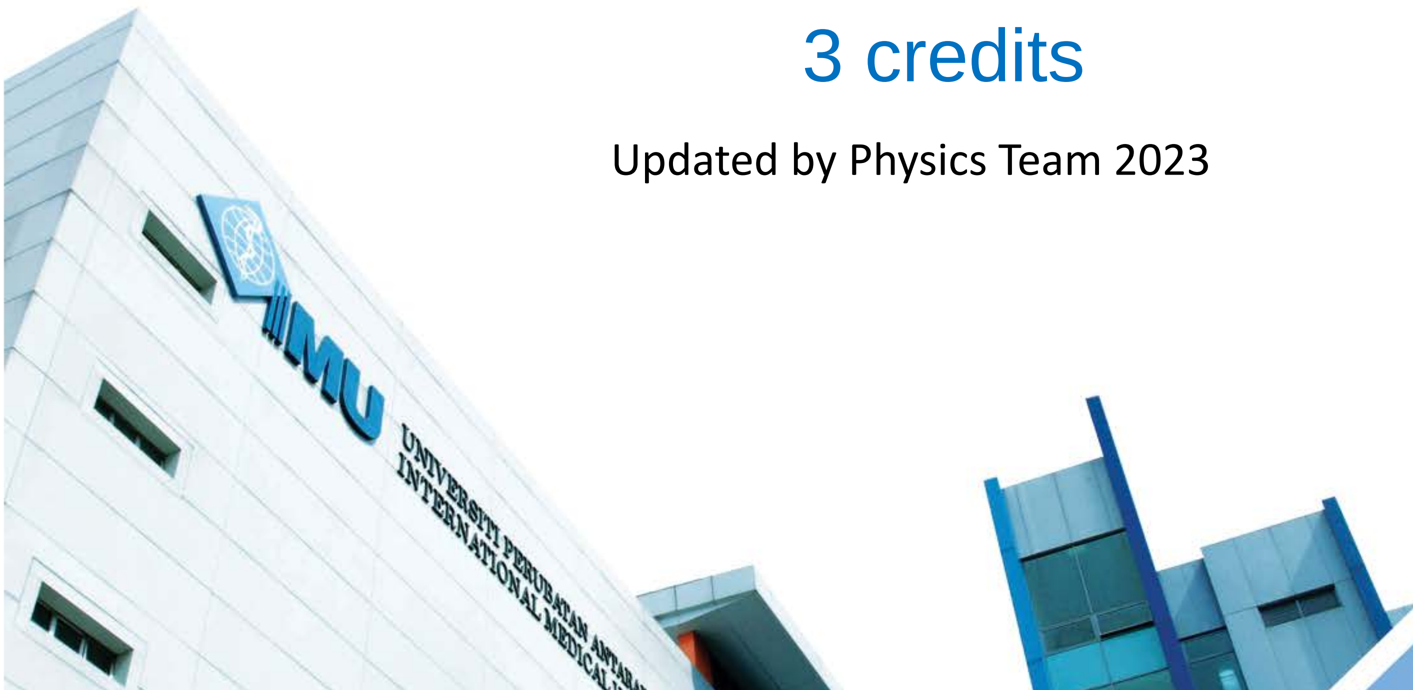
IMU
INTERNATIONAL MEDICAL UNIVERSITY
MALAYSIA

Foundation in Science

Physics for Health Sciences

FS2053
3 credits

Updated by Physics Team 2023



Become the future of better healthcare

FS2053 Course Outline:

1. *Forces acting on the body (Lecture – 3 hours)*
2. Kinematics (Lecture – 2 hours)
3. Biomechanics (Lecture – 2 hours)
4. Heat and body temperature (Lecture –2 hours)
5. Pressure, fluids, gases and breathing (Lecture – 2 hours)
6. Sound and hearing (Lecture – 2 hours)
7. Electromagnetic Spectrum, light and vision (Lecture – 4 hours)
8. Electricity (Lecture – 4 hours)
9. Diagnostic X-rays (Lecture – 1.5 hours)
10. Radioprotection in medicine (Lecture – 1.5 hours)

FS2053 reading list:

1. Dr Zainal Abidin (2022) Physics for Matriculation Semester 1, SAP Publication.
2. Poh Liong Yong 5th Edition (2018) Physics for Matriculation Semester 1, Oxford Fajar Publication.
3. Poh Liong Yong 4th Edition (2019) Physics for Matriculation Semester 2, Oxford Fajar Publication.

FS2053 Chapter 5 - Learning outcomes

Pressure, fluids, gases and breathing

By the end of the lesson, you should be able to:

- Explain the gas laws and their application to the behaviour of gases in different conditions.
- Define pressure, pascal principle and explain its significance in various contexts.
- Describe the process of breathing.
- Differentiate between lung volume, lung capacity and understand their relevance to respiratory physiology.
- Understand the function of blood pressure and blood vessels in the human body, including arteries, veins, and capillaries.

The Gas Laws

- a set of fundamental principles in physics and chemistry that describe the behaviour of gases under different conditions.
- establish relationships between the variables such as :

  Pressure (P) in Pa or Nm^{-2}
  Volume (V) in m^3
  Temperature (T) in K
  Amount Of Substance (n) in mole

- can be used to compare two different gases, or determine the properties of a gas after one of its state variables have changed
- There are several gas laws, including Avogadro's Law, Boyle's Law, Charles's Law, Pressure Law, and the Ideal Gas Law.

The Gas Laws

Properties	Description
V/n = constant	**Avogadro's Law** states that equal volumes of all ideal gases (at the **same temperature and pressure**) contain the same number of particles, 6.02×10^{23}
PV = constant	**Boyle's Law** states that equal pressure is inversely proportional to volume (when **temperature is constant**)
$\frac{V}{T}$ = constant	**Charles's Law** states that volume is proportional to temperature **(when pressure is constant).**
$\frac{P}{T}$= constant	**Pressure Law** states that pressure is proportional to temperature (**when volume is constant**).

These separate gas laws are then combined to give one overall equation that governs the behavior of gasses – **The Ideal Gas equation**

Ideal Gas equation

Pressure x Volume $\propto$ Temperature

$$\boxed{PV = nRT}$$

Where $\boldsymbol{R = 8.314\, JK^{-1}.mol^{-1}}$ and **n=number of moles**

Atmospheric pressure
$\boldsymbol{= 76\ cmHg = 1.013 \times 10^{5} Pa = 1.013 \times 10^{5}\ Nm^{-2} = 10\ m\ water}$

This very important equation governs the behaviour of the world around us and many of the processes in the human body.

Boyle's Law

A bubble is at 25m below the surface of the sea. When the bubble rises to the surface of the sea, its volume becomes 10 cm^3. What is the original volume of the bubble?

Charles' Law

A cylinder contains 200 cm^3 of gas at a temperature of 27^oC. The gas is heated until its temperature increases by 30^oC. What is the final volume of the gas?

Pressure Law

A fixed mass of gas in an enclosed metal container has a pressure of 2.5×10^5 Pa. If the gas is heated from 27^oC to 87^oC, calculate the final pressure of the gas.

The Constant Volume Gas Thermometer

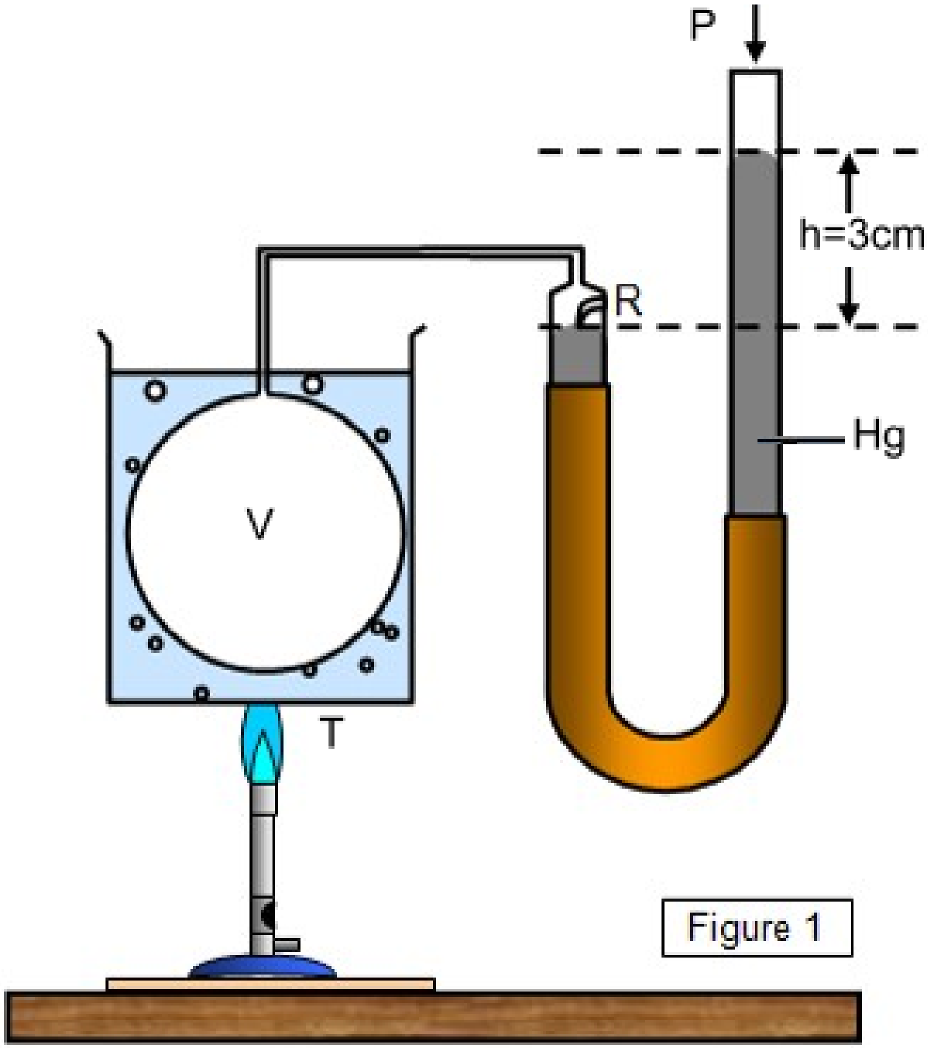


Figure 1

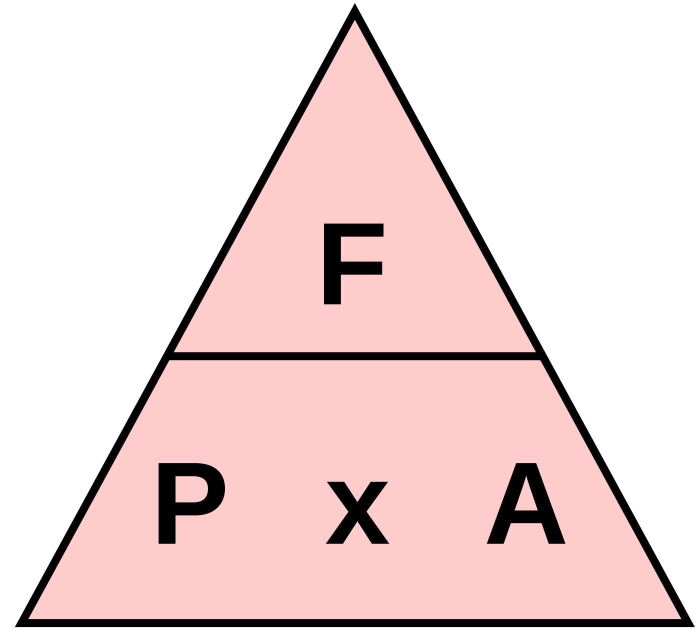
Gas Thermometer

- a thermometer containing gas (such as hydrogen) as the enclosed thermometric substance, variations in temperature being indicated by the change in pressure of a fixed quantity of gas required to maintain the gas at a constant volume or the change in volume of a fixed quantity of gas maintained at a constant pressure.

Calculating pressure

Pressure is the force per unit area and is calculated using this formula:

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$



Pressure is measured in:
Newtons per square metre (Nm^{-2}), which are also called **pascals** (**Pa**).

