colour Code

Heliox

Helium

Argon 1.6.5

Chemical Symbol	Ar
Atomic Weight	39.95
Boiling Point	-185.9oC
Melting Point	-189.2oC
Density	1.664 g/l
Specific Gravity	1.38

Argon (a "noble" gas as is helium) is colourless, odourless and tasteless and is heavier than air at equal temperatures. It is chemically inert and is found in air in small quantities, i.e. 0.93%. It has been tried as dilutent gas in diving but is not used. It is similar to nitrogen, but is twice as narcotic and suffers the same problems with depth restrictions. It is denser than nitrogen and therefore increases the work of breathing effort.

Argon is produced industrially by the fractional distillation of liquid air

Solubility in water at 10oC and 1 atm= 0.00025 (wt/%).

It is sometimes found as a shield gas during welding but otherwise is unlikely to be found offshore.

Colour code - Blue cylinder

Colour Code

Hydrogen 1.6.6

Molecular Formula	H_2
Molecular Weight	2.016
Boiling Point	-252.8oC
Melting Point	-259.2oC
Gas Density	0.0838 g/l
Specific Gravity of Gas	0.0695

Hydrogen is colourless, odourless and tasteless. It is the lightest gas known with a density one fourteenth that of air at equal temperature and pressure.

Hydrogen is highly flammable with a wide range of flammability in both air and oxygen.

Hydrogen has been tested with a view to its being the dilutent in very deep diving. Hydrox: O_2/H_2 and Hydreliox: $O_2/H_2/He$ have been trialled, most thoroughly by Comex, but the inherent dangers of Hydrogen explosion (O_2 content must be less than 1% and external chambers are in inert environment) and also a degree of H narcosis have deterred further use .

Colour Code

Solubility in water at 10oC and 1 atm = 0.00017 (wt/%).

It is unlikely to be used generally offshore because of its highly unstable and dangerous characteristics.

Colour Code - Orange Bottle

Carbon Dioxide 1.6.7

Molecular Formula	CO_2
Molecular Weight	44.01
Triple Point at 4.17 bar (g)	-56.6oC
Specific Gravity	1.52
Density (20oC 1 ata)	1.84 gm/l

Carbon dioxide is a colourless gas that has a slightly pungent odour at high concentrations.

It is about 1½ times heavier than air at equal temperatures and pressure.

The gas is a product of several naturally occurring processes such as cellular metabolism, combustion and fermentation.

Although carbon dioxide is not generally considered poisonous, in excessive amounts it is harmful to the diver; this is called Hypercapnia. While some CO_2 is necessary to stimulate external respiration, increased partial pressures give rise to a succession of symptoms which can lead to unconsciousness and death. It must be remembered that acceptable levels in a gas at 1ata may exceed tolerable limits at increased pressures.

Colour Code

CO2 is extremely soluble in water = 0.23 (wt/%).

Colour code - Black cylinder with grey collar/shoulder

Carbon Monoxide 1.6.8

Molecular Formula	CO
Molecular Weight	28.01
Specific Gravity of Gas (Air = 1)	0.968
Density of Gas (20°C 1 ata)	1.161 gm/l

Carbon monoxide is a poisonous gas. It is colourless, odourless and tasteless, is slightly lighter than air and is difficult to detect. It is produced in small quantities by the body, especially in smokers, but the main source is from the incomplete combustion of hydrocarbons.

Typical problem areas are compressor intakes sited by engine exhausts or possible overheating in a compressor which breaks down the lubricant, producing toxic contamination of the gas.

CO is readily picked up by the oxygen carrier within the blood (i.e. haemoglobin) at the expense of the oxygen itself. Thus the body tissues become hypoxic. Low concentrations are extremely toxic so great care must be taken.

For additional information on the above mentioned contaminant gases, see the Section on Gas Toxicity.

Section 2

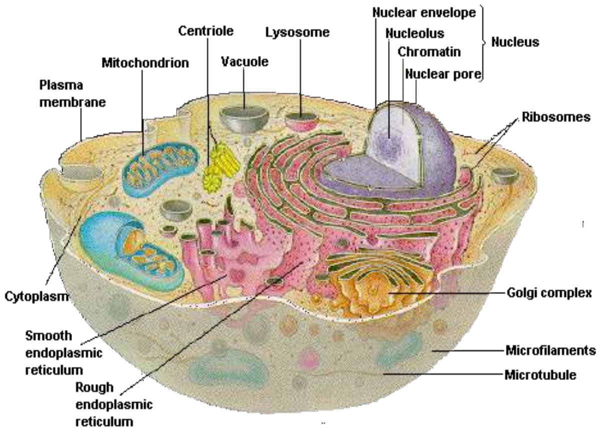
Anatomy & Physiology

CELLS AND TISSUE 2.1

The human body has billions of individual cells. Each one of these microscopic, but complex structures contains all the genetic information necessary to build all the body tissues and organs.

Each cell is a separate living organism and must be supplied with oxygen and nutrients by the bloodstream in **capillaries**. The bloodstream also removes the waste products from the cell. The most important of these waste products, from the diver's point of view, is carbon dioxide. The body consumes, or metabolises oxygen at the rate of 0.5 lts/minute, the ratio it produces carbon dioxide is one to one, ie the body also produces carbon dioxide at the rate of 0.5 lts/minute.

The Cell



To make the oxygen pass from the blood into the cell there must be a suitable pressure gradient. In other words, the partial pressure, or tension, of oxygen in the blood must be higher than that in the cell.

To remove the carbon dioxide from the cell, the pressure gradient must slope the other way. There must be a higher carbon dioxide tension in the cell than in the blood.

The exchange of oxygen and carbon dioxide between the bloodstream and the cells is known as **internal respiration or perfusion.** This is to distinguish it from the exchange of oxygen and carbon dioxide between the capillaries and the alveoli in the lungs, which is known as **external respiration or diffusion.**

Each cell has a limited life and cells are constantly dying and being created in the body. In the average human lifetime every cell will be replaced several times over.

If a cell is deprived of oxygen it will die very quickly. In the less important organs, this may not cause any immediate difficulty, but in the brain for example, irreparable damage can occur in only a few minutes.

When cells are deprived of oxygen the condition is known as **hypoxia**. In extreme cases where there is a complete lack of oxygen, it is known as **anoxia.**

Similar cells are grouped together to form **tissues,** each carrying out a specific function. Related tissues join to form **organs**, adapted to perform specific tasks. Groups of organs responsible for a series of interrelated functions form the **body systems.**

Body systems of particular interest in diving physiology include:

- The Respiratory System
- The Cardiovascular System
- The Nervous System
- The Special Sensory Organs
- The Skeletal System
- The Muscular System

No system operates independently. The Respiratory System, for example, is controlled by signals from the Nervous System, which in turn are initiated or triggered by carbonic acid levels in the Circulatory System.

RESPIRATORY SYSTEM 2.2

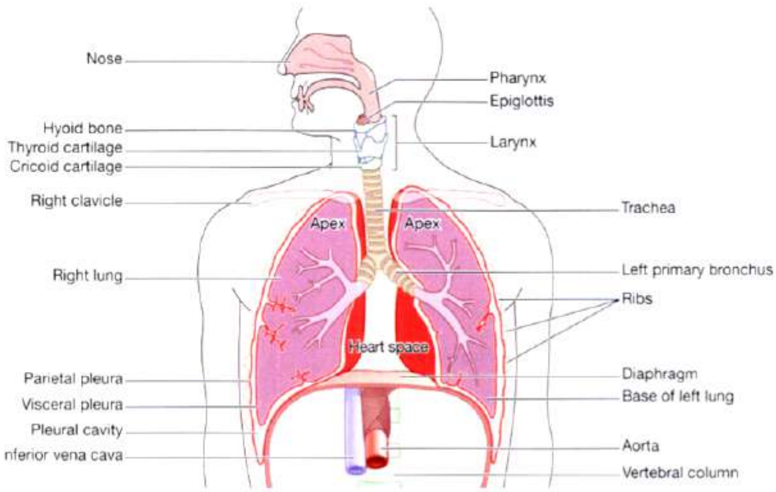
The cells of the body need energy for their chemical activity that maintains homeostasis. Most of this energy is derived from chemical reactions, which can only take place in the presence of oxygen (O_2). The main waste product of these reactions is carbon dioxide (CO_2). The respiratory system provides the route by which the supply of oxygen present in the atmospheric air gains entry to the body and it provides the route of excretion of carbon dioxide.

As the air breathed in moves through the air passages to reach the lungs, it is warmed or cooled to body temperature, moistened to become saturated with water vapour and 'cleaned' as particles of dust stick to the mucus which coats the lining membrane. Blood provides the transport system for these gases between the lungs and the cells of the body.

Exchange of gases between the blood and the lungs is called *external respiration* and that between the blood and the cells *internal respiration.*

The Organs Of The Respiratory System Are:

- Nose
- Pharynx
- Larynx
- Trachea
- Two bronchi (one bronchus to each lung)
- Bronchioles and smaller air passages
- Two lungs and their coverings, the pleura
- Muscles of respiration, the inter-costal muscles and the diaphragm



The Airway 2.2.1

The Nose

Respiratory Function of the Nose

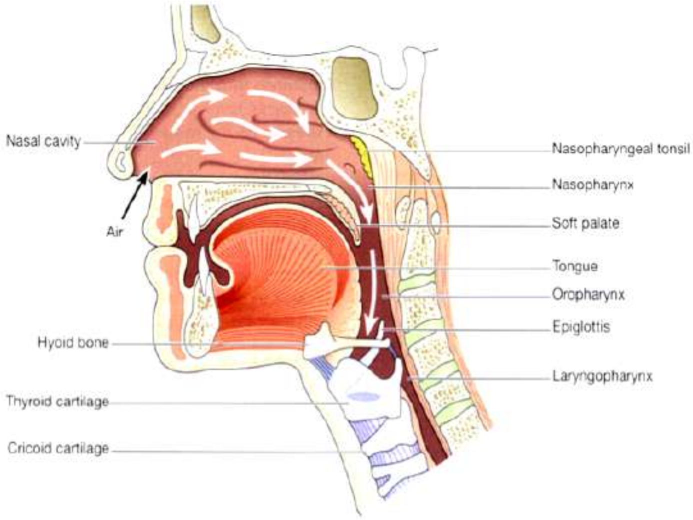
The nose is the first of the respiratory passages through which the inspired air passes. The function of the nose is to begin the process by which the air is *warmed, moistened and 'filtered'.*
The projecting *conchae* increase the surface area and cause turbulence, spreading inspired air over the whole nasal surface. The large surface area.

Filtering and Cleaning of Air.

This occurs as hairs at the anterior nares trap larger particles. Smaller particles such as dust and microbes settle and adhere to the mucus. Mucus protects the underlying epithelium from irritation and prevents drying. Synchronous beating of the cilia wafts the mucus towards the throat where it is swallowed or expectorated.

Humidification

This occurs as air travels over the moist mucosa and becomes saturated with water vapour. Irritation of the nasal mucosa results in *sneezing,* a reflex action that forcibly expels an irritant. maximises warming, humidification and filtering.



The Pharynx

The pharynx is a tube 12 to 14 cm long that extends from the base of the skull to the level of the 6th cervical vertebra. It lies behind the nose, mouth and larynx and is wider at its upper end.

For descriptive purposes the pharynx is divided into three parts: *nasopharynx, oropharynx* and *laryngopharynx.*

The Nasopharynx

The nasal part of the pharynx lies behind the nose above the level of the soft palate. On its lateral walls are the two openings of the *eustacian tubes,* one leading to each middle ear. On the posterior wall there are the *pharyngeal tonsils* (adenoids).

The Oropharynx

The oral part of the pharynx lies behind the mouth, extending from below the level of the soft palate to the level of the upper part of the body of the 3rd cervical vertebra. The lateral walls of the pharynx blend with the soft palate to form two folds on each side.

During swallowing, the nasal and oral parts are separated by the soft palate and the *uvula.*

The Laryngopharynx

The laryngeal part of the pharynx extends from the oropharynx above and continues as the oesophagus below, i.e. from the level of the 3rd to the 6th cervical vertebrae.

Functions of the Pharynx

Passageway for Air and Food

The pharynx is an organ involved in both the respiratory and the digestive systems: air passes through the nasal and oral parts, and food through the oral and laryngeal parts.

Warming and Humidifying

By the same methods as in the nose, the air is further warmed and moistened as it passes through the pharynx.

Taste

There are olfactory nerve endings of the sense of taste in the epithelium of the oral and pharyngeal parts.

Hearing

The auditory tube, extending from the nasal part to each middle ear, allows air to enter the middle ear. Satisfactory hearing depends on the presence of air at atmospheric pressure on each side of the *tympanic membrane* (ear drum).

Protection

The lymphatic tissue of the pharyngeal and laryngeal tonsils produces antibodies in response to anti- gens, e.g. microbes. The tonsils are larger in children and tend to atrophy in adults.

Speech

The pharynx functions in speech; by acting as a resonating chamber for the sound ascending from the larynx, it helps (together with the sinuses) to give the voice its individual characteristics.

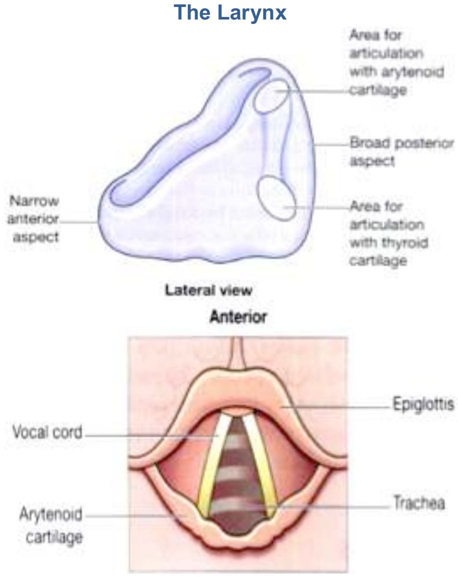
The Larynx

The larynx is composed of several irregularly shaped cartilages attached to each other by ligaments and membranes.

The Main Cartilages Are:

- 1 Thyroid cartilage
- 1 Cricoid cartilage
- 1 Hyaline cartilage
- 2 Arytenoid cartilages
- 1 Epiglottis

The Larynx



The Thyroid Cartilage

This is the most prominent and consists of two flat pieces of hyaline cartilage, or *laminae,* fused anteriorly, forming the *laryngeal prominence* (Adam's apple). Immediately above the laryngeal prominence the laminae are separated, forming a V-shaped notch known as the *thyroid notch.*

The Cricoid Cartilage

This lies below the thyroid cartilage and is also composed of hyaline cartilage. It is shaped like a signet ring, completely encircling the larynx with the narrow part anteriorly and the broad part posteriorly.

The Epiglottis

This is a leaf-shaped fibroelastic cartilage attached to the inner surface of the anterior wall of the thyroid cartilage immediately below the thyroid notch. It rises obliquely upwards behind the tongue and the body of the hyoid bone. If the larynx is likened to a box then the epiglottis acts as the lid; it closes off the larynx during swallowing, protecting the lungs from accidental inhalation of foreign objects.

Interior of the Larynx

The *vocal cords* are two pale folds of mucous membrane with cord-like free edges, which extend from the inner wall of the thyroid prominence anteriorly to the arytenoid cartilages posteriorly.

When the muscles controlling the vocal cords are relaxed, the vocal cords open and the passageway for air coming up through the larynx is clear; the vocal cords are said to be *abducted*. The pitch of the sound produced by vibrating the vocal cords in this position is low. When the muscles controlling the vocal cords contract, the vocal cords are stretched out tightly across the larynx —they are said to be *adducted.* When the vocal cords are stretched to this extent, and are vibrated by air passing through from the lungs, the sound produced is high pitched. The pitch of the voice is therefore determined by the tension applied to the vocal cords by the appropriate sets of muscles.

Functions of the Larynx

Production of Sound

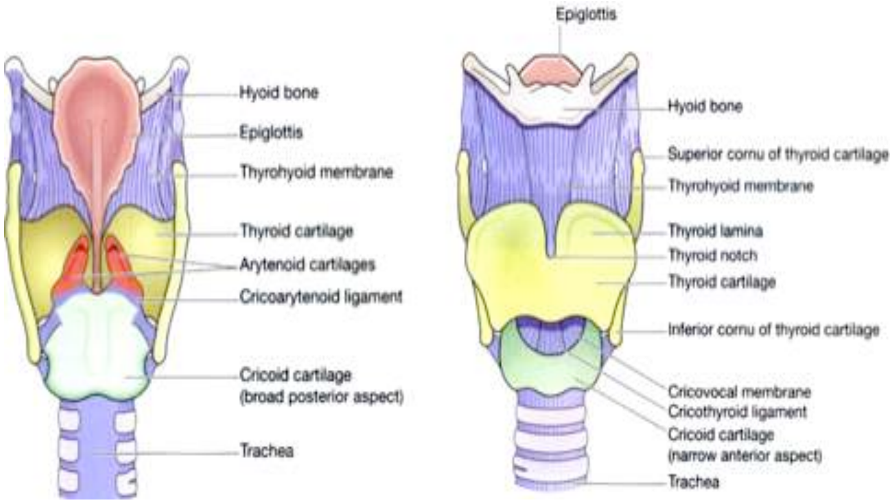
Sound Has The Properties Of *Pitch, Volume* And *Resonance:*

- Pitch of the voice depends upon the *length* and *tightness* of the cords. At puberty, the male vocal cords begin to grow longer, hence the lower pitch of the adult male voice.
- Volume of the voice depends upon *the force* with which the cords vibrate. The greater the force of expired air the more the cords vibrate and the louder the sound emitted.
- Resonance, or tone, is dependent upon the shape of the mouth, the position of the tongue and the lips, the facial muscles and the air in the para-nasal sinuses.

Speech

This occurs during expiration when the sounds produced by the vocal cords are manipulated by the tongue, cheeks and lips.

The Larynx



Protection Of The Lower Respiratory Tract

During swallowing (deglutition) the larynx moves upwards, occluding the opening into it from the pharynx and the hinged epiglottis closes over the larynx. This ensures that food passes into the oesophagus and not into the lower respiratory passages.

Passageway for Air

This is between the pharynx and trachea.

Humidifying, Filtering and Warming

These continue as inspired air travels through the larynx.

The Trachea

The trachea is composed of from 16 to 20 incomplete (C-shaped) rings of hyaline cartilages lying one above the other. The cartilages are incomplete posteriorly. Connective tissue and involuntary muscle join the cartilages and form the posterior wall where they are incomplete. The soft tissue posterior wall is in contact with the oesophagus.

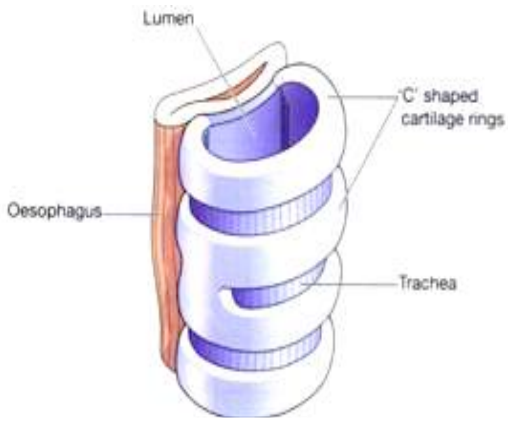
There are three layers of tissue, which 'clothe' the cartilages of the trachea.

The outer layer. This consists of fibrous and elastic tissue and encloses the cartilages.

The middle layer. This consists of cartilages and bands of smooth muscle that wind round the trachea in a helical arrangement. There is some areolar tissue, containing blood and lymph vessels and autonomic nerves.

The inner lining. This consists of ciliated columnar epithelium, containing mucus-secreting goblet cells.

The Trachea



Functions of the Trachea

Support and Patency

The arrangement of cartilage and elastic tissue prevents kinking and obstruction of the airway as the head and neck move. The absence of cartilage posteriorly allows the trachea to dilate and constrict in response to nerve stimulation, and for indentation as the oesophagus distends during swallowing.
The cartilages prevent collapse of the tube when the internal pressure is less than intrathoracic pressure, i.e. at the end of forced expiration.

Mucociliary Escalator

This is the synchronous and regular beating of the cilia of the mucous membrane lining that wafts mucus with adherent particles upwards towards the larynx where it is swallowed or expectorated.

Cough Reflex

Nerve endings in the larynx, trachea and bronchi are sensitive to irritation that generates nerve impulses, which are conducted by the vagus nerves to the respiratory centre in the brain stem. The reflex motor response is deep inspiration followed by closure of the glottis. The abdominal and respiratory muscles then contract and suddenly the air is released under pressure expelling mucus and/or foreign material from the mouth.

The Lungs 2.2.2

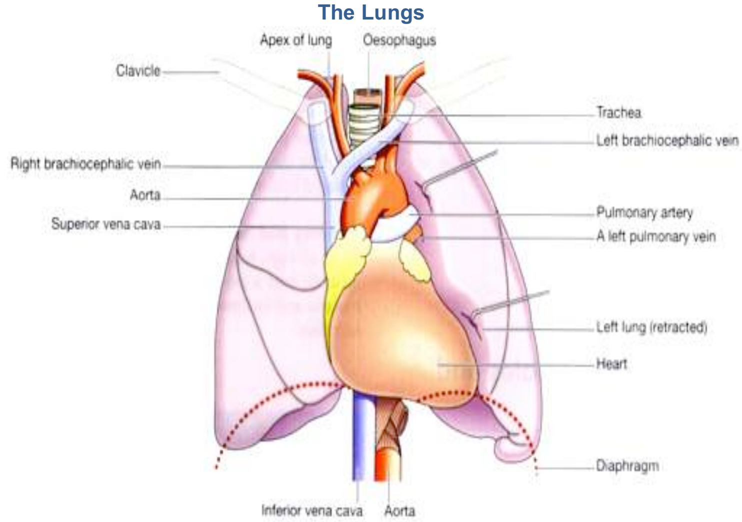
Bronchus

The two primary bronchi are formed when the trachea divides, i.e. about the level of the 5th thoracic vertebra.

The right bronchus. This is wider, shorter and more vertical than the left bronchus and is therefore the more likely of the two to become obstructed by an inhaled foreign body. It is approximately 2.5cm long. After entering the right lung at the hilum it divides into three branches, one to each lobe. Each branch then subdivides into numerous smaller branches.

The left bronchus. This is about 5 cm long and is narrower than the right. After entering the lung at the hilum it divides into two branches, one to each lobe. Each branch then subdivides into progressively smaller tubes within the lung substance.

The Lungs



Bronchi and Bronchioles Structure

The bronchi are composed of the same tissues as the trachea. They are lined with ciliated columnar epithelium. The bronchi progressively subdivide into *bronchioles*, *terminal bronchioles, respiratory bronchioles, alveolar ducts* and finally, *alveoli.* Towards the distal end of the bronchi the cartilages become irregular in shape and are absent at bronchiolar level. In the absence of cartilage the smooth muscle in the walls of the bronchioles becomes thicker and is responsive to autonomic nerve stimulation and irritation. Ciliated columnar mucous membrane changes gradually to non-ciliated cuboidal shaped cells in the distal bronchioles.

Respiratory Bronchioles And Alveoli

Lobules are the blind ends of the respiratory tract distal to the terminal bronchioles, consisting of: *respiratory bronchioles, alveolar ducts* and *alveoli* (tiny air sacs). It is in these structures that the process of gas exchange occurs. The walls gradually become thinner until muscle and connective tissue fade out leaving a single layer of simple squamous epithelial cells in the alveolar ducts and alveoli. These distal respiratory passages are supported by a loose network of elastic connective tissue in which macrophages, fibroblasts, nerves and blood and lymph vessels are embedded. The alveoli are surrounded by a network of capillaries. The exchange of gases during respiration takes place across two membranes, the alveolar and capillary membranes.

Functions Of Respiratory Bronchioles And Alveoli

Defence Against Microbes

At this level, ciliated epithelium, goblet cells and mucus are no longer present.

Defence relies on protective cells present within the lung tissue. These include lymphocytes and plasma cells, which produce antibodies in the presence of antigens, and macrophages and polymorphonuclear lymphocytes, which are phagocytic. These cells are most active in the distal air passages where ciliated epithelium has been replaced by flattened cells.

Lungs

There are two lungs, one lying on each side of the midline in the thoracic cavity. They are cone-shaped and are described as having an *apex,* a *base, costal surface* and *medial surface.*

The Apex

This is rounded and rises into the root of the neck, about 25 mm (1 inch) above the level of the middle third of the clavicle. The structures associated with it are the first rib and the blood vessels and nerves in the root of the neck.

The Base

This is concave and semilunar in shape and is closely associated with the thoracic surface of the diaphragm.

The Costal Surface

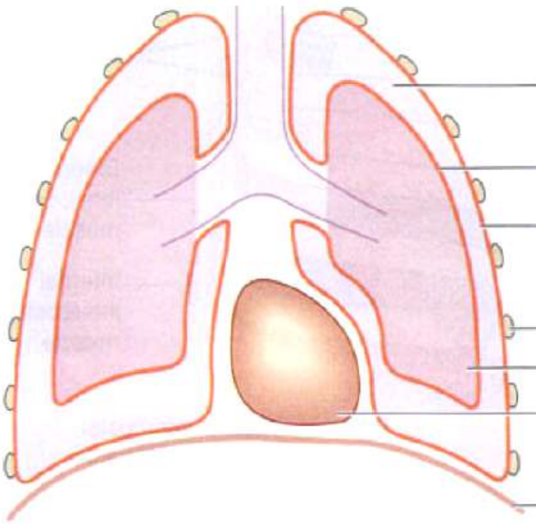
This surface is convex and is closely associated with the costal cartilages, the ribs and the intercostal muscles.

The Medial Surface

This surface is concave and has a roughly triangular-shaped area, called the *hilum,*at the level of the 5th, 6th and 7th thoracic vertebrae. Structures, which form the *root of the lung* enter and leave at the hilum. These include the primary bronchus, the pulmonary artery supplying the lung and the two pulmonary veins draining it, the bronchial artery and veins, and the lymphatic and nerve supply.
The area between the lungs is the *mediastinum.* The heart, great vessels, trachea, right and left bronchi, oesophagus, lymph nodes, lymph vessels and nerves occupy it.

Organisation of the Lungs

The *right lung* is divided into three distinct lobes: superior, middle and inferior.
The *left lung* is smaller as the heart is situated left of the midline. It is divided into only two lobes: superior and inferior.



Pleura and Pleural Cavity

The pleura consists of a closed sac of serous membrane (one for each lung) which contains a small amount of serous fluid. The lung is invaginated into this sac so that it forms two layers: one adheres to the lung and the other to the wall of the thoracic cavity.

The Visceral Pleura

This is adherent to the lung, covering each lobe and passing into the fissures which separate them.

The Parietal Pleura

This is adherent to the inside of the chest wall and the thoracic surface of the diaphragm. It remains detached from the adjacent structures in the mediastinum and is continuous with the visceral pleura round the edges of the hilum.

The Pleural Cavity

This is only a potential space. In health, the two layers of pleura are separated by only a thin film of serous fluid, which allows them to glide over each other, preventing friction between them during breathing.

The two layers of pleura, with serous fluid between them, behave in the same way as two pieces of glass separated by a thin film of water. They glide over each other easily but can be pulled apart only with difficulty, because of the surface tension between the membranes and the fluid. If either layer of pleura is punctured, the underlying lung collapses due to its inherent property of elastic recoil.

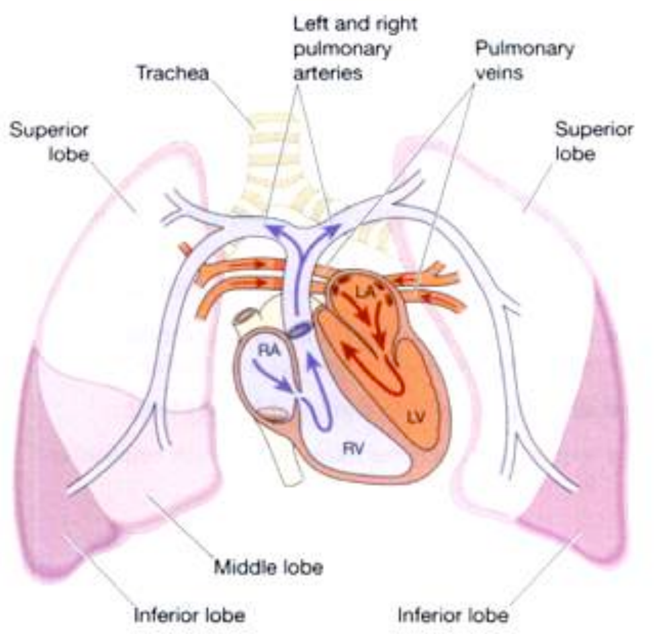
Interior of the Lungs

The lungs are composed of the bronchi and smaller air passages, alveoli, connective tissue, blood vessels, lymph vessels and nerves. The left lung is divided into two lobes and the right, into three. Each lobe is made up of a large number of lobules.

Pulmonary Blood Supply

The *pulmonary artery* divides into two, one branch conveying *deoxygenated blood* to each lung. Within the lungs each pulmonary artery divides into many branches, which eventually end in a dense capillary network around the walls of the alveoli. The walls of the alveoli and those of the capillaries each consist of only one layer of flattened epithelial cells. The exchange of gases between air in the alveoli and blood in the capillaries takes place across these two very fine membranes. The pulmonary capillaries join up, eventually becoming *two pulmonary veins* in each lung. They leave the lungs at the hilum and convey *oxygenated blood* to the left atrium of the heart. The innumerable blood capillaries and blood vessels in the lungs are supported by connective tissue.

The Lungs



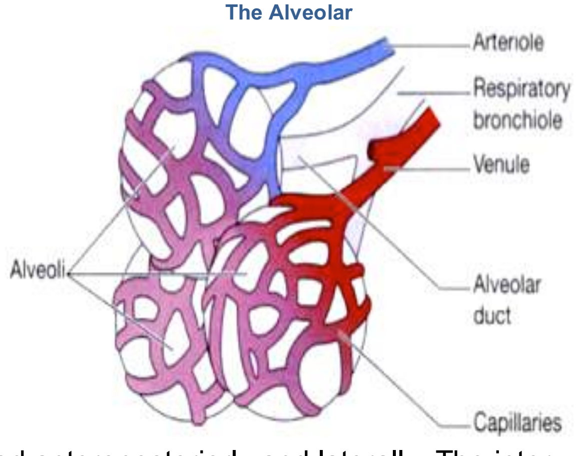
Muscles of Respiration

The expansion of the chest during inspiration occurs as a result of muscular activity, partly voluntary and partly involuntary. The main muscles of respiration in normal quiet breathing are the *inter-costal muscles* and the *diaphragm.* During difficult or deep breathing they are assisted by the muscles of the neck, shoulders and abdomen.

Intercostal Muscles

There are 11 pairs of intercostal muscles that occupy the spaces between the 12 pairs of ribs. They are arranged in two layers, the external and internal inter-costal muscles.

The Alveolar



The External Inter-Costal Muscle Fibres.

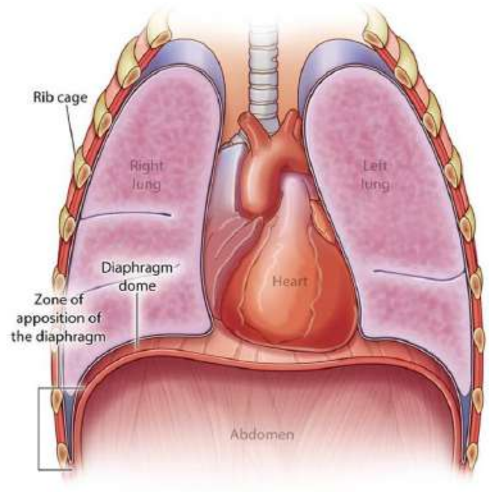
These extend in a downwards and forwards direction from the lower border of the rib above to the upper border of the rib below.

The Internal Inter-Costal Muscle Fibres

These extend in a downwards and backwards direction from the lower border of the rib above to the upper border of the rib below, crossing the external inter-costal muscle fibres at right angles.

The first rib is fixed. Therefore, when the inter-costal muscles contract they pull all the other ribs towards the first rib. Because of the shape of the ribs they move outwards when pulled upwards. In this way the thoracic cavity is enlarged anteroposteriorly and laterally. The inter-costal muscles are stimulated to contract by the *inter-costal nerves.*

The Diaphragm



Diaphragm

The diaphragm is a dome-shaped structure separating the thoracic and abdominal cavities. It forms the floor of the thoracic cavity and the roof of the abdominal cavity and consists of a central tendon from which muscle fibres radiate to be attached to the lower ribs and sternum and to the vertebral column by two crura. When the muscle of the diaphragm is relaxed, the central tendon is at the level of the 8th thoracic vertebra. When it contracts, its muscle fibres shorten and the central tendon is pulled downwards to the level of the 9th thoracic vertebra, enlarging the thoracic cavity in length. This decreases pressure in the thoracic cavity and increases it in the abdominal and pelvic cavities.

Respiration 2.2.3

Cycle of Respiration

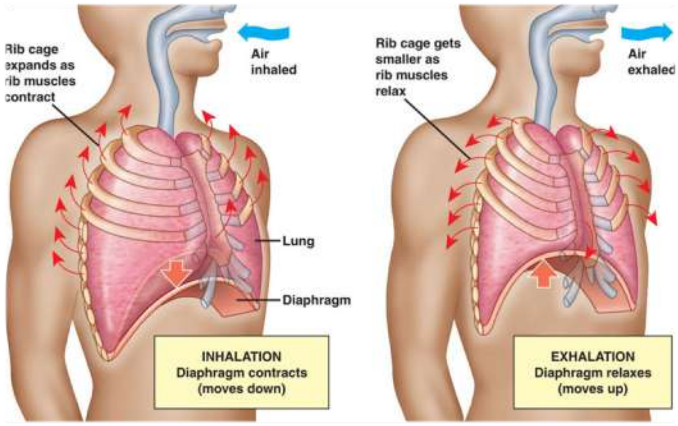
This Occurs 12 To 16 Times Per Minute And Consists Of Three Phases:

- Inspiration
- Expiration
- Pause.

Inspiration

When the capacity of the thoracic cavity is increased by simultaneous contraction of the inter-costal muscles and the diaphragm, the parietal pleura moves with the walls of the thorax and the diaphragm. This reduces the pressure in the pleural cavity to a level considerably lower than atmospheric pressure. The visceral pleura follows the parietal pleura pulling the lung with it. This stretches the lungs and the pressure within the alveoli and in the air passages falls, drawing air into the lungs in an attempt to equalise the atmospheric and alveolar air pressures.
The process of inspiration is *active,* as it requires expenditure of energy for muscle contraction. The negative pressure created in the thoracic cavity aids venous return to the heart and is known as the *respiratory pump.*

Respiration



Expiration

Relaxation of the inter-costal muscles and the diaphragm results in downward and inward movement of the rib cage and elastic recoil of the lungs. As this occurs, pressure inside the lungs exceeds that in the atmosphere and therefore air is expelled from the respiratory tract. The lungs still contain some air and are prevented from complete collapse by the intact pleura. This process is *passive* as it does not require the expenditure of energy. After expiration, there is a *pause* before the next cycle begins.

Physiological Variables Affecting Respiration

Elasticity

Elasticity is the term used to describe the ability of the lung to return to its normal shape after each breath. Loss of elasticity of the connective tissue in the lungs necessitates forced expiration and increased effort on inspiration.

Compliance

This is a measure of the distensibility of the lungs, i.e. the effort required to inflate the alveoli. When compliance is low the effort needed to inflate the lungs is greater than normal, e.g. in some diseases where elasticity is reduced or when insufficient surfactant is present. It should be noted that compliance and elasticity are opposing forces.

Airflow Resistance

When this is increased, e.g. in broncho-constriction, more respiratory effort is required to inflate the lungs. Lung volumes and capacities In normal quiet breathing there are about 15 complete respiratory cycles per minute. The lungs and the air passages are never empty and, as the exchange of gases takes place only across the walls of the alveolar ducts and alveoli, the remaining capacity of the respiratory passages is called the *anatomical dead space* (about 150 ml).

Tidal Volume (TV)

This is the amount of air, which passes into and out of the lungs during each cycle of normal breathing (about 500ml – 750ml depending on body mass).

Inspiratory Reserve Volume (IRV)

This is the extra volume of air that can be inhaled into the lungs during maximal inspiration.

Inspiratory Capacity (IC)

This is the amount of air that can be inspired with maximum effort. It consists of the tidal volume (500ml) plus the inspiratory reserve volume.

Functional Residual Capacity (FRC)
This is the amount of air remaining in the air passages and alveoli at the end of quiet expiration.

Expiratory Reserve Volume (ERV)
This is the largest volume of air, which can be expelled from the lungs during maximal expiration.

Residual Volume (RV)
This cannot be directly measured but is the volume of air remaining in the lungs after forced expiration.

Vital Capacity (VC)
This is the maximum volume of air, which can be moved into and out of the lungs:

$$VC = \text{Tidal volume} + IRV + ERV$$

Alveolar Ventilation
This is the volume of air that moves into and out of the alveoli per minute. It is equal to the tidal volume minus the anatomical dead space, multiplied by the respiratory rate:

Alveolar Ventilation =

= (TV - anatomical dead space) x respiratory rate
= (500-150) ml x 15 per minute
= 5.25 litres per minute

Composition of Air
Atmospheric pressure at sea level is 101.3 kilopascals (kPa) or 760mmHg. With the increase in height above sea level, atmospheric pressure is progressively reduced and at 5500 m, about two-thirds the height of Mount Everest (8850 m), it is about half that at sea level. Under water, pressure increases by approximately 1 atmosphere per 10 m below sea level.

Air is a mixture of gases: nitrogen, oxygen, carbon dioxide, water vapour and small quantities of inert gases. Each gas in the mixture exerts a part of the total pressure proportional to its concentration, i.e . the *partial pressure*. This is denoted as, e.g. PO_2, PCO_2.

The Composition Of Inspired And Expired Air		
	Inspired Air %	Expired Air %
Oxygen	21	16
Carbon Dioxide	0.04	4
Nitrogen And Rare Gases	78	78
Water Vapour	Variable	Saturated

Alveolar Air
The composition of alveolar air remains fairly constant and is different from atmospheric air. It is saturated with water vapour and contains more carbon dioxide, and less oxygen. Saturation with water vapour provides 6.3kPa (47 mmHg) thus reducing the partial pressure of all the other gases present. Gaseous exchange between the alveoli and the bloodstream *(external respiration)* is a continuous process, as the alveoli are never empty, so it is independent of the respiratory cycle. During each inspiration only some of the alveolar gases are exchanged.

Expired Air
This is a mixture of alveolar air and atmospheric air in the dead space.

Diffusion of Gases
Exchange of gases occurs when a difference in partial pressure exists across semi-permeable membranes. Gases move by diffusion from the higher concentration to the lower until equilibrium is established. Atmospheric nitrogen is not used by the body so its partial pressure remains unchanged and is the same in inspired and expired air, alveolar air and in the blood.

External Respiration
This is exchange of gases by diffusion between the alveoli and the blood. Each alveolar wall is one cell thick and is surrounded by a network of tiny capillaries (the walls of which are also only one cell thick). The total area for gas exchange in the lungs is 70 to 80 square metres. Venous blood arriving at the lungs has travelled from all the active tissues of the body, and contains high levels of CO_2 and low levels of O_2.

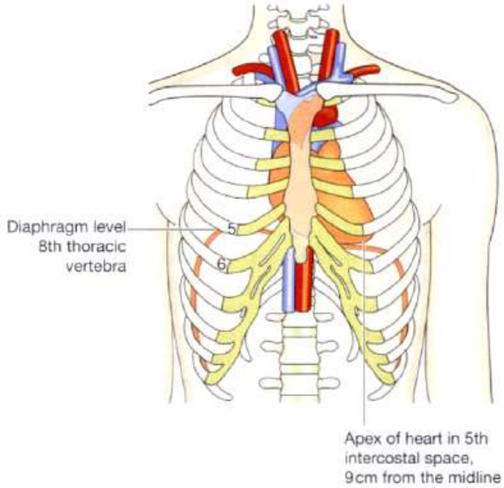
Carbon dioxide diffuses from venous blood down its concentration gradient into the alveoli until equilibrium with alveolar air is reached. By the same process, oxygen diffuses from the alveoli into the blood. The slow flow of blood through the capillaries increases the time available for diffusion to occur. When blood leaves the alveolar capillaries, the oxygen and carbon dioxide concentrations are in equilibrium with those of alveolar air.

CARDIO-VASCULAR SYSTEM 2.3

The Heart 2.3.1

The heart is a roughly cone-shaped hollow muscular organ. It is about 10 cm long and is about the size of the owner's fist. It weighs about 225g in women 310g and men in.

The heart lies in the thoracic cavity in the mediastinum between the lungs. It lies obliquely, a little more to the left than the right, and presents a *base* above, and an *apex* below. The apex is about 9 cm to the left of the midline at the level of the 5th inter-costal space, i.e. a little below the nipple and slightly nearer the midline. The base extends to the level of the 2nd rib.



Structure

The heart is composed of three layers of tissue: pericardium, myocardium and endocardium.

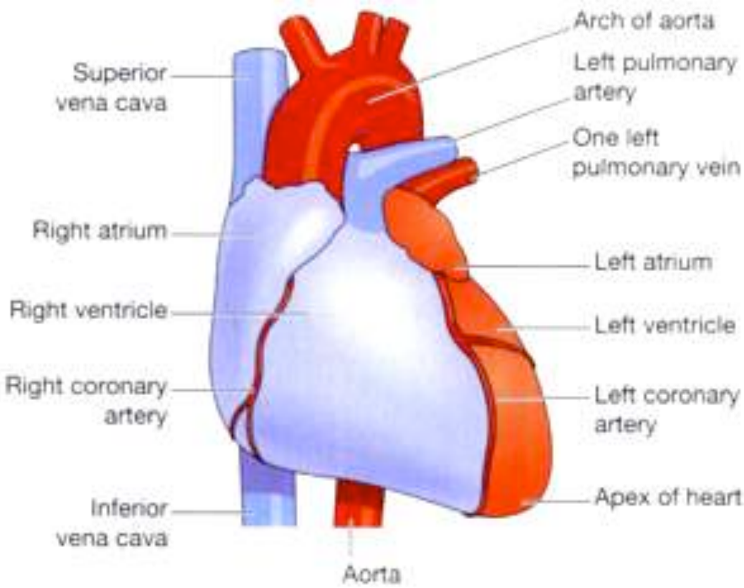
Pericardium

The pericardium is made up of two sacs. The outer sac consists of fibrous tissue and the inner of a continuous double layer of serous membrane.

The outer fibrous sac is continuous with the tunica adventitia of the great blood vessels above and is adherent to the diaphragm below. Its inelastic, fibrous nature prevents overdistension of the heart.

Myocardium

The Heart



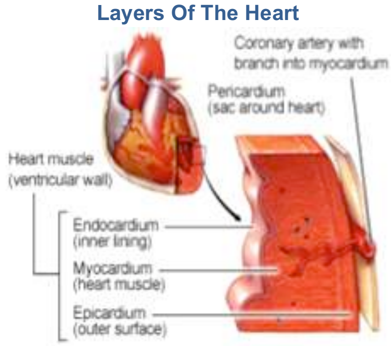
The myocardium is composed of specialised cardiac muscle found only in the heart.

It is not under voluntary control but, like skeletal muscle, cross-stripes are seen on microscopic examination. Each fibre (cell) has a nucleus and one or more branches. The ends of the cells and their branches are in very close contact with the ends and branches of adjacent cells.

This arrangement gives cardiac muscle the appearance of being a sheet of muscle rather than a very large number of individual cells.

Because of the end-to-end continuity of the fibres, each one does not need to have a separate nerve supply. When an impulse is initiated it spreads from cell to cell via the branches and intercalated discs over the whole 'sheet' of muscle, causing contraction. The 'sheet' arrangement of the myocardium enables the atria and ventricles to contract in a coordinated and efficient manner.

Layers Of The Heart



The myocardium is thickest at the apex and thins out towards the base. This reflects the amount of work each chamber contributes to the pumping of blood. It is thickest in the left ventricle.

A ring of fibrous tissue that does not conduct electrical impulses separates the atria and the ventricles. Consequently, when a wave of electrical activity passes over the atrial muscle, it can only spread to the ventricles through the conducting system, which bridges the fibrous ring from atria to ventricles.

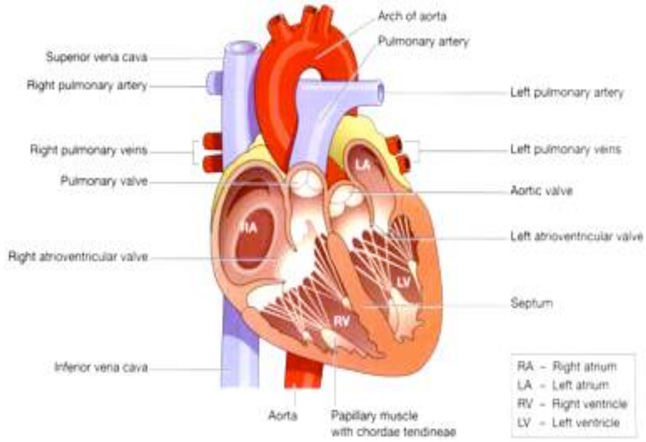
Endocardium

This forms the lining of the myocardium and the heart valves. It is a thin, smooth, glistening membrane, which permits smooth flow of blood inside the heart. It consists of flattened epithelial cells, continuous with the endothelium that lines the blood vessels.

Interior of the Heart

The heart is divided into a right and left side by the *septum*, a partition consisting of myocardium covered by endocardium.

The Heart (Internal)



After birth, blood cannot cross the septum from one side to the other. An atrioventricular valve into an upper chamber, the atrium, and a lower chamber, the ventricle divides each side.

Double folds of endocardium strengthened by a little fibrous tissue form the atrioventricular valves. The *right atrioventricular valve* (tricuspid valve) has three flaps or *cusps* and the *left atrioventricular valve* (mitral valve) has two cusps.

The valves between the atria and ventricles open and close passively, according to changes in pressure in the chambers. They open when the pressure in the atria is greater than that in the ventricles.

During *ventricular systole* (contraction) the pressure in the ventricles rises above that in the atria and the valves snap shut preventing backward flow of blood.

The valves are prevented from opening upwards into the atria by tendinous cords, called *chordae tendineae.*

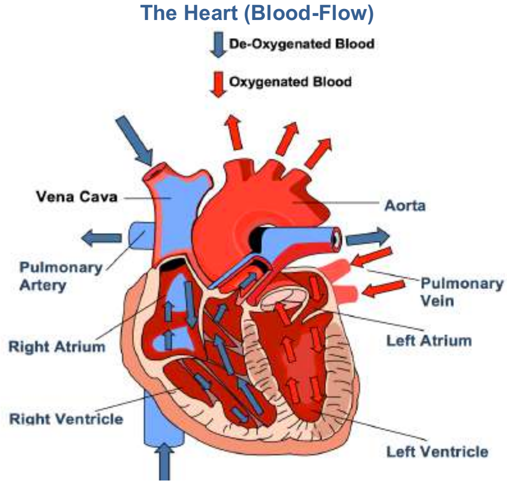
Flow Of Blood Through The Heart

The two largest veins of the body, the *superior* and *inferior venae cavae,* empty their contents into the right atrium.

This blood passes via the right atrio-ventricular valve into the right ventricle, and from there it is pumped into the *pulmonary artery* or *trunk* (the only artery in the body which carries deoxygenated blood).

The pulmonary valve, formed by three semilunar cusps, guards the opening of the pulmonary artery.

The Heart (Blood-Flow)

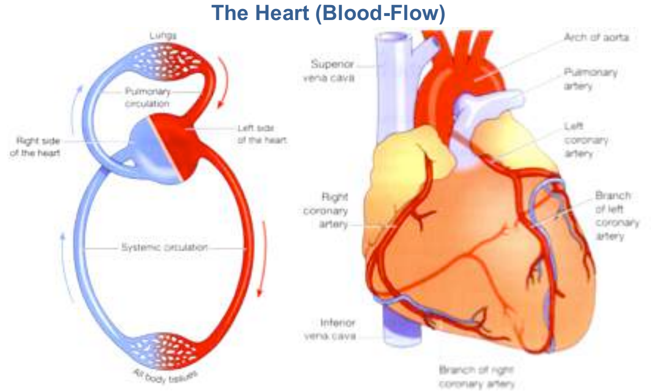


This valve prevents the back flow of blood into the right ventricle when the ventricular muscle relaxes. After leaving the heart the pulmonary artery divides into *left* and *right pulmonary arteries,* which carry the venous blood to the lungs where exchange of gases takes place: carbon dioxide is excreted and oxygen is absorbed.

Two *pulmonary veins* from each lung carry *oxygenated blood* back to the *left atrium.* Blood then passes through the left atrio-ventricular valve into the left ventricle, and from there it is pumped into the aorta, the first artery of the general circulation. The aortic valve, formed by three semilunar cusps, guards the opening of the aorta.

From this sequence of events it can be seen that the blood passes from the right to the left side of the heart via the lungs, or pulmonary circulation. However, it should be noted that both atria contract at the same time and this is followed by the simultaneous contraction of both ventricles.

The Heart (Blood-Flow)



The muscle layer of the walls of the atria is very thin in comparison with that of the ventricles. This is consistent with the amount of work it does. The atria, usually assisted by gravity, only propel the blood through the atrio-ventricular valves into the ventricles, whereas the ventricles actively pump the blood to the lungs and round the whole body. The muscle layer is thickest in the wall of the left ventricle.

The pulmonary trunk leaves the heart from the upper part of the right ventricle, and the aorta leaves from the upper part of the left ventricle.

Blood Supply To The Heart

Arterial supply

The heart is supplied with arterial blood by the *right and left coronary arteries,* which branch from the aorta immediately distal to the aortic valve.

The coronary arteries receive about 5% of the blood pumped from the heart. The coronary arteries traverse the heart, eventually forming a vast network of capillaries.

Venous Drainage

Most of the venous blood is collected into several small veins that join to form the *coronary sinus,* which opens into the right atrium.

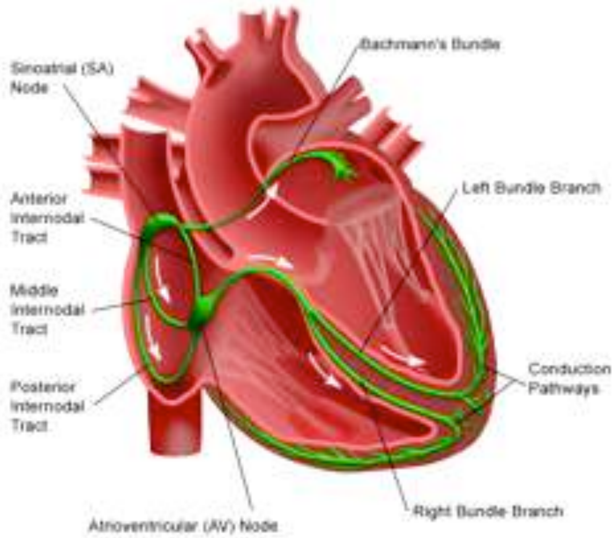
The remainder passes directly into the heart chambers through little venous channels.

Electrical Conducting System Of The Heart

The heart has an intrinsic system whereby the cardiac muscle is automatically stimulated to contract without the need for a nerve supply from the brain. However, the intrinsic system can be stimulated or depressed by nerve impulses initiated in the brain and by circulating chemicals including hormones.

There are small groups of specialised neuromuscular cells in the myocardium, which initiate and conduct impulses causing coordinated and synchronised contraction of the heart muscle.

The Heart (Electrical Pathway)



Sinoatrial Node (SA node)

This small mass of specialised cells is in the wall of the right atrium near the opening of the superior vena cava. The SA node is the *'pace-maker'* of the heart because it normally initiates impulses more rapidly than other groups of neuromuscular cells.

Atrioventricular Node (AV node)

This small mass of neuromuscular tissue is situated in the wall of the atrial septum near the atrio-ventricular valves. Normally the AV node is stimulated by impulses that sweep over the atrial myocardium.

Atrioventricular Bundle (AV bundle or bundle of His)

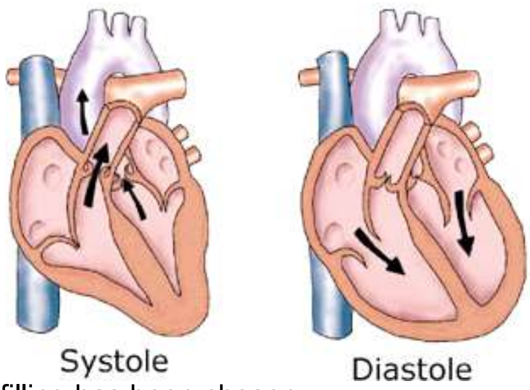
This is a mass of specialised fibres that originate from the AV node. The A V bundle crosses the fibrous ring that separates atria and ventricles then, at the upper end of the ventricular septum, it divides into *right and left bundle branches.* Within the ventricular myocardium the branches break up into fine fibres, called the *Purkinje fibres.*

The AV bundle, bundle branches and Purkinje fibres convey electrical impulses from the AV node to the apex of the myocardium where the wave of ventricular contraction begins, then sweeps upwards and outwards, pumping blood into the pulmonary artery and the aorta.

The Cardiac Cycle

The function of the heart is to maintain a constant circulation of blood throughout the body. The heart acts as a pump and its action consists of a series of events known as the *cardiac cycle*.

During each heartbeat, or cardiac cycle, the heart contracts and then relaxes. The period of contraction is called *systole* and that of relaxation, *diastole.*



Stages of the Cardiac Cycle

The normal number of cardiac cycles per minute ranges from 60 to 80. Taking 74 as an example each cycle lasts about *0.8 of a second* and consists of:

- Atrial systole (contraction of the atria).
- Ventricular systole (contraction of the ventricles).
- Cardiac diastole (relaxation of the atria and ventricles).

It does not matter at which stage of the cardiac cycle a description starts. For convenience the period when the atria are filling has been chosen.

The superior vena cava and the inferior vena cava transport deoxygenated blood into the right atrium *at the same time* as the four pulmonary veins convey oxygenated blood into the left atrium.

The atrio-ventricular valves are open and blood flows through to the ventricles. The SA node triggers a wave of contraction that spreads over the myocardium of both atria, emptying the atria and completing ventricular filling (atrial systole 0.1s). When the wave of contraction reaches the AV node it is stimulated to emit an impulse, which quickly spreads to the ventricular muscle via the AV bundle, the bundle branches and Purkinje fibres. This results in a wave of contraction, which sweeps upwards from the apex of the heart and across the walls of both ventricles pumping the blood into the pulmonary artery and the aorta (ventricular systole 0.3s). The high pressure generated during ventricular contraction is greater than that in the aorta and forces the atrioventricularvalves to close, preventing backflow of blood into the atria.

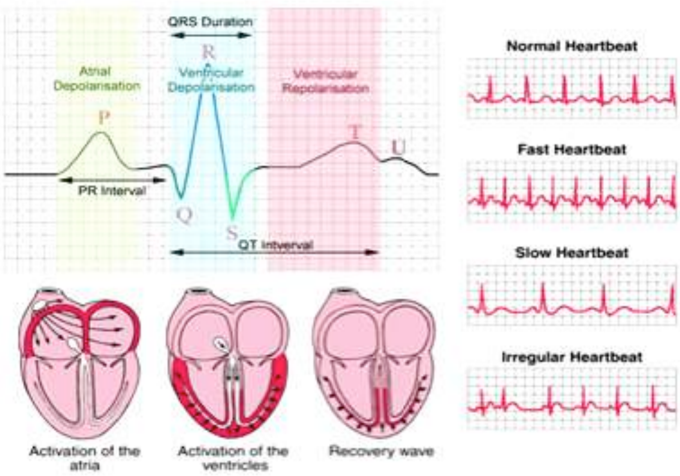
After contraction of the ventricles there is *complete cardiac diastole,* a period of *0.4 seconds,* when atria and ventricles are relaxed. During this time the myocardium recovers until it is able to contract again, and the atria refill in preparation for the next cycle.

The valves of the heart and of the great vessels open and close according to the pressure within the chambers of the heart. The AV valves are open while the ventricular muscle is relaxed during atrial filling and systole. When the ventricles contract there is a gradual increase in the pressure in these chambers, and when it rises above atrial pressure the atrio-ventricular valves close.

When the ventricular pressure rises above that in the pulmonary artery and in the aorta, the pulmonary and aortic valves open and blood flows into these vessels. When the ventricles relax and the pressure within them falls, the reverse process occurs. First the pulmonary and aortic valves close, then the atrio-ventricular valves open and the cycle begins again. This sequence of opening and closing valves ensures that the blood flows in only one direction. This figure also shows how the walls of the aorta and other elastic arteries stretch and recoil in response to blood pumped into them.

Electrical Changes in the Heart

The Heart (Electrical Pathway)



As the body fluids and tissues are good conductors of electricity, the electrical activity within the heart can be detected by attaching electrodes to the surface of the body. The apparatus used is an *electrocardiograph* and the tracing is an *electrocardiogram* (ECG).

The normal ECG tracing shows five waves which, by convention, have been named P,Q, R, S and T. The P wave arises when the impulse from the SA node sweeps over the atria. The QRS complex represents the very rapid spread of the impulse from the A V node through the A V bundle and the Purkinje fibres and the electrical activity of the ventricular muscle. The T wave represents the relaxation of the ventricular muscle.

The ECG described above originates from the SA node and is known as *sinus rhythm.* The rate of sinus rhythm is 60 to 100 beats per minute. A faster heart rate is called *tachycardia* and a slower heart rate, *bradycardia.*

By examining the pattern of waves and the time interval between cycles and parts of cycles, information about the state of the myocardium and the cardiac conduction system is obtained.

Cardiac Output

The cardiac output is the amount of blood ejected from the heart. The amount expelled by each contraction of the ventricles is the *stroke volume.* Cardiac output is expressed in litres per minute (1/min) and is calculated by multiplying the stroke volume by the heart rate (measured in beats per minute):

Cardiac output = Stroke volume x Heart rate

In a healthy adult at rest, the stroke volume is approximately 70ml and if the heart rate is 72 per minute, the cardiac output is 5L/minute. This can be greatly increased to meet the demands of exercise to around 25L/minute, and in athletes up to 35L/minute. This increase during exercise is called the *cardiac reserve.*

Stroke Volume

The volume of blood in the ventricles determines the stroke volume immediately before they contract, i.e. the ventricular end-diastolic volume (VEDV), sometimes called *preload.* This depends on the amount of blood returning to the heart through the superior and inferior venae cavae (the *venous return).*

Increased VEDV leads to stronger myocardial contraction, and more blood is expelled. In turn the stroke volume and cardiac output rise. This capacity to increase the stroke volume with increasing VEDV is finite, and when the limit is reached.

Other Factors That Increase Myocardial Contraction Include:

- Increased stimulation of the sympathetic nerves innervating the heart
- Hormones, e.g. adrenaline, noradrenaline, thyroxine.

Arterial Blood Pressure

This affects the stroke volume as it creates resistance to blood being pumped from the ventricles into the great arteries. This resistance (sometimes called *afterload)* is determined by the distensibility, or *elasticity,* of the large arteries and the *peripheral resistance* of arterioles.

Blood Volume

This is normally kept constant by the kidneys and if deficient the stroke volume, cardiac output and venous return decrease.

Venous Return

Venous return is the major determinant of cardiac output and, normally, the heart pumps out all blood returned to it. The force of contraction of the left ventricle ejecting blood into the aorta is not sufficient to return the blood through the veins and back to the heart. Other factors are involved.

The position of the body. Gravity assists the venous return from the head and neck when standing or sitting and offers less resistance to venous return from the lower parts of the body when an individual is lying flat.

Muscular Contraction

Valves, especially when standing, prevent this causes back flow of blood in veins of the limbs. The contraction of skeletal muscles surrounding the deep veins puts pressure on them, pushing blood towards the heart. In the lower limbs, this is called the *skeletal muscle pump.*

The Respiratory Pump

During inspiration the expansion of the chest creates a negative pressure within the thorax, assisting flow of blood towards the heart. In addition, when the diaphragm descends during inspiration, the increased intra-abdominal pressure pushes blood towards the heart.

Blood Pressure

Blood pressure is the force or pressure, which the blood exerts on the walls of the blood vessels.
The systemic arterial blood pressure, usually called simply arterial blood pressure, is the result of the discharge of blood from the left ventricle into the already full aorta.

When the left ventricle contracts and pushes blood into the aorta the pressure produced within the arterial system is called the *systolic blood pressure.* In adults it is about 120 mmHg (millimeters of mercury).

When *complete cardiac diastole* occurs and the heart is resting following the ejection of blood, the pressure within the arteries is called *diastolic blood pressure.* In an adult this is about 80mmHg. The difference between systolic and diastolic blood pressures is the *pulse pressure.*

These figures vary according to the time of day, the posture, gender and age of the individual. During bed rest at night the blood pressure tends to be lower. It increases with age and is usually higher in women than in men.
Arterial blood pressure is measured with a *sphyg-momanometer.*

It Is Usually Expressed In The Following Manner:

$$BP = {}^{120}/_{70} \text{ mmHg}$$

Pulse

The pulse is a wave of distension and elongation felt in an artery wall due to the contraction of the left ventricle forcing about 60 to 80 millilitres of blood through the already full aorta and into the arterial system.

When the aorta is distended, a wave passes along the walls of the arteries and can be felt at any point where a superficial artery can be pressed gently against a bone. The number of pulse beats per minute normally represents the heart rate and varies considerably in different people and in the same person at different times. An average of 60 to 80 is common at rest.

Information That May Be Obtained From The Pulse Includes:

- The rate at which the heart is beating.
- The regularity with which the heartbeats occur (i.e. the length of time between beats should be the same).
- The volume or strength of the beat (it should be possible to compress the artery with moderate pressure, stopping the flow of blood; the compressibility of the blood vessel gives some indication of the blood pressure and the state of the blood vessel wall).

- The tension (the artery wall should feel soft and pliant under the fingers).

Circulation Of Blood 2.3.2

Blood Vessels

The right side of the heart pumps blood to the lungs (the pulmonary circulation) where gas exchange occurs; i.e. CO_2 leaves the blood and enters the lungs, and O_2 leaves the lungs and enters the blood. The left side of the heart pumps blood into the systemic circulation, which supplies the rest of the body.

Here, tissue wastes are passed into the blood for excretion, and body cells extract nutrients and O_2.

Arteries and Arterioles

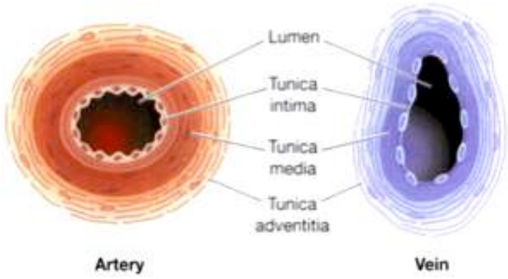
These are the blood vessels that transport blood away from the heart.

They Vary Considerably In Size And Their Walls Consist Of Three Layers Of Tissue:

- *Tunica adventitia* or outer layer of fibrous tissue.
- *Tunica media* or middle layer of smooth muscle and elastic tissue.
- *Tunica intima* or inner lining of squamous epithelium called *endothelium.*

The amount of muscular and elastic tissue varies in the arteries depending upon their size. In the large arteries, sometimes called elastic arteries, the tunica media consists of more elastic tissue and less smooth muscle. These proportions gradually change as the arteries branch many times and become smaller until in the *arterioles* (the smallest arteries) the tunica media consists almost entirely of smooth muscle. Arteries have thicker walls than veins and this enables them to withstand the high pressure of arterial blood.

Blood Vessels

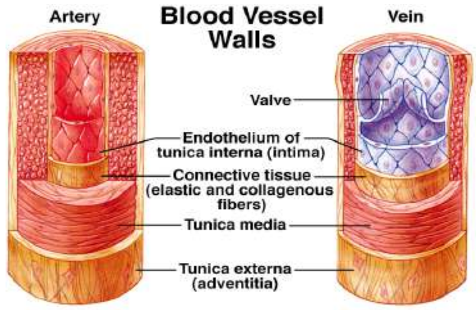


Veins and Venules

The veins are the blood vessels that return blood at low pressure to the heart. The walls of the veins are thinner than those of arteries but have the same three layers of tissue. They are thinner because there is less muscle and elastic tissue in the tunica media. When cut, the veins collapse while the thicker-walled arteries remain open.

When an artery is cut blood spurts at high pressure while a slower, steady flow of blood escapes from a vein.

Some veins possess *valves,* which prevent backflow of blood, ensuring that it flows towards the heart. Valves are abundant in the veins of the limbs, especially the lower limbs where blood must travel a considerable distance against gravity when the individual is standing.



Valves are absent in very small and very large veins in the thorax and abdomen.

They are formed by a fold of tunica intima strengthened by connective tissue. The cusps are *semilunar* in shape with the concavity towards the heart.

The smallest veins are called *venules.*

Systemic or General Circulation

The blood pumped out from the left ventricle is carried by the *branches of the aorta* around the body and is returned to the right atrium of the heart by the *superior* and *inferior venae cavae.*

Pulmonary Circulation

This consists of the circulation of blood from the right ventricle of the heart to the lungs and back to the left atrium. In the lungs, CO_2 is excreted and O_2 absorbed.

The pulmonary artery or trunk, carrying *deoxygenated blood,* leaves the upper part of the right ventricle of the heart. It passes upwards and divides into left and right pulmonary arteries at the level of the 5th thoracic vertebra.

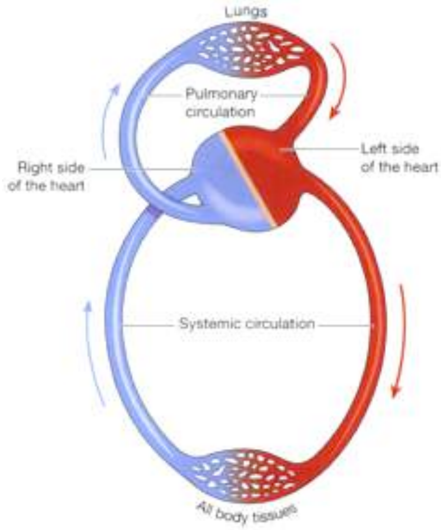
The left pulmonary artery runs to the root of the left lung where it divides into two branches, one passing into each lobe.

The right pulmonary artery passes to the root of the right lung and divides into two branches. The larger branch carries blood to the middle and lower lobes, and the smaller branch to the upper lobe.

Within the lung these arteries divide and subdivide into smaller arteries, arterioles and capillaries. The inter-change of gases takes place between capillary blood and air in the alveoli of the lungs. In each lung the capillaries containing oxygenated blood join up and eventually form two veins.

Two pulmonary veins leave each lung, returning oxygenated blood to the left atrium of the heart. During atrial systole this blood passes into the left ventricle, and during ventricular systole it is forced into the aorta, the first artery of the general circulation.

Systemic Circulation



Venous Circulation Of Blood To The Upper Limb

The veins of the upper limb are divided into two groups: deep and superficial veins.

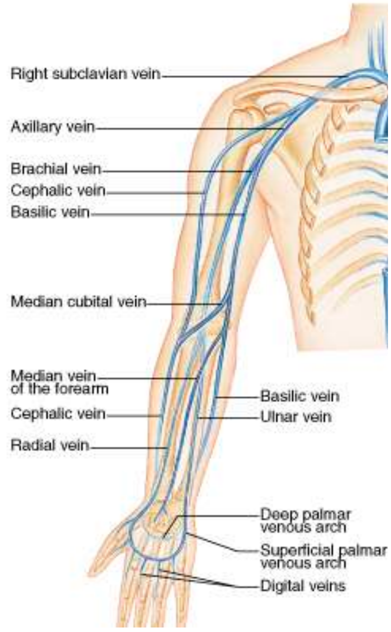
The *Deep Veins* Follow The Course Of The Arteries And Have The Same Names:

- Palmar metacarpal veins
- Deep palmar venous arch
- Ulnar and radial veins
- Brachial vein
- Axillary vein
- Subclavian vein.

The *Superficial Veins* Begin In The Hand And Consist Of The Following:

- Cephalic vein
- Basilic vein
- Median vein
- Median cubital vein.

Veins Of The Arm



The *cephalic vein* begins at the back of the hand where it collects blood from a complex of superficial veins, many of which can be easily seen. It then winds round the radial side to the anterior aspect of the forearm.

In front of the elbow it gives off a large branch, the *median cubital vein,* which slants upwards and medially to join the *basilic vein.* After crossing the elbow joint the cephalic vein passes up the lateral aspect of the arm and in front of the shoulder joint to end in the axillary vein. Through its length it receives blood from the superficial tissues on the lateral aspects of the hand, forearm and arm.

The *basilic vein* begins at the back of the hand on the ulnar aspect. It ascends on the medial side of the forearm and upper arm then joins the axillary vein. It receives blood from the medial aspect of the hand, forearm and arm. There are many small veins, which link the cephalic and basilic veins.

The *median vein* is a small vein that is not always present. It begins at the palmar surface of the hand, ascends on the front of the forearm and ends in the basilic vein or the median cubital vein.

The *brachiocephalic vein* is formed when the subclavian and internal jugular veins unite. There is one on each side.

The *superior vena cava* is formed when the two brachio-cephalic veins unite. It drains all the venous blood from the head, neck and upper limbs and terminates in the right atrium. It is about 7 cm long and passes downwards along the right border of the sternum.

Blood Composition 2.3.3

The total body water in adults of average build is about 60% of body weight. This proportion is higher in young people and in adults below average weight. It is lower in the elderly and in obesity in all age groups. About 22% of body weight is extracellular water and about 38% is intracellular water.

Extracellular Fluid

The extracellular fluid (ECF) consists of blood, plasma, lymph, cerebrospinal fluid and fluid in the interstitial spaces of the body. Interstitial or intercellular fluid (tissue fluid) bathes all the cells of the body except the outer layers of skin. It is the medium through which substances pass from blood to the body cells, and from the cells to blood. Every body cell in contact with the ECF is directly dependent upon the composition of that fluid for its wellbeing.

Intracellular Fluid

The composition of intracellular fluid (ICF) is largely controlled by the cell itself, because there are selective uptake and discharge mechanisms present in the cell membrane. The composition of ICF can therefore be very different from ECF. Thus, sodium levels are nearly ten times higher in the ECF than in the ICF. Conversely, many substances are found inside the cell in significantly higher amounts than outside, e.g. ATP, protein and potassium.

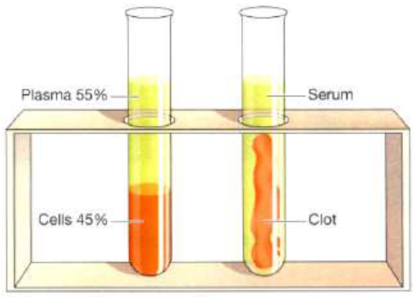
Fluid Distribution

Total Body Water 40 Litres	Extracellular Fluid (ECF) 12 Litres (Plasma 2.5 Litres / Interstitial Fluid 9.5 Litres)
	Intracellular Fluid 28 Litres

Blood is a connective tissue. It provides one of the means of communication between the cells of different parts of the body and the external environment.

Blood Transports:

- Oxygen from the lungs to the tissues and carbon dioxide from the tissues to the lungs for excretion
- Nutrients from the gut to the tissues and cell wastes to the excretory organs, principally the kidneys.
- Hormones secreted by endocrine glands to their target glands and tissues heat produced in active tissues to other less active tissues.
- Protective substances, e.g. antibodies, to areas of infection.
- Clotting factors that coagulate blood, minimising its loss from ruptured blood vessels.



Blood makes up about 7% of body weight (about 5.6 litres in a 70 kg man). This proportion is less in women and considerably greater in children, gradually decreasing until the adult level is reached.

Blood in the blood vessels is always in motion. The continual flow maintains a fairly constant environment for the body cells.

Blood volume and the concentration of its many constituents are kept within narrow limits by homeostatic mechanisms.

Blood Composition

Blood is composed of a straw-coloured transparent fluid, *plasma,* in which different types of cells are suspended. Plasma constitutes about 55% and cells about 45% of blood volume.

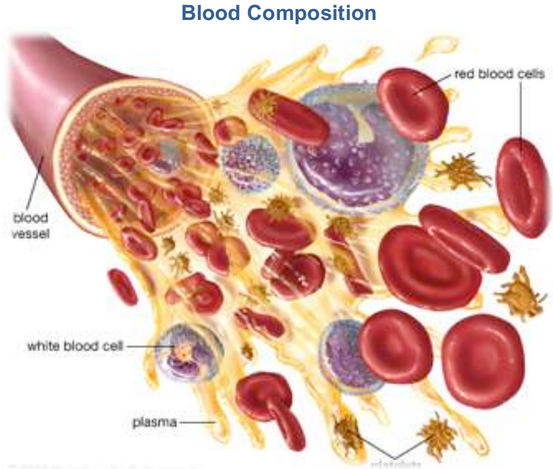
Plasma

The constituents of plasma are water (90 to 92%) and dissolved substances.

These Include:

- Plasma proteins: albumins, globulins (including *antibodies),* fibrinogen, clotting factors.
- Inorganic salts (mineral salts): sodium chloride, sodium bicarbonate, potassium, magnesium, phosphate, iron, calcium, copper, iodine & cobalt.
- Nutrients, principally from digested foods, e.g. monosaccharides (mainly glucose), amino acids, fatty acids, glycerol and vitamins.
- Organic waste materials, e.g. urea, uric acid, creatinine.
- Hormones enzymes, e.g. certain clotting factors.
- Gases, e.g. oxygen, carbon dioxide, nitrogen.

Blood Composition



Plasma Proteins

Plasma proteins, which make up about 7% of plasma, are normally retained within the blood, because they are too big to escape through the capillary pores into the tissues.

They are largely responsible for creating the osmotic pressure of blood, which keeps plasma fluid within the circulation.

If plasma protein levels fall, because of either reduced production or loss from the blood vessels, osmotic pressure is also reduced, and fluid moves into the tissues (oedema) and body cavities.

Albumins

These are formed in the liver. They are the most abundant plasma proteins and their main function is to maintain a normal plasma osmotic pressure. Albumins also act as carrier molecules for lipids and steroid hormones.

Globulins

Most are formed in the liver and the remainder in lymphoid tissue.

Their Main Functions Are:

- As antibodies (immunoglobulins), which are complex proteins produced by lymphocytes that play an important part in immunity. They bind to, and neutralise, foreign materials (antigens) such as micro-organisms.
- Transportation of some hormones and mineral salts; e.g. thyroglobulin carries the hormone thyroxine and transferrin carries the mineral iron.
- Inhibition of some proteolytic enzymes.

Clotting Factors

These are substances essential for coagulation of blood. *Serum* is plasma from which clotting factors have been removed.

Fibrinogen

This is synthesised in the liver and is essential for blood coagulation.
Plasma viscosity (thickness) is due to plasma proteins, mainly albumin and fibrinogen. Viscosity is used as a measure of the body's response to some diseases.