Using low pressure

A force spread over a large area means **low pressure**, e.g. skis and snowboards.

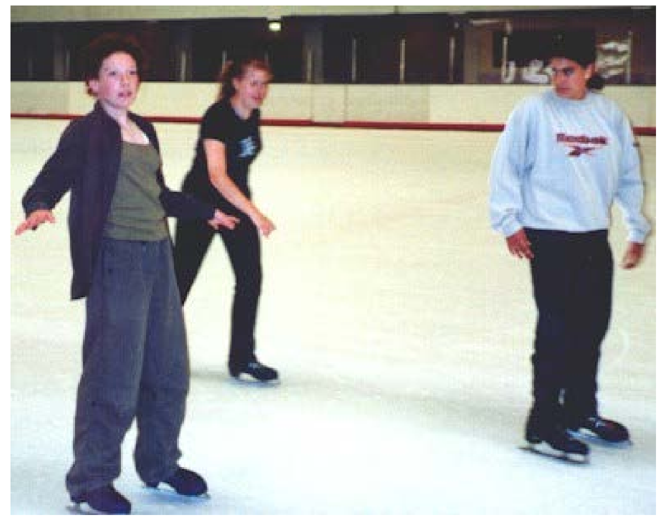
The large surface area of the board means the skier exerts very little pressure on the snow.

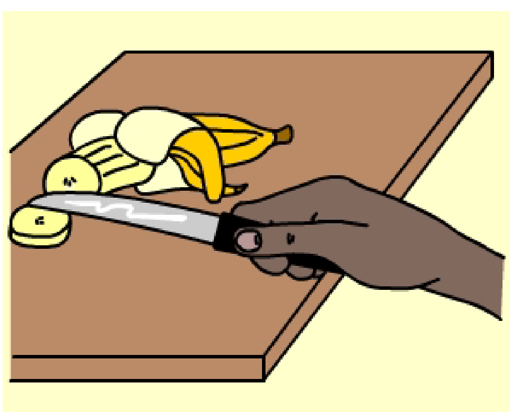
This means he slides over the top of the snow and does not sink into it.

Using high pressure

A force concentrated on a small area means **high pressure**, e.g. high heeled shoes, needles, ice skates, sharp knives.

The high pressure of the blade of an ice-skate melts the ice and helps the skater slide across the surface.



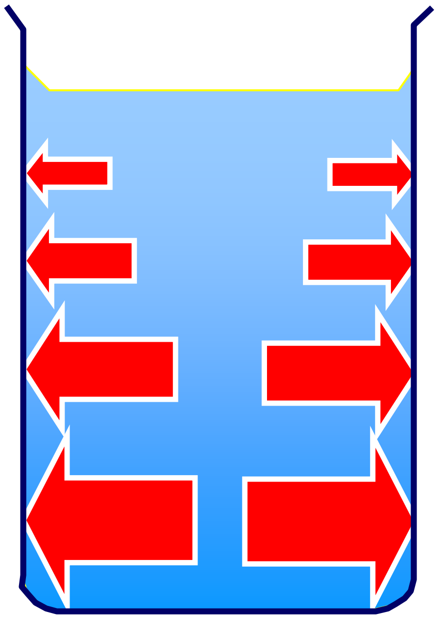


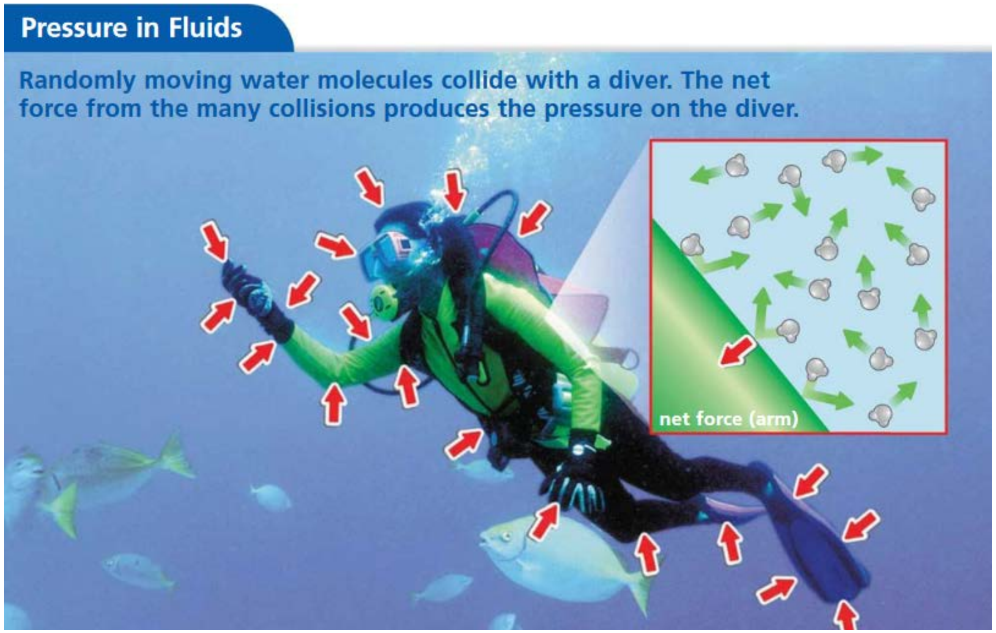
The narrow blade of a knife means that it exerts a high pressure and makes it easier to cut fruit and vegetables.

Pressure in a liquid

Pressure in a liquid :

- increases with depth
- acts in all directions

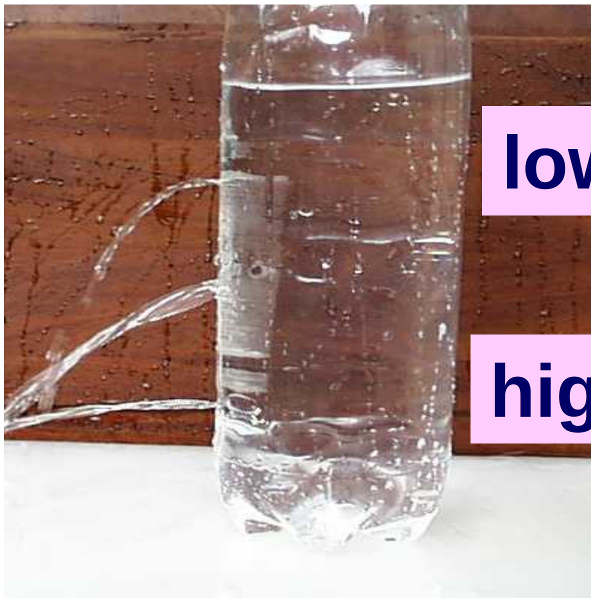




A liquid can be used to transmit pressure from one place to another = **Hydraulics**

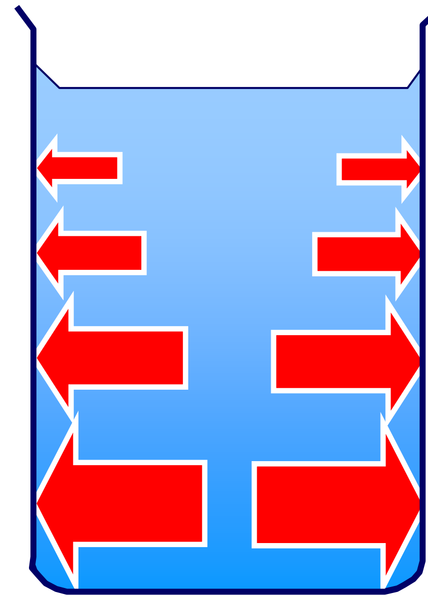
Pressure in a liquid

The relationship between pressure and depth is shown by a water bottle with holes along its length.



low pressure

high pressure

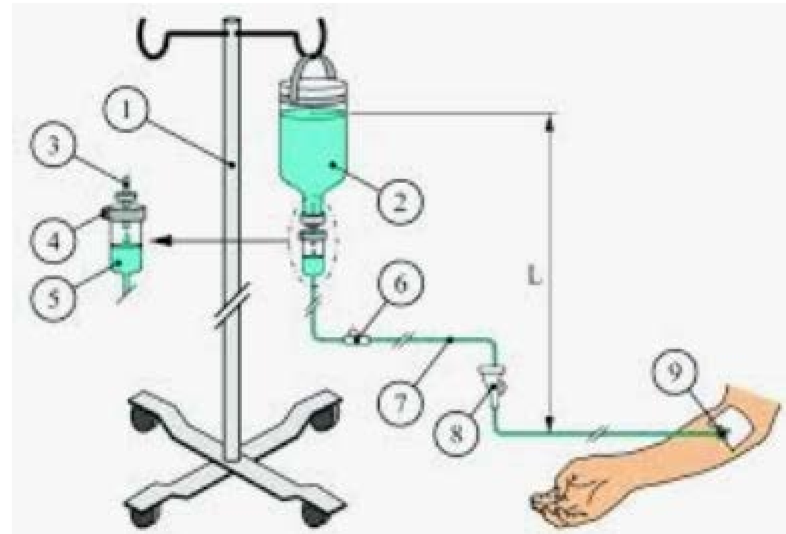


Pressure (Nm^{-2}) = $h\rho g$

h=depth from the surface of the liquid
ρ=density of the liquid
g=the pull of gravity

Poiseuille's law: IV fluids

The flow of fluids through an IV catheter can be described by Poiseuille's Law.



The flow of fluids increases when:

- The larger the diameter of a catheter.
- The lower the viscosity of the fluid.
- Utilizing pressure bag or pressurized infusion devices.
- Shorter the length of tubing.

$$Q = \frac{\pi P r^4}{8 \eta l}$$

Q	Flow rate
P	Pressure
r	Radius
η	Fluid viscosity
l	Length of tubing

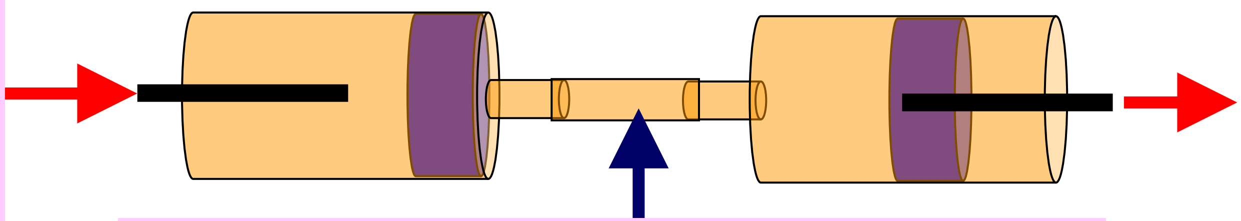
Hydraulics

Hydraulic systems use the principle that pressure is transmitted equally throughout an enclosed liquid (Pascal Principle).

They are used to transfer movement from one part of a machine to another without linking the parts mechanically.

All hydraulic systems use two pistons linked via a pipe carrying a special oil called hydraulic fluid.