Inorganic salts (mineral salts or Electrolytes)

The amounts of intracellular and extracellular fluids contained in a person's body are extremely important to his healthy physiology. Losses of body fluids by vomiting, diorrhea, or excessive perspiration can produce illness or even death. Whenever body fluids are lost, the substances dissolved in the fluids are also lost. Certain inorganic substances are found in the body's fluids. These are called "electrolytes." Examples of electrolytes are potassium and chloride. These electrolytes exist in their "ion" state in the body fluids.

This means that each ion can combine with one or more ions to form needed body compounds or can produce electro-chemical equilibrium (or balance). One example of this is the osmotic pressure that causes water to flow across a cell membrane. The relationship between the concentrations of sodium and potassium electrolytes in the cells and the extracellular fluid causes the water to flow into and out from the cells. There is usually a low level of sodium in the cells and a high concentration of potassium. Alkalinity and acidity are expressed in terms of pH, which is a measure of hydrogen ion concentration, or [H^+].

The pH of blood is maintained between 7.35 and 7.45 by an ongoing complicated series of chemical activities, involving buffering systems.

The movement of electrolytes is governed by their electrical charge. Some are positively charged and are called "cations." Others are negatively charged and called "anions." Below are the major electrolytes, their chemical abbreviations, and the amount of each contained in a litre of extracellular fluid.

Sodium (Na^+) 135 – 145 mmol/L

The most abundant positive electrolyte (or cation) in the extracellular fluid and is also present in intracellular fluid. The main function of sodium is in maintaining normal osmotic pressure.

Chloride (Cl^-) 95 -110 mmol/L

The most abundant negative electrolyte (or anion) in extracellular fluid and is present in intracellular fluid as well. Chloride is essential to maintain normal osmotic pressure and is found in the stomach fluid.

Potassium (K^+) 3.5-5.0 mmol/L

Potassium is the most abundant electrolyte in the intracellular fluid. Potassium is also required for osmotic pressure but has other vital functions. Potassium is required to convert dextrose (a sugar) into body energy and is vital in transmitting electrical impulses within the heart.

Bicarbonate (HCO_3^-) 19 – 25 mmol/L

Bicarbonate helps to maintain the acid-base balance within the body.

Phosphate (PO_4) 0.5 – 1.6 mmol/L

Phosphate is required for the formation of bones, teeth, and body enzymes.

Magnesium (Mg^{++}) 0.6 – 1.0 mmol/L

Magnesium is essential for the formation of enzymes within the body.

Calcium (Ca^{++}) 2.1 – 2.8 mmol/L

Calcium is essential for the formation of bones and teeth. Calcium is needed to help in blood clotting and in maintaining the rhythm of the heartbeat.

Acid Base Ballance

For proper body functions to continue normally, this internal environment must be kept constant (homeostasis) and within a very narrow limit.

The acid-base balance of the blood is maintained by the chemical balance between the cations and the anions, which must be there in a very delicate balance. The cations are sodium (Na+), potassium (K+), calcium (Ca+) and magnesium (Mg+). The anions are chloride (Cl–), bicarbonate (HCO_3-) and phosphate (PO_4). The acid-base balance is normally expressed as the "pH." The normal range of the blood pH is 7.35 to 7.45.

The body is always slightly alkaline. The body's acid-base balance is effectively maintained under normal circumstances by the various buffer processes, which neutralize strong acids or strong bases (alkalines) using the body's various buffer systems (chemical, organic, and so forth) to help excrete excess body system products.

Nutrients

Food is digested in the alimentary tract and the resultant nutrients are absorbed, e.g. monosaccharides, amino acids, fatty acids, glycerol and vitamins. Together with mineral salts they are required by all body cells to provide energy, heat, materials for repair and replacement, and for the synthesis of other blood components and body secretions.

Organic Waste Products

Urea, creatinine and uric acid are the waste products of protein metabolism. They are formed in the liver and conveyed in blood to the kidneys for excretion. Carbon dioxide, released by all cells, is conveyed to the lungs for excretion.

Hormones

These are chemical compounds synthesised by endocrine glands. Hormones pass directly from the cells of the glands into the blood, which transports them to their target tissues and organs elsewhere in the body, where they influence cellular activity.

Gases

Oxygen (approximately 15% of the circulating volume), carbon dioxide and nitrogen are transported round the body in solution in plasma. Oxygen and carbon dioxide are also transported in combination with haemoglobin in red blood cells. Most oxygen is carried in combination with haemoglobin and most carbon dioxide as bicarbonate ions dissolved in plasma. Atmospheric nitrogen enters the body in the same way as other gases and is present in plasma but it has no physiological function.

Cellular Content of Blood

There Are Three Types Of Blood Cells:

- Erythrocytes or red cells
- Thrombocytes or platelets
- Leukocytes or white cells

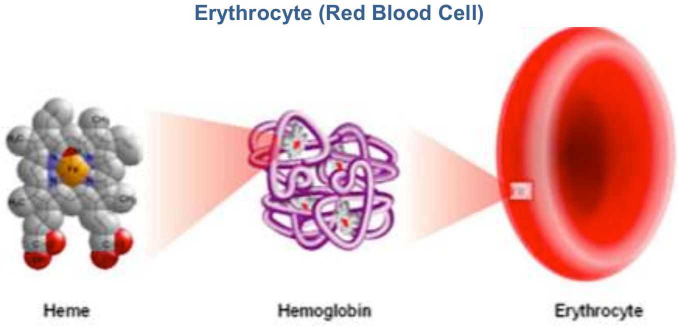
All blood cells originate from *pluripotent stem cells* and go through several developmental stages before entering the blood. Different types of blood cells follow separate lines of development. The process of blood cell formation is called *haemopoiesis* and takes place within red bone marrow.

Erythrocytes (red blood cells / R.B.C.)

Red blood cells (also referred to as erythrocytes) are the most common type of blood cell and the principal means of delivering oxygen (O_2) to the body tissues via the blood flow through the circulatory system.

These cells are rich in hemoglobin, an iron-containing bio-molecule that can bind oxygen and is responsible for the blood's red color.

Erythrocyte (Red Blood Cell)



Mature red blood cells are flexible biconcave disks that lack a cell nucleus and most organelles. 2.4 million new erythrocytes are produced *per* second. The cells develop in the bone marrow and circulate for about 100–120 days in the body before their components are recycled by macrophages. Each circulation takes about 20 seconds. Approximately a quarter of the cells in the human body are red blood cells.

Packed red blood cells, which are made from whole blood with the plasma removed, are used in transfusion medicine.

Erythrocyte count (Male: 4.5×10^{12}/l to 6.5×10^{12}/l (4.5 to 6.5 million/mm^3). Female: 4.5×10^{12}/l to 5×10^{12}/l (4.5 to 5 million/mm^3))

This is the number of erythrocytes per litre or per cubic millimetre (mm^3) of blood.

Packed Cell Volume (PCV) or haematocrit (0.4 to 0.5 l/l (40 to 50/mm3))

This is the volume of red cells in 1 litre or 1 mm3 of whole blood.

Mean Cell Volume (MCV) 80 to 96 fl

This is the average volume of cells, measured in femtolitres (fl =10L-15L).

Haemoglobin Male: (13 to 18g/100ml Female: 11.5 to16.5 g/100 ml)

This is the weight of haemoglobin in whole blood, measured in grams per 100ml.

Leukocytes (white blood cells)

These cells have an important function in defending the body against microbes and other foreign materials. Leukocytes are the largest blood cells and they account for about 1% of the blood volume. They contain nuclei and some have granules in their cytoplasm. There are two main types:

- Granulocytes (polymorphonuclear leukocytes) — neutrophils, eosinophils and basophils
- Agranulocytes — monocytes and lymphocytes.

Granulocytes (polymorphonuclear leukocytes)

During their formation, *granulopoiesis,* they follow a common line of development through *myeloblast* to *myelocyte* before differentiating into the three types.

- Neutrophils
- Eosinophils
- Basophils

All granulocytes have multilobed nuclei in their cytoplasm. Their names represent the dyes they take up when stained in the laboratory. Eosinophils take up the red acid dye, eosin; basophils take up alkaline methylene blue; and neutrophils are purple because they take up both dyes.

Neutrophils 2.5 to 7.5 x 10^9/l

Their main function is to protect against any foreign material that gains entry to the body mainly microbes, and to remove waste materials, e.g. cell debris. They are attracted in large numbers to any area of infection by chemical substances, released by damaged cells, called *chemotaxins.* Neutrophils pass through the capillary walls in the affected area by *amoeboid movement*. Thereafter they engulf and kill the microbes by *phagocytosis*. Their granules are *lysosomes* that contain enzymes that digest the engulfed material. The pus that may form in the affected area consists of dead tissue cells, dead and live microbes, and phagocytes killed by microbes.

Neutrophil (white blood cell)

There is a physiological increase in circulating neutrophils following strenuous exercise and in the later stages of normal pregnancy.

Numbers Are Also Increased In:

- Microbial infection.
- Tissue damage, e.g. inflammation, myocardial infarction, burns, crush injuries.
- Metabolic disorders, e.g.diabetic ketoacidosis, acute gout.
- Leukaemia.
- Heavy smoking.
- Use of oral contraceptives.

Eosinophils 0.04 to 0.44 x 10^9/l

Eosinophil (white blood cell)

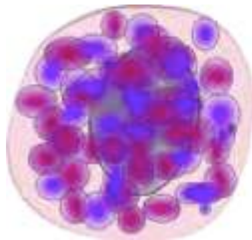
Eosinophils, although capable of phagocytosis, are less active in this than neutrophils; their specialised role appears to be in the elimination of parasites, such as worms, which are too big to be phagocytosed. They are equipped with certain toxic chemicals, stored in their granules, which they release when the eosinophil binds an infecting organism.

Eosinophils are often found at sites of allergic inflammation, such as the asthmatic airway and skin allergies. There, they promote tissue inflammation by releasing their array of toxic chemicals, but they may also dampen down the inflammatory process through the release of other chemicals, such as an enzyme that breaks down histamine.

Basophils 0.015 to 0.1 –x 10^9/l

Basophils, which are closely associated with allergic reactions, contain cytoplasmic granules packed with *heparin* (an anticoagulant), *histamine* (an inflammatory agent) and other substances that promote inflammation.

Basophil (white blood cell)



Usually the stimulus that causes basophils to release the contents of their granules is an *allergen* (an antigen that causes allergy) of some type. This binds to antibody-type receptors on the basophil membrane. A cell type very similar to basophils, except that it is found in the tissues, not in the circulation, is the *mast cell.* Mast cells release their granule contents within seconds of binding an allergen, which accounts for the rapid onset of allergic symptoms following exposure to, for example, pollen in hay fever.

Agranulocytes

The types of leukocyte with a large nucleus and no granules in their cytoplasm are *monocytes* and *lymphocytes* and they make up 25% to 50% of all leukocytes.

Monocytes

These are large mononuclear cells that originate in red bone marrow. Some circulate in the blood and are actively motile and phagocytic while others migrate into the tissues where they develop into *macrophages.* Both types of cell produce *interleukin 1* which:

Monocyte (white blood cell)

- Acts on the hypothalamus, causing the rise in body temperature associated with microbial infections
- Stimulates the production of some globulins by the liver
- Enhances the production of activated T-lymphocytes.

Macrophages have important functions in inflammation and immunity.
Macrophages function in close association with monocytes in the blood and with lymphocytes, which influence their activity. They are actively phagocytic and if they encounter large amounts of foreign or waste material, they tend to multiply at the site and wall off the area, isolating the material, e.g. in the lungs when foreign material has been inhaled. Their numbers are increased in microbial infections, collagen diseases and some non-infective bowel conditions.

Lymphocytes

Lymphocytes are smaller than monocytes and have large nuclei. They circulate in the blood and are present in great numbers in lymphatic tissue such as lymph nodes and the spleen. Lymphocytes develop from pluripotent stem cells in red bone marrow, then travel in the blood to lymphoid tissue elsewhere in the body where they are *activated,* i.e. they become immuno-competent which means they are able to respond to *antigens* (foreign material).

Examples Of Antigens Include:

- Cells regarded by lymphocytes as abnormal, e.g. those that have been invaded by viruses, cancer cells, tissue transplant cells.
- Pollen from flowers and plants.
- Fungi.
- Bacteria.
- Some large molecule drugs, e.g. penicillin, aspirin.

Platlets

Although all lymphocytes originate from one type of stem cell, when they are activated in lymphatic tissue, two distinct types of lymphocyte are produced— *T-lymphocytes* and *B-lymphocytes.*

Thrombocytes **(Platelets) 200 - 350 x 10^9/l**

These are very small non-nucleated discs, 2 to 4 um in diameter, derived from the cytoplasm of megakaryocytes in red bone marrow. They contain a variety of substances that promote blood clotting, which causes *haemostasis* (cessation of bleeding).

The normal blood platelet count is between 200 000 to 350 000/mm^3. The control of platelet production is not yet entirely clear but it is believed that one stimulus is a fall in platelet count and that a substance called *thrombopoietin* is involved. The life span of platelets is between 8 and 11 days and those not used in haemostasis are destroyed by macrophages, mainly in the spleen.

Haemostasis (Blood Clotting) 2.3.4

When a blood vessel is damaged, loss of blood is stopped and healing occurs in a series of overlapping processes, in which platelets play a vital part.

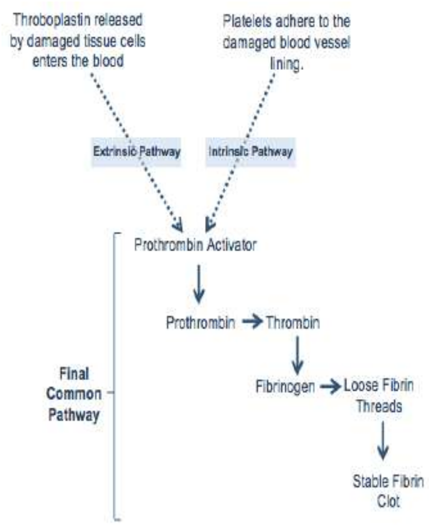
Vasoconstriction

When platelets come in contact with a damaged blood vessel, their surface becomes sticky and they adhere to the damaged wall. They then release *serotonin* (5-hydroxytryptamine), which constricts (narrows) the vessel, reducing blood flow through it. The damaged vessel itself releases other chemicals that cause vasoconstriction, e.g. thromboxanes.

Platelet Plug Formation

The adherent platelets clump to each other and release other substances, including *adenosine diphosphate* (ADP), which attract more platelets to the site. Passing platelets stick to those already at the damaged vessel and they too release their chemicals. This is a positive feedback system by which many platelets rapidly arrive at the site of vascular damage and quickly form a temporary seal the *platelet plug.*

Clotting Cascade



Coagulation (blood clotting)

This is a complex process that also involves a positive feedback system and only a few stages are included here. Their numbers represent the order in which they were discovered and not the order of participation in the clotting process.

Blood clotting results in formation of an insoluble thread-like mesh of *fibrin,* which traps blood cells and is much stronger than the rapidly formed platelet plug. In the final stages of this process *prothrombin activator* acts on the plasma protein *prothrombin* converting it to thrombin.

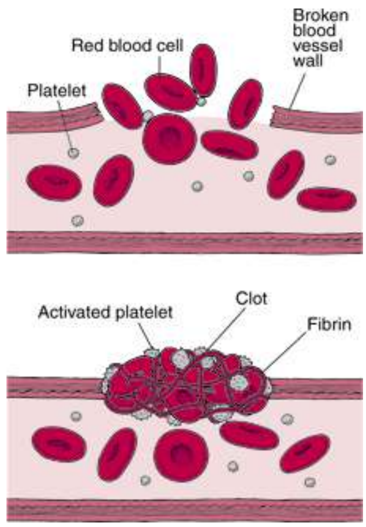
Thrombin then acts on another plasma protein *fibrinogen* and converts it to fibrin.

Two processes, which often occur together, can form prothrombin activator: the extrinsic and intrinsic pathways. The *extrinsic pathway* occurs rapidly (within seconds) when there is tissue damage outside the circulation.

Damaged tissue releases a complex of chemicals called *thromboplastin* or tissue factor, which initiates coagulation. The *intrinsic pathway* is slower (3-6 minutes) and is confined to the circulation. It is triggered by damage to a blood vessel lining (endothelium) and the effects of platelets adhering to it.

After a time the clot shrinks, squeezing out *serum,* a clear sticky fluid that consists of plasma from which clotting factors have been removed.

Clot Formation



Fibrinolysis

After the clot has formed the process of removing it and healing the damaged blood vessel begins. The breakdown of the clot, or fibrinolysis, is the first stage. An inactive substance called *plasminogen* is present in the clot and is converted to the enzyme *plasmin* by activators released from the damaged endothelial cells.

Plasmin initiates the breakdown of fibrin to soluble products that are treated as waste material and removed by phagocytosis.

As the clot is removed, the healing process restores the integrity of the blood vessel wall.

Control of Coagulation

The process of blood clotting relies heavily on several processes thatare self-perpetuating that is, once started, a positive feedback mechanism promotes their continuation. For example, thrombin is a powerful stimulator of its own production. The body therefore possesses several mechanisms to control and limit the coagulation cascade; otherwise once started the clotting process would spread throughout the circulatory system, far beyond requirements.

The Main Controls Are:

- The perfect smoothness of normal blood vessel lining; platelets do not adhere to this surface
- The binding of thrombin to a special thrombin receptor on the cells lining blood vessels; once bound, thrombin is inactivated.
- The presence of natural anticoagulants, e.g. heparin, in the blood, which inactivate clotting factors.

CENTRAL NERVOUS SYSTEM 2.4

The nervous system detects and responds to changes inside and outside the body. Together with the endocrine system it controls important aspects of body function and maintains homeostasis. Nervous system stimulation provides an immediate response while endocrine activity is, in the main, slower and more prolonged.

The nervous system consists of the brain, the spinal cord and peripheral nerves. Organisation of nervous tissue within the body enables rapid communication between different parts of the body.

Response to changes in the internal environment maintains homeostasis and regulates involuntary functions, e.g. blood pressure and digestive activity. Response to changes in the external environment maintains posture and other voluntary activities.

For Descriptive Purposes The Parts Of The Nervous System Are Grouped As Follows:

- *The central nervous system* (CNS), consisting of the brain and the spinal cord
- *The peripheral nervous system* (PNS) consisting of all the nerves outside the brain and spinal cord.

The PNS comprises paired cranial and sacral nerves, some of these are sensory (afferent), some are motor (efferent) and some mixed.

It Is Useful To Consider Two Functional Parts Within The PNS:

- The sensory division
- The motor division

Nerves 2.4.1

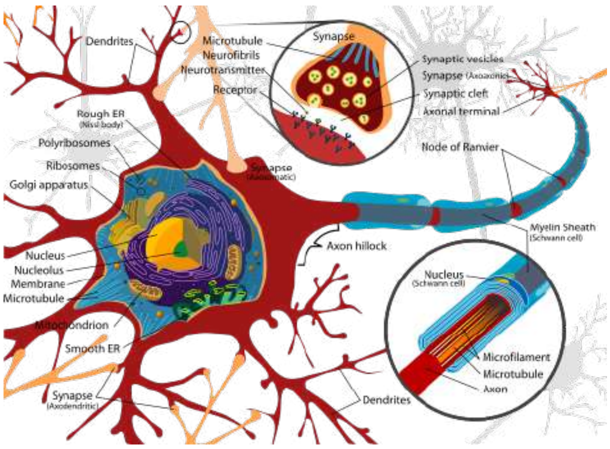
Neurones

The nervous system consists of a vast number of cells called *neurones*, supported by a special type of connective tissue, *neuroglia.* Each neurone consists of a *cell body* and its processes, one *axon* and many *dendrites.* Neurones are commonly referred to simply as nerve cells. Bundles of axons bound together are called *nerves.* Neurones cannot divide and for survival they need a continuous supply of oxygen and glucose. Unlike many other cells, neurones can synthesise chemical energy (ATP) only from glucose.

The physiological 'units' of the nervous system are *nerve impulses,* or *action potentials,* which are akin to tiny electrical charges. However, unlike ordinary electrical wires, the neurones are actively involved in conducting nerve impulses. In effect the strength of the impulse is maintained throughout the length of the neurone.

Some neurones initiate nerve impulses while others act as 'relay stations' where impulses are passed on and sometimes redirected.

Neurone



Properties of Neurones

Neurones have the characteristics of *irritability* and *conductivity.*

Irritability is the ability to initiate nerve impulses in response to stimuli from:

- Outside the body (e.g. touch, light waves).
- Inside the body (e.g. a change in the concentration of CO_2 controls respiration; a thought may result in voluntary movement).

In the body this stimulation may be described as partly electrical and partly chemical-electrical in that motor neurones and sensory nerve endings initiate nerve impulses, and chemical in the transmission of impulses between one neurone and the next or between a neurone and an effector organ.

Conductivity means the ability to transmit an impulse.

Cell Bodies

Nerve cells vary in size and shape but they are all too small to be seen by the naked eye.

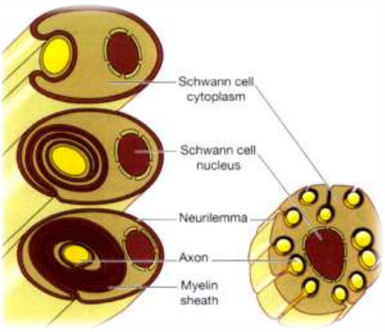
Cell bodies form the *grey matter* of the nervous system and are found at the periphery of the brain and in the centre of the spinal cord. Groups of cell bodies are called *nuclei* in the central nervous system and *ganglia* in the peripheral nervous system.

Axons and Dendrites

Axons and dendrites are extensions of cell bodies and form the *white matter* of the nervous system. Axons are found deep in the brain and in groups, called *tracts,* at the periphery of the spinal cord. They are referred to as *nerves* or *nerve fibres* outside the brain and spinal cord.

Axons

Each nerve cell has only one axon, carrying nerve impulses away from the cell body. They are usually longer than the dendrites, sometimes as long as 100cm.



Structure of an Axon

The membrane of the axon is called *axolemma* and it encloses the cytoplasmic extension of the cell body.

Large axons and those of peripheral nerves are surrounded by a *myelin sheath*. This consists of a series of *Schwann cells* arranged along the length of the axon. Each one is wrapped around the axon so that it is covered by a number of concentric layers of Schwann cell plasma membrane.

Between the layers of plasma membrane there is a small amount of fatty substance called *myelin.* The outermost layer of Schwann cell plasma membrane is sometimes called *neurilemma.* There are tiny areas of exposed axolemma between adjacent Schwann cells, called *nodes of Ranvier,* which assist the rapid transmission of nerve impulses.

Postganglionic fibres and some small fibres in the central nervous system are *non-myelinated.* In this type a number of axons are embedded in Schwann cell plasma membranes. The adjacent Schwann cells are in close association and there is no exposed axolemma. The speed of transmission of nerve impulses is significantly slower in non-myelinated fibres.

Dendrites

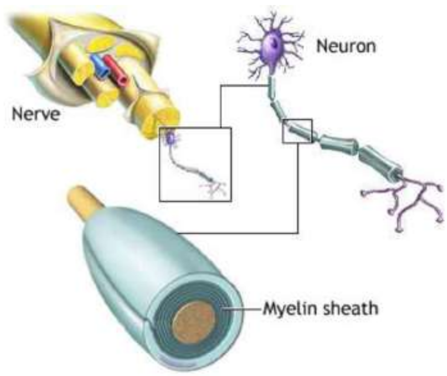
The dendrites are the many short processes that receive and carry incoming impulses towards cell bodies.

They have the same structure as axons but they are usually shorter and branching. In motor neurones they form part of synapses and in sensory neurones they form the sensory receptors that respond to stimuli.

The Nerve Impulse (action potential)

An impulse is initiated by stimulation of sensory nerve endings or by the passage of an impulse from another nerve. Transmission of the impulse, or action potential, is due to movement of ions across the nerve cell membrane. In the resting state the nerve cell membrane is *polarised* due to differences in the concentrations of ions across the plasma membrane.

Nerve Structure



This means that there is a different electrical charge on each side of the membrane that is called the *resting membrane potential.* At rest the charge on the outside is positive and inside it is negative.

The Principal Ions Involved Are:

- Sodium (Na^+) the main extracellular cation
- Potassium (K^+) the main intracellular cation.

In the *resting state* there is a continual tendency for these ions to diffuse along their concentration gradients, i.e. K^+ outwards and Na^+ into cells. When stimulated, the permeability of the nerve cell membrane to these ions changes. Initially Na^+ floods into the neurone from the ECF causing *depolarisation,* creating a *nerve impulse* or *action potential.* Depolarisation is very rapid, enabling the conduction of a nerve impulse along the entire length of a neurone in a few milliseconds (ms). It passes from the point of stimulation in one direction only, i.e. away from the point of stimulation towards the area of resting potential.

During this process K^+ floods out of the neurone and the movement of these ions returns the membrane potential to its resting state. This is called the *refractory period* during which restimulation is not possible. As the neurone returns to its original resting state, the action of the *sodium pump* expels Na^+ from the cell in exchange for K^+.

In myelinated neurones, the insulating properties of the myelin sheath prevent the movement of ions. Therefore electrical changes across the membrane can only occur at the gaps in the myelin sheath, i.e. at the nodes of Ranvier. When an impulse occurs at one node, depolarisation passes along the myelin sheath to the next node so that the flow of current appears to 'leap' from one node to the next. This is called *saltatory conduction*.

The speed of conduction depends on the diameter of the neurone: the larger the diameter, the faster the conduction. Myelinated fibres conduct impulses faster than unmyelinated fibres because saltatory conduction is faster than the complete conduction, or *simple propagation*.

The fastest fibres can conduct impulses to, e.g., skeletal muscles at a rate of 130 metres per second while the slowest impulses travel at 0.5 metres per second.

Types of Nerves

Sensory or Afferent Nerves

When action potentials are generated by sensory receptors on the dendrites of these neurones, they are trans- mitted to the spinal cord by the sensory nerve fibres. The impulses may then pass to the brain or to connector neurones of reflex arcs in the spinal cord.

Sensory Receptors

Specialised endings of sensory neurones respond to different stimuli (changes) inside and outside the body. *Somatic, cutaneous* or *common senses.*

These originate in the skin. They are: pain, touch, heat and cold. Sensory nerve endings in the skin are fine branching filaments without myelin sheaths.

When stimulated, an impulse is generated and transmitted by the sensory nerves to the brain where the sensation is perceived.

Proprioceptor Senses

These originate in muscles and joints and contribute to the maintenance of balance and posture. *Special senses.* These are sight, hearing, smell, touch and taste.

Autonomic Afferent Nerves

These originate in internal organs, glands and tissues, e.g. baroreceptors, chemoreceptors, and are associated with reflex regulation of involuntary activity and visceral pain.

Motor or Efferent Nerves

Motor nerves originate in the brain, spinal cord and autonomic ganglia. They transmit impulses to the effector organs: muscles and glands.

There Are Two Types:

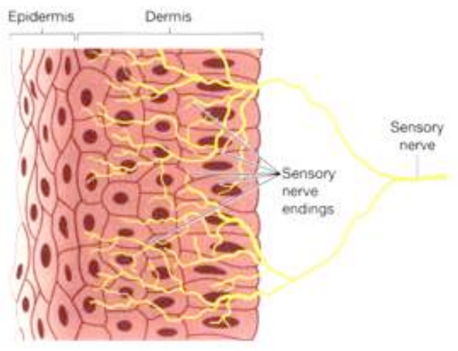
- *Somatic nerves* - Voluntary and reflex skeletal muscle contraction.
- *Autonomic nerves* (sympathetic and parasympathetic) - involved in cardiac and smooth muscle contraction and glandular secretion.

Mixed Nerves

In the spinal cord, sensory and motor nerves are arranged in separate groups, or *tracts.*

Outside the spinal cord, when sensory and motor nerves are within the same sheath of connective tissue they are called *mixed nerves.*

Sensory Nerve



The Synapse And Neurotransmitters

There is always more than one neurone involved in the transmission of a nerve impulse from its origin to its destination, whether it is sensory or motor. There is no physical contact between these neurones. The point at which the nerve impulse passes from one to another is the *synapse.* At its free end the axon of the *presynaptic neurone* breaks up into minute branches, which terminate in small swellings called *synaptic knobs,* or terminal boutons. These are in close proximity to the dendrites and the cell body of the *postsynaptic neurone.*

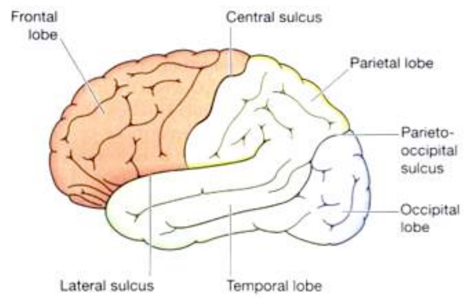
The space between them is the *synaptic cleft.* In the ends of synaptic knobs there are spherical *synaptic vesicles,* containing a chemical, the *neurotransmitter,* which is released into synaptic clefts. Neurotransmitters are synthesised by nerve cells, actively transported along the axons and stored in the synaptic vesicles.

They are released by exocytosis in response to the action potential and diffuse across the synaptic cleft. They act on specific receptor sites on the postsynaptic membranes. Their action is short lived as immediately they have stimulated the post-synaptic neurone or effector organ, such as a muscle fibre; they are either inactivated by enzymes or taken back into the synaptic knob.

The Brain 2.4.2

The brain constitutes about one-fiftieth of the body weight and lies within the cranial cavity.

The Brain



The Parts Are:

- Cerebrum
- Midbrain (the brain stem)
- Pons (the brain stem)
- Medulla oblongata (the brain stem)
- Cerebellum

Blood Supply To The Brain

The circulus arteriosus and its contributing arteries play a vital role in maintaining a constant supply of oxygen and glucose to the brain even when a contributing artery is narrowed or the head is moved. The brain receives about 15% of the cardiac output, approximately 750ml of blood per minute.

Autoregulation keeps blood flow to the brain constant by adjusting the diameter of the arterioles across a wide range of arterial blood pressure (about 65-140 mmHg) with changes occurring only outside these limits.

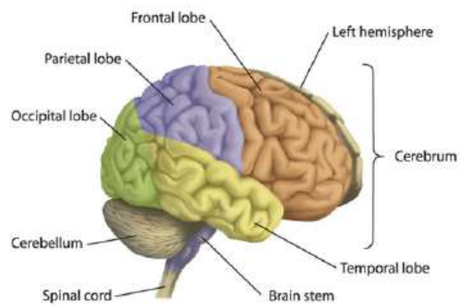
Cerebrum

This is the largest part of the brain and it occupies the anterior and middle cranial fossae. It is divided by a deep cleft, the *longitudinal cerebral fissure,* into *right* and *left cerebral hemispheres,* each containing one of the lateral ventricles. Deep within the brain the hemispheres are connected by a mass of white matter (nerve fibres) called the *corpus callosum.* The falx cerebri is formed by the dura mater. It separates the two hemispheres and penetrates to the depth of the corpus callosum. The superficial (peripheral) part of the cerebrum is composed of nerve cell bodies or grey matter, forming the *cerebral cortex,* and the deeper layers consist of nerve fibres or white matter.

The cerebral cortex shows many infoldings or furrows of varying depth. The exposed areas of the folds are the *gyri* or *convolutions* and these are separated by *sulci* or *fissures.* These convolutions greatly increase the surface area of the cerebrum.

Each hemisphere of the cerebrum is divided into *lobes,* which take the names of the bones of the cranium under which they lie.

The Brain



They Are:

- Frontal
- Parietal
- Temporal
- Occipital.

Interior of the Cerebrum

The surface of the cerebral cortex is composed of grey matter (nerve cell bodies). Within the cerebrum the lobes are connected by masses of nerve fibres, or tracts, which make up the white matter of the brain.

Functions of the Cerebrum

There are three main varieties of activity associated with the cerebral cortex:

- Mental activities involved in memory, intelligence, sense of responsibility, thinking, reasoning, moral sense and learning are attributed to the *higher centres*
- Sensory perception, including the perception of pain, temperature, touch, sight, hearing, taste and smell
- Initiation and control of skeletal (voluntary) muscle contraction.

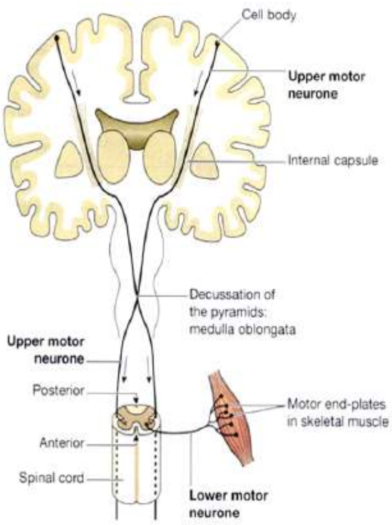
Functional Areas of the Cerebrum

The main areas of the cerebrum associated with sensory perception and voluntary motor activity are known but it is unlikely that any area is associated exclusively with only one function. Except where specially mentioned, the different areas are active in both hemispheres.

The Precentral (motor) Area

This lies in the frontal lobe immediately anterior to the *central sulcus.* The cell bodies are pyramid shaped (Betz's cells) and they initiate the contraction of skeletal muscles. A nerve fibre from a Betz's cell passes downwards through the internal capsule to the medulla oblongata where it crosses to the opposite side then descends in the spinal cord. At the appropriate level in the spinal cord the nerve impulse crosses a synapse to stimulate a second neurone, which terminates at the motor endplate of a muscle fibre. This means that the motor area of the *right hemisphere* of the cerebrum controls voluntary muscle movement on the left side of the body and vice versa. The neurone with its cell body in the cerebrum is the *upper motor neurone* and the other, with its cell body in the spinal cord, is the *lower motor neurone*. Damage to either of these neurones may result in paralysis.

In the motor area of the cerebrum the body is represented upside down, i.e. the cells nearest the vertex control the feet and those in the lowest part control the head, neck, face and fingers. The sizes of the areas of cortex representing different parts of the body are proportional to the *complexity of movement* of the body part, not to its size.



The Premotor Area

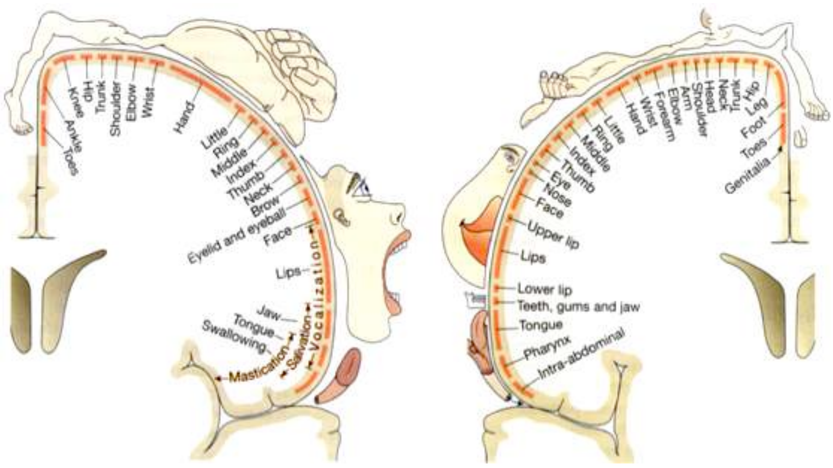
This lies in the frontal lobe immediately anterior to the motor area. The cells are thought to exert a controlling influence over the motor area, ensuring an orderly series of movements. For example, in tying a shoe lace or writing, many muscles contract but the movements must be coordinated and carried out in a particular sequence. Such a pattern of movement, when established, is described as *manual dexterity.*

In the lower part of this area just above the lateral sulcus there is a group of nerve cells known as the *motor speech (Broca's) area,* which controls the movements necessary for speech. It is dominant in the *left hemisphere* in *right-handed people* and vice versa.

The Frontal Area

This extends anteriorly from the premotor area to include the remainder of the frontal lobe. It is a large area and is more highly developed in humans than in other animals. It is thought that communications between this and the other regions in the cerebrum are responsible for the behaviour, character and emotional state of the individual. No particular behaviour, character or intellectual trait has, so far, been attributed to the activity of any one group of cells.

Sensory Centres



The Postcentral (sensory) Area

This is the area behind the central sulcus. Here sensations of pain, temperature, pressure and touch, knowledge of muscular movement and the position of joints are perceived.

The sensory area of the *right hemisphere* receives impulses from the *left side of the body* and vice versa. The size of the areas representing different parts of the body is proportional to the *extent of sensory innervation,* e.g. the large area for the face is consistent with the extensive sensory nerve supply by the three branches of the trigeminal nerves (5th cranial nerves).

The Parietal Area

This lies behind the postcentral area and includes the greater part of the parietal lobe of the cerebrum. Its functions are believed to be associated with obtaining and retaining accurate knowledge of objects.

It has been suggested that objects can be recognised by touch alone because of the knowledge from past experience (memory) retained in this area.

The Sensory Speech Area

Situated in the lower part of the parietal lobe and extends into the temporal lobe. It is here that the spoken word is perceived. There is a dominant area in the *left hemisphere* in *right-handed* people and vice versa.

The Auditory (hearing) Area

This lies immediately below the lateral sulcus within the temporal lobe. The cells receive and interpret impulses transmitted from the inner ear by the cochlear (auditory) part of the vestibulo-cochlear nerves (8th cranial nerves).

The Olfactory (smell) Area
This lies deep within the temporal lobe where impulses from the nose via the olfactory nerves (1st cranial nerves) are received and interpreted.

The Taste Area
This is thought to lie just above the lateral sulcus in the deep layers of the sensory area. This is the area where impulses from special nerve endings in taste buds in the tongue and in the lining of the cheeks, palate and pharynx are perceived as taste.

The Visual Area
This lies behind the parieto-occipital sulcus and includes the greater part of the occipital lobe. The optic nerves (2nd cranial nerves) pass from the eye to this area, which receives and interprets the impulses as visual impressions.

Other Areas Of The Cerebrum
Deep within the cerebral hemispheres there are groups of cell bodies called *nuclei* (previously called ganglia), which act as relay stations where impulses are passed from one neurone to the next in a chain.

Important Masses Of Grey Matter Include:

- Basal nuclei
- Thalamus
- Hypothalamus.

Basal Nuclei
These are areas of grey matter, lying deep within the cerebral hemispheres, with connections to the cerebral cortex and thalamus. The basal nuclei form part of the extrapyramidal tracts and are thought to be involved in initiating muscle tone in slow and coordinated activities. If control is inadequate or absent, movements are jerky, clumsy and uncoordinated.

Thalamus
The thalamus consists of two masses of nerve cells and fibres situated within the cerebral hemispheres just below the corpus callosum, one on each side of the third ventricle. Sensory input from the skin, viscera and special sense organs is transmitted to the thalamus before redistribution to the cerebrum.

Hypothalamus
The hypothalamus is composed of a number of groups of nerve cells. It is situated below and in front of the thalamus, immediately above the *pituitary gland.* The hypothalamus is linked to the posterior lobe of the pituitary gland by nerve fibres and to the anterior lobe by a complex system of blood vessels. Through these connections, the hypothalamus controls the output of hormones from both lobes of the gland.

Other Functions With Which The Hypothalamus Is Concerned Include Control Of:

- The autonomic nervous system.
- Appetite and satiety.
- Thirst and water balance.
- Body temperature.
- Emotional reactions, (e.g. pleasure, fear, rage).
- Sexual behaviour (including mating and child rearing).
- Biological clocks or circadian rhythms, (e.g. sleeping cycles, body temperature and secretion of some hormones).

Brain Stem

Midbrain
The midbrain is the area of the brain situated around the cerebral aqueduct between the cerebrum above and the *pons* below. It consists of groups of cell bodies and nerve fibres (tracts), which connect the cerebrum with lower parts of the brain and with the spinal cord. The cell bodies act as relay stations for the ascending and descending nerve fibres.

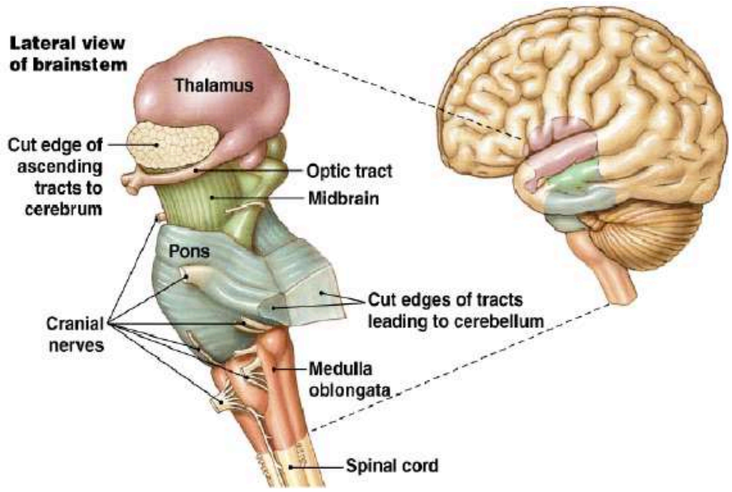
Pons
The pons is situated in front of the cerebellum, below the midbrain and above the medulla oblongata. It consists mainly of nerve fibres, which form a bridge between the two hemispheres of the cerebellum, and of fibres passing between the higher levels of the brain and the spinal cord. There are groups of cells within the pons which act as relay stations and some of these are associated with the cranial nerves.

Medulla Oblongata

The medulla oblongata extends from the pons above and is continuous with the spinal cord below. It is about 2.5 cm long and it lies just within the cranium above the foramen magnum. Central fissures mark its anterior and posterior surfaces. The outer aspect is composed of *white matter,* which passes between the brain and the spinal cord, and *grey matter* lies centrally. Some cells constitute relay stations for sensory nerves passing from the spinal cord to the cerebrum.

The vital centres, consisting of groups of cells associated with autonomic reflex activity, lie in its deeper structure.

The Brain Stem



These Are The:

- Cardiac centre
- Respiratory centre
- Vasomotor centre
- Reflex centres of vomiting, coughing, sneezing and swallowing.

The Medulla Oblongata Has Several Special Features:

- *Decussation (crossing) of the pyramids.* In the medulla *motor nerves* descending from the motor area in the cerebrum to the spinal cord in the pyramidal (corticospinal) tracts cross from one side to the other. This means that the left hemisphere of the cerebrum controls the right half of the body, and vice versa. These tracts are the main pathways for impulses to skeletal (voluntary) muscles.
- *Sensory decussation.* Some of the *sensory nerves* ascending to the cerebrum from the spinal cord cross from one side to the other in the medulla. Others decussate at lower levels, i.e. in the spinal cord.
- *The cardiovascular centre* controls the rate and force of cardiac contraction. Sympathetic and parasympathetic nerve fibres originating in the medulla pass to the heart. Sympathetic stimulation increases the rate and force of the heartbeat and parasympathetic stimulation has the opposite effect.
- *The respiratory centre* controls the rate and depth of respiration. From this centre, nerve impulses pass to the phrenic and intercostal nerves, which stimulate contraction of the diaphragm and intercostal muscles, thus initiating inspiration. The respiratory centre is stimulated by excess carbon dioxide and, to a lesser extent, by deficiency of oxygen in its blood supply and by nerve impulses from the chemoreceptors in the carotid bodies.
- *The vasomotor centre* controls the diameter of the blood vessels, especially the small arteries and arterioles, which have a large proportion of smooth muscle fibres in their walls. Vasomotor impulses reach the blood vessels through the autonomic nervous system. Stimulation may cause either constriction or dilatation of blood vessels depending on the site.
- The sources of stimulation of the vasomotor centre are the arterial baroreceptors, body temperature and emotions such as sexual excitement and anger. Pain usually causes vasoconstriction although severe pain may cause vasodilatation, a fall in blood pressure and fainting.
- *Reflex centres.* When irritating substances are present in the stomach or respiratory tract, nerve impulses pass to the medulla oblongata, stimulating the reflex centres, which initiate the reflex actions of vomiting, coughing and sneezing to expel the irritant.

Reticular Formation

The reticular formation is a collection of neurones in the core of the brain stem, surrounded by neural pathways, which conduct ascending and descending nerve impulses between the brain and the spinal cord. It has a vast number of synaptic links with other parts of the brain and is therefore constantly receiving 'information' being transmitted in ascending and descending tracts.

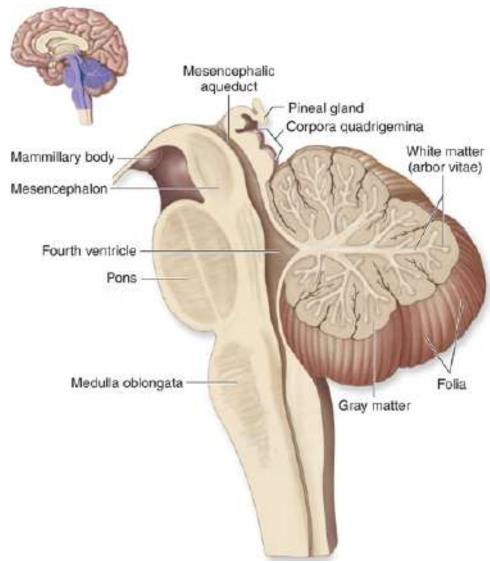
The Reticular Formation Is Involved In:

- Coordination of skeletal muscle activity associated with voluntary motor movement and the maintenance of balance.
- Coordination of activity controlled by the autonomic nervous system, e.g. cardiovascular, respiratory and gastrointestinal activity.
- Selective awareness that functions through the *reticular activating system* (RAS), which selectively blocks or passes sensory information to the cerebral cortex, (e.g. the slight sound made by a sick child moving in bed may arouse his mother but the noise of regularly passing trains may be suppressed).

Cerebellum

The cerebellum is situated behind the pons and immediately below the posterior portion of the cerebrum occupying the posterior cranial fossa. It is ovoid in shape and has two hemispheres, separated by a narrow median strip called the *vermis.* Grey matter forms the surface of the cerebellum, and the white matter lies deeply.

The Cerebellum



The cerebellum is concerned with the coordination of voluntary muscular movement, posture and balance. Cerebellar activities are not under voluntary control. The cerebellum controls and coordinates the movements of various groups of muscles ensuring smooth, even, precise actions. It coordinates activities associated with the *maintenance of the balance and equilibrium* of the body.

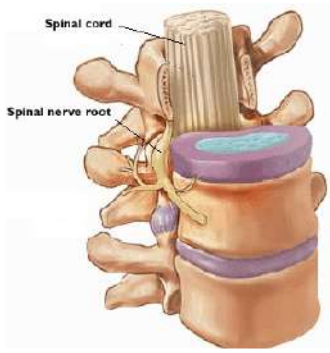
The sensory input for these functions is derived from the muscles and joints, the eyes and the ears. *Proprioceptor impulses* from the muscles and joints indicate their position in relation to the body as a whole and those impulses from the eyes and the semicircular canals in the ears pro- vide information about the position of the head in space. Impulses from the cerebellum influence the contraction of skeletal muscle so that balance and posture are maintained.

Damage to the cerebellum results in clumsy uncoordinated muscular movement, staggering gait and inability to carry out smooth, steady, precise movements.

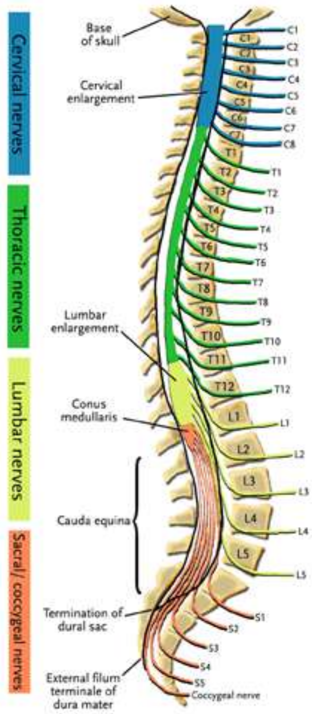
The Spinal Cord 2.4.3

The spinal cord is the elongated, almost cylindrical part of the central nervous system, which is suspended in the vertebral canal surrounded by the meninges and cerebroespinal fluid. It is continuous above with the medulla oblongata and extends from the *upper border of the atlas* to the lower border of the 1st *lumbar vertebra*. It is approximately 45 cm long, and is about the thickness of the little finger.

The Verterbrae



The Spinal Cord



Except for the cranial nerves, the spinal cord is the nervous tissue link between the brain and the rest of the body.

Nerves conveying impulses from the brain to the various organs and tissues descend through the spinal cord. At the appropriate level they leave the cord and pass to the structure they supply. Similarly, sensory nerves from organs and tissues enter and pass upwards in the spinal cord to the brain.

Some activities of the spinal cord are independent of the brain, i.e. *spinal reflexes.* To facilitate these there are extensive neurone connections between sensory and motor neurones at the same or different levels in the cord.

The spinal cord is incompletely divided into two equal parts, anteriorly by a short, shallow *median fissure* and posteriorly by a deep narrow septum, the *posteriormedian septum.*

A cross-section of the spinal cord shows that it is composed of grey matter in the centre surrounded by white matter supported by neuroglia.
The other side is the same.

Grey Matter

The arrangement of grey matter in the spinal cord resembles the shape of the letter H, having *two posterior, two anterior* and *two lateral columns.*

The area of grey matter lying transversely is the *transverse commissure* and the central canal, an extension from the fourth ventricle, containing cerebrospinal fluid, pierces it.

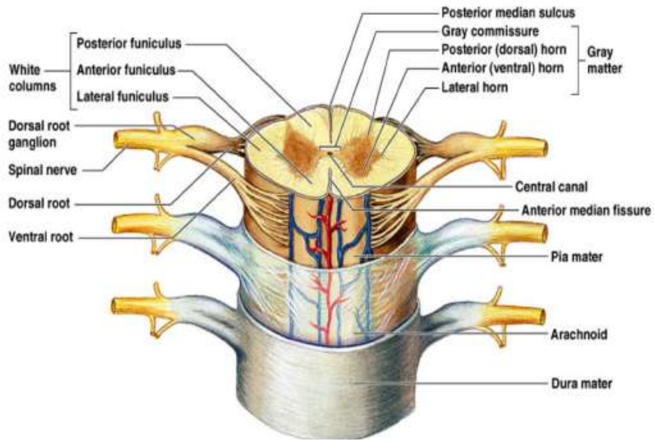
The Cell Bodies May Be:

- *Sensory cells,* which receive impulses from the periphery of the body

- *Lower motor neurones,* which transmit impulses to the skeletal muscles
- *Connector neurones,* linking sensory and motor neurones, at the same or different levels, which form spinal reflex arcs.

At each point where nerve impulses are passed from one neurone to another there is a synaptic cleft and a neurotransmitter.

The Spinal Cord



Posterior Columns Of Grey Matter

These are composed of cell bodies, which are stimulated by *sensory impulses* from the periphery of the body. The nerve fibres of these cells contribute to the formation of the white matter of the cord and transmit the sensory impulses upwards to the brain.

Anterior Columns Of Grey Matter

These are composed of the *cell bodies of the lower motor neurons,* which are stimulated by the axons of the upper motor neurones or by the *cell bodies of connector neurones* linking the anterior and posterior columns to form reflex arcs.

The posterior root (spinal) ganglia are composed of cell bodies, which lie just outside the spinal cord on the path- way of the sensory nerves. All sensory nerve fibres pass through these ganglia. The only function of the cells is to promote the onward movement of nerve impulses.

White Matter

The white matter of the spinal cord is arranged in three *columns* or *tracts;* anterior, posterior and lateral. These tracts are formed by *sensory nervefibres* ascending to the brain, *motor nerve fibres* descending from the brain and fibres of *connector neurones.*
Tracts are often named according to their points of origin and destination, e.g. spinothalamic, corticospinal.

Sensory Nerve Tracts (Afferent Or Ascending) In The Spinal Cord

There are two main sources of sensation transmitted to the brain via the spinal cord.

The Skin

Sensory receptors (nerve endings) in the skin, called *cutaneous receptors,* are stimulated by pain, heat, cold and touch, including pressure. Nerve impulses generated are conducted by three neurones to the sensory area in the *opposite hemisphere of the cerebrum* where the sensation and its location are perceived. Crossing to the other side, or *decussation,* occurs either at the level of entry into the cord or in the medulla.

The Tendons, Muscles and Joints

Sensory receptors are nerve endings in these structures, called *proprioceptors,* and they are stimulated by stretch. Together with impulses from the eyes and the ears they are associated with the maintenance of balance and posture and with perception of the position of the body in space.

These Nerve Impulses Have Two Destinations:

- By a three-neurone system the impulses reach the sensory area of the *opposite hemisphere of the cerebrum*
- By a two-neurone system the nerve impulses reach the *cerebellar hemisphere on the same side.*

Motor Nerve Tracts (Efferent Or Descending) In The Spinal Cord

Neurones, which transmit nerve impulses away from the brain, are motor (efferent or descending) neurones.

Motor Neurone Stimulation Results In:

- Contraction of skeletal (striated, voluntary) muscle.
- Contraction of smooth (involuntary) muscle, cardiac muscle and the secretion by glands controlled by the *autonomic nervous system*.

Voluntary Muscle Movement

The contraction of the muscles, which move the joints, is, in the main, under conscious (voluntary) control, which means that the stimulus to contract originates at the level of consciousness in the cerebrum.

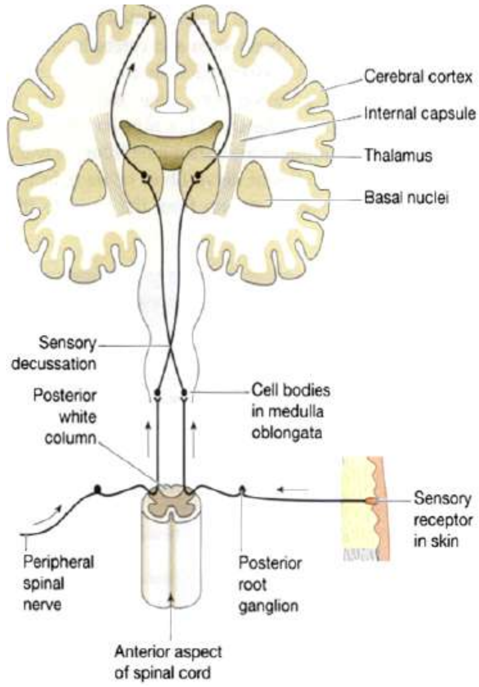
However, some nerve impulses, which affect skeletal muscle contraction, are initiated in the midbrain, brain stem and cerebellum. This involuntary activity is associated with coordination of muscle activity, e.g. when very fine movement is required and in the maintenance of posture and balance.

Efferent nerve impulses are transmitted from the brain to the body via bundles of nerve fibres or *tracts* in the spinal cord.

The *motor pathways* from the brain to the muscles are made up of two *neurones*.

These Tracts Are Either:

- Pyramidal (corticospinal).
- Extrapyramidal.



The motor fibres that form the pyramidal tracts travel through the internal capsule and are the main pathway for impulses to voluntary (skeletal) muscles. Those motor fibres that do not pass through the internal capsule form the extrapyramidal tracts and have connections with multiple parts of the brain (including the basal nuclei and the thalamus).

The Upper Motor Neurone

This has its cell body (Betz's cell) in the *precentral sulcus area* of the cerebrum. The axons pass through the internal capsule, pons and medulla. In the spinal cord they form the *lateral corti-cospinal tracts* of white matter and the fibres terminate in close association with the cell bodies of the *lower motor neurones* in the anterior columns of grey matter.

The axons of these upper motor neurones make up the pyramidal tracts and decussate in the medulla oblongata, forming the pyramids.

The Lower Motor Neurone

This has its cell body in the *anterior horn of grey matter* in the spinal cord. Its axon emerges from the spinal cord by the *anterior root,* joins with the incoming sensory fibres and forms the *mixed spinal nerve* which passes through the *intervertebral foramen.* Near its termination in muscle the axon branches into a variable number of tiny fibres, which form *motor endplates,* each of which is in close association with a sensitive area on the wall of a muscle fibre. The motor endplates of each nerve and the muscle fibres they supply form a *motor unit*.

The neurotransmitter that conveys the nerve impulse across the synapse to stimulate the muscle fibre is *acetylcholine.* Motor units contract as a whole and the strength of contraction of a muscle depends on the number of motor units in action at a time.

The lower motor neurone has been described as the *final common pathway* for the transmission of nerve impulses to skeletal muscles. The cell body of this neurone is influenced by a number of upper motor neurones originating from various sites in the brain and by some neurons, which begin and end in the spinal cord.

Some of these neurones stimulate the cell bodies of the lower motor neurone while others have an inhibiting effect. The outcome of these influences is smooth, coordinated muscle movement, some of which is voluntary and some involuntary.

Involuntary Muscle Movement

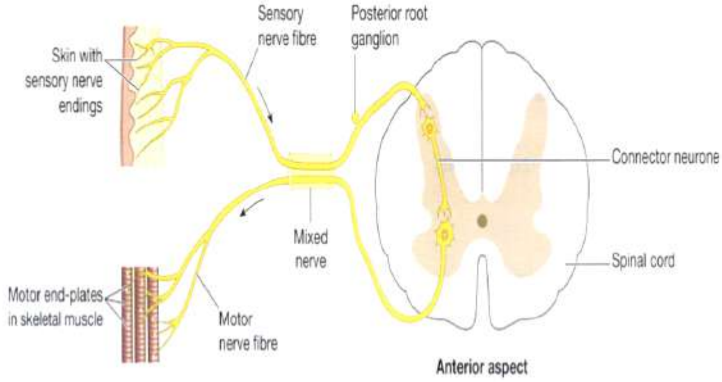
Upper Motor Neurones.

These have their cell bodies in the brain at a level *below* the cerebrum, i.e. in the midbrain, brain stem, cerebellum or spinal cord. They influence muscle activity in relation to the maintenance of posture and balance, the coordination of muscle movement and the control of muscle tone.

Spinal Reflexes

These Consist Of Three Elements:

- Sensory neurons.
- Connector neurones in the spinal cord.
- Lower motor neurones.



In the simplest *reflex arc* there is only one of each. A *reflex action* is an immediate motor response to a sensory stimulus. Many connector and motor neurones may be stimulated by afferent impulses from a small area of skin, e.g. the pain impulses initiated by touching a very hot surface with the finger are transmitted to the spinal cord by sensory nerves. These stimulate many connector and lower motor neurones in the cord, which results in the contraction of many skeletal muscles of the hand, arm and shoulder, and the removal of the finger.

Reflex action takes place very quickly, in fact, the motor response may have occurred simultaneously with the perception of the pain in the cerebrum. Reflexes of this type are invariably protective but they can on occasion be inhibited.

Stretch Reflexes

Only two neurones are involved. The cell body of the lower motor neurone is stimulated by the sensory neurone. There is no connector neurone involved. The *knee jerk* is one example, but this type of reflex can be demonstrated at any point where a stretched tendon crosses a joint. By tapping the tendon just below the knee when it is bent, the sensory nerve endings in the tendon and in the thigh muscles are stretched. This initiates a nerve impulse, which passes into the spinal cord to the cell body of the lower motor neurone in the anterior column of grey matter on the same side. As a result the thigh muscles suddenly contract and the foot kicks forward. This is used as a test of the integrity of the reflex arc. This type of reflex has a protective function it prevents excessive joint movement that may damage tendons, ligaments and muscles.

Peripheral Nervous System 2.4.4

This Part Of The Nervous System Consists Of:

- 31 pairs of spinal nerves.
- 12 pairs of cranial nerves.
- The autonomic part of the nervous system.

Most of the nerves of the peripheral nervous system are composed of *sensory nerve fibres* conveying afferent impulses from sensory end organs to the brain, and *motor nerve fibres* conveying efferent impulses from the brain through the spinal cord to the effector organs, e.g. skeletal muscles, smooth muscle and glands.

Each nerve consists of numerous nerve fibres collected into bundles. Each bundle has several coverings of protective connective tissue.

There Structure Includes:

- *Endoneurium* is a delicate tissue, surrounding each individual fibre, which is continuous with the septa that pass inwards from the perineurium.
- *Perineurium* is a smooth connective tissue, surrounding each *bundle* of fibres.
- *Epineurium* is the fibrous tissue, which surrounds and encloses a number of bundles of nerve fibres. Most large nerves are covered by epineurium.

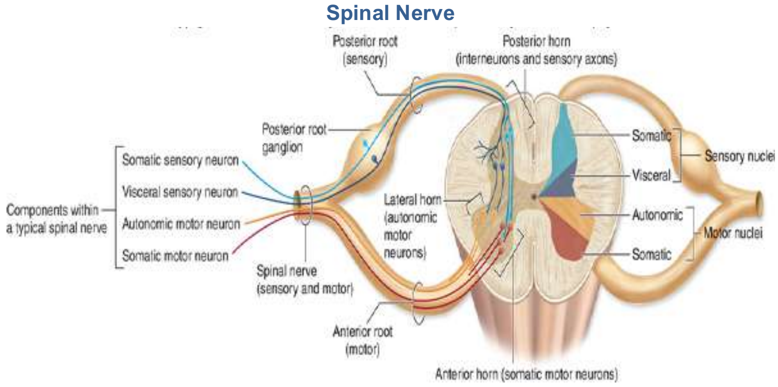
Spinal Nerves

There are *31 pairs of spinal nerves* that leave the vertebral canal by passing through the intervertebral foramina formed by adjacent vertebrae. They are named and grouped according to the vertebrae they are associated with.

These Are:

- 8 cervical
- 12 thoracic
- 5 lumbar
- 5 sacral
- 1 coccygeal

Spinal Nerve



Although there are only seven cervical vertebrae, there are eight nerves because the first pair leaves the vertebral canal between the occipital bone and the atlas and the eighth pair leaves below the last cervical vertebra. Thereafter the nerves are given the name and number of the vertebra immediately *above.*

The lumbar, sacral and coccygeal nerves leave the *spinal cord* near its termination at the level of the first lumbar vertebra, and extend downwards inside the vertebral canal in the subarachnoid space, forming a sheaf of nerves, which resembles a horse's tail, the *cauda equina.* These nerves leave the vertebral canal at the appropriate lumbar, sacral or coccygeal level, depending on their destination.

The spinal nerves arise from both sides of the spinal cord and emerge through the inter-vertebral foramina. Each nerve is formed by the union of a *motor and a sensory nerve root* and is, therefore, a *mixed nerve.* Each spinal nerve has a contribution from the sympathetic part of the autonomic nervous system in the form of a *preganglionic fibre*.

Nerve Roots

The anterior nerve root consists of *motor nerve fibres,* which are the axons of the nerve cells in the anterior column of grey matter in the spinal cord and, in the thoracic and lumbar regions, *sympathetic nerve fibres,* which are the axons of cells in the lateral columns of grey matter.

The posterior nerve root consists of *sensory nerve fibres.* Just outside the spinal cord there is a *spinal ganglion* (posterior root ganglion), consisting of a little cluster of cell bodies. Sensory nerve fibres pass through these ganglia before entering the spinal cord. The area of skin supplied by each nerve is called a *dermatome*.

For a very short distance after leaving the spinal cord the nerve roots have a covering of *dura* and *arachnoid maters.* These terminate before the two roots join to form the mixed spinal nerve. The nerve roots have no covering of pia mater.

Immediately after emerging from the intervertebral foramen each spinal nerve divides into a ramus commu- nicans, a posterior ramus and an anterior ramus.

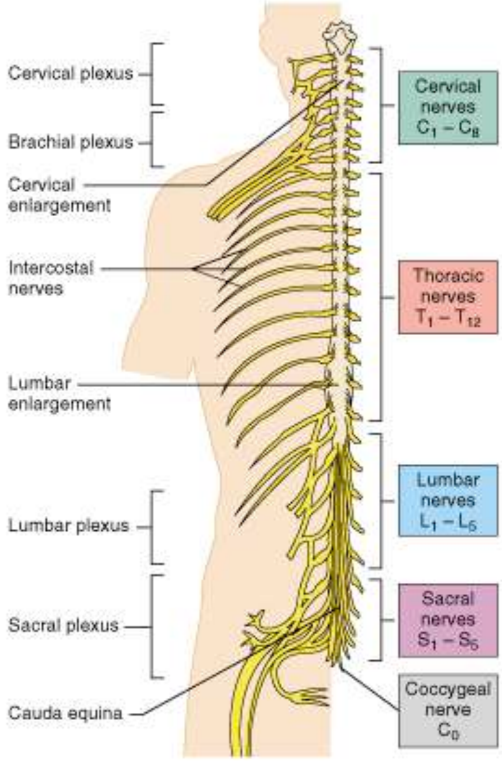
The rami communicans are part of preganglionic sympathetic neurones of the autonomic nervous system. *The posterior rami* pass backwards and divide into medial and lateral branches to supply skin and muscles of relatively small areas of the posterior aspect of the head, neck and trunk. *The anterior rami* supply the anterior and lateral aspects of the neck, trunk and the upper and lower limbs.

In the cervical, lumbar and sacral regions the anterior rami unite near their origins to form large masses of nerves, or *plexuses,* where nerve fibres are regrouped and rearranged before proceeding to supply skin, bones, muscles and joints of a particular area. This means that these structures have a nerve supply from more than one spinal nerve and therefore damage to one spinal nerve does not cause loss of function of a region.

In the thoracic region the anterior rami do not form plexuses.

There are five large plexuses of mixed nerves formed on each side of the vertebral column.

Spinal Nerve Roots



They Are The:

- Cervical plexuses.
- Brachial plexuses.
- Lumbar plexuses.
- Sacral plexuses.
- Coccygeal plexuses.

Cervical Plexus

This is formed by the anterior rami of the first four cervical nerves. It lies opposite the 1st, 2nd, 3rd and 4th cervical vertebrae under the protection of the sterno-cleidomastoid muscle.

The superficial branches supply the structures at the back and side of the head and the skin of the front of the neck to the level of the sternum.

The deep branches supply muscles of the neck, e.g. the sternocleidomastoid and the trapezius.

The phrenic nerve originates from cervical roots 3,4 and 5 and passes downwards through the thoracic cavity in front of the root of the lung to supply the muscle of the diaphragm with impulses, which stimulate contraction.

Brachial Plexus

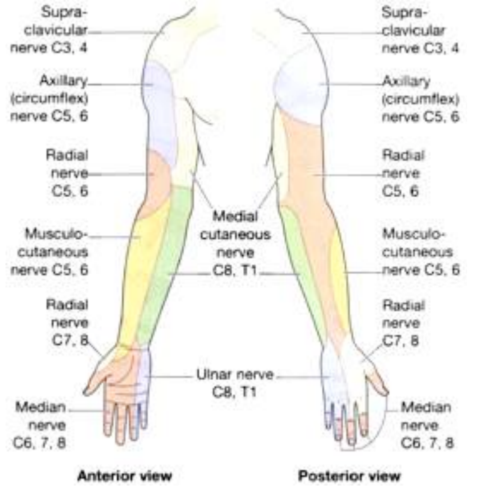
The anterior rami of the lower four cervical nerves and a large part of the first thoracic nerve form the brachial plexus. The plexus is situated in the neck and shoulder above and behind the subclavian vessels and in the axilla.

The branches of the brachial plexus supply the skin and muscles of the upper limbs and some of the chest muscles. Five large nerves and a number of smaller ones emerge from this plexus, each with a contribution from more than one nerve root, containing sensory, motor and autonomic fibres.

These Are:

- Axillary (circumflex) nerve: C5, C6.
- Radial nerve: C5, C6, C7, C8, T1.
- Musculo-cutaneous nerve: C5, C6, C7.
- Median nerve: C5, C6, C7, C8, T1.
- Ulnar nerve: C7, C8, T1.
- Medial cutaneous nerve: C8, T1.

Nerve Sensations Of The Arms



The Axillary (Circumflex) Nerve

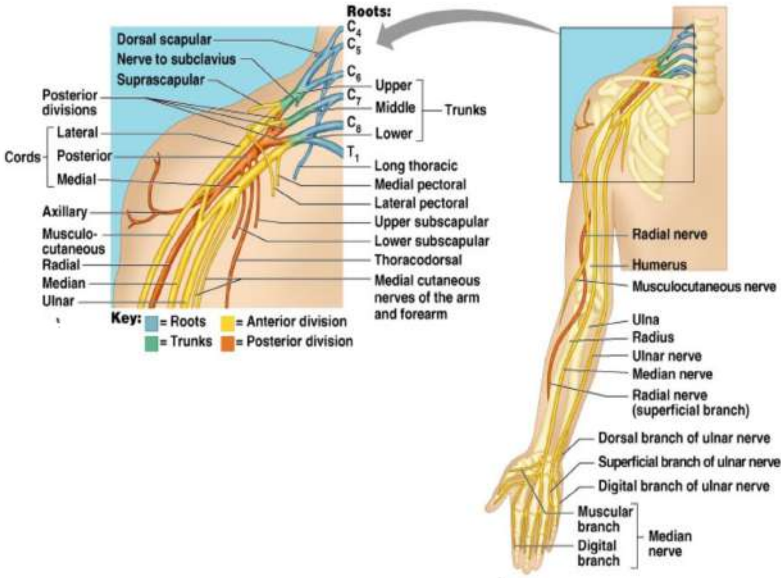
Winds round the humerus at the level of the surgical neck. It then breaks up into minute branches to supply the deltoid muscle, shoulder joint and overlying skin.

The Radial Nerve

The largest branch of the brachial plexus. It supplies the triceps muscle behind the humerus, crosses in front of the elbow joint then winds round to the back of the forearm to supply extensors of the wrist and finger joints.

It continues into the back of the hand to supply the skin of the thumb, the first two fingers and the lateral half of the third finger.

Nerve Roots Of The Arm



The Musculo-Cutaneous Nerve

Passes downwards to the lateral aspect of the forearm. It supplies the muscles of the upper arm and the skin of the forearm.

The Median Nerve

Passes down the midline of the arm in close association with the brachial artery. It passes in front of the elbow joint then down to supply the muscles of the front of the forearm. It continues into the hand where it supplies small muscles and the skin of the front of the thumb, the first two fingers and the lateral half of the third finger. It gives off no branches above the elbow.

The ulnar nerve descends through the upper arm lying medial to the brachial artery. It passes behind the medial epicondyle of the humerus to supply the muscles on the ulnar aspect of the forearm. It continues downwards to supply the muscles in the palm of the hand and the skin of the whole of the little finger and the medial half of the third finger. It gives off no branches above the elbow.

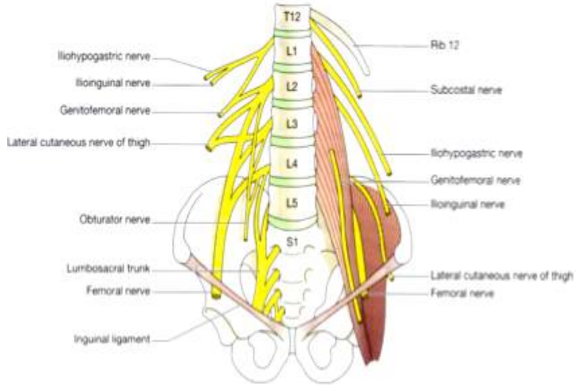
Lumbar Plexus

The lumbar plexus is formed by the anterior rami of the first three and part of the fourth lumbar nerves. The plexus is situated in front of the transverse processes of the lumbar vertebrae and behind the psoas muscle.

The Main Branches, And Their Nerve Roots Are:

- Iliohypogastric nerve: L1.
- Ilioinguinal nerve: L1.
- Genitofemoral: L1, L2.
- Lateral cutaneous nerve of thigh: L2, L3.
- Femoral nerve: L2, L3, L4.
- Obturator nerve: L2, L3, L4.
- Lumbosacral trunk: L4, L5.

Lumbar Plexus



Iliohypogastric, Ilioinguinal And Genito-Femoral Nerves

Supply muscles and the skin in the area of the lower abdomen, upper and medial aspects of the thigh and the inguinal region.

The Lateral Cutaneous Nerve Of The Thigh

Supplies the skin of the lateral aspect of the thigh including part of the anterior and posterior surfaces.

The Femoral Nerve

One of the larger branches. It passes behind the inguinal ligament to enter the thigh in close association with the femoral artery. It divides into cutaneous and muscular branches to supply the skin and the muscles of the front of the thigh. One branch, the *saphenous nerve,* supplies the medial aspect of the leg, ankle and foot.

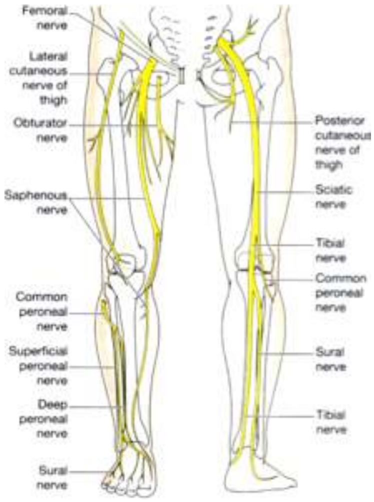
The Obturator Nerve

Supplies the adductor muscles of the thigh and skin of the medial aspect of the thigh. It ends just above the level of the knee joint.

The Lumbo-Sacral Trunk

Descends into the pelvis and contributes to the sacral plexus.

Sacral Plexus



Sacral Plexus

The sacral plexus is formed by the anterior rami of the lumbosacral trunk and the first, second and third sacral nerves. The lumbosacral trunk is formed by the fifth and part of the fourth lumbar nerves. It lies in the posterior wall of the pelvic cavity.

The sacral plexus divides into a number of branches, supplying the muscles and skin of the pelvic floor, muscles around the hip joint and the pelvic organs. In addition to these it provides the *sciatic nerve* which contains fibres from L4, 5, S1, 2, 3.

Sciatic Nerve

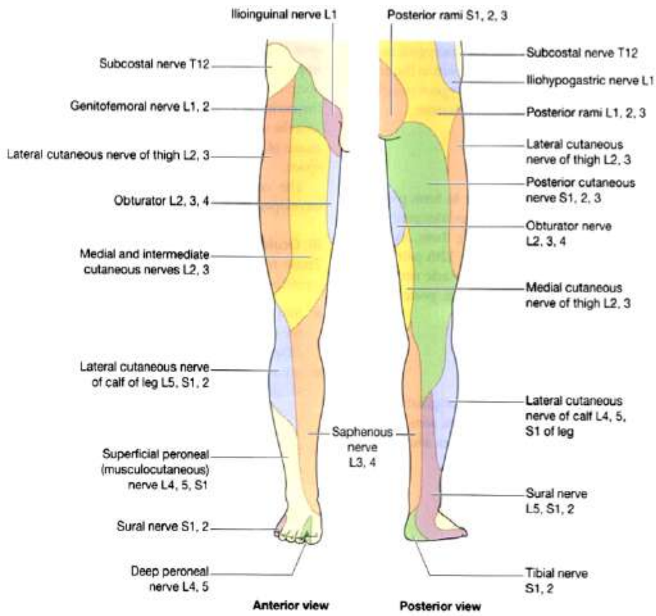
The largest nerve in the body. It is about 2 cm wide at its origin. It passes through the greater sciatic foramen into the buttock then descends through the posterior aspect of the thigh supplying the hamstring muscles. At the level of the middle of the femur it divides to form the *tibial* and the *common-peroneal nerves.*

The tibial nerve descends through the popliteal fossa to the posterior aspect of the leg where it supplies muscles and skin. It passes under the medial malleolus to supply muscles and skin of the sole of the foot and toes.

One of the main branches is the *sural nerve,* which supplies the tissues in the area of the heel, the lateral aspect of the ankle and a part of the dorsum of the foot.

Common Peroneal Nerve

Descends obliquely along the lateral aspect of the popliteal fossa, winds round the neck of the fibula into the front of the leg where it divides into the *deep peroneal* (anterior tibial) and the *superficial peroneal* (musculocutaneous) nerves. These nerves supply the skin and muscles of the anterior aspect of the leg and the dorsum of the foot and toes.



Pudendal Nerve (S2, S3, S4)

The perineal branch supplies the external anal sphincter, the external urethral sphincter and adjacent skin

Coccygeal Plexus

The coccygeal plexus is a very small plexus formed by part of the fourth and fifth sacral and the coccygeal nerves. The nerves from this plexus supply the skin in the area of the coccyx and the levators ani and coccygeus muscles of the pelvic floor and the external anal sphincter.

Thoracic Nerves

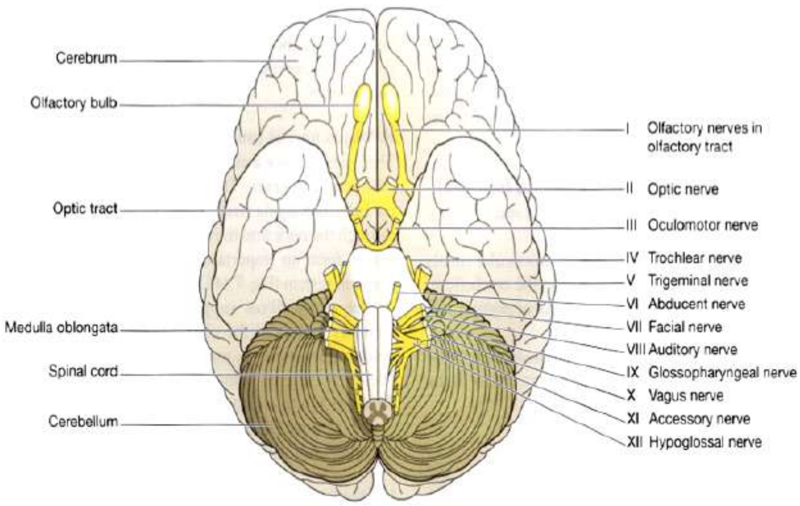
The thoracic nerves *do not* intermingle to form plexuses. There are 12 pairs and the first 11 are the *inter-costal nerves.* They pass between the ribs supplying them, the inter- costal muscles and overlying skin. The 12th pair are the *sub-costal nerves.* The 7th to the 12th thoracic nerves also supply the muscles and the skin of the posterior and anterior abdominal walls.

The Cranial Nerves 2.4.5

There are 12 pairs of cranial nerves originating from nuclei in the inferior surface of the brain, some sensory, some motor and some mixed.

Their Names And Numbers Are:

I. Olfactory: sensory
II. Optic: sensory
III. Oculomotor: motor
IV. Trochlear: motor
V. Trigeminal: mixed
VI. Abducent: motor
VII. Facial: mixed
VIII. Vestibulocochlear (auditory): sensory
IX. Glossopharyngeal: mixed
X. Vagus: mixed
XI Accessory: motor
XII. Hypoglossal: motor.



I. Olfactory Nerves (Sensory)

i. Olfactory Nerve

These are the nerves of the *sense of smell.* Their nerve endings and fibres originate in the upper part of the mucous membrane of the nasal cavity, pass upwards through the cribriform plate of the ethmoid bone and then go to the *olfactory bulb*.

The nerves then proceed backwards as the olfactory tract, to the area for the perception of smell in the temporal lobe of the cerebrum.

II. Optic Nerves (Sensory)

These are the nerves of the *sense of sight.* The fibres originate in the retinae of the eyes and they combine to form the optic nerves. They are directed backwards and medially through the posterior part of the orbital cavity. They then pass through the *optic foramina* of the sphenoid bone into the cranial cavity and join at the *optic chiasma.*

II. Optic Nerve

The nerves proceed backwards as the *optic tracts* to the *lateral geniculate bodies* of the thalamus. Impulses pass from these to the centre for sight in the occipital lobes of the cerebrum and to the cerebellum. In the occipital lobe sight is perceived, and in the cerebellum the impulses from the eyes contribute to the maintenance of balance, posture and orientation of the head in space.

The central retinal artery and vein enter the eye enveloped by the fibres of the optic nerve.

III. Oculomotor Nerve

III. Oculomotor Nerves (Motor)

These nerves arise from nerve cells near the cerebral aqueduct. They supply:

- Four extraocular muscles, which move the eyeball, i.e. the *superior, medial* and *inferior recti* and the *inferior oblique muscle.*
- Intraocular muscles:
  - *Ciliary muscles,* which alter the shape of the lens, changing its refractive power.
  - *Circular muscles of the iris,* which constrict the pupil
- The *levator palpebrae* muscle, which raises the upper eyelid.

IV. Trochler Nerve

IV. Trochlear Nerves (Motor)

These nerves arise from nerve cells near the cerebral aqueduct. They supply the *superior oblique muscles* of the eyes.

V. Trigeminal Nerves (Mixed)

V. Trigeminal Nerve

These nerves contain motor and sensory fibres and are among the largest of the cranial nerves. They are the chief sensory nerves for the face and head (including the oral and nasal cavities and teeth), receiving impulses of pain, temperature and touch. The motor fibres stimulate the muscles of mastication.

There are three main branches of the trigeminal nerves. *The ophthalmic nerves* are sensory only and supply the lacrimal glands, conjunctiva of the eyes, forehead, eyelids, anterior aspect of the scalp and mucous membrane of the nose.

The maxillary nerves are sensory only and supply the cheeks, upper gums, upper teeth and lower eyelids.

The mandibular nerves contain both sensory and motor fibres. These are the largest of the three divisions and they supply the teeth and gums of the lower jaw, pinnae of the ears, lower lip and tongue. The motor fibres supply the muscles of mastication.

VI. Abducent Nerves (Motor)

VI. Abducent Nerve

These nerves arise from a group of nerve cells lying under the floor of the fourth ventricle. They supply the *lateral rectus muscles* of the eyeballs.

VII. Facial Nerves (Mixed)

VII. Facial Nerve

These nerves are composed of both motor and sensory nerve fibres, arising from nerve cells in the lower part of the pons. The motor fibres supply the muscles of facial expression.

The sensory fibres convey impulses from the taste buds in the anterior two-thirds of the tongue to the taste perception area in the cerebral cortex.

VIII. Vestibulocochlear (Auditory) Nerves (Sensory)

VIII. Vestibulochlear Nerve

These nerves are composed of two distinct sets of fibres, vestibular nerves and cochlear nerves.

The vestibular nerves arise from the semicircular canals of the inner ear and convey impulses to the cerebellum. They are associated with the maintenance of posture and balance.

The cochlear nerves originate in the organ of Corti in the inner ear and convey impulses to the hearing areas in the cerebral cortex where sound is perceived.

IX. Glossopharyngeal Nerves (Mixed)

IX. Glossopharyngeal Nerve

These nerves arise from nuclei in the medulla oblongata. The motor fibres stimulate the muscles of the tongue and pharynx and the secretory cells of the parotid (salivary) glands.

The sensory fibres convey impulses to the cerebral cortex from the posterior third of the tongue, the tonsils and pharynx and from taste buds in the tongue and pharynx.

These nerves are essential for the swallowing and gag reflexes.

X. Vagus Nerves (Mixed)

X. Vagus Nerve

These nerves have a more extensive distribution than any other cranial nerves. They arise from nerve cells in the medulla oblongata and other nuclei, and pass down through the neck into the thorax and the abdomen. These nerves form an important part of the parasympathetic nervous system.

The motor fibres supply the smooth muscles and secretory glands of the pharynx, larynx, trachea, heart, oesophagus, stomach, intestines, pancreas, gall bladder, bile ducts, spleen, kidneys, ureter and blood vessels in the thoracic and abdominal cavities.

The sensory fibres convey impulses from the lining membranes of the same structures to the brain.

XI. Accessory Nerves (Motor)

XI. Accessory Nerve

These nerves arise from cell bodies in the medulla oblongata and in the spinal cord. The fibres supply the *sternocleidomastoid* and *trapezius muscles.*

Branches join the vagus nerves and supply the *pharyngeal* and *laryngeal muscles.*

XII. Hypoglossal Nerves (Motor)

XII. Hypoglossal Nerve

These nerves arise from cells in the medulla oblongata.

They supply the muscles of the tongue and muscles surrounding the hyoid bone and contribute to swallowing and speech.

Summary of the cranial nerves			
Name *and* no.	**Central connection**	**Peripheral connection**	**Function**
I. Olfactory (sensory)	Smell area in temporal lobe of cerebrum through olfactory bulb	Mucous membrane in roof of nose	Sense of smell
II. Optic (sensory)	Sight area in occipital lobe of cerebrum Cerebellum	Retina of the eye	Sense of sight Balance
III. Oculomotor (motor)	Nerve cells near floor of aqueduct of midbrain	Superior, inferior and medial rectus muscles of the eye Ciliary muscles of the eye Circular muscle fibres of the iris	Moving the eyeball. Focusing Regulating the size of the pupil
IV. Trochlear (motor)	Nerve cells near floor of aqueduct of midbrain	Superior oblique muscles of the eye	Movement of the eyeball
V. Trigeminal (mixed)	Motor fibres from the pons Sensory fibres from the trigeminal ganglion	Muscles of mastication Sensory to gums, cheek, lower jaw, iris, cornea	Chewing Sensation from the face
VI. Abducent (motor)	Floor of fourth ventricle	Lateral rectus muscle of the eye	Movement of the eye
VII. Facial (mixed)	Pons	Sensory fibres to the tongue Motor fibres to the muscles of the face	Sense of taste Movements of facial expression
VIII. Vestibulocochlear (sensory) (a) Vestibular (b) Cochlear	Cerebellum Hearing area of cerebrum	Semicircular canals in the inner ear Organ of Corti in cochlea	Maintenance of balance Sense of hearing
IX. Glossopharyngeal (mixed)	Medulla oblongata	Parotid gland Back of tongue and pharynx	Secretion of saliva Sense of taste Movement of pharynx
X. Vagus (mixed)	Medulla oblongata	Pharynx, larynx; organs, glands ducts, blood vessels in the thorax and abdomen	Movement and secretion
XI. Accessory (motor)	Medulla oblongata	Sternocleidomastoid, trapezius, laryngeal and pharyngeal muscles	Movement of the head, shoulders, pharynx and larynx
XII. Hypoglossal (motor)	Medulla oblongata	Tongue	Movement of tongue

THE AUDITORY SYSTEM 2.5

The Ear

The ear is the organ of hearing. It is supplied by the 8th *cranial nerve,* i.e. the *cochlear part* of the *vestibulocochlear* nerve, which is stimulated by vibrations caused by sound waves.

With the exception of the auricle (pinna), the structures that form the ear are encased within the petrous portion of the temporal bone.

The Ear Is Divided Into Three Distinct Parts:

- Outer ear.
- Middle ear (tympanic cavity).
- Inner ear.

Outer Ear

The outer ear consists of the auricle (pinna) and the external acoustic meatus.

The Auricle (pinna)

The auricle is the expanded portion projecting from the side of the head. It is composed of *fibroelastic cartilage* covered with skin. It is deeply grooved and ridged and the most prominent outer ridge is the *helix.*

The lobule (earlobe) is the soft pliable part at the lower extremity, composed of fibrous and adipose tissue richly supplied with blood.

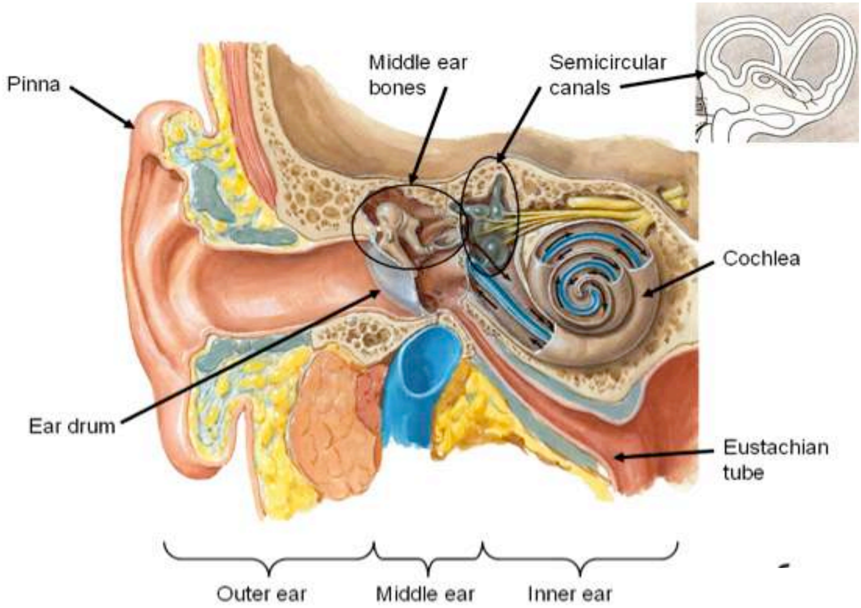
External Acoustic Meatus (Auditory Canal)

This is a slightly 'S'-shaped tube about 2.5cm long extending from the auricle to the *tympanic membrane* (eardrum). The lateral third is cartilaginous and the remainder is a canal in the temporal bone. The meatus is lined with skin containing hairs continuous with that of the auricle. There are numerous *sebaceous* and *ceruminous glands* in the skin of the lateral third.

Ceruminous glands are modified sweat glands that secrete *cerumen* (wax), a sticky material containing lysozyme and immunoglobulins. Foreign materials, e.g. dust, insects and microbes, are prevented from reaching the tympanic membrane by wax, hairs and the curvature of the meatus. Movements of the temporomandibular joint during chewing and speaking 'massage' the cartilaginous meatus, moving the wax towards the exterior.

The tympanic membrane (eardrum) completely separates the external acoustic meatus from the middle ear. It is oval-shaped with the slightly broader edge upwards and is formed by three types of tissue: the outer covering of *hairless skin,* the middle layer of *fibrous tissue* and the inner lining of *mucous membrane* continuous with that of the middle ear.

Anatomy Of The Ear



Middle Ear (Tympanic Cavity)

This is an irregular-shaped *air-filled* cavity within the petrous portion of the temporal bone. The cavity, its con- tents and the air sacs, which open out of it are lined with either simple squamous or cuboidal epithelium.

The lateral wall of the middle ear is formed by the tympanic membrane.

The roof and floor are formed by the temporal bone.

The posterior wall is formed by the temporal bone with openings leading to the *mastoid antrum* through which air passes to the air cells within the mastoid process.

Tympanic Membrane

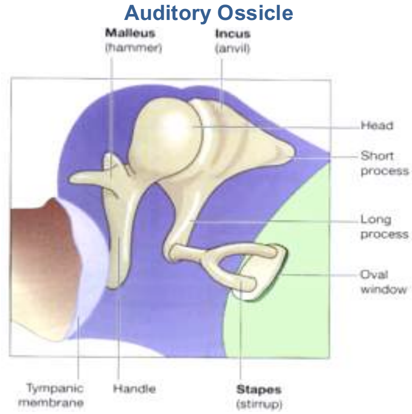
The medial wall is a thin layer of temporal bone in which there are two openings:

- Oval window.
- Round window.

The oval window is occluded by part of a small bone called the *stapes* and the round window, by a fine sheet *of fibrous tissue.*

Air reaches the cavity through the *pharyngotympanic* (*auditory or Eustachian*) tube, which extends from the nasopharynx. It is about 4 cm long and is lined with ciliated epithelium. The presence of air at atmospheric pressure on both sides of the tympanic membrane is maintained by the pharyngotympanic tube and enables the membrane to vibrate when sound waves strike it. The pharyngotympanic tube is normally closed but when there is unequal pressure across the tympanic membrane, e.g. at high altitude, swallowing opens it or yawning and the ears 'pop', equalising the pressure again.

Auditory Ossicle



Auditory Ossicles

These are three very small bones that extend across the middle ear from the tympanic membrane to the oval window. They form a series of movable joints with each other and with the medial wall of the cavity at the oval window. They are named according to their shapes. *The malleus.* This is the lateral hammer-shaped bone.

The handle is in contact with the tympanic membrane and the head forms a movable joint with the incus.

The incus. This is the middle anvil-shaped bone. Its body articulates with the malleus, the long process with the stapes, and it is stabilised by the short process, fixed by fibrous tissue to the posterior wall of the tympanic cavity.

The stapes. This is the medial stirrup-shaped bone. Its head articulates with the incus and its footplate fits into the oval window.
The three ossicles are held in position by fine ligaments.

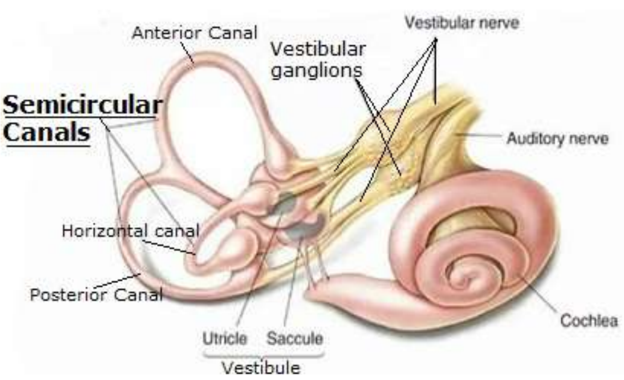
Inner Ear

The inner (internal) ear or labyrinth (meaning 'maze') ear contains the organs of hearing and balance. It is generally described in two parts, the *bony labyrinth* and the *membranous labyrinth.*

Bony Labyrinth

This is a cavity within the temporal bone lined with periosteum. It is larger than, and encloses, the membranous labyrinth of the same shape, which fits into it, like a tube within a tube. Between the bony and membranous labyrinth there is a layer of watery fluid called *perilymph* and within the membranous labyrinth there is a similarly watery fluid, *endolymph.*

Bony Labrynth



The Bony Labyrinth Consists Of:

- 1 vestibule.
- 1 cochlea.
- Semicircular canals.

The Vestibule

This is the expanded part nearest the middle ear. It contains the oval and round windows in its lateral wall.

The Cochlea

This resembles a snail's shell. It has a broad base where it is continuous with the vestibule and a narrow apex, and it spirals round a central bony column.

The Semicircular Canals

These are three tubes arranged so that one is situated in each of the three planes of space. They are continuous with the vestibule.

Membranous Labyrinth

This contains endolymph and lies within its bony counterpart.

The Cochlea

It Comprises:

- The vestibule, which contains the *utricle* and *saccule*
- The cochlea
- Three semicircular canals.

The Cochlea

A Cross-Section Of The Cochlea Contains Three Compartments:

- The Scala vestibule.
- The scala media, or *cochlear duct.*
- The scala tympani.

In cross-section the bony cochlea has two compartments containing perilymph: the scala vestibuli, which originates at the oval window, and the scala tympani, which ends at the round window. The two compartments are continuous with each other.

The cochlear duct is part of the membranous labyrinth and is triangular in shape. On the *basilar membrane,* or base of the triangle, there are *supporting cells* and specialised *cochlear hair cells* containing auditory receptors. These cells form the *spiral organ* (of Corti), the sensory organ that responds to vibration by initiating nerve impulses that are then perceived as hearing by the brain.

The *auditory receptors* are dendrites of efferent nerves that combine forming the cochlear (auditory) part of the vestibul-ocochlear nerve (8th cranial nerve), which passes through a foramen in the temporal bone to reach the hearing area in the temporal lobe of the cerebrum

The Semicircular Canals and Vestibule

The semicircular canals have no auditory function although they are closely associated with the cochlea. They provide information about the position of the head in space, contributing to maintenance of posture and balance.

There are three semicircular canals, one lying in each of the three planes of space. They are situated above and behind the vestibule of the inner ear and open into it.

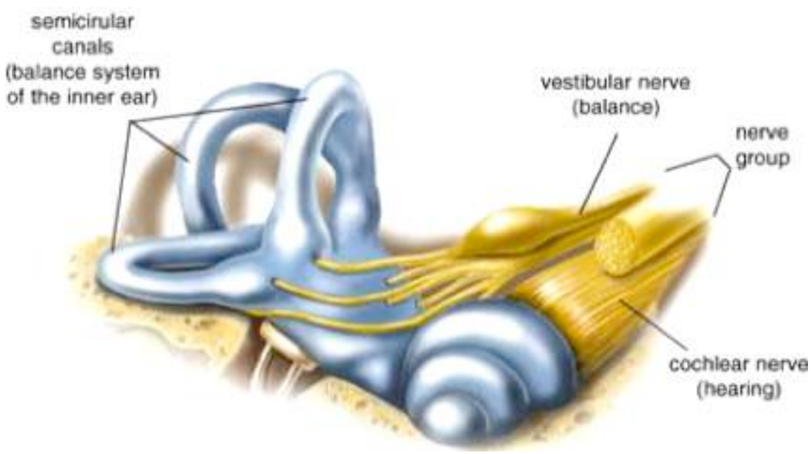
The semicircular canals, like the cochlea, are composed of an outer bony wall and inner membranous tubes or *ducts.* The membranous ducts contain endolymph and are separated from the bony wall by perilymph.

The utricle is a membranous sac, which is part of the vestibule and the three membranous ducts open into it at their dilated ends, the *ampullae.* The *saccule* is a part of the vestibule and communicates with the utricle and the cochlea.

In the walls of the utricle, saccule and ampullae there are fine specialised epithelial cells with minute projections, called *hair cells.* Amongst the hair cells there are sensory nerve endings, which combine forming the *vestibular part* of the vestibulocochlear nerve.

Physiology of Balance

The Organ Of Ballance



The semicircular canals and the vestibule (utricle and saccule) are concerned with balance. Any change of position of the head causes movement in the perilymph and endolymph, which bends the hair cells and stimulates the sensory nerve endings in the utricle, saccule and ampullae.

The resultant nerve impulses are transmitted by the vestibular nerve, which joins the cochlear nerve to form the vestibulocochlear nerve. The vestibular branch passes first to the *vestibular nucleus,* then to the *cerebellum.*

The cerebellum also receives nerve impulses from the eyes and proprioceptors (sensory receptors) in the skeletal muscles and joints. Impulses from these three sources are coordinated and efferent nerve impulses pass to the cerebrum and to skeletal muscles. This results in awareness of body position, maintenance of upright posture and fixing of the eyes on the same point, independently of head movements.

THE URINARY SYSTEM 2.6

The urinary system is one of the excretory systems of the body.

It Consists Of The Following Structures:

- 2 kidneys (which secrete urine).
- 2 ureters (which convey the urine from the kidneys to the urinary bladder).
- 1 urinary bladder (where urine collectsand is temporarily stored).
- 1 urethra (through which the urine is discharged from the urinary bladder to the exterior).

The urinary system plays a vital part in maintaining homeostasis of water and electrolyte concentrations within the body. The kidneys produce urine that contains metabolic waste products, including water, the nitrogenous compounds urea and uric acid, excess ions and some drugs.

The Main Functions Of The Kidneys Are:

- Formation and secretion of urine.
- Production and secretion of erythropoietin (the hormone responsible for controlling the rate of formation of red blood cells).
- Production and secretion of renin (an important enzyme in the control of blood pressure).
- Assisting in acid base balance.

Urine is stored in the bladder and excreted by the process of *micturition.*

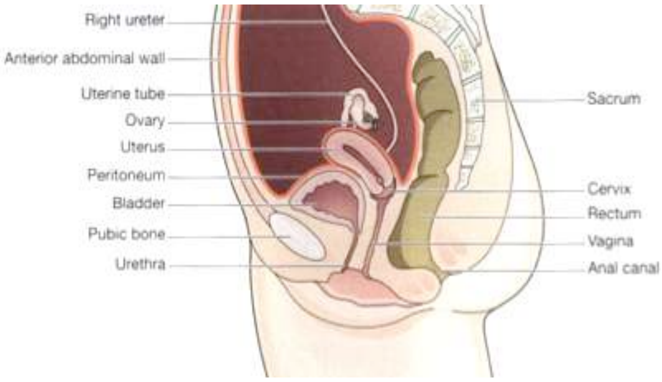
The urinary bladder is a reservoir for urine. It lies in the pelvic cavity and its size and position vary, depending on the amount of urine it contains. When distended, the bladder rises into the abdominal cavity.

The bladder is roughly pear-shaped, but becomes more oval as it fills with urine. It has anterior, superior and posterior surfaces. The posterior surface is the *base.*

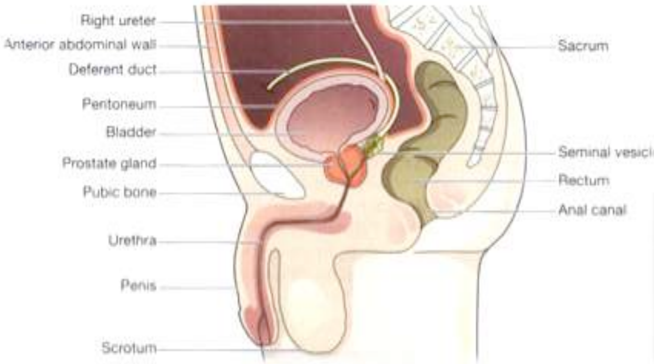
The bladder opens into the urethra at its lowest point, *the neck.*

The *peritoneum* covers only the superior surface before it turns upwards as the parietal peritoneum, lining the anterior abdominal wall. Posteriorly it surrounds the uterus in the female and the rectum in the male.

The Female Urinary System



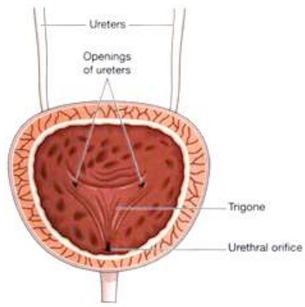
The Male Urinary System



The Bladder

The Bladder Wall Is Composed Of Three Layers:

The Bladder



- The outer layer of loose connective tissue, containing blood and lymphatic vessels and nerves, covered on the upper surface by the peritoneum.
- The middle layer, consisting of a mass of interlacing smooth muscle fibres and elastic tissue loosely arranged in three layers. This is called the *detrusor muscle* and it empties the bladder when it contracts.
- The mucosa, lined with transitional epithelium.

When the bladder is empty the inner lining is arranged in folds, or rugae, and these gradually disappear as the bladder fills. The bladder is distensible but when it con- tains 300 to 400 ml the awareness of the desire to urinate is initiated. The total capacity is rarely more than about 600 ml.

The three orifices in the bladder wall form a triangle or *trigone*. The upper two orifices on the posterior wall are the openings of the ureters. The lower orifice is the point of origin of the urethra. Where the urethra commences is a thickening of the smooth muscle layer forming the *internal urethml sphincter.* This sphincter is not under voluntary control.

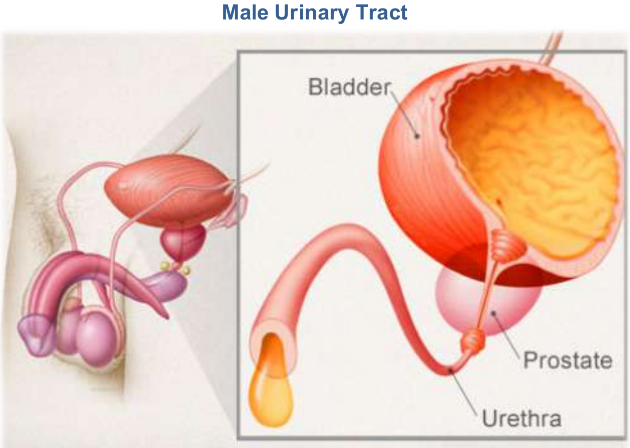
Urethra

The urethra is a canal extending from the neck of the bladder to the exterior, at the external urethral orifice. Its length differs in the male and in the female.

The female urethra is approximately 4 cm long. It runs downwards and forwards behind the symphysis pubis and opens at the *external urethral orifice* just in front of the vagina. The external urethral sphincter guards the external urethral orifice*,* which is under voluntary control. Except during the passage of urine, the walls of the urethra are in close apposition.

The male urethra provides a common pathway for the flow of urine and semen, the combined secretions of the male reproductive organs. It is about 19 to 20 cm long and consists of three parts. The *prostatic urethra* originates at the urethral orifice of the bladder and passes through the prostate gland. The *membranous urethra* is the shortest and narrowest part and extends from the prostate gland to the bulb of the penis, after passing through the perineal membrane. The *spongiose* or *penile urethra* lies within the corpus spongiosum of the penis and terminates at the external urethral orifice in the *glans penis.*

Male Urinary Tract



There are two urethral sphincters. The *internal sphincter* consists of smooth muscle fibres at the neck of the bladder above the prostate gland. The *external sphincter* consists of skeletal muscle fibres surrounding the membranous part.

Prostate Gland (Males)

The prostate gland lies in the pelvic cavity in front of the rectum and behind the symphysis pubis, surrounding the first part of the urethra. It consists of an outer fibrous covering, a layer of smooth muscle and glandular substance composed of columnar epithelial cells.

The prostate gland secretes a thin, milky fluid that makes up about 30% of *semen,* and gives it its milky appearance. It is slightly alkaline, which provides a protective local environment for sperm arriving in the acidic vagina. It also contains a clotting enzyme, which thickens the semen in the vagina, increasing the likelihood of semen being retained in the vicinity of the cervix.

Penis (Males)

The penis has a *root* and a *body.* The root lies in the perineum and the body surrounds the urethra. It is formed by three cylindrical masses of *erectile tissue* and involuntary muscle. The erectile tissue is supported by fibrous tissue and covered with skin and has a rich blood supply.

The two lateral columns are called the *corpora caver-nosa* and the column between them, containing the urethra, is the *corpus spongiosum.* At its tip it is expanded into a triangular structure known as the *glans penis.* Just above the glans the skin is folded upon itself and forms a movable double layer, t*he foreskin* or *prepuce.* Arterial blood is supplied by deep, dorsal and bulbar arteries of the penis, which are branches from the internal pudendal arteries. A series of veins drain blood to the internal pudendal and internal iliac veins. Autonomic and somatic nerves supply the penis. Parasympathetic stimulation leads to filling of the spongy erectile tissue with blood, caused by arteriolar dilatation and venoconstriction, which increases blood flow into the penis and obstructs outflow. The penis therefore becomes engorged and erect, an essential prerequisite for coitus.

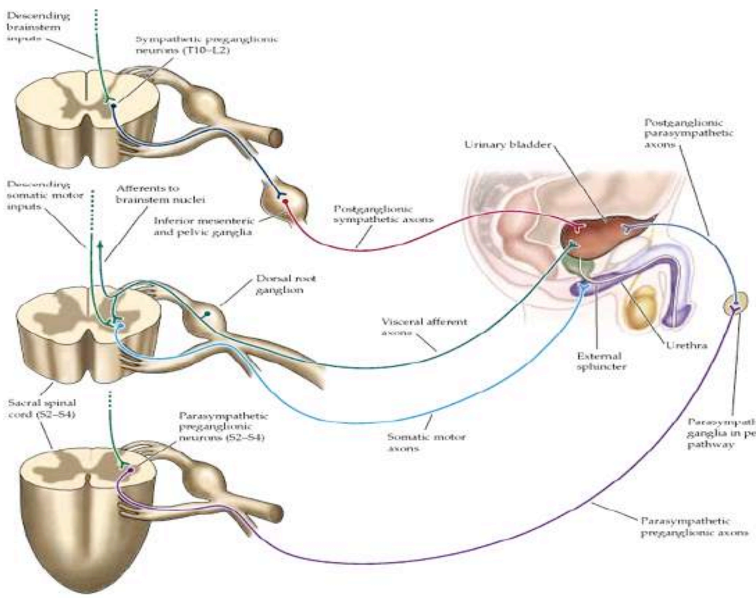
Micturition

The urinary bladder acts as a reservoir for urine. When 300 to 400 ml of urine has accumulated, afferent autonomic nerve fibres in the bladder wall sensitive to stretch are stimulated. In the infant this initiates a *spinal reflex action* and micturition occurs. Micturition occurs when autonomic efferent fibres convey impulses to the bladder causing contraction of the detrusor muscle and relaxation of the internal urethral sphincter.

When the nervous system is fully developed the micturition reflex is stimulated but sensory impulses pass upwards to the brain and there is an awareness of the desire to pass urine. By conscious effort, reflex contraction of the bladder wall and relaxation of the internal sphincter can be inhibited for a limited period of time.

In adults, micturition occurs when the detrusor muscle contracts, and there is reflex relaxation of the internal sphincter and voluntary relaxation of the external sphincter. It can be assisted by increasing the pressure within the pelvic cavity, achieved by lowering the diaphragm and contracting the abdominal muscles (Valsalva's manoeuvre).

Urinary Micturition



Over-distension of the bladder is extremely painful, and when this stage is reached there is a tendency for involuntary relaxation of the external sphincter to occur and a small amount of urine to escape, provided there is no mechanical obstruction.

THE SKIN 2.7

The skin completely covers the body and is continuous with the membranes lining the body orifices.

It Provides:

- Protects the underlying structures from injury and from invasion by microbes.
- Contains sensory *(somatic)* nerve endings of pain, temperature and touch.
- Is involved in the regulation of body temperature.

The skin has a surface area of about 1.5 to 2 m^2 in adults and it contains glands, hair and nails.

There Are Two Main Layers:

- Epidermis
- Dermis.

Between the skin and underlying structures there is a layer of subcutaneous fat.

Epidermis

The epidermis is the most superficial layer of the skin and is composed of *stratified keratinised squamous epithelium,* which varies in thickness in different parts of the body. It is thickest on the palms of the hands and soles of the feet. There are no blood vessels or nerve endings in the epidermis, but its deeper layers are bathed in interstitial fluid from the dermis, which provides oxygen and nutrients, and is drained away as lymph.

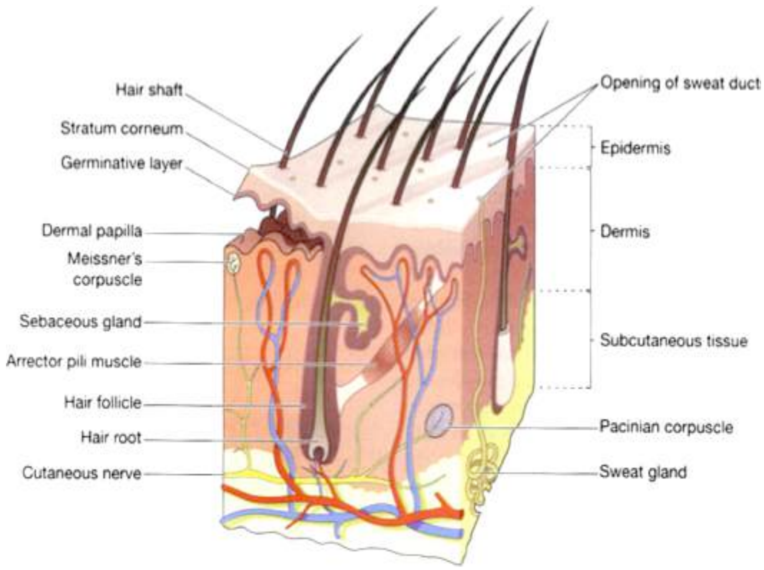
There are several layers (strata) of cells in the epidermis, which extend from the deepest *germinative layer* to the surface *stratum corneum* (a thick horny layer). The cells on the surface are flat, thin, non-nucleated, dead cells

These cells are constantly being rubbed off and replaced by cells. Complete replacement of the epidermis takes about 40 days.

The Maintenance Of Healthy Epidermis Depends Upon Three Processes Being Synchronised:

- Desquamation (shedding) of the keratinised cells from the surface.
- Effective keratinisation of the cells approaching the surface.
- Continual cell division in the deeper layers with newly formed cells being pushed to the surface.

Skin Anatomy



Hairs, secretions from sebaceous glands and ducts of sweat glands pass through the epidermis to reach the surface.

The surface of the epidermis is ridged by projections of cells in the dermis called the *papillae.* The pattern of ridges is different in every individual and the impression made by them is the 'fingerprint'.

The downward projections of the germinative layer between the papillae are believed to aid nutrition of epidermal cells and stabilise the two layers, preventing damage due to shearing forces.

Blisters develop when acute trauma causes separation of the dermis and epidermis and serous fluid collects between the two layers.

The Colour Of The Skin Is Affected By Three Main Factors:

- *Melanin,* (A dark pigment derived from the amino acid tyrosine and secreted by *melanocytes* in the deep germinative layer). The amount is genetically determined and varies between different parts of the body, between members of the same race and between races. Exposure to sunlight promotes synthesis of increased amounts of melanin.
- *The level of oxygenation of haemoglobin* and the amount of blood circulating in the dermis give the skin its pink colour.
- *Bile pigments* in blood and *carotenes* in subcutaneous fat give the skin a yellowish colour.

Dermis

The dermis is tough and elastic. It is formed from connective tissue and the matrix contains *collagen fibres* inter- laced with *elastic fibres.* Rupture of elastic fibres occurs when the skin is overstretched, resulting in permanent *striae,* or stretch marks, that may be found in pregnancy and obesity.

Collagen fibres bind water and give the skin its tensile strength, but as this ability declines with age, wrinkles develop. Fibroblasts, macrophages and mast cells are the main cells found in the dermis. Underlying its deepest layer there is areolar tissue and varying amounts of adipose tissue (fat).

The Structures In The Dermis Are:

- Blood vessels.
- Lymph vessels.
- Sensory (somatic) nerve endings.
- Sweat glands and their ducts.
- Hairs, arrector pili muscles and sebaceous glands.

Blood Vessels

Arterioles form a fine network with capillary branches supplying sweat glands, sebaceous glands, hair follicles and the dermis. The epidermis has no blood supply. It obtains nutrients and oxygen from interstitial fluid derived from blood vessels in the papillae of the dermis.

Lymph Vessels

These form a network throughout the dermis.

Sensory Nerve Endings

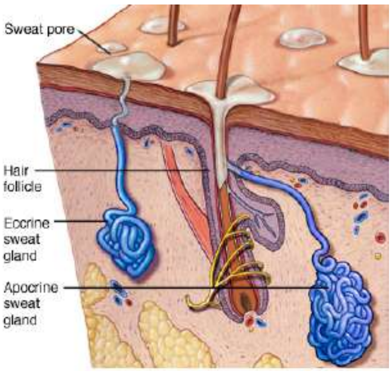
Sensory receptors (specialised nerve endings), which are sensitive to *touch, change in temperature, pressure* and *pain* are widely distributed in the dermis. Incoming stimuli activate different types of sensory receptors. The skin is an important sensory organ through which individuals receive information about their environment.

Nerve impulses, generated in the sensory receptors in the dermis, are conveyed to the spinal cord by sensory *(somatic cutaneous)* nerves, then to the sensory area of the cerebrum where the sensations are perceived.

Sweat Glands

Sweat glands are found widely distributed throughout the skin and are most numerous in the palms of the hands, soles of the feet, axillae and groins. They are composed of epithelial cells. The bodies of the glands lie coiled in the subcutaneous tissue. Some ducts open onto the skin surface at tiny depressions, or pores, and others open into hair follicles.

Sweat Glands



Glands opening into hair follicles do not become active until puberty. In the axilla they secrete an odourless milky fluid, which if decomposed by surface microbes, causes an unpleasant odour.

Sympathetic nerves in response to raised body temperature and fear stimulate sweat glands.

The most important function of sweat secreted by glands opening on to the skin surface is in the regulation of body temperature. Evaporation of sweat from body surfaces takes heat from the body and the temperature-regulating centre in the hypothalamus governs the amount of sweat produced.

Excessive sweating may lead to dehydration and serious depletion of body sodium chloride unless intake of water and salt is appropriately increased. After 7 to 10 days' exposure to high environmental temperatures the amount of salt lost is substantially reduced but water loss remains high.

Functions Of The Skin

Protection

The skin forms a relatively waterproof layer that protects the deeper and more delicate structures. As an important non-specific defence mechanism.

It Acts As A Barrier Against:

- Invasion by microbes.
- Chemicals.
- Physical agents, e.g. mild trauma, ultraviolet light.
- Dehydration.

The dermis contains specialised immune cells called Langerhans cells. They phagocytose intruding antigens and travel to lymphoid tissue, where they present antigen to T-lymphocytes, thus stimulating an immune response.

Due to the presence of the sensory nerve endings in the skin the body reacts by reflex action to unpleasant or painful stimuli, protecting it from further injury.

Regulation of Body Temperature

The temperature of the body remains fairly constant at about 36.8°C across a wide range of environmental temperatures. In health, variations are usually limited to between 0.5 and 0.75°C, although it is raised slightly in the evening, during exercise and in women just after ovulation. When metabolic rate increases body temperature rises and when it decreases body temperature falls.

A constant temperature balance is maintained between heat produced in the body and heat lost to the elements.

Heat Production

Some of the energy released in the cells during metabolic activity is in the form of heat. The most active organs, chemically and physically, produce the most heat.

The Principal Organs Involved Are As Follows:

- *The muscles.* Contraction of skeletal muscles produces a large amount of heat and the more strenuous the muscular exercise the greater the heat produced. Shivering involves muscle contraction and produces heat when there is the risk of the body temperature falling below normal.
- *The liver* is very chemically active, and heat is produced as a by-product. Metabolic rate and heat production are increased after eating.
- *The digestive organs* produce heat during peristalsis and by the chemical reactions involved in digestion.

Heat Loss

Most of the heat loss from the body occurs through the skin. Small amounts are lost in expired air, urine and faeces.

Only the heat lost through the skin can be regulated to maintain a constant body temperature. There is no control over heat lost by the other routes.

Heat loss through the skin is affected by the difference between body and environmental temperatures, the amount of the body surface exposed to the air and the type of clothes worn. Air is a poor conductor of heat and when layers of air are trapped in clothing and between the skin and clothing they act as effective insulators against excessive heat loss.

A balance is maintained between heat production and heat loss. Control is achieved mainly by thermo-receptors in the hypothalamus.

Mechanisms of Heat Loss

- In *evaporation* (the body is cooled when sweat converts to water vapour).
- In *radiation* (exposed parts of the body radiate heat away from the body).
- In *conduction* (clothes and other objects in contact with the skin take up heat).
- In *convection* (air passing over the exposed parts of the body is heated and rises, cool air replaces it and convection currents are created).

Control of Body Temperature

Nervous Control

The *temperature regulating centre* in the hypothalamus is responsive to the temperature of circulating blood. This centre controls body temperature through autonomic nerve stimulation of the sweat glands.

The *vasomotor centre* in the medulla oblongata controls the diameter of the small arteries and arterioles, and therefore the amount of blood, which circulates in the capillaries in the dermis. The vasomotor centre is influenced by the temperature of its blood supply and by nerve impulses from the hypothalamus. When body temperature rises the skin capillaries dilate and the extra blood near the surface increases heat loss by radiation, conduction and convection. The skin is warm and pink in colour. When body temperature falls arteriolar constriction conserves heat and the skin is whiter and feels cool.

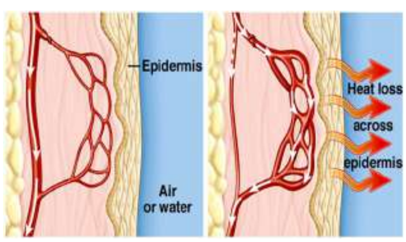
Activity of the Sweat Glands

When the temperature of the body is increased by 0.25 to 0.5°C the sweat glands are stimulated to secrete sweat, which is conveyed to the surface of the body by ducts. When sweat droplets can be seen on the skin the rate of production is exceeding the rate of evaporation. This is most likely to happen when the environmental air is humid and the temperature high.

Loss of heat from the body by unnoticeable evaporation of water through the skin and expired air occurs even when the environmental temperature is low. This is called *insensible water loss* (around 500 ml per day) and is accompanied by insensible heat loss.

Effects of Vasodilatation

Vasoconstriction - Vasodilation



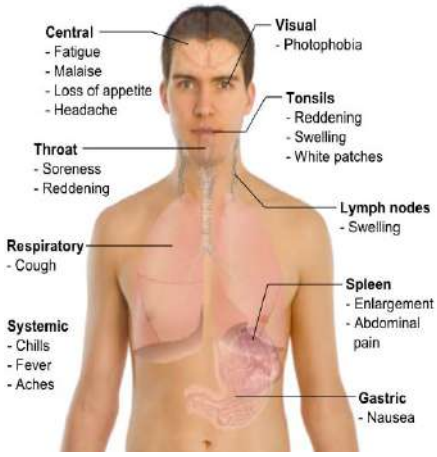
The amount of heat lost from the skin depends to a great extent on the amount of blood in the vessels in the dermis. As heat production increases, the arterioles become dilated and more blood pours into the capillary network in the skin. In addition to increasing the amount of sweat produced the temperature of the skin is raised and there is an increase in the amount of heat lost by radiation, conduction and convection.

If the external environmental temperature is low or if heat production is decreased, vasoconstriction is stimulated by sympathetic nerves. This decreases the blood flow near the body surface, conserving heat.

Fever

This is often the result of infection and is caused by release of chemicals *(pyrogens)* from damaged tissue and the cells involved in inflammation. Pyrogens act on the hypothalamus, which releases prostaglandins that reset the hypothalamic thermostat to a higher temperature. The body responds by activating heat-promoting mechanisms, e.g. shivering and vasoconstriction until the new higher temperature is reached. When the thermostat is reset to the normal level, heat-loss mechanisms are activated. There is profuse sweating and vasodilatation accompanied by warm, pink (flushed) skin until body temperature falls to the normal range again.

Viral Fever



Hypothermia

This is present when core temperature, e.g. the rectal temperature, is below 35°C. At a rectal temperature below 32°C, compensatory mechanisms to restore body temperature usually fail, e.g. shivering is replaced by muscle rigidity and cramps, vasoconstriction fails to occur and there is lowered blood pressure, pulse and respiration rates. Mental confusion and disorientation occur.

Death usually occurs when the temperature falls below 25°C.

THE MUSCULO-SKELETAL SYSTEM 2.8

The Skeletal System 2.8.1

The skeletal system consists of bones and associated connective tissues, including cartilage, tendons and ligaments. The skeletal system provides a rigid framework for support and protection and provides a system of levers on which muscles act to produce body movements. The skeletal system contains 206 individual bones.

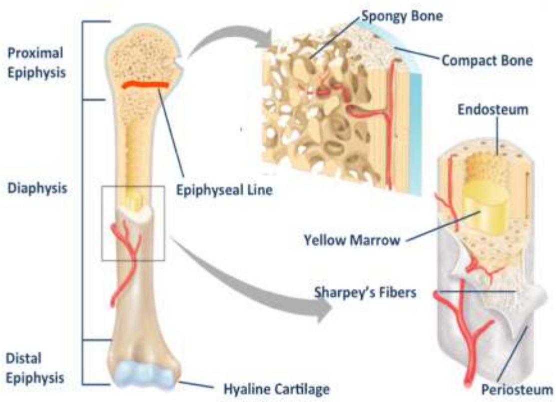
Bone Structure

Bones are rigid organs that constitute part of the endoskeleton of vertebrates. They support and protect the various organs of the body, produce red and white blood cells and store minerals.

Bone tissue is a type of dense connective tissue. Bones come in a variety of shapes and have a complex internal and external structure, are lightweight yet strong and hard, and serve multiple functions.

One of the types of tissue that makes up bone is the mineralized osseous tissue, also called bone tissue that gives it rigidity and a coral-like internal structure.

Bone Structure



Other types of tissue include marrow, endosteum, periosteum, nerves, blood vessels and cartilage.

Bones Are Divided Into Two Categories:

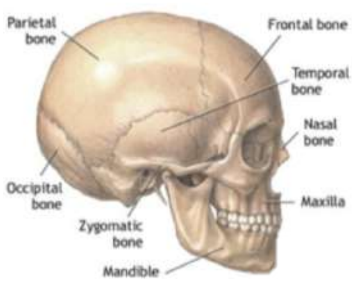
- The axial skeleton.
- The appendicular skeleton.

Axial Skeleton

The Axial Skeleton Consists Of:

- The skull.
- The hyoid bone.
- The vertebral column.
- The thoracic cage.

The Skull



The Skull

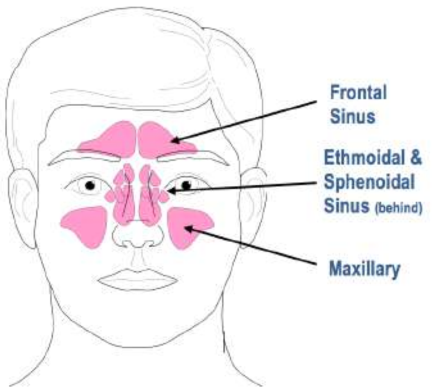
The skull is composed of 28 separate bones divided into the following groups: the auditory ossicles, cranial vault, and facial bones. The 6 auditory ossicles (3 on each sides of the head) are located inside the cavity of the temporal bone. The auditory ossicles function in hearing.

The cranial vault consists of 6 bones that surround and protect the brain. They are the parietal, temporal, frontal, occipital, sphenoid, and ethmoid bones.

The 14 facials bones from the structure of the face in the anterior skull but do not contribute to the cranial vault. The bones include the maxilla, mandible, zygomatic, palatine, nasal, lacrimal, vomer, and inferior concha bones. The frontal and ethmoid bones contribute to both the cranial vault and the face.

Air spaces are present in certain bones in the skull, which decrease the weight of those bones and give resonance to the voice. These are called the **sinuses**. Each person has 4 pairs of sinuses, and while the size and shape is variable between individuals, the positions are normally similar.

The Sinus Cavities

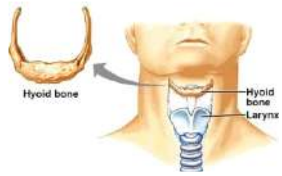


The 4 Pairs Are:

- The Frontal Sinuses (located above the eyebrows)
- The Maxillary Sinuses (the largest pair, located in the cheekbones).
- The Sphenoid Sinuses (set deep in the head behind the nose).
- The Ethmoid Sinuses (located beside the bridge of the nose).

Tiny canals connect the sinuses with the nasal cavity allowing any pressure differences between the sinuses and the nasal passages to be equalised. Each sinus is lined with a mucous membrane, which is continuous with that of the nose and throat. Mucous produced by the sinuses normally drains into the nasal passage but, if the connecting canal becomes blocked, pressure within the sinus can build up to cause pain. If an infection of the membrane lining occurs, the painful condition called **sinusitis** results.

The Hyoid Bone



The Hyoid Bone

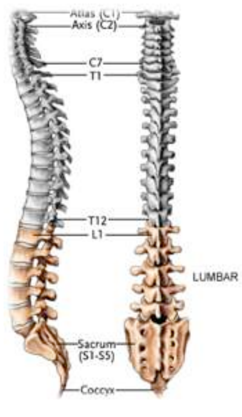
The hyoid bone is attached to the skull by muscles and ligaments and floats in the superior aspect of the neck, just below the mandible. The hyoid bone serves as the attachment point for several important neck and tongue muscles.

The Vertebrae

The vertebral column consists of 26 bones, which can be divided into five regions: 7 cervical vertebrae, 12 thoracic vertebrae, 5 lumbar vertebrae, 1 sacral bone, and 1 coccygeal bone. A total of 34 vertebrae originally from during development, but the 5 sacral vertebrae fuse to form 1 bone, as do the 4 or 5 coccygeal bones.

The weight-bearing portion of the vertebrae is a bony disk called the body. Intervertebral disks, located between the bodies of adjacent vertebrae, serve as shock absorbers for the vertebral column, provide additional support for the body, and prevent the vertebral bodies from rubbing against each other.

The Vertebral Column



The vertebral arch and the dorsal portion of the body protect the spinal chord. A transverse process extends laterally from each side of the arch, and a single spinous process is present at the point of junction. Much vertebral movement is accomplished by the contraction of skeletal muscles attached to the transverse and the spinous processes.

The Thoracic Cage

The thoracic cage protects vital organs within the thorax and prevents the collapse of the thorax during respiration. It consists of the thoracic vertebrae, ribs with their associated costal cartilages, and sternum.

The Thoracic Cage

The 12 pairs of ribs can be divided into true or false ribs. The superior 7 (the true ribs) articulate with the thoracic vertebrae and attach directly through their costal cartilages to the sternum. The inferior 5 (the false ribs) articulate with the thoracic vertebrae but do not attach directly to the sternum. The eight, ninth, and tenth ribs are joined to a common cartilage, which is attached to the sternum. The eleventh and twelfth ribs are "floating" ribs that have no attachment to the sternum.

The sternum is divided into three parts: the manubrium, body, and xyphoid process. At the superior margin of the manubrium is the jugular notch, which can easily be palpated at the anterior base of the neck. The point at which the manubrium joins the body of the sternum is the sternal angle. The second rib is found lateral to the sternal angle and is used clinically as starting point for counting the other ribs.

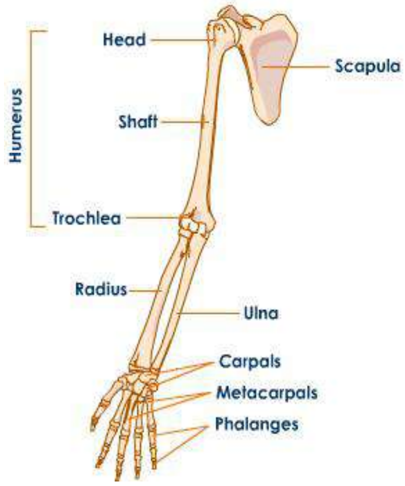
Appendicular Skeleton

The Appendicular Skeleton Consists Of The:

- Upper extremities.
- Lower extremities.
- And their girdles (by which they are attached to the body).

The Upper Extremities

The Upper Extremities



The scapula and clavicle constitute the pectoral girdle, which attaches the upper limbs to the axial skeleton. The direct point of attachment between the bones of occurs at the sterno-clavicular joint between the clavicle and the sternum.

The humerus is the second longest bone in the body. The head of the humerus articulates with the scapula the greater and the lesser tubercles are on the lateral and anterior surfaces of the proximal end of the humerus, where they function as sites of muscles attachment. The humerus articulates with the radius and the ulna at its distal end. The capilatulum (lateral aspect of the humerus) articulates with the head of the radius, and the trochlea (medial aspect of the humerus) articulates with the ulna. Proximal to the trochlea and capitulum are the medial and lateral epicondyles, respectively, which function as muscles attachments for the muscles of the forearm.

The large bony process of the ulna (the olecranon process) can be felt at the point of the elbow. This process fits in a large depression on the posterior surface of the humerus known as the olecranon fossa. The structural relationship between these two processes makes movement of the joint possible. The distal end of the ulna has a small head that articulates with the radius and the wrist bones. The posterior medial side of the head has a small stilloid process to which the ligament of the wrist is attached. The proximal end of the radius articulates with the humerus, and the medial surface of the head constitutes a smooth cylinder where the radius rotates against the radial notch of the ulna. Major anterior arm muscles (biceps brachii) are attached to the radial tuberosity.

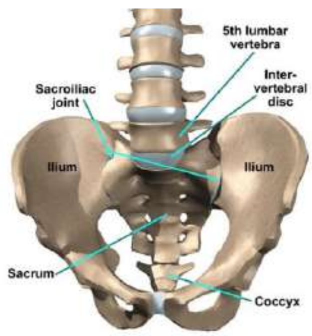
The wrist is composed of 8 carpal bones, which are arranged in two rows of 4 each. A total of 5 metacarpals are attached to the carpal bones and constitute the bony framework of the hand.

A total of 28 phalanges make up the 10 digits of the hands. There are two phalanges for each thumbs and 3 for each finger.

The Lower Extremities

The pelvic girdle attaches the leg to the trunk. The girdle consists of two coxa (hip bones), one located on each side of the pelvis. Each coxa surrounds a large obturator foramen, through which muscles, nerves and blood vessels pass to the leg. A fossa called the acetabulum is located on the lateral surface of each coxa and is the point of articulation of the lower limb with the girdle. During development, each coxa is formed by the fusion of 3 separate bones: the ilium, ischium and pubis. The superior portion of the ilium is the iliac crest. The crest ends anteriorly as the anterior-superior iliac spine and posteriorly as the superior-posterior spine.

The Pelvis



The femur is the longest bone in the body. It has a well-defined neck and a prominent rounded head that articulates with the acetabulum. The proximal shaft has 2 tuberosities: a great trochenter lateral to the neck and a smaller or lesser trochenter inferior and posterior to the neck. Both trochenters are attachment sites for muscles that attach the hip to the thigh. The distal end of the femur has medial and lateral condyles that articulate with the tibia. Located laterally and proximally to the condyles are the medial and lateral epicondyles, which are sites of muscle and ligament attachment.

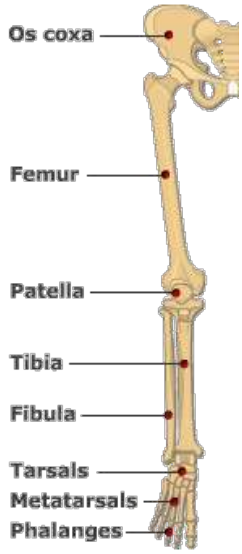
Distally, the femur also articulates with the patella, which is located in a major tendon of the thigh muscle. The patella allows the tendon to turn the corner over the knee.

The 2 bones of the lower leg are the tibia and the fibula.

The tibia is the largest of the 2 and supports most of the weight of the leg. A tibial tuberosity can be seen and palpated just inferior to the patella. The proximal end of the tibia has flat medial and lateral condyles that articulate with the condyles of the femur. The distal end of the tibia forms the medial malleolus, which helps to form the medial side of the ankle joint.

The foot consists of 7 bones. The talus articulates with the tibia and the fibula to form the ankle joint. The calcaneus is located inferior and jus lateral to the talus, supporting the bone. It protrudes posteriorly where the calf muscles attach to it and easily identified as the heel.

The Lower Extremities



The foot consists of tarsals, metatarsals, and phalanges, which are arranged in a manner similar to the metacarpals and phalanges of the hand, the great toe being analogous to the thumb. The ball of the foot is the junction between the metatarsals and the phalanges. Strong ligaments and leg muscles tendons normally hold the foot bones firmly in their arched position.

Joints

With the exception of the hyoid bone, every bone in the body connects to at least 1 other bone.

The connections or joints commonly are named according to the bones or portions of the bones that are united at the joint.

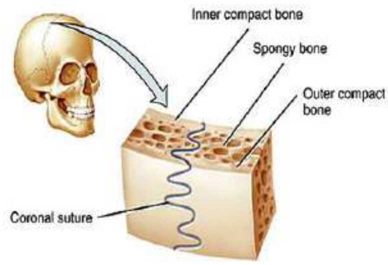
The Three Major Classifications Of Joints Are:

- Fibrous.
- Cartilaginous.
- Synovial.

Fibrous Joints

Fibrous joints consists of 2 bones united by fibrous tissue that have little or no movement. The joints are further divided on the basis of structure into sutures, syndesmosomes, or gomphoses. Structures (seams between flat bones) are located in the skull bones and may be completely immobile in adults. In newborns, the sutures have gaps between them, called fontanelles; these gaps are fairly wide to allow give to the skull during birth and allow growth of the head during development.

Fibrous Joints

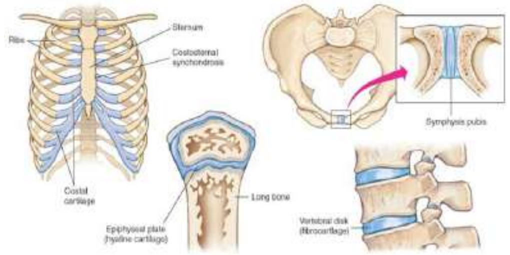


A syndesmosis is a fibrous joint in which the bones are separated by a greater distance than in a suture and are joined by ligaments. These ligaments may provide some movement of the joint. An example of these joints is the radioulnar syndesmosis that binds the radius and the ulna together.

A gomphosis joint consists of a peg that fits into a socket. The peg is held in place by fine bundles of collagenous connective tissue. The joints between the teeth and the sockets along the processes of the mandible and maxillae are examples of gomphoses joints.

Cartilaginous Joints

Cartilaginous Joints



Cartilaginous joints unit two bones by means of hyaline cartilage (synchondrose) or fibrocartilage (symphyses). A synchondrosis allows only slight movement at the joint. Common examples of this type of joint are epiphysial plate of a growing bone and the cartilage rod between most of the ribs and the sternum.

Symphyses joint are slightly moveable because of flexible nature of the fibrocartilage. Symphyses include the junction between the manubrium and the body of the sternum in adults, the symphisis pubis of the coxae, and the Intervertebral disks.

Synovial Joints

Synovial joints contain synovial fluid, a thin, lubrificating film that allows considerable movement between articulating bones. Most joints that unite the bones of the appendicular skeleton are synovial. The articular surfaces of bones within synovial joints are covered with a thin layer of hyaline cartilage, which provides a smooth surface where the bones meet. The joint is enclosed by a joint capsule, which consists of an outer fibrous capsule and an inner synovial membrane.

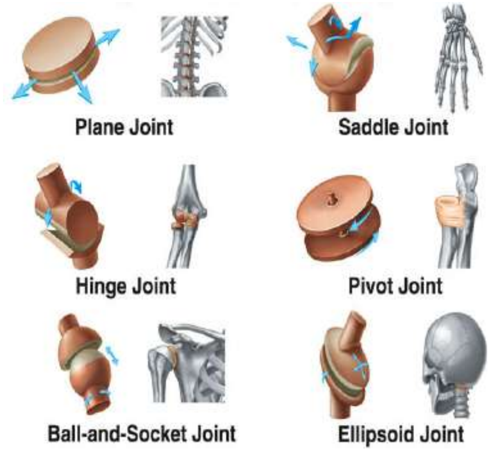
The synovial membrane lines the joint and produces synovial fluid.

Synovial Joints Are Classified Into Six Divisions According To The Shape Of The Adjoining Articular Surfaces:

- Plane or gliding joints (consist of two opposed flat surfaces that are about equal in size. Examples of these joints are the articular processes between vertebrae).

- Saddle joints (consist of two saddle-shaped articulating surfaces oriented at right angles to one another. Movement in these joints can occur in two planes. An example of saddle joint is the carometacarpal joint of the thumb).
- Hinge joints (consist of a convex cylinder in one bone applied to a corresponding concavity in another bone. These joints permit movement in one plane only. Examples of hinge joints are those of the elbow and the knee).
- Pivot joints (consist of a relatively cylindrical bony process that rotates within a ring composed partly of bone and partly of ligament. An example of pivot joint is the head of the radius articulating with the proximal end of the ulna).
- Ball-and-socket joints (consist of a ball (head) at the end of one bone and a socket into an adjacent bone into which a portion of the ball fits. These joints allow wide ranges of movement in almost any direction. Examples are the shoulder and the hip joints).
- Ellipsoid joints (modified ball-and-socket joint where the articular surfaces are ellipsoid. The shape of the joint limits the movement, making it similar to a hinge motion, but the motion occurs in two planes. The atlantooccipital joint is an ellipsoid joint).

Sinovial Joints

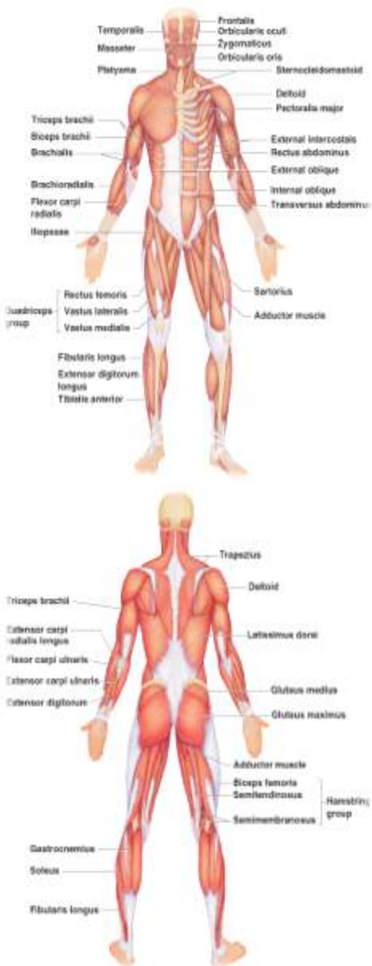


The Muscular System 2.8.2

Muscle comprises of approximately 40% of the bodys total bio-mass.

Muscle cells contain protein filaments that slide past one another, producing a contraction that changes both the length and the shape of the cell. Muscles function to produce force and cause motion. They are primarily responsible for maintenance of and changes in posture, locomotion of the organism itself, as well as movement of internal organs, such as the contraction of the heart and movement of food through the digestive system via peristalsis.

Body Muscle



The Three Primary Functions Of The Muscular System Are:

- Movement.
- Postural maintenance.
- Heat production.

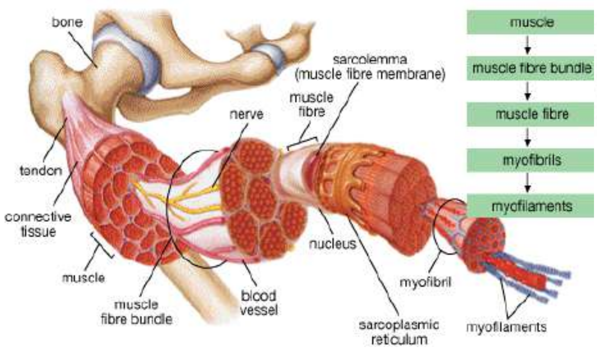
The major types of muscles are skeletal, cardiac, and smooth muscle. Skeletal muscle is far more common than other types of muscles in the body and is the focus of this section.

Physiology Of Skeletal Muscle

Muscle tissue consists of specialized contractile cells or muscle fibers. Skeletal muscle contracts in response to electrochemical stimuli. Nerve cells regulate the function of skeletal muscle fibres by controlling the series of events that result in muscle contraction.

Each skeletal muscle fibre is filled with thick and thin myofilaments, which are fine, threadlike structures. The thick myofilaments are formed from the protein myosin, and the thin myofilaments are composed of the protein actin.

Muscle Anatomy



The sarcomere is the contractile unit of skeletal muscle, containing thick and thin myofilaments.

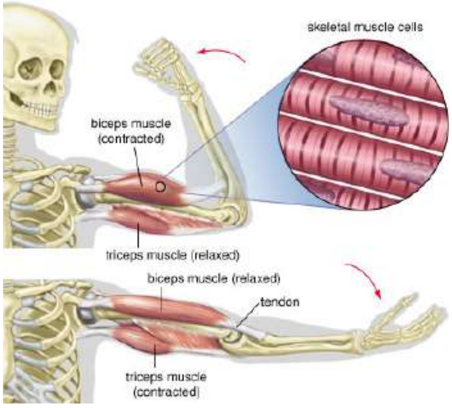
During the contraction process, energy obtained from ATP molecules enables the two types of myofilaments to slide toward each other and shorten the sarcomere and eventually the entire muscle.

Neuromuscular Junction

A nervous impulse enters the muscle fiber through a specialized nerve known as the motoneuron. The point of contact between the nerve ending and the muscle fiber is the neuromuscular junction or synapse. Each muscle fiber receives a branch of an axon, and each axon innervates more than a single muscle fiber. When a nerve impulse passes through this junction, specialized chemicals are released, causing the muscle to contract.

Skeletal Muscle Movement

Muscle Movement



Most muscles extend from one bone to another and cross at least one joint. Muscles contraction causes most body movement by pulling one of the bones toward the other across the moveable joint. The points of attachment of each muscle are the origin and insertion. The origin is the end of the muscle attached to the more stationary of the two bones. The insertion is the end of the muscle attached to the bone undergoing the greatest movement.

Some muscles of the face are not attached to bone at both ends but attach to the skin, which moves when muscles contract.

The contraction of some muscles with the simultaneous relaxation of others produces movement. Muscle that work in cooperation with one other to cause movement are called synergist, and a muscle working in opposition to another muscle (moving the structure to an opposite direction) is called an antagonist.

The muscle that is primarily responsible for a particular movement is called the prime mover. For example, the biceps brachii, brachialis, and triceps brachii muscles are all involved in flexion and extension of the forearm at the elbow joint. The biceps brachii is the prime mover during flexion, and the brachialis is the synergic muscle.

When the biceps brachii and the brachialis muscles flex the forearm, the triceps brachii relaxes (antagonistic muscle). During extension of the forearm, the triceps brachii becomes the prime mover, and the biceps and the brachialis become the antagonisic muscles. The coordinated activity of synergists and antagonists is what makes muscular movement smooth and gracefull.

Types Of Muscle Contraction.

Muscle contractions are classified as either isometric or isotonic, depending on the type of contraction that predominates. In isometric contractions, the length of the muscle does not change, but amount of tension increases during the contraction process. Isometric contractions are responsible for the constant length of the postural muscles of the body.

During isotonic contractions, the amount of tension produced by the muscle is constant during contraction, but the length of the muscle changes. An example of isotonic contraction is the movement of the arms or fingers. Most muscle contractions are a combination of isotonic and isometric contractions.

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Section 3

Effects of Pressure

BAROTRAUMA SQUEEZE'S 3.1

Injury or discomfort resulting from the effects of pressure imbalance is called barotrauma. This imbalance is caused by the inability to equalise the gas spaces of the body with the pressure of the external environment.

A *squeeze* occurs whenever fixed volume gas spaces within the body or diving gear are not pressure counterbalanced to surrounding depth.

The human body automatically adjusts to any change in the pressure of the surrounding environment; it usually does so without the person involved noticing the change.

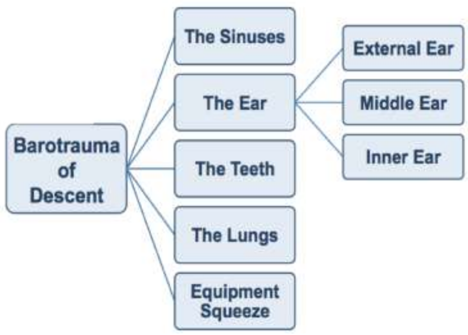
Most of the body is composed of watery tissue that can transmit imposed pressure without deformation, but there are a few areas where this is not true. If the gas pressure within some air-filled cavities of the body, such as the middle ear or the bony sinuses of the skull, is not easily equalised with the surrounding pressure, an individual undergoing even mild pressure changes (such as those that occur diving or flying) may be aware of the pressure difference.

In more severe cases, pain, accompanied by fluid and blood in the middle ears and sinuses, may be the result of a "squeeze" in these areas.

Such effects are exaggerated in divers because the water that surrounds them is much denser and heavier than air. The ability of diving equipment automatically to deliver breathing gases that are the same pressure as the surrounding depth of water makes diving possible, but these compressed gases must infiltrate into all the rigid bony cavities (the middle ear, sinuses, and chest cavity) to equalise the pressure inside, or the resulting deformations will lead to pain caused by compression and contraction of tissues.

If the pressure difference is allowed to increase, blood vessels may haemorrhage and rupture.

Barotrauma Squeeze's



Types of Squeezes Include:

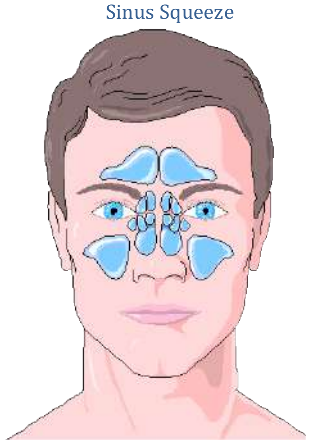
- Sinus Squeeze.
- Ear squeeze.
- Thoracic Squeeze.
- Face or Body Squeeze.
- Tooth Cavities Squeeze.

Sinus Squeeze 3.1.1

The sinus cavities are air pockets located within the skull bones that have openings into the nasal passages. These cavities are lined with a mucous membrane.

Sinus squeeze normally is the result of diving with a cold or head congestion. Adequate ventilation and pressure equalisation in the para-nasal sinuses are important in diving. Both descent and ascent depend to a large degree on adequate nasal function. Inflammation and congestion of the nasal mucosa caused by allergies, smoking, chronic irritation from prolonged or excessive use of nose drops, upper respiratory tract infections, or structural deformities of the nose can result in blockage of the para-nasal sinus openings.

Sinus Squeeze



The inability to equalise pressure on descent creates negative relative pressure within the sinus cavity, deforming the mucous membrane and causing swelling, fluid exudation, haemorrhage, and pain. Para-nasal sinus barotrauma also may occur during ascent. In this case, the key mechanism is thought to be one-way blockage of the sinus opening by cysts or polyps located within the sinus that allow pressure equalisation during descent but not during ascent.

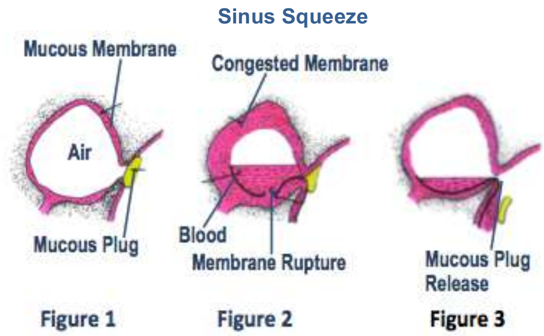
Figure 1. Normal on the surface at 1 bar. The sinus duct is clear and no pressure gradient is present.

Figure 2. Shows a blockage obstructing the duct, preventing equalisation of the cavity with the increased external pressure. This increase in pressure to 2 bar absolute has reduced the gas to one half of its original volume (Boyle's Law). The increased solubility of gases with increasing pressure (Henry's Law) has reduced the volume further. This has caused a partial vacuum in the cavity which has ruptured the membrane lining causing internal bleeding.

The diver, unable to clear his sinuses will be in severe pain.

Figure 3. A drop in pressure resolves the problem. A reduction to 1.5 bar results in the gas volume increasing and the obstruction being cleared. Where there has been membrane rupture, this removal of the blockage is accompanied by bleeding from the sinuses into the nasal cavity.

Presentation of Sinus Squeeze:



- Sensation of fullness or pain over the involved sinus or in the upper teeth.
- Numbness of the front of the face.
- Bleeding from the nose.

Management of Sinus squeeze:

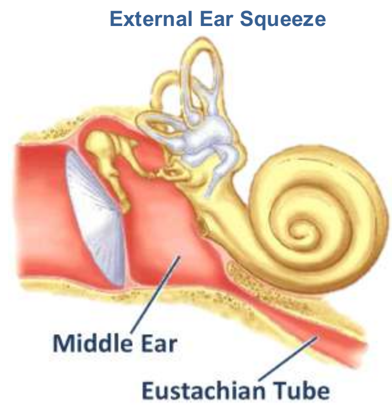
- Appropriate equalization technique.
- Cessation of compression / ascending.
- Nasal vasoconstrictors / oral antihistamines (To promote nasal mucosal shrinkage of the sinus.)
- Divers who have symptoms for longer than 5 to 10 days should see a specialist.
- If severe pain and nasal bleeding are present or if there is a yellow or greenish nasal discharge, with or without fever, a specialist should be seen promptly.
- Divers with a history of nasal-sinus disease should have an E.N.T. evaluation before beginning to dive.