Force applied here

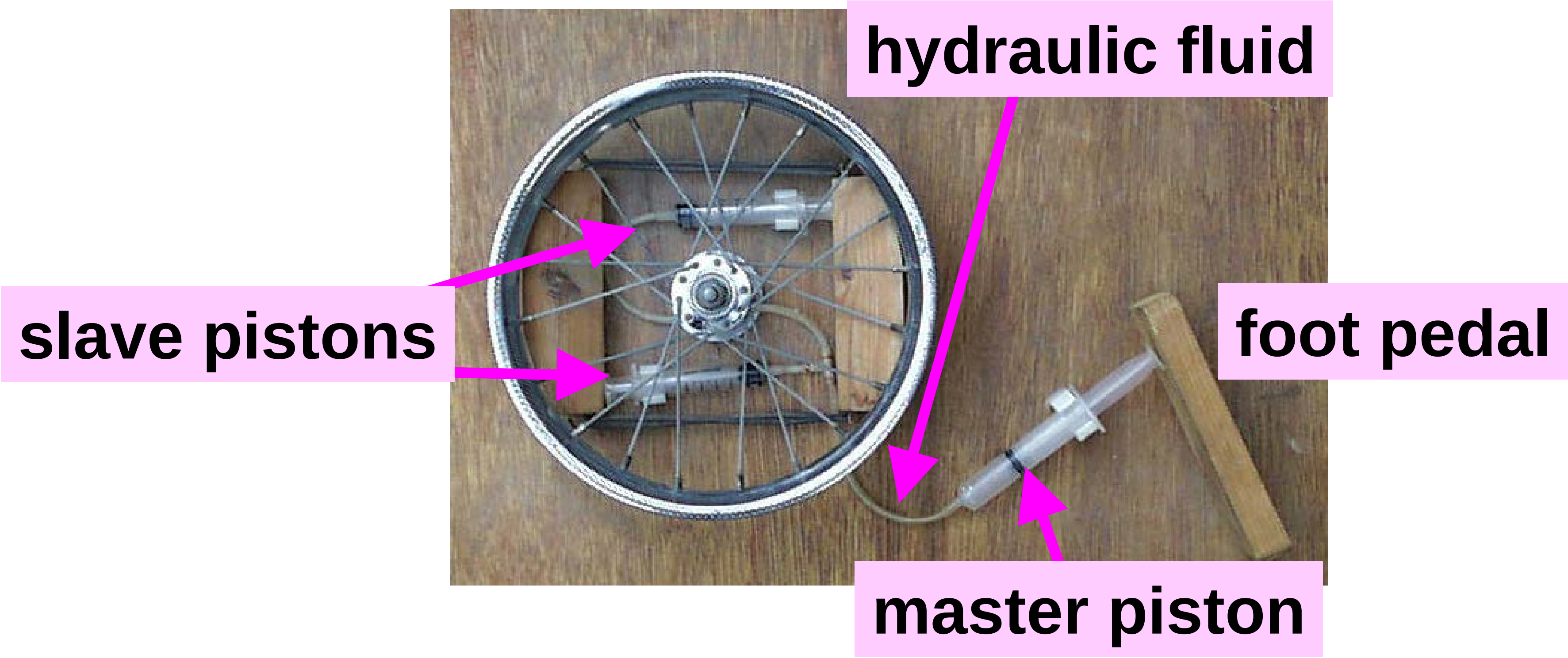


Force transferred here

Pressure inside all parts of the hydraulic system is the same

Hydraulic brake

All hydraulic brake systems (e.g. in a car) use a **small** master piston and a **bigger** slave piston.



The master piston is used to apply a force. This puts the liquid under pressure. The pressure is transmitted to the pistons on all four wheels of the car.

Hydraulic brake – pressure equations

The pressure exerted by the master piston on the hydraulic fluid can be calculated using this equation:

$$\textbf{pressure} = \frac{\textbf{force applied}}{\textbf{area of master piston}}$$

The pressure is transmitted to the slave pistons and so the force exerted by the slave piston can be calculated using:

$$\textbf{pressure} = \frac{\textbf{force exerted}}{\textbf{area of slave piston}}$$

force exerted = pressure x area of slave piston

The slave piston has a larger area than the master piston. So, the force exerted by the slave pistons on the brakes is greater than the force exerted by the driver on the brake pedal.

Hydraulic brake – calculations

The master piston of a car has an area of $5cm^2$.

1. If a force of 10N is applied to the master piston, calculate the pressure created in the brake pipes.

2. If the slave piston has an area of $50\ cm^2$, calculate the force exerted on the brake disc.

Basics of breathing

Humans breathe to ensure that oxygen enters the body and that carbon dioxide leaves the body.

The breathing system

Oxygen (O_2)

Carbon Dioxide (CO_2)

The 2 cycle breathing processes

The body separates the procedure of breathing in and breathing out.

Breathing in is one process and is known as…

Breathing out is a separate process and is known as…

Inhalation

(When we breathe in, we inhale)

Exhalation

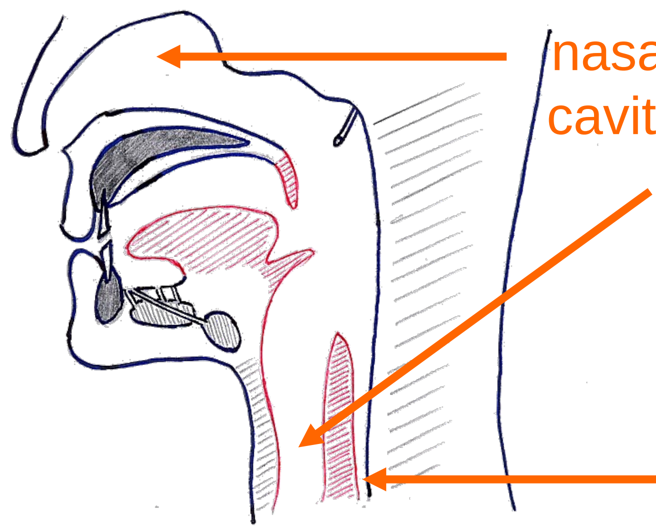
(When we breathe out, we exhale)

By separating these two processes, the body can concentrate on the two tasks in turn.

The pharynx

As the air passes through the nasal cavity, the air is smelt, warmed, filtered and moistened slightly.
The air meets at the pharynx, a junction at back of the oral cavity.

The pharynx is a junction between two tubes. The air must travel down only one of these tubes. One is the windpipe (trachea) and the other is the gullet (oesophagus).

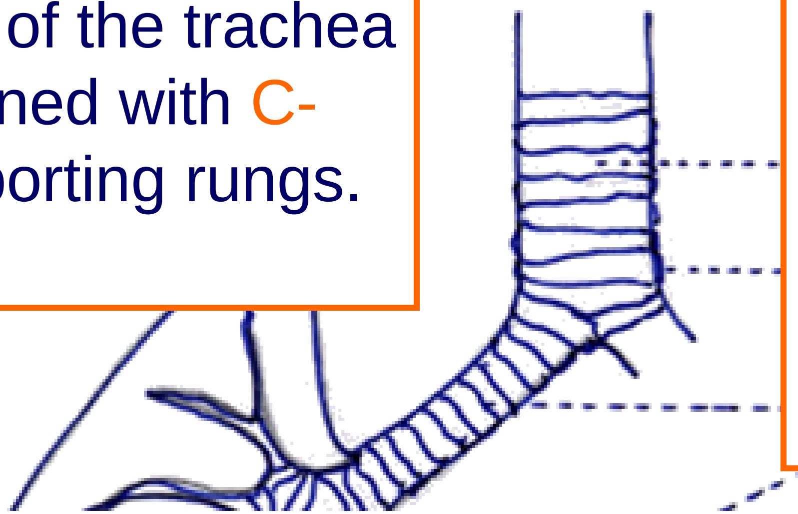


As the name suggests, air must pass down through the windpipe (trachea).

Cartilage in trachea

Diagram of trachea with cartilage rungs.

You can think of the trachea as a tube lined with C-shaped supporting rungs.

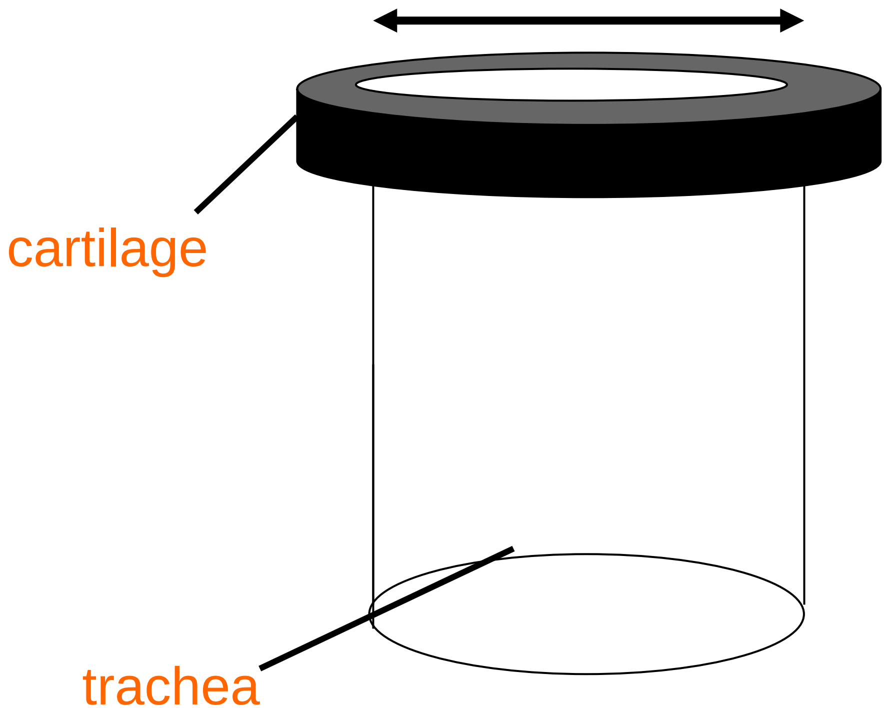


These rings are made of a tough material called cartilage. They help to hold the tube open.

You may be wondering why they are *C-shaped* and not *full circles*.

A clever design

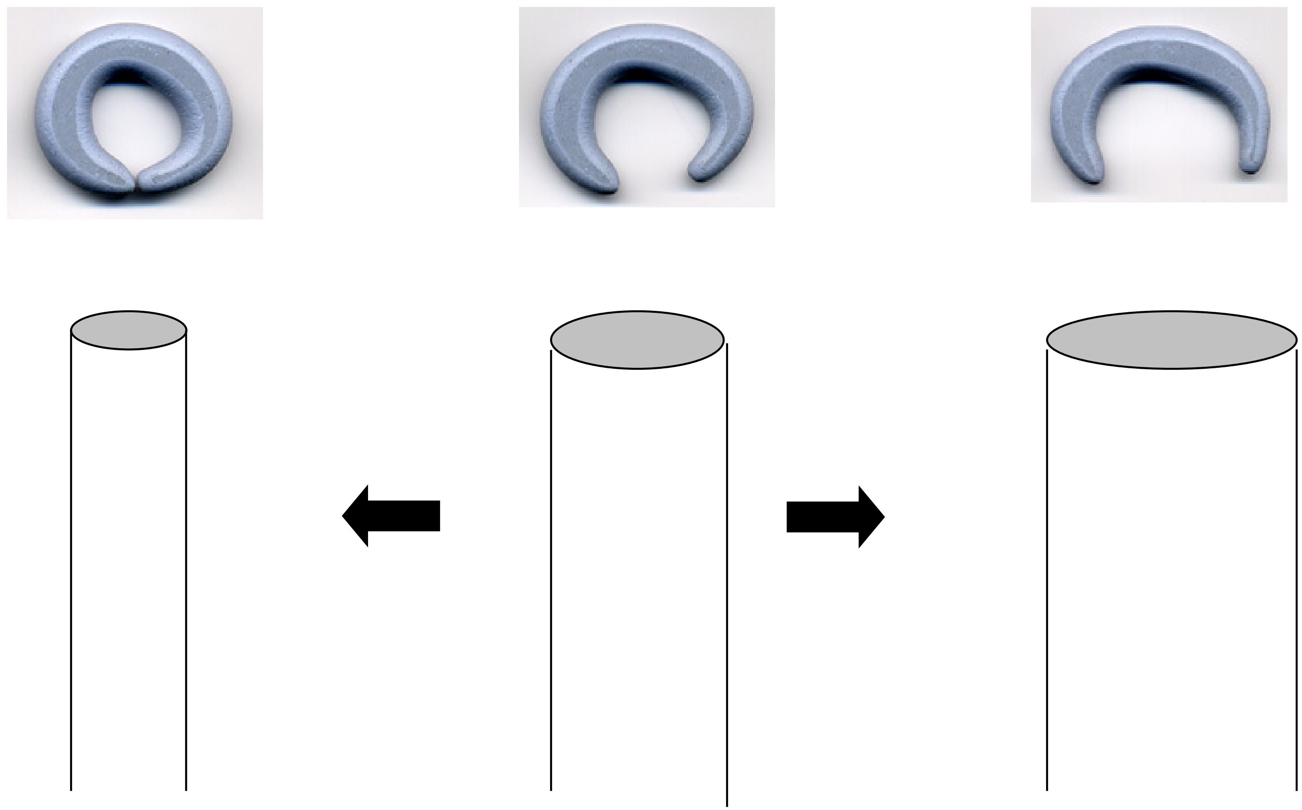
Well, if a tube were lined with fixed circles of cartilage, it would have a fixed diameter…



Although this would stop the tube from collapsing, this would also mean that the tube would not be able to expand.