External Ear Squeeze 3.1.2

Injury to the external ear canal due to inability to equalise the external ear space as a result of an obstruction. This is generally caused by tight hoods, ear-plugs, and most commonly wax. In this case, if the Eustachian tube is functioning normally, the pressure in the external ear canal is negative relative to the outside atmosphere, the air in the nose and in the middle ear. The ear drum bulges outwards, blood and tissue fluid is forced under the skin of the external ear canal forming blood blisters and ultimately the ear drum may rupture.

Notable presentation includes severe ear pain and possible inflammation of the external ear canal. Worsening of this condition by increasing the pressure differential may lead to a ruptured eardrum resulting from the squeeze.

Rupture may occur with as little as 100hGmm difference between the external auditory canal and the middle ear (only 1metre of sea water).



Presentation Of External Ear Squeeze:

- Fullness or pressure in region of the external ear canals.
- Pain.
- Blood or fluid from external ear.
- Rupture of ear-drum (entrance of cold water into the middle ear).
  - Extreme dizziness (vertigo).
  - Nausea, and possible vomiting.

Management of External Ear Squeeze:

- Appropriate equalization technique.
- Cessation of compression / ascending.
- Ear-drum rupture should be treated according to the procedures for treating middle ear barotraumas.

Middle Ear Squeeze 3.1.3

This is the most common transient ear problem associated with diving or barotrauma. It is defined as physical damage between the eardrum and eustachian tube, which is caused by inadequate pressure equalisation between the middle ear and the external environment.

Most commonly it is due to blockage of the Eustachian tubes, with catarrh or mucus. Nasal conditions such as congestion and discharge increase the likelihood of poor eustachian tube function during the dive. Absence of pre-dive symptoms does not guarantee that a diver will not develop middle ear barotrauma.

Presentation Of A Middle Ear Squeeze:

- The symptoms of middle ear squeeze consist initially of pain and a sensation of ear blockage.
- Conductive hearing loss (but may not be the primary complaint because of the intense ear pain).
- Mild tinnitus and vertigo.
- Blood in middle ear / eardrum.

Middlr Ear Squeeze

- If the ear drum ruptures;
  - The pain is usually relived.
  - Cold water may enter the middle ear causing:
    - Dizziness.
    - Nausea.
    - Ringing in ears.
    - Acute or chronic infection with resultant temporary or permanent deafness.
- Excessive Valsalva manoeuvre may cause damage to the oval window.

Management of Middle Ear Squeeze:

- Divers should attempt to re-establish pressure balance as quickly as possible.
- If unable to resolve this difficulty quickly, the diver should ascend to the surface.
- Often, returning to the surface is all that is necessary to relieve the symptoms of mild ear squeeze, (but it may take a few days for the fluid or blood to drain from or be absorbed from the middle ear cavity).
- A nasal decongestant spray, nose drops, a mild vasoconstrictor medication, or an antihistamine taken by mouth may help.
- Chewing gum, yawning, or swallowing may also help.
- If examination reveals that the diver has a rupture of the ear drum, the diver should:
  - Be seen by a physician.
  - Stay out of the water until the tear has healed, which usually occurs quickly (unless infected).
  - Monitor the healing process and take steps to control infection in the damaged ear.

Barodontalgia (Tooth Cavities Squeeze) 3.1.4

Pain or injury in a tooth and a filling caused by increased pressure on faulty fillings or decayed teeth.
Airspace underneath a filling may cause implosion on descent, a venting tooth cavity may fail on ascent leading to explosion of filling from tooth, or in extreme cases the tooth itself may explode.

Barodontaglia

Presentation Of Tooth Squeeze:

- Pain in affected tooth.
- Maxillary sinus pain.
- Tooth may implode.

Management Of Tooth Squeeze:

- Stop descent - return to surface.
- Analgesic management as required.
- Dental review.

Face or Body Squeeze 3.1.5

This is caused by sudden non-equalisation of a facemask, suit, or hardhat resulting from failure of surface gas supply / non-functioning of non-return valve, or a rapid increase in depth without compensating gas pressure.
Pain caused by local tissue compression and possible haemorrhage of blood vessels in affected tissue.

Presentation of Face / Body Squeeze:

- Pain around eyes.
- Pain at the site of the squeeze.
- Blood-shot eyes.
- Bleeding into skin, around eyes, or from nose may occur.
- Puffed-swollen cheeks.

Face Squeeze

Management of Face / Body Squeeze:

- Mild - none.
- Severe - stop diving until clear.
- Analgesia medication as necessary.

Thoracic (Lung) Squeeze 3.1.6

This barotrauma is caused by compression of lungs to less than their residual volume resulting from an extremely deep free dive (breath holding) or pronounced body squeeze.

May produce significant lung damage due to blood and tissue fluids being forced into the alveoli and air passages.

Presentation Of Thoracic Squeeze:

- Feeling of chest compression during descent.
- Pain in the chest.
- Difficulty in breathing on return to the surface.
- Bloody sputum.

Thoracic Squeeze

Management Of Thoracic Squeeze:

- In severe cases, the diver requires assistance to the surface.
- Implement reduced consciousness care.
- Implement airway / breathing interventions.
- Medically assess & evaluate

G.I.T. Barotrauma 3.1.7

Discomfort in the stomach and / or bowel due to distension with expanding gas. This is caused by trapped gas expanding on ascent.

Divers become more susceptible to this condition after air swallowing at depth, drinking fizzy drinks (particularly during a chamber dive) or using effervescent medication before the dive.

G.I.T.

Presentation of Gastrointestinal Expansion

- Abdominal discomfort.
- Abdominal pain (sharp in nature.).

Management of Gastrointestinal Expansion

- Usually self-curing by belching or passing wind.
- If severe, slow down rate of ascent.
- If occurring in chamber, chew peppermints

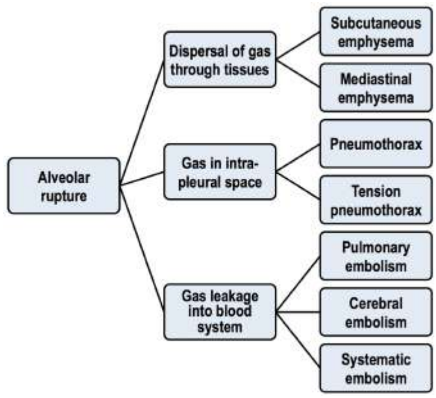
PULMONARY BAROTRAUMA'S 3.2

Barotrauma is physical damage to body tissues caused by a difference in pressure between an air space inside or beside the body and the surrounding fluid.

Barotrauma typically occurs to air spaces within a body when that body moves to or from a higher pressure environment, such as when a diver or an airplane passenger ascends or descends, or during uncontrolled decompression of a pressure vessel. Boyle's law defines the relationship between the volume of the air space and the ambient pressure.

Damage occurs in the tissues around the body's air spaces because gases are compressible and the tissues are not. During increases in ambient pressure, the internal air space provides the surrounding tissues with little support to resist the higher external pressure. During decreases in ambient pressure, the higher pressure of the gas inside the air spaces causes damage to the surrounding tissues.

Pulmonary Barotrauma



Pneumothorax 3.2.1

A pneumothorax occurs when alveolar gas escapes into the pleural space. This is an over expansion injury which has caused alveolar over expansion & rupture.

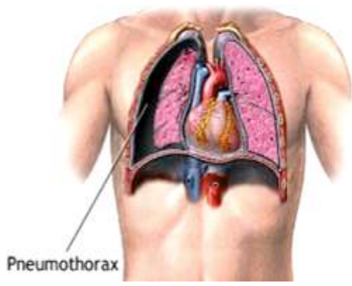
This is not a life-threatening condition because it is possible to survive with one intact lung and it is most unusual for both lungs to be involved simultaneously. Occasionally, however, the leak is such that gas escapes into the pleural space with each breath, but is unable to return to the lung. The volume of the pneumothorax gradually increases.

This is known as a tension pneumothorax.

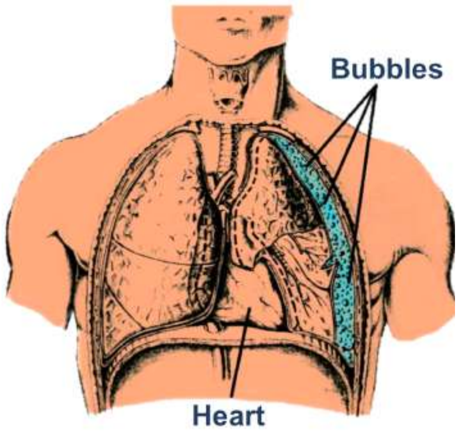
Presentation of a Pneumothorax (severe)

- Commonly the pneumothorax is small and there are fewsigns.
- Abnormal airway signs: Distress / wheeze.
- Neck Signs: Trachea deviation (late sign) / distended neck Veins / Emphysema present / Larynx intact.
- Breathing (RISE – FALL): rapid Rate / aSymmetrical movement / gross Effort & accessory muscle use / Feel emphysema / hyper-resonant on affected side / breath sounds: absent on affected side.
- Difficulty speaking (will need to take a breath in the middle of a sentence).
- Painful breathing / complain of chest pain.
- Rapid pulse rate (tachycardia).
- Non-palpable radial pulse (Reduced blood pressure).
- Reduced conscious level (cerebral hypoxia).
- Pale, clammy skin / Grey or blue lips and skin (cyanosis).

Over-expansion Pneumothorax



Closed Pneumothorax



Management of a Pneumothorax

A Small Pneumothorax Can Be Treated Conservatively:

- Contact duty medic / supervisor.
- Conduct primary / secondary survey & record observations.
- Administer high flow O_2 on the surface.

All Tension Pneumothoraces Require Draining.

- Conduct primary / secondary survey & record observations.
- Implement compromised airway / breathing management.
- Alert Medical personnel / supervisor & prepare to evacuate.
- Observe for & treat A.G.E.'s.
- Assess for tension pneumothorax & implement treatment.
- Treat Shock. (Always Insert an I.V. cannula, give I.V. fluid as instructed).
- Continually assess casualty.

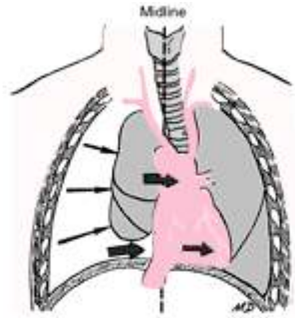
Tension Pneumothorax 3.2.2

A Tension Pneumothorax is almost exclusively an over expansion event. The presence of a diving over expansion tension pneumothorax is related an increased incidence of A.G.E's and D.C.I. in the victim.

Presentation of Tension Pneumothorax

- Standard Tension Pneumothorax presentation.
- Possible P.A.G.E. / C.A.G.E.
- Possible Neurological / musco-skeletal D.C.I.
- Mediastinal and subcutaneous emphysema in neck / shoulders.

Over-Expansion Tension Pneumothorax



Management Of Tension Pneumothorax

- Contact duty medic / supervisor.
- Conduct primary / secondary survey & record observations.
- Administer high flow O_2 on the surface.
- Implement Tension Pneumothorax treatment.
- Implement shock management. (O_2 , I.V.I. etc).
- Implement A.G.E. / D.C.I. / subcutaneous emphysema management.
- Continually assess casualty & record observations.
- Prepare to evacuate (as per company S.O.P's).
- A trained medic should place a chest drain on the affected side as soon as possible.

Mediastinal and Subcutaneous Emphysemia 3.2.3

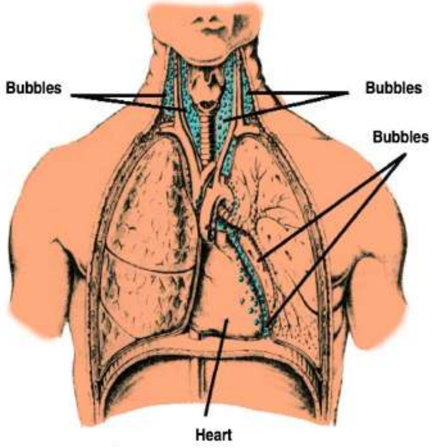
If gas escapes into the interstitial tissue space, it may track along the outside of the airways and blood vessels to the hila of the lungs and from there into the mediastinum.

This is the space between the lungs, which contains the heart, great vessels, and major airways. The presence of a little gas in the mediastinum is often symptomless.

Occasionally, considerable quantities of gas escape from the lung and this may track down into the abdomen and, rarely, the pelvis. The gas is retroperitoneal and may outline the liver and kidneys. It is unusual for such gas to generate symptoms.

However, if tissues are stretched by a substantial amount of gas, may be felt.

Mediastinal Emphysema



Presentation of Mediastinal And Subcutaneous Emphysemia.

- Often symptomless.
- A change in the tone of the voice or hoarseness.
- Swelling or crepitation (the skin "crackles') in the neck & face.
- A sensation of fullness in the chest or throat.
- Mild to moderate retrosternal pain.

Management Of Mediastinal And Subcutaneous Emphysemia.

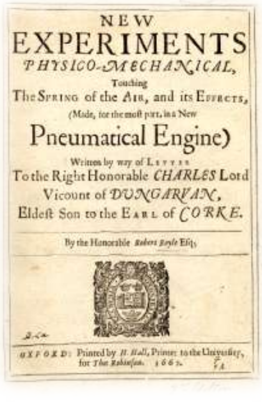
- Usually resolves gradually without specific treatment.
- If there are troublesome symptoms:
  - Giving 100% O_2 on the surface.
  - Recompression as per company S.O.P. (in the very rare instances where there are serious symptoms).

HISTORY OF DECOMPRESSION ILLNESS 3.3

The "bends" is today readily associated with SCUBA diving. It is, in fact, an old-fashioned term used originally to describe the appearance of workers returning from 'caissons' during the construction of bridges in the 19th century. The air inside these underwater enclosures was pressurised to counteract the weight of the surrounding water. Following their shifts, some men would return to the surface suffering joint pain that made it difficult for them to stand straight. Their appearance was similar to the 'Grecian bend' adopted by fashionable women of the time - hence the name. Many workers died or suffered permanent disability because of "Caisson disease", as the condition became known.

Caisson Workers

The connection between the workers' return to the surface and their symptoms led to the introduction of surface based recompression chambers to treat the afflicted. However, the reason for the condition was not fully recognised until 1878, when Paul Bert published his theory that the cause was the formation of nitrogen bubbles within the body. He also correctly stated that it was possible to avoid their harmful affects by ascending to the surface gradually - and that hyperbaric chambers worked, in part, because they decreased the size of bubbles.


NEW EXPERIMENTS PHYSICO-MECHANICAL, Touching The SPRING of the AIR, and its EFFECTS, (Made, for the most part, in a New Pneumatical Engine) Written by way of LETTER To the Right Honorable CHARLES Lord Vicount of DUNGARVAN, Eldest Son to the EARL of CORKE. By the Honorable Robert Boyle Esq;

OXFORD: Printed by H. Hall, Printer to the University, for Tho. Robinson. 1660.

Bert noted the work of the scientist Robert Boyle. In 1667, Boyle observed that following exposure to a compressed atmosphere, and subsequent decompression, a bubble formed in the eye of a viper. The animal also appeared distressed by the experience.

As stated by Boyle's Law, ascending from a hyperbaric environment towards the surface results in an increase in the volume of a fixed amount of gas, including those found in the body. In the case of oxygen, the body quickly reabsorbs the extra volume as the cells use it up. Carbon dioxide, a waste product of metabolism, is excreted through the lungs very efficiently and therefore does not present a problem when decompressing.

The body does not use nitrogen, however, which forms almost 79% of the air. For the purposes of discussing decompression, it is an 'inert' gas, as is helium. Unless enough time is allowed for the inert gas to be excreted through the lungs, any collection within the body's tissues can increase in volume to the point where bubbles are formed.

Steel Ball Hospital

These can lead to the formation of emboli (singular: embolus) that cause adverse physiological effects by impeding blood flow and/or damaging tissues or nerves. It should be noted that the presence of inert gas bubbles does not in itself lead to problems - what is important is the eventual size of these bubbles, their location, and the ability (or inability) of the body to rid itself of them before they cause damage.

The first recorded chamber was built and run by a British clergyman named Henshaw. He built a structure called the *domicilium* that was used to treat a multitude of diseases. The chamber was pressurized with air using bellows.

The French surgeon Fontaine, who built a pressurized, mobile operating room in 1879, continued the idea of treating patients under increased pressure.

Dr. Orville Cunningham, a professor of anaesthesia, ran what was known as the "Steel Ball Hospital." The structure, erected in 1928, was 6 stories high and 64 feet in diameter. The hospital could reach 3 atmospheres of pressure. The hospital was closed in 1930 because of the apparent lack of scientific evidence indicating that such treatment alleviated disease. It was deconstructed during World War II for scrap to aid the war effort.

DYSBARISM 3.4 (The Diseases of Diving)

Dysbarism refers to medical conditions resulting from changes in ambient pressure. Various activities are associated with pressure changes. Diving is the most common, but pressure changes also affect people who work in other pressurized environments (caisson workers).

Within diving the term dysbarism can be used to describe a host of diving conditions.

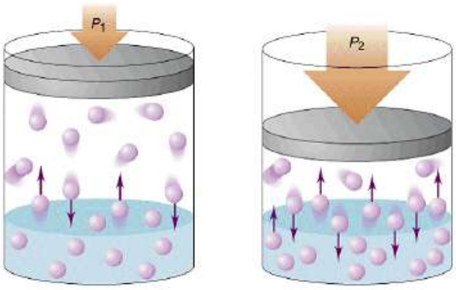
These Include;

- Barotraumas.
- Arterial Gas Embolisms (A.G.E.)
- Decompression Sickness.

Acute Decompression Illness 3.4.1

Decompression Illness (DCI) is a term that has been used for over 50 years. DCI includes both A.G.E.'s and Decompression Sickness.

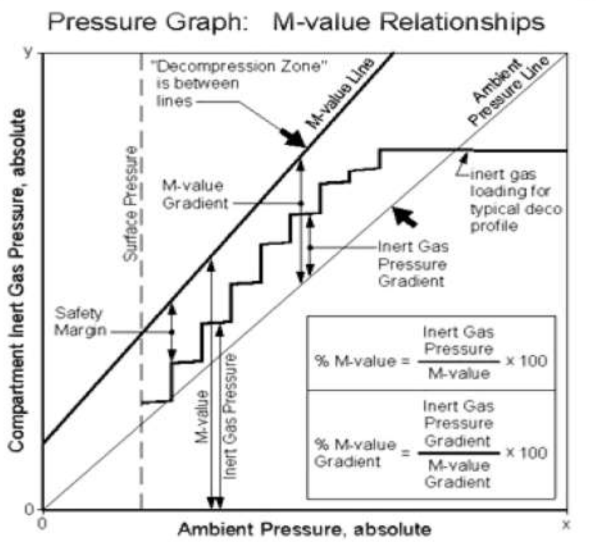
Acute decompression illness (DCI) is a syndrome of numerous possible manifestations, which may develop following decompression. It is thought to be initiated by the presence of bubbles of inert gas in the body tissues and blood stream. Although the means where, by these bubbles cause tissue dysfunction have yet to be fully understood, the manifestations have been recognised for many years and are described below.



Disease Mechanisms

There Are A Number Of Sources Of These Gas Bubbles:

Dissolved gas. The partial pressure of inert gas in arterial blood is approximately the same as the partial pressure in the gas mixture, which is being breathed. For example, at sea level, both air and arterial blood contain approximately 0.79 bar of nitrogen. During most dives or hyperbaric exposures, the partial pressure of the inert gas being breathed increases with depth and the concentration of that gas in arterial blood increases accordingly. For example the partial pressure of nitrogen in air at 2 bar is approximately 1.58; when this is breathed the partial pressure of nitrogen in the arterial blood is also approximately 1.58 bar. This effect is the same with different mixes and inert gases such as helium. Under these circumstances, the partial pressure of inert gas in tissues will gradually increase due to blood/tissue gas transfer until it equals the ambient partial pressure. In this state the tissues are considered to be saturated.



During decompression, inert gas moves in the opposite direction, from the tissues into the blood, where it is carried to the alveoli in the lungs and exhaled. If this process occurs in a controlled manner, so that the inert gas tension in the tissues does not reach a sufficient level of super saturation (exceeding M values) then bubbles of gas will not form and the decompression will progress uneventfully. However, if the rate of decompression is such that the capacity of the tissues, cardiovascular system and lungs to remove inert gas is exceeded, bubbles of that gas may start to form in tissues or blood.

The human body is capable of tolerating a certain bubble burden. Bubbles in venous blood, for example, are efficiently removed from the circulation by the lungs and numerous studies have demonstrated the presence of such bubbles in asymptomatic divers. Furthermore, bubbles may form in some tissues (such as adipose tissue) without causing overt disease. However, other tissues, particularly nervous tissue, are much more sensitive and the presence of even a small number of gas bubbles may result in abnormal tissue function.

Arterial gas bubbles. The lungs are excellent filters of gas bubbles. However, this capacity is finite; if the bubble burden is such that this is exceeded, they will transit the lungs and enter the arterial circulation. This can occur after heavy gas tissue loading and a rapid decompression.

The transit of venous bubbles to arterial blood may occur before the pulmonary filter is overwhelmed. In approximately 25-30% of the normal, adult population, the septum that separates the upper chambers of the heart contains a potential or actual defect, which is known as a Patent Foramen Ovale or PFO (This is a relic of the foetal circulation and normally results in no ill effects). However, it does offer a possible route for bubbles to bypass the pulmonary filter and consequently, along with other right-to-left shunts, has the potential to promote the arterialization of otherwise relatively harmless venous bubbles.

Bubbles in arterial blood physically obstruct small blood vessels and thereby cause tissue ischaemia (oxygen starvation through reduced blood flow).

This Localised Ischaemia Create A Cascade Reaction Which;

- Initiates local tissue inflammatory reaction.
- Increases localised tissue ischaemia.
- Increased endothelial permeability + leakage of plasma.
- Increased local pressure.
- Resulting in further inflammatory reaction & activation of the immunological complement.

Although it is recognised that tissue bubbles may arise from two fundamentally different processes it is often difficult, in individual cases, to be certain of the origins of the disease-provoking gas. Indeed, with respect to some organ systems, such as the ear and lungs, it may occasionally be difficult to distinguish between a bubble-induced condition and the results of barotrauma.

Consequently, it is now recognised that, for practical purposes, the distinction between the conditions that used to be known as decompression sickness and arterial gas embolism was artificial. As a result, the term decompression illness, which encompasses the two, is increasingly being used to reflect this.

Manifestation of D.C.I. 3.4.2

DCI type	Bubble location	Signs & symptoms (clinical manifestations)
Musculoskeletal	Mostly large joints (elbows, shoulders, hip, wrists, knees, ankles)	• Localized deep pain, ranging from mild to excruciating. Sometimes a dull ache. • Active and passive motion of the joint aggravates the pain. • The pain may be reduced by bending the joint to find a more comfortable position.
Neurologic	Brain	▪ Altered sensation, tingling or numbness paresthesia, increased sensitivity hyperesthesia. ▪ Confusion or memory loss. ▪ Visual abnormalities. ▪ Unexplained mood or behaviour changes. ▪ Seizures, unconsciousness.
Neurologic	Spinal cord	▪ Ascending weakness or paralysis in the legs. ▪ Girdling abdominal or chest pain. ▪ Urinary incontinence and fecal incontinence.
Audio-vestibular (Neurologic)	Inner ear	▪ Loss of balance. ▪ Dizziness, vertigo, nausea, vomiting. ▪ Hearing loss.
Constitutional (Probable Neurologic)	Whole body	▪ Headache. ▪ Unexplained fatigue. ▪ Generalised malaise, poorly localised aches.
Pulmonary	Lungs	▪ Dry persistent cough. / Shortness of breath. ▪ Burning chest pain under the sternum, aggravated by breathing.
Cutaneous	Skin	▪ Itching, usually around the ears, face, neck, arms, and upper torso. ▪ Sensation of tiny insects crawling over the skin. ▪ Mottled or marbled skin usually around the shoulders, chest and abdomen, with itching. ▪ Swelling of the skin, accompanied by tiny scar-like skin depressions (pitting odeama).
Lymphatic	Lymphatic Vessel	▪ Localised tissue swelling / oedema. ▪ Possibly due to blockage of the lymphatic vessels draining a specific group of lymph nodes (usually in trunk, head or neck).

How DCI manifests is generally complicated. DCI is a multi-system disease with single organ involvement is uncommon. The effects of the gas bubble load tends to attack the densest of tissue (or the slowest compartments), these are the nervous system, tendons / synovial joints, lymphatic tissue and adipose (fat).

DCI may present with a bewildering array of symptoms, which can lead the clinician to suspect what the underlying system effected is.

Traditional Classification Of DCI 3.4.3

As discussed, DCI as a disease / syndrome has been in existence for over 150 years. It is not surprising then that the disease has had many names and tools to describe its effects.

In addition to the "bends", the effects of "Caisson disease" have several other descriptive terms, the "chokes", "staggers" and "niggles".
From the 1950's the label 'decompression sickness' (DCS) was introduced in place of "Caisson disease".

Decompression Sickness Was Divided Into Three Subsections:

- Arterial Gas Embolisms.
- Type 1.
- Type 2.

The different classification reflects the effect, and therefore the severity, of the condition. Diagnosing DCS as one (or both) of just two categories does not enable proper identification or discrimination.
Arterial Gas Embolisms are discussed in Barotraumas. However, the two types are described here.

Type 1 D.C.I.

Type 1 DCS can occur when bubbles affect the tissues around skeletal joints. Decompression sickness might also present as a skin (cutaneous) .

- Local pain, usually in joints of arms or legs (knees, elbows and shoulders).
- Pain made worse by exercise.
- Itching, blotchy skin rash, mottling, raised section of the skin.

Type 2 D.C.I.

Type 2 Decompression Sickness reflects involvement of the Central Nervous System (CNS) and / or the cardio-respiratory system.
More than half of those diagnosed with DCS will be classified as Type 2. Cerebral symptoms arise from interruption of the blood supply to the main part of the brain, and include confusion, reduced mental function and unconsciousness.
Involvement of the cerebellum may lead to tremors, loss of balance ("staggers") and a lack of co-ordination (ataxia). Balance may also be affected by damage to the vestibular part of the inner ear.

Symptoms Include:

- Dizziness.
- Ringing in ears.
- Difficulty in seeing.
- Shortness of breath.
- Rapid breathing.
- Choking.
- Severe pain.
- Pain in abdomen.
- Extreme fatigue.
- Loss of sensation (numbness).
- Weakness of extremities.
- Collapse or unconsciousness.

The advantages of using the 'classical' classification system are overall familiarity, for over 50 years it has been the accepted description of the manifestation of DCI.
However there are multiple disadvantages in the use of this classification system; precise mechanistic diagnosis is often impossible due to the fact that DCI frequently have multiple manifestations.
It is common for multiple physicians to describe a condition as both Type 1 & Type 2 leading to a wide variations in diagnosis and ultimate treatment.

Modern Terminology Of DCI 3.4.4

Since the late 1990's a much more modern, descriptive-manifestation system of classifying DCI was introduced (At a 1991 Undersea and Hyperbaric Medical Society workshop)
Since decompression illness can interfere with the function of a wide range of body tissues, the number of potential signs and symptoms is truly enormous. Rather than using a somewhat artificial classification on

the decompression disorders (types I and II), a better understanding of DCI is likely to result if a descriptive system is used.

This System Is Split Into Three Components:

- Time of onset of symptoms.
- The evolution of symptoms.
- The actual symptoms.

Onset

The time of symptom onset is a key factor in the diagnosis of DCI 98% of all DCI's will present within exit from the water. The term "acute" is used to distinguish these conditions from possible "chronic" consequences of diving such as dysbaric osteonecrosis.

- Acute. The condition has manifested recently.
- Chronic. The condition has manifested some time ago.

Evolution

The evolution term is used to describe the development of the condition PRIOR TO RECOMPRESSION. DCI is frequently a rapidly changing condition.

The Evolution Of The Symptoms May Be Described As:

- Progressive. A progressive condition would be if the number or severity of symptoms or signs is increasing.
  - Increasing severity of limb pain and the involvement of additional joints.
  - A neurological presentation in which the loss of motor or sensory function is becoming more profound.
  - The development of a new manifestation.
  - Terms such as "rapidly" or "slowly" may be used to enhance the description of this evolution.
- Static. This is self-explanatory. Neither the severity nor number of manifestations is changing substantially.
- Spontaneously Improving. DCI that improves, without recompression.
  - Cutaneous skin bends. (Substantial improvement must occur for this term to be applied).
  - As with other evolution terms, "improving" should only be used to describe events prior to recompression.
- Relapsing. Occasionally, cases that have improved spontaneously undergo a secondary deterioration.
  - Common with neurological manifestations.
  - When a condition gets worse in the absence of spontaneous improvement it is described as "progressive".
  - "Relapsing" should be reserved for cases, which have, at some stage in their evolution, undergone substantial and spontaneous improvement.

Symptom Manifestations

There are a number of manifestations of decompression illness, which occur commonly, and these are outlined below. They may occur alone or in combination.

- **Limb Pain.** One the most frequent manifestation of DCI (second to lethargy / fatigue).
  - Deep aching pain in or around one or more joints.
  - Following 'bounce' dives, the upper limbs and the shoulder is involved particularly frequently.
  - Conversely, in saturation divers, it is the lower limbs and the knees, which are involved most commonly.
  - The pain is usually poorly localised; it may resolve spontaneously and is then known as a 'niggle'. Niggles may flit from joint to joint.
  - If the pain gets worse, it becomes more readily localised and is described as a dull, boring ache, similar in character to tooth ache. Sometimes the joint is held in a particular position that is least painful, but pain is seldom made worse by movement.
  - If the pain is in a lower limb, weight bearing may be poorly tolerated on that limb.
  - The 'classical' signs of inflammation: redness, swelling, warmth to the touch and tenderness are missing.
- **Girdle Pain.** This is a poorly localised, aching or 'constricting' sensation, generally in the abdomen or pelvis.

- Girdle pain is generally considered ominous since it frequently portends neurological deterioration.

- **Neurological.** Involvement of the nervous system may be subtle and multi-focal. Consequently symptoms can be of bewildering variety and very difficult to localise. Both the central and peripheral nervous systems may be involved and the manifestations can be broken down into the loss of certain functions:
  - Aberration of thought processes, loss of memory, speech disorders, alteration to the level of consciousness including seizures; loss of co-ordination; loss of strength or sensation.
  - Dysfunction of special senses and loss of sphincter control, especially of the bladder.
  - Loss of consciousness to the point of disorientation is a frequent finding and coma may occasionally ensue.
  - Motor and other sensory deficits.
  - Signs such as a change of mood, dulling of intellect and loss of short-term memory.

- **Neurological (Spinal).** Spinal cord is involved in neurological DCI with some frequency. It may appear to be involved alone or with other parts of the nervous system.
  - Short, deep dives with a rapid ascent to the surface are commonly involved.
  - The onset of symptoms commonly occurs shortly after dive (about half of cases are symptomatic within 10 minutes).
  - Less than 10% of serious cases present more than 4 hours after completing the dive.
  - In severe cases, the condition is often heralded by the onset of girdle pain.
  - Shortly afterwards, the patient may notice pins and needles, numbness and muscular weakness in the legs.
  - Which may rapidly progresses to paraplegia.
  - Neurogenic (spinal) shock may complicate the clinical picture.
  - The bladder is frequently involved (difficulty to void or full retention).

- **Audio-Vestibular (Neurological).** This is a unique subclass of neurological decompression illness. It is thought that there are two mechanisms whereby the audio-vestibular system may be involved: barotrauma (perilymph fistula / oval round window rupture) and tissue injury resulting from the formation of bubbles from dissolved gas.
  - Targets of these micro-bubbles include; the cochlea, the eighth nerve nuclei and cortical pathways.
  - It is very difficult to distinguish between these mechanisms or sites of injury by clinical examination alone.
  - The syndrome includes: vertigo (a sense of rotation), tinnitus, nystagmus or loss of hearing after a dive.
  - Nausea and vomiting may accompany these symptoms.
  - Previously there has been hesitation before prescribing recompression in such cases for fear of further tissue damage.
  - Recompression does not have an adverse effect on pathology due to round or oval window rupture.

- **Pulmonary. (The Chokes)** Related to the lungs: decompression pulmonary barotrauma and the cardiopulmonary consequences of massive venous gas embolism.
  - The mechanisms are distinctly different; it may be difficult to distinguish between them immediately in a clinical setting, because many of the symptoms and some of the signs are shared.
  - Those which imply pulmonary (or, rarely, cardiac) involvement in decompression illness are: chest pain, cough, haemoptysis, shortness of breath, cyanosis and, rarely, cardiogenic shock.
  - Progressive disease (where the symptoms are worsening) may be due either to a tension pneumothorax or massive gas embolism of the lungs.
  - Where there has been a dive, which has induced a low gas burden, it is most likely that a pneumothorax. This may be diagnosed clinically from the classic signs (described in the Gas Embolism section).

- **Cutaneous.** The skin may be affected in two manifestations of decompression:
  - Cutaneous DCI generally presents with severe itching around the shoulders or over the trunk.
  - This develops into an erythematous rash, which may progress to cyanotic mottling or marbling of the skin.

- **Lymphatic.**
  - Lymph nodes may become enlarged and tender and this may be associated with oedema.
  - The skin feels thickened and may have the ‘pitted' appearance of orange peel.
  - If pressure is applied to the skin for about a minute or so, a visible indentation remains.

- **Constitutional.** There are a number of non-specific symptoms that occur after diving and which, if severe or accompanied by other manifestations, may be considered part of the decompression illness syndrome.

- Symptoms include headache, fatigue, malaise (may include nausea and vomiting) and anorexia (loss of appetite)

Applying The Terminology

By including the onset, evolution and manifestation terms in the phrase "decompression illness", a highly flexible diagnostic label can be applied to any case. This label imparts a great deal of information and because it does not require the observer to guess at either a mechanism of the disease or location of the lesion, it should be possible for these terms to be applied consistently.

This is an important tool because the diagnosis of DCI is overall a clinical one (there is no diagnostic blood test or xray).

The disadvantage of this system is that it is generally verbose and it marginally ignores pathophysiology (rather than distinguish between musculo-skeletal and neurological pain, it simply uses 'limb pain').

Example Diver

25 year old male, diving on air.

- 2 dives:
  - 32 metres for 45 minutes total dive time.
  - 2 hour surface interval.
  - 32 metres for 35 minutes total dive time.

Worsening pain in left shoulder, with associated tingling in left hand, 30 mins after surfacing from 2nd dive.

Description:
Acute Progressive Neurological and Limb Pain DCI.

The advantages of this system are; an improved data collection with regards to manifestations of DCI, No real need for precise mechanistic diagnosis, a uniformity of reporting cases of DCI and once a clinician is use to the system it is relatively easy to use.

Examples Of How The Terminology Is Used Include:

Acute , Relapsing, Neurological, DCI

or:

Acute, Progressive, Limb Pain And Cutaneous DCI

In rare, highly complex cases, rather than enumerate a long list of manifestations, it may be appropriate to use the term 'multi-system'.

Additional DCI Factors 3.4.5

While the descriptive diagnostic terminology imparts a considerable amount of information, it is inadequate, of itself, to summarise a case of decompression illness. As was mentioned above, this a poorly understood syndrome and if a better understanding is to evolve, it is important that additional information is collected:

The Time Of Symptom Onset

DCI usually presents within a 24hr period following a dive although rarely it can present outside of this. Symptoms may become apparent before surfacing in saturation and occasionally in bounce dives, particularly where decompression has been omitted.

Most symptoms occur after surfacing and the majority of serious neurological or pulmonary symptoms are usually manifest within about 30 minutes.

The onset of limb pain also occurs in this time period but this may be delayed for many hours after a dive. It should be remembered that decompression illness might be provoked or made worse many hours after a dive if the diver takes a flight. If a diver has been asymptomatic for 48 or more hours after a dive and has not flown, then symptoms, which develop subsequently, are probably not DCI.

% Cases	First Symptoms
42%	Within 1 Hour
60%	Within 3 Hours
83%	Within 8 Hours
98%	Within 24 Hours
100%	Within 48 Hours

The time of onset of symptoms influences prognosis, a short latency implies severe disease (e.g A.G.E. / C.A.G.E.), late severe symptoms indicates a secondary pathology (such as haemorrhage).

An exceptionally delayed DCI should not be completely discounted due to the possibility of 'diver denial', this is a basic reluctance of an individual diver to admit that they have relevant symptoms.

Gas Burden

When considering possible mechanisms for DCI, it is desirable to estimate the amount of gas that is likely to be present in the various tissues. Consequently it is important that the dive profile is recorded as accurately as possible with the inclusion of the gas mix breathed. Where a dive computer or depth-time recorder was worn, the information should be retrieved from this source.

Presence of Risk Factors

It is important to evaluate the possible risk factors associated with the dive, these risk factors include;

- Dive profiles (Sawtooth pattern / shallow to deep dives / rapid ascent / multiple daily dives / omitted decompression / new dive / exercise at depth / during or after decompression).
- Individual diver (Age-fitness-weight of diver / dehydration / Patent foramen ovale (PFO) / Limb tourniquetion).
- Temperature (High temperatures lead to dehydration > blood plasma loss > reduced venous off-gassing. Low temperatures cause vasoconstriction & reduced off-gassing, particularly in adipose tissue).

- Altitude exposure (This does not have to be flying alone; a mountain ascent is an equal risk factor).

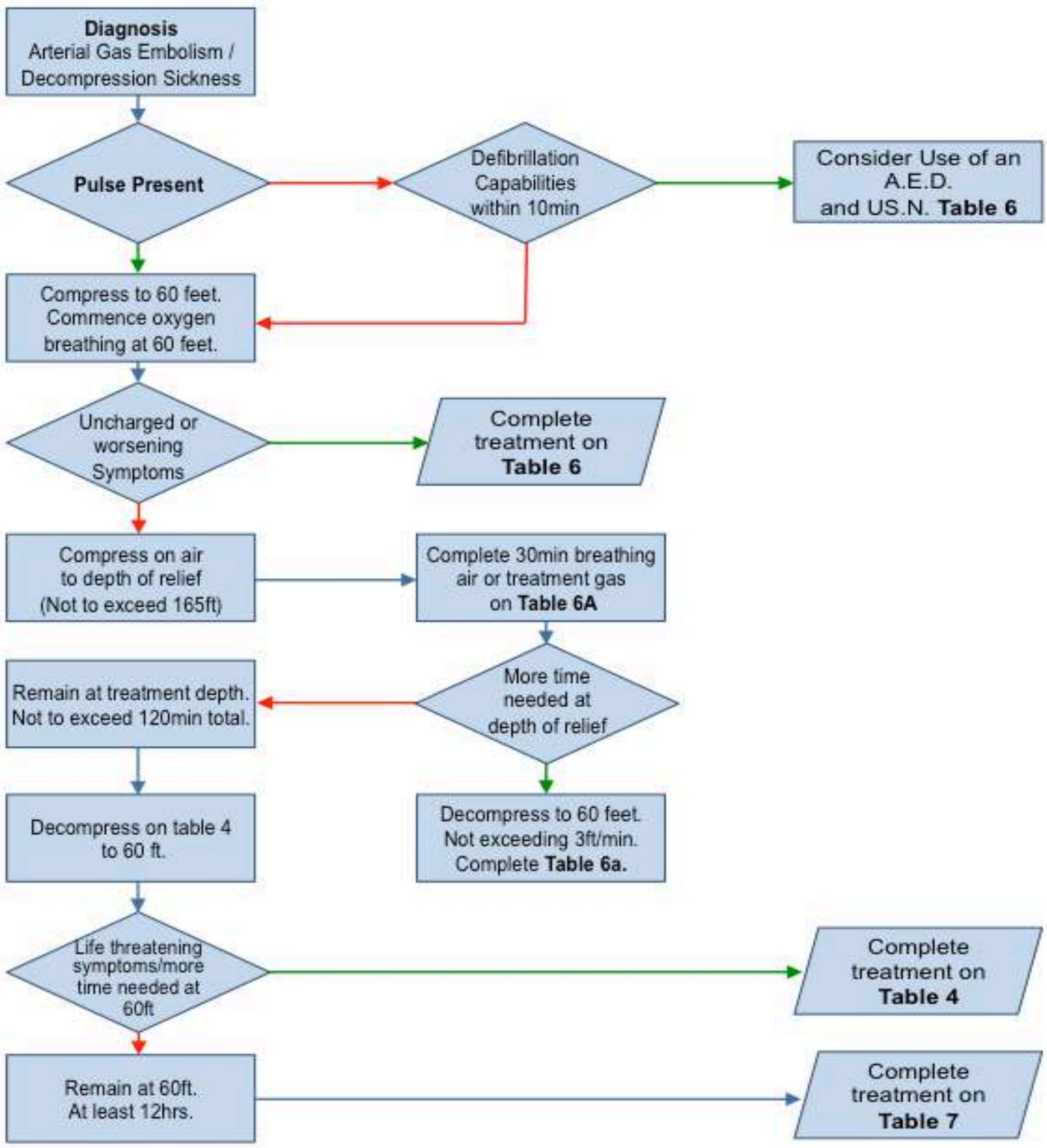
Treatment of D.C.I. 3.4.6

Immediate Actions in D.C.I.

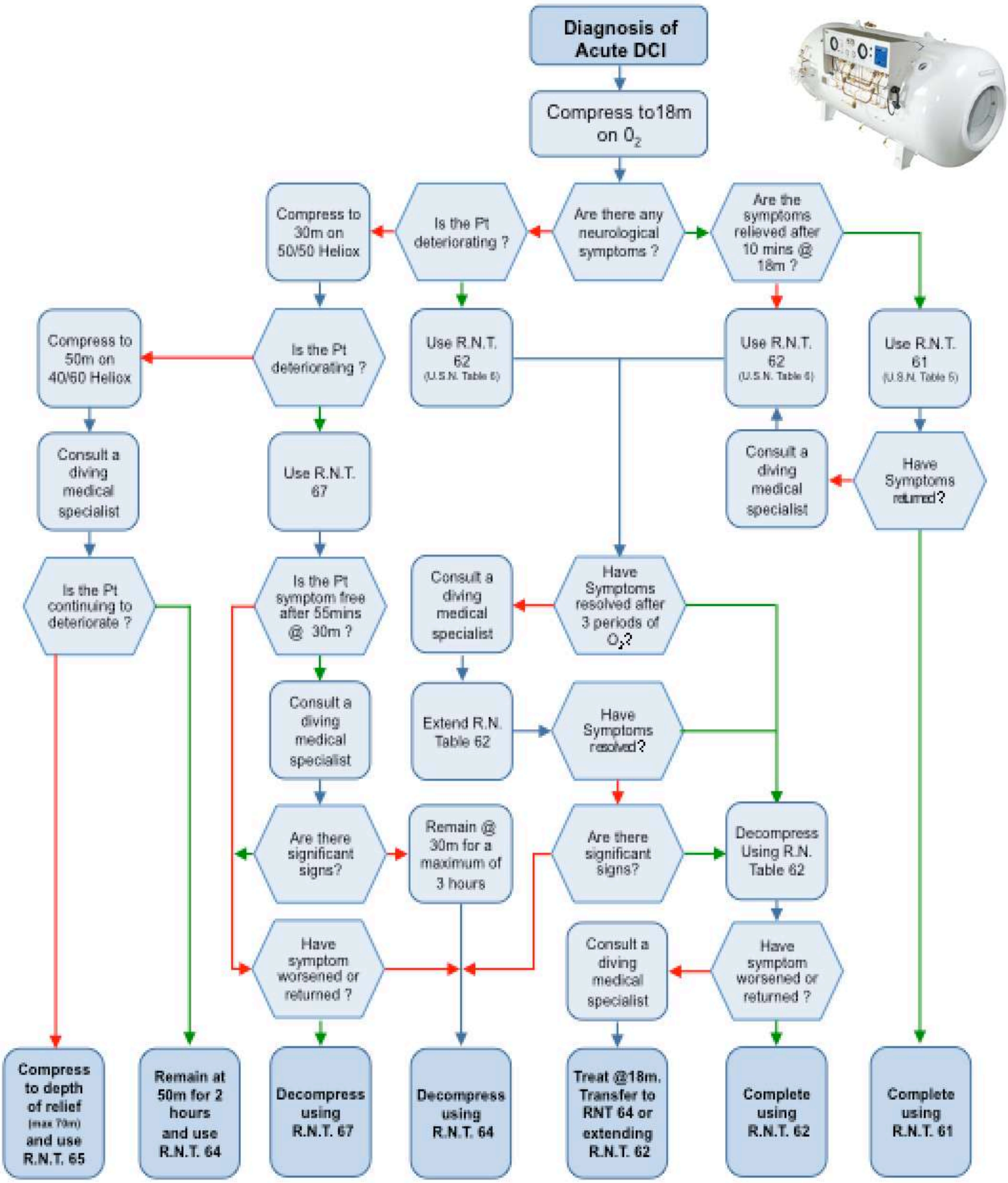
If a diver is suspected of suffering decompression illness the following immediate actions should take place.

- Contact duty medic / supervisor.
- Conduct primary / secondary survey (including full neuro exam) & record observations.
  - Apply D.C.I. manifestation criteria (ONSET – EVOLUTION – SYMPTOMS).
- Lay the casualty flat and administer high flow O_2.
- Implement airway / breathing management.
- Implement Shock Management as indicated.
- Start immediate recompression on appropriate treatment table (as advised by medical specialist or company SOP).
  - Use appropriate treatment algorithm such as the R.N or U.S.N.
- Repeat, and complete physical examination when patient is at treatment depth in recompression chamber.
  - Continue to apply treatment algorithm in accordance with the divers condition.

United States Navy D.C.I. Treatment Algorithm



Royal Navy D.C.I. Treatment Algorithm



ARTERIAL GAS EMBOLISM'S (A.G.E.) 3.5

A gas embolism occurs when a bubble of gas causes a blockage of the blood supply to the heart, brain or other vital tissue. The condition is worsened if the embolism occurs at depth, as the bubble will increase in size as the pressure decreases.

When divers hold their breath or have local air trapped in their lungs during ascent, the pressure-volume relationships will cause a rapid over expansion.

Alveoli can rupture or air can be forced across apparently intact alveoli. If air bubbles enter the pulmonary veins, they are swept to the left side of the heart and pumped out into the aorta. Bubbles can enter the coronary arteries supplying the heart muscle, but they are more commonly swept up the carotid arteries to embolise the brain.

As the bubbles pass into smaller arteries, they reach a point where they can move no further and here they occur immediately or within 5 minutes after surfacing.

Pulmonary Arterial Gas Embolism (P.A.G.E.) 3.5.1

Decompression pulmonary barotrauma is a syndrome, which results in dissolved gas rapidly coming out of solution and entering either the interstitial space within the lung, the pleural cavity or the blood stream.

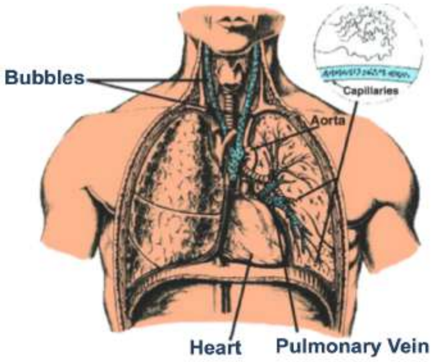
At the simplest level, if gas that has been breathed while at depth is trapped within the lung during ascent, then the resulting expansion in volume of that gas, in accordance with Boyle's Law, may be sufficient to cause the architecturally delicate pulmonary tissue to rupture and overwhelming the pulmonary filter.

The gas may be trapped as a result of breath holding, or as a result of pulmonary pathology.

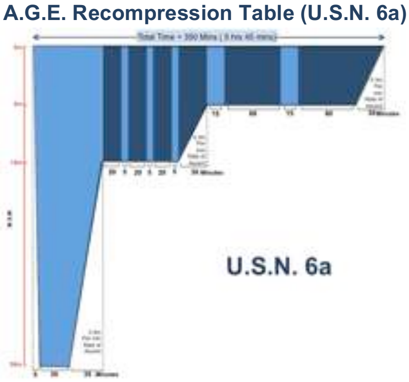
Presentation of Pulmonary Arterial Gas Embolism

- Rapid onset symptoms (usually < 10 minutes):
  - 9% occur during ascent.
  - 83% occur in less than 5 minutes of surfacing.
  - 8% occur between 5-10 minutes.
- Possible pneumothorax (associated pulmonary barotrauma rupture).
- Abnormal airway signs: Distress / wheeze / Haemoptesis (Bloody, frothy sputum).
- Neck Signs: Trachea Deviation possible / distended neck Veins / possible Emphysema.
- Breathing (RISE – FALL): rapid Rate / possible aSymmetrical movement / gross Effort & accessory muscle use / hypo-resonant on affected side / breath sounds: absent or crepitus.
- Difficulty speaking (will need to take a breath in the middle of a sentence).
- Low SPO_2 levels.
- Cardiogenic shock.
- Chest pain (usually behind the breastbone).
- Neurological signs:
  - Confusion.
  - Visual disturbances such as blurring.
  - Seizure (Focal / Generalised).
  - Sudden unconsciousness (usually immediate after surfacing but sometimes before surfacing).
- Pulmonary / Cardiac Arrest.

P.A.G.E.



A.G.E. Recompression Table (U.S.N. 6a)



Management of Pulmonary Arterial Gas Embolism

- Conduct primary / secondary survey (Including neuro exam) & record observations.
- Contact duty medic / supervisor (URGENTLY).
- Implement tension pneumothorax management as indicated.
- Implement airway / breathing management (ALWAYS initiate O_2, R.S.I. is often required for intubation).
- Implement Shock Management as indicated. (O_2 , I.V.I. etc).
- Positioning the patient in a horizontal -15% inclination.
- Start immediate recompression (as advised by medical specialist or if unavailable company SOP often USN 6a is appropriate).
- Continually assess casualty & record observations.
- Prepare to evacuate (as per company S.O.P's).

Cerebral Arterial Gas Embolism (C.A.G.E.) 3.5.2

Arterial gas emboli arise from gas bubbles in the pulmonary capillaries, which then pass to the pulmonary veins to the left side of the heart (possibly causing coronary artery emboli). The gas will pass via the internal carotid and vertebro-basilar arteries to the brain.

The gaseous foam or bubbles block arteries of the 30-60 micron and cause distal ischemia and neuronal swelling. As the bubble passes over the endothelium, there are direct cellular effects (within 1-2 minutes). The bubble itself has surface effects causing local swelling, downstream coagulopathy with focal hemorrhages.

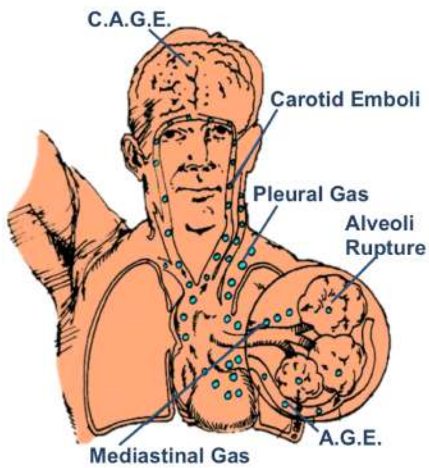
There is immediate increased permeability of the blood-brain barrier, loss of cerebral auto-regulation, rise in CSF and a rise in the systemic blood pressure.

CAGE is a life-threatening emergency with the clinical picture of a stroke and requires immediate medical treatment in line with a P.A.G.E.

Presentation of Cerebral Arterial Gas Embolism

- Symptoms of P.A.G.E. (including rapid onset).
- Neurological changes;
  - Stroke (F.A.S.T.).
  - Headache.
  - Blindness (partial or complete).
  - Numbness and tingling.
  - Weakness or paralysis.
  - Seizure (Focal / Generalised).
  - Sudden unconsciousness (usually immediate after surfacing but sometimes before surfacing).
- Pulmonary / Cardiac Arrest.

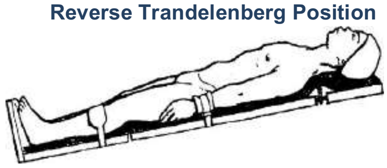
C.A.G.E.



Management of Cerebral Arterial Gas Embolism

- Implement P.A.G.E. management.
- Contact duty medic / supervisor (URGENTLY often evacuation for neurosurgical review is necessary).
- Implement seizure management.
- Implement stroke & cerebral compression management.
  - Often stabilization with ventilation & sedation is mandatory.
  - Maintain a flat or a 15^{o} reverse trandelenberg position.
- Prepare to evacuate (as per company S.O.P's).

Reverse Trandelenberg Position



DECOMPRESSION THERAPY 3.6

It is important that a A.L.S.T. orientates themselves to their company's S.O.P.'s with regards to treatment of DCI with compression therapy.

Standard recompression algorithms are readily available, but it is not uncommon for specific operators to modify or enhance treatment algorithms.

We have included a 'Tender Responsibilities' section in this chapter, which highlights the R.N. Tables 66, 62 & 67. These responsibilities can be altered to suit any chamber.

Personnel Requirements For Chamber Operations

The minimum team for conducting any recompression operation consists of a Diving Supervisor, an inside Tender, outside Chamber Assistant and depending on the circumstances, a Diving Physician.

Diving Supervisor

The diving supervisor is in charge of the operation and must be familiar with all phases of chamber operation and treatment procedures. The supervisor must ensure that communication, logging, and all phases of treatment are as per company SOP's.

Diving Physician

The diving physician is trained in the treatment of diving accidents. Although it may not be possible to have a diving physician present during all treatments, it is essential that the diving supervisor be able to consult by telephone or radio with a diving physician.

Chamber Tender

The inside tender must be familiar with all treatment procedures and with the signs, symptoms and treatment of diving related injuries and illnesses. They are responsible for the direct care of the casualty & communicating their condition with the dive supervisor / duty medic.

Choosing the Right Personnel

When a recompression treatment is conducted for pain-only decompression illness, an experienced physician or DMT should tend the patient inside the chamber.

If it is known before the treatment begins that specialised medical aid must be administered to the patient, or if a gas embolism is suspected an appropriately trained medic should accompany the patient inside the chamber. If the chamber is sufficiently large, a second tender may also enter the chamber to assist during treatment. Inside the chamber, the tender ensures that the patient is lying down and positioned to permit free blood circulation to all limbs.

When a diver is being recompressed, all the tending personnel must work as a team for the benefit of the patient. Whether the inside or the outside tender operates the chamber will be dictated by the availability of qualified personnel and the circumstances of the casualty being treated.

If the patient has symptoms of serious DCI or gas embolism, the team will require additional personnel. If the treatment if prolonged, a second team may have to relieve the first.

Whenever possible, patients with serious DCI or gas embolism should be accompanied inside the chamber by a DMT or a diving physician, but treatment should not be delayed to comply with this recommendation.

Effective recompression treatment requires that all members of the treatment team be thoroughly trained and practised in their particular duties. It's advisable to cross train members to carry out the duties of their teammates.

Chamber Attendant Responsibilities 3.6.1

State Of readiness

Since a recompression chamber is emergency equipment, it must be kept in a state of readiness. The chamber needs to be well maintained and equipped with all necessary accessory equipment. *A chamber is not to be used as a storage compartment.*

Key Responsibilities Include:

- Ensuring that the pre-dive checklist is completed.
- Ensuring the cleanliness of the chamber interior.
- Ensuring provision of chamber medical supplies in line with SOP's / DMAC regulations.
  - Ensure medical specific items are available in line with patient needs.
- Effectively communicating with the chamber supervisor.
- Ensuring the patient does not carry forbidden items into the chamber.
- Are there factors that preclude the casualty from the treatment:- of a cold or a toothache.
- Fully assess patient:
  - Providing assistance with the patient's activities of daily living as required.
- Ensuring exhaust & equalization valves are in the 'closed' position.
- The tender manually ensures the seal of the inner lock.
- Ensuring the patient's wear hearing protection during various treatment stages (descent, and flushing).
- Monitor the patient's for ear discomfort, halting the ascent as required until pain has been relieved.
  - Administrating treatment gas to the patient when instructed by the chamber supervisor.
  - Monitor effects of treatment gas.
  - Ensuring that the patient's are in a position that permits free blood circulation to all extremities.
  - Ensuring that BIBS mask is comfortable, well sealed and free of gas leaks.
- Discontinuing treatment gas to the patient when instructed by the chamber supervisor.
- Providing normal assistance to the patient's as required.
- Providing first aid as required by the patient's.
- Responding to any internal chamber emergencies in accordance with S.O.P's.
- Assisting in post treatment chamber / BIBS cleaning.
- Preparing chamber for subsequent treatment.
- Ensure the completion of the post-dive checklist.

General Chamber Safety Precautions:

- Do not use petroleum based products on or anywhere near the chamber or associated equipment.
- Ensure the securing dogs (medical lock) are in good operating condition and seals are tight.
- Do not allow open flames, smoking materials, or any flammables to be carried in the chamber.
- Do not permit electrical appliances to be used in the chamber (unless verified by SLST).

Tender Decompression Needs

The experience of being in a hyperbaric chamber physiologically is identical to diving. And just like scuba diving the length of time an attendant can stay at depth is dictated by how much nitrogen they absorb from the air (79% of air is nitrogen).

All chamber supervisors are highly experienced diving supervisors who are experts at calculating tenders decompression needs in accordance with internationally recognized dive tables.

During various stages of the treatment table the chamber attendant is instructed to 'go on oxygen'.

This has two actions. Firstly, no further nitrogen is being breathed and therefore any accumulation of the gas ceases. Secondly the attendant will actually 'off gas', as absorbed nitrogen will be removed at an accelerated rate due to an increased osmotic pull.

Tenders should not fasten the oxygen masks to their heads, but should hold them on their faces. The risk of the tender experiencing oxygen toxicity is amazingly low (they only consume a fraction of the oxygen that the patient does). If however the tender does experience oxygen toxicity, the exclusion of head straps ensures that the oxygen will simply fall away from the airway.

U.S. Navy Dive Tables

Table 9-9. Air Decompression Table (Continued).
(DESCENT RATE 75 FPM—ASCENT RATE 30 FPM)

Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (FSW) Stop times (min) include travel time, except first air and first O_2 stop 100	90	80	70	60	50	40	30	20	Total Ascent Time (M:S)	Chamber O_2 Periods	Repet Group
170 FSW														
5	5:40	AIR									0	5:40	0	D
		AIR/O_2									0	5:40		
10	5:00	AIR									2	7:40	0.5	G
		AIR/O_2									1	6:40		
15	5:00	AIR									7	12:40	0.5	J
		AIR/O_2									4	9:40		
In-Water Air/O_2 Decompression or SurDO$_2$ Recommended														
20	4:40	AIR								1	29	35:20	1	L
		AIR/O_2								1	15	21:20		
25	4:20	AIR							1	6	46	58:00	1	N
		AIR/O_2							1	4	23	33:20		

Royal Navy Table 62 Recompression Therapy (U.S.N. Table 6) 3.6.2

This table is used for the great majority of cases of DCI. Its use is dictated by patient response in the treatment algorithm.

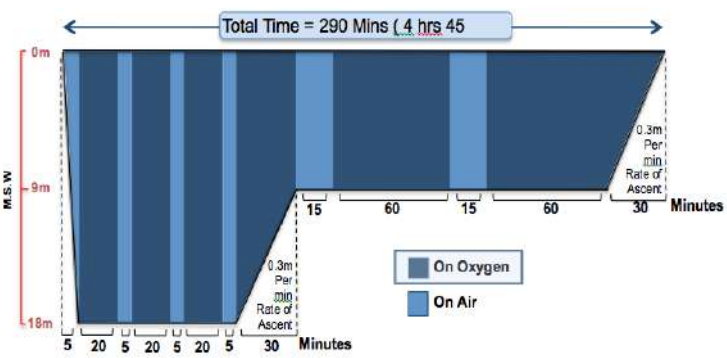
Proceed As Follows:

- Descend to 18m over 3-5 minutes (stopping only if the patient or attendant has difficulty in clearing their ears).
- The timing of the treatment starts on reaching 18m.
- Upon reaching 18m the patient is re-assessed.
  - The assessment should take no more than 2-3 minutes.
  - The patient's condition to have stabilised or improved, if the algorithm is followed strictly, the decision to change to R.N. Table 61 may be made (however many specialist believe that the R.N.T. should always be completed).
  - However, patients who have presented with serious symptoms may continue to deteriorate at 18m. In such cases, the chamber should be compressed to 30m on air with the patient breathing 50/50 Heliox (50% oxygen / 50% helium). Decompression will then normally be completed using RN Table 67.
- If the time between reporting symptoms and receiving treatment is greater than 8 hours or if the symptoms have remained static or improved incompletely after three 20 minute periods on 100% O_2 at 18m, RN Table 62 may be extended with one or two further O_2 breathing periods, separated by a 5 minute air break.
- If the signs and symptoms have not resolved after 2 extensions at 18m further advice from the diving medicine specialist should be sought.
- Symptoms may recur during ascent to 9m or at 9m. In such circumstances;
  - STOP THE ASCENT and return to 18m.
  - Consult a Diving Medicine Specialist.
- RN Table 62 may be extended for one or two 1hour O_2 breathing periods at 9m, separated by 15 minutes air breaks.

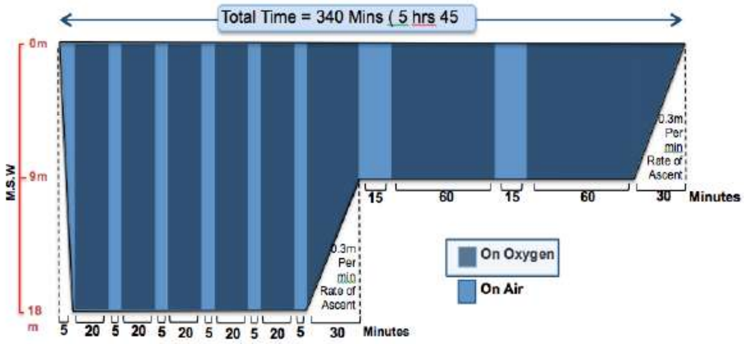
Attendant Decompression Needs;

- For an unmodified R.N.T. 62 or a R.N.T 62 with one extension, at 9m or 18m, the attendant must:
- Breathe O_2 for the last 30 minutes at 9m and during the ascent from 9m to the surface (60 minutes in total). If RN Table 62 is extended more than once, then the attendant should breathe O_2 for the whole of the final O_2 period at 9m and the ascent to the surface (90 minutes in total).
- If the attendant has undergone a hyperbaric exposure in the preceding 24 hours, an additional 60 minute period breathing O_2 at 9m (150 minutes in total) should be undertaken.

Royal Navy Table 62



Royal Navy Table 62++ (with 2 extensions)



Royal Navy Table 67 Recompression Therapy 3.6.3 (Comex 30 Heli/Ox)

This table, a modified version of the COMEX 30 table, is to be used for the treatment of more serious or more threatening cases of D.C.I.

These Cases Include;

- Gross Neurological symptoms within 24hrs of diving.
- Diving deeper than 50m.
- Diving on mixed gas.
- The patient continues to deteriorate following an initial compression of 18m on 100% O_2.
- Omitted decompression on very deep dives, when the diver has completed less than 15 minutes of stops and the stops missed were at depths in excess of 18m.
- On the advice of a Diving Medicine Specialist for the treatment of DCI.

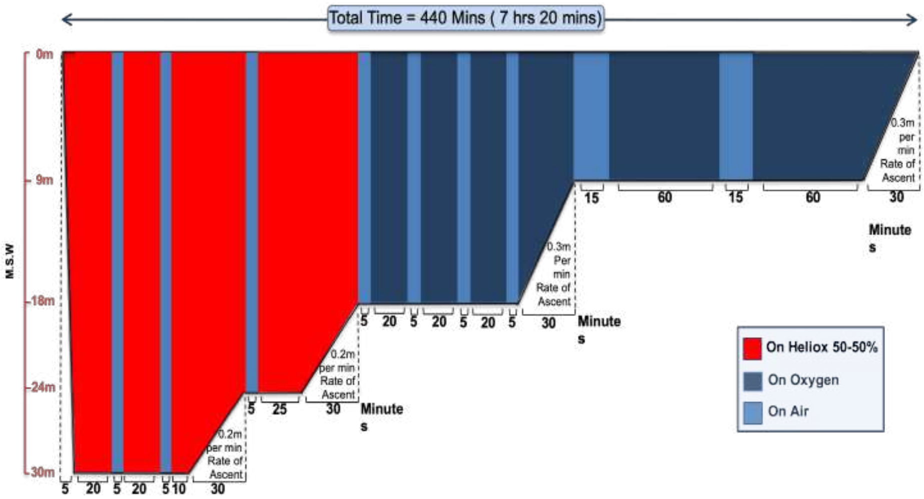
Proceed As Follows:

- The patient breathes 50:50 O_2:He on the surface, or from 18m when transferring from RN Table 62.
- Descend to 30m over 5-10 minutes (stopping only if the patient or attendant has difficulty in clearing their ears).
- The timing of the treatment starts on reaching 30m.
- Upon reaching 30m the patient must be reassessed.
  - This assessment should take no more than 2-3 minutes.
- If symptoms have remained static or improved incompletely after 55 minutes at 30m up to 5 additional 20 minute periods breathing 50:50 O_2:He, separated by 5 minute air breaks, may be added on the advice of Diving Medicine Specialist.
  - On completion of extensions decompression should be by RN Table 64 with 50:50 O_2:He breathed during the ascent from 30-24m.
  - A 5 minute air break is taken on arrival at 24m with 50:50 O_2:He breathed during the remaining 25 minutes of the 24m stop and the ascent from 24-18m.

Attendant Decompression Needs;

- For an unmodified RN Table 67 the attendant must breathe O_2 during both 60-minute O_2 periods at 9m and during the ascent from 9m to the surface (total 150 minutes).
- If the RN Table 67 is extended at 18m, by either one or two additional O_2 periods, it must also be extended by an additional 60 minute O_2 period at 9m during which time the attendant is to breathe O_2 (210 minutes).
- If the RN Table 67 is extended at 9m the attendant must breathe O_2 for an additional 60-minute period (total 210 minutes).
- If the attendant has undergone a hyperbaric exposure in the preceding 24 hours RN Table 67 should be extended at 9m to permit the attendant to breathe O_2 for an additional 60-minute period (total 210 minutes).

Royal Navy Table 67



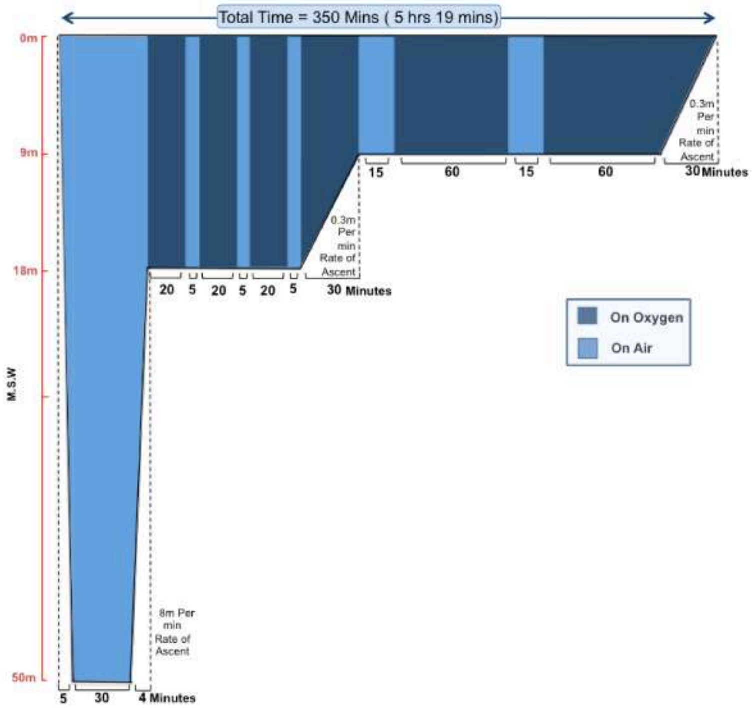
Royal Navy Table 63 Recompression Therapy (U.S.N. Table 6a) 3.6.4

This table was developed specifically for the treatment of arterial gas embolism. Given the difficulties in making such a diagnosis and the potential disadvantages associated with the initial compression to 50 m use of this table is reserved for those patients who present with rapid onset of severe symptoms following dives with minimal inert gas uptake and who show no significant improvement, or are continuing to deteriorate, when assessed following compression to 18 m breathing oxygen.
In practice this means that Table 63 will rarely be used except following massive rapid ascents or overt gas embolisms.

Proceed as Follows:

- Pressurise the chamber, without delay with air to 50m at the fastest rate that can be tolerated by the patient and attendant up to 30m per minute.
  - If a gas mixture of 32 O_2 :67 He is available, this should be breathed by the patient via BIBS.
- If the patient is free of symptoms and signs after 25 minutes, and 0_2 is available:
  - Decompression may be commenced using Table 63.
  - If 0_2 is not available Table 64 should be used, omitting the oxygen.
  - If there are persisting symptoms and signs after 30 minutes at 50 m, no matter how minor, Table 64 should be used.
- If the patient is deteriorating at 50 m, contact a Diving Medicine Specialist as a matter of urgency.
  - It may be necessary to compress the patient further and continue treatment using Table 65. This should not be contemplated however, unless:
    - A Diving Medicine Specialist is consulted.
    - The chamber is capable of supporting a prolonged treatment.
- Decompression from 50 m to 18 m should take 4 minutes after which Table 63 proceeds as for Table 62, except that the attendant must always breathe 0_2 during the final 60 minutes at 9 m and subsequent ascent (90 minutes in total).
- If the attendant has had a previous hyperbaric exposure within 24 hours oxygen should be breathed for both 60 minute periods at 9 m and during the ascent (total 150 minutes).

Royal Navy Table 63



Failure Of Recompression Treatment 3.6.5

Four major complications may effect the recompression treatment of a patient.

These Are:

- Worsening of the patient's condition during treatment.
- Recurrence of the patient's original symptoms or development of new symptoms during treatment.
- Recurrence of the patient's original symptoms or development of new symptoms after treatment.
- Failure of symptoms of decompression illness or gas embolism to resolve despite all efforts using standard treatment procedures.

When any of these complications occurs, the advice of diving medicine experts should be sought immediately, because alternative treatment procedures have been developed and used successfully when standard treatment procedures have failed.
These special procedures may involve the use of saturation diving decompression schedule; cases of this type occur more frequently when a significant period of time has elapsed between the onset of symptoms and the initial recompression.

DISORDERS OF DIVING 3.7

Adiabatic Compression 3.7.1

Adiabatic compression is the term used to explain Charles's Law relation to diving. Temperature increases with pressure. In a hyperbaric vessel (decompression chamber or bell), temperature will increase on compression (when the bell is blown down or the chamber pressurized).

It is important that pressurization speeds set down by your diving company are not exceeded.

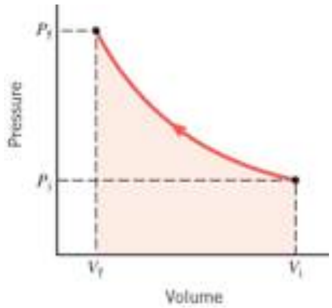
Oxy/Helium is about 6 times more conductive of heat than air, and if the humidity is high (over about 85%), then the body's ability to sweat and loose heat is reduced, resulting in an increase risk of heat exhaustion / stroke.

Normally the chamber environment should be maintained around 27 or 28°C and 75% humidity.

Prevention of Adiabatic Compression:

- Do not exceed pressurisation speeds.
- Monitor chamber temp during compression (check temp reader is calibrated).
- Do not overheat chamber prior to compression.
- Keep chambers in hot climates shaded.

Adiabatic Compression



Management of Adiabatic Compression:

- Conduct primary / secondary survey & record observations.
- Douse chamber exterior with cold water (cover with blankets and soak).
- Flush chamber with correct mixture.
- Decompress if emergency (chamber atmosphere will cool down).
- Use chamber heating system (if appropriate) on "cold cycle" to act as "heat sink".
- Cool occupants with cold water (shower, ice, sponge), and give cool fluids (weak salt water).
- Implement heat illness measures for chamber occupants.
- Seek medical advice from duty medic.

Aseptic Bone Necrosis 3.7.2

Aseptic bone necrosis is dead bone tissue in the absence of infection or disease process occurring in part of a bone, which is otherwise normal. This is thought to be caused by an absence of a blood supply to part of the bone due to condition such as trauma, iatrogenic (physician-induced) side effects of treatment using steroids or radiation, some blood disorders or alcoholism. Aseptic bone necrosis is often referred to as Avascular Necrosis.

Towards the end of the last century, aseptic bone necrosis was found to occur in men who worked in caissons; as a result this condition was originally known as Caisson Disease of Bone.

Dysbaric Osteo-necrosis (DON) 3.7.3

This is aseptic bone necrosis occurring in divers and compressed air workers. The earliest description of this condition was in 1888 and X-ray findings were first described in compressed air workers in 1911.

The condition was first described in divers in 1941. It is thought to be a chronic occlusion of bone blood vessels by bubbles or other mechanisms related to accumulation of gas in the tissues.

Definite lesions have been noted 17% or caisson air workers have definite lesions and 3% of commercial divers.

DON generally affects the; humerus, femur and tibia.

Dysbaric Osteo-necrosis

Presentation of Dysbaric Osteo-necrosis;

- Possibly symptomless.
- Sudden and persistent pain in a joint.
- Gradually increasing pain, stiffness and loss of movement of a joint;
  - Indicating the development of degenerative arthritis.

Management of Dysbaric Osteonecrosis

- If DON is discovered ceasing diving is recommended.
- Severe lesions will require orthopedic surgical intervention.

High Pressure Nervous Syndrome (HPNS) 3.7.4

High Pressure Nervous Syndrome (HPNS) is a derangement of central nervous system function that occurs during deep helium/oxygen dives, particularly saturation dives.

The cause is unknown. HPNS is first noted between 150m – 200m, and the severity appears to be both depth and compression rate dependent.

With slow compression, depths of 350m may be achieved with relative freedom from HPNS.

Beyond that, some HPNS may be present regardless of the compression rate.

Attempts to block the appearance of the syndrome have included the addition of nitrogen or hydrogen to the breathing mixture and the use of various drugs. No method appears to be entirely satisfactory.

HPNS

Presentation of HPNS:

- Nausea.
- Fine tremor – imbalance.
- Coarse tremor.
- Loss of manual dexterity - In-coordination.
- Jerky movements.
- Loss of alertness - Disorientation.
- Abdominal cramps and diarrhoea develop occasionally.
- In animal experiments convulsions have also been recorded.
- In severe cases; vertigo, extreme indifference to his surroundings, confusion.

In 1965 the Royal Navy Physiological Laboratory was conducting a series of deep dives in a compression chamber to depths of 200 – 350m. The condition appeared to improve after 90 mins at depth, and the subjects gradually returned to normal.

EXAMPLE:

In a series of dives, the following symptoms were reported. Using a compression rate of 2.5m/min without rest stops:

- At 200m: Tremors appeared.
- At 240m: Changes in the brain activity was recorded by electro-encephalogram.
- At 320m: Development of muscular in-coordination.
- At 330m: Subjects beginning to experience loss of alertness.
- At 350m: Subjects develop extreme indifference, and decreased comprehension.

Some reports have recorded bouts of sleep occurring from which the subject is readily awakened. Difficulty in right-left orientation has also been reported.

The development and severity of High Pressure Nervous Syndrome appears to be related to the rate of compression at great depths being particularly more noticeable at faster rates.

Investigations into other possible contributory causes, such as the effects of oxygen, carbon dioxide, temperature, and fluid shift within the tissues due to gas pressure, have been found to have little, or no part in the incidence of HPNS.

It has been found that the inclusion of nitrogen, or other heavier narcotic gases has significantly reduced the cost of the mixture, alleviated the effects of voice distortion, and reduced the dangers of excess heat loss. For this reason it is common to use a "TRI-MIX" of oxygen, nitrogen and helium when diving deeper than 200m.

Prevention / Management of HPNS:

- Follow the general rule, "the deeper the dive, and the slower the rate of compression".
- Use appropriate gas mix.
- Include rest stops on compression.
- Monitor divers closely for signs of HPNS.
- Exclude – abort diver with severe symptoms.

Hydrostatic Nervous Syndrome 3.7.5

A similar condition to High Pressure Nervous Syndrome may occur when the subject has been exposed to extreme depths for long periods. It is not dependent on rate of compression.

Although the symptoms of this condition are similar to those of HPNS, the exact mechanism of this action is not fully understood. The main difference is in its occurrence after the depth has been stable for some time. The main form of treatment in both cases when symptoms are severe is to gradually decompress the individuals involved until the symptoms disappear.

Compression Arthralgia 3.7.6

Hyperbaric arthralgia is pain in the joints due to raised ambient pressure.

A diver suffering from hyperbaric arthralgia sometimes hears a creaking and cracking from his joints and feels as if his joint surfaces are dry (no "joint fluid"). Joints hurt especially on movement. The condition is aggravated by a too-rapid compression.

A compression rate of not more than 1m / min often avoids the painful effects of this condition although the cracking of the joints continues.

Tinnitus 3.7.7

Tinnitus or spontaneous noise or ringing in the ear can occur with middle ear disease that causes a conductive hearing loss, in terms of diving a perilymphic fistula or audio-vestibular DCI (very rare) may be the underlying cause. but it is usually associated with inner ear or brain disease.

HEARING LOSS Is Classified In To Three Categories:

- Conductive hearing loss, caused by;
  - Complete occlusion of the external auditory canal by wax.
  - Inflammation, swelling of the ear-drum or lining of the middle ear.
  - Fluids in the middle ear.
  - Changes in middle ear gas densities, pressure gradients across the ear drum.
  - Fixation of the ear bones, or loss of elasticity of the eardrum caused by scaring or large perforations.
- Neuro-sensory or nerve hearing loss, caused by nervous or vascular insufficiency in the inner ear;
  - Head injury.
  - Stroke.
  - Bubbles (DCI).
  - Round or oval window rupture.
  - Excessive noise exposure, or various other inner ear disease or conditions.
- Mixed or combined conductive and neuro-sensory hearing loss caused by simultaneous dysfunction of the middle and inner ear.

Management of Tinnitus:

- Seek ENT specialist review.
- Treat underlying cause of Tinnitus.

Vertigo 3.7.8

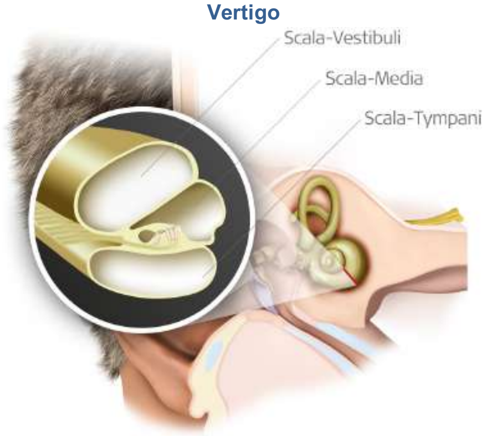
The occurrence of vertigo underwater is dangerous, being a potential cause of fatal underwater accidents. Normal balance under physiological conditions on dry land is maintained by the inter-action of gravity and a series of sensory organs. Joints and muscles, vision, and the vestibular organs all give complementary information to the brain about position in space, movements etc.

Underwater a profound change takes place. Buoyancy reduces the value of clues from joints and muscles. Darkness precludes visual clues and a great deal more reliance is placed upon sensations from the semi-circular canals and the vestibular apparatus generally.

Under calm conditions a diver gains extra clues from incidental observations such as bubble streaming, and buoyancy of objects with known behaviour at the depth involved, but under emergency or panic conditions this information too may not be available and sensation from the ear organs becomes a vital matter for survival.

DCI can cause gas release in the semi-circular canals or vestibule, causing physical disruption of the hair cells, which detect the relative movement of the labyrinthine fluids.

Vertigo



Presentation of Vertigo:

- False sensations of movement of the subject or of his surroundings, known as vertigo.
- Spinning sensation, such as is felt after getting off a roundabout,
- Swaying or falling sensation.

- Nystagmus – (a flickering movement of the eye).
- Severe nausea.

Management of Vertigo:

- Gain orientation as soon as symptoms of vertigo present.
- Report episodes & undergo review by dive doctor.
- Treat underlying cause.

Alternobaric Vertigo 3.7.9

Unequal or asymmetrical clearing of the middle ear during descent or ascent, and particularly during ascent, can cause vertigo. Regardless of the cause, vertigo and its accompanying spatial disorientation are hazardous if they occur during a dive.

Alternobaric Vertigo

Management of Alternobaric Vertigo

- Avoid diving if; there is difficulty clearing ears or if a Valsalva manoeuvre on the surface produces vertigo.
- If there is vertigo, ear blockage or ear fullness during compression, they should;
  - Stop any further descent.
  - Ascend until the ears can be cleared.

Omitted Decompression 3.7.10

In situations such as blow-up, loss of air supply, bodily injury or other emergencies, a diver may be required to surface prematurely, without taking the required decompression.

Surface decompression has been a recognised feature of commercial diving for many reasons for decades. It has earned the title 'bend and mend' as an overall policy.

Management of Omitted Decompression;

- Use appropriate tables / company procedures for surface decompression.
- Be suspicious. Observe diver for possible dysbaric condition (D.C.I. / A.G.E. / barotrauma).
  - If present apply appropriate treatment & compression table.
- If the diver shows no ill effects from omitted decompression, the diver should;
  - Be monitored for at least 4 hours.
  - Stay within the vicinity of a recompression chamber for 24-48hrs.
- Recompression may be considered as a precaution.
- In-water treatment for omitted, asymptomatic decompression should not be performed.

Surface Decompression

GAS TOXICITY 3.8

Gas toxicity is defined as ill health caused by absorbing airborne gas via the:

- Respiratory system.
- Skin.
- Mucous membrane.

The Factors That Influence The Casualty's Response To The Agent Are:

- The specific gas (some gases are far more toxic than others).
- Exposure time.
- Concentration / partial pressure of the gas.
- Workload (the higher the workload, the higher the respiratory rate, the higher the absorption of gas).
- General fitness.

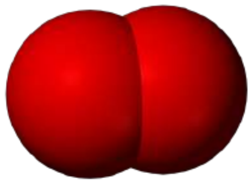
Pulmonary Oxygen Toxicity 3.8.1

If O_2 is breathed at a high partial pressure for long periods it becomes toxic, particularly to the lungs. If a very high partial pressure of O_2 is breathed, even for short periods of time, it may rapidly become toxic to the brain (C.N.S. Oxygen Toxicity).

For practical purposes, pulmonary oxygen toxicity will not arise from normal air 'bounce' diving to less than 50 metres.

This is because decompression considerations will limit exposure to O_2 to within safe limits. Diving near the time/depth limits, particularly when such dives are performed repetitively, may provoke pulmonary O_2 toxicity in sensitive individuals.

Patients being treated with fully extended recompression Tables 62 and 63 or Tables 64 and 65 may also experience pulmonary O_2 toxicity, particularly where repeated treatments are applied.



Unit Pulmonary Toxic Dose

Where prolonged exposure to hyperbaric oxygen is necessary, such as during recompression therapy, an estimate of the reduction in vital capacity (VC) can be calculated from the following equation: Where kp is a factor derived from the $p0_2$ using the table below, and "t" the duration of exposure (in minutes).

The "Kp" Table For UPTD Calculation Is: UPTD = kp X t

The appropriate kp value is multiplied by the period of time (in minutes) spent at each oxygen partial pressure. These values are then summed to generate the total UPTD value for the exposure. Standard USN Table 6 or RN 62 Treatment Table without extensions are equivalent to 625 UPTD's.

Below is a table, which presents approximate values for expected decrement in vital capacity as a result of various UPTD exposures. It should be recognised that individuals may vary considerably in their response to high partial pressures of oxygen and the UPTD value is useful only as a guide. Generally, a dose of 1425 UPTD is considered to be the upper limit of acceptable exposure.

UPTD Units	% Decrease in VC
615	2 %
825	4 %
1035	6 %
1230	8 %
1425	10 %
1815	15 %
2190	20 %

$p0_2$(BA)	kp	$p0_2$(BA)	kp	$p0_2$(BA)	kp
0.5	0.00	1.3	1.48	2.1	2.64
0.6	0.26	1.4	1.63	2.2	2.77
0.7	0.47	1.5	1.78	2.3	2.91
0.8	0.65	1.6	1.93	2.4	3.04
0.9	0.83	1.7	2.07	2.5	3.17
1.0	1.00	1.8	2.21	2.6	3.31
1.1	1.16	1.9	2.36	2.7	3.44
1.2	1.32	2.0	2.49	2.8	3.57

Presentation of Pulmonary Oxygen Toxicity

- Tickling sensation in the throat, which is worse on inspiration.
- Irritating cough.
- A sensation of substernal burning.
- Coughing becomes uncontrollable.
- Shortness of breath eventually prevents even mild exertion.
- Acute Respiratory Distress Syndrome will present in severe cases.

Management of Pulmonary Oxygen Toxicity

- Reduce the concentration of O_2 in the breathing mixture, (preferably to 0.2 BAR. *$IP0_2$*).
- If substernal burning is present in patients who are responding well to treatment; discontinue oxygen.
- If significant neurological deficit remains and improvement is continuing (or if deterioration occurs when oxygen breathing is interrupted), oxygen breathing should be continued as long as considered beneficial or until pain limits inspiration.
- If oxygen breathing must be continued beyond the period of substernal burning, or if the 4 hour air breaks on long air tables cannot be used because of deterioration upon the discontinuance of oxygen, the oxygen breathing periods should be changed to 20 min on oxygen, followed by 10 min breathing chamber air.

C.N.S. Oxygen Toxicity 3.8.2

There is no fixed O_2 exposure at which toxicity becomes apparent. Instead, susceptibility varies both between individuals and within the same person from day to day. As a consequence, there is no cerebral equivalent of the UPTD.

The onset of C.N.S. Oxygen Toxicity is unlikely in resting individuals at depths of 15m or shallower, and very unlikely at 10m or shallower no matter what the level of activity.

However, patients with severe cerebral decompression illness may be abnormally sensitive to oxygen.

Presentation of C.N.S. Oxygen Toxicity

The classic presentation of CNS Oxygen Toxicity is: V.E.N.T.I.D.C.:

- Vision (Tunnel vision) which may include any abnormality, such as tunnel vision (a contraction of the normal field of vision, as if looking through a tube) .
- Ears (Ringing/Tinnitus), which may include any abnormality of hearing.
- Nausea may be intermittent.
- Twitching appears first in the lips or other facial muscles but may affect any muscle. (This is the most frequent and clearest warning of oxygen poisoning).
- Irritability, which includes any change in behaviour, such as anxiety, confusion, and unusual fatigue.
- Dizziness, an apparent increase in breathing resistance, noticeable clumsiness or lack of co-ordination.
- Convulsions such as generalized clonic tonic seizure.

Management of C.N.S. Oxygen Toxicity:

C.N.S. Oxygen Toxicity

- Reduce the concentration of O_2 in the breathing mixture, (preferably to 0.2 BAR. *IPO_2*)
- Conduct primary / secondary survey & record observations.
- Implement Seizure Management.
- Stop decompression. (Refer to company SOP's).
- Contact duty medic / supervisor.
- Prepare to evacuate (as per company S.O.P's).

Convulsions While In Water Diving:

- The diver's depth should be kept as constant as possible until at least the tonic phase of the convulsion ends.
- He should then be returned to the surface / bell.
- Implement airway / breathing management.
- If a diver surfaces because of an oxygen convulsion or must be surfaced to prevent drowning.
  - Observe for pulmonary barotrauma / A.G.E. / D.C.I.
- On reaching safety, remove the breathing apparatus and place the casualty in fresh air to recover.
- Treat for possible near drowning.

Note. The symptoms of c.n.s. O_2 toxicity may be made transiently worse when the inspired PO_2 falls. This is the so-called 'Off Phenomenon'. Consequently the onset of symptoms or signs may be delayed by up to 5 minutes after leaving the water, coming off O_2, or during a decompression stop where the partial pressure of O_2 is reduced.

Hypoxia 3.8.3

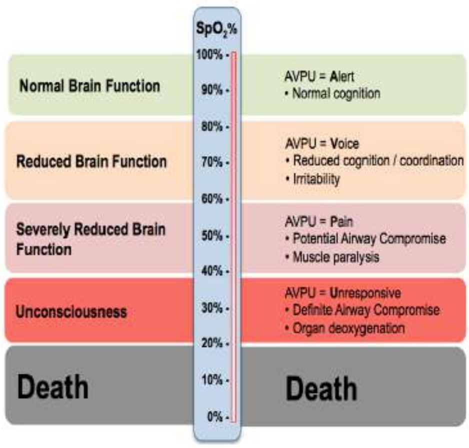
The term 'hypoxia' means 'low oxygen in the blood' (When O_2, is less than 0.16bar) The term 'Anoxia' means 'an absence oxygen in the blood'.

The Causes Of Hypoxia / Anoxia Are Varied:

- External (reduced / absent O_2 supply in breathing gas).
- Airway impairment.
- Breathing impairment.
- Circulation impairment.
- Respiratory control centre impairment.

Presentation of Hypoxia

- See Hypoxia in Immediate Care Section.
- Cyanosis (Blueing of fingers, earlobes).
- Hyperventilation.
- Increased heart rate.
- Poor co-ordination.
- Sudden collapse.



Presentation of Anoxia

- Profound cyanosis (Blueing of fingers, earlobes).
- Death.

Management of Hypoxia / Anoxia;

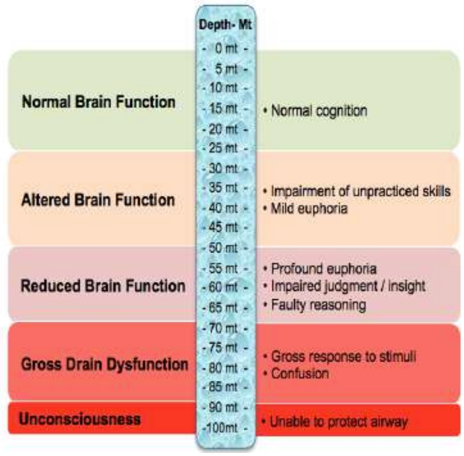
- See Hypoxia in First Aid Section.
- Give high flow O_2 and monitor effects.
- Be prepared to resuscitate.

Nitrogen Narcosis 3.8.4

Narcosis while diving (also known as narced, inert gas narcosis or "the raptures of the deep"), is a reversible alteration in consciousness that occurs while diving at depth.

The Greek word *ναρκωσις* (narcosis) is derived from narke, "temporary decline or loss of senses and movement, numbness".

Narcosis produces a state similar to alcohol intoxication or nitrous oxide inhalation, and can occur during shallow dives, but usually does not become noticeable until greater depths, beyond 30 metres.



Presentation of Nitrogen Narcosis

- Responses significantly slow down.
- Loosing short-term memory.
- Lack of insight / faulty reasoning.
- Calculation errors.
- Idea fixations.
- Increased anxiety, anger or euphoria.
- Narrowing of a divers mental focus.

Management of Nitrogen Narcosis

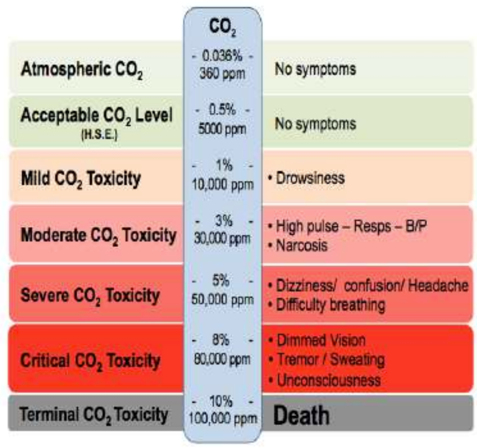
- Decrease depth.
- Change mix (Nitrox?).

Hypercapnia (CO_2 Poisoning) 3.8.5

Also known as hypercarbia, is a condition where there is too much carbon dioxide (CO_2) in the blood. Carbon dioxide is a gaseous product of the body's metabolism and is normally expelled through the lungs. Acceptable levels of CO_2 (As set by H.S.E.) is 5000 ppm or 0.5% in a breathing mix for 8hrs maximum.

Causes of Hypercapnia;

- Increased workload.
- Pre existing medical condition.
- Failure of CO_2 absorption (closed / semi closed).
  - Channelling.
  - Soda lime canister exhausted.
- Large dead space.
- CO_2 in gas mix.



Presentation of Hypercapnia

- Increase in respiration & pulse rate.
- Headache.
- Sweating.
- Dizziness.
- Nausea.
- Anxiety.
- Unconsciousness.

Management of Hypercapnia

- Manage unconsciousness / reduced consciousness as per Immediate Care.
- Ventilate environment / breathing mix.
- Change soda lime.
- Flush chamber.
- Equalize chamber with entry lock.

Carbon Monoxide Poisoning 3.8.6

Carbon monoxide poisoning occurs after enough inhalation of carbon monoxide (CO).

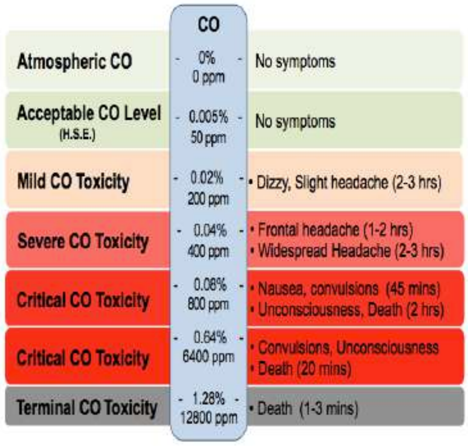
CO is a colourless, odourless, tasteless, and initially non-irritating toxic gas.

CO is a product of incomplete combustion of organic matter due to insufficient oxygen supply to enable complete oxidation to carbon dioxide (CO_2). It is often produced in domestic or industrial settings by older motor vehicles and other gasoline-powered compressors, heaters, and cooking equipment.

Exposures at 100 ppm or greater can be dangerous to human health. Generally caused in diving by a badly sited compressor intake or from oil breakdown in an overheating compressor.

CO has affinity to Haemoglobin 200 times greater than O_2

Presentation of Carbon Monoxide Poisoning



- Breathlessness on exertion.
- Lassitude.
- Dizziness / headache.
- Tinnitus.
- Confusion Loss of consciousness.
- Cherry red complexion (unreliable, rare and fatal).

Management of Carbon Monoxide Poisoning

- Change gas supply.
- Jump standby to assist divers ascent.
- Recompression (As per company SOP usually RNT 60 / 61).
- Administrating pure O_2 by BIBS (flushes out CO).
- Instigate reduced consciousness management.

Hydrogen Sulfide Poisoning 3.8.7

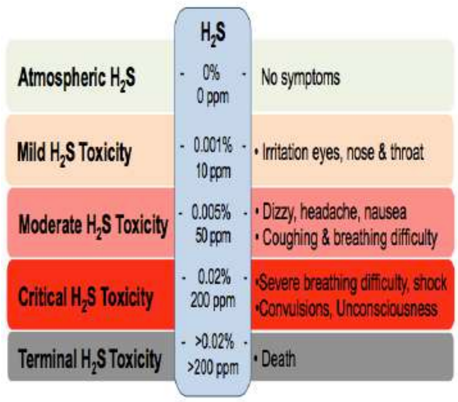
H_2S is an extremely hazardous, toxic compound. It is a colourless, flammable gas that can be identified in relatively low concentrations, by a characteristic *rotten egg* odor. The gas occurs naturally in coal pits, sulfur springs, gas wells, and as a product of decaying sulfur-containing organic matter, particularly under low oxygen conditions. It is therefore commonly encountered in places such as sewers, sewage treatment plants (H₂S is often called *sewer gas*), mines, and the holds of fishing ships.

H_2S occurs naturally in the mud around the well-head of a drill rig. The gas is heavier than air and initially leaves a sulfurous (rotten egg) odour before permanently destroying the sense of smell and therefore becoming tasteless and odourless. Due to the fact the gas is heavier than air / $HE0_2$ it forces the air or gas mix above it leaving any unsuspecting diver to asphyxiate due to lack of oxygen.

When a diver is working on this site they can accumulate this mud on their equipment, bringing it back to the bell/chamber/deck upon their return. This allows the gas to escape into its surrounding environment.

Presentation of Hydrogen Sulphide Poisoning

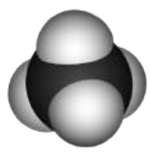
- Initial smell of rotten eggs.
- Headaches.
- Loss of smell.
- Cough / Haemoptysis.
- Vertigo.
- Confusion.
- Nausea and vomiting.
- Asphyxiation.
- Possible loss of consciousness.
- Seizure.
- Death.



Management of Hydrogen Sulfide Poisoning

- If presence of H_2S is suspected then evacuate to a high point until the area is confirmed clear.
- Administer pure O_2 (flushes out H_2S).
- Instigate reduced consciousness management.

Hydrocarbon Poisoning 3.8.8



Within the commercial gas /oil industry there is often an associated risk of hydrocarbon vapour contamination.

There is likelihood for contamination of the bell atmosphere from vapourised contaminants carried on dive suits and umbilical's.

Potentially fatal, levels of hydrocarbons can accumulate in the enclosed environment of a diving bell. Hydrocarbon vapour has a profoundly sedative quality, so even if fatal levels are not reached immediately, divers may be incapacitated before they can initiate environmental flushing measures.

Presentation of Hydrocarbon Toxicity

Hydrocarbon vapours in the bell and can reach anaesthetic levels within minutes.

- Divers can suffer the effects within a few breaths.
- Even before unconsciousness, the ability to react normally becomes impaired:
  - o 52% of the anaesthetic level of cyclo-hexane causes convulsions.
  - o 44% of the anaesthetic level of benzene causes uncontrolled jerking of limbs.
  - o 33% of the anaesthetic level of toluene leads to hyperactivity.
  - o 13% of the anaesthetic level of xylene causes tremors, which could impair actions.

Bell Vapour Analysis

Management of Hydrocarbon Poisoning

- Ensure hydrocarbon analysis equipment is functioning & divers are trained in its use.
- Immidiatly don BIBS & flush compartment on contamination.
- Closley observe & manage casualtys who have sucomed to the effects of hydrocarbon exposure.
- Decontaminate bell (as per company SOP's).

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TRAUMA TRAINING

Section 4

Legislation

DIVING REGULATIONS AND OTHER REQUIREMENTS 4.1

Requirements can be divided into two sections:
- Legal and statutory obligations
- Codes of practice, recommendations, accepted safe practices

Legal and Statutory Obligations – UK 4.1.1

Legislation

A. Health and Safety at Work etc., Act 1974 (Application outside Great Britain) Order 1995 SI 263

B. Diving at Work Regulations (DWR) 1997 SI 2776, [which replaced the Diving Operations at Work (Amendment) Regulations 1990 (SI 966), which in turn had replaced the Diving Operations at Work Regulations 1981 (SI 399)]

C. Merchant Shipping (Diving Safety) Regulation 2005.

D. The Offshore Installations (Inspectors and Casualties) Regulations 1973 SI 1842.

E. The Offshore Installations (Operational Safety, Health and Welfare and Life saving Appliances) (Revocations) Regulations 1989 SI 1672.

Diving At Work Regulations 1997 ACOP

Duties Of Supervisor

The supervisor shall, in respect of the diving operation for which he has been appointed as supervisor ensure that it is carried out, so far as is reasonably practicable without risk to the health and safety of all those taking part in that operation and of other persons who may be affected thereby in accordance with the requirements and prohibitions imposed on him by or under any relevant statutory provisions. In accordance, where this would not conflict with the diving project plan.

Prior to the commencement of the operation, ensure that each person taking part is aware of the contents of the diving project plan which relate to that operation; and enter in the diving operation record the particulars required by regulation 6(4) during the course of the operation.

The supervisor shall not dive during the diving operation, which he is supervising unless the diving project plan which relates to that operation specifically provides for the supervisor to so dive.

Power Of Supervisor To Give Directions

A supervisor may, whilst supervising the diving operation in respect of which he is appointed, give such reasonable directions to any person taking part in that operation or who may affect the safety of that operation as are necessary to enable him to comply with regulation 10.

Summary

The Diving at Work Regulations (DWR) 1997 (SI 2776) replaced the Diving Operations at Work (Amendment) Regulations 1990 (SI 996). These had revoked the Offshore Installations (Diving Operations) Regulations 1960 (SI 1229 and the Diving Operations Special Regulations 1960 SI 688).

The Regulations give broad outlines intended to cover all 'diving at work'. More detailed requirements are contained in the five Approved Codes of Practice (ACOP), which accompany the Regulations.

The principal Regulations apply to diving operations conducted in Great Britain in circumstances covered by the Health and Safety at Work etc., Act 1974 (Application outside Great Britain) Order 1995 (SI 263).

Approved Codes of Practice (ACOP)

The DWR are accompanied by five Approved Codes of Practice (ACOP).
These cover the various 'diving at work' activities, namely:

a) Commercial diving project offshore.
b) Commercial diving projects inland / inshore.
c) Media diving project.
d) Recreational diving projects.
e) Scientific and archaeological diving projects.

All offshore diving comes under (a), which also covers:

- Closed bell (saturation) diving.
- Diving from DP vessels.

- All commercial dives below 50 msw.

The ACOP gives detailed expression to the 'bare bones' of the DWR, and was written with the assistance of IMCA. In the case of inshore diving this assistance was given by the ADC (Association of Diving Contractors).

The Diving Contractor

No person shall act as a diving Contractor unless they are registered with the HSE. No person at work shall dive in a diving project and no employer shall employ any person in such a project unless there is one person and one person only who is the diving Contractor for that project.

The diving Contractor is the person who employs the diver or divers engaged in the diving project, or who dives in diving project as a self-employed diver.

If more than one person falls under this category then one person must be appointed in writing to act as the diving Contractor.

Duties of the Diving Contractor

The diving Contractor shall ensure that, so far as is reasonably practicable, that the diving project is planned, managed and conducted in a manner which protects the health and safety of all persons taking part in the project.

The Diving Contractor Shall:

- Ensure that a diving project plan is prepared and updated as necessary during the project.
- Appoint a person to supervise any diving operation, make a written record of the appointment, provide the person with that written record, and ensure that he is supplied with a copy of the diving project plan.
- Ensure that there are sufficient people with sufficient competence to carry out both the diving project and any foreseeable emergency action connected with the project.
- Ensure that suitable and sufficient plant is available to carry out both the diving project and any foreseeable emergency action connected with the project.
- Ensure that the said plant is maintained in safe working condition.
- Ensure, so far as is reasonably practicable, that any persons taking part in the diving project complies with requirements and prohibitions imposed on him.
- Ensure that a record, containing certain specific information, is kept of each diving operation.
- Retain the record for at least two years.

The Diving Project Plan

The DWR introduced the idea of a 'diving project' comprising one or more 'diving operations'. The Regulations require all diving projects to have a diving project plan. This shall be based upon an assessment of the risks to the health and safety of any person taking part in the diving project.

It will consist of a record of the outcome of the planning carried out in accordance with the requirement to ensure that the project is planned, managed, and conducted in a manner which protects the health and safety of all persons taking part in the project.

The plan shall also identify which approved codes of practice apply to the project, and shall identify each diving operation that makes up the project. Each such operation shall be such that it can be safely supervised by one person.

The Diving Supervisor

Only one supervisor shall be appointed to supervise a diving operation at any one time.
No person shall be appointed, or shall act, as a supervisor unless he is competent and, where appropriate, suitably qualified to perform the functions of supervisor in respect of the diving operation, which he is appointed to supervise.

Duties of the Diving Supervisor

It is the duty of the Diving Supervisor to ensure that each diving operation for which he is appointed is carried out, so far as is reasonably practicable,:

- Without risk to the health and safety of all those taking part in that operation and other persons who may be affected,
- In accordance with the requirements an prohibitions imposed on him by or under any relevant statutory provisions,

- In accordance with the diving project plan (where this does not conflict with either of above).

The Supervisor shall not dive during the diving operation, which he is supervising unless:

- He is guiding persons engaged in recreational diving using SCUBA,
- The dive is for archaeological, educational or scientific purposes using SCUBA
- He can do so without risk to the health and safety of those taking part in that operation, and
- The diving project plan specifically provides for the supervisor to dive.

Approved Codes of Practice

The DWR are accompanied by five Approved Codes of Practice (ACOP). These cover the various 'diving at work' activities.

Namely:

- Commercial diving project offshore.
- Commercial diving projects inland/inshore.
- Media diving project.
- Recreational diving projects.
- Scientific and archaeological diving projects.

All offshore diving comes under (a), which also covers:

- Closed bell (saturation) diving.
- Diving from DP (Dynamic Positioning) vessels.
- All commercial dives below 50msw.

The ACOP gives detailed expression to the 'bare bones' of the DWR, and was written with the assistance of IMCA. In the case of inshore diving this assistance was given by the ADC (Association of Diving Contractors).

Other Obligations Apart From Statutory Instruments (UK) 4.1.2

Standards And Classification Societies Required By Law

Some British and Norwegian standards apply to equipment used in diving operations by reference in the statutes. Where not specifically mentioned they would be required as an interpretation of any rule that maintains a system or individual item of equipment should be suitable for its intended use.

This rule would also apply to classification societies for the initial construction of plant and equipment and for major test and certification. (Lloyds Register of Shipping (LRS), American Bureau of Shipping (ABS), Det Norske Veritas (DNV) etc.)

Obligations To Follow Procedures And Recommendations

Most Clients stipulate in their contract with diving Contractors that all the relevant legislation, plus recommendations from HSE and others, will be followed, including the Contractor's own procedure manual.

Client Specifications

Some Clients have their own specifications for diving equipment and Contractor's procedures. These are normally in excess of any statutory requirements or Contractor's normal specifications or procedures. They are a contractual obligation and must be adhered to.

Recommendations And Guidelines

Bodies as the International Marine Contractors Association (IMCA), the Diving Medical Advisory Committee (DMAC), and the International Maritime Organisation (IMO), intermittently publish guidance notes and recommendations for use by their members and others.

Such publications are normally followed rigorously by the member Contractors.

HSE and NPD recommendations are followed except in exceptional circumstances.

Guidelines for such items as DP vessels usually have a large input from the industry. As such they are normally acceptable to diving Contractors before publication. In any event, under normal circumstances all guidelines and recommendations are followed. Not to, in the event of an accident or incident, would be in contravention of legislation in that the equipment or procedures were not safe or suitable.

In practice, 'agency' agreements exist between the various Departments of State having formal responsibility for the various Acts and Regulations. These result in the division of responsibilities summarised at the start of this section. UK Government Diving Inspectors have the right to visit and inspect, within reason, any site, installation or vessel from which diving operations are being carried out. Within the terms of the relevant statutory instruments, they may examine all plant and equipment and hold discussions with all personnel concerned with the operation. It is clearly necessary for them to develop a rapport with key personnel in order to assist in the improvement of safety standards without inhibiting the efficiency of the diving operation. Good communications between the Inspectors and relevant personnel, depending on the nature of particular problems and circumstances, is clearly vitally.

Diving Supervisor

The Diving Contractor should appoint Diving Supervisors to be in immediate control of each diving operation. Where two or more Diving Supervisors are appointed in respect of an operation, the Diving Contractor must specify which part of the diving operation each is to supervise. However, if it is permitted by the Diving Contractor in their specific written appointments, two Supervisors may arrange the time at which one may take over dive responsibility from the other.

A Diving Supervisor should be a competent person with adequate knowledge of the diving techniques to be used in the diving operation, and must be appointed in writing.

Ideally a Supervisor should have had experience of the particular techniques employed in the diving operations, which he is appointed to supervise or alternatively have a sound knowledge of the principals of the techniques to be used.

The Diving Supervisor Should Ensure:

- As far as is reasonably practicable, the diving operation that they are being asked to supervise complies with the requirements of the ACOP.
- The proposed dive site and the water and weather conditions are suitable.
- The risk assessment is still current for the circumstances prevailing on the day and during the dive,
- They understand their own areas of responsibility and who is responsible for any relevant areas.
- The personnel that they are to supervise are appropriately qualified and competent to carry out the work required of them.
- The diving project plan and arrangements for dealing with any foreseeable emergencies are clearly understood by all those engaged in the diving operation.
- The plant that they propose to use is adequate, safe, properly certified and maintained.
- The possible hazards from complex or potentially hazardous plant have been evaluated and are understood by all relevant parties and that, if required, training is given.
- All relevant people are aware that a diving operation is to start or continue.
- They have adequate means of communicating with any such personnel under their supervision. So long as they have such communication they do not need to be able to operate physically every control under their responsibility. For example, a supervisor should be able to supervise adequately the raising and lowering of a diving bell if their is a direct audio link with the winch operator, even though the winch may be located where the supervisor cannot see it or have ready access to it.
- Proper records of the diving operation are maintained.
- They are able to see divers in the bell or compression chamber during saturation operations.
- They maintain the diving operation record throughout the diving operation for which they are responsible.

The Diving Supervisor is responsible for the health and safety of divers and other personnel under his control. This responsibility includes divers under pressure and ranges from the treatment of decompression sickness (using well established techniques) to the treatment of medical problems. He must seek advice from a suitable, experienced Doctor if a diver in his team needs special medical attention.

Whilst the Doctor will advise on the treatment to be followed, the Diving Supervisor has ultimate responsibility for accepting or rejecting it under exceptional circumstances, having assessed all the circumstances of the case.

The Doctor acts in an advisory role; the Supervisor retains overall responsibility for the compression aspects of any treatment prescribed until he formally hands over responsibility of the Diver undergoing treatment to another person, for example at an onshore hyperbaric treatment facility. (This applies to Doctors at a diving site or at an onshore medical facility).

The Diving Supervisor, therefore, has very considerable responsibility for the diving operation. Whilst the Owner, OIM, Master, Harbour Master, Client's Representative and others may require him to terminate a dive, he is the only person who can authorise the actual commencement of a dive and control its detailed conduct thereafter.

Diver

The diver has a general duty of care for his own safety as well as for other members of the diving team. The diver may under certain rare circumstances, where he is his own employer, also be the Diving Contractor when he would have additional responsibilities.

Before taking part in any diving operation,

A Diver Must:

- Have a valid certificate of training or competence.
- Have a valid medical certificate.
- Be competent to carry out safely the work that he is called upon to perform.
- Inform his Diving Supervisor if he judges himself to be unfit, or if there is any other reason why he should not dive or remain underwater or pressure.
- Maintain a diver's log-book containing required specific information. He should sign every entry and ensure that it is countersigned by the Diving Supervisor. (At medical examinations he should present his log book to his Doctor. He should retain the book for at least two years from the date of the last entry).
- Carry out work in accordance with the instructions of the Diving Supervisor.

Regulatory requirements relating to minimum standards for divers vary from one country to another but arrangements have been made for the mutual recognition for bell and air diving between the UK and Norway. In the UK, diving regulations establish minimum qualifications for divers. These are defined in the regulations, and minimum training standards have been established with the approval of the Health and Safety Executive (HSE). In the UK, all new training certificates must be issued either by or on behalf of the HSE. An appeal procedure exists if the HSE refuses to issue a Certificate of Training or revokes a certificate that has been issued.

Initially there were four grades of diver in the UK, in ascending order of qualification they were:

Part IV Air Diver with self-contained equipment (where no surface compression chamber is required on site).

Part III Air Diver (where no surface compression chamber is required on site).

Part I Basic Air Diver.

Part II Mixed gas or bell diver.

These grades have been revised down to three new grades.

These are:

SCUBA Diver.

Surface Supply Diver (with a 'Top Up' required for working offshore).

Closed Bell Diver.

Associated with these grades are 'competencies' which include various work tasks that may be required of them.

Certification to a particular grade does not imply that the Diver may carry out all work associated with his grade. In this respect, the training standards are minimum standards only. An additional responsibility is placed on the diver and all others concerned with the diving operation (particularly the Diving Contractor and Diving Supervisor) to ensure that he receives the additional training or familiarisation to ensure that he is competent to carry out safely the work, which he is required to perform. This additional training may involve tools, equipment, techniques and other matters.

Standby Diver

A standby diver should be in immediate readiness to provide any necessary assistance to the diver, whenever the diver is in the water. There should be one standby diver for every two divers in the water.

He should be dressed to enter the water, but does not have to wear a mask or helmet. However the equipment should be immediately to hand.

For surface supplied diving the standby diver should remain on the surface.

Fir closed bell diving the standby diver, or bellman, should remain inside the bell. Another diver should be on the surface with equipment suitable for intervention within the surface diving range. This diver does not have to be dressed for diving provided that the equipment is readily available, and may undertake duties within the dive team while the bell is under water.

Diving Technicians

Diving Technicians include equipment technicians and others who support the diving team, the diving operation and the necessary plant and equipment. Job titles and responsibilities vary considerably from Diving Contractor to Diving Contractor and from contract to contract depending on the nature of the work and the type of plant and equipment needed to support the diving operations.

Duties include the maintenance of plant and equipment, the operation of winches, gantries, handling equipment, lifting tackle and cranes, the cleaning of equipment and the mobilisation, control and demobilisation of the equipment the diver(s) may need to carry out their work underwater.

Whatever the qualifications, experience and responsibilities of these important personnel, they all have a duty of care for their own safety and for the safety of other members of the diving team. Functionally they all report to the Diving Supervisor.

NORWEGIAN REGULATIONS 4.2

On the 1st of January 2011, new regulations relating to Health, Environment and Safety (HES) entered into force. At the same time the "Acts, Regulations and Provisions for the Petroleum Activity" regulations 11th June 1990 No. 471 relating to Manned Underwater Operations (MUO) (The two NPD white-books) were repealed. On the 1st January 2004 The Petroleum Safety Authority (PSA) took over responsibility for safety, Emergency preparedness and the working environment in the Petroleum Sector from NPD

The new regulations relating to the Health, Safety and Environment in the Petroleum Activities on Offshore and Onshore facilities that are subject to the Petroleum Safety Authority (PSA), entered into force 1st Jan 2011.

Joint Regulations Offshore and Onshore

The Framework Regulations and the Management Regulations are Joint Regulations and are thus applicable both offshore & onshore, at certain facilities. The Purpose of joint regulations in the field of HSE is to secure a coherent and coordinated regulation of activities in the best possible way. This also applies to the regulatory supervision of the activities

The Regulations are the Framework Regulations, the Management Regulations, the Technical and Operations Regulations, the Facilities Regulations and the Activities Regulations. In support of the regulations, guidelines are issued. The regulations are in pursuance of, amongst others, the Petroleum Act and the Working Environment (WEA).

The structure and the content of these regulations, the extensive use of common and functional requirements, means the regulations must be read in context with each other and the acts.

Therefore, the only way of reading the regulations properly are electronic versions (they are not published on paper) and using the cross references to the other regulations

http://www.ptil.no/regulations/category87.

Listed in Appendix 6 are selected sections from the five regulations.

OTHER COUNTRIES 4.3

Denmark 4.3.1

Danish Diving Act 1979 and various notices which are, in effect, additions to the Act.

NB: Some parts of this Act apply only to standard dress, harbour diving.

Normally Clients in Denmark will insist on UK diving regulations being followed as well as the Danish Diving Act.

To work offshore, divers must have British or Norwegian Certificates.

To work in Danish inland waters and harbours, etc., a Danish Diving Certificate is required. British and Norwegian Certificates are not acceptable.

The enforcement of diving rules in Denmark is carried out by the Governments Ships Inspection Service.

Holland 4.3.2

Up till 2002 there were two separate diving regulations: one for offshore diving under the Mining legislation, and one for all other diving under the Working conditions legislation.

As of January 1st 2003 all diving comes under the Working conditions legislation.

Enforcement in the oil & gas industry remains the task of the State supervision of Mines, all other diving at work is under supervision of the Labour Inspectorate.

In Dutch this legislation is called : Arbeidsomstandighedenwetgeving or for short Arbowet.

The Arbo legislation is concerned with all kinds of working conditions. In it you'll find rules about diving, about working with asbestos, safety at the building site, noise, working in offices, etc.

Much of it is based on EU regulations.

The Arbowet Consists Of The Following Four Levels, Going From Very General To Great Detail.

- Arbowet = Arbo Law
- Arbobesluit = Arbo Act
- Arboregeling = Arbo Regulation
- Arbo beleidsregel = Arbo Guidance

The first three have strength of law. With regards to Arbo beleidsregel, you do not have to comply with, but you'll have to prove, based on you risk analysis, that what you do do gives the same level of safety as the guidance does.

Key principles

The Key Principles Of The Arbo Legislation Are:

- Working conditions must be as safe and healthy as possible;
- Employers and employees have a shared responsibility for the working conditions;
- A risk inventory and evaluation is compulsory at various stages before, during and after the job.

Whether you are considered to be an employer or employee depends not on whether money changes hands but on rather complicated jurisprudence. Deciding factor is whether there is an authoritative relationship, i.e. does the one have authority over the other.

In case of diving special provision is made so that relevant Arbo regulations and working time regulations apply to all members of the diving team, whether employer, employee or self employed.

Stricter Rules

At the same time that the two regulations were merged, some of the rules have become stricter.

1. Employers must give 5 days notice before start of job to the proper authority, i.e. State Supervision of Mines or the Labour Inspectorate of all diving work

- In water deeper than 9 meters or
- Current is stronger than 0,5 meters per second, or
- With planned decompression, or
- With breathing gas other than air, or
- Over a period longer than a week, or
- In the oil & gas industry.

If it is impossible to give 5 days notice, than the notification must be given as soon as possible.
In case of diving in the oil & gas industry extra information about safety measures is required.
This replaces the diving permit issued by the State Supervision of Mines.

2. All divers must hold a medical certificate of fitness to dive, to be renewed at least every year, issued by a registered diving doctor, conducting the medical in accordance with the Arbo regulation.

3 The diving supervisor must hold a diving supervisor certificate, issued by the Minister of Social Affairs and Labour, or a certifying authority, so designated by same Minister (the Netherlands Diving Centre at this time is the only institution so designated) after successfully completing a diving supervisor training course.
There is a one-year grandfather scheme, ending 31st December 2003.
All Divers, Diving Supervisors and Diver Medics wishing to work in Dutch waters, must also hold Dutch certificates by 1st January 2004.
The certification scheme for divers and diver medics was already in place since 1995.

The Arbo Act mentions 3 diver-training certificates:

- Category A for SCUBA diving.
- Category B for Surface Supply diving.

- Category C for Mixed Gas/bell diving.

The Arbo Act mentions 3 diver medic certificates:

- Diver First Aid - for 2 man diving teams only.
- Medical Aspects of Diving A (MAD-A) for all air diving.
- Added Medical Aspects of Diving B (MAD-B) for mixed gas/bell diving.

4. A certifying authority, accredited by the Accreditation Board must certify all diving equipment. This will come into force on a date still to be established.

- In accordance with EU regulations, as of January 1st 2003, diving, diver medical and diving supervisor certificates issued by EU or EER member states that are assessed to be equivalent by the Minister of Social Affairs and Labour, or by a certifying authority, so designated by same Minister (the Netherlands Diving Centre at this time is the only institution so designated) will be equated with the equivalent Dutch certificates.
- In the case of EU or EER member states, certificates will be deemed to be equivalent, unless they are in essence substantially unequal.
- Certificates of all other countries will be assessed for full compliance with the relevant legislation. For EU and EER certificates there is a transitional period of one year, ending 31st December 2003.

5. Though in theory it is still allowed to dive with a team of two divers, under the new Arbo guidance this will in practice only be possible for diving work such as cleaning windows in the aquariums of the Zoo.

Ireland 4.3.3

The Safety and Industry (Diving Operation) Regulations 1981 SI 422. These regulations were based on, and similar to, the old UK regulations (The Diving Operations at Work Regulations, SI 399).

General

Some countries diving inspectors, e.g., Danish Ships Ministry, can issue notices from time to time, which form part of legal requirements in the country concerned.

TRAUMA TRAINING

Section 5
Air & Gas Handling

AIR REQUIREMENTS AODC / IMCA014 5.1

The AODC/IMCA 014 Guidance Note on Minimum Quantities of Gas Required Offshore states:

A. Sufficient compressed air must always be available for two emergency dives to the full intended diving depth as reserve. This air must either be stored in containers or else supplied by two totally independent dedicated sources.

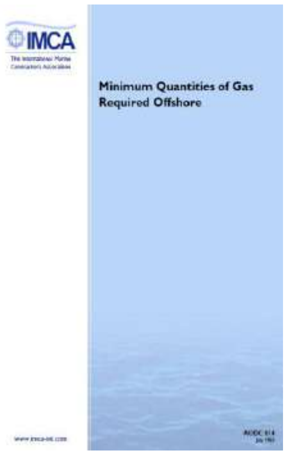
B. Sufficient compressed air must be available to pressurise both locks of the deck decompression chamber to the maximum possible treatment depth plus sufficient air for three complete surface decompression cycles. This air must either be stored in containers or else supplied by two totally independent dedicated sources.

NB:

1) Two totally independent sources could be two separate compressors one of which is connected to the rig or vessel emergency electric power or separate power source (e.g. diesel) or one compressor plus compressed air storage containers.

2) Rig air should not normally be considered as a dedicated air supply for diving as it is principally provided for other purposes and may not be available to the quality, or in the quantity or at the pressures required.

3) 90m^3 (3,200 cu ft) of breathing oxygen must be available for emergency treatment procedures.



GAS SAFETY 5.2

Safety Rules relating to gas handling and mixing include:-

- Oxygen shall be marked for "diving" only and comply with the purity standards.
- Pre-mix shall be for diving purposes and comply with the purity standards.
- Shore base must obtain a purity and analysis certificate from the supplier.

Poor gas handling has caused a number of fatalities both by explosion and by supply of the wrong gas to the diver.

High Pressure Gas 5.2.1

High-pressure gas is dangerous. A loose or broken fitting can blow off and cause severe injury or death. A free hose end can whip with sufficient force that it can also cause serious injury or death.

- Always use the correct hoses and fittings.
- Check the condition of all hoses and fittings before use. In particular, check hose end fittings for fatigue cracks.
- Tie hose ends to the quad to prevent whipping in the event of a fitting failing.
- Route all hoses safely and correctly, making sure that both ends are marked clearly with the percentage and destination.
- Make sure that any single bottles are secured in the upright position. If a bottle fell and broke its pillar valve it would be propelled with sufficient force to penetrate a steel bulkhead.
- Never close or open a valve without checking with the Supervisor, LST or Gasman.

- Open all valves slowly, at arms length, and look away from the valve.
- If you are venting gas, wear ear defenders or cover your ears. There is a risk of long-term damage to your hearing.
- Never play games with HP gas. A jet of gas can blind.
- Never connect a supply without analysing the gas first. The information on the tube or quad may be wrong and the wrong gas can kill.

Low Pressure Gas 5.2.2

Low-pressure gas can kill and injure as easily as high-pressure gas and should be treated with the same respect and according to the same procedures.

Particular care should be taken when changing filters or operating medical locks. A clamp can fly open with sufficient force to kill if it is released under only a few bar of pressure.

The diver in the chamber should also be aware of the risks of suction.

Oxygen 5.2.3

Oxygen, especially high-pressure oxygen, carries an additional risk of explosion. It is highly reactive. The heat of compression when oxygen is allowed to flow rapidly into a pipe can raise the temperature high enough to cause ignition of the metal.

Combustion occurs with the speed of an explosion and there have been numerous accidents involving serious burns and fatalities.

Principles of Safe Oxygen Handling Include:

- Never smoke when you are handling oxygen, or go near anybody who is smoking or near any naked flame for at least fifteen minutes after handling pure oxygen. Oxygen can accumulate in your clothing and your clothing will ignite easily.
- Ensure that all fittings are oxygen clean. This means completely free of oil, grease and dirt. Fittings are submerged in a biox solution until clean then rinsed in a soap and water solution. The fittings are then dried before use.
- Keep flexible hose to a minimum and use only hoses, which are kept specifically for oxygen and are oxygen clean. The hoses should be marked to stop confusion, i.e. colour coded.
- Previously it was forbidden to use any stainless steel tubing or fittings. Certain grades of stainless steel corrode in HP oxygen. Now reference is made to IMCA D012, which allows the use of certain grades.
- Use recommended O_2 compatible lubricants on O_2 valves and fittings.
- DO NOT USE PTFE thread tape on O_2 fittings. Compatible sealants can be used, e.g. Loktite Hydraulic Sealant 542. (However the part in DVIS 3, which mentions the production of Phosgene gas is a falsehood).
- Never use quarter turn valves. Opening them can generate sufficient heat of compression to cause ignition on pure oxygen. (Quarter turn valves may be in the line as emergency shut off valves).
- Ensure all oxygen transfer pumps are well maintained and only used for the transfer of oxygen. NEVER USE THEM FOR GAS OR AIR.

Oxygen Stowage

- All oxygen must be reduced to 40 bar at the quad.
- Pure oxygen and oxygen mix (over 25% O_2), shall be kept in the suppliers bank only.
- All oxygen and oxygen rich mixes shall be stowed in an open area, well ventilated, light and weather protected.
- All oxygen and oxygen rich mixes should be stowed well away from the diving system.
- The stowage area must be clearly marked : "O_2 STOWAGE - NO SMOKING".
- A fire hydrant must be within 10 m of the stowage area.
- If transfer of oxygen is taking place, a sign must be displayed: "O_2 UNDER TRANSFER".

Protective Clothing

- If possible, protective clothing should be worn when transferring oxygen.
- Nylon overalls should not be worn, as static electricity can build up on nylon.
  - This can lead to a spark discharge, which, in turn, could ignite any oxygen present.

CONNECTING A GAS SUPPLY 5.3

As the supervisor you have to be informed and kept up to date on the on all matters, when you ask someone to connect a new gas supply they should do the following:

- Analyse and note the starting pressure of the new quad or tube, which is to be connected. Tell you when they are disconnecting the old supply. They should note the final pressure of the quad or tube and check the positions of all the valves in the line they must vent the line and take all the precautions for handling HP gas, even if there are only a few bar left in the line. Vent the supply at the panel to clear out any old gas in the line before you take a sample for analysis.(if required).
- Connect the new supply.
- Open the valves to the panel.
- Analyse and note the pressure of the new supply at the panel.
- If the pressure does not agree with the pressure at the quad, a valve could still be closed or half closed, or connected to the wrong supply.
- They will inform the Supervisor that the new supply is connected and give the pressure and analysis.
- If the gas is being supplied to the diver there should be an in line analyser with audio- visual hi-lo alarms. The alarms must be activated.

Colour Coding Of Gas Supply 5.3.1

A colour coding system is used to identify pressurised gases.

An air diver may well be working on a vessel, which is carrying helium oxygen mixtures, pure oxygen and other gases for welding or burning operations.

A wrongly connected gas supply can kill and every diver should know the colour coding system.

It is unlikely that the air quads, which are generally separate from the mixed gas system, will contain anything other than air, but if there is the least doubt the supply should be analysed. All gas must be analysed before going on line. O_2 and CO_2 analysers should always be available, plus sometimes a helium analyser and/or gas chromatograph for special operations, e.g. hyperbaric welding.

Remember that colour coding only tells you what should be in the quad, it does not always tell you what is in the quad.

The Colour Coding of Gases			
Gas	**Bottle or Quad Body**	**Bottle or Quad Top**	
Nitrox mixtures (inc. Air)	Grey	Black and white quarters	
Diving Oxygen	Black	White	
Industrial Oxygen	Black	Black	
Helium	Brown	Brown	
Heliox mixtures	Brown	Brown & white quarters	
Tri-mix mixtures	Brown	Black, white & brown thirds	

Gas Register

A log-book is kept for all gases, including air. All entries are to be signed by the Supervisor. Upon delivery, the following should be entered in the register:-

- Date
- Quad number/gas contents
- Analysis - i.e. 5% O_2/95% He
- Quad pressure
- On-line date
- Finish pressure
- Date returned

In addition to a gas register, a daily gas-log must be kept showing the date, vessel, different percentage of gases, total volume, amount of gas used, gas arrived, gas departed, and gas on line.

All daily gas sheets should be signed by the supervisors.

Prior to using any gas it must be analysed before going "on line". Diver's on line breathing gas must be continually analysed in dive control.

GAS DELIVERY EQUIPMENT 5.4

Gas Hoses 5.4.1

Hoses are also referred to as *'whips'* and may be of heavy wire braided construction or made of far lighter synthetic materials like Synflex.

Swivel fittings are usually used on hose ends to allow tightening without twisting the hose.

They may be fixed onto wire-braided hose with simple hand tools but Synflex hose fittings need a special swaging tool.

Pressurised hoses should always be tied off. At the ends, attach the rope to the hose and not the end fitting. The hose should always be clearly visible with regular warning notices attached.

Hoses should always be run with sufficient slack to allow for take up when the hose is under pressure. They should be routed to avoid working areas and heat sources and twisting and small radius curves should be avoided.

Principles of Safe Whip Handling:

- Hoses used for oxygen transfer should be made of the non-conductive material, of proper working pressure, and have an ID of ½" (Normally Orange in colour to indicate that they are only to be used with gases >25% Oxygen).
- Oxygen whips must never be used for transferring mix gas (<25% O_2) or air.
- Oxygen whips should be stored away from other gas transfer hoses, ideally locked away to stop inadvertent use as non O_2 hoses.
- All lines are to be marked clearly as to their function at both ends (particularly long whips).
- All hoses must be kept clean and free from grease and oil.
- All end fittings should be protected with end caps when not in use.
- All hoses should be kept to a safe minimum length and protected on deck.
- Hoses are to be securely “whip checked” at both ends to reduce the risk of injury if a fitting was to fail.

Gas Fittings 5.4.2

A large range of fittings are designed to fulfil a variety of functions and it is essential that all the fittings used in the system are compatible with the pressure being used and with each other.

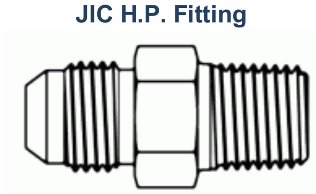
After repeated use, especially if they have been over tightened, hose and fittings may develop fatigue cracks.

They should always be checked before use and changed if necessary.

JIC **(Joint International Council)**

- These fittings are designed for use with HP hose.
- The seal is provided by the conical seating and no additional sealant is required.
- Do not over tighten these fittings as the sealing flange may split.

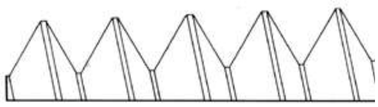
JIC H.P. Fitting



NPT **(National Pipe Taper)**

- These fittings have a tapered thread and a sealant is required.
- Remarkably large variety of different fittings.
- It is vitally important that the correct fittings are used in both connections.
- Beneath is a chart giving the various different American / international fittings.
- Even though the fittings may look similar, one may be American & the other International.
- It is tempting to simply use 'more' sealant tape. But this is unlikely to secure the fitting.

NPT H.P. Fitting



ISO 262 Metric Screw Thread

- 60^{O} Thread Angle
- Pitch Measured In Millimetres
- Truncation & Root Crest Are Flat & Of Different Widths
- Diameter Measured In Millimetres

ISO 7/1 Tapered Thread

- 55^{O} Thread Angle
- Pitch Measured In Millimeters
- Truncation of Root & Crest Are Round
- Taper Angle 1° 47'

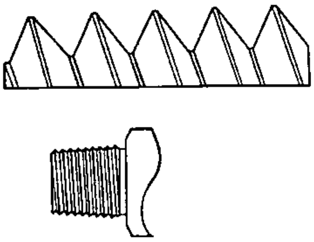
American Standard Screw Thread

- 60^{O} Thread Angle
- Pitch Measured In Inches
- Truncation & Root Crest Are Flat
- Diameter Measured In Inches

ISO 2281/1 Parallel Pipe Thread

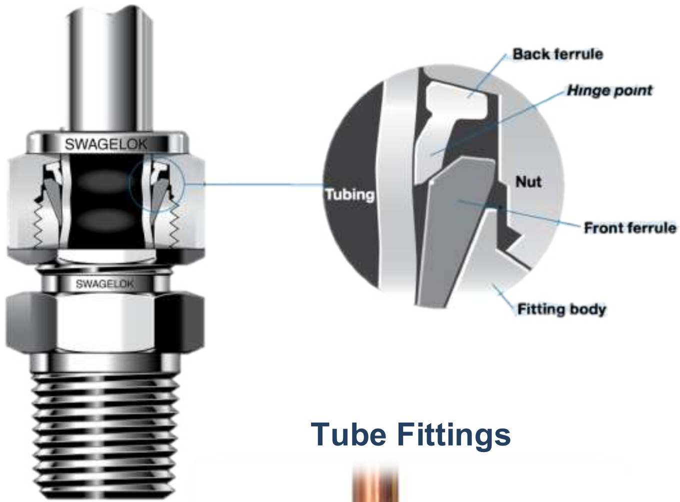
- 55^{O} Thread Angle
- Pitch Measured In Inches
- Truncation & Root Crest Are Round
- Diameter Measured In Inches

American Standard NTP Tapered Thread



- 60^{O} Thread Angle
- Pitch Measured In Inches
- Truncation of Root & Crest Are Flat
- Taper Angle 1° 47'

Swagelock H.P. Fittings



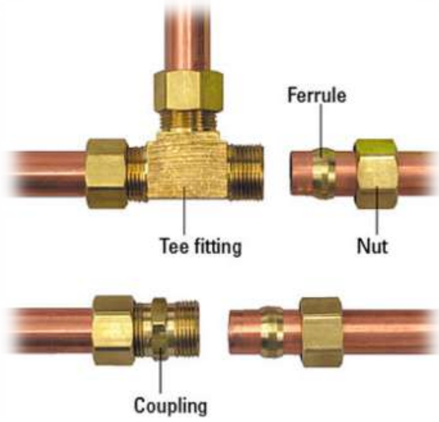
Swagelock

- These fittings are designed for use with HP stainless steel tubing.
- The seal is provided by a patented toothing and no additional sealant is required.
- Care is needed when tightening these fittings as the sealing mechanism needs to be accurately engaged.

Tube Fittings

- Tube fittings are used to connect LP copper tubing.
- The seal is provided by a copper olive (ferrule), which slides over the tube and is compressed as the fitting is tightened.
- Sealants are not needed.

Tube Fittings



Teflon Tape

Teflon tape, also called thread tape or PTFE tape, is commonly use to increase the sealant ability of certain gas fittings.

- It is wound round the threads before fitting.
- Two wraps will suffice keeping the tape two threads clear from the end of the fitting.
- Put the tape on so that it does not unwind as the fitting is tightened.
- Excessive amounts may be carried into the pipe work, causing blockages in valves or reducers.
- Never use on JIC fittings or Swagelock fittings.
- Use only on thread to thread sealing fittings.
- Only use O_2 compatible Teflon tape on O_2 circuits.
- All fittings are to be rates for the proper pressures and made of correct material.
- Ensure all fittings are clean and free from grease and oil.

P.T.F.E. Tape

Quads 5.4.3

A quad is a bank of nine, twelve or sixteen large bottles, connected by a manifold.
Each bottle has separate isolation valves and is connected via the manifold to the two king valves.

Each bottle normally has a floodable volume of about 50litre. The widely used sixteen bottle quad has a total floodable volume of 800 litre or 0.8m^3. At a working pressure of 200bar it would contain 160m^3.

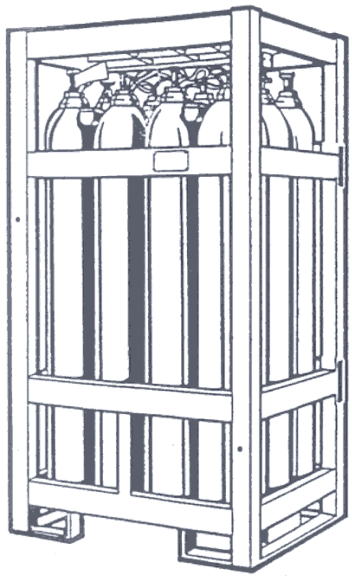
A superquad, which is used in mixed diving more than air diving, consists of sixty-four bottles.

Quads must have a visible hydrostatic test certificate - to be renewed every five years and should be in a good overall condition, always check the valves, pipe work, paint etc.

Quads must never be pressurised above the maximum working pressure.

Gas should not be mixed into any quads, which have contained air and should not be mixed into the suppliers bank.

All quads must clearly indicate the percentage of its constituent gases and must be colour coded accordingly.

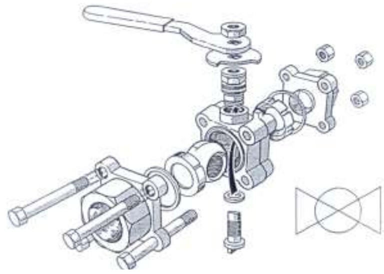


Length:	1.08m (3ft 6in)
Width:	0.82m (2ft 8in)
Height:	1.96m (6ft 5in)
Capacity:	Helium: 109 m³ (3852 scf) Oxygen: 105 m³ (3720 scf)
Working pressure:	Helium: 2845 psig Oxygen: 2500 psig
Weight:	1.10 tonnes
Volume/weight ratio:	Helium: 99.1 m³/tonne Oxygen: 95.5 m³/tonne
Deck space occupied:	0.85 square metres (9 square feet)
Hold volume occupied:	1.73 cubic metres (60 cubic feet)
Size and type of outlet:	Oxygen / Air 5/8" BSP Female Helium / Heliox 21.8 mm 14 TPI Male
Identification colours:	Brown: helium Brown / white: helium/oxygen Grey / black / white: diving air Black / white: oxygen
Finish:	Corrosion-resistant valves and trim, shot blasted frame coated with marine-duty paints

Valves 5.4.4

Quarter Turn Valves

Quarter Turn Valve



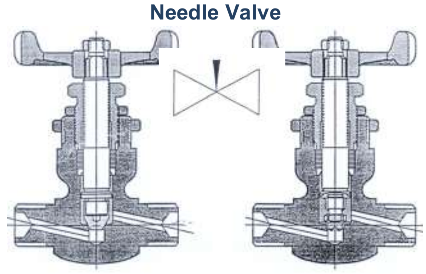
These are used where only a coarse flow control is required or may be used as Emergency Shut-off valves. They can be opened and closed quickly and the position of the handle indicates immediately whether the valve is open or closed.

If the handle is in line with the pipe the valve is open, if it is across the line of the pipe it is closed, although great care should be taken if the valve design allows the handle to be fitted in the wrong position.

Quarter turn valves should not be used on oxygen lines, since static discharge and friction associated with operating the valve may cause ignition in pure oxygen.

Needle Valves

Needle Valve



These provide a fine flow control but give no indication of whether the valve is open or closed.

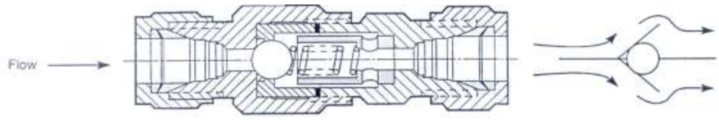
If a needle valve is fully open it is normal practice to turn it back for a quarter turn.

The valve is then free to turn in either direction and is clearly open.

Non-Return Valves

As the name implies they allow flow in only one direction and are widely used on helmets, control panels and chambers.

Non-Return Valve

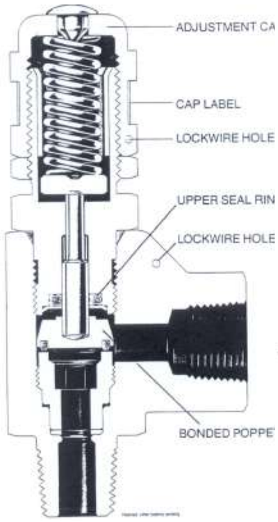


Relief Valves

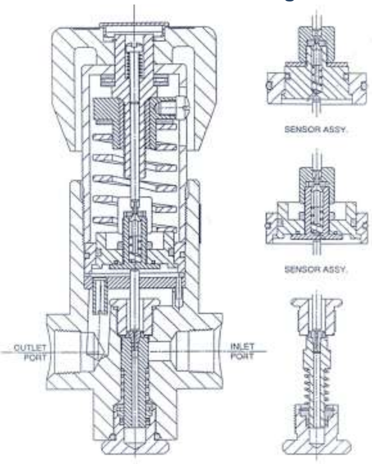
These are used on circuits, which are regulated to a specified pressure by O_2 circuits.

The relief valves are present to open above a chosen pressure. Thus if the regulator fails and allows higher pressures to pass, the relief valve protects the circuit by venting off the excess gas.

Relief Valve



Hand Loaded Pressure Regulator



Reducers or Regulators

These valves limit the pressure of the gas passing through the valve. They may be pre-set, as in the first stage of a scuba demand valve, or adjustable, as on a control panel.

The outlet pressure may also be influenced by a pilotage line. This is a pressure line coming from the chamber into the reducer. It ensures that if a pressure of 10bar is set on the reducer it will delivery air at 10bar over chamber pressure.

OXYGEN PIPE CLEANING 5.5

There are three times when the cleaning procedure for oxygen needs to be follows:-

- During the initial assembly/construction of the diving systems.
- During any major refit or modifications to existing equipment.
- Whenever outside contamination of the system is suspected.

The purpose of this cleaning is to ensure that all contaminants are removed.

Examples Of The Contaminants To Be Removed Are:-

- Hydrocarbon oils and greases.
- Thread lubricants.
- Paints and varnishes.
- Fluxes.
- Filings, burns and powdered metal oxides.
- Any other foreign substances that may be in the line.

The following previously used substances are NOT to be used, as their fumes and residues are extremely toxic.

- Trichlorethane, 'Genclene'.
- Carbon tetrachloride.
- Choroethane.

Use of these materials requires that great care be taken to ensure that all traces are removed, usually by detergent cleaning, fresh-water flushing, and then drying by purging the lines with an oil-free dry gas such as nitrogen. The effectiveness of this secondary cleaning is always suspect, especially where the piping could absorb some of the original cleaning material.

The diving industry recognises biox as a suitable agent for O_2 cleaning, however, experience gained during the American Space Programme showed that the use of detergents can achieve the same high degree of cleanliness as the previously used chemicals.

Oxygen Pipe Cleaning Procedure 5.5.1

Prepare The Cleaning Solution:-

- Add 6 grams (0.21 ounces) 'Diflex' powder to 2 litres (2.1 quarts) of hot, clean, fresh water.
- Stir until all of the 'Diflex' granules have dissolved.
- NB: The solution is alkaline and must be handled with care.

Cleaning Pipework

- Fill pipe with warm solution.
- Allow solution to remain in pipe for at least 20 minutes.
- Empty a small portion of the solution from the pipe and agitate for at least 2 minutes.
- After soaking and agitation, drain the pipe with care.
- Flush the pipe with running fresh water for at least 3 minutes, (rotating to ensure that all of the solution is flushed out).

Cleaning Fittings

- Place the fittings in warm solution.
- After 10 minutes, scrub the fitting with a bristle brush whilst in the solution.
- Allow the fitting to remain in the solution for a further 10 minutes.
- Rinse the fitting for at least 3 minutes in running fresh water, ensuring that all portions are thoroughly rinsed.

Drying

- Pipes and fittings should be blown dry using a dry, oil-free gas. (This should be regulated to 1 bar or less to avoid the possibility of gas embolism due to a high pressure gas stream impinging on the skin).
- NB: Ensure eye protection is worn.

Storage

Fittings

- Unless they are to be used immediately, fittings should be placed in gas tight clean polythene bags on completion of the cleaning process.

Pipes and Hoses

- Unless they are to be immediately used, the pipes, etc. should have both ends sealed on completion of the cleaning process. This can be done using cleaned plugs or by placing the ends in gas tight clean polythene bags and taping the bag shut around the pipe, well away from the end.
- Under no circumstances should tape, (silver, masking, electrical, etc.) be used to seal the end of the pipe.

Tools And Clothing Used During Cleaning Process:-

Tools

- All tools should be subjected to the cleaning procedures for fittings before they are used on cleaned parts.

Clothing

- Clean overalls or laboratory coats should be worn while cleaning and also during the re-assembly of cleaned valves, regulators, etc. Protective gloves (household washing-up type are suitable) must be worn during the cleaning, rinsing and drying stages.
- A plastic or rubber apron should be worn during the cleaning and rinsing stages.
- Safety glasses should be worn at all times during the process.
- During re-assembly, clean, lint-free gloves should be worn.

First Aid

- If, during the cleaning process, any chemical comes into contact with the body, liberally rinse the affected areas with fresh water.
- If in the eyes, a slightly acidic proprietary eye-wash can be used, and following a thorough rinsing medical attention should be sought.
- Due to the loss of skin oils through frequent or prolonged exposure, skin cracking and soreness may develop; treat with lanolin-based hand cream after cleaning work is completed.

"Safe" Lubricants

For Direct Exposure to 100% Oxygen

- Krytox 240 AC grease. Manufactured by EI DuPont Nemours & Company Inc., Petroleum Chemical Division, Wilmington, Delaware 19898, USA.

- Fomblin, fluids and greases. Manufactured by Mont-Edison (UK) Ltd., 11a West Halkin Street, London, SW1X 8LF, UK.

For Exposure to Elevated Percentages of Oxygen

- The following compounds can be used where the oxygen percentage may be elevated, (30% oxygen maximum) and there are no un-oxidised aluminium surfaces, the temperature will not exceed 100°C and there is no likelihood of exposure to a stream of oxygen.
- Acceptable compounds:
  - MS4.
  - Other similar silicon-based lubricants.

GAS COMPRESSION 5.6

The helium-oxygen breathing gases used in deep diving operations can be purchased in a premixed condition or as pure gases.

Even if the company's usual practice is to use premixed gases, the LST or Gasman needs to know the various ways and techniques of mixing gases, as on occasion a special mix or further supply may be required.

There are several methods of mixing gases, based on weight, volume and partial pressure. This can be done in individual cylinders, 'quads', or the diving chambers.

When Mixing Gas, The Following Points Must Be Kept In Mind:-

- Cylinders or quads should never be brought to atmospheric pressure as this would allow moisture to enter. The only exception is when a vacuum pump is going to be employed to evacuate the cylinders or quads.
- Analyse the contents prior to mixing.
- Ensure that all hoses are cleaned of lubricants or contaminants.
- Always add oxygen at the lowest possible pressure.
- Only a specially designed oxygen pump should be used for pure oxygen.
- The use of high-pressure oxygen is restricted by regulations, therefore the pipe runs (copper, monel or brass) or hoses must be as short as possible and used only for oxygen.
- Always use needle valves on oxygen lines and open them slowly.
- Check the maximum storage pressure of the cylinders or quads to be used and ensure that the pressure necessary to create the desired mixture does not exceed the rating of the storage vessel.

Compressors 5.6.2

Compressors may be required to supply high-pressure gas or air for filling SCUBA bottles and quads or low-pressure air for supply direct to the diver.

In general, the gas or air is compressed in stages to the required pressure. The gas or air will be cooled between stages and traps will remove moisture and oil particles.

A chemical filter will remove any trace gases such as carbon monoxide together with any remaining oil or water.

The compressor may be driven by a diesel or petrol engine or an electric motor.

The compressor is rated according to the free volume of air it will take in per minute and the maximum pressure at which it will delivery the air.

For example, a rating of 5 cubic feet per minute at 200 ats means that it will take 16 minutes to fill an 80 cubic foot bottle to 200 ats.

H.P. Compressors

The schematic diagram shows a typical HP compressor. It is a three-stage compressor with air-cooling between stages. Larger compressors like the Williams & James 175 may have water-cooling.

Relief valves in the second and third stages prevent over pressurisation of the system, and pressure regulators ensure that the compressor works at maximum efficiency. The compressor may be operated manually or have various types of automatic control systems.

Pressure stop systems will switch the compressor off at a set pressure, usually 200 bar.

Automatic systems will switch the compressor on when the pressure is below a certain level and off when the pressure is above a certain level. Extreme care should be taken when changing filters or carrying out maintenance on auto start compressors. The power supply should be disconnected.

Precise operating procedures will vary from compressor to compressor, but in general:-

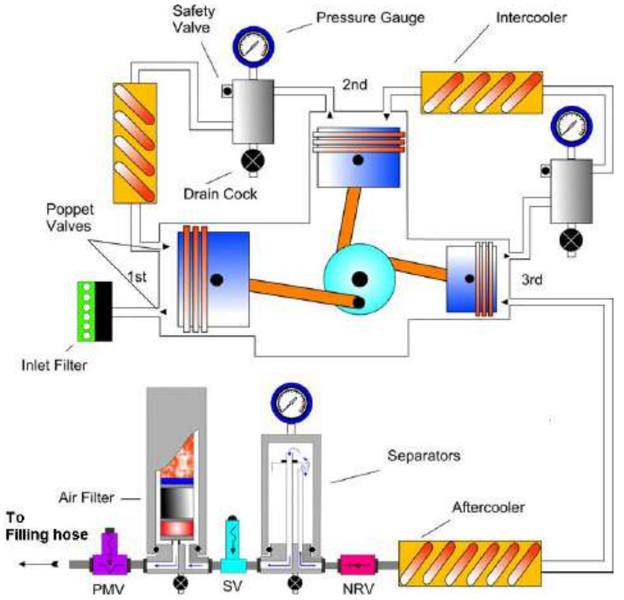
Before Starting:-

- Check oil levels in the compressor and in the engine driving the compressor.
- Check water levels in the cooling system, if applicable or check circulating water is running.
- Drain the oil and water traps.

Starting:-

- Open all the drains. The compressor should never be started under load.
- Check that all outlet valves are in the correct positions.
- Start the engine.
- Check oil pressures and switch off if they do not reach correct levels within about 30 seconds.
- Close the drain valves.
- When the pressure is higher than the pressure in the bottle or quad, open the valves slowly. (Never put back pressure on a compressor).

H.P. Compressor



Running:-

- Check pressures.
- Check oil pressures.
- Operate drain valves.
- Check filters.