When we breathe in, the trachea must expand to allow more air in.

Expansion potential

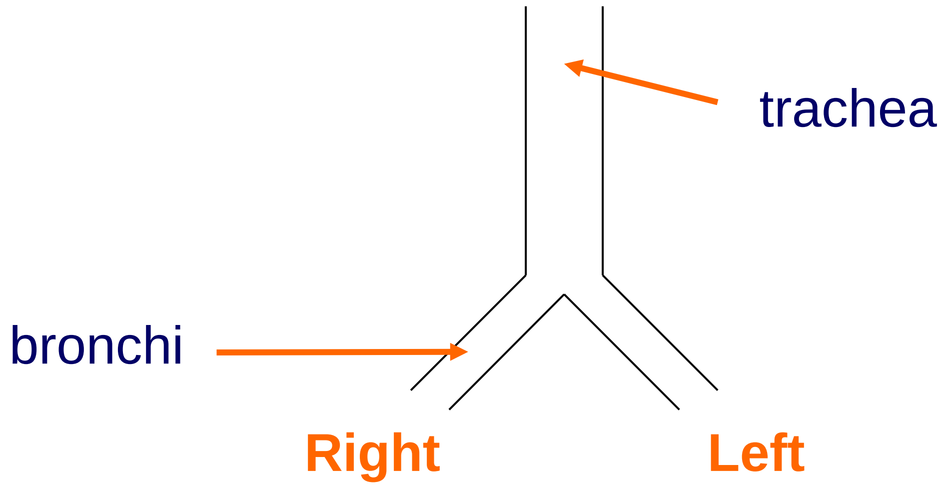


Therefore, a C-shaped piece of cartilage can change shape.

Bronchi

Eventually the trachea branches, dividing into two smaller tubes called the left and right **bronchi**.

(The singular of bronchi is a bronchus.)



Don't forget that in a picture of the human body, right becomes left and left becomes right.
Check by holding up your right hand in a mirror. The person staring back at you will be holding up their left hand.

Lungs and bronchi

Each Bronchus connects the trachea to a large air sac known as a **lung**.
You have two bronchi and therefore your body has two lungs, a left and a right.

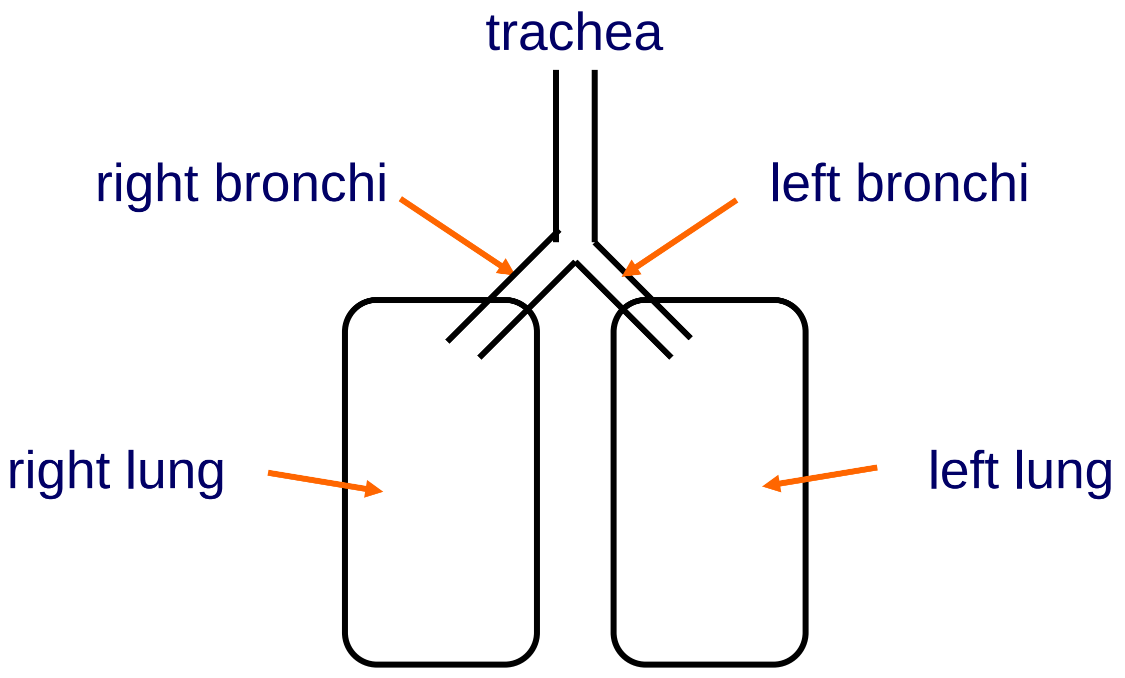
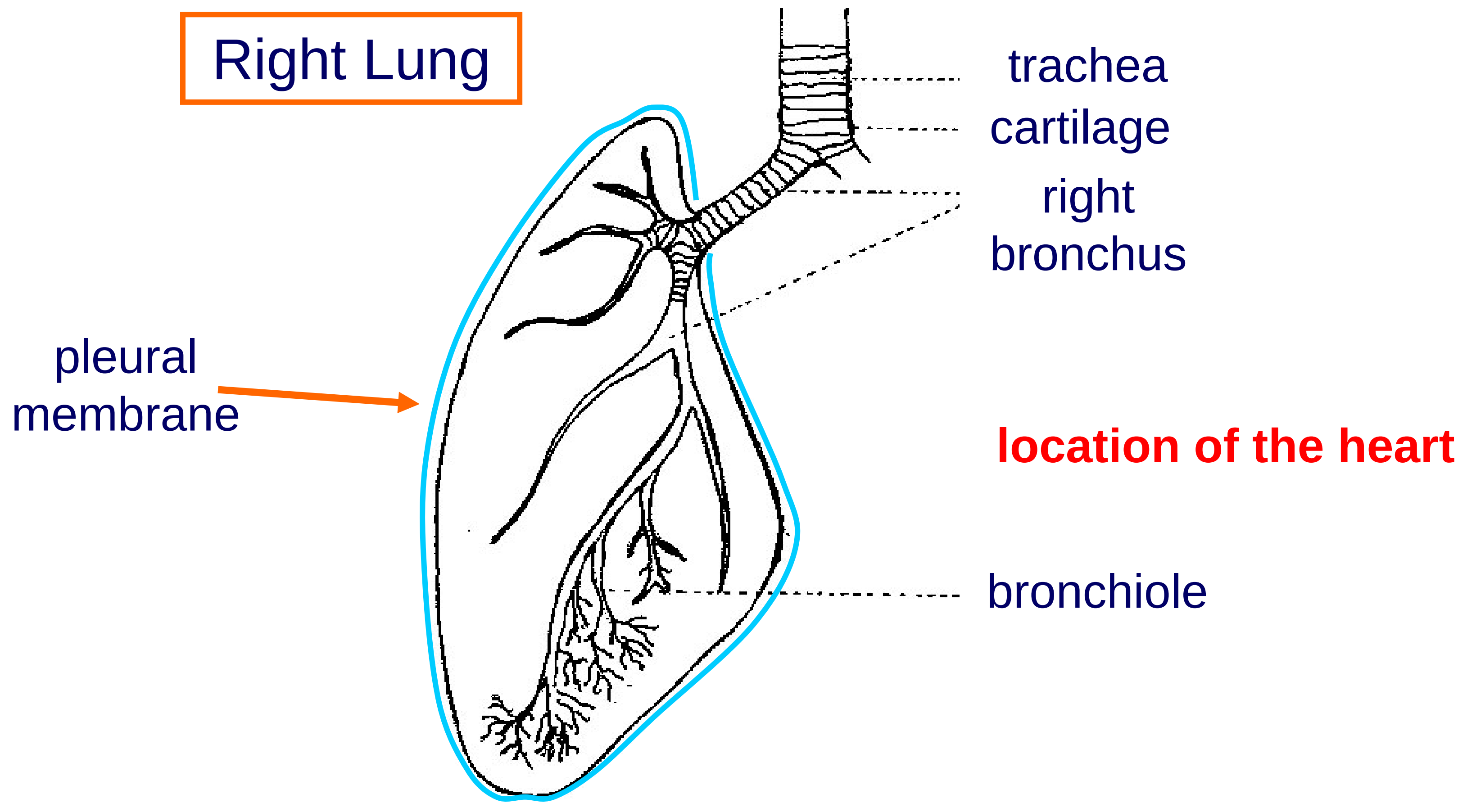


Diagram of a lung

In reality, the lungs are different in shape.
Here is a more accurate diagram.

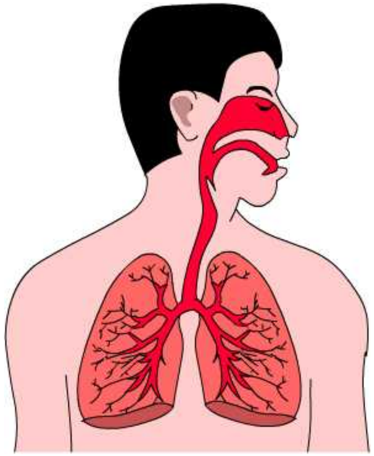


Problems with lung expansion

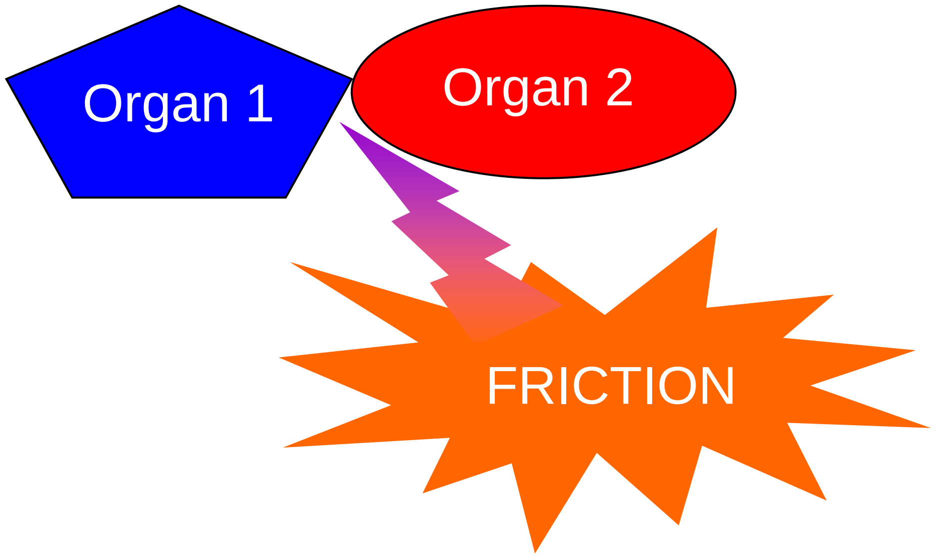
With air entering and leaving the lungs, they increase and decrease in size on a regular basis.

When organs in the body increase in size, they will touch other organs because of the lack of space.

This is a danger because living tissue is very delicate and when tissues rub against each other, friction could be generated.