Shutting Down:-

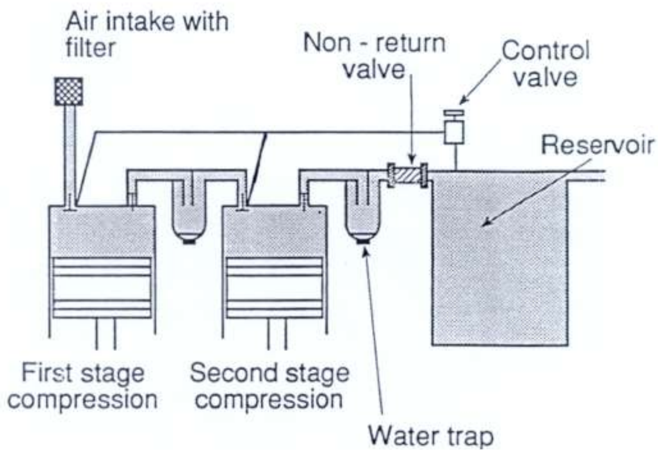
- Switch off.
- Close bottle or quad.
- Vent air from compressor. Taking care to protect your ears.

L.P. Compressors

The schematic diagram shows a typical LP compressor. LP compressors operate according to the same basic principles as HP compressors but are generally two stage. The same general operating procedures should be followed.

The compressor pumps into a reservoir and a regulating valve opens when the working pressure is reached. The compressor will then idle until pressure starts to drop in the reservoir.

L.P. Compressor



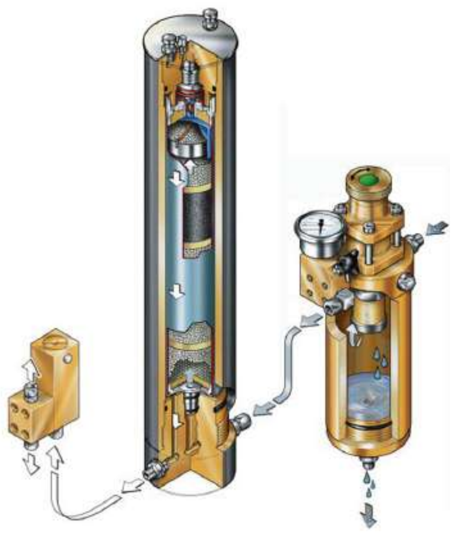
Filter Systems

Air supplied for diving must conform to British Standard 4001. The maximum level of impurities allows are shown in the section on Gas Purity.

Carbon monoxide may be introduced into the air supply by placing the compressor intake close to an engine exhaust or be produced in the compressor itself by partial burning of lubricating oil.

Correct placing of the air intake and correct maintenance of the compressor can avoid both these problems, but the effects of carbon monoxide poisoning are so serious that it is usual to pass the air supply through a chemical filter as an additional precaution.

Compressor Filtration



The same filter will remove any oil and water vapour and dust particles.
The diagram shows an air filter and the functions of each part.
Intake filters are designed to stop grit or dust being drawn into the compressor.

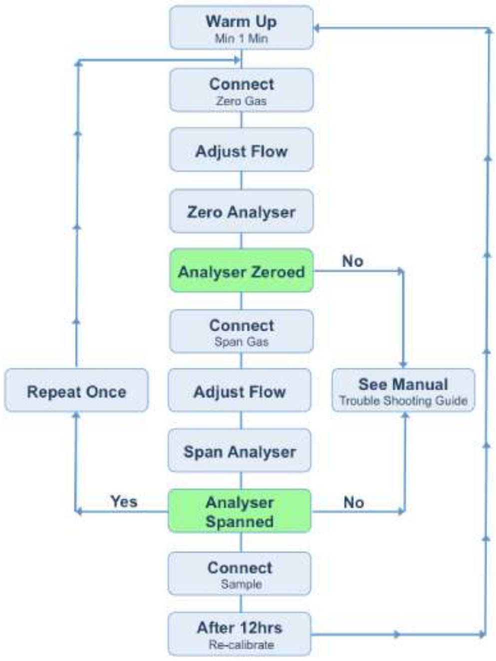
GAS ANALYSIS 5.7

The LST is principally concerned with the measurement of oxygen and carbon dioxide levels in both bell and chamber atmospheres and also in the gas supplied to both. He or she may use one of a large range of main electrical or battery analysers or possibly a colorimetric tube.

All analysers read partial pressure, and while those designed for use under pressure will give a direct readout in partial pressure, those on the surface give a readout in either percentage or parts per million. Thus a surface readout must be multiplied by the absolute pressure to give a partial pressure at the relevant depth.

The only exception to this rule is with colorimetric tubes, on which the scale is in concentration (% or ppm) but used frequently under pressure.

Calibration Flowchart



Analyzers

Analyzers vary considerably in complexity and ease of use. Some require a long warm up time before stabilization, others are ready for use after switching on, some require internal calibration, some do not etc.. The full information regarding the setting up of analysis equipment will be found in the manufacturers manual, but after initial stabilization of the instrument the principle of calibration is common to all analyzers, namely the setting of a low point or zero and of a high point or span. The sample gas will give a readout between these points at a level corresponding to its content.

It is very important in instruments with meter readouts that the mechanical zero is set before switch on. Misalignment of the mechanical zero can considerably alter the accuracy of the analyzer.

Setting Zero

Not all analyzers require zero calibration as the zero position is present at the point where there is no signal output from the sensor, but for most a flow of zero gas, normally pure helium, is required.

Check in-line filters. The makers manual will state what filters are required and also the most suitable flow rates. Pass the zero gas through the analyzer at the recommended rate, allow a stabilising period and then adjust the readout to zero. On some digital analyzers there is no negative position, set the zero at a point where the readout is flashing between 0.0 and 0.1, i.e. just at the positive side of zero.

Setting the Span

Always tcalibrate on the range that you will be working with, as you do sometimes have differences between the ranges.

Flow a calibration gas of known concentration through the analyzer at the prescribed flow rate. Using the span control either set the value directly or to the value displayed on the graph which accompanies some instruments.

With some oxygen analysers, especially microfuel cell analyzers, the sensors can be exposed to air and calibrated to 20.9%. Ensure that there is a reasonable ventilation system in operation as the oxygen content in air can vary in confined areas.

If the zero and span adjustments are large it is advisable to redo the zero and span calibration, but after the initial warm up and setting up is complete, it is usual to zero and span once only.

Analyzing

It is important that the gas samples to be analyzed arrive at the analyzer through the same filters and at the same flow rates as the gases used for calibration.

Re calibration periods vary greatly between analyzers, some recommend, in their handbooks, four hours while others speak in terms of weeks.

UK regulations state that re calibration must be carried out on a 12-hourly basis (Norway 24 hours), hence each shift must carry out a re calibration. This is good practice any way. It ensures that each shift has verified the calibration and has checked the alarm points. However the tendency to continually adjust the analyzers, which are maybe only a few millibars out, is not recommended.

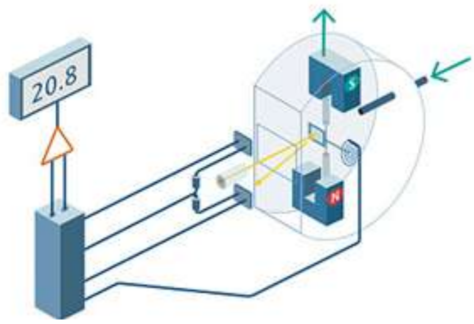
Oxygen Analysis 5.7.1

There are two main systems used to analyse oxygen levels, they are: Paramagnetism and Polarography.

Paramagnetism

The Servomex analyser works on the principle that oxygen is a paramagnetic gas.

Two hollow quartz spheres, each filled with an inert gas, are positioned at either end of the rod forming a "dumb-bell", which is suspended in a non-uniform magnetic field. The spheres, being slightly diamagnetic, take up a position away from the most intense part of the magnetic field.



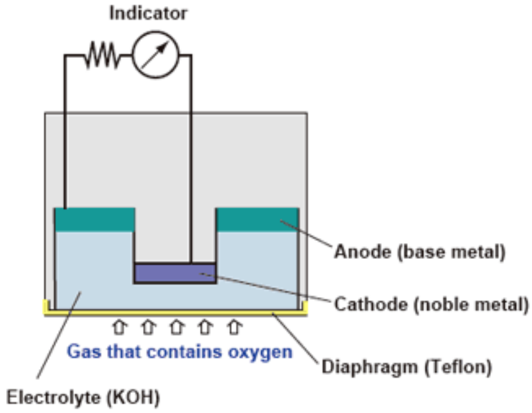
The zero position of the "dumb-bell" is sensed by a split photo cell receiving light reflected by a mirror on the suspension. The measuring system is therefore null balanced.

When the surrounding gas contains oxygen, the dumb-bell spheres are pushed further out of the field by the relatively strong paramagnetism of the oxygen. Thus the movement of the mirror on the suspension alters the pathways of the light beam and thus its position at the photocell. The output of the photocell is amplified and fed back to a coil wound onto the suspension, which returns the dumb-bell to its null position. This feed back current value is proportional to the amount of oxygen in the sample, giving a readout on the instrument as an oxygen percentage.

Polarography

The majority of O_2 analysers currently used offshore use the principle of polarography with the micro-fuel cell as the sensor component.

The sensor operates as an electrical cell whose output is affected by available oxygen. The diagram shows the main components, notably a lead anode, a gold cathode, a conducting electrolyte, normally potassium chloride (KCl) and a Teflon diffusion barrier.



The gold cathode serves as a reaction site for the reduction of oxygen molecules into hydroxyl ions. These hydroxyl ions react with the lead anode forming lead oxide and releasing electrons. The electron flow between anode and cathode is through an external load resistor, producing an output voltage. The output voltage is therefore a function of the number of oxygen molecules reduced at the gold cathode. Only a span calibration is required as the zero position is built into the sensor as no output voltage.

As in all chemical reactions, temperature fluctuations alter the speed of reaction. To overcome this, each sensor has a thermistor in the circuit, either on the cell itself or close by in the cell holder.

A thermistor is a resistor with a negative co-efficient, which will ensure that the signal to the readout is kept constant when temperature fluctuations occur.

The cells available have a limited life span, which is determined by the amount of lead in the anode and the amount of oxygen being monitored.

The sensor is influenced very little by other gases.

A problem may arise if water condenses on the membrane affecting its permeability to O_2. Thus it operates at $< 99\%$ RH

Carbon Dioxide Analysis 5.7.2

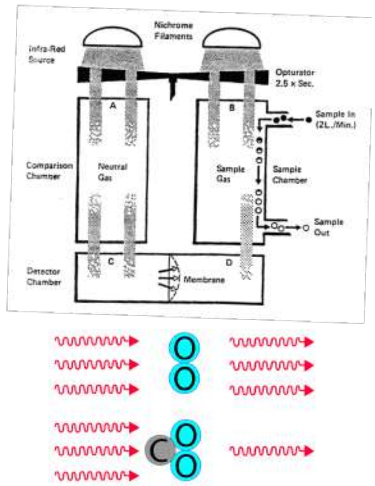
Most CO_2 analysers work on the principle of infra-red light absorption. Carbon dioxide absorbs infra-red radiation in amounts proportional to its concentration.

Two identical beams of infra-red radiation pass along parallel optical paths, the sample cell and the reference or comparison cell, to a sensing element - the detector. The comparison cell is filled with an inert gas containing no carbon dioxide so that the light beam on that pathway arrives at the detector unchanged.

Any carbon dioxide in the sample cell absorbs a corresponding amount of infra-red radiation, thus disturbing the balance between the pathways.

The detector cell is a dual chamber cell filled with the gas that is measured, i.e. in this case CO_2. The CO_2 at the detector absorbs the incoming radiation resulting in a temperature and thus pressure increase. The amount of pressure/temperature increase is proportional to the amount of radiation arriving. This in turn depends on the amount of CO_2 in sample. The reference / comparison side will be constant but the sample side will fluctuate depending on CO_2 content. The pressure inequality between the chambers of the detector cell is converted and amplified to give an output signal to the readout.

Infra-Red CO_2 Absorption Analyser



Air Purity Analysis 5.7.3

In the UK sector, BS EN 12021 gives the standard for care and maintenance of equipment used in compressed air diving. Part of this document gives information on the purity standard required of breathing air. The maximum levels of contaminants, as stipulated in BS EN 12021.

In addition, the air must be free of all dust or metallic particles, be odourless and should not contain any toxic or irritating substances.

To avoid the contamination of compressed air for breathing purposes. onboard compressors and cylinders should be operated and maintained in accordance with manufacturers handbook and instructions. Ensure that suitable filtration is used and properly maintained, e.g. particle filters, charcoal, etc. Consider the position of the air intake and of wind direction while running the compressor to avoid contamination of breathing gas by engine exhaust fumes.

It is a requirement that all compressors should submit a three monthly sample for analysis. Should this analysis not conform to the standard, then the compressor may not be used for pumping breathing gas until the necessary improvements or maintenance has been undertaken and a new sample has been analysed satisfactorily.

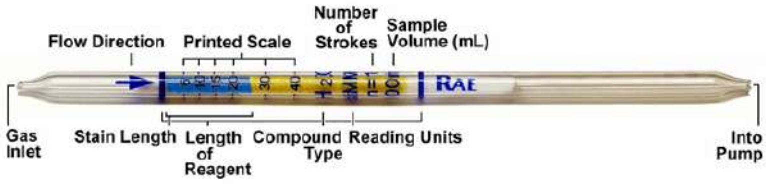
Air Purity Levels	
Carbon Monoxide	3 parts per million
Carbon Dioxide	500 parts per million
Oil	0.5 mg per m^3
Water	35 mg per m^3

Colorimetric Tubes

Colorimetric tubes, e.g. Dräger, MSA, Gastec, are commonly used offshore, notably for the measurement of carbon dioxide in bells and chambers but also for the identification and quantification of other trace gases. The tubes give a readout due to colour change brought about by the reaction between gas tested and the chemical indicator. The tubes are calibrated to be used on the surface so special care must be taken when they are used under pressure.

Over 100 different detection tubes are available.

Colorimetric Tubes



Some hints on the use of colorimetric tubes:

- Check pump gas tightness by inserting unopened tube and compressing bellows. (If the bellows open then there is a gas leak).
- Open inlet end of tube first, then outlet end.
- Insert tube into pump with arrow pointing to pump.
- N = number of pumps, i.e. N = 5 = 5 pumps.
- Take reading from end of discoloration.
- Do not use the same tube twice.
- Ensure that the tube is in-date.
- Always allow bellows to fully expand after each pump.

Note: Tubes normally give a reading in percent or parts per million (ppm).

To Convert This Reading To A Partial Pressure:

At Depth	Readout in % x 10	=	partial pressure in mbar
	Readout in ppm	=	partial pressure in µbar
On Surface	Readout in % x Abs Pressure x 10	=	partial pressure in mbar
	Readout in ppm x Abs Pressure	=	partial pressure inµbar

Humidity has no influence on readings.

Section 6
Dive Systems

TECHNIQUES AND PROCEDURES 6.1

Diving procedures and checklists have been made up on the basis of many years of diving experience. They are designed to cope with adverse conditions, equipment failure and human error.

General Procedures

These include details of manning requirements, gas supplies, equipment and checklists.

Manning

There must always be sufficient personnel to ensure that the diving operation can be carried out safely. In saturation diving this includes life support personnel and a deck crew to handle bell lock on and lock off.

Gas Supplies

In addition to the gas required for the dive, there should be sufficient gas available for emergency use. The requirements are complex and details of minimum recommended requirements are given in the AODC/IMCA Guidance Note 014 on the Minimum Quantities of Gas Required Offshore.

Equipment

Every piece of the systems equipment is essential and the Supervisor should be sure he knows how to use it and ensure that it is in full working order.

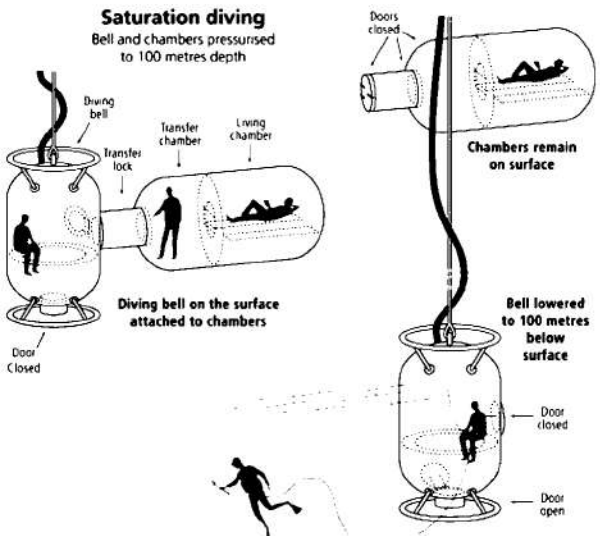
Checklists

Checklists should always be followed carefully. When you are familiar with checklists there is a tendency to skip over items without checking them thoroughly. This is always potentially dangerous and has led to fatal accidents. Make sure that you check your checklists properly.

Transfer Under Pressure

Both bounce diving and saturation diving will involve transfer under pressure from chamber to bell and bell to chamber. The diagram opposite shows the general procedure.

Every stage of the operation involves the divers in the bell, the divers in the chamber, the Supervisor, the LST and the deck crew. An error by any of these people could have serious and perhaps fatal consequences. Good communication and correct procedures are essential.



Procedures vary from company to company but they are all aimed at safeguarding the bell and chamber system from an accidental pressure loss

Every stage of the operation should only be carried out on the direct orders of the Supervisor.

During the actual transfer, the chamber system should be safeguarded by having a diver in the chamber controlling the trunk door or preferably by isolating the transfer lock from the rest of the system.

The trunking clamp should never be removed without:-

- The direct orders of the Supervisor
- Checking the trunking pressure
- Opening the bleed valve on the trunking to check the pressure. Gauges can be faulty.

All systems now have pressure interlocks to prevent the trunking being opened under pressure but like any mechanical system they may fail. Do not rely on these. Stick to the procedure.

Bounce Dives 6.1.1

The divers enter the bell at surface pressure and close the external bottom door. As the bell is lowered to the working depth, the door seals, and maintains surface pressure in the bell. In terms of decompression the dive has not yet started.

When the bell is at working depth, the diver may get ready and assess the job. Only when they are completely ready is the bell pressurised.

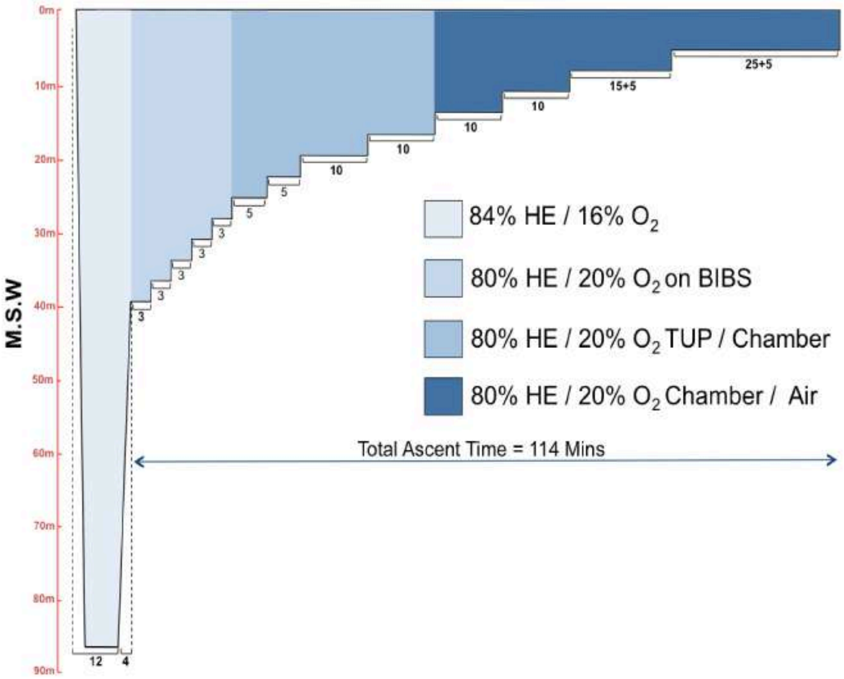
Bottom time starts when the pressurisation starts. Pressurisation must be carried out at the rate laid down in the tables, as a too fast compression may leave the diver unfit to work.

When the bell is at pressure, the door will open and the diver will go out, complete his work as rapidly as possible and return to the bell.

The bell will normally be lifted with the internal top door closed, and the external bottom door ajar. Maintain pressure in the bell while the bell is lifted to the surface. The divers in the bell control their decompression by venting the bell as instructed by the surface.

At a convenient point in the table they will transfer under pressure to the chamber to complete their decompression.

A Bounce Dive to 87 Metres Using Heliox 84/16



Saturation Dives 6.1.2

Pressurisation

The divers may be bounced into saturation or pressurised from the surface in the chamber.

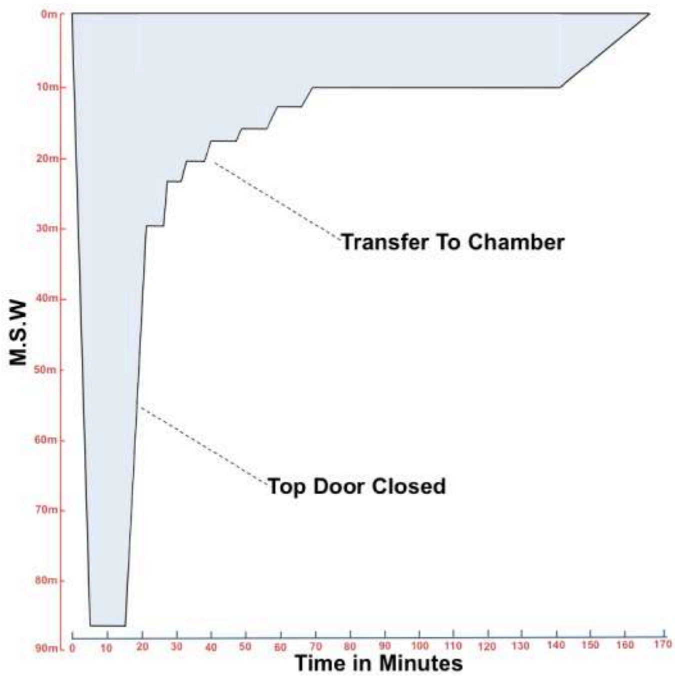
To bounce into saturation the divers are pressurised in the bell for a bounce dive as described above and simply transfer to the chamber at saturation depth at the end of the dive.

Pressurisation in the chamber is more comfortable and convenient. The compression rate is as per company requirements, and blowdown gases are chosen to give correct oxygen levels at storage depth.

Special precautions should be taken if a low oxygen mix is used to start the pressurisation as leaking doors may allow the chamber atmosphere to flush and rapidly become hypoxic, therefore it is wise to confirm a seal using a higher PPO_2 mix, e.g. 16-20% O_2.

Environmental control units and internal scrubbers should be running during pressurisation to ensure satisfactory mixing of the gas in the chamber. Clouds of low oxygen mix have resulted in divers becoming unconscious in the chamber.

A Bounce Dive Profile



Doors should never be dogged internally except on those systems where the dog can be operated from the outside. It must always be possible to get into the chamber in an emergency.

Any ear clearing problems should always be reported immediately. It is generally possible to deal with the problem by stopping the pressurisation or by decompressing a metre or so.

Excursion Dives

Working depth will generally be deeper than the living depth or storage depth in the chamber.

After transfer under pressure to the bell, the bell will be lowered and pressurised as necessary.

The Health & Safety Executive Diving Division recommend that bell runs should not last more than eight hours from lock off to lock on.

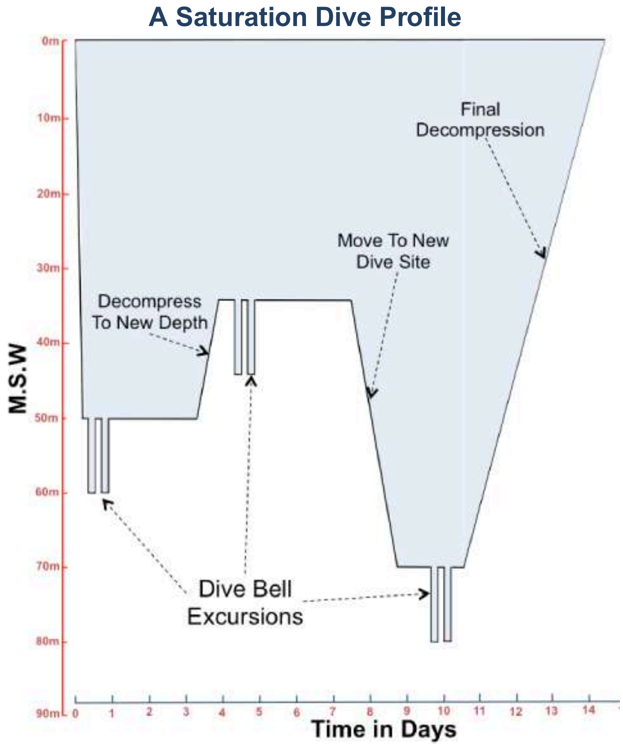
Normal practice is to limit the lock out time of a diver to 4 hours during any one bell dive. For 3 man bell runs, 6 hours lock out is allowed if the divers take it in turns to act as the bellman and so remain dry.

Note: Diver safety must always be paramount and it is vital to remember that a diver must have the necessary reserves of strength and stamina to recover himself or a colleague in an emergency (DMAC 20, Rev. 1).

The bleed from working depth to storage depth must be carried out at the rate laid down in the tables.

Split Level Saturations

On some worksites, work may be required at several different depths and chambers in the system will consequently be at different storage depths. On a one bell system the transfer lock will have to be alternately bled and pressurised to allow different teams of divers into the bell. Items which could be damaged by pressure changes should not be left in the transfer lock and care should be taken with door equalisation valves and oxygen levels.



Mixed Gas Decompression 6.1.3

At depths beyond 50 msw in both the UK and Norwegian waters Air must be replaced as a breathing gas by Oxygen and Helium mixtures. Similarly all diving deeper than 50m must be carried out from a submersible breathing chamber or bell.

In other parts of the world mixed gas may be used in a similar way to Air using either "in water" or surface decompression techniques, but this is not allowable in UK waters.

US Navy Helium Partial Pressure Tables are used for "Bounce Dives" to 55 msw and 75 msw incorporating Transfer Under Pressure from the bell to the deck chambers prior to the divers commencing breathing pure oxygen via the BIBS.

For the 100 msw bounce dive and subsequent "bounce into sat" at 55 m storage depth, bell excursions and final saturation decompression, SCS Tables will be used.

BOUNCE DIVING 6.2

This technique involving transport to the worksite at one atmosphere, bell pressurisation and short period lock out before decompression back to surface, is used only for relatively shallow dives of short duration.

USN ppHe decompression tables are selected according to the actual ppHe expressed in "feet absolute" the diver is breathing at his deepest depth.

This is estimated by multiplying the percentage of Helium in the mix, expressed as a decimal, by the depth in feet absolute.

Example

Depth 280 fsw, using 84/16 heliox.

Formula $\frac{AP\ (fsw) \times He\ \%}{100}$

$= \frac{313 \times 84}{100}$

$= 263$ *ft ABS*

$\therefore$ use 270 ppHe Table

N.B. *The increments of the Table are in 10s.*

An important consideration that must be considered when gas mixing is the pp of O_2:

The Partial Pressure of Oxygen for the dive profile must be suitable so as not to cause CNS O_2 toxicity problems at depth or hypoxia during ascent.

If the diver is not carrying out TUP and decompressing in the water all the way back to surface he must have a minimum of 16% O_2 so that on arrival at surface he is breathing a minimum PPO_2 of 0.16 ATA.

At depth he must not exceed PPO_2 of 1.6 ATA.

Calculations (Daltons Law) for Maximum Percent O_2 for depth:

$$\text{Max } O_2\,\% = \frac{1.6 \text{ ATA} \times 100}{\text{Absolute Pressure (AP)}}$$

e.g. What is the Maximum O_2% for a dive to 360 FSW?

$$\text{Max } O_2\,\% = \frac{1.6 \times 100}{11.9}$$

$$= 13.5\%$$

What Maximum Depth can the Diver descend with a particular Mix? How deep can he dive breathing 16% O_2?

$$\text{Absolute Pressure} = \frac{(PP \times 100)}{\%}$$

$$= \frac{1.6 \times 100}{16}$$

$$= 297 \text{ feet}$$

N.B. The higher the PPO_2 during the dive, the shorter the exposure to avoid Pulmonary Oxygen toxicity problems.

Partial Pressure of He	=	PPHe Tables
Depth	=	Feet Absolute = D' + 33'
Percent Helium	=	Varies depending on depth and Oxygen limitation.
Minimum O_2	=	16% for Surface orientated Dives (Min PPO = 0.16 Ba or 160 Mb).
PPHe Table Selection	=	Depth Absolute x Helium Content
Maximum %O_2 for Depth	=	Daltons Law Calculations Max PPO_2 = 1.6 Ba.
Maximum Depth for %O_2	=	Daltons Law Calculations Max PPO_2 = 1.6 Ba.
Bottom Time	=	Leaving Surface to Leaving Bottom or Commence Pressurisation to LB.
Ascent Rate	=	Varies according to actual depth and first stop divided by time.
Travel Between Stops	=	60'/Min included in stop time.

SATURATION DECOMPRESSION 6.3

Bounce dive tables are calculated for tissues, which load and unload gas fairly quickly in a short period but saturation tables are based on tissues, which load and unload gas slowly.

From this point of view saturation decompression is safer than bounce dive tables but is only commercially viable where a considerable period of time has been spent at depth, i.e. over 12 hours and up to 28 days (UK). The longer the saturation the more economical the procedure as the decompression time stays the same for 12 hours, 12 days or, in theory, 12 weeks (although evidence suggests that stays in excess of 4 weeks may be physiologically demanding).

Chamber decompression can either proceed with continuous or step-wise bleeding of the chamber. When carrying out a step-wise decompression, stops are to be performed every half metre. The corresponding times shall result in an equal ascent rate as for a continuous decompression. One minute is used to travel from one half metre stop to the next.

Saturation Decompression Ascent Rates

Depth	Ascent Rate
Storage depth to 15 metres	50 minutes/metre
15 metres to surface	80 minutes/metre

Gas Levels

Depth	Chamber Oxygen	Chamber CO_2
Storage depth to 15 metres	0.48 - 0.5 bar PO_2	0.005 bar maximum
15 metres to surface	21% - 24% O_2	0.005 bar maximum

Make up O_2 levels to required amount during 30 minutes prior to move.

USN Saturation Decompression

This is a linear table as follows:

Range	Rate
1600 - 200 FSW	6 feet per hour
200 - 100 FSW	5 feet per hour
200 - 50 FSW	4 feet per hour
50 - 0 FSW	3 feet per hour

Decompression is only carried out for 16 hours in 24, i.e. rest periods:

2400 - 0600 Stop
1400 - 1600 Stop

Gas Levels

O_2 PPO.35 - 0.4 ata
CO_2 PP < 0.005 ata
N_2 PP < 1.5 ata

Excursion Tables 6.3.1

These are tables, which allow a range of working depths deeper or shallower than the saturation storage depth for an "unlimited duration" without requiring stops.

Different saturation tables have different excursion table procedures and limitations and they should not be interechanged. For example, SCS excursion dives permit the divers to reach various working depths from a given storage depth.

There Are Two Types Of Excursions:

- Ascending excursions are bell dives to depths shallower than the storage depth.
- Descending excursions are bell dives to depths deeper than the storage depth.

Excursions are characterised by the distance between the storage depth and the working depth.

There Are Two Types Of Excursion Distances:

- Standard excursion distance
- Maximum excursion distance, which corresponds to approximately twice the standard excursion distance, and has restrictions as to its use.

A given diver can perform any type of excursion during a saturation, provided he carries out the specified stabilisation period in between his various bell excursion dives.

USN Tables ascent and descent rate is up to 60 ft Min -1 with the upward excursion restricted by the deepest depth of the dive. (PPO_2 in Bell as per Chambers.)

The upward excursion limit may be used to initiate decompression as long as it is within the constraints of the table times and maximum depth reached.

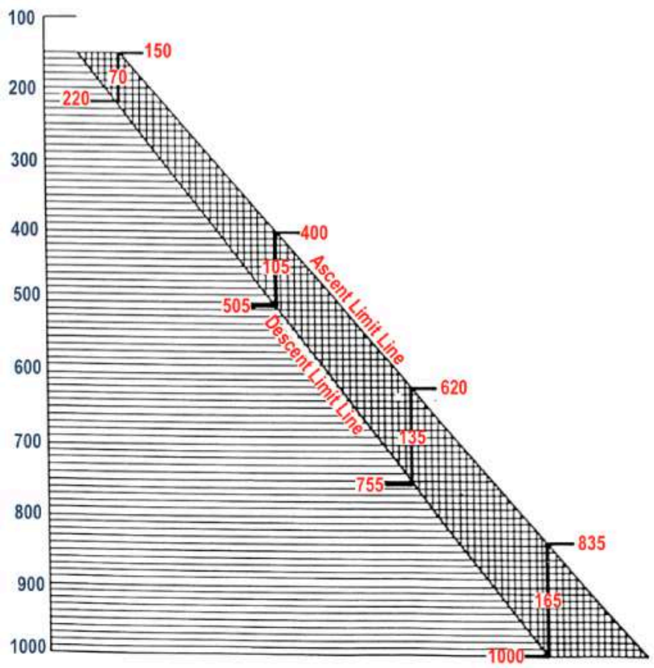
On arrival at shallower depth the saturation table schedule commences at the beginning of the stop.

Upward excursions must never be used following treatment of decompression sickness.

Unlimited Duration Saturation Excursions Tables

Storage Depth	Standard Descending Excursion Distance	Standard Ascending Excursion Distance	Maximum Descending Excursion Distance	Maximum Ascending Excursion Distance
10-17 m	3 m	2 m	Forbidden	Forbidden
18-22 m	4 m	4 m	Forbidden	Forbidden
23-29 m	5 m	5 m	10 m	Forbidden
30 m	6 m	6 m	12 m	Forbidden
31-39 m	7 m	7 m	14 m	14 m
40-59 m	8 m	8 m	16 m	16 m
60-79 m	9 m	9 m	18 m	18 m
80-99 m	10 m	10 m	20 m	20 m
100-119 m	11 m	11 m	22 m	22 m
120-139 m	12 m	12 m	24 m	24 m
140-179 m	13 m	13 m	26 m	26 m
180-350 m	15 m	15 m	30 m	30 m

U.S.N. Unlimited Duration Excursions Tables



Each set of tables have their own special procedures and contingency arrangements should problems occur, Such As:

- Aborting the Dive
- Loss of Oxyhelium
- Loss of Oxygen
- Decompression Sickness

It is most important that the procedures laid down in the diving manual being used are followed.

Always refer to your particular Diving Operations Manual for guidance.

DIVE SYSTEMS 6.4

Diving systems can be divided into two groups: air or mixed gas. The mixed gas types can be further subdivided into bounce or saturation diving types.

As the depth of operation increases, first air diving is used, then mixed gas bounce diving, followed by mixed gas saturation diving. There is, however, a considerable overlap with these techniques.

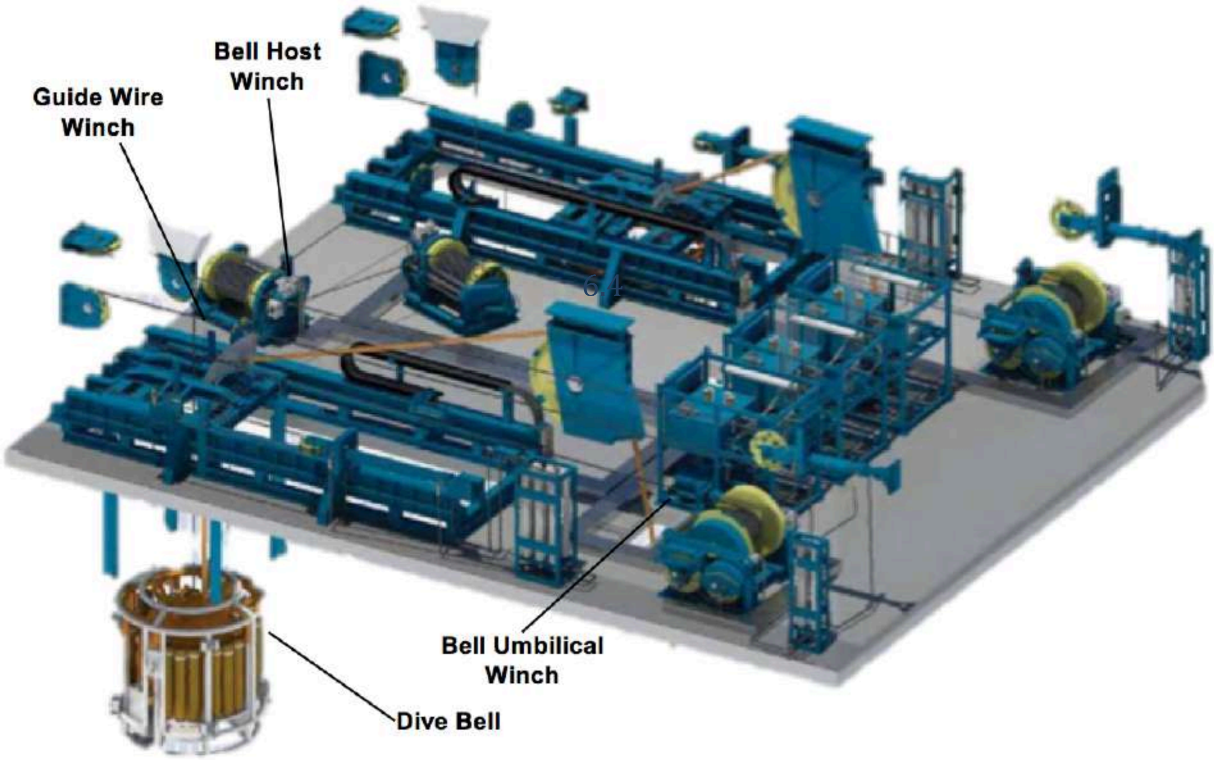
The diagram overleaf illustrates the main components of a saturation diving system.

The Saturation Diving System Comprises Five Main Parts:-

- Diving Bell.
- Bell Handling and Dive Control.
- Deck Compression Chamber Complex.
- Chamber Control.
- Life Support Equipment

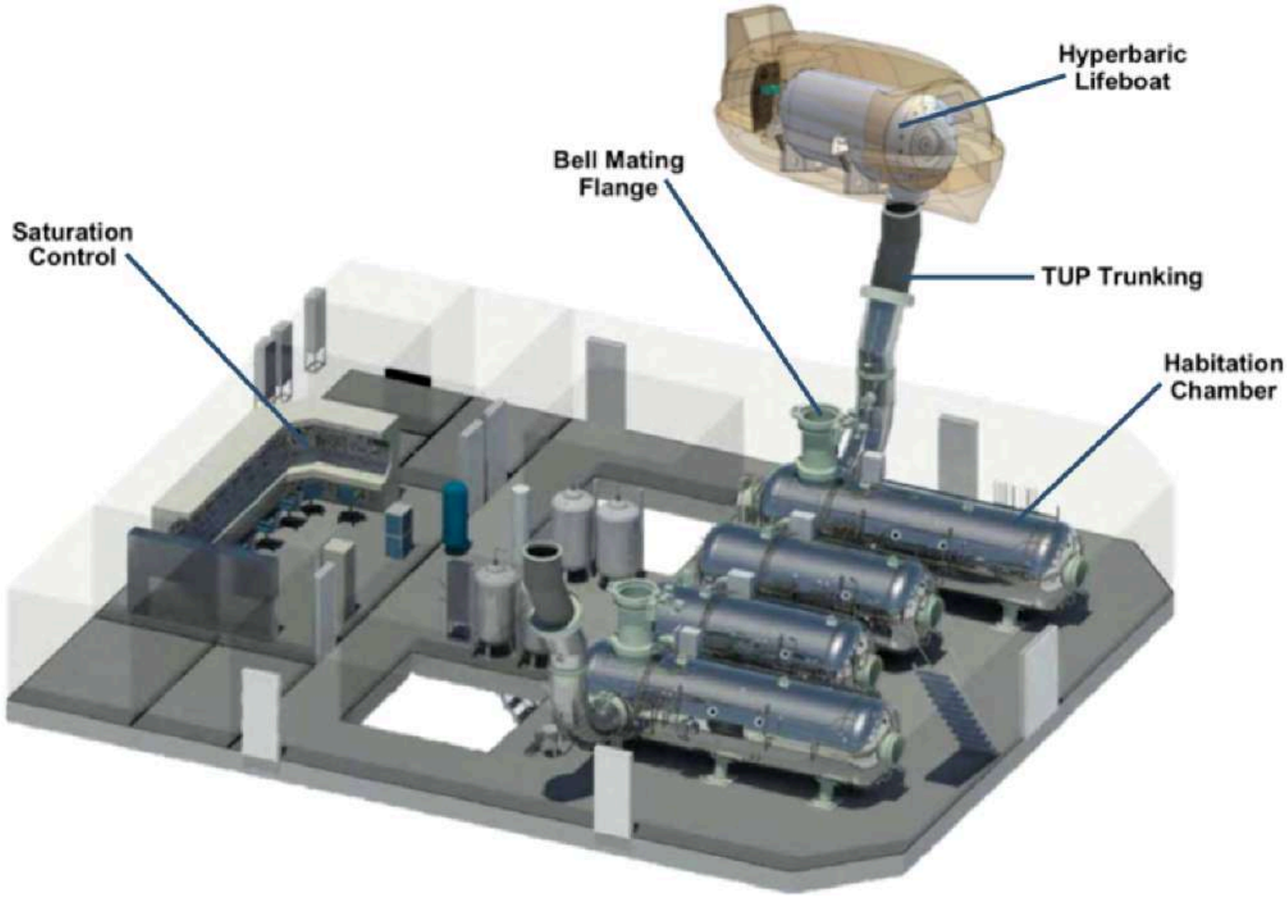
Major Components of A Dive Saturation System

LEVEL 1

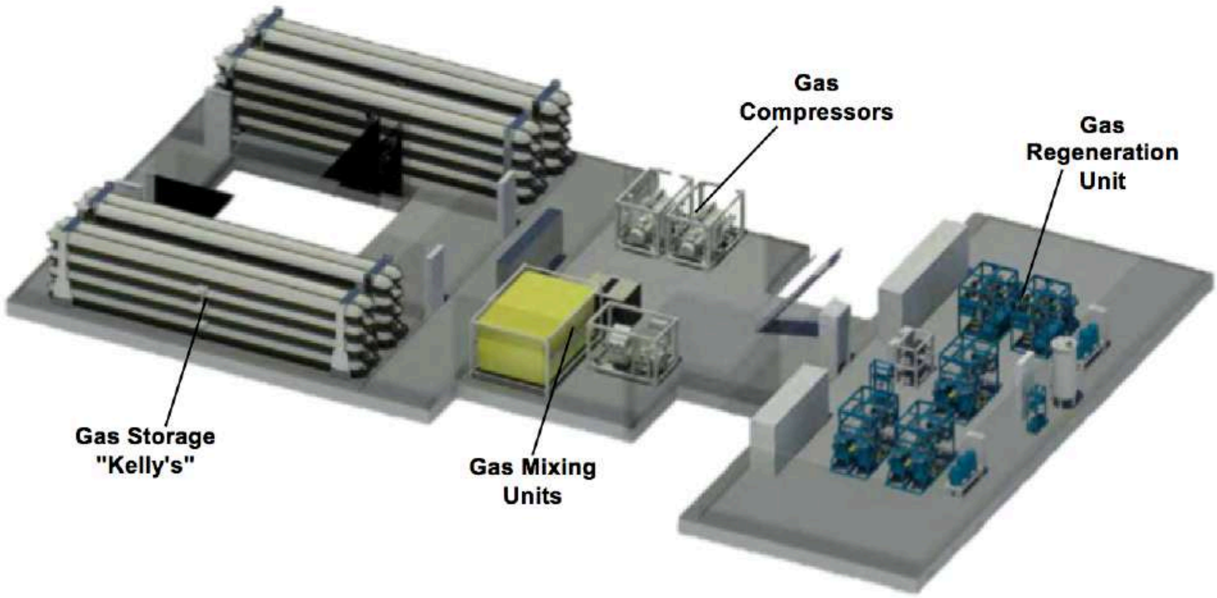


Major Components of A Dive Saturation System

LEVEL 2



LEVEL 3



DIVING BELLS 6.5

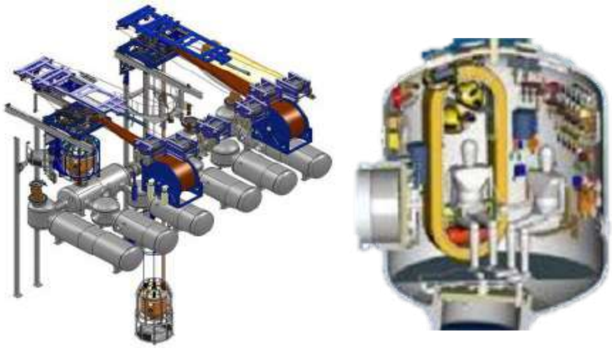
The Diving Bell or Submersible Decompression Chamber (SDC) is a chamber which can be lowered into the water with the divers inside and transport them to the worksite either under pressure or at surface pressure. It must be used for all diving operations deeper than 50 metres although it can be used at shallower depths. Over 50 metres, mixed gas and heating must be provided.

All bells operating in the United Kingdom must conform to the Diving Operations at Work Regulation 1997, SI 2776.

In Particular, They Must Have The Following Features:

- A means of allowing a diver to leave and enter the bell safely.
- A means of allowing divers to transfer under pressure to a deck compression chamber.
- Doors which act as pressure seals and which may be opened from either side.
- Be equipped with valves, gauges and other fittings to control the pressure within the bell and to indicate the external pressure to both the divers and the supervisor.
- Be fitted with adequate equipment to supply both the diver and the standby diver (bellman) with a suitable breathing mix.
- Be fitted with oral communications.
- Be fitted with heating and lighting.
- Have a manlift for rescuing an injured diver and have a first aid kit.
- Be able to sustain the lives of the occupants for 24 hours during an emergency.
- Have a transponder or other suitable system by which the bell can be located quickly if it is lost on the seabed.
- Have handling gear suitable for raising and lowering the bell without undue lateral, vertical or rotational movement.
- Be provided with a means of raising the bell should the main wire part. If this involves shedding weights there should be a device to stop their accidental release.

Diving Bell Life Support



The bell must be well designed and certified before it can be put into operation. During its life it must be well maintained and updated when new legislation or guidelines are published. Procedures and checklists must be developed and held in dive control to aid the safe operation of the system.

The Panel

Dive Panel

The bell internal panel must be designed to conform with Department of Energy Safety Notice 83/10,

Which States That:

- Supplies to other divers must not be lost if a divers umbilical is severed.
- Onboard gas must not be able to exhaust up the bell umbilical in the event of the main umbilical being severed.

In addition to the above points, panels should be easy to use and gas routes should be easy to follow.

There are several ways of achieving this and a variety of panel types are in use at the present moment.

Main umbilical pressure is set on the surface at about 20 bar above the bell internal pressure and the bell regulator is set at 12 bar. The onboard gas is set on the outside of the bell to 9.5 bar using a tracking regulator whose pilot line sensors the internal pressure of the bell. Therefore, the onboard gas will be a constant 9.5 bar above bell pressure.

When the diver is breathing he will use gas from the umbilical as this is at the highest pressure. If the surface gas fails the onboard gas will cut in automatically when supplying pressure drops to 9.5 bar. If one of the divers' umbilicals fail, the surface gas will be lost but the onboard gas for the other diver will be unaffected as the non-return valve will stop it from crossing over the panel.

Non-return valves fitted to the blowdown lines stop gas from escaping up a ruptured main umbilical.

Diver 3 can have a choice of onboard mixes and is always linked to a different gas from the other diver.

The bail-out worn by the diver is set at 12.5 bar and will therefore override all other gases if it turned on. An addition to this type of panel is a rotawink, which changes from green to red when the onboard gas is being used.

Breathing Gas Systems

During normal bell excursions and operations the diving bells breathing atmosphere is supplied from the surface via the umbilical assembly. However external HeO_2 cylinders are required to supplement the internal breathing environment in the event of a surface interruption of gas supply. In addition to the HeO_2 cylinders of oxygen are also carried on the outside of the bell to blend / replace breathed O_2 within the bell during an interruption in the surface gas supply.

The gas pressure is reduced on the outside and comes into the bell at about 10 bars. There must be some device or system to stop too much oxygen from entering the atmosphere. A flowmeter or a buffer cylinder may be fitted to carry out this function.

There should be enough oxygen carried onboard to keep the divers alive for at least 24 hours. Using a breathing rate of 0.5 litres per minute, 3 divers would use approximately 43 bars from a standard 50 litre cylinder. Of course, the bottom depth and the inlet pressure would need to be added to this figure. However, it can be seen that there should be no need to pump oxygen as decanting from the main banks should gain sufficient pressure to fulfil the requirements.

Bell Reserve Gas

Gas Reclaim

Helium replaces nitrogen as the carrier gas in mixed gas diving. It is an expensive gas. This has led to the introduction of reclaim systems so that the helium can be used several times. Reclaim systems fall into two distinct types: *Diver Systems* and *Chamber Systems*.

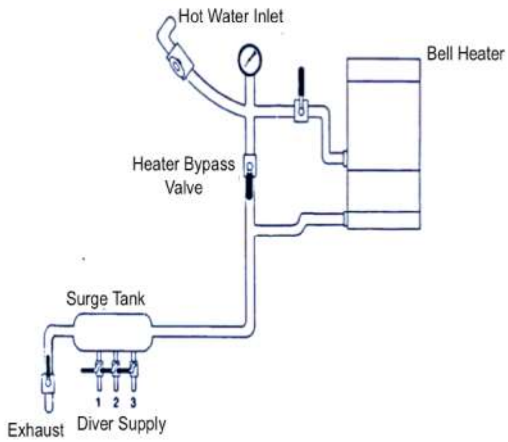
Bell Heating

Bells are normally heated by hot water, which is fed from the surface down the umbilical. It is mandatory for all bells operating over 50 metres to have an internal heating system and for the diver to be heated. This is normally carried out by one hot water line, which after entering the bell, goes through a heating element before going to the diver. Bell gas is circulated over the heating element by an electrically driven fan. A bypass is also provided so that if the bell becomes too hot the bellman can cut down the flow going to the heater.

A temperature gauge should be fitted in the bell and in dive control. Alarms are provided in dive control in case the water becomes too hot or too cold.

Some bells are fitted with radiators on the outside through, which some of the flow can be routed. This allows a certain amount of control of the hot water by the bellman, which can save time during bounce dives.

Bell Heating



Note: When operating hot water systems there should always be a flow of water. Therefore, when changing routes always open a valve before closing another.

Carbon Dioxide Removal

Carbon dioxide is removed by passing the bell atmosphere through a CO_2 absorbent (sodasorb). This is normally carried out in the bell using an electrically driven fan (scrubber). The sodasorb is packed into a canister, which sits on the scrubber. A spare scrubber canister is always carried in the bell in case of emergencies or prolonged bell runs.

Dive Bell Access

Access

All bells are fitted with a trunking at the bottom, which allows the diver access to the sea. This trunking can be used to mate the bell on to the system or a second trunking can be fitted which allows the bell to mate sideways with the system. These trunkings are fitted with one or two doors, which should allow the bell to be pressure sealed both internally and externally. These doors should be capable of being opened from either side. Where a castellated door is fitted any locking device should also be capable of being operated from both sides.

If a bell is dropped on to the seabed the diver should still be able to gain access. This can be accomplished by fitting some form of framework, which will prevent the bell grounding or alternatively by having detachable weights which will allow the bell to float clear. The bell is still attached to the weights by a second longer strop, which can be dropped later.

Gauges

Bells are fitted with internal and external depth gauges. The internal gauge (or caisson gauge) is open to the bell atmosphere and gives a direct depth reading.

Bell Depth Gauge

The gauge indicating external depth is plumbed through to the outside of the bell and is therefore open to seawater. If this is connected to a bag full of silicon oil, the seawater, and therefore any corrosion, is eliminated.

The supervisor's panel will be fitted with gauges, which will indicate the bell internal and external depth as well as any diver's depth.

Communications

Hard wire communications must be provided to the bell and to the divers. It is common practice to have two systems to the bell, a normal diver comms system and a sound powered telephone.

Through water comms are used to provide a backup in case of a severed umbilical. These are often noisy but clear enough to be used in an emergency. Through water comms are normally tested during deployment of the bell to the worksite.

An emergency communications card is fitted to the outside and inside of bells to allow a rescue diver to communicate with a stricken bell by using the described tapping code.

View Ports

Ports used in bells are similar to those used in chambers, however, they must seal in both directions. Ports, which face upwards should be covered with guards as protection from falling objects, etc.

Emergency Location Devices

Bells are fitted with one or more devices to allow them to be found quickly in an emergency. These could be:
Strobes
These are devices, which could give off intense flashes of light which can be seen by the diver or ROV.
Transponders
These are devices which, when interrogated by a locator held by the diver, gives off a signal. The delay between the interrogation signal being sent and the transponder signal being received can be displayed as a distance on the locator. This distance, along with the bearing, can be used to give an accurate position of a lost bell. This is the method preferred and recommended by IMCA and the HSE. Most bells in the British Sector are fitted with Sonardyne Transponders which can be interrogated on 38.5 kHz (Channel A) or 39.5 kHz (Channel B) and have a common reply frequency of 37.5 kHz. Bells operating from dynamic positioning ships will normally be fitted with a ship's transponder.
Pingers
These are devices, which continuously send signals when immersed in the water. These signals are picked up by a hand held locator and indicate the direction to - but not the distance of - the lost bell.

Survival Equipment

In the Regulations, bells should carry enough survival equipment to keep the occupants alive for 24 hours. In practice, this has not been achieved in a heliox atmosphere. The major problem is heat loss. Because helium conducts heat at a faster rate than air, the divers will rapidly cool down when hot water is lost. To conserve heat there must be a survival suit in the bell for each occupant.

Bell Survival Kit

This suit normally comes in two packs. One contains a survival bag along with a towel and undersuit. The other contains a lung-powered scrubber, water, high-energy rations and sanitary bags. During trials using these systems it was found that divers who dried themselves thoroughly had the least heat loss.

The lung-powered scrubber is filled with sodasorb or high-grade soda lime such as MPDU 797 and is fitted with a thermal regenerator to lessen the heat loss from breathing. In trials carried out on the lung powered scrubbers the thermal regenerators proved to be 95% efficient at 300 metres. Further to this, the chemical reaction, which removes carbon dioxide from the divers exhaled gas creates a small amount of heat which is passed to the thermal regenerator. A by-pass valve is fitted to the system to dump some of this heat if the breathing gas becomes too hot.

Bell Analysers

It is important to know the oxygen and carbon dioxide levels in the bell atmosphere both during normal operations and in emergency situations.

During normal operations a sample line is connected to the bell via the umbilical and the gas analysed on the surface. Depending on the length of the umbilical there may be a considerable time delay between a sample leaving the bell and registering on the analysers.

A quicker method is to have the analysers in the bell. This also allows the divers the monitor the bell atmosphere if the umbilical is severed. Oxygen analysers internally carried in the bell, are normally of the fuel cell type and read in partial pressure.

Gas Analysis

Carbon dioxide levels can be measured using chemical tubes such as Draeger tubes. This is carried out every hour by the bellman and the reading must be converted to a % CO_2 or PPmCO_2. Continuous sampling can be carried out in dive control using infra-red absorption type analysers.

In addition to the normal atmospheric gases, the diving bell may be subjected to exposure from dangerous gas contamination. These include Hydrocarbons (a byproduct of oil exploration), which can reach anaesthetic levels, Carbon monoxide and Hydrogen Sulphide (which is particularly deadly). Analysers such as the Analox Hypergas are routinely used in the bell. If a dangerous gas is identified the divers can quickly don BIBS & commence environmental decontamination procedures.

Bell Cameras

Most bells are fitted with a CCTV either looking into the bell or underneath the trunking.

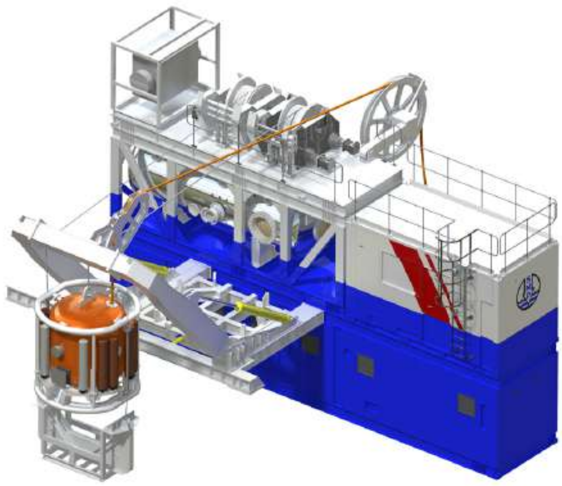
An internal camera can be used to check the bellman and is extremely useful in a loss of comms emergency.

A trunking camera can be used to check the diver's equipment for leaks or function and most can be removed and taken to the worksite for use there.

First Aid Kits

The bell will carry a first aid kit, which is primarily designed to restore breathing and stop large flows of blood. The Company manual should list what is carried in this kit. However, guidance can be found in DMAC 15 guidelines. A date should be written on the pack showing the next time it is to be checked.

Bell Handling devices



Handling Equipment

Bell handling equipment should be designed in such a way as to lower and raise the bell without undue lateral, vertical or rotational movement. It should allow the bell to be mated with the system in all weather conditions.

A variety of designs exist according to the individual requirements of the operator, etc. However, the first task is to remove the bell from the system and transport it to the launch point.

This can be carried out either by using an "A" frame or a gantry system.

Minimum Gas Supplies (IMCA/AODC Guidance No 014/83) 6.5.1

Bounce Diving

- Bounce dive mixed gas must be available for the divers in the water or bell to carry out their planned work plus additional gas to allow a complete dive to be made to the maximum depth as an emergency.
- Sufficient mixed gas must be available to pressurise the deck chamber to the transfer depth twice.
- Sufficient heliox mixed gas must be available to pressurise the decompression chamber to maximum diving depth and then carry out a full saturation decompression in the event of an emergency medical treatment being required. In this case sufficient oxygen must also be available.

Saturation Diving

- Sufficient mixed gas must always be available to carry out the intended bell run plus the same quantity of gas as a reserve.
- Prior to the start of a saturation there must be sufficient mixed gas available to pressurise all the deck chambers to the maximum intended storage depth, plus at least an equal amount as a reserve.

- Sufficient gas to allow a full decompression from storage depth to the surface twice, allowing for the normal daily consumption of gas due to leakage, lock runs and toilet flushing.
- Sufficient oxygen to allow for metabolic consumption by each diver plus that is required to maintain PO_2 during decompression. The quantity should be doubled for safety reasons.

All Diving

There should be sufficient mixed gas carried on the bell to supply the diver for 30 minutes. Breathing rates for calculating this vary from between 40 litres per minute to 50 litres per minute.

There should be sufficient oxygen carried on the bell to make up that used by the divers using a metabolic rate of 0.5 litres per minute per diver over a 24-hour period.

The diver should carry with him sufficient gas to provide 1 minute breathing for every 10 metres of umbilical deployed. Breathing rates vary between 40 litres per minute to 62.5 litres per minute.

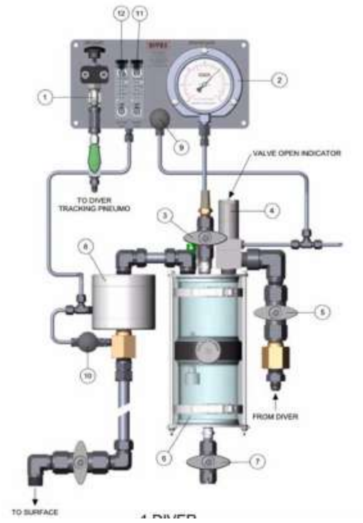
Diver Bell Equipment 6.5.2

Diver Reclaim System

These systems take the Gas the diver breaths out, re-processes it (removes CO_2 moisture, odours and bacteria and adds Oxygen), then delivers it back to the diver for re-use.

The system may be carried by the diver, operated from the Bell or operated from the surface.

Electric Gasmizer Reclaim



Gasmizer Reclaim System

- *General Description.* The purpose of the system is to recover gas mixtures breathed by the divers, re-process it and deliver it into the supply system.
- *Steps:-*
  - Gas is removed from the helmet or mask as it is exhaled by a recovery valve (Helinaut Valve).
  - Gas returns to the Bell where excess moisture can be removed prior to returning to surface.

The Surface Unit

- Scrubs the Gas to remove CO_2.
- Filters the Gas to remove: Moisture, Particulates & Biological Contaminants.
- Oxygen is replenished
- Gas is compressed and delivered to storage until required.
- Reclaimed Gas is supplied to the Bell via the supply console.

Diver Helmet

Diving Hat

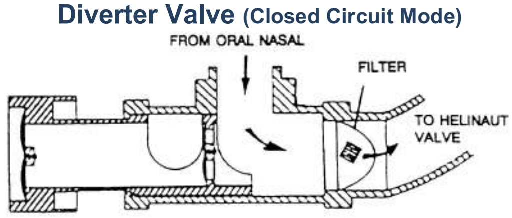
The divers hat consists of an Ultraflow demand regulator diverter valve assembly and a helinaut valve. This is fitted to a conventional Kirby 17B or 18B. If using an 18B, care has to be taken with the hood as any minor leaks can diminish gas recovery.

When carrying out maintenance on these hats, consult the Gas Services Manual before replacing any parts as some are not compatible with standard Kirby parts. Further to this, there are other types of hats, the Ultraflow 350, Ultraflow 501 and Ultrajewel 601 (reclaim hat), which again have different parts.

Diverter Valve - General Description and Function

The main function of the diverter valve is to provide a rapid means of selecting open circuit operation, isolating the exhaust circuit from the diver. In addition, this assembly houses the flood mushroom valve and the filter screen, which prevents foreign material passing into the HELINAUT valve. The diagrams below illustrate the diverter valve in its three operational modes.

Diverter Valve (Closed Circuit Mode)



In closed circuit mode, the diverter plunger is pulled OUT. Exhaled gas passes through the diverter valve assembly, via the filter screen to the HELINAUT valve.

The overpressure mushroom lifts when the exhale resistance is 16 cm WG, allowing open circuit exhalation.

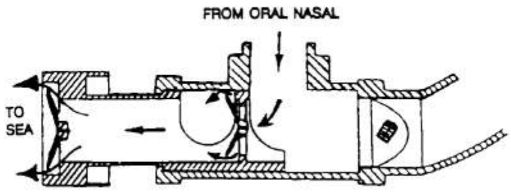
Thus, if gas recovery is interrupted for any reason, the diver can continue to exhale without any immediate action. He will however be alerted by the increased breathing resistance.

If the diverter plunger is pushed IN, exhaled gas is dumped via a mushroom valve into the sea, with low breathing resistance.

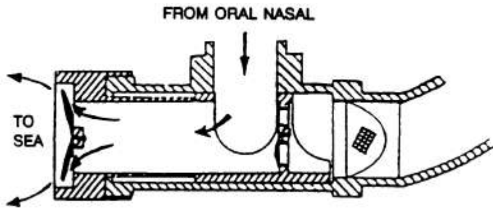
In the unlikely event of a negative pressure of 30 cm WG developing within the diverter valve, the flood valve will open filling the exhaust hose with water. Since the viscosity of water is much higher than gas, this will effectively isolate the diver from the exhaust.

The body of the diverter valve is manufactured from 316 stainless steel to provide corrosion resistance, and the plunger from Delrin.

Diverter Valve (Over Pressure Mode)



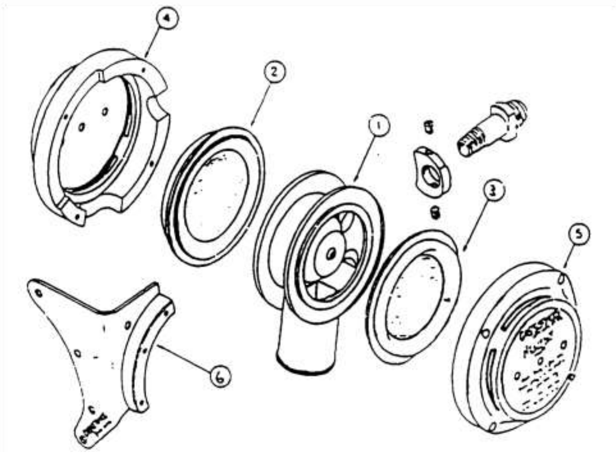
Diverter Valve (Open Circuit Mode)



Helinaut Valve

The Helinaut valve is a simple device which controls exhaled breathing gas within precise limits. It is manufactured from, predominantly 316 stainless steel for corrosion resistance, plus Delrin which feature resilience, lightweight, high strength and Delrin, which feature resilience, lightweight, high strength and very low moisture absorption. The valve consists of 4 main parts: the body (1), a pair of diaphragms (2/3), a pair of caps (4/5) and the mounting bracket (6).

Helinaut Valve



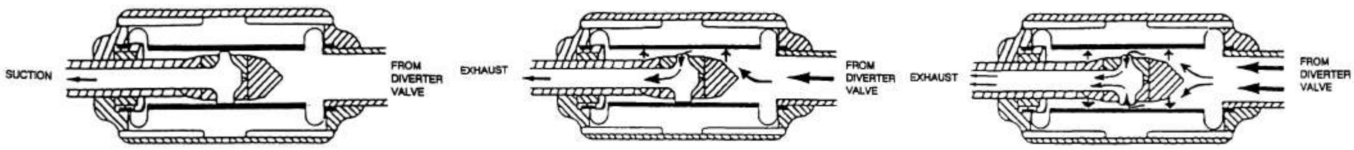
In operation, the Helinaut valve removes the diver's exhaled gas in a controlled manner by means of the sequence illustrated below.

In its normal (closed) position a negative pressure, approximately 1.5 Bar below diver ambient, is applied to the outlet connection. This negative pressure holds the diaphragms firmly over the 2 nozzles, forming a seal.

As the diver exhales, gas is routed between the diaphragms. The diaphragms, sensing the increase in pressure, lift allowing gas to enter the outlet chamber and pass into the exhaust umbilical. Initially, the diaphragm covering the small pilot nozzle opens.

As exhalation continues, the main diaphragm lifts allowing full flow. Upon completion of the exhalation cycle, both diaphragms return to their normal closed position.

Helinaut Valve (Operationally)



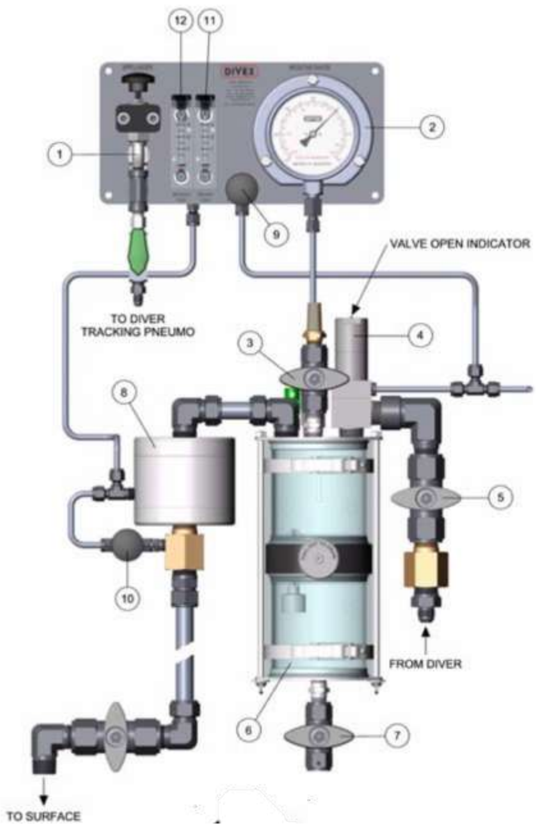
During a breathing cycle, the Helinaut valve regulates the flow of gas into the exhaust umbilical to be exactly equal to the quantity of gas exhaled by the diver.

Bell Equipment: General Description

The Bell equipment carries out several functions. First, the pressure in the diver's exhaust umbilical is regulated to the optimum valve. Second, a water trap is provided to remove free water prior to return gas to surface. In addition, the SAECO valve, which performs an important safety function is housed within the Bell equipment.

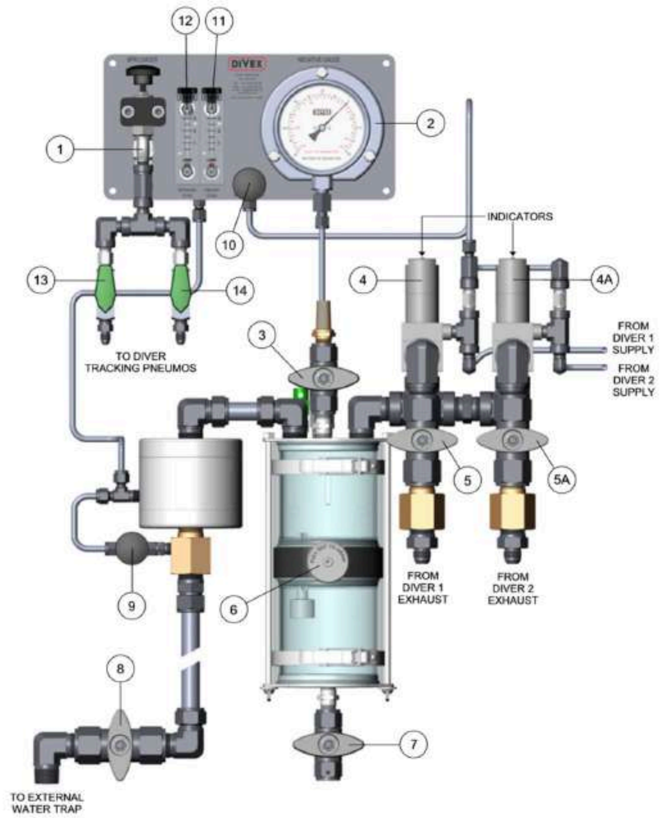
The overall layout of the Bell equipment is shown in the diagram overleaf. The main components are as follows (numbers refer to the layout drawing):

1 Diver Lockout



1. BPR Loader
2. Negative Pressure Gauge
3. Bell Scrubber Valve
4. Saeco Valve
5. Diver Exhaust Manifold
7. Drain Valve
8. Diver Exhaust Hull Va
9. BPR Bleed Valve
10. Pneumo Supply Valv
11. Pneumo Meter
12. BPR Bleed Flow Mete

2 Diver Lockout



1. BPR Loader
2. Negative Pressure Gauge
3. Bell Scrubber Valve
4&4a Saeco Valve
5&5a. Diver Exhaust Manifold Valve
6. Water Trap Isolation
8. Diver Exhaust Hull Valve
9. BPR Bleed Valve
10. Pneumo Supply Valve
11. Pneumo Meter
12. BPR Bleed Flow Meter
13&14. For one diver lockout, clos tracking pneumo valve no

1. The back-pressure regulator (BPR) loader valve controls the setting of the back pressure regulator.
2. Pressure gauge - records the pressure in the water trap which is the same as the pressure in the exhaust umbilical if the isolating valve and SAECO valve are open.
3. Bell scrubbing valve - allows recovery and re-cycling of Bell gas.
4. SAECO valve - (supply actuated exhaust cut-off valve) isolates the exhaust umbilical from negative pressure in the event of gas supply failure.
5. Exhaust umbilical isolating valve.
6. Water trap - collects any water present in the exhaust umbilical.
7. Water trap drain valve - allows the removal of water from the water trap.
8. Back pressure regulator (BPR) - regulates the pressure in the exhaust umbilical.
9. Metering valve 1 - associated with the diver tracking system.
10. Metering valve 2 - BPR bleed valve associated with the diver tracking system.
11. Flowmeters 1 and 2 respectively.
12. Flowmeters 1 and 2 respectively.

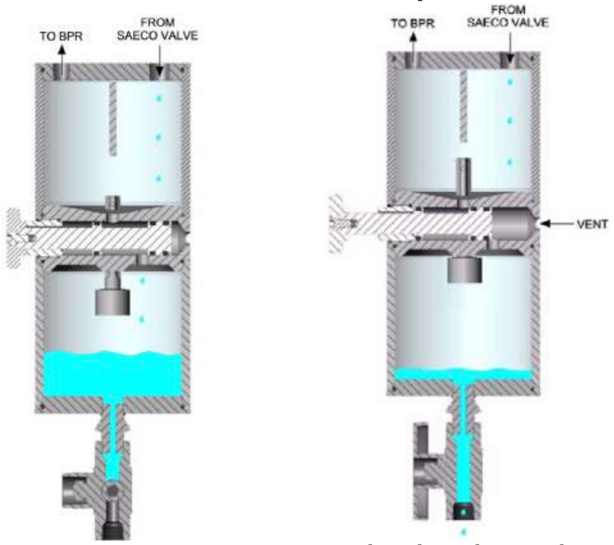
Gas from the diver exhaust umbilical first enters the exhaust manifold. An inward relieving relief valve set to lift at 3.5 Bar (50 psi) is provided on the umbilical connection to avoid damage to either the umbilical or the diver equipment if the Bell is pressurised with an umbilical and diver head gear connected.

Gas then passes through a SAECO valve into the water trap. The function of the SAECO valve is to isolate the diver umbilical from the negative pressure automatically in the event of any interruption in the gas supply.

The function of the water trap is to collect any free water, which may have entered the exhaust circuit. A diagram and working explanation of the water trap is given below.

The negative pressure gauge indicated the pressure in both the water trap and the diver's umbilical. The overpressure relief valve is set to lift at 30 psi (2 Bar). Typically, it would protect the water trap in the event that all valves were closed and the Bell was being depressurised.
The negative pressure relief valve is set to lift at -3.5 Bar (-50 psi). This could occur if the bell BPR was improperly loaded or the Bell was being pressurised with valves to the water trap closed.
From the water trap, gas passes through a back pressure regulator, the purpose of which is to control the negative pressure in the diver's umbilical to the optimum value, giving minimum breathing resistance. Note that this back-pressure regulator is automatically adjusted by the diver tracking system to maintain the optimum exhaust pressure as the diver changes depth. Thus, diver depth is sensed by a diver tracking pneumo, which is continuously purged by a slow bleed of gas. In this way, the BPR loader valve can maintain the Back Pressure regulator at a fixed pressure below diver ambient rather than Bell depth.
The supply system is completely conventional. The only modification to the existing supply manifold is the addition of a connection required for the diver tracking system and SAECO valve, which will be described later.

Water Trap



With the plunger in the normal (in) position, trapped water may pass through to the lower cylinder.