Danger of friction



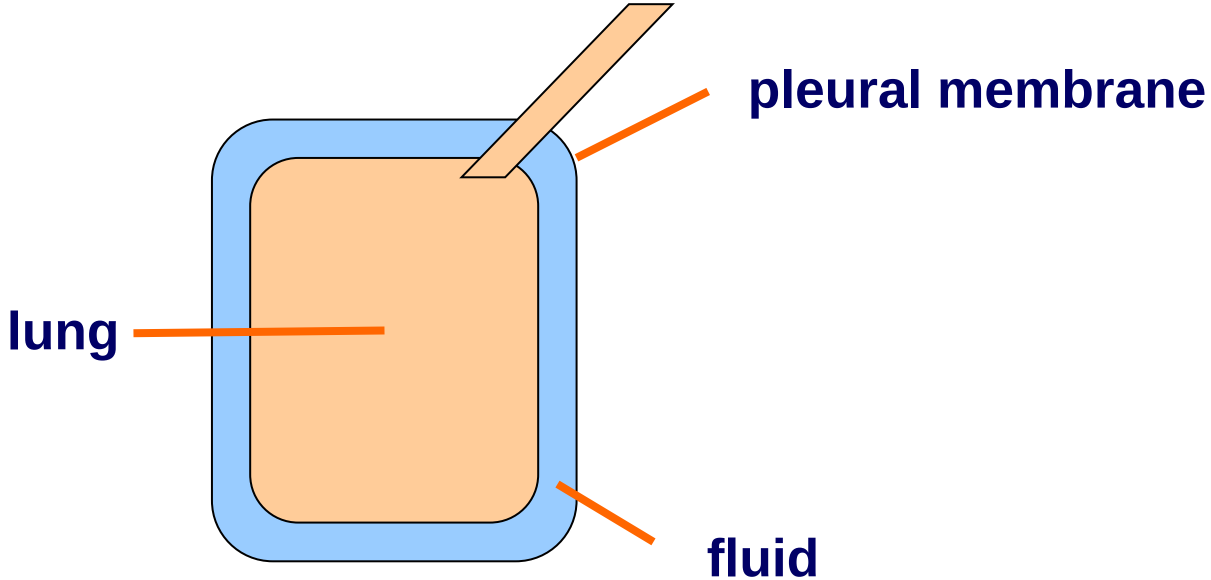
This friction could damage the tissue and kill cells.

Therefore, a protective bag called the **pleural membrane** surrounds the lungs, which are likely to rub against other organs during the breathing process.

The pleural membrane

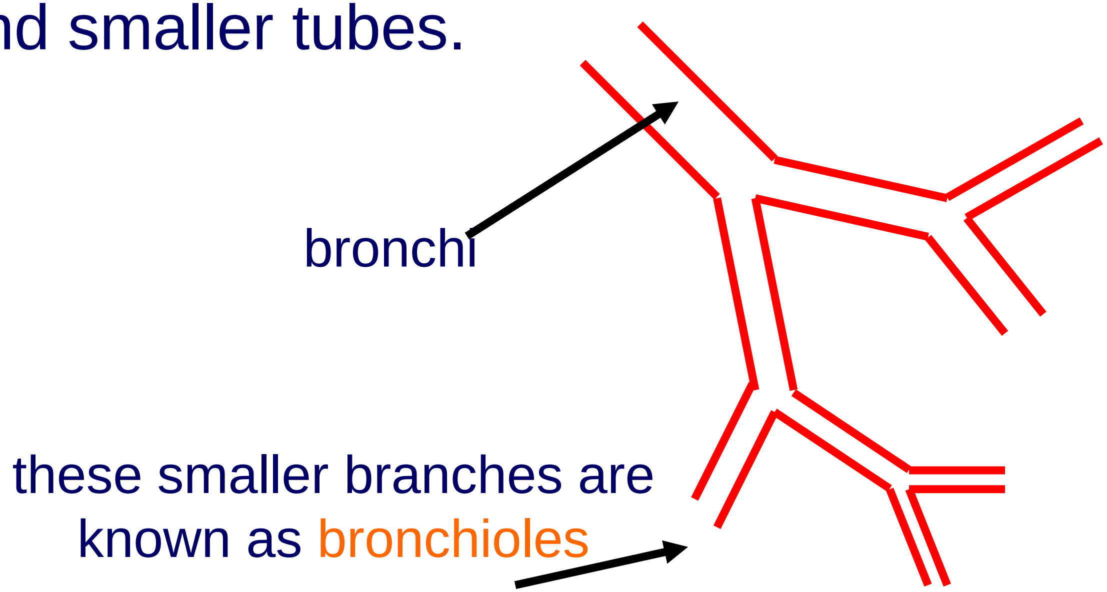
A fluid is found within this bag, surrounding the lungs.

This fluid lubricates the lining of the lungs and stops friction being generated.



Branching bronchi

Each bronchus now starts branching to produce smaller and smaller tubes.



One bronchus gives rise to many bronchioles. The overall effect is similar to the branching of a tree from a central trunk.

This branching of the bronchi occurs within both lungs.

The route that the oxygen gas takes

Oxygen will pass…

Down the **trachea**

Through each **bronchus**

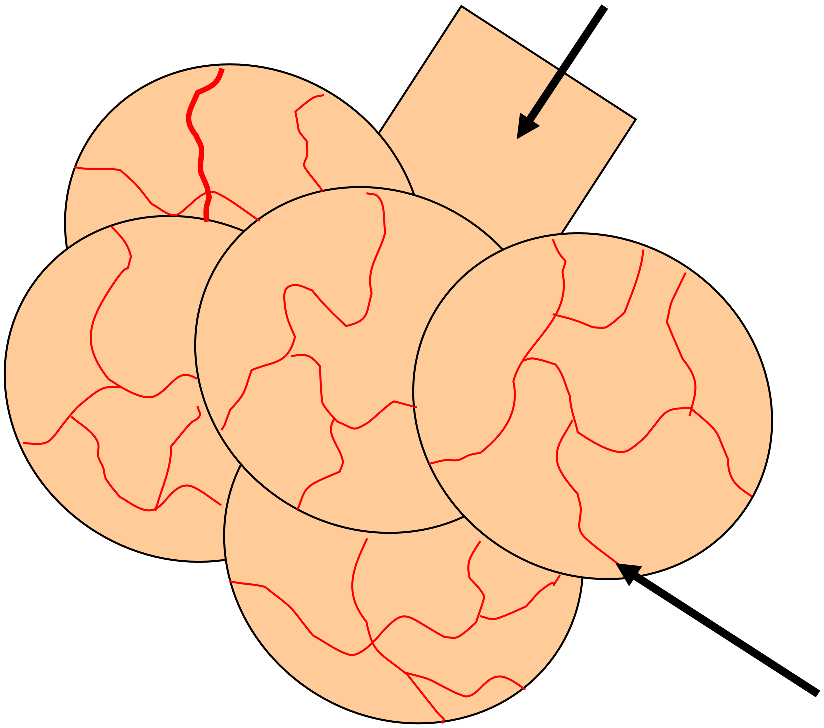
And through all the **bronchioles** within each lung

BUT WHAT HAPPENS NEXT?

Always remember that the CO_2 is moving in the opposite direction!

Inside an alveolus

Oxygen makes its way to special air sacs.

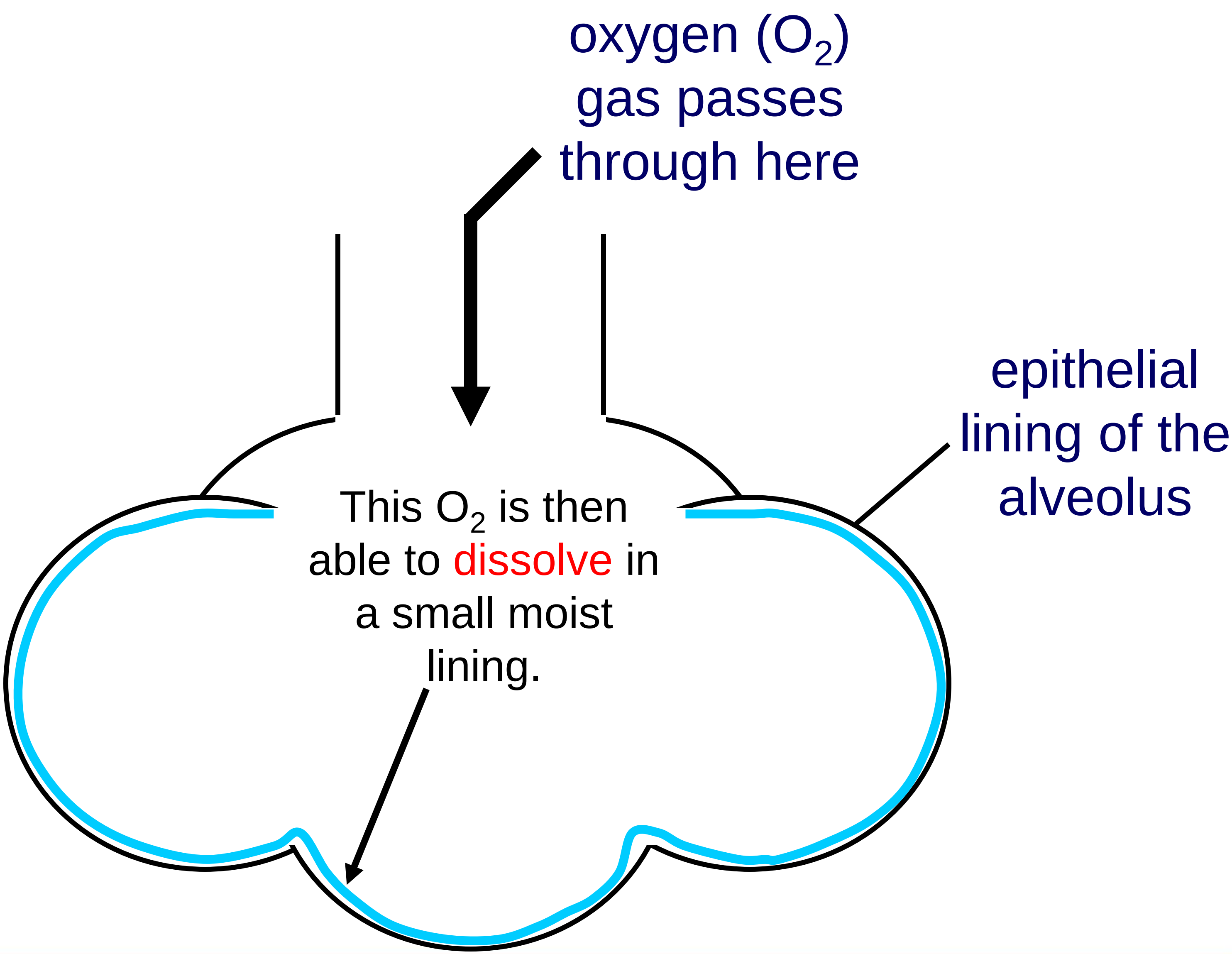


Actually, each air sac is found to be a bundle of air sacs. Together, they are known as an **alveolus**.

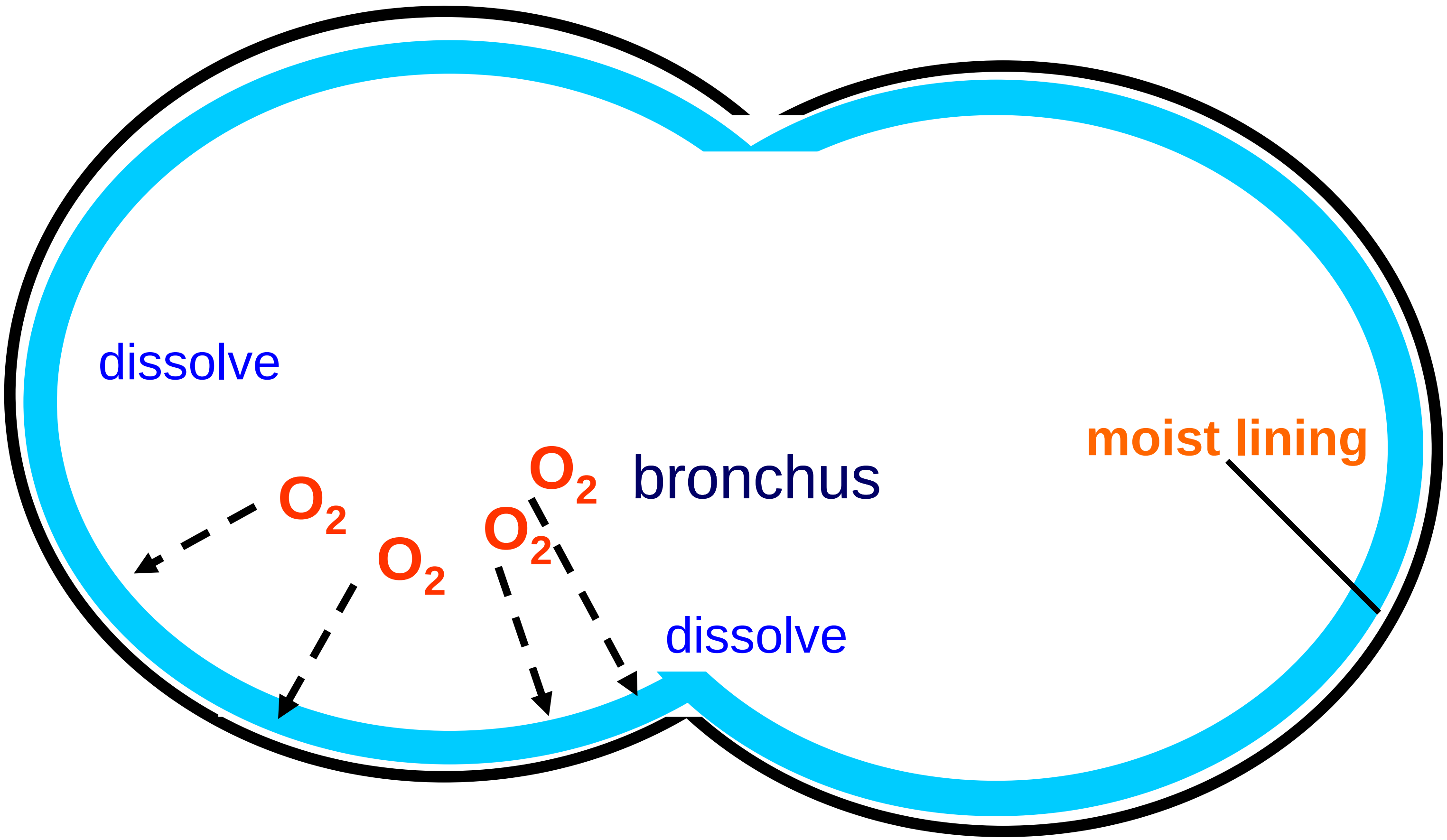
The outside of the alveolus is covered with tiny blood vessels.

We can look inside the alveolus to get some idea of why they are shaped the way they are.

A cross-section of an alveolus

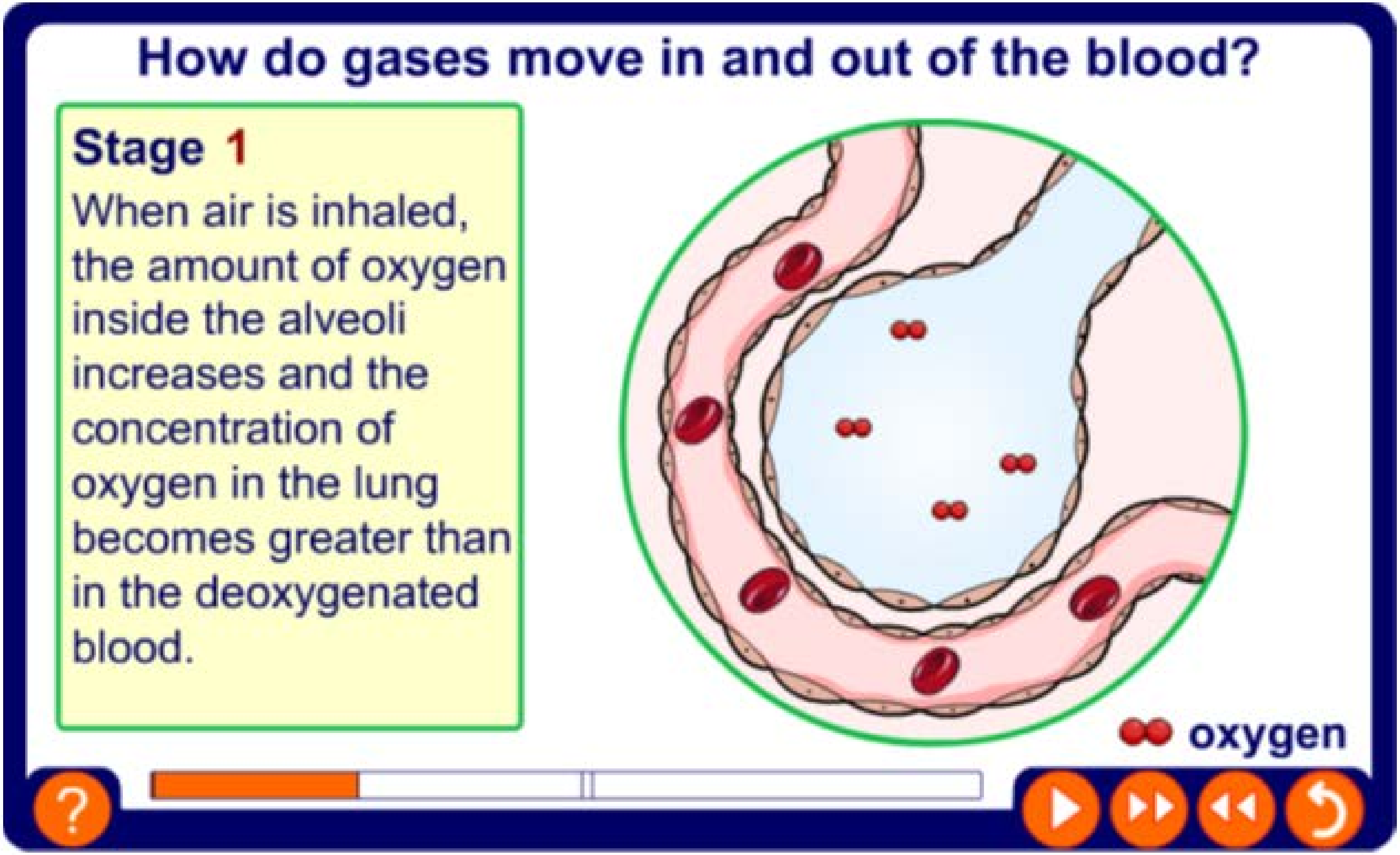


Keeping the environment right



This moist lining also stops the alveolus from drying and cracking. It lubricates the insides of the air bag.

Gases moving in and out of the blood

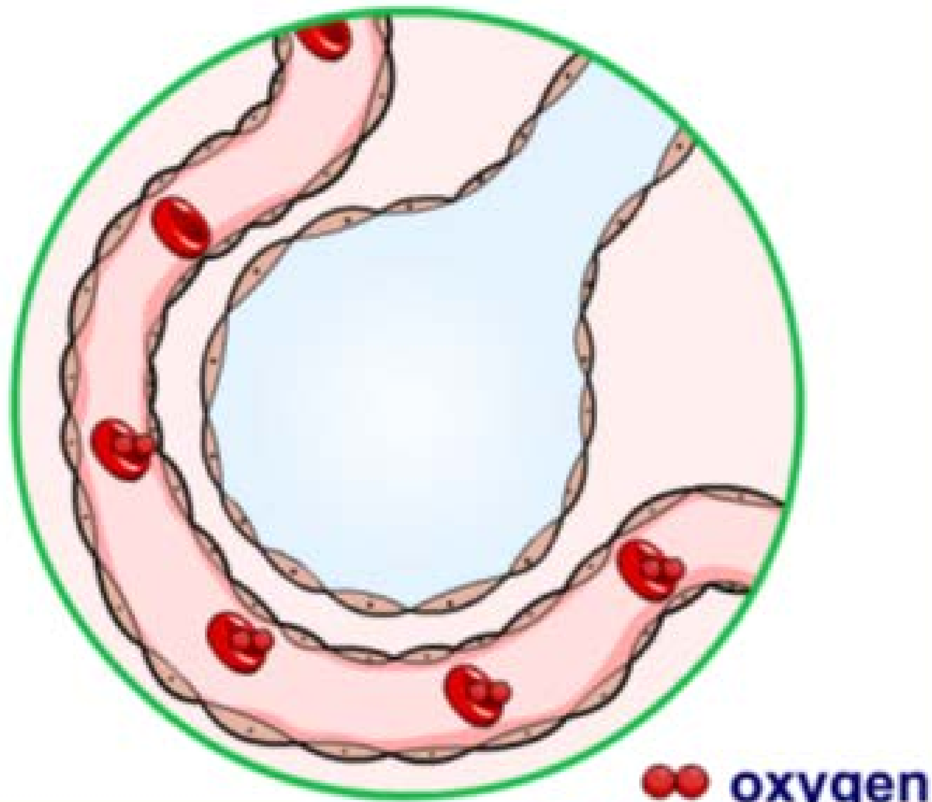


Gases moving in and out of the blood

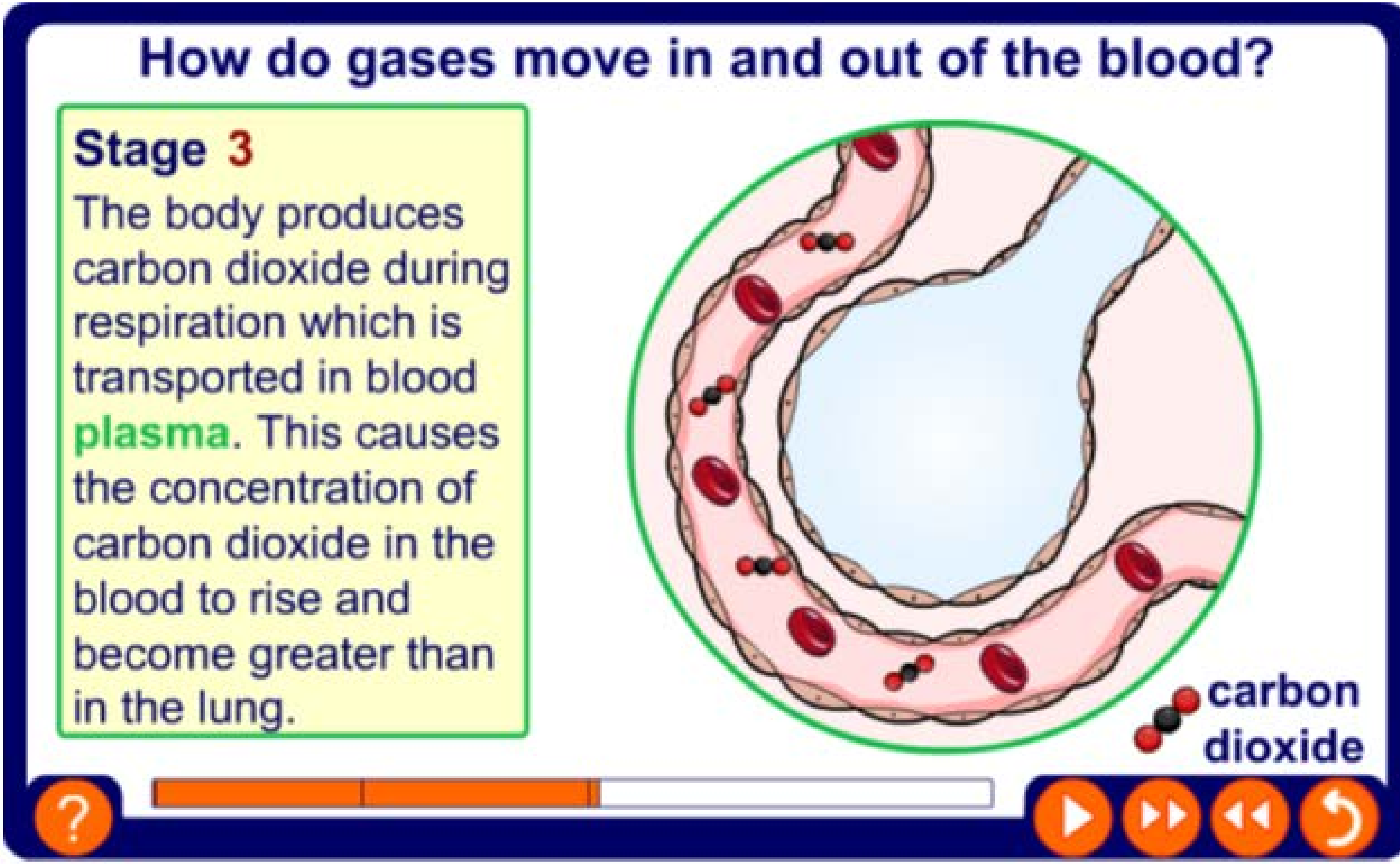
How do gases move in and out of the blood?