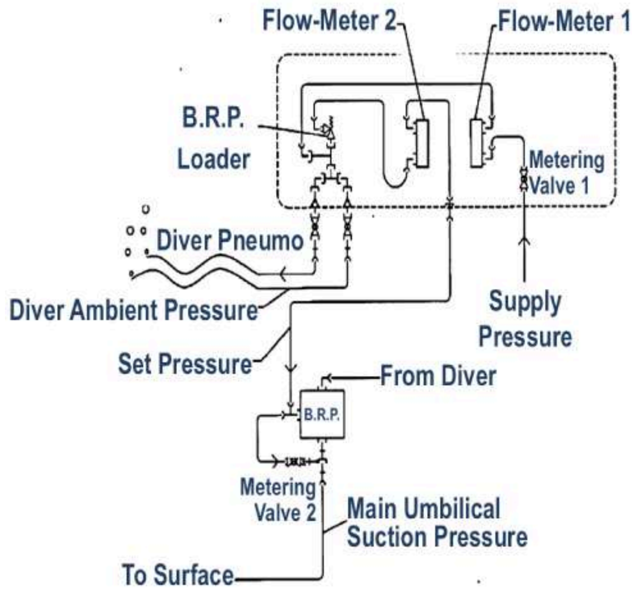
When the isolation valve is pulled out, the upper and lower halves of the water trap are isolated and the lower half is vented to Bell ambient pressure. The drain valve may now be opened to remove water while the upper half continues to collect water from the flowing gas.

Diver Tracking System

In order to obtain minimum breathing resistance from the Helinaut valve it is important to maintain the pressure in the return umbilical approximately 1-2 Bar below diver ambient. Thus, as the diver moves above or below the Bell, it is desirable to adjust the BPR loading accordingly. This is accomplished automatically by means of the diver tracking system. The system is shown schematically in the diagram below.

A $^{1}/_{8}{}^{th}$ inch bore pneumo line is added to the diver umbilical. A slow gas bleed is drawn from the Bell gas supply to this pneumo. Thus, gas bubbles will be seen to emerge continually from this line at a slow rate.

Diver Tracking Systems



The loader is, in effect, a modified inward relieving relief valve, which controls the set pressure for the BPR. As suction is first applied to the system, gas will be drawn from the BPR loader line, reducing the pressure until it reaches the set pressure of the loader when it will lift, allowing gas to flow to prevent further depressurisation. In this way, a fixed reference pressure is available for the BPR.

The pressure in the diver pneumo line is applied to a piston (having the same area as the valve opening) on the bottom of the BPR loader. As the diver changes depth, the change in pressure in the pneumo line will in effect change the set pressure of the loader, e.g. as the diver goes deeper, an increased force will be produced, causing the loader to relieve maintaining a higher pressure in the BPR loading line.

In fact, because of the design of the loader assembly, it maintains a constant difference in pressure between diver ambient and the BPR reference pressure. In this way, once the BPR loader has been set to give minimum breathing resistance in the Helinaut valve, it will adjust the exhaust pressure automatically to compensate for changes in diver depth.

The functions of the diver tracking system components are:

- Diver Pneumo (to record diver depth).
- Metering Valve 1 (to adjust the supply gas to purge the diver pneumo - a maximum of 0.4 litre/min is recommended).
- Flowmeter 1 (Indicates the flow through metering valve 1).

Excessive flow will adversely affect gas recovery figures. Only a slow trickle of bubbles from the pneumo line should be evident to the diver.

- BPR Loader (maintains a constant pressure difference between diver and ambient and BPR setting).
- Back Pressure Regulator (controls the exhaust umbilical pressure to be equal to the BPR loading setting).
- Metering Valve 2 (controls the gas bleed through the BPR loader to give stable operation. Should be set to 0.5 litre/min).
- Flowmeter 2 (records the flow through metering valve 2).

Bell External Equipment

A check valve and water trap is mounted external to the Bell. The purpose of the check valve is to prevent reverse flow of gas from the umbilical into the Bell equipment, e.g. when the Bell is being depressurised. The external water trap simply collects any additional free water, which is either carried over through the main umbilical exhaust hose. Little water is anticipated at this point so it is sufficient that it should be drained at infrequent intervals when the Bell is on surface.

Reprocessing Unit

General Description

The function of the reprocessing unit is to add Oxygen to restore the gas mixture then scrub the recovered divers gas to remove CO_2 and any other contaminants. Its operation can be broken down into two sections:

The Inlet Section

Consists of a moisture separator and float valve to prevent water being passed into the reprocessing unit, an Oxygen injection point and two receivers, which primarily smooth out fluctuations in the flow to the electric gas booster.

The Outlet Section

Gas is discharged to this section from the electric gas booster outlet. It consists of further filtration to remove water particles and any solid material. Chemical scrubbing is also employed to remove Carbon Dioxide and any other trace contaminants.

Filters/Moisture Separators

Both Moisture Separator 1 and Filter 2 have a coalescing filter element.

The elements for these filters are:

- Filter 1 - 1 micron
- Filter 2 - .01 micron

These filter elements coalesce the small liquid droplets into larger liquid droplets which drain to the bottom of the housing. It is recommended that filter elements be replaced at intervals of 500 operating hours.

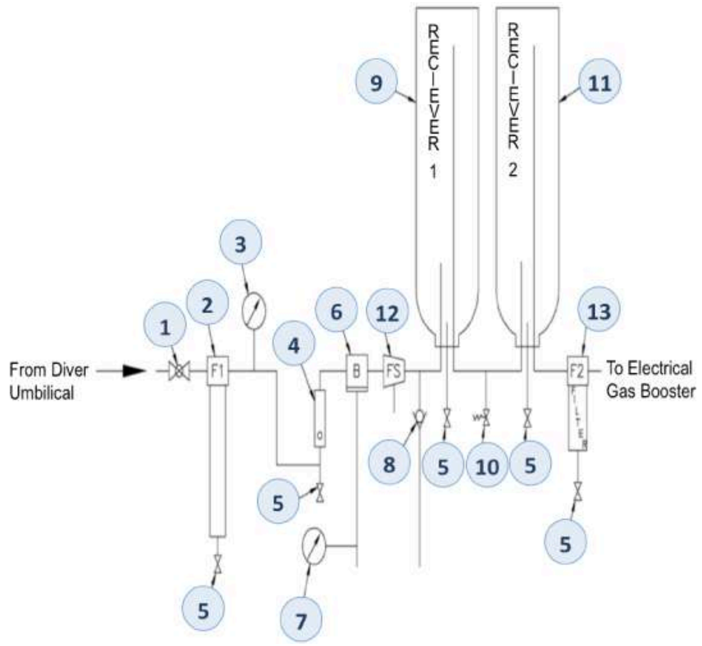
Float Valve

If water accumulates in the float valve body, the float will rise to seal off the outlet, preventing water from flooding the topside unit. This would occur if, for example, there were a loose fitting on the main umbilical at the Bell. A drain valve allows any accumulated water to be removed.

Oxygen Injection System

Oxygen is bled into Receiver 1 directly from the Oxygen panel.

Inlet Selection



Flow Switch

The flow switch senses the gas flow through the system. This switch controls two functions. First, it activates an alarm in the control panel when the flow through the topside unit stops. In addition, it stops Oxygen addition in the absence of flow.

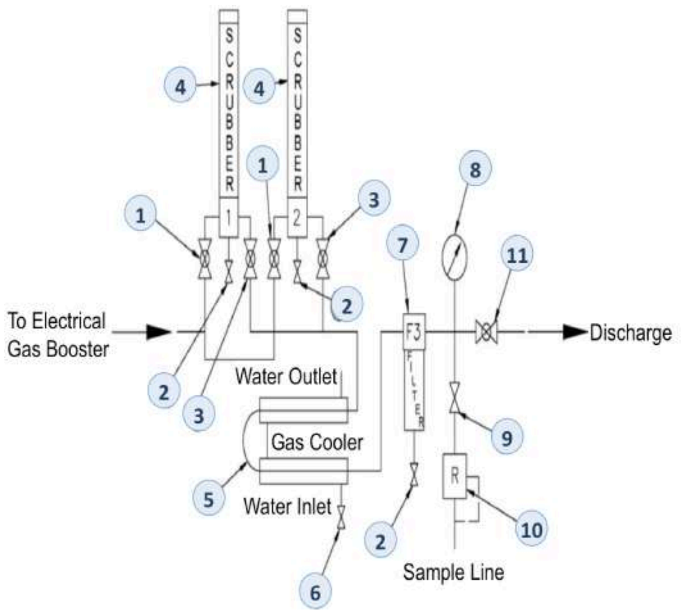
Back Pressure Regulator

Control the pressure in the return umbilical.

The Inlet section consists of the following components:

1. Exhaust hose ball valve - isolates the system from the exhaust umbilical.
2. Moisture separator F1 - removes liquid and solid particles down to 1 micron.
3. Exhaust hose pressure gauge - monitors pressure in the return umbilical.
4. Float valve - closed if water enters, preventing contamination of the topside unit.
5. Drain valves - provided on both moisture separator and float valve.
6. Back pressure regulator - controls the pressure in the main umbilical, eliminating any possibility of umbilical collapse.
7. BPR loader gauge - indicates the reference pressure applied to the back-pressure regulator.
8. Oxygen injections - supplies an oxygen bleed from the control panel entering the system via a check valve prior to gas entering the first receiver.
9. Receiver 1 - prevents exhaust side pulsation resulting from compressor operation and allows O_2/Helium mixing to take place.
10. Relief valve - provides overpressure protection. It is set to lift at 1100 psi.
11. Receiver 2 - as Receiver 1.
12. Flow switch - detects flow through the unit, sounding an alarm at the control panel when the flow stops and controls Oxygen make up.
13. Filter F2 - removes liquid and solid particles down to .01 micron.

Outlet Selection



The outlet section consists of the following components:

1. Scrubber inlet valves - provide manual shut-off of the scrubber unit.
2. Scrubber/filter vent value - provides manual venting of the scrubber or filter prior to changing.
3. Scrubber out valve - provides manual shut-off of the scrubber outlet6.5.2
4. Scrubber assembly - removes CO_2 and odours by passing the gas through a bed of sodalime and purafil.
5. Heat exchanger - cools the exhaust gas to condense water vapour to a minimum.
6. Cooling water inlet valve - provides manual shut-off of cooling water to the heat exchanger.
7. Filter F3 - 1 micron coalescing filter which collects moisture condensed in the heat exchanger.
8. Diver supply pressure gauge - indicates the pressure of gas leaving the topside unit.
9. Sample regulator shut-off valve - isolates sample regulator.
10. Sample regulator - provides gas to analyzers at 10 psi.
11. The diver supply valve - provides manual shut-off of the gas supply from the topside unit.

Control Console

The control console, which is normally situated in dive control operates and monitors the various parts of the system.

This breaks down into four parts:

- Booster Panel
  Monitors and controls the operation of the electric gas booster.
- Oxygen Panel
  Monitors and controls the flow of make up Oxygen into the system.
- Control Panel
  Monitors the gasmizer system during operation.
- *Make Up Panel*
  This has two parts - the make up gas for making up any losses and the Oxygen enriching which can rapidly add Oxygen when changing to a shallower depth.

Operating the System

The Supervisor sets up the surface control panel, which leaves the divers to set up the Bell equipment. A Bell card is provided and should be followed logically step by step.

Before the diver leaves the Bell he should check that the helinaut valve is working. This is done after checking that the negative pressure gauge is between -7 to -27 MSW and opening the exhaust valves 5 and 5A. First insert the flowmeter into the demand regulator opening and the stopper into the diverter opening, both in the oral nasal. Observe the flowmeter. No flow should be discharged. Press the purge button on the demand regulator 3 or 4 times while observing the flowmeter and the diaphragms in the helinaut valve. Apart from a short pulse, as the purge button is released no flow should be observed on the flowmeter. Both diaphragms should be observed operating in the helinaut valve.

Every 8 man-hours the soda sorb canister in the processing unit should be changed. This can be done after switching to a new scrubber, which allows the unit to keep operating.

Safety Levels

First Level - Helinaut Valve

The simplicity of the Helinaut valve provides inherent reliability; the profile of the nozzles and the resilience of the diaphragms makes it extremely difficult for foreign matters to prevent them sealing. In addition, a filter in the diverter valve presents the entrance of foreign objects into the Helinaut valve. The diver is able to perform a simple test prior to each dive to check the integrity of the exhaust system.

Second Level - Demand Regulator

Under normal operating conditions, leakage of the Helinaut valve could not be simulated. However, it must be considered what would occur if a leak were possible. In this event, the demand regulator would see the leak as an inhalation and flow sufficient gas to prevent de-pressurisation.

Third Level - SAECO Valve

In the event of the diver losing his gas supply the SAECO valve would close off the exhaust circuit.

Fourth Level - Flood Valve

If the SAECO valve does not seal effectively, the flood valve located in the diverter valve body will open at 20-30 cm of water suction and flood the Helinaut valve. Since the viscosity of water is much greater than that of gas, this will effectively block the exhaust circuit.

Fifth Level

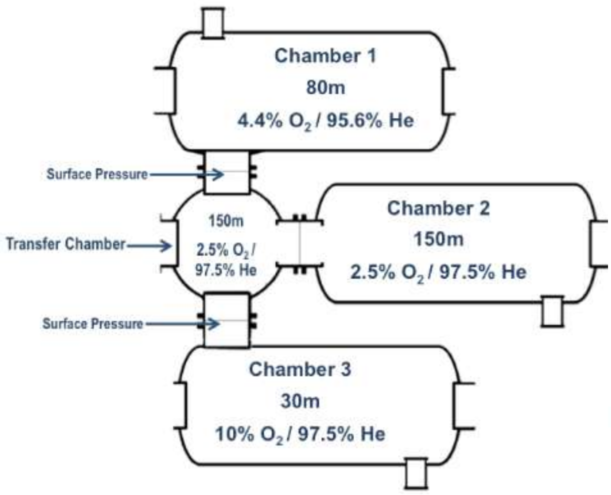
At any time, the diver can operate the diverter valve plunger, isolating the Helinaut valve.

SATURATION CHAMBERS 6.6

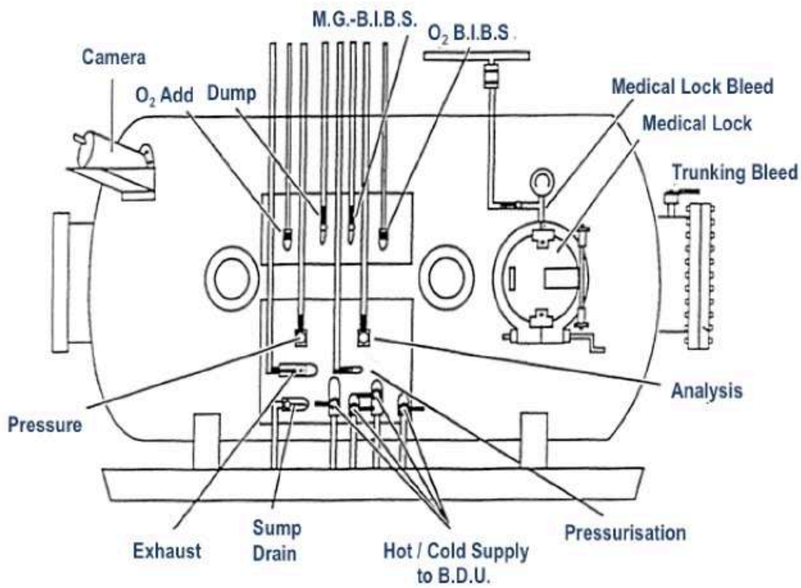
Chambers used in diving operations should conform with the H.S.E. Diving Operations at Work Regulations 1997, SI 2776. Saturation chambers are designed to allow divers to remain under pressure for more than 12 hours and therefore should be more than 2m in diameter, however, if it has been in use since before 1 July, 1982, they need only be greater than 1.75 m in diameter. The chambers described in the following paragraphs are saturation or deep dive systems and not air chambers designed to go to a maximum of 50 m.

Within the equipment register there should exist a log of the manufacturing details and clarification of chamber and details such as working pressure, test pressure, inspection details etc. will be stamped on a plate welded to the chamber external surface.

Saturation System (Multi-Depth)

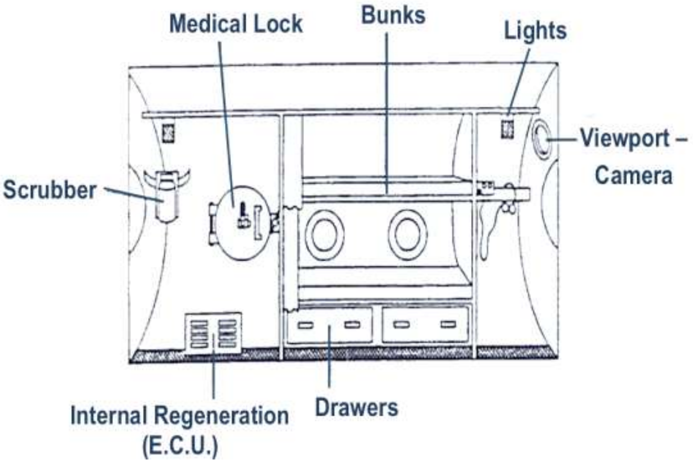


Saturation Chamber (External)

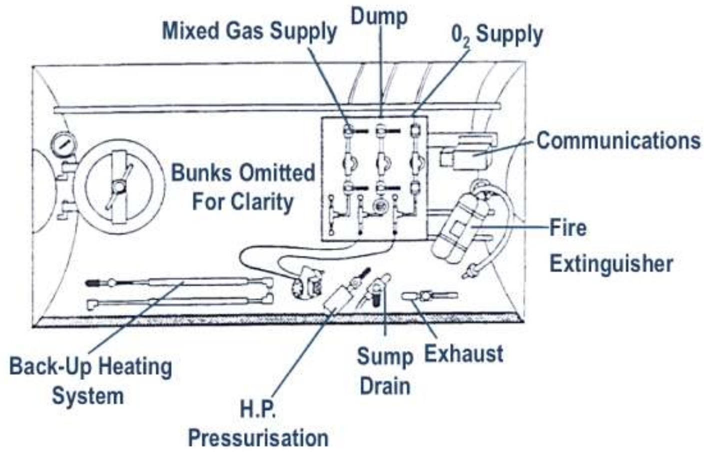


Saturation Chamber (Internal)

Left Side



Right Side



Doors

Most saturation chambers have a trunking at each end and a side or top door, this allowing flexibility of system design and configuration.

With the exception of some one man chambers and food and equipment locks, doors always close from the inside, with the pressure differential sealing the door onto the trunking sealing face.

The seal is made by an 'O' ring in a groove on the face of the trunking, or on the door. 'O' rings should be regularly checked for wear, cuts or gross flattening which does happen over a period of time.

To replace or refit an 'O' ring, grease it with silicon, position it over the groove and locate at points around the groove, e.g. 12 o'clock, 3 o'clock, 6 o'clock etc. Continue to push the 'O' ring in at opposite points around the door until it is in place.

Saturation Chamber Door

The mating faces of door and trunk must meet evenly when the door is closed. If this is not the case, the door can be balanced using the alignment mechanism.

When the door is closed it can be held in place by a strong-back or dogs on the outside. A strong-back that is put on tightly when the Chamber is under pressure may be hard to shift when the Chamber is back on the surface, due to the reduction of internal pressure.

Doors can also be held shut by dogs on the inside. If these dogs can only be controlled from the inside they should not be used. If divers in the Chamber become unconscious it would be impossible to get into them, therefore internal dogs should be removed.

When a door is open it should be held open by a catch to prevent movement in heavy seas. The door should never be tied back when the system is under-pressure as it may have to be closed quickly in an emergency. The ideal solution is for the door to be held in the closed position by a magnetic catch.

Some doors have an equalisation valve. This should be frequently checked and well maintained, since it is one of the few valves on the system, which has no back up on the other side.

The correct positioning of internal system doors is essential to the occupants security and thought should be given to the best configuration, with the main lock internal door routinely in the closed position.

Care should also be taken to position doors correctly when using external regeneration systems set to circulate from one chamber to another as wrongly closed doors will seal causing a pressure shift within the chamber.

View-Ports

Saturation Viewport

View-Ports are usually made of acrylic and are extremely strong but should nevertheless be checked for pitting or damage on a regular basis.

Covers should be made to place over the ports on the outside as external lights can disturb the divers while they are attempting to sleep.

It is not good practice for the divers to put covers over, or tape up the ports on the inside. In an emergency, the LST may need to look in.

One port is usually taken up by the TV camera and ports on top of the chamber can be used for an external lighting system. Frequent examination of the lighting parts is advisable to ensure that there is no heat damage to the acrylic material.

Built In Breathing System (BIBS)

BIBSs are fitted to chambers to allow the divers to breathe a gas mixture different from the chamber atmosphere.

Built In Breathing System (B.I.B.S.)

This may be 100% Oxygen, either for routine decompression or for therapeutic purposes, an O_2 enriched gas for loss of pressure emergencies or a breathable safe gas supply should the chamber atmosphere become contaminated and unbreathable.

These gases are "on line" to the chamber via the saturation control panel at all times so that the diver inside can use his BIBS without external assistance.

Inside the Chamber the BIBS are connected to the gas supply and exhaust by quick connect fittings.

The majority of saturation complexes and chambers use a BIBS with an overboard dump system so that exhaled gases go outside the chamber and avoid contaminating the chamber atmosphere.

The supply is normally reduced in saturation control to about 7-10 Bars above chamber pressure but they may also have a small "bonnet" type regulator fitted inside the chamber.

The exhaust or dump must be fitted with a back pressure regulator inside the Chamber set a few PSI lower than the internal pressure so that the diver is protected from excessive pressure differential.

The BIBS supply is similar to that in an air decompression chamber. There will normally be two supply lines, one for oxygen and rich therapeutic mixes, and another for normal bottom mix.

Valves

All hull penetrations should have a valve on both sides. These are commonly known as skin valves.

If a valve is damaged on the outside it can be closed off on the inside to prevent pressure loss.

Quarter Turn Pressurisation

Pressurisation

The pressurisation line has a quarter turn valve on both the inside and the outside of the chamber and a non-return valve on the inside. There is also a silencer on the inside.

Over a long period of time, dirt may accumulate inside the silencer and restrict the gas flow. In an extreme case the silencer may burst and regular checks are advisable.

Exhaust

The exhaust valve has a quarter turn valve inside and out and is usually fitted with a T-piece or drilled metal tube on the inside to protect the divers against the effects of suction. For reasons unknown, divers have occasionally stuck their fingers in exhaust valves and suffered painful injuries.

There may be two exhaust lines, one for a fast bleed and the other for a fine bleed or a single line which is split at the control panel to give fine and course control.

Depth-Penetrator

If the line to the depth gauge is accidentally closed, the gauge will no longer show chamber depth and will usually show a steady pressure loss as gas leaks from the line.

The surface crew may then add gas to the chamber and cause a depth increase, which will at the very least be inconvenient and may be dangerous.

Small-bore valves are generally used and any leak would be slow, or else a blank drilled with a 1/8" hole is used instead of an internal valve.

Analysis-Penetrator

Like the depth line, the analysis line is usually small bore. On some systems depth and analysis are on the same line. Analysis lines must be regulated at source to prevent over-pressurisation damage to on line analysers.

Toilet Water Supply and Sump Drain Valves

The toilet water supply and sump drain valves should be closed when not in use.

Water Supply

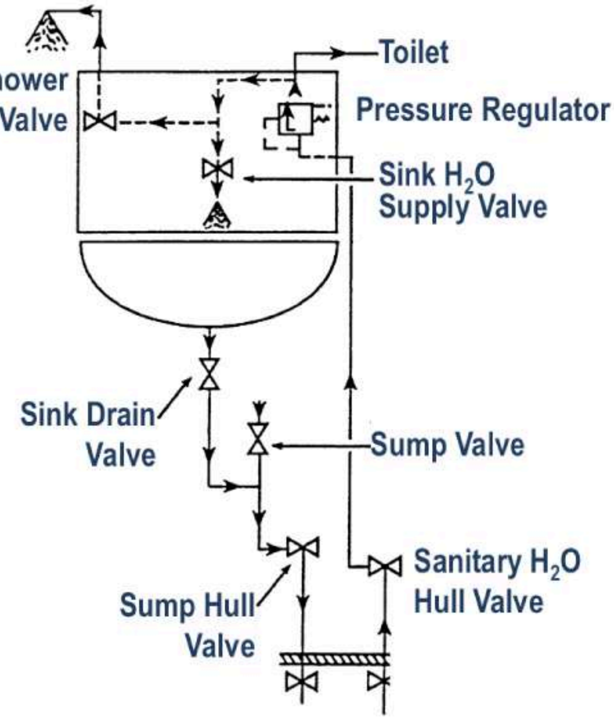
Since the chamber is under pressure, water must be put under pressure to get into the chamber. This may be done with a pump or by using a pressurised water tank. Like all penetrations, water connections are fitted with valves on both sides of the hull.

Sump Drain

The sump drain is a flexible hose or rigid pipe, which extends from a skin valve to under the deck plates. After showering or cleaning the chamber, water is removed from the floor by suction. Both internal and external skin valves are normally closed. As with all chamber operations, good communications with the surface are essential during drainage. The suction is considerable and the diver should keep his feet and fingers clear.

Saturation Chamber Sanitary System

6.6



Toilets

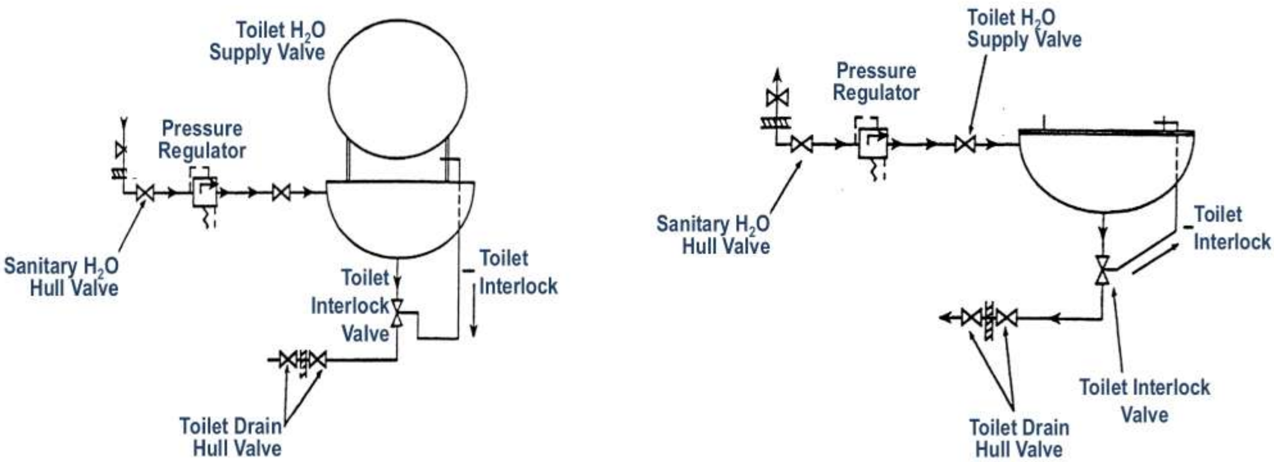
Toilets are carefully designed with interlocking valves, to make sure that the toilet cannot be flushed while it is in use. There may also be internal or external holding tanks.

There should always be a gap between the toilet seat and the toilet bowl to avoid possibly lethal suction effects in the event of a leak.

Flushing the toilet may involve the operation of four or five valves, inside and outside the chamber. The laid down procedure should be followed throughout.

Saturation Chamber Toilet Operation

Step 1 **Step 2**



Medical Locks

Medical locks and the large equipment locks are the only part of the saturation system where doors are locked against the pressure. It makes good sense to keep the internal door closed as much as possible.

You should never operate any lock without checking with saturation control LST's first and the divers should never operate any lock without asking the topside LST.

Every lock should have a pressure gauge, vent valve and interlock on the outside. The interlock prevents the outer door being opened when the lock is pressurised.

Do not overfill the lock. Rubbish or laundry can get sucked into the exhaust valve and block it. Remember to remove the tops from jars and leave holes in any sealed rubbish bags.

Always take the lock off slowly. Dishes of food on the way in may get blown over.

Use of Medical and Equipment Locks

Compression and decompression of locks is carried out as described in the system procedures.

The chamber operator must keep very strict control of every item that is locked in to the chamber.

Medical-Lock

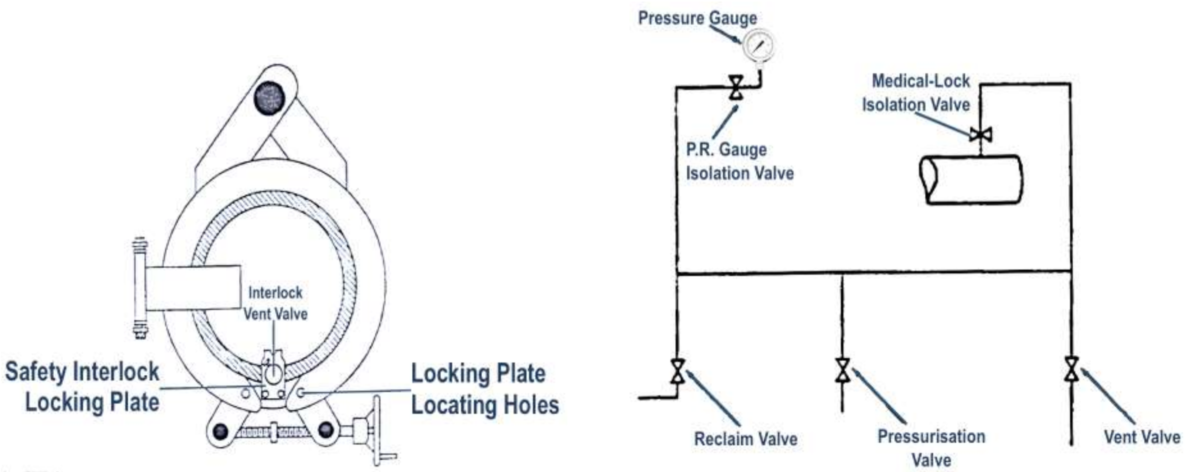
They must examine every item and check:-

- Is it a fire risk?
- Is there a toxicity risk?
- Is there a health risk?
- Is there a risk of explosion on decompression?
- Will it withstand the pressure (implosion)?
- Will it withstand the rate of compression (implosion)?

Three points to note:

- On compression:- Never leave the lock blowing down. Always stand by until the lock has equalised with the system.
- On decompression:- Always stop for a check on the inside door seal before continuing to the surface.
- After use:- Never leave the external door open - always secure the lock!

Saturation Medical-Lock Operation



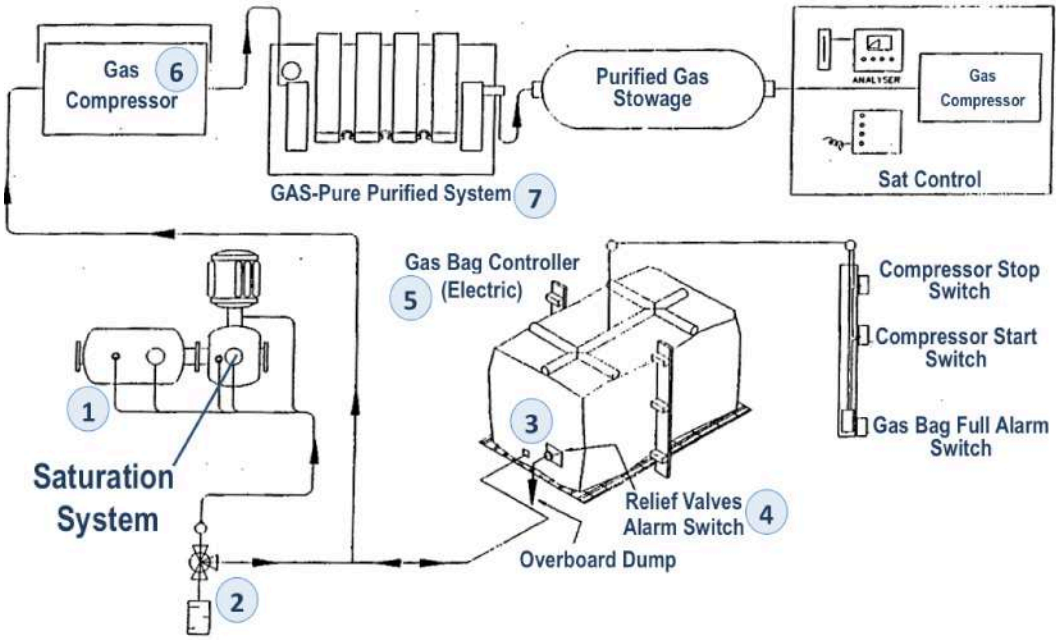
Chamber Gas Recovery Systems

Chamber recovery systems will be operated by the LSTs so a greater knowledge of how these work will be required. The Gas Recovery System fitted to some systems is the Gas Services Gaspure and its basic operation is as follows:

- Gas is routed from the Chamber Exhausts, Medical Locks, Equipment Locks and the Bell Mating Trunk (1) via pressure piping to a 3-way valve (2).
- Note: Low-pressure tubing such as copper or PVC is quite adequate if a suitable relief valve is connected bypassing the 3-way valve.
- The 3-way valve routes gas to atmosphere or the Gas Bag (3).
- **Note:** Gas is not normally recovered at depths less than 66 FSW (20 MSW) due to the high Oxygen.
- Gas would then enter the Gas Bag inflating it until the Gas Bag Level Controller (5A) (5B) turned on the Gas Compressor (6A) (6B). The Gas Bag level Controller would also turn off the Gas Compressor after deflating it to a pre-determined level. The Gas Bag Level Controller can also be of either mechanical (5A) or photo-electric (5B) type.
- Note: The Gas Bag is protected from over inflation by Relief Valves (4) which should be connected to discharge overboard.
- The Gas Compressor would draw from the Gas Bag and discharge into the Gaspure Purifier System (7) where Water Vapour, Particles, Bacteria, Carbon Dioxide, Carbon Monoxide, Hydrogen Disulphide, Sulphur Dioxide, Ammonia, Mercaptans, Nitrous Oxides, Heavy Hydrocarbons, Methane and other Light Hydrocarbons are removed at a Flow rate up to 80 SCFM (136 SCMH).
- **Note:** In fact the purified gas is at least 400,000 times cleaner than the air we normally breathe.

- Gas recovered from the chambers is contaminated with nitrogen. If reclaimed gas is to be used for chamber make up, care must be taken to ensure that the level of nitrogen that is already present in the chamber atmosphere should not exceed the permitted level of 1.5 bar PPN_2 at any given depth or, according to levels of contaminants laid down by diving company guidelines.

Gas Recovery Systems



CHAMBER EMERGENCY TAPPING CODE 6.7

IMCA bell emergency code of communication by tapping signal.

This standardised code has been designed to allow rescue divers to communicate with the occupants of a diving bell stranded or entangled at bottom. It might prove of some value only if the umbilical has been severed and the ultrasonic through water communications are not operating. The code is very basic and designed solely to assess a few factors critical during a rescue. The code is printed on a plastic card. One card must be fixed on a prominent place outside the bell, a second one must be fixed inside the bell.

Emergency Line Signals

These emergency line signals are to be used only in emergency and must be answered and obeyed immediately. These signals must be perfectly known by divers, tenders and Diving Supervisor.

CODE	SITUATION
3-3-3	Communications opening procedure
1	Yes or affirmative or agreed
3	Nor or negative or disagreed
2-2	Repeat please
2	Stop
5	Have you got a seal?
6	Stand by to be pulled
1-2-1-2	Get ready for through water transfer
2-3-2-3	You will not release your ballast
4-4	Do release your ballast in 30 minutes from now
1-2-3	Do increase your pressure
3-3-3	Communication closing procedure

These signals use short and distinct pulls on diver’s umbilical.

Signal	Bellman	Diver
Succession of pulls	Standby diver on his way	Emergency - I need assistance
4 pulls	Come back to bell	Coming back to bell, or Pull me back
3 pulls	Go down	Going down, or Give me some slack
1 pull	Stop	Stop

Section 7
Life Support

CHAMBER CHECKLISTS 7.1

All offshore dive systems must have a documented procedures and checklists file to provide a standard for pre-dive bell and chamber safety checks. It is the responsibility of the Dive Supervisor to ensure that this detailed list of pre-dive checks is available and the duty of the Life Support Supervisor to ensure their implementation. Chambers will vary in their valve and fitting configurations so the following is a guide only.

Internal Checks - Before The Dive, Ensure That:-

- The internal lights are operational.
- The communications, both electrical and sound powered if fitted.
- Internal scrubbers, if fitted, are operational.
- If external scrubbers are fitted, check the operation of the flow fuses or any flow cut off device and ensure that there is adequate flow to ventilate the chamber.
- The number and operation of the BIBS is correct.
- All O-rings in the doors, manways and medical locks are fitted correctly and are lubricated with a smear of silicone grease.
- The bilge is clean and dry.
- The valve checks have been completed.
- The view ports are clear of obstruction.

External Checks - Before The Dive, Ensure That:-

- The valve checks have been completed.
- The supply hoses are in good condition.
- The main gas supply is connected with the analysers on line.
- The secondary gas supply is on line and regulated.
- The oxygen supply quad is on line with the pressure regulated at the quad.
- There is sufficient oxygen to undertake a full DCS treatment table and the normal decompression.
- A stopwatch is at the control panel (bounce dive only).
- If fitted, check operation of external scrubbing units taking care that all valves are in the correct position. Note: Extra care should be taken with crossover valves.

Chamber Operations

- Take all precautions against fire.
- Provide fire extinguishers.
- Use fire retardant paint and materials in the chamber.
- Ventilate the chamber according to specified rates and gas mixture.
- Ensure proper decompression of all personnel entering the chamber.
- Ensure that the chamber and its auxiliary equipment are in proper operating condition at all times.
- Ensure that all relevant personnel are properly trained in the operation of the equipment.
- Prepare the chamber for immediate re-use following a treatment.
- Never use oil on any oxygen fitting or equipment in oxygen service.
- Never allow gas supply tanks to be depleted or reach low capacity.
- Never allow damage to door seals and dogs. Use minimum force in "dogging down".
- Never leave doors dogged after pressurisation.
- Never allow open flames, matches, cigarette lighters or pipes to be carried into the chamber.
- Never permit electrical appliances to be used in the chamber (other than the intrinsically safe chamber equipment e.g. scrubber, heater and lights).
- Never permit products into the chamber which may contaminate or off-gas into the chamber atmosphere.

CHAMBER MONITORING 7.2

The Life Support Supervisor (LSS) is responsible for controlling the internal environment of the compression chambers. This involves the establishment of the correct depth, oxygen, carbon dioxide, temperature and humidity levels, then the maintenance of these levels within the recommended ranges to provide a comfortable environment for the occupants.

Time 7.2.1

Accuracy is necessary when carrying out life support procedures. A suitable clock in saturation control should be supplied and set to read the time which is common throughout the vessel.

Depth 7.2.2

Analogue gauges, and frequently transducer digital depth readouts, are provided to indicate chamber depth. These are very important instruments, which must be calibrated or checked at six monthly intervals by a competent instrument technician. It is also necessary to have a high and low alarm system, which gives warning of a depth change out with the pre-set parameters.

Oxygen 7.2.3

Very strict control of the oxygen levels must be maintained.

The reasons for this are:-

- To provide for the diver's bodily requirements.
- To avoid hypoxia.
- To avoid oxygen toxicity (hyperoxia).
- To maintain the effectiveness of the decompression schedule.
- To minimise fire hazard.

Company procedure will specify the required levels of oxygen to be maintained at the various stages of a dive.

For any particular depth, different levels of oxygen may be specified for:-

- The DDC when at living depth or during decompression.
- BIBS, for therapeutic purposes.
- The diver's breathing supply during diver lockout.
- The bail-out gas supply.

Oxygen must be carefully added to the DDC to maintain the correct levels. Special care must be taken to ensure good mixing of the oxygen and that all fire hazard precautions are taken. The chamber oxygen should never exceed 25% volume. The rate at which additional oxygen will be required will depend on the number of divers and their levels of physical activity. Some systems have automatic oxygen make up systems. Under normal conditions these work very well, but they must be monitored closely. If not, and a problem develops, then very high oxygen levels can occur. In some situations, when a life support system is switched off for instance, then the automatic oxygen system must be switched off.

In General, Raised Partial Pressures Of Oxygen Can Have Advantages Including:-

- Faster decompression times.
- Reduced DCS incidence.
- Greater tolerance to sudden loss of gas supply.
- Higher percentages give more accuracy when monitoring at depths greater than 300 m, when the percentage becomes very low.

But Upper Limits Are Imposed Because:-

- Oxygen poisoning can occur.
- An increased fire hazard may arise at depths shallower than 50 m.
- A reduction in oxygen tolerance will occur if the diver has been subjected to levels higher than normal. This may affect any therapeutic procedures from effectively being carried out.

Carbon Dioxide 7.2.4

Carbon dioxide must be kept at very low levels for the comfort and safety of the divers.

The DDC CO_2 level should normally be kept below 10 mbar (some companies have an upper limit of 5 mbar), whilst a slightly higher level of 20 mbar may be accepted for shorter periods spent, say, in the diving bell. If the level exceeds 50 mbar then BIBS or an oral-nasal CO_2 scrubbers should be used by the divers until the level return to normal.

Temperature 7.2.5

Because of the high thermal conductivity of helium, chamber temperatures during a heliox saturation must be kept higher than it would be in air, normally around 28-32°C depending on depth. As depth increases the comfortable temperature range narrows to ± 1°C at around 300 metres.

The most important factor in chamber temperature control is the comfort of the diver and great care is required not only to maintain this comfort, but also to avoid danger of both overheating (hyperthermia) and cooling (hypothermia). Emergency procedures are required to cater for the accidental occurrence of both these conditions.

The temperature of inspired breathing gas of a diver in the water also becomes increasingly important as depth increases, as respiratory heat loss when breathing heliox can be a big problem in deeper diving. Thus regulations require special gas heating equipment to be provided for the diver at 150 metres and deeper. Special care should be taken to ensure the gas supplied to the diver is not too hot as this can lead to the diver becoming hyperthermic. Diver suit heating is required by regulations at 50 metres and deeper.

Chamber temperature recording is normally by means of an internal temperature sensor, which relays a signal to an external readout.

Humidity 7.2.6

Humidity levels in the saturation chamber are important for a number of reasons. If it is too dry then respiratory irritation results, and in addition the effectiveness of the carbon dioxide scrubber is reduced. If it is too humid the growth of harmful bacteria within the chamber is enhanced threatening the fitness and health of the divers (see section on hygiene). It is desirable to maintain a relative humidity level of between 50 and 70%, ideally at around 55%. Relative Humidity (R.H.) is a measurement of vapour present in a gas relative to the maximum amount that can exist in that gas at that temperature, e.g. 50% Rh at 30°C means that the gas is holding 50% of its capacity at that temperature.

If the temperature drops to 25°C then the gas can hold less water in vapour form. Therefore, if the water content has remained the same then as the temperature drops the RH increases. If the temperature continues to drop then at some point the RH will reach 100%, i.e. at that temperature the actual water content equals the maximum amount possible. A temperature drop below that point (called the dew point) results in the water vapour condensing thus forming a mist in the chamber. This occurs only in large rapid de-pressurisations, e.g. surfacing of bells.

The RH Is Measured Using:

- Mechanical means - a hair hygrometer, which relies on the expansion and contraction of either natural horse-hair or some synthetic equivalent, in response to humidity levels. The amount of stretch is converted mechanically to give a read-out on a 0 to 100% gauge. This is an adequate means of recording RH, is inexpensive and gives a direct readout, but the response time is slow and accuracy is less than perfect. Some have calibration controls, which is an advantage over the ones with pre-set calibration.
- An electrochemical sensor within the chamber, which relays a signal to an external readout. These are obviously much more expensive but accuracy is improved greatly and response time is rapid.

LOG KEEPING 7.3

The LST probably consumes more time carrying out this task task LST than all the other tasks combined. While it might seem to be sheer drudgery, the log itself can be important in the event of a medical problem and it should be kept as complete and as accurate as possible.

Parameters to be Recorded

- Chamber
  - All compartments of a chamber complex should be recorded. This information should preferably be recorded on one sheet per day, alternatively a log book for each chamber can be kept. However, this can cause confusion when trying to recover information as more paperwork is generated.
- Date
  - This should be noted at the top of each page and whenever it changes.
- Time
  - Twenty-four hour clock is the preferred method of watch keeping as it helps prevent confusion.
- Depth
  - Either msw or fsw depending on decompression table being used and gauge scale. It should be indicated in the column heading.
- Oxygen
  - As a percentage or partial pressure, or both, depending on the diving company policy. The partial

pressure is preferred for saturation while percentage is usual for bounce. The method should be indicated in the heading on the recording sheet.

- Carbon Dioxide
  - Normally as a partial pressure in mbar or as a surface equivalent concentration in either percentage or ppm.
- Temperature
  - Recorded as either °C or °F, there is no reason for preference, scale should be indicated although it is normally obvious.
- Relative Humidity
  - A percentage figure.

When to Record

As a general procedure the entire range of parameters for each chamber and/or lock should be recorded every 30 minutes or 60 minutes, depending on company requirements. This is especially important during saturation storage and continuous ascent decompression routines.

Other Items That Should Be Recorded Along With Time, Depth And Chamber Are As Follows:-

- The start and completion of each change of pressure.
- Medical lock usage.
- Reports by the divers concerning their condition.
- Transfer of the divers to and from the SDC, hyperbaric lifeboat, or fly-away chamber, including the diver's names (or team number for bell runs).
- Medicines given to and used by the divers, including the diver's names.
- Changing of CO_2 absorbents.
- Draining of the dehumidifier, including chamber.
- BIBS usage including divers involved, gas mixture they are being supplied with and the chamber.
- Details of any treatment routine to be followed in the event of a medical problem or decompression sickness.
- Cleaning of the chamber.
- Any other appropriate comments.

TRAUMA TRAINING

Chamber Log

Vessel:				**Location:**			**Date:**
Date	Time	Depth	ppO_2 (Mb)	$ppCO_2$ (Mb)	Temp (ºC)	Rh%	Comments

GAS CONSUMPTION MONITORING 7.4

There are two primary reasons that the rate and amount of gas usage must be monitored. First, the amount used is a necessary piece of knowledge as the client is usually charged for purchase gases (helium, helium-oxygen mixtures, oxygen) as an agreed consumable. Secondly, it is necessary to know when and how much gas to re-order.

Reporting 7.4.1

To Diving Superintendent

The Diving Superintendent should be informed on a day-to-day basis of the amount of the various gases used, the amount remaining, and the amount left before the reserve stocks are reached, (both quantity and approximate amount of diving that it permits).

To the Client

If it has been agreed that the Client's representative will receive a periodic report of gas consumption, this will be reported to him via the Diving Superintendent. This can be daily, weekly, fortnightly or monthly.

Information Transmitted To The Client Should Include:-

- Volume of each gas at the start of the period.
- Amount of each gas delivered during that period.
- Volume of each gas at the end of the period.
- Total amount of each gas used.

To the Company Office Responsible for the Diving Operation

A Weekly Report Indicating:-

- Daily gas consumption.
- Gas delivered, including:
- Cylinder / quad / trailer / skid, ID and pressure, bill of loading / delivery note, and date of receipt.
- Cylinders/quads / skids / trailers returned including:
- ID, pressure, receipt signed by remover, and date of return.

A sample weekly reporting form is shown overleaf.

Weekly Gas Status Report

Vessel:	**Location:**	**Week Ending:**
Client:	**Date:**	**Senior LST:**

Gas	Initial Volume M^3 or Ft^3	Volume Consumed (M^3 or Ft^3)							Delivered (M^3 or Ft^3)	Volume Available (M^3 or Ft^3)
		MON	TUE	WED	THU	FRI	SAT	SUN		

Gas Deliveries				Gas Returns			
Date	Identity	Pressure (Psig / Bar)	Volume M^3 or Ft^3	Date	Identity	Pressure (Psig / Bar)	Volume M^3 or Ft^3

Comments:

WATCH HAND-OVER 7.5

Watch hand-over is one of the more important occasions in all Life Support personnel's shift. This is because information regarding changes in decompression routine, equipment function, diver well-being, etc., can be forgotten and thus not passed on to the next shift. As a result, a Watch Hand-Over Log should be used. These forms should become part of the permanent chamber log, although the importance attached to hand-over notes varies considerably between companies.

Watch Hand-Over Log Requirements 7.5.1

There are several key areas that a watch handover log should require.

These Include:

Identification

- Vessel, location and contract number.
- Date and time.
- LSTs names, (both going off shift and coming on).

Decompression

- Depth at the end of the shift of each chamber.
- Time of the next move - either running time or 24 hour clock time.
- Rate of decompression - most important if a continuous ascent routine is being used.
- Changes to schedule.

Excursions

- Time of the next excursion or dive.
- Divers going on excursion.
- Depth of excursion or dive - is storage depth sufficient?
- Special supplies required inside SDC.

Gases on-line

- Percentage oxygen and balance gas.
- Pressure.
- Gas mix supplied to BIBS in each chamber.
- Changes to gas supply status during the watch.

Status

- Status of the divers.
- Comments on each diver.

Messages

- Formal messages regarding elements that are not covered in other areas.

Comment on Completed Watch

- Status of the watch.

Signature

- Signature of the LSSs (going off and coming on).
- This must also be dated.
- This makes the handover sheet a legal document.

SUGGESTED LIFE SUPPORT TECHNICIAN HAND-OVER LOG

Date: ____________ Time:____________hrs LST going off: ______ _____

Vessel: ____________ Contract: ____________ LST coming on: ______ _____

Location: ___________________________________ PRINT SIGN

Status of divers (Name) (Comment)

________________________ ____________________________________

________________________ ____________________________________

________________________ ____________________________________

________________________ ____________________________________

Depth at end of each watch (msw/fsw): ____________________________________

Time of next move (dive time/24 hr clock): ____________________________________

Rate of decompression: ____________________________________

Changes to decompression schedule: ____________________________________

Time of next excursion/dive: ____________ Divers: ________________________

Depth of excursion dive: ____

Special SDC supplies required: ____

Gases on Line: LINE ID	Gas Composition	Pressure
______________	______________	__________________
______________	______________	__________________
______________	______________	__________________
______________	______________	__________________

Changes to gas supply status during watch: ______________________________

____

Messages: ____

____

Comments on completed watch: ____

____

GAS COMPOSITION 7.6

Air Saturation

Chamber gas should be kept as close as possible to the normal composition of atmosphere air unless company procedures dictate a different arrangement.

Heliox Saturation

- **Oxygen:**
  - Storage depth levels vary with companies between 0.35 bar (350 mbar) and 0.45 bar (450 mbar).
- **Nitrogen:**
  - There is a difference between companies to how this should be read - some as a percentage, others as a partial pressure.
  - Excessive Nitrogen in a heliox saturation will affect the excursion and decompression tables at levels well below those at which toxicity problems become apparent.
  - When using premix gas there will not be a problem with nitrogen levels in saturation but when a reclaim system is in operation, nitrogen levels in the reclaimed gas can be instrumental in raising the chamber nitrogen levels above the desired levels.
  - It is important to be aware of the composition of the gas in use and to keep the chamber nitrogen levels below the limits issued by the company.
- **Carbon Dioxide:**
  - The maximum level of carbon dioxide allowable in a saturation chamber, again, vary with company procedures, but are normally taken as 0.01 bar or 10 mbar.
- **Helium:**
  - Remainder
- **Relative Humidity:**
  - Between 50-70% RH is the range most comfortable to the diver.

Heliox-nitrogen Saturation (Trimix)

As above, except that the nitrogen content will be specified either as a percentage of the volume or a constant partial pressure. If a percentage, then ± 0.5% should be achieved. If a partial pressure then ± 0.1 bar.

CHAMBER ENVIRONMENT 7.7

Temperature Control 7.7.1

Chambers

The temperature in the chamber is maintained at a comfortable level for the occupants by use of a temperature regulated gas heater within the regeneration system.

The wearing of light clothes (track suits/overalls) in a chamber environment is not uncommon and the controlled use of heat can help in maintaining a comfortable living environment.

Chamber Heating Failure

When there is more than one chamber, the DDC heating supplies to each chamber are usually cross-connected in case one should fail.

If emergency heaters are fitted within the chamber they should be switched on. Extra blankets and "woolly bears" may also be provided.

Bells

The requirement to maintain a thermal balance in deep diving operations cannot be over emphasised. The diver using heliox is always open to the effects of hypothermia (heat loss). 85% of heat loss is through the respiratory system whilst 15% is through skin diffusion.

Humidity Control 7.7.2

Chamber gas should be kept between about 50% and 70% relative humidity. Prolonged periods outside this range can cause respiratory problems. A high atmospheric humidity will reduce a diver's tolerance to ambient temperature changes and increase the risk of infections.

Humidity Can Be Controlled By Various Means:-

- Externally mounted refrigeration and heating plant which operate a dehumidifier - as in habitat conditioning unit.
- Externally mounted absorption as in regen's - chemical units.
- Silica gel in internal emergency scrubber or in the actual habitat conditioning units. Care should be exercised in this since use of this method restricts CO_2 elimination.

Humidity / Evaporation

Dynamic equilibrium in gas and rate of evaporation which will take place is governed by:-

- The temperature of the liquid - a greater temperature will increase the rate of evaporation.
- The temperature of the gas - a high temperature will increase the capacity of gas to hold vapour.
- The pressure of the gas - a greater pressure will increase the density of the gas molecules present and thus reduce its capacity to contain water vapour.

A gas saturated with water vapour can become supersaturated, or partially saturated gas can become saturated by:-

- Increasing the pressure of the gas (e.g. collection of water in a compressor).
- Lowering the temperature of the gas (the temperature to which a partially saturated gas must be lowered to become supersaturated is known as the Dew point).

Humidity is the presence of water vapour in a gas. Humidity can be measured in two ways:

- Absolute Humidity - the mass of water per unit volume of gas (gm/m^3).
- Relative Humidity - the ratio of the amount of water vapour contained in gas to the amount that could be present at the temperature and pressure, if the gas was saturated (as a percentage).

The main problem with controlling humidity is keeping the level down. Apart from the use of dehumidifiers, care must be taken by the divers within the DDC to avoid unnecessary increases in humidity.

This Includes:-

- Keeping wet equipment from the bell separate from the DDC.
- Prudent use of the shower.
- Regularly checking the DDC bilge for water and draining as necessary.

Noise Control 7.7.3

On systems which conduct a continuous dive programme, it is likely that there will be a dive team asleep in the chamber at all times.

It must be remembered that noises from outside the chamber may be transmitted throughout the system. Any excessive lock noise or banging noises must be avoided.

Anything which disrupts the sleeping pattern of the occupants can affect their physical and mental well-being and possibly their performance and safety in the water.

Boredom Control 7.7.4

Long saturation decompressions are inevitably boring, and in some respects the diver's personality will have to be such that he is prepared to live in a confined space over a number of days or weeks with the other chamber occupants. In many ways this can be one of the most challenging aspects of saturation diving.

Games, books, and newspapers have traditionally helped to pass the time. In recent years the topic of in-chamber electronic devices have become a real issue.

Many companies allow the use of tablet devices (such as iPAD's / Galaxy's) inside the chamber. The use of these devices can be life changing for the divers due to there ability to store massive amounts of multi-media entertainment and connect to the outside world via a wi-fi connector. Their use is strictly controlled by each individual companies SOP's. Many devices have the theoretical risk of creating a fire in a hyperbaric environment due to lithium battery rupture/off-gassing. So there use should be under strict guidelines.
The diver may tend to become very critical of the surface attendants, food and general amenities

This is a common phenomenon whenever bodies of men are forcibly isolated for a period of time.

If the surface crews are properly trained, they are able to pre-empt these 'tantrums' by providing a stimulating / varied environment. Modern saturation systems are now equipped with cinema equipment, mood lighting and internet enabled keyboards with external monitors.

GAS CONCENTRATION 7.8

Oxygen

Oxygen is required to support life. The dangers of excess O_2 (hyperoxia) or too little O_2 (hypoxia) must be taken into account when planning any dives. As must be appreciated, the percentage O_2 in any diving mix must be reduced with increasing depth, whilst maintaining the partial pressure of oxygen at the required level.

Normal diving parameters fall within 0.5 - 0.9 bar absolute, and for saturation the habitat environment falls between 0.35 - 0.45 bar absolute, whereas the therapeutic gases usually fall within 1.5 - 2.8 bar absolute.

Whilst care should always be used in maintaining the correct pO_2 in the complex when personnel are in storage, equal care should be given to correct pO_2 during decompression.

Carbon Dioxide

CO_2 content in the hyperbaric complex should not exceed 10 mbar. CO_2 content in the bell should not exceed 20mbar or, in an emergency, 30 mbar.

CO_2 is usually maintained at an acceptable level in both types of environment. In addition to standard equipment, most hyperbaric complexes in use today have an additional back-up scrubber, which is a small electrically-driven fan which pushes the chamber atmosphere past a CO_2 absorbent (soda sorb or equivalent).

CO_2 poisoning causes a snowballing effect on the respiratory system. It induces the bodily requirement to breath quicker, which becomes instrumental in producing CO_2. It is therefore necessary to have continuous CO_2 monitoring on any hyperbaric complex or bell. Should this system fail, the use of CO_2 tubes gives a reading,which can be worked with.

Failing all this, the absorbent should be changed at half the time interval previously in use, and personnel continually monitored.

DIVER DECOMPRESSION 7.9

The availability of decompression schedules is the direct responsibility of the diving company. Diving tables including decompression schedules, therapeutic schedules and emergency schedules are to be approved by the Secretary of State under the provisions of the relevant Diving Operations Regulations. As has already been discussed, a careful monitoring of the divers' environment should be made at all times.

The correct PO_2 should be maintained throughout the actual decompression. It is common practice to slowly build up the O_2 prior to a move, so full benefit of the enriched atmosphere can be achieved by the personnel at the next stop.

It is important for systems using automatic injection in the living chambers only, that any connecting chambers are manually built up to the required PO_2 level.

When adding O_2 to the system care should be taken to ensure that the maximum percentage tolerance is not exceeded prior to the move. Adding oxygen should be at a controlled nature, i.e. 15 seconds, 30, 45 and 60 second bursts (modified to suit the system in question), ensuring that adequate homogenisation occurs. At no time should the O_2 percentage in the chamber exceed 25%.

Decompression Schedules 7.9.1

The majority of diving companies classify their decompression schedules as commercial in confidence. Schedules available for general use are those supplied by CIRIA and those available in US Navy publications.

Abort Schedules

These are used in the event that a saturation dive has to be terminated early.

Emergency Schedules

When conducting short duration dives, emergency schedules must be available for the dive that runs over time, e.g. transfer to saturation.

Therapeutic Treatment

The recommendations for therapeutic treatment tables has been drawn up by the Undersea Biomedical Society in conjunction with the AODC.

Material requirements are:-

- Copy of the recommendations.

- USN or RN therapeutic tables.

In any case of difficulty a doctor, qualified in underwater medicine, should be consulted. Additional advice may be obtained from the authorities listed in the HSE's Diving Safety Memorandum.

ENVIROMENTAL CONTROL 7.10

Oxygen, carbon dioxide, temperature and humidity must be maintained within specific limits during saturation. This may be done by an internal or external environmental control unit (ECU) or regeneration system.

In most modern systems the chamber gas is first passed through a soda lime filter to remove carbon dioxide then over cooling coils, which drop the temperature sufficiently to cause condensation and extract the moisture. The gas is finally re-heated before being re-sent back into the chamber. Trace gases and odours are removed by purafill or activated charcoal in the soda lime filter.

Oxygen is added to the system close to the circulating pump to ensure adequate mixing. Some older systems use silica gel as a drying agent instead of cooling coils.

Internal systems are compact and requre only a low power fan to circulate the gas. They are, however, awkward to maintain under pressure and divers may have to be woken to change soda lime filters.

The cooling and heating systems are located outside the chamber where cold and hot fluid is circulated by an external pump.

This fluid flow is often used to drive the circulating fan inside the chamber.

External systems require large pressure vessels to contain the filters and cooling and heating plant and require large bore piping and powerful pumps to circulate the gas.

Maintenance and filter changes are easy. Inlet and outlet valves for external systems are usually about 2 inches (50mm) internal diameter. The inlet valve is fitted with a non-return valve on the inside. The outlet valve is fitted with a flow-reducing valve.

This valve is designed to close if the flow rate exceeds a certain level, as it would if the pipe was broken externally.

Internal carbon dioxide scrubbers are provided in the chamber in case the main environmental control unit fails. They may also be used to assist mixing of the chamber atmosphere during pressurisation.

Enviromental Control Units 7.10.1

The physical and mental well being of diving personnel under pressure is of prime importance, since any deterioration of the physical or mental state of personnel could result in an accident which otherwise could have been avoided. It is therefore extremely important to maintain the chambers in an environment, which is both relaxing and as comfortable as possible.

Two types of units are at present in general use offshore which fulfil these requirements. Each uses a different method of achieving the same end. One by controlling the chamber environment from inside; the second by removing the chamber atmosphere, and correcting it then re-introducing it back into the chamber in a continuous cycle.

Environmental Control System (Method Number One)

This consists of two major assemblies, the Control Master Unit (CMU) which provides fluid for temperature and humidity control and the Habitat Conditioning Unit (HCU) which translates the fluid input into heating, cooling, gas circulation CO_2 removal and dehumidification functions.

Control Master Unit

The Environmental Control System (ECS) uses a 50/50 water/glycol mixture to control habitat temperature. The fluid exchanges heat with the breathing gas thereby heating or cooling chamber environment as required. The ECS will not rapidly change temperature. Thus no sudden uncomfortable blasts of hot or cold gas will be experienced.

Primary fluid temperature is controlled by two control valves. These valves mix hot or cold fluid to provide the required temprature. For an increase in temperature, the valves allow more fluid to pass through the condenser and, if required, a supplemental electrical immersion heater is activated if the fluid is too cool. If a decrease in breathing gas temperature is required, fluid will pass through the second evaporator. If neither heating nor cooling is required, the valves allow fluid to bypass both condenser and evaporator.

Temperature control valves are controlled by actuators, which are attached to the valve bodies. The actuators are moved by electrical signals from a temperature sensor in the habitat and temperature control potentiometer on the control panel.

Fluid in the temperature control system (primary pressure) is pumped at high pressure by the primary pump. The pump is belt driven by an electric motor. A pressure gauge is provided on the CMU to monitor primary system pressure.

If secondary fluid cooling is required, the valve allows fluid to pass through the first evaporator. If fluid cooling is not required due to the humidity of the breathing gas being at or below the required level, fluid will bypass the evaporator.

The humidity control valve is controlled by an actuator that is attached to the valve body. This actuator is moved by signals from the humidity sensor in the habitat and humidity control potentiometer on the control panel.

Fluid in the temperature control system (secondary pressure) is pumped at low pressure by the secondary pump. The pump is belt driven by an electric motor. A pressure gauge is provided on the CMU to monitor secondary system pressure.

Habitat Conditioning Unit

This is situated inside the chamber and consists of a temperature and humidity section and a containment scrubbing section (normally CO_2 removal).

A fan is driven by the primary gas supply, circulating the gas through the Unit.

The unit splits the gas, allowing a portion to go through the scrubber and the rest to go through the dehumidification and reheat section.

Condensate normally drops into the chamber sump or else can be collected into a container, which aids sump draining.

The O_2 adds system on these internal units should terminate by the outlet of the HCU.

External Regeneration System

This consists of a remote regeneration unit linked to the chamber system by means of two hoses - the supply and return lines.

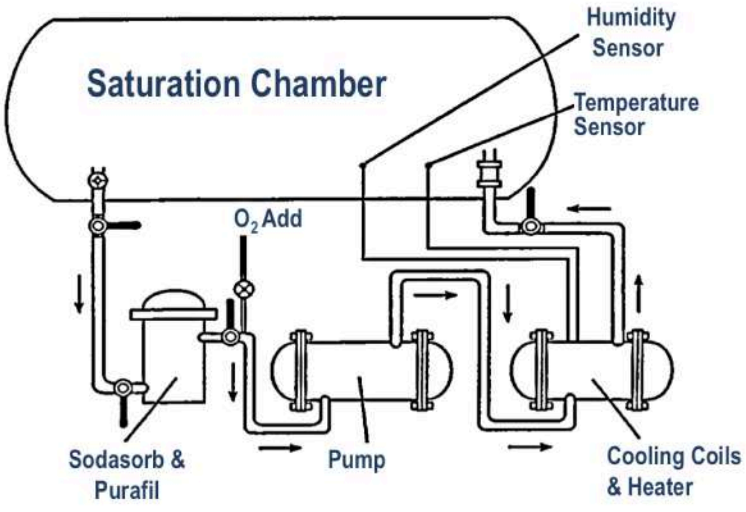
Because the gas is being circulated at chamber pressure the regeneration system must have a pressure rating comparable to the chamber system.

The chamber gas is circulated through the regeneration unit by means of a pump, which may be adjusted to alter flow rates, and then returned to the chamber in the required condition.

CO_2 removal is normally first in line so that the chamber gas goes through sodasorb (or equivalent) before the humidity has to be adjusted. If the gas is too dry, the sodasorb reaction will not occur and no CO_2 will be absorbed.

Humidity is controlled by either the use of a drying agent, e.g. silica gel, or by using condenser coils. Regulation may be manual using a bypass valve to alter the proportion of gas passing through the drying filters, or else by electrical control of fluid in the condenser.

EXTERNAL REGENERATION SYSTEM



A gas heater, last in line, heats the gas before it returns to the chamber.

The chamber internal pressure is used to regulate the gas heater setting to compensate for heat loss in the return hoses.

Oxygen injection takes place at the regeneration unit, to maintain chamber levels and ensure mixing.

CHAMBER HYGINE 7.11

Since the upsurge in saturation diving it has become routine to have diving complexes and the divers within, held under pressure for longer periods of time The life support systems on these saturation work sites will control the chamber parameters of temperature, humidity, O_2 and pollutants to provide and maintain a comfortable environment for the diver. Unfortunately, when the internal environment is at its most comfortable for the diver, it also provides excellent breeding conditions for bacteria.

These ideal conditions combined with the confinement and close contact of personnel within chambers, promote the growth of bacterial colonies and increases the risk of infection and subsequent cross infection.

In order to minimise these risks a strict regime of personal and chamber hygiene must be followed.

Personal Hygiene 7.11.1

It is important for divers under pressure to maintain a high level of personal cleanliness to reduce the risk of infection. It is important to shower daily paying special attention to those areas of the body that are more likely to promote bacterial growth, i.e. the axillae (armpits), groin, navel and between the toes. Ordinary toilet soap is adequate but the use of a bactericidal soap is preferred by many divers. There are some simple principles for in chamber personal administration.

These Are:

- Always use a clean towel for each shower.
- Hands should, as always, be washed after visits to the toilet or before having meals.
- Change bed linen every 2-3 days.
- Always renew bedding when swapping bunks.
- Ideally use two, personal towels - one for the head and one for the body, and change them daily.
- Never swap head sets.
- Change clothes daily, passing dirty clothes out for cleaning (in well marked bags).

Ear Infections

External ear infection has been a severe problem in saturation diving in the North Sea. The unique environment of the saturation chamber favours the replacement of the normal GRAM positive flora of the ear canal with opportunist GRAM negative bacteria, mainly enterobacteria and *Pseudomonas aeruginosa* (PYO), the latter especially is associated with very painful external ear infection.

It is important that divers entering saturation are free from infection. Divers should be swabbed 24 hours before pressurisation to confirm they are free from infection. Once under pressure the divers ears should be swabbed once or twice weekly.

Whilst under pressure, divers use, systematically, prophylactic (preventative) ear-drops, normally a propriety mix of aluminium acetate in 2% acetic acid called *OTIC DOMEBRO*. These are effective by altering the ear canal environment to make it less attractive to the infecting bacteria.

Standard Approach to Ear Hygiene:

- Follow company S.O.P's with regard to ear care (each company can have very different policies).
- Use prophylactic ear-drops as instructed if issued.
- Do not insert anything into the ear canal, or rub or scratch the canal as this will remove the protective layer and irritate the tissue beneath.
- Preventative drops should be used from the onset of pressurisation to the completion of decompression if used.
- Observe for signs of infection (pain / discharge / swelling).
  - If signs present, swab the ear canal & send for culture & sensitivity.
  - Inform medical staff if signs present & follow instructions.
  - Avoid diving.
  - Pain-killers can be taken in extreme cases but care must be taken not to mask any bend symptoms during decompression.

Skin Infections

There have been periodic outbreaks of skin infections in saturation work sites, which can be difficult to control. Any small cut or abrasion in saturation can become infected so it is important to clean and cover any injury.

In the event of an injury becoming infected it is preferable to identify, by swabbing, the bacteria involved so that treatment can be successful.

When the infection is in an area, which is liable to come into contact with shared equipment, e.g. band masks, oral nasals, then great care must be taken to avoid any spread. This includes the cleaning and disinfecting of equipment, e.g. O/N, hoods, between dives as these areas harbour bacteria.

If the fitness to dive of the other divers in saturation is put in jeopardy, a decision must be made by the Superintendent and his medical support, as to whether the infection is to be treated in saturation or the infected diver has to decompress.

Notes on Swabs

When sending swabs into divers, ensure that each swab is clearly marked with Chamber Number, swab site (i.e. name and (L) or (R) ear if for personnel, or with toilet, deck plate, etc., for system swabs). Ensure that the swab seal is intact and then puncture the swab tube with a small hole at the handle end. This stops the tube compressing on lock pressurisation and separation of tube from swab on lock decompression.

If the swabs are to be sent to the laboratory for culturing and analysis make sure that arrangements have been made to collect the swabs and transport them to the bacteriology labs as soon as possible. Package the swabs securely and label the package.

The results should be transmitted by fax within 48 hours although confirmed Gram (-ve) results are indicated by telephone immediately and confirmed by fax as before.

Chamber Hygiene 7.11.2

It does not take long, normally 4 to 5 days, before the introduction of GRAM negative bacilli in the wet pot areas and unless action is taken the contamination will become widespread throughout the system. It is virtually impossible to eliminate bacterial growth within the system but regular cleaning will keep contamination to a minimum. Cleaning and disinfecting throughout the system is essential but for obvious reasons the toilet and shower areas are especially important.

Ideally the wet pots should be completely cleaned daily, and the whole area disinfected. Special attention should be paid to the more likely problem areas such as the toilet bowl, wash-basin, shower head, shower tray and deck plates. Each chamber which has a toilet bowl will require a supply of disinfectant to be present at all times. It is important for the divers to use the disinfectant after every use of the toilet and washbasin.

Living chambers are less likely to become badly contaminated and require only weekly cleaning unless swab results or infection demands otherwise. It is important in living chambers, especially those with internal regeneration, to drain any condensate from below the deck plates.

Susceptible areas e.g. the toilet bowl, wash basin, shower head, shower tray and deck plates should be swabbed on a regular basis, as should samples of the fresh water supply to the chamber.

Chamber Cleaning

Only use the recommended detergents. They are used to break down greasy matter such as spilt food, etc. Preparations such as green soap, Savlon, etc., are useless in the control of pseudomonas aeruginosa and other pathogenic organisms.

For a long time the most widely used cleaning agents used offshore were *Panaclean* and *Panacide*. However they are unpleasant chemicals to handle and their effectiveness has diminished over the years, and so in recent years other cleaning agents, such as *Tego, Trigene* and *Hycolin*, have been taking their place.

Whichever cleaning agent is to be used it is important to ensure that the correct concentrations are made up and that the cleaning is carried out in a systematic manner.

A chamber should always be cleaned after surfacing from a saturation. Also if the chamber has been on the surface and unoccupied for some time it may be necessary to clean it before use. When a chamber is to be cleaned under pressure all rubbish and bedding should be locked out prior to the cleaning material being locked in. After the chamber has been cleaned, the clean bedding can be passed in.

There has been an increasing incidence of skin problems during saturation. Commonly the surface layer of skin from the palm and fingers has been peeling off. It is thought that disinfectants could be the cause, although this has yet to be proven. Therefore rubber gloves shall be worn whilst using disinfectants.

Cleaning Under Pressure

Infections can be controlled by cleaning and disinfecting, but with some difficulty; both cleaning and disinfecting have to be done carefully and thoroughly to be effective.

Divers will plan to clean the chamber during their 12 hours on shift. Consideration must be given to others' sleep periods.. All bedding should be sent out before cleaning. The chamber must be cleaned when everyone is awake so that all laundry can be sent out, with rubbish, crockery, etc., before cleaning. When this has all been removed then the cleaning gear can be sent in.

It has also been proven that ordinary cloths tend to harbour bacteria, and may even produce strains of bacteria resistant to disinfectants. These will then be spread round the system as the cloths are repeatedly used for cleaning. Therefore all manual cleaning/disinfection shall take place using disposable equipment (disposable paper cloths made from durable, no-lint paper). The paper cloths shall be dampened with cleaning/disinfectant solution, put in a plastic bag, and sent into the chambers. Each paper cloth shall be used for an area of approximately one to two m^2, then, when used, placed in a plastic rubbish bag and sent out.

Do not remove or clean under deck plates whilst under pressure.

Cleaning on the Surface

There are three stages. Cleaning, rinsing and drying as follows:

- Take out all equipment/objects that can be affected by damp.
- Cover up equipment/objects that can be damaged by damp, but which cannot be taken out. The equipment is covered with plastic sheeting which is taped in place.
- Place all deck plates so that they can be hosed down on both sides
- One person dresses up in appropriate protective clothing and with air supply from an AGA mask and bottle, or alternative.
- The person who is appropriately dressed disinfects the chamber by means of portable spraying equipment.
- Allow the disinfectant to work for approximately half an hour.
- The pressurised water equipment is removed and water suction equipment is sent in.
- When all visible water has been removed, the water suction equipment is sent out.
- Drying equipment is sent into the chamber and is operated until the chamber is dry.
- The equipment is removed and the chamber is prepared for pressurisation.

Cleaning of Personal Diving Equipment

Individual diving equipment is recommended during the saturation period. Each diver is responsible for his own personal equipment:

- Nose clip.
- Oro-nasal.
- Chin protection.
- Neck dam.
- Hat liner.

Personal diving equipment shall be cleaned after diving with cleaning/disinfectant solution, rinsed well and dried. The rinsing process is very important. Multiple cases of contact dermatitis have been reported from inappropriately rinsed items, generally caused by sweating during work & activation of caustic disinfectant.

It must also be noted that 'personal equipment' may not be very personal in certain party of the world. It is standard practice in the North Sea to issue all divers with two sets of personal equipment, however reports of multiple users utilizing 'personal equipment' which dramatically increases the risk of bacterial / viral spread.

Cleaning of Medical Locks

Medical locks shall be disinfected/cleaned a minimum of once per shift. The same procedure shall be followed each time dirty equipment has been sent out. Especially after the chamber has been emptied of rubbish, laundry, etc., prior to cleaning. A spray of TEGO 2000 mix is available at the lock sites

Cleaning of Suits and Clothing

- Diving suit
- Warm-up suit.
- Gloves.
- Socks.

- Personal clothing.

The diving suits are disinfected in the approved disinfectant solution, and well rinsed afterwards. Other clothing is washed in 60°C water or disinfected and washed in 40°C water.