Stage 2

Oxygen molecules diffuse across the lining of the alveoli into the bloodstream of the capillary. There they bind with the haemoglobin in red blood cells, forming **oxyhaemoglobin**.



Gases moving in and out of the blood

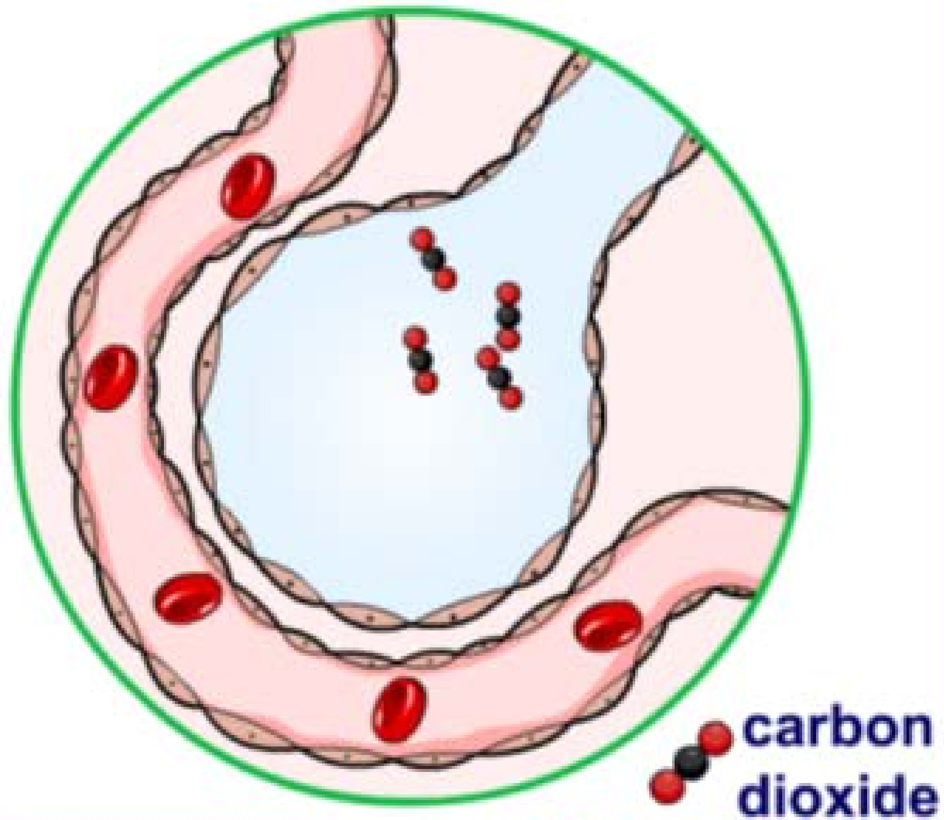


Gases moving in and out of the blood

How do gases move in and out of the blood?

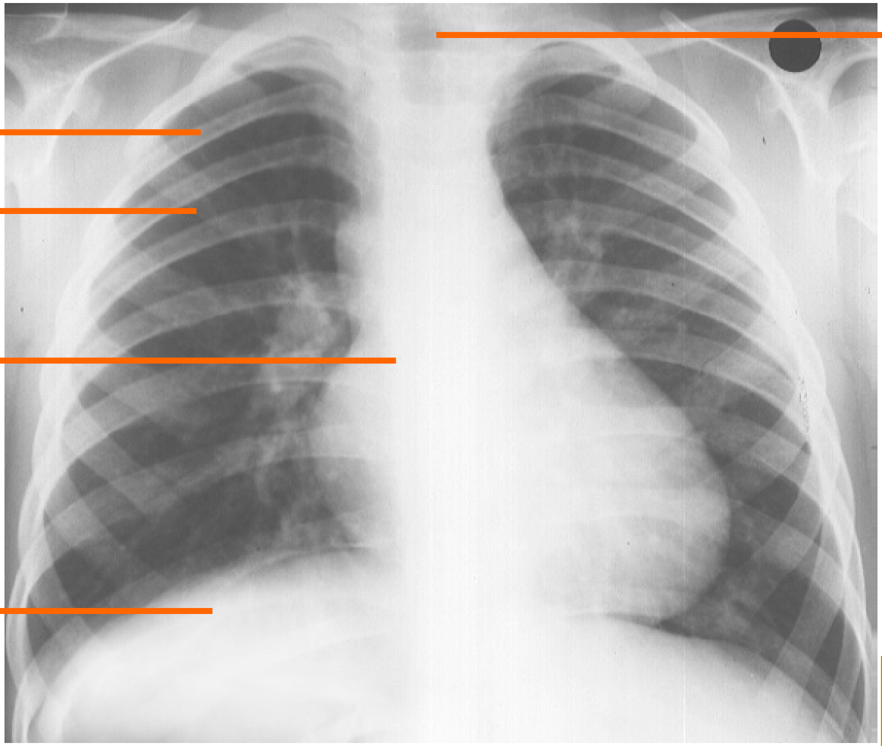
Stage 4

Carbon dioxide dissolved in the blood diffuses from the capillary into the alveoli, from where it is exhaled.



Breath-taking features

The breathing system does not have a fixed shape.



It has the ability to move, whilst remaining enclosed within the protection of the ribcage.

Features of inhalation and exhalation

These changes can be summarised in the table below:

Feature	Inhaling	Exhaling
External intercostal muscle	contract	relax
ribs	up and out	down and in
Diaphragm muscle	contract	relax
Diaphragm	flatten	domed
Volume chest cavity	increases	Decreases
Air pressure inside	decreases	Increases
Air outside	Diffuses into the lungs	Diffuses outside the lungs

Multiple choice section Q1

Which of these statements about breathing in and breathing out is **true**?

A) They require active transport to function.

B) They use different organs but in a cycle.

C) They both use the same organs.

D) They are always under concious control.

Multiple choice section Q2

Where is the air we breathe in **moistened and warmed**?

A) the alveoli

C) the nasal cavity

B) after it reaches the lungs

D) before the air is inhaled

Multiple choice section Q3

What best describes the action of **cilia and mucus** in the breathing system?

A) removal of unwanted particles and microbes

B) control of the direction of air flow in the lungs

C) increasing surface area for better gas diffusion

D) none of these

Multiple choice section Q4

Which of the following statements about the **trachea** is **false**?

A) The trachea is lined with ciliated epithelial cells.

C) It has a rigid structure with a fixed diameter.

B) The trachea branches into the bronchi.

D) The trachea has C-shaped rings of cartilage.

Multiple choice section Q5

Which structure prevents damage being caused by **friction forces**?

A) the pleural membrane

C) the epithelial cells

B) the rib muscles

D) none of these

?

Multiple choice section Q6

What is the **correct order** of parts through which air passes when we breathe in?

A) trachea - bronchioles - bronchi - alveoli

C) alveoli - bronciholes - bronchi - trachea

B) bronchi - trachea - bronchioles - alveoli

D) trachea - bronchi - bronchioles - alveoli

Multiple choice section Q7

What is the **outside** of an **alveolus** covered in?

A) a moist layer

B) ciliated epithelial cells

C) tiny blood vessels

D) none of these

Multiple choice section Q8

Which vessel does **blood arriving** at the lungs come from?

A) coronary vein

B) pulmonary vein

C) aorta

D) pulmonary artery

Breathing in or out?

1) Which process rids the body of potentially harmful carbon dioxide?

breathing in

breathing out

Breathing in or out?

2) Which process is performed by contracting the diaphragm and the outer rib muscle?

breathing in

breathing out

Breathing in or out?

3) Which process causes the pressure inside the lungs to drop?

breathing in

breathing out

Breathing in or out?

4) Which process returns the diaphragm to its dome shape?

breathing in

breathing out

Breathing in or out?

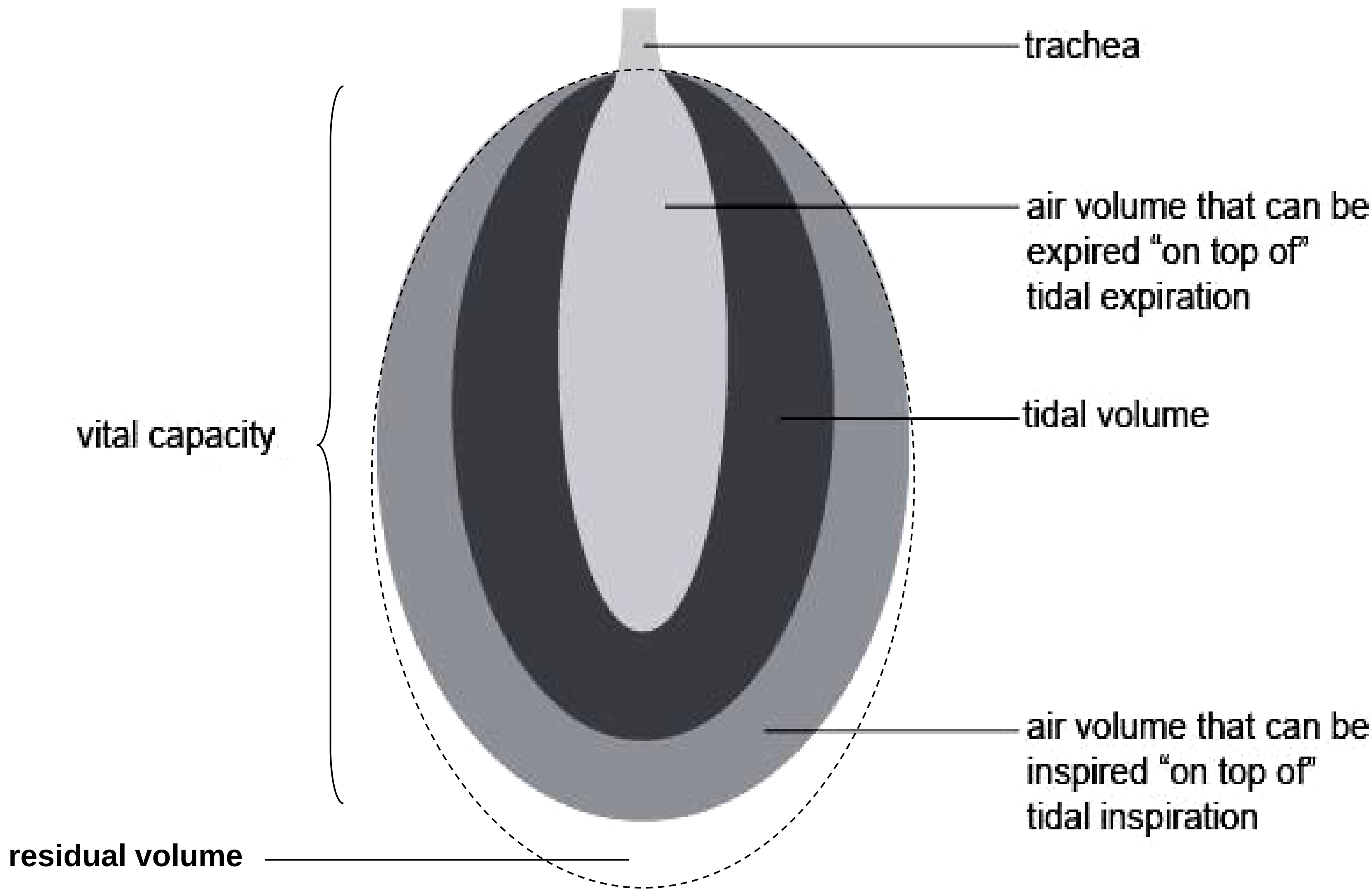
5) Which process decreases the volume of the chest cavity?

breathing in

breathing out

Lung Volume

- Lung volume is to describe the changes of the lung volume during one breathing at static conditions, also called static lung volume.
- Term in lung volume
- TV (tidal volume): 500ml
- IRV (inspiratory reserve volume)
- ERV (expiratory reserve volume)
- RV (residual volume)


trachea
air volume that can be expired “on top of” tidal expiration
tidal volume
air volume that can be inspired “on top of” tidal inspiration
vital capacity
residual volume

Definition

- Tidal Volume: TV
  - The amount of gas inspired or expired with each normal breath.
  - About 500 ml
- Inspiratory Reserve Volume: IRV
  - Maximum amount of additional air that can be inspired from the end of a normal inspiration.