GAS CONTAMINANTS 7.12

Most life support gas analysis is concerned with monitoring only oxygen and carbon dioxide. However, other gases can sometimes appear. These can be highly toxic even at very low levels and therefore tests should be made to reduce the risk of such occurrences. These tests can be carried out using chemical colour-indicating tubes or electronic instruments.

As a rough guide, the following sources of contaminants and their relative degrees of toxicity should be appreciated.

Soursces Of Toxic Gas 7.12.1

Overheating or Burning

Overheating or burning of electrical insulation and other materials can cause smoke without fire. The chemicals in the smoke and fumes can be highly poisonous. They affect the eyes, lungs and skin. Even trace quantities, when absorbed into the bloodstream, can attack the nervous system and quickly incapacitate the diver.

Just A Few Of The Poisonous Gases That Can Be Formed Are:-

- Ammonia NH_3
- Carbon Dioxide CO_2
- Carbon Monoxide CO
- Hydrogen Chloride HCl
- Hydrogen Cyanide HCN
- Hydrogen Fluoride HF
- Nitrogen Dioxide NO_2
- Sulphur Dioxide SO_2

Some of the materials in a diving system that can produce these gases include PVC, polystyrene, polyester, polyurethane, phenol-formaldehyde, wool, silk, acrylics, rubber, nylon and PTFE.

Gases Produced from Electrical Arcing

Apart from ozone and oxides of nitrogen, most of these products are not a problem in the short term, however, a long-term exposure could be.

Task Oriented Contaminants

Contaminant gases can appear in a diving system via the diving bell. These can appear if the divers return to the bell with contaminated equipment/suits, or if the system is located over:-

- An area of seabed, which is degassing.
- A diver using oxy-arc equipment.
- An open pipeline end.

All of these sources can and should be avoided with proper diving practice.

Some additional gases which can appear are:-

- Acetone CH_3COCH_3
- Acetylene C_2H_2
- Benzene C_6H_6
- Ethyl alcohol C_2H_5OH
- Hydrogen H2
- Hydrogen Sulfide H_2S
- Methane CH_4
- Oxygen O_2
- Other Hydrocarbons
- Various Halogens

Toxic Levels

The following table gives the relative toxicity of some example gas contaminants. Note the low concentrations.

	SURFACE EQUIVALENT VALUES		
Gas	Concentration to produce rapid death (ppm)	Concentration tolerable for a short time (ppm)	Threshold limit value (TLV) (ppm)
NH_3	*	*	25
CO	4000 - 5000	400 - 500	50
HCl	1000 - 2000	50 - 100	5
HCN	100 - 300	*	10
HF	50 - 250	*	3
H_2S	800 - 1000	20	10
NO_2	200 - 700	*	5
SO_2	400 - 500	50	5

*** No information available.**

HAZARDS AND CONTROL OF DIVING 7.13

Professionalism in diving begins with understanding the fundamentals of what and why you do something. Equally the ability to think ahead, to understand what you as a team member are expected to do.

General Safety

Be aware of who you are, what you are and where you are. Treat people and equipment with the consideration and respect due.

Human error can be due to tiredness, overwork, misunderstanding questions, giving information wrongly, being unsure of equipment and procedures, assuming something has been done when it has not been seen to be done.

ACCIDENTS BEGIN WITH A CAUSE - THE EFFECT CAN BE CATASTROPHIC

People You Work With

Non-diving personnel who work on the support ship with you are all potential hazards. Most support vessels retain a core of non-diving personnel who are in general more enlightened in what can or cannot be done, whilst the vessel is in a diving mode.

Be continually aware of what is happening on deck - it is as much your responsibility as maintaining the saturation complex. Mention any potentially dangerous situations to the Shift Supervisor. It could stop a potentially hazardous situation developing, which, in turn, could injure the divers in the diving complex.

Mobilisation

Mobilisation of the support vessel normally falls to the technicians, this in turn is governed by the Diving Legislation and Company Rulings. It is the best time to learn about systems, and the problems encountered, giving good background experience. As most Diving Companies have standardised equipment to minimise mobilisation time, it is sometimes just a matter of plugging all the various pieces together.

Equipment should always be checked upon arrival, damage can easily occur during transit. Pre-check and cross-check every pipe/pipe fitting and piece of equipment in use. Larger pieces of equipment will have test certificates or will be given test certificates prior to going operational. Pressure test all relevant equipment prior to any commitment to diving.

Diving Gases (see also Section 5)

Oxygen

Caution is the optimum word when you are required to handle this gas. Too little can result in asphyxiation. Too much oxygen in certain diving situations can lead to physical injury or death.

High levels of oxygen are found offshore in therapeutic gas. When using this gas - valves, pipes, pressure vessels - must be hydrocarbon free. Decontamination of equipment prior to introducing the gas must be your first concern. This can be achieved by using recommended chemicals such as Biox, followed by rinsing with soap and water. The equipment should be flushed with water before drying takes place.

Be aware that oxygen supports combustion. If in any oxygen rich environment, e.g., when mixing or transferring gas, clothing becomes saturated, it can take up to 15 minutes in a ventilated atmosphere before it dissipates.

Do Not:-

- Smoke or approach anyone who is smoking.
- Vent any gas above 22% to atmosphere within a 16 feet radius of any combustible material or hydrocarbons, e.g. oils, grease.
- Use oil or paint covered clothing when handling O_2 equipment.
- Fill oxygen into cylinder unless it is BS 5495.
- Use clothes or rags for cleaning equipment, or to assist in the handling, unless first saturating the material in an inert gas, i.e. Helium/Nitrogen.

Always pressurise pipelines slowly since excessive gas velocities can cause ignition of steel pipelines (they burn vigorously once ignited).

Oxygen analysis is normally carried out by the manufacturer prior to despatch.

Diving grade oxygen would be:-

Gas	Concentration	Analysis method
Oxygen	99.5%	
Nitrogen	0.3%	Servomex pure oxygen
Methane	0.25 ppm	Infra-red spectroscopy
Other	2 ppm	
Dew Point	30 ppm	Dew point meter

Helium

Pure Helium, when used offshore, must be recognised as being an extremely hazardous gas. Stored in high-pressure containers, transportation from storage point to work site necessitates the use of hose, pipes and fittings, all of which are potentially hazardous situations if not handled correctly.

If pure helium is to be used as part of an extensive deep diving programme, then it should be hard plumbed and made so that all fittings and whips are unique, making it impossible to cross connect.

Pure Helium's primary function is that of a carrier gas, it transports oxygen to the body and assists in the removal of waste gases. Helium has no smell and has no sensory identification, being inert it does not supports life. Should a person inadvertently breathe pure Helium, it WILL KILL.

The effect of breathing pure Helium robs the body of residual oxygen. As no residual oxygen is left, unconsciousness is followed by death.

Due to the number of accidents involving pure Helium the AODC recommended that a minimum of 2% O_2 should be added to all helium quads.

Typical manufacturers analysis of Pure Helium:-

Gas	Concentration	Analysis method
Helium	99.997%	
Oxygen	6 ppm	Gas chromatography
Nitrogen	25 ppm	Gas Chromatography
Hydrogen	1 ppm	Gas Chromatography
Neon	3 ppm	Gas Chromatography
Dew Point	10 ppm	Dew Point Meter
Others	1 ppm	Infra Red Spectroscopy

Figures relevant to gas percentages, plus or minus tolerances are given as follows:

Gas and Equipment generally specify to 2.5% of minor component concentration

These specifications also apply to Nitrogen concentrations in mixes.

Specifications for other constituents in mixes apply as per pure gas concentrations, depending on mix ratios of gases.

Prior to being put on line gas quads should always be analysed and the person running the shift informed of the relevant percentages.

O_2 In Mix (%)	Minimum	Maximum
4	3.9	4.1
5	4.87	5.13
6	5.85	6.15
8	7.8	8.2
10	9.75	8.2
12	11.7	12.3
14	13.65	14.35
16	15.6	16.4
18	17.55	18.45
20	19.5	20.5
30	29.95	30.75
50	49	51

Gas Storage and Mixing

Due to the volume of gas used during bounce/saturation diving the available space on the support vessel requires that the gas be stored in high pressure vessels, e.g. cylinders/quads, usually pressurised to 3000 psi/200 bar.
The gas itself, be it Helium, Oxygen or Mix, will be supplied by the manufacturer as being pure (see examples), with a plus or minus tolerance of the percentage mix required by the Diving Company on the particular job site it is destined for.

On modern custom built DSVs there is normally permanent gas storage tubes. In this case the quads arriving on board are emptied into the storage then the empty quads off loaded.

Gas Transportation

This can be defined as the movement of gas from storage point to point of use, without any supply pressure loss.

Storage quads, usually at an initial pressure of 3000 psi/200 bar, require the use of hoses, piping, valves and fittings, which are compatible to diving gases, extremes of ecological climates and continual exposure to salt solutions.

Critical factors associated with gas transportation is where and how piping runs are situated in a working environment. Protect all hoses and piping whenever and wherever possible. Use whatever protection is available including walls, ceilings, existing piping conduits. It will be inevitable that some situations will necessitate the running of piping or hoses from storage point to point of use across open decks. Such runs can be protected with the controlled use of angle iron or electrical conduit, reinforced with metal bracing. Fittings (valves, etc.), if in a potentially hazardous situation can be equally protected by the use of guard frames or covers.

Remember to tie off hose ends when connected to equipment. Fittings break, and 30 ft of hose spilling gas at 3000 psi can be lethal.

Remember the shortest distance between two points is not always the safest.

Intentionally Blank for Notes

TRAUMA TRAINING

Section 8
Emergency Procedures

CHAMBER EMERGENCIES 8.1

Although the chamber is considerably safer than the sea-bed it is still a potentially dangerous place. There have been several fatalities and numerous near misses in incidents, some of which were the result of surface error but others were caused by, or aggravated by, the divers' lack of knowledge of the inside of the chamber.

It is imperative that before blowdown the chamber is prepared and equipped to cope with any emergency and although it is difficult to control this readiness once the chamber is under pressure, it must be emphasised to the divers that any alteration of valve positions or unplugging of BIBS etc. may endanger their security. All divers entering the system must be aware of the internal layout and of emergency procedures.

Unbreathable Atmosphere 8.1.1

The atmosphere may become unbreathable due to either contamination by a toxic gas or by the reduction of the pO_2 to hypoxic levels.

If possible, evacuate the chamber and isolate it. In any case go onto BIBS, which should always be in a state of readiness. Keep the divers informed of your actions.

Do not underestimate the effects of toxic or hypoxic atmospheres. Divers must stay on BIBS until the atmosphere is breathable. There should be enough gas on board to keep all the divers in the chamber supplied on BIBS for a minimum of four hours (AODC recommendations). In practice there will probably be considerably more.

Once they are on BIBS and isolated then the subsequent actions will be determined by the seriousness of the situation. On no account must the divers be allowed to re-enter the contaminated chamber until it is absolutely certain that the environment is safe.

Fire 8.1.2

Before a fire can start there must be sufficient oxygen, a combustible material and a source of ignition.

Oxygen

In some cases the chamber atmosphere is unable to support combustion. As the depth is increased the oxygen concentration is reduced in order to maintain a constant oxygen partial pressure. An oxygen concentration of 8% or less is not sufficient to support combustion and the risk of fire is negligible. Although there is some risk, fire remains unlikely until oxygen levels approach 20%.

Above 20% the risk increases considerably and at no time should the chamber atmosphere oxygen level be allowed to exceed 25%. The diagram below shows the three zones of combustion as a consequence of oxygen percentage and depth.

Fuel

Great care should be exercised in the selection of material to be used in or allowed into the chamber system. The chamber paint-work should be fire resistant as should all loose coverings, e.g. bedding and curtains. Large amounts of newspapers and books should not be allowed to accumulate within the chamber.

Heat

Heat or a source of ignition is restricted to the electrical supply or perhaps a static discharge. Consequently there is strict regulation on electrical supplies to chambers and to the design and security of all internal wiring and fittings.

In general, the fire risk in the chamber is very low, however the consequence of fire is extremely serious and precautions to minimise the risk must be taken. In addition all surface and dive personnel must be conversant with the procedures to be taken in the event of fire.

A fire occurring due to high oxygen levels would be a flash fire, which almost constitutes an explosion. This has never happened in a saturation chamber although there have been a number of fatalities in air-filled chambers.

If a normal fire occurs, the divers should evacuate the chamber, close the door and go on to BIBS. The greatest danger may come from toxic fumes. They should then inform surface who will vent the burning chamber. As the pO_2 drops, the fire will go out.

If the cause is a smouldering electrical fire then obviously the initial action by the surface crew would be to shut off the electrical supply. The divers, on BIBS, may then extinguish the fire and then evacuate to another chamber to allow an assessment to be made as to the subsequent remedial action.

If it is impossible to evacuate the chamber, the divers should go on to BIBS and use the available fire fighting equipment.

Hyperbaric Fire Extinguisher

Fire in Saturation Control Room or Outside Chamber

In the event of this type of fire occurring, the following steps may be taken to regain control:-

- Life Support personnel to don breathing apparatus.
- Isolate all oxygen and electrical supplies but maintain chamber communication.
- Inform the Diving Superintendent and Dive Control of the situation.
- Inform divers in the chamber and, if necessary, put divers on BIBS.
- Attempt to extinguish the fire with locally sited appliances until help arrives.
- Keep an eye on the chamber depth.
- Keep chambers cool by hosing down with cold water paying particular attention to O_2 and gas lines.
- Prepare to transfer divers into the HRV or to another diving vessel with a compatible bell system.

Fire Safety 8.1.3

Fire, while a major hazard to the diver, is one of the hazards most amenable to minimisation or elimination. Three conditions must exist at the same time and in the same place for a fire to occur. These are combustible materials, oxygen and a source of ignition.

By eliminating or separating any one of those items from the other two it becomes impossible for a fire to occur. While it is often difficult to accomplish either of those tasks, it is up to the chamber/diving system designer to do as much as possible to keep the unit inherently safe. Beyond that the responsibility rests with the LSS and the divers themselves to ensure that all possible precautions are taken.

Precautions:-

"No Smoking"

Open flames or burning materials are never to be allowed inside the chamber. On all occasions, including when the chamber is open to the atmosphere, all matches, lighters, cigarettes, tobacco, pipes etc. should be left outside the chamber. By building this habit it is less likely that someone may inadvertently take such items into the chamber when it is about to be pressurised.

Constant Watch

At all times when the chamber environment is capable of supporting combustion, a constant watch over the chamber interior should be maintained. During periods when the divers are awake they should be alert to any signs of a developing fire and avoid creating conditions conducive to the start of or rapid growth of a fire. During those periods when the divers are asleep or concentrating on other activities, the LSS must maintain a closer watch on the chamber. Ideally, and now required under Norwegian regulations, he will have devices to assist him in this matter.

Training

as the types of fires they are suitable for dealing with. In addition they should practise the company's emergency procedures periodically to ensure a rapid and proper response to the situation. Similarly, the Life Support personnel involved in the operation of the chamber should know and practice the correct response to this type of situation.

Prevention

As mentioned in the general section, separation or elimination of one of the three elements necessary to a fire's existence will prevent it. It is possible to build and equip a system in which the only item that could burn is the diver, but such a system would be excessively expensive and rather lacking in creature comforts. Therefore this section shall concentrate on minimising the possibility and risk of fire.

Both prior to and following any dive, the diver or LST checking the chambers should examine the condition of all internal wiring for wear and damage.

Any electrically driven motors should be checked for ease of operation and that nothing can interfere and cause the rotor to lock.

Rules

The following rules, if carefully followed, will do much to prevent a fire from occurring or limit the spread of the fire.

- Maintain the oxygen concentration/partial pressure as low as possible, preferably within the region of non-combustion. The oxygen percentage must never exceed 25%.
- Use an overboard dump system when oxygen or high pO_2 mixtures are breathed by mask.
- Eliminate ignition sources.
- Use combustible materials sparingly, excluding completely flammable liquids, powders and gases.
- If combustible materials must be used, the type, quantity and arrangement in the chamber must be carefully controlled.
- Fire-walls and other containment techniques should be used to isolate potential high-risk fire zones.

Detection

Because of the speed of fire development in oxygen-enriched atmospheres and the resultant extreme hazard to personnel, detection equipment capable of activating fire extinguishing systems or other emergency action should be used. The detection system should be capable of volume surveillance and be able to detect incipient combustion as well as flame.

Summarising briefly, the detectors rely on temperature rise, radiation emission, or combustion products of the flame process for activation, but certain of these detectors, such as the overheat or rate-of-temperature rise detectors are not acceptable for oxygen-enriched environments because of their slow response time and limited volume coverage. In addition, smoke detectors using low-level radiation are not suitable as increased density of the hyperbaric environment affects their operation.

Extinguishing

Fire can be extinguished by physical action, chemical action, or a combination of both. The table below provides a comparative summary of the types.

Fire Extinguishing Agents for Oxygen Enriched Atmospheres

Agent	Mode of Action	Personnel	Use In O_2-Fires
Water	1,2,5	Excellent	Good
Foam	1,3.5	Good	Unknown
Dry powder ($NaHCO_3$, ABC)	3,4,5	Good	Unknown
CO_2	1,2	Fair	Poor
N_2	2	Poor (Anoxia)	Poor
Halon*	1,2,4	Good*	Very Good

*** May decompose in heat to yield toxic products.**

Mode of Action:-

1. Quenching (cooling).
2. Inerting (oxygen dilution).
3. Blanketing.
4. Chemical inhibition.
5. Radiation shielding.

Water

At present, due to safety considerations, the best extinguishing agent for use in hyperbaric chambers is water. Water extinguishing operates primarily by cooling. It works best if it strikes the flame or wets the fire, but wetting most substances will retard or prevent their burning, even oxygen. Simultaneously with discharge of water, all electrical power within the chamber must be switched off to prevent shorting and electrical shocks to personnel within the chamber.

Foam

High-expansion foam has been shown to be an effective means of extinguishing fires that have been allowed to build up to their full intensity. However, little is yet known about the harm the foam or its pyrolysis products can do to the human body, especially under a high partial pressure.

Hyperbaric Fire Extinguisher

Gas Dilution

Agents such as nitrogen and carbon dioxide depend primarily on the dilution of the oxygen content to a level, which will no longer support combustion. In the absence of a special breathing system to protect against carbon dioxide toxicity, carbon dioxide extinguishing cannot safely be employed in a hyperbaric chamber. In an attempt to replace carbon dioxide as a gaseous fire-quenching agent, both nitrogen and helium have been considered and tested.

It appears that neither of these gases is of value (except by the rapid dilution method in which the entire chamber atmosphere is rapidly diluted), as it is not possible to maintain a significant concentration of the gas in a given location.

Dry Powders

Although dry chemical agents should provide rapid suppression of flame and excellent radiation shielding when initially discharged, the permanency of the fire extinguishing is doubtful. It should be noted that dry chemicals are not suitable for vertical or overhead surface use, thereby limiting their use to spot suppression of fires in the lower half of the chamber.

Halon

Although monobromotrifluromethane ($CBrF_3$, "Halon" 1301) and Chlorobromomethane (Freon 1011) have been shown to be effective extinguishing agents, a delayed application of the extinguishing agent could produce toxic pyrolysis products if the fire has a good hold. Its use as a fire-extinguishing agent requires concentrations in the order of 4-7% in air. These concentrations are below the known toxicity level of 10% Halon 1301 in air at sea level. Halon 1301 as a possible fire-extinguishing agent may be considered for use in hyperbaric chambers provided that the human exposure is brief, i.e. 3 minutes or less. However, its safety for use in hyperbaric chambers remains questionable.

Material Prohibited in the Chamber 8.1.4

The following items comprise a comprehensive listing of materials that should not be allowed into a DDC. The letter(s) following each item indicates the general reason for prohibiting it, (the coding is shown below):-

Listings

- Adhesives (F)
- Aerosols (D,E,F)
- Aftershave (D,F)
- Alcohol (D,F,P)
- Batteries with unprotected leads (F)
- Chemical cleaner, e.g. trichloroethylene, 'Freon' (D)
- Cigarettes, cigars, tobacco of all kinds (F, M)
- Cleansing powder (C,F,P)
- Drugs (not on permitted drugs list) (P)
- Electrical equipment (F)
  - (Some electrical instruments run on battery (<6V) and are allowable.)
- Explosives (E)
- Glass thermometers (C,D,P)
- Lighters (F)
- Matches (F)
- Non-diving watches (L,M)
- Petroleum based lubricants, greases, fluids (F)
- Thermos flasks (L,P)
- Non-fireproof bedding (blankets, sheets, pillows, mattresses) (F)
- Excessive newspapers & books (F)

Code	Reason
C	Possibility of damaging the chamber.
D	Contamination of the environment.
E	Explosion risk.
F	Fire source or a combustible substance.
L	Could be damaged by pressure.
M	Will possibly cause a mess.
P	Affects ability of diver.

LOSS OF PRESSURE 8.2

Accidental loss of pressure in a chamber can result in decompression sickness, barotrauma or hypoxia affecting the divers within.

The effects vary greatly with the speed and volume of the pressure loss and also with the depth at which the loss occurs.

e.g.: A rapid pressure loss from 160 to 140 metres can occur with little or no consequences whereas a similar loss from 30 to 10 metres would create serious problems. Although the pressure loss in both situations is the same, i.e. 2bar, because of pressure/volume relationships, the results are very different.

Noise levels can be such that communication with the chamber occupants is impossible. In a situation like this it is essential to have a thorough knowledge of the saturation system, inside and out, and of the procedures to follow.

The divers in the chamber should attempt to identify the source of the leak and isolate it. The surface crew will be doing the same and attempting to maintain pressure by blowing gas into the chamber.

Ideally the divers should evacuate the leaking chamber and close the door. As soon as possible they should go onto BIBS. The chamber atmosphere may be hypoxic or even hyperoxic if rich mixes have been used to maintain pressure.

Storage Point to Chamber Control

A leak from storage point to the chamber control panel does not constitute an immediate threat to the physical or mental well-being of the divers under pressure, since isolation can be achieved as the storage point or the chamber control panel by closing the relevant valves.

A slow leak will probably be first noticed as a pressure drop in the upstream supply gauge pressure, during routine chamber checks, (dependent on actual loss). Locating and curing a leak may be a long laborious job of circuit isolation. Whereas a fast leak usually makes plenty of noise and can be easily found, slow, silent leaks require the use of a leak detecting agent, e.g. SNOOP, to locate the leak.

The danger of a slow leak, although not giving immediate threat to the personnel under pressure, is that an important gas supply line is taken out of service while maintenance is achieved, so leaving the systems supply network weak. If the leak is rapid, apart from the above danger, a considerable amount of expensive gas is lost and if the working gas margin is close, could require the termination of the dive programme until further supplies arrive. Additionally the atmosphere in a gas storage or other area can become unbreathable due to the leak.

SNOOP Leak Detection

Chamber Control

Most diving companies employ the use of a separate control panel for each part of the complex, which can be isolated and treated as an individual pressure vessel. Leaks on these panels do not normally fall under the rapid loss criteria since most leaks are limited to valves and piping runs in the actual panels, detection is usually audible or by touch. The leak's position determines the course of action required to cure it.

Upstream leaks, i.e. from storage point to panel, require the supply lines to be closed down since on most panels the supply lines are common to each control panel. We then have the situation described in Storage Point to Chamber Control above.

Downstream leaks, i.e. from panel to point of exit, require that panel to be effectively shut down until repairs are effected. Since in most circumstances the complex will have a number of panels in use, this poses no immediate risk, but you should remain aware that should an emergency happen, the pressure vessel, whose panel is under repair, cannot be effectively isolated or given any surface back-up, although in some panels there are crossover systems to overcome this.

Chamber Control to Chambers

Leaks which occur downstream of the control panels are the hardest to detect, since down line pressures are seldom gauged. It is strongly recommended that a routine is implemented which will systematically check for leaks throughout each watch period, as any leak will normally only register itself in a complex pressure loss or when the leak reaches the rapid category.

Chambers

Detection of pressure loss in the actual chamber complex, if of the slow type, will be registered in the control van before the diving personnel under pressure notice any change. Action by the surface/diving personnel follows the lines already discussed.

A rapid pressure-loss will be noticed by personnel under pressure and the control van crew.

If a slow leak is present in a dive complex then the separation of the different units will show from which chamber the leak is occurring. It is then a matter of sequential closing and opening of valves in that chamber to isolate the exact point of leakage.

Once the source of the leak is detected the relevant valves should be closed to secure the chamber while work is done to remedy the situation. If the leak cannot be controlled or is of the nature that it threatens the physical or mental well-being of the personnel under pressure, then evacuation of that part of the complex, followed by isolation of the personnel under pressure is the most obvious action. When the personnel are safe, the problem can then be looked at and corrected.

Environmental Control Unit

The environment control system works as a closed circuit, and contamination to the complex atmosphere should in theory not occur. Leaks developing in the complex attributed to these units, can be easily remedied by isolating the actual habitat conditioning unit. However, such action should not be taken until the dive technician has been informed and has given confirmation that such a leak is attributed to the control system.

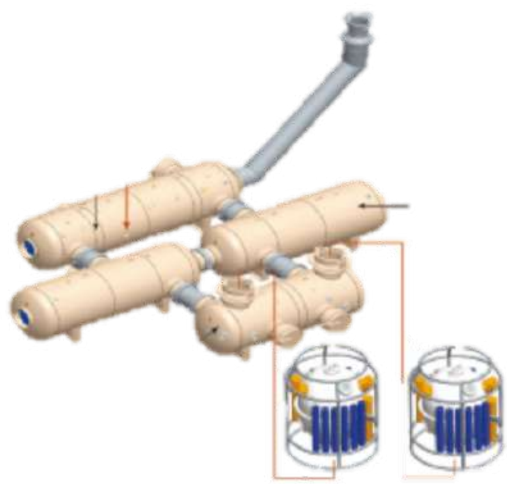
NB: Isolation without taking corrective or shut down procedures on the control master unit could seriously damage that unit and effectively eliminate habitat environment control for the complex or chamber in question for the duration of the diving mode.

Regenerative Control Unit

Since this system works at complex pressure, leaks can and do occur. The procedures to be followed have already been discussed, i.e. locate leak, isolate circuit, bring to atmospheric pressure, corrective maintenance, re-introduce circuit to complex.

NB: When changing soda sorb silica gel units ensure they are isolated from main system pressure - bring to atmospheric pressure before removing chemicals. Upon completion return to system pressure slowly. Chamber control will register a pressure drop but this is normal since the regeneration system works at chamber pressure and the lost gas is due to the repressurisation of the chemical unit.

Pressure Leak Detection



Bells

Bells are used to transfer personnel to and from the complex to the work site by a system of pressure sealed doors.

All communications, electrical power, hot water, analysis depth monitoring and gas supplies, are via the main bell umbilical. If a gas leak occurs in the bell, the leak must be detected and reported to the surface. If a significant internal pressure increase or decrease occurs, close the appropriate skin valve, informing surface at all times what action has been taken.

In a diving mode, should an internal pressure loss develop which is traced to the pressure sealed doors, ports or port-seal, the bell should be lowered until internal and external pressures equalise, the divers would by this time have readied their diving equipment and dressed in, in case repairs had to be completed in a flooded bell.

In a bounce dive prior to commitment to pressure-up, such a leak external to internal would necessitate the bell being returned to the surface.

Ports are made of acrylic (plastic) and are robust in the extreme. Subsurface ramming of equipment due to poor visibility is rare. The ports themselves being normally amply protected by the bell's buffer rings and equally by their varied position. What occasionally occurs is that a port has been removed for other maintenance work and although replaced and torqued up correctly has only been pressure tested from the inside out. Subsequently, when the internal pressure is atmospheric and the bell lowered to working depth, a leak may occur. Remedial action is to return the bell to the surface and re-torque bolts.

When locking out of the bell it is of benefit to give a routine visual inspection of all external valves and piping to see if any leaks are present.

Possible Points Where A Leak Can Occur On A Hyperbaric System:

- Quad pillar valves, interconnecting pipes, fittings.
- Quad manifold. Hose connectors, hoses.
- Hose connections to control panel.
- Control panel hoses, common manifolds and piping.
- Across control panel valves, gauges, reducers, line purges.
- Downstream hoses, hose fittings, hard piping and associated fittings.
- Pressure vessels. (Skin valves/penetration adapters, hoses, hose end fittings and associated valves and piping).
- Internal back-up skin valves (penetration adapters, hoses, hose end fittings, hard piping and valves and piping).
- Failure of pressure vessels, ports, port seals through failure or actual damage.
- Failure of manway seals, interconnecting door seals, medical lock, medical lock seals.
- Failure of electrical penetrator valves and fittings.
- Leaks through hot water system (back feed) bell.
- Failure of umbilical through damage. Bell door seals.

HYPERBARIC RESCUE PROCEDURES 8.3

There are a number of emergency situations, which may present a particular problem for divers with respect to abandonment of support ship or structure.

These are as follows:-

- Vessel or structure may be in danger of capsize or sinking.
- Severe fire or explosion of leakage of toxic gas.
- Fire within the diving system or mechanical failure of an integral part of the chamber complex.
- A lost diving bell situation.
- Medical problems with individual divers who may require evacuation to a special treatment centre without the inconvenience of decompressing the whole complex.

The more immediate of these situations in the North Sea all come under the general safety arrangement known as the Sector Club Organisation which is designed to handle emergencies of a general nature and is administered by the major oil companies.

The location and capability of vessels with an emergency support facility are recorded weekly. This information is made available to individual sector co-ordinators who can then assess the most suitable units available for any given situation.

The responsibility for handling diving emergencies is shared between the oil company and diving contractor. Their precise responsibility being defined in the regulations.

The key to successful emergency co-ordination is to have a thorough contingency plan for all foreseeable situations.

This Plan Should Cover The Following Main Headings:-

Cover from shore side operations:-

- Location and establishment of an incident control room.
- Communications.
- Recall of key personnel.

Provision should be made for liaison with:-

- Sector club co-ordinators.
- Other vessels and structures in the vicinity.
- Other diving contractors.
- Helicopter services.
- HSE.
- Police/Coastguard/Medical services - as appropriate.
- Press.

Provision afloat should cover:-

- Individual procedures and responsibilities.
- Communications, (in particular the main line of communication between the offshore site and the co-ordinating base ashore).

From Here A Typical Schedule Of Procedures May Be As Follows:-

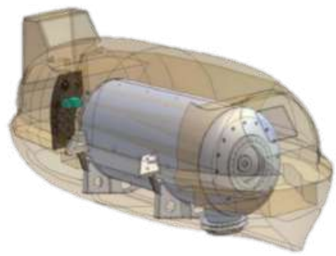
Diving Supervisor takes immediate action by notifying:-

- His own crew on site.
- Master of the vessel/OIM.
- Operator's representative.
- Contractor's office ashore.

Hyperbaric Lifeboats 8.3.1

This is a decompression chamber housed inside a totally enclosed lifeboat, designed to provide a means of evacuating a whole team of divers whilst under pressure. The lifeboat is therefore connected to the saturation diving system as a permanent feature and is maintained, in readiness, at a depth a few metres shallower than the deepest storage depth In the event of an emergency the diving team transfer to the hyperbaric lifeboat and are launched with the other ship's or structure's lifeboats on final abandonment.

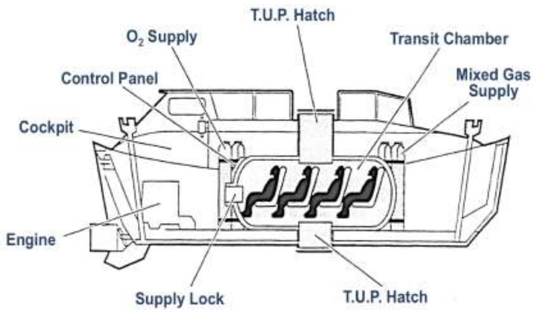
Hyperbaric Lifeboat (HBL)



The hyperbaric lifeboats has its own means of propulsion and its operating crew will comprise the Diving Supervisor, Life Support Supervisor, Dive Systems Mechanic and Coxswain. The lifeboat is then hopefully recovered from the water prior to being mated to a compatible diving system close at hand, which is, in theory, a straightforward system. In practise this again is a "last ditch" effort.

Norwegian legislation requires all systems to be fitted with a means of hyperbaric rescue and for the operators to have a contingency plan in the event that the hyperbaric rescue system has to be used.

H.B.L. Schematic



Bell to Bell Transfer

This is a means whereby should a diving bell become either trapped underwater or loses contact with its mother vessel, the divers inside are transferred to another diving bell from a second diving system. A detailed procedure for such a drill has been published by the AODC in the light of experience gained in the UK. A system of bell to bell communications and a pinger and transponder/locator system are now standard fit on diving bells in the North Sea.

The Rescue of Divers Under Pressure 8.3.2

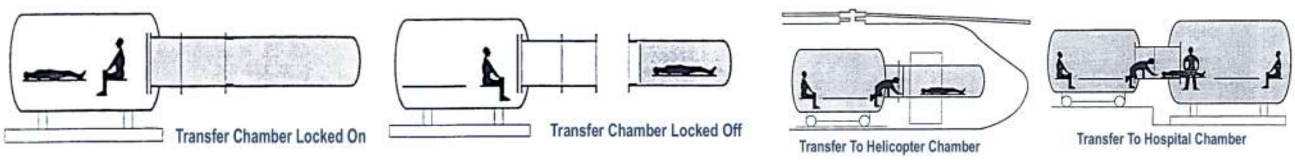
Hyperbaric rescue is the name given to the methods by which divers living in decompression chambers or who are in a diving bell may transfer to a separate chamber complex or diving bell. This type of rescue situation is not confined entirely to emergency situations but may be used for evacuating a number of divers or an individual for medical reasons. Transfer arrangements may be reasonably simple for a single diver as a routine operation. Hyperbaric evacuation in an emergency is however a very complex and hazardous operation which should only be considered as a "last ditch" measure.

Each evacuation system requires a special procedure. Each will probably be dependent on services provided by the parent vessel or structure in the form of power or gas supplies, or even only stability. Any of these may well be affected by the emergency at the time.

The Norwegian section of the North Sea requires hyperbaric evacuation facilities for divers to be provided by law. The British sector requires diving systems to be fitted to accommodate an evacuation capsule. These are very different standpoints.

Hyperbaric Evacuation May Take Any Of The Following Forms:-

TUP Transfer Under Pressure System



Transfer Under Pressure (TUP) Diver Recovery Systems

This is primarily for a medical evacuation and involves the connecting of a one-man chamber, usually made of titanium, to one of the main deck chambers in the diving system. This is §man handled to a slightly larger chamber in a helicopter, which is in turn connected once ashore to a large chamber with full surgical facilities installed. The TUP facility should be considered as a possible alternative in emergencies but is primarily designed for simple patient medical evacuation. In the North Sea the system of chambers, which makes this evacuation possible is jointly owned by the Grampian Health Board and the oil companies, and is operated by the National Hyperbaric Centre.

Typical TUP Diver Rescue Operation

Heli-Transfer

- A 24V supply is connected to the helicopter for running the chamber's life support system.
- An HP gas hose with a quick connector is passed to the helicopter to pressure up the helicopter chamber.
- The transfer chamber is manhandled from the helicopter to the DCC.
- The transfer chamber is connected to the adapter spool and its door is left open. The transfer chamber and trunking can be equalised with the DCC.
- The attendant opens the door of the DCC.
- The attendant transfers the diver into the transfer chamber.
- When everything is ready for a quick transfer, the attendant fits and shuts the door of the transfer chamber. It is held shut until a seal is obtained. At this point, the helicopter chamber with medic(s) is pressured up.
- The attendant shuts the door of the DCC and holds until a seal is obtained by venting the trunking.
- The trunking is then fully de-pressurised and the DCC pressure adjusted if necessary.
- The crew disconnect the transfer chamber and manhandle it (using a crane if necessary), to the helicopter.
- The period whilst the diver is alone and inaccessible in the transfer chamber should be as short as possible and the chamber should be handled gently.
- The transfer chamber is connected to the helicopter chamber.
- The medical attendants in the helicopter equalise the trunking with the helicopter and transfer chamber.
- The helicopter chamber attendant opens the doors to allow the diver through.
- The diver is brought through into the helicopter chamber and attended by the doctor and attendant.
- The attendant shuts the helicopter chamber door and holds until a seal is obtained by venting the transfer chamber and trunking.
- The transfer chamber is disconnected when completely de-pressurised.
- The helicopter delivers the system to the nearest heliport or helipad.
- The helicopter chamber is connected to the hospital chamber.
- The trunking is equalised with the two chambers.
- The chamber doors are opened and the diver transferred into the hospital chamber.
- All personnel under pressure locate in the hospital chamber.
- The door is closed.
- The trunking is vented to obtain a seal.

Hyperbaric Lifeboat Reception Facilities 8.3.3

The provision of HBL's without a receiving centre has been likened to 'just changing the place the bodies are stored'.

Fixed Site Receiving Centre's

Life support in HBL's is scaled at 72hrs in the Norwegian sector and 24hrs in the British sector. It must be considered that the decompression needs that a diver may need if they are saturated to 100+ metres is far in excess of these scaling's.

Norwegian and Australian authorities require a Hyperbaric Reception Facility to support all saturation diving operations

Certain clients require them to support all saturation diving operations.

Within the North Sea there are two fixed site operations:

Bergen, Norway: N.U.I.

- A purpose-built receiving and decompression facility.
- For all types of hyperbaric rescue units, including HBL's.
- Able to transfer and accommodate up to 24 divers in saturation.
- 37 bar capability.

N.U.I., Bergen, Norway

Aberdeen, Scotland: N.H.C.

- A purpose-built receiving and decompression facility.
- For all types of hyperbaric rescue units, including 'small' HBL's.
- Able to transfer and accommodate up to 16 divers in saturation.
- 40 bar capability.

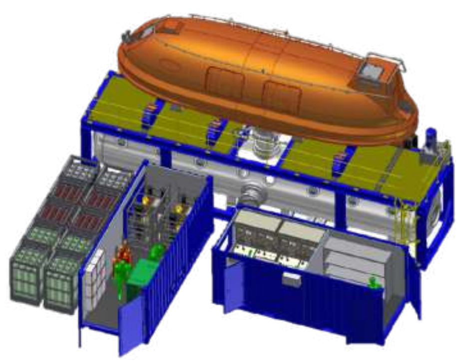
N.H.C., Aberdeen, Scotland

Mobile Receiving Centres

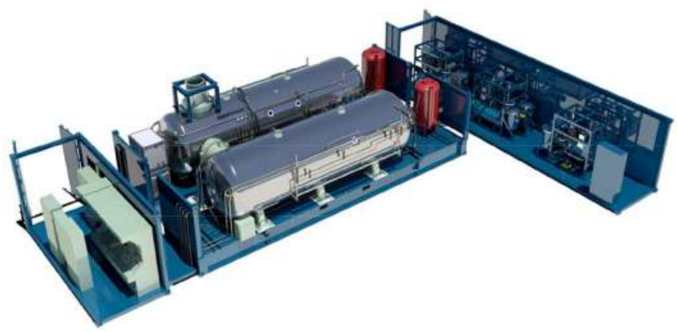
Several companies operate mobile / containerised facilities that can be mobilised and travel to an appropriate site if the need arose, These facilities could be constructed within the holding capacity limits of the HBL's life support system's.

To this date the facilities have never been used in a 'real world' situation.

S.M.P. Mobile Containerised Facility



Technip Mobile Containerised Facility



Section 9
Plant Maintenance

MAINTENANCE, EXAMINATION AND TESTING OF PLANT 9.1

This section provides guidance on the testing, examination and certification of all plant and equipment used as part of any diving operation.

The need for examination and testing of diving equipment followed the introduction of diving regulations into the North Sea in the 1970's. The AODC produced several documents to offer guidance on the process.

The Current Document That Covers This Area Is:

IMCA D 018, 1999. The Code of Practice on The Initial and Periodic Examination, Testing and Certification of Diving Plant and Equipment.

The code offers *"examples of good practice"*, and gives advice on ways in which inspection and testing can be carried out. Although it carries no direct legal status, the Diving at Work Regulations references it, and therefore a company not complying with it would need to show that they had an equivalent or better system in place.

The Code contains an alphabetical index of equipment involved in diving operations. Each item is allocated to one of a number of 'Detail Sheets'. These give instructions on the type of examination/test required by the equipment, the frequency of such tests, and the competency required by the person conducting the test.

Testing and examination is required when equipment is new, first installed or moved, and at regular intervals when in service. At the end of any satisfactory test and/or examination, the competent person must issue a certificate confirming that in his view the item of plant and equipment complies with relevant regulations.

All of the tests / inspections must be carried out by a 'competent' person.

There Are Four Categories Of Competency:

Category 1 A diving or life support supervisor.

Category 2 A certified technician.

Category 3 A Classification Society or Insurance Company Surveyor (but may be an in-house Chartered Engineer or equivalent),

Category 4 The manufacturer or supplier of the equipment, or a company specialising in such work.

All plant and equipment used in diving operations should be properly designed, of adequate strength, good construction, suitable for use and it should not be used unless it is maintained in a safe condition.

A plant and equipment register should be kept up to date and should contain individual test and examination certificates and a record of all subsequent examinations.

The plant and equipment register should contain all certificates and information relating to the plant and equipment used. In particular, the certificates need to have been completed by a competent person certifying that the individual items comply with the appropriate regulations.

D.E.S.I.G.N. 9.1.1

In order to ensure that all equipment, procedures and personnel involved in diving operations meet the standards required for UK diving operations, IMCA also publish the 'Diving Equipment Systems Inspection Guidance Note' or D.E.S.I.G.N.

This is an annual audit checklist,

Examples of Tests and Frequencies

Item	Test	Frequency
Man-riding basket	Load test to 1.25 SWL	12 months
Compressors	Gas purity	6 months
Cylinders/pressure vessels not taken underwater (dry)	PLT to WP	2.5 years
	Internal inspection & 1.1 *x* PLT	5 years
Cylinders/pressure vessels not taken underwater (wet)	Internal inspection and PLT to WP	15 months
	Internal inspection and 1.5 *x* PLT	5 years
Cylinders taken underwater	Internal inspection & PLT	2 years
	Hydraulic test to 1.5 *x* WP	4 years
Bailout bottles	As above plus internal inspection	6 months
Lifting appliances *** man-riding**	Static load test to 1.5 *x* SWL & NDT + static load test to 1.25 *x* SWL	12 months * 6 months
Hydraulic power units	Fluid analysis or replacement	12 months
Pipework systems, valves, regulators, etc.	PLT at max. WP	2 years
Relief valves	Function test at required settings	2.5 years
Bursting discs	PLT to WP	2.5 years
	Replace	10 years
Pressure Vessels for Human Occupancy	Internal exam & PLT to WP	2.5 years
Viewports	Complete renewal	10 years
Welded pressure vessels (not PVHO)	Internal inspection & PLT to WP	2.5 years
Umbilicals	PLT to max. WP	2 years
Wire rope and terminations (man riding)	Cut back beyond first sheave and test to destruction, re-terminate and apply static load test to 1.5 x SWL	12 months
Bell ballast release systems	Test to 1.5 x static load in air and NDT function test of all components test and confirm bell positively buoyant	12 months
Lift bags	Load test to SWL	12 months
Hyperbaric evacuation launch systems	Visual exam	12 months
	Falls turned end for end	2.5 years
	Normally renew	5 years
Emergency survival packs and passive scrubbers	Bell: Unpack and check	12 months
	HLB: Unpack and check	3 years

This list is for information only and is not exhaustive.
See IMCA D018 for full details.

Maintenance of Plant 9.1.2

This section provides general guidance on maintenance procedures for the major items of diving plant and equipment to ensure they are maintained to a safe standard.

It is important that maintenance is carried out to a high standard, efficiently and regularly, and that records are kept within the framework of a Planned Maintenance Programme. Various record systems can be used, depending on the size of the diving Contractor and the extent and complexity of the plant and equipment. They range from an entirely manual approach to a fully computerised system. However, the need for strict procedure (covering the type, frequency and method of recording the technical data), is the same whatever approach is adopted.

Once organised and put into practice, a Planned Maintenance Programme should ensure that efficient and properly maintained plant and equipment is always available for use. The following notes and examples describe, in general terms, the main features that need to be considered when setting up such a Programme.

It is essential that this work is carried out under proper supervision by personnel having suitable training or experience.

The purpose of a Planned Maintenance Programme is to provide field and support personnel with all necessary instructions and schedules to enable them to carry out and record the various maintenance tasks. Although it must have a clear structure, it should have flexibility to cater for unexpected events such as breakdowns and extended operational usage. Normally most companies will institute the planned maintenance system from base. It will be specifically designed by quality control engineers for the individual system. In a computerised system the daily, weekly and monthly maintenance tasks will be identified by the computer and sent offshore as required by telex or computer link. These tasks will then be addressed by the individual having responsibility for them, such as a dive technician or electrical technician, and when complete he will notify the base or office from which the instructions were sent.

Maintenance Intervals

The frequency of maintenance checks, inspections and adjustments is obviously dependent on the particular item of plant and equipment, its expected usage rate, environmental conditions and other factors. It is not possible within this manual to define exact periods; some items may have to be related to hours or operational usage rather than a fixed period. However, most maintenance is likely to involve work at daily, weekly, monthly, six monthly and yearly intervals.

Daily and weekly checks are generally fairly basic to ensure that all items are functioning correctly, are in good working order, and free from apparatus defects.

The monthly maintenance operations, although possibly based on or including the shorter term checks, involve additional work as recommended by the equipment supplier, such as oil changes and filter replacement.

Longer term maintenance is often considerably more comprehensive - involving major overhauls and total parts replacement, together with any testing and examination required by statutory regulations.

Spares And Special Tools

It is essential that an adequate supply of spare parts is readily available to enable plant to be serviced or repaired with the minimum of delay. Spares coverage should, in the first instance, be based on recommendations from equipment suppliers but due account should be taken of expected delivery times and any supply problems that may be envisaged. These factors, combined with practical experience, may indicate that a higher level of spares stocks is required. Any special tools that may be required should be readily available and it is suggested that they are made part of the ‘spares kit’.

Safety

The safety of technicians and other personnel must always be considered when preparing a maintenance programme. Full account should be taken of conditions at the work site, including ease of access (which could be of particular importance if lifting operations are involved) equipment location (i.e. whether it is in a hazardous area) and other considerations such as electrical safety.

At any work site there should be a comprehensive set of safety rules and regulations covering all activities likely to be carried out there. They must be followed at all times but, in addition, technicians and other personnel should be working to their own company's safety rules. The following notes on electrical safety are included as a typical example.

Authorisation

Before commencing work on any electrical system it is necessary to ensure that the proposed work does not conflict with work site safety procedures. This is normally achieved through a 'permit to work' scheme.

Circuit Isolation

Where appropriate, circuits should be switched off before work commences. Isolation should be checked using a suitable voltmeter. Other conducts or switch-gear sufficiently close to the area of work to constitute a hazard should also be similarly isolated.

Once isolated it is important to ensure that circuits cannot be accidentally reconnected. This can be achieved in a number of ways. Isolator switches should be padlocked in the off position, fuses removed or other action taken to ensure that isolated circuits cannot accidentally by reconnected.
Suitable notices should be displayed to indicate that work is being carried out on electrical circuits.

Personnel Safety

When working with live conductors, another person must be at hand to assist in the event of an accident. Other personnel who may enter the work area should be warned of the potential hazard from live conductors exposed for test purposes.

Temporary cable runs should always be routed clear of walkways, access doors, etc.

The use of 240 v power tools should be avoided wherever possible. A 110 v supply, with a residual current circuit breaker (RCCB) in line, should be used, and the system should be checked prior to use.

PLANT MAINTENANCE DOCUMENTATION 9.2

Any Planned Maintenance Programme (P.M.P.) should be supported by appropriate documentation. As part of this, each operation should be recorded formally, noting the spare parts or consumables used and any additional work found to be necessary. A rigidly controlled recording system provides vital information on the condition of all items of plant and equipment together with the level of spares coverage that needs to be catered for.

The documentation for each item of plant and equipment comprises technical data sheets, maintenance schedules, maintenance records and reference documents.

Technical data sheets

Technical data sheets should provide the equipment department and maintenance technicians with an abbreviated listing of relevant technical data and other information.

Typical Headings For A Compressor Are:

- Equipment name and model number.
- Equipment serial number.
- Location at work site.
- Details of manufacturer or agent.
- Location of reference documents, e.g., maintenance manuals, spares lists.
- Test and examination information,
- Technical data:

Type	Speed Range
Maximum rating	Electrical and motor details
Number of cylinders and stroke	Bore size
Cooling system	Direction of rotation
Lubrication system	Oil pressure
Consumable capacities	Recommended lubricants
Torque loadings	Component weights and dimensions

Maintenance Schedules

The maintenance schedules for each item of plant and equipment should specify, in sufficient detail, the checks to be made at each time interval.

Where Appropriate It Should Include Details On:

- Special safety instructions to be followed.

- Information on spares and consumables that need to be available, and (possibly)
- Information on the time that the more comprehensive checks will take to complete (thereby indicating the number of personnel required to complete a task in the time available).

Maintenance Records

A maintenance operation is incomplete without an accurate report of the task carried out, including spare parts used and any additional work found to be necessary. Accordingly, formal procedures should be implemented for recording all planned maintenance checks (and any unplanned repairs that may arise due to breakdowns or failures). The reports should be completed by the technician doing the work and checked by the Senior Supervisor, with copies being retained at the work site, the onshore equipment department and any other appropriate locations.

The Planned Maintenance Report Should Include, But Not Necessary By Limited To:

- Period (from / to).
- Work Site.
- Equipment name.
- Equipment identification number.
- Type of maintenance performed (weekly / monthly, etc.).
- Spare parts used.
- General comments.

The repairs report should provide details of any failure or breakdown occurring either during or between a planned maintenance inspection.

It Should Include:

- Work site.
- Equipment name.
- Equipment identification number.
- Hours run.
- Date of last inspection.
- Description of failure.
- Reason for failure.
- Description of repair.
- Spare parts used. Maintenance Of Plant
- Any limitations on further use.
- Signature of person carrying out the work.

For ease of use and continuity of presentation, these reports could be (and vey often are) in the form of pre-printed pads.

Reference Documents

A full set of operations and maintenance handbooks for each item of plant and equipment should be available at the work site. They should be obtained from the equipment supplier and used by technicians when operating, servicing or dismantling equipment. Handbooks should be prepared in-house for plant and equipment that has been produced by or on behalf of the Contractor and for which standard documentation is not available.

LOGGING OF DIVING OPERATIONS 9.3

Diving Contractors should provide a diving operations log book (record) and the Diving Supervisor has a specific responsibility to complete it on a day-to-day basis, and to sign all entries during the course of the diving operation that he controls.

In the UK it is required that the diving operations log book contains prescribed information. A clear record should be kept of all incidents affecting the safety of members of the diving team.

Log books should be maintained for all conventional diving operations, as well as for simulated diving in surface compression chambers for which equivalent records need to be kept.

The following particulars are required by the DWR to be included in the diving operations record.

- Name and address of diving Contractor.
- Date of entry and name of the supervisor(s).
- Location of the diving operation, including the name of the vessel or installation.
- Names of those taking part in the diving operation as divers and other members of the team.

- ACOP that applies to the diving operation.
- Purpose of the diving operation.
- Breathing apparatus and mixture used by each diver.
- Time at which diver leaves and returns to atmospheric pressure and bottom time.
- Maximum depth, which each diver reached.
- Decompression schedule containing details of the pressures and the duration of time that divers spent at those pressures during decompression.
- Emergency support arrangements.
- Any emergency or incident of special note which occurred during the operation, including details of any decompression illness and the treatment given.
- Details of the pre-dive inspection of all plant being used in the operation.
- Any defect recorded in the functioning of any plant used in the operation.
- Particulars of any relevant environmental factors during the operation.
- Any other factors likely to affect the safety or health of any persons engaged in the operation.
- Name and signature of the supervisor completing the record.
- Company stamp (if appropriate).

Diver's Log Book and Certificate of Training 9.3.1

Each diver should maintain a personal diving log-book containing his photograph, medical certificate and details of his diving activity. A diver's log book should also be kept by anyone who is exposed to pressure for the purpose of diving operations, including those who may be involved in simulated diving in surface compression chambers.

Anyone who may have to enter a surface compression chamber in an emergency need not keep a log book. In the UK, the medical certificate must be an integral part of the log book, be up-to-date and have been completed by an approved doctor.

It is the diver's personal responsibility to ensure his log-book is kept up-to-date, to keep it safe and to ensure that it contains the necessary certificates. The day-to-day 'dive record' which the diver maintains in his log book should be countersigned by the Diving Supervisor responsible for the day's diving operations. If a diver loses his log book, medical certificate or certificate of training, he should notify his Diving Supervisor or his employer as soon as possible. If these documents are not at the diving site, he should not be allowed to dive.

If he loses his medical certificate, he will need to be re-certified as fit to dive. Wherever possible the diver should contact the approved doctor who last examined him and request re-certification. If this is not possible he must submit himself to another approved doctor for a full examination. If he is passed fit, a new medical certificate will be issued.

If he loses his certificate of training, he must first inform his Diving Supervisor or employer and then apply for a replacement to the person or organisation that issued the original certificate. In the UK, he may be referred to the Health and Safety Executive and may have to attend an interview before a new certificate is issued.

Each diver, and any other person who requires a divers log book, should keep his log book for a period of at least two years from the date of his last entry in it. It cannot be over stressed that the safe keeping of a divers log book is the divers personal responsibility, and without it he should not be allowed to work.

Specific details should be entered in the divers log book in respect of each diving operation in which he takes part. Whilst there is no prescribed or preferred log book for divers, the standard IMCA log book is acceptable to the UK and Norwegian authorities and is used on a world-wide basis.

The following details are required in the diver's log by the Commercial Diving Offshore ACOP:

- The name and signature of the diver.
- Name and address of the diving Contractor.
- Date to which entry relates.
- The location of the diving operation, including the name of any vessel or installation from which the diving is taking place.
- The maximum depth reached on each occasion.
- The time the diver left the surface, his bottom time and the time he reached the surface on each occasion.
- Where the dive includes time spent in a compression chamber, details of any time spent outside the chamber at a different pressure.

- Breathing apparatus and breathing mixture used by the diver.
- Any decompression schedules followed by the diver on each occasion.
- Any work done by the diver on each occasion and the plant (including any tools) used in that work,
- Any episode of barotrauma, discomfort or injury suffered by the diver, including details of any decompression illness and the treatment given.
- Any emergency or incident of special note which occurred during the operation.
- Any other factor relevant to his safety or health.
- Name and signature of the authorised representative of the diving Contractor (this will normally be the supervisor) who confirms the details recorded.

ACCIDENT REPORTING 9.4

Most countries and (all) Diving Contractors have a requirement to report accidents and near misses. Although they differ in minor details most companies' procedures are very similar.

Accident reporting in the UK is governed by RIDDOR.

RIDDOR 9.4.1

The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 (RIDDOR), came into effect on 1st April1996. This requires injuries, diseases, and dangerous occurrences to be reported to the HSE.

The duty to report an incident falls on the 'responsible person'.

Offshore This Is:

Event	Responsible person
1. Injury or dangerous occurrence on an offshore installation	Installation owner or operator
2. Injury or dangerous occurrence during a diving operation	Diving contractor
3. Injury occurring during an activity in connection with an offshore installation or a well or during pipeline works (other than an injury under 1 or 2 above)	Employer of employee or person in control of place where self-employed person injured.
4. Dangerous occurrence at a pipeline	Pipeline owner
5. Dangerous occurrence at a well	Well operator or concession owner
6. Dangerous occurrence during an activity in connection with an offshore installation or during pipeline works (other than an occurrence under 1 or 2 above)	Person in control of place where incident occurs (e.g. vessel owner or contractor)
7. Case of disease	Employer of employee or self-employed person.

When To Report

Injuries

The Offshore Safety Division (OSD) of the HSE must be notified without delay, normally be a phone call, of any fatal or major injuries. The site of an incident must not be disturbed for 3 days without an inspector's permission.

Within ten days this must be followed up with a completed accident report form (OIR/9B). If anyone suffers an injury that is not considered major, but results in them being away from work or unable to do their normal work for more than three days, OIR/9B must also be completed and sent to OSD within 10 days.

Dangerous Occurrences

If something happens which does not result in a reportable injury, but which could have done, it may be a dangerous occurrence that must be reported immediately, normally be telephone.

Within 10 days this must be followed up with a completed OIR/9B.

Disease

If a doctor diagnoses that an employee is suffering from a reportable disease it must be reported (on form F2508A).

Record-keeping

A record must be kept of any reportable injury, dangerous occurrence or case of disease. This must include the date, time and place, personal details of those involved and a brief description of the nature of the event or disease.

What <u>Has</u> To Be Reported

Reportable Major Injuries:

- Fracture, other than to the fingers, thumbs or toes.
- Amputation.
- Dislocation of the shoulder, hip, knees or spine.
- Loss of sight (temporary or permanent).
- Chemical or hot metal burn to the eye or penetrating injury to the eye.
- Injury resulting from electric shock or electrical burn leading to unconsciousness or requiring resuscitation or admittance to hospital for over 24 hours.
- Any other injury leading to hypothermia, heat induced illness or unconsciousness; or requiring resuscitation; or requiring admittance to hospital for over 24 hours.
- Unconsciousness caused by asphyxia or by exposure to a harmful substance or biological agent.
- Acute illness requiring medical treatment or loss of consciousness, arising from the absorption of any substance by inhalation, ingestion or through the skin.
- Acute illness requiring medical treatment where there is reason to believe that this resulted from exposure to a biological agent or its toxins or infected material.

Reportable Dangerous Occurrences

The following is a summary of the reportable dangerous occurrences, which may occur offshore.

The identifying number should be given in the report.

Identifying number	Dangerous Occurrence
1	Collapse, overturning or failure of load-bearing parts of lifts and lifting equipment;
2	Explosion, collapse or bursting of any closed vessel or associated pipework;
3	Failure of any freight container in any of its load-bearing parts;
5	Electric short circuit or overload causing fire or explosion;
6	Any unintentional explosion;
7	Accidental release of a biological agent likely to case severe human illness;
8	Failure of industrial radiography or irradiation equipment to de-energise or return to its safe position after the intended exposure period;
9	Malfunction of breathing apparatus while in use or during testing immediately before use;
10	Failure or endangering of diving equipment, the trapping of a diver, an explosion near a diver, or an uncontrolled ascent;
11	Collapse or partial collapse of a scaffold over five metres high, or erected near water where there could be drowning after a fall;
13	Incidents in relation to a well;
14	Incidents in relation to a pipeline or pipeline works;
73	Release of petroleum hydrocarbon on or from an offshore installation;
74	Fire or explosion at an offshore installation, other than one to which paragraph 73 applies;
75	Release or escape of a dangerous substance other than petroleum hydrocarbon on or from an offshore installation;
76	Collapse of an offshore installation or its plan;
77	Failure of equipment required to maintain a floating offshore installation on station; dropped objects on an offshore installation or an attendant vessel or into water nearby; or damage to or on an offshore installation caused by adverse weather conditions;
78	Collision between a vessel or aircraft and an offshore installation;
79	Occurrences with the potential for a collision between a vessel and an offshore installation;
80	Subsidence or local collapse of the seabed near an offshore installation;
81	Loss of stability or buoyancy of a floating offshore installation;
82	Evacuation (not otherwise reportable) of an offshore installation, in the interests of safety.

Reportable Diseases

The list includes:

- Certain poisonings.

- Some skin diseases such as occupational dermatitis, skin cancer, chrome ulcer, oil folliculitis/acne.
- Lung diseases including: occupational asthma, pneumoconiosis, asbestosis, mesothelioma.
- Infections such as: hepatitis, legionellosis, tuberculosis and tetanus.
- Other conditions such as: occupational cancer; certain musculoskeletal disorders; decompression illness and hand-arm vibration syndrome.
- Food poisoning / bacterial or viral gastroenteritis.

Fatal Accident Procedures

This procedure is followed whether or not the fatality occurs subsea or on the surface, and whether or not the body has been recovered.

The Superintendent / Offshore Manager will inform:

- The Client's representative,
- The Vessel Master.

The Superintendent / Offshore Manager will give accident details to:

- The Police,
- An Inspector of the Health and Safety Executive Diving Inspectorate,
- Senior Officers of his employer.

Informing Next Of Kin

No communication should be made to the news media, next of kin or others outside of the above groups.

The Superintendent/Offshore Manager shall ensure that the following actions are taken:

- Resuscitation attempts must be the priority. Any adjustments made to any equipment during these attempts must be recorded so that original positions are known.
- The accident site and equipment must not be disrupted for three full days or until a person acting for the police and/or the Secretary of State has completed the investigation within the limitations.

EQUIPMENT CHECKLISTS 9.5

This Section Presents Guidance On:

- The examination of plant and equipment in the six hours before the start of a diving operation.
- Examinations to be undertaken immediately before the start of the operation.

The two sections apply, as appropriate, to inland, inshore and offshore diving operations.

The tables provide a comprehensive checklist of the main items of plant and equipment to be examined before a diving operation starts.

The lists may be used as a guide by Diving Supervisors in preparing their operational lists in accordance with relevant national requirements and local site conditions. Operational lists will also be governed by the frequency of diving - in a continuous shift-based diving operation, some checks need to be done only at the start of the whole operation, while others should be undertaken before every new shift starts.

The diving Contractor should advise the Diving Supervisor on the procedures to be followed in drawing up his operational lists.

Six hour Checklist and Pre-Dive Checklist 9.5.1

All plant and equipment used in any diving operation should be checked by a competent person in the six hours before the diving operation starts.

In the UK, the diving regulations and accompanying guidance notes use the word ‘examination’ in the context of this pre-dive work as well as for the detailed inspections.

In order to differentiate between the detailed examinations and these more visual and functional examinations, the word ‘check’ is used here for the six hour and immediate pre-dive ‘examinations’.

The Checks Are In Two Distinct But Related Groups:

- Checks that can be undertaken at any time in the six hours prior to the start of the dive
- Checks that, for safety reasons, need to be undertaken as close to the start of the dive as practicable, i.e., within about 30 minutes.

The Diving Supervisor is responsible for ensuring that all these checks are carried out by a member of his team who has the necessary knowledge and experience. He should decide which members of his team should carry out the many and varied checks required. He should take into account the skill and experience of the individuals, and recognise fully the need for these important checks to be carried out in an effective and responsible way, bearing in mind his ultimate responsibility for the safety of the divers and other team members under his control.

Pre-dive checks should be recorded in the diving operations log-book. The Diving Supervisor should require members of his team designated to carry out individual checks to initial sections of his master list as appropriate. When it is complete, the Diving Supervisor should sign the full list and keep a record of it to support the entry made by him in the diving operations log-book.

The six-hour and pre-dive checks are generally visual, supported where necessary and reasonably practicable by function checks. The overall aim is to try to ensure that the plant and equipment is in working order. Some of the items in the tables may not be included in the plant and equipment made available for a specific operation and the lists, therefore, should be used on a selective basis. Conversely, items and checks may have to be added to cover special plant, or local conditions or regulations.

It should be noted that some of the pre-dive checks can only be reasonably carried out once the bell or diver has entered the water or reached the working depth.

In bell diving operations, arrangements should be made for recording all communications and it is recommended that such recordings should include the pre-dive checks.

The following tables show the checks that should be made not more than six hours before the start of a diving operation.

DIVING BELL (External) 9.5.2	
Item	**Checks**
General	Check for internal cleanliness Check that all identification labels are present Check that pre-dive checklist is available in bell Check that all certificates are in date
Doors	Check for ease of operation
Medical lock	Check for ease of operation Clean mating surfaces if necessary Inspect seals Check operation of clamping device
Door equalising valve	Check condition and operation
Viewports	Visually check for damage and security
Emergency diver winch	General visual inspection, including security of fixings Check winch operation Check harness for damage Check lifting wire and fittings
Diver seat harness	Check for damage, security of fixings and free operation
Primary CO_2 scrubber	Check security of units Check charge of new absorbent and spare supply Check electrical connector Functional check
Secondary CO_2 scrubber	Check availability, ensuring that any pre-packed units are undamaged
O_2 make up	Check security Check valves are in good condition and freely operable
O_2 analyser	Check security Function check using test gas
CO_2 analyser	Check security of test tubes or analyser
Gas supply non-return valves	Check security, damage and operation where applicable Check that all valves are in good condition and freely operable
Electrical penetrators	Visually check for damage and test security
Electrical wiring	Visually check for damage and test security
Primary lighting	Check security of units Check bulbs fitted Check connectors Functional check
Secondary lighting	Check security of units Functional check
Primary communications	Functional check
Secondary communications	Check equipment available
Tertiary communications	Functional check (sound powered system)
Primary heating system	Check for security and damage Check pipe connections Check electrical connectors
Emergency heating system	Visually check for damage and security
Hot water thermometer	Check for damage and security
Ballast weights	Check on weight release system
Inlet silencers	Visually check for damage and security

DIVING BELL (General). 9.5.3	
Item	**Checks**
Diver Umbilicals	Visually check umbilical and end connections for damage Check that all certificates are in-date
BIBS	Check for security Functional check Check that all certificates are in-date
Breathing mask	Visually check
Bail-out cylinder	Check physical security and inspect for damage Check content of cylinder for gas purity, mixture and pressure Check that valve is in good condition and freely operable Check integrity of hose to breathing mask Check that all certificates are in-date
Survival suits	Check installed and undamaged
Survival stores	Check date and quantity
Bell Handling System	
General	Visually check the whole of the system for damage and security Check that identification labels are present Check that all certificates are in-date
Winch power supplies - primary	Visual check Functional check
Winch power supplies - secondary	Visual check Functional check
Hoist winch	Visual check Functional check
Main lifting wire	Check for obvious damage between bell and winch Check condition of outermost wire on winch drum
Guide wire winches	Visual check Functional check
Guide wires	Check for obvious damage between ballast weights and winches Check condition of outermost wire on winch drum
Umbilical winch	Visual check Functional check
Umbilical - on reel	Check for obvious damage between bell and winch Check condition of outermost layer on winch drum (this exercise should be supplemented by a visual check of the umbilical as it is payed out during the diving operation) Check all connections between umbilical (winch) and individual services
Umbilical - flaked out on deck	Check for obvious damage where practicable (this exercise should be supplemented by a visual check of the umbilical as it is payed out during the diving operation) Check all connections between umbilical and individual services
A-frame or handling trolley	Visually check all bearings, pins and security fasteners for damage General visual inspection of frame members, including A-frame raising/lowering mechanism
Rolling doors	Functional check to ensure free operation
Sheaves	Visually check all lifting wire, guide wire and umbilical sheaves for condition and security
Lighting	Visually check that electrical cables and fittings are secure and free of obstructions Functional check
Communications systems	Functional check

Bell Control 9.5.4	
Item	**Checks**
Gauges - internal bell - External depth - Breathing mixtures - HW temperature - Bell temperature - Humidity - Diver depth	Check that gauges are showing correct reading and are in-date Check that isolation valves are in good condition and freely operable
Valves - HW - Breathing mixtures - Pre-mix	Check that they are in good condition and freely operable
Communications - Bell primary - Bell secondary - Bell tertiary - To winches - To chamber control - To bridge - Dive abort alarm - TV surveillance system - Tape recorder	Functional check Check supplies of spare tape available
Gas supply lines	Analyse all gases
Gas status board	Check that it is up to date
Fire fighting equipment	Check availability, date and condition
BA	Functional check
Diving tables	Check availability and date
Logs	Check availability and date
Gas analysers	Check availability and calibrate
Remote winch controls	Check security and condition of lines Functional check

Deck Decompression Chamber (mixed gas) – External 9.5.5	
Item	**Checks**
General	Check that no flammable or explosive material has been placed closed to the chambers(s) Check that no overhead objects could fall onto the chamber(s) Overall visual check for damage Check that all identification labels are present Check that all certificates are in-date
Doors	Check for ease of operation Check mating surfaces Inspect seals Check operation of latching device
Medical lock	Check operation of doors Clean mating surfaces if necessary Inspect seals Check operation of clamping device
Viewports	Visually check for damage and security
Valves	Check that all valves are in good condition and freely operable
Electrical penetrators	Visually check for damage and security
Fire fighting equipment	Check availability and condition
Bell mating clamp	Visually check for damage and functional check

Deck Decompression Chamber (mixed gas) - Control Room. 9.5.6	
Item	**Checks**
General	Check that all identification labels are present Check that all certificates are in-date
Gauges - chamber - gas supply - temperature and humidity	Check that all gauges are showing correct readings and are in-date Check that isolation valves are in good condition and are freely operable
Valves	Check that all valves are in good condition and freely operable
Communications	Functional check all comms.
TV surveillance system	Functional check
Gas	Analyse all gases Check diving system 'sniffer' system
Fire fighting equipment	Check availability and condition
BA	Functional check
Diving tables	Check availability and date
Logs	Check availability and date
Gas analysers	Check availability and calibrate

Deck Decompression Chamber (Air) – Internal. 9.5.7	
Item	**Checks**
General	Check for internal cleanliness Check that all identification labels are present Check that all certificates are in-date
Viewports	Visually check for damage and security
BIBS	Check for security Functional check
Inlet silencer	Visually check for damage and security
Valves	Check that all valves are in good condition and freely operable
Gauges	Check that gauges are showing correct readings and are in-date Check that isolation valves are in good condition and freely operable
Medical kit	Check availability and date
Electrical penetrators	Visually check for damage and security
Electrical wiring	Visually check for damage and security
Lighting	Check security of units Check connectors Functional check
Communications	Functional check
Heating system	Check for damage and security Check pipe work connections Functional check
Bedding etc.	Check cleanliness etc. Check that no flammable material is present
CO_2 scrubber	Check security of unit Check new charge of absorbent and spare supplies Check electrical connector Functional check

Deck Decompression Chamber (mixed gas) – Internal. 9.5.8	
Item	**Checks**
General	Check for internal cleanliness Check that all identification labels are present Check that all certificates are in-date
Viewports	Visually check for damage and security
Primary CO_2 scrubber	Check security of units Check charge of new absorbent and spare supplies Check electrical connector Functional check
Secondary CO_2 scrubber	Check availability, ensuring all pre-packed units are undamaged
BIBS	Check for security Functional check
O_2 Make up	Check that valves are in good condition and freely operable Functional check
Mixed gas supply	Check that valves are in good condition and freely operable
Inlet silencer	Visually check for damage and security
Gas sampling line	Check that valves are in good condition and freely operable
Electrical penetrators	Visually check for damage and security
Electrical wiring	Visually check
Lighting	Check security of units Check connectors Functional check
Communications	Functional check
TV surveillance system	Check security of units Check connectors Functional check
Heating system	Check for security and damage Check pipe connections Functional check
Environmental controls	Visually check for damage Functional checks
Instruments	Check that gauges are showing correct reading Check that any isolation valves are in good condition and freely operable
Over pressure alarm system	Visually check wiring and connectors Functional check
Shower	Check security of fitting and connectors Functional check
Wash basin	Check security of fitting and connectors Functional check
Toilet	Check security of fitting and connectors Functional check
Bedding, etc.	Check cleanliness where appropriate Check that non-flammable materials only are present
Medical kit	Check availability and date
Fire extinguisher	Check availability, date and condition
Pre-dive check lists	Check availability

Surface Demand Diving Equipment. 9.5.9	
Item	**Checks**
General	Visually check security and condition of control panel and related equipment Check that all identification labels are present Check that all certificates are in-date
Hoist winch power supply	Visual check Functional check
Hoist winch	Visually check whole system for damage and security Check wire for obvious damage between stage and winch Check condition of outermost layer on drum as far as practicable
Main lifting wire	Check wire for obvious damage between stage and winch Check condition of outermost layer on drum as far as practicable
Handling frame	Visually check all bearings, pins and security fasteners for damage General visual inspection of frame members and sheaves, including A-frame raising and lowering mechanism
Diving stage	Visually check for security and condition Check connection between lifting wire and stage, including pin and safety device Visually check wire socket connection] Check fixings between stage and basket Check condition of basket, ensuring all safety devices fitted
Ladders	Check security and condition
Divers umbilicals	Visually check umbilical and end connections for damage
Breathing equipment	Functional test
Gas cylinders	Check physical security and inspect for damage Check content of each cylinder for gas purity and pressure Check that valves are in good condition and freely operable
Bail-out cylinders	Check physical security and inspect for damage Check content of each cylinder for gas purity and pressure Check that valves are in good condition and freely operable
Gauges - HP air - LP air - depth	Check that gauges are showing correct readings and are in-date Check that isolation valves are in good condition and freely operable
Valves - HP air inlet - Reducer	Check that valves are in good condition and freely operable
Lighting	Visually check that electrical cable and fittings are secure and free of obstructions Functional check
Communications	Functional check
Strobe lights	Check availability

Gas Storage; Compressors; Generators. 9.5.10	
Item	**Checks**
Gas storage: bottles, quads, tubes and associated pipe work	
Siting	Check that single cylinders and quads are secure Check that there are no overhead objects that could fall onto the unit(s) Check that no flammable or explosive material has been placed close by Check that O_2 cylinders, or cylinders with an O_2 content of 25% or higher, are sited separately from other gas supplies and in a safe place
General	Visual examination for general condition Check that all identification labels are present Check that all certificates are in-date
Gas test	Carry out gas test on all cylinders for purity, pressure and content
Valves	Check that all valves and isolation valves are in good condition and freely operable
Gas cylinder manifold	Inspect for damage Check security of all connectors Check that all valves are in good condition and freely operable
O_2 pressure regulator	Functional check
Fire fighting equipment	Check that suitable fire fighting equipment is in a suitable location and in good condition
Compressors	
General	Visual examination for damage and defects Check that all identification labels are present Check that all certificates are in-date
Filter unit	Check information contained in running log and replace filter in accordance with manufacturers instructions
Inlet/exhaust	Check that inlet and exhaust are suitably located
Safety relief valve	Functional check
Emergency Diesel Generator	
Fuel	Check level
Lubricant	Check level
Starter	Check condition, including batteries and air bottle
Operation	Functional check

Pre-Dive Checklist. 9.5.11	
Item	**Checks**
Breathing equipment	Check that al breathing equipment is functioning properly
Communications	Check functions of all systems
Decompression tables	Check availability
Divers kit	Thoroughly check all individual equipment associated with the diver once kitted up
Doors	Check that all doors are closed and latching devices in the correct positions
Electrical switches	Check that all switches are in the correct positions
Emergency procedures	Check availability
Gauges	Check that all gauges are showing the correct readings
Lighting	Check function on all systems
O_2 analyser	Check that reading is correct
Relocation device	Check that unit is switched on and functioning correctly
Strobe light	Check that unit is switched on and functioning correctly
TV system	Check that unit is switched on and functioning correctly
Valves	Check that all valves are in their correct positions
Winch brakes	Check operation of guide wire winch, main hoist winch and umbilical winch
In water	
Bell heating	Check function
Communications	Check function
Depth gauge(s)	Check reading
Divers gas heating	Check function
Divers suit heating	Check function

TRAUMA TRAINING

Website: www.trauma-training.org
E-mail: info@trauma-training.org