- Expiratory Reserve Volume: ERV
  - The maximum volume of additional air that can be expired from the end of a normal expiration.
- Residual Volume: RV
  - The volume of air remaining in the lung after a maximal expiration

Terms in lung capacity

IC (inspiratory capacity):

- Maximum volume of air that can be inspired from end expiratory position
- IC= TV+IRV

FRC (functional residual capacity):

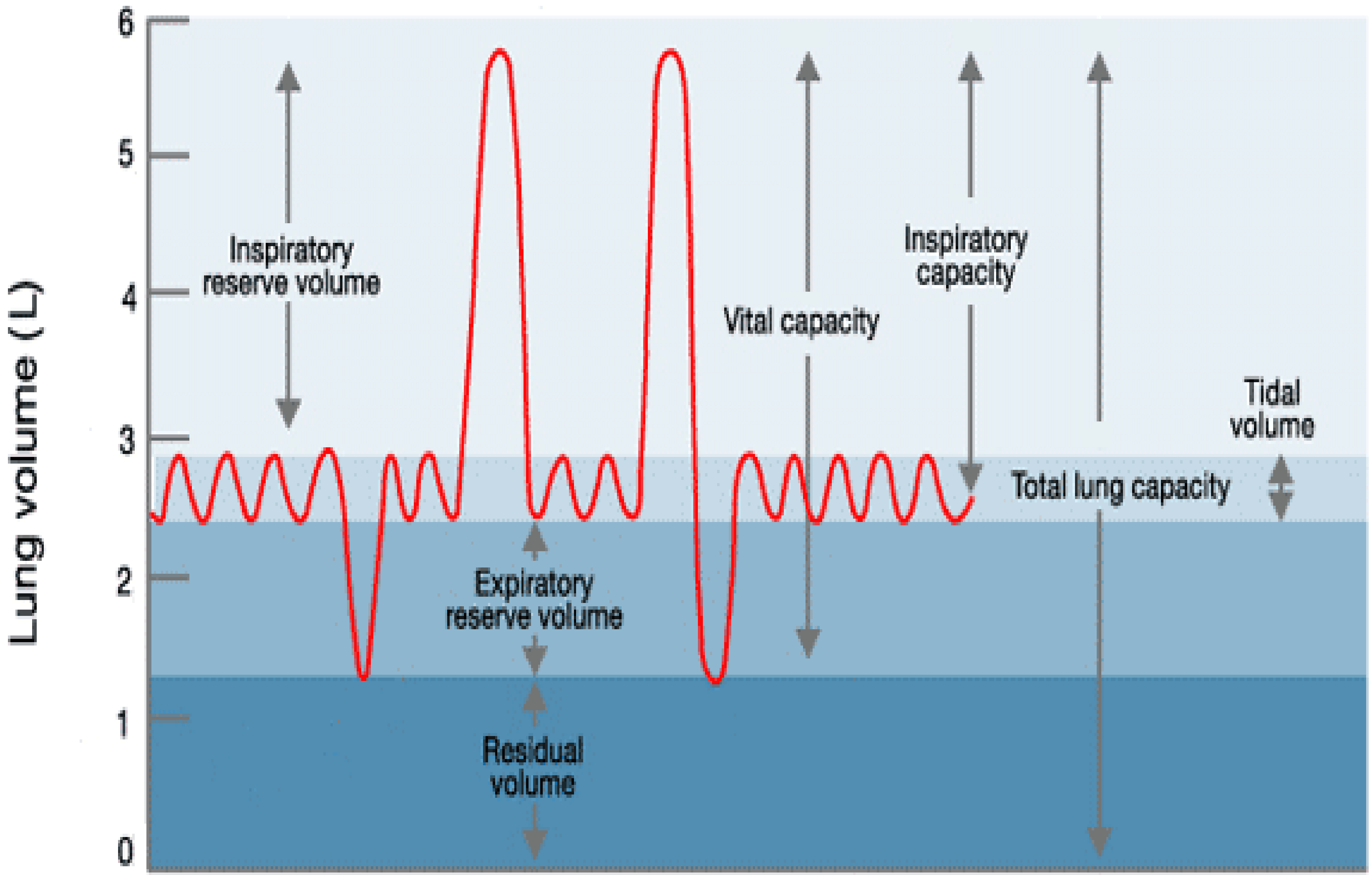
- The volume of air remaining in the lung at the end of a normal expiration.
- FRC= RV+ERV

VC (vital capacity) :

- The maximum volume of air that can be forcefully expelled from the lungs following a maximal inspiration.
- VC= IRV+TV+ERV = TLC - RV

TLC (total lung capacity):

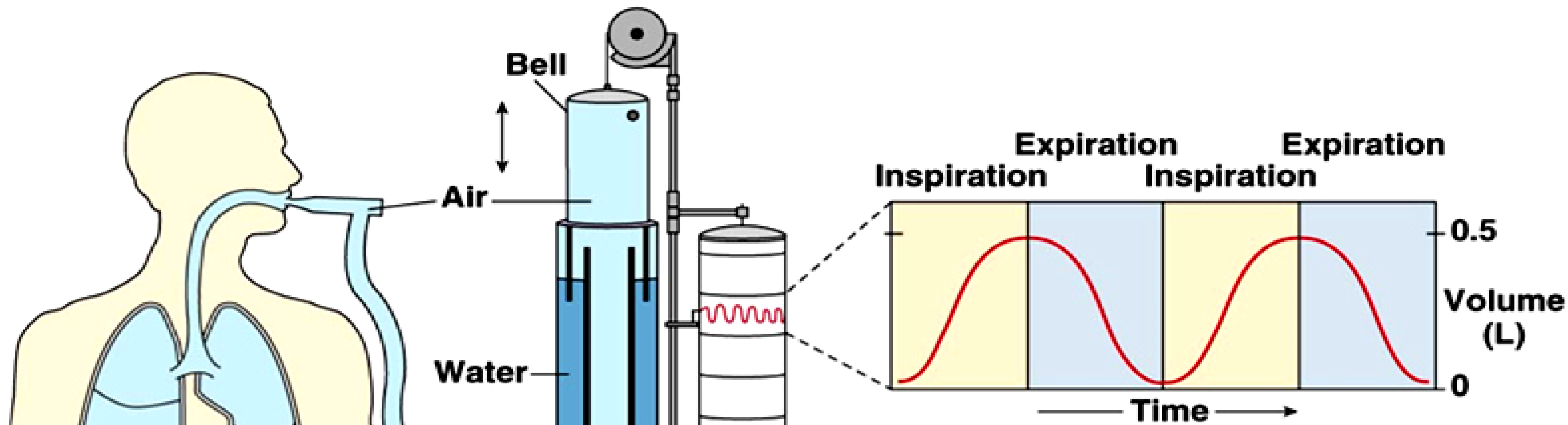
- The volume of air contained in the lungs at the end of a maximal inspiration.
- TLC= IRV+TV+ERV+RV


Lung volume (L)
6
5
4
3
2
1
0
Inspiratory reserve volume
Vital capacity
Inspiratory capacity
Tidal volume
Total lung capacity
Expiratory reserve volume
Residual volume

Forced expiratory volume (FEV)

- Pulmonary Function Tests
  - Tests to diagnose several lung diseases.
  - The simplest but one of the most informative tests of lung function is a forced expiration.

- **Spirometer**: an instrument used to measure respiratory volumes and capacities
- **Spirometry** can distinguish between
  - Obstructive pulmonary disease—increased airway resistance (e.g., bronchitis)
  - Restrictive disorders—reduction in total lung capacity due to structural or functional lung changes (e.g., fibrosis or TB)



When the subject inhales, air moves into the lungs. The volume of the bell decreases, and the pen rises on the tracing.

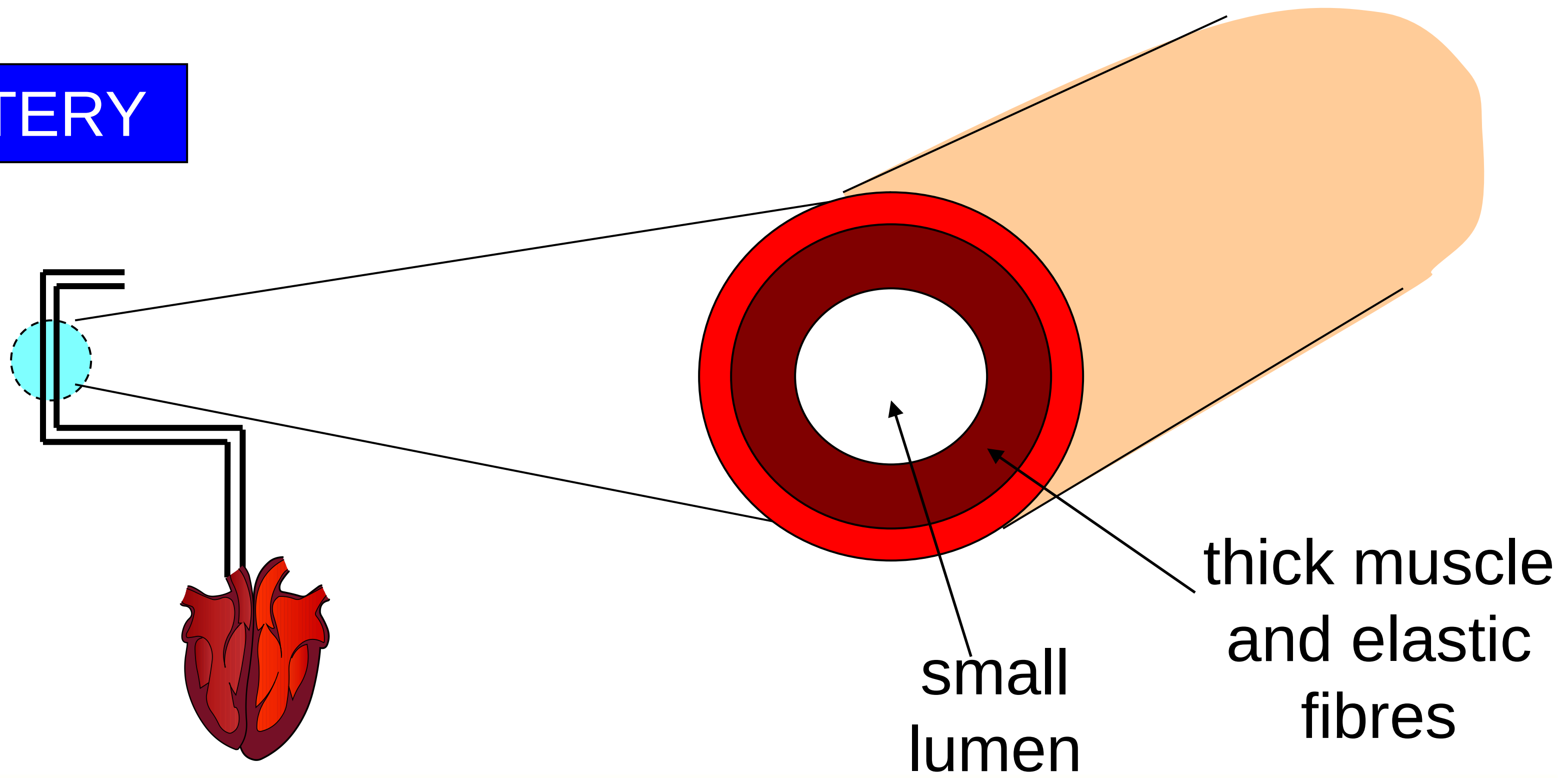
- Minute ventilation: total amount of gas flow into or out of the respiratory tract in one minute
- Forced vital capacity (FVC): gas forcibly expelled after taking a deep breath
- Forced expiratory volume (FEV): the amount of gas expelled during specific time intervals of the FVC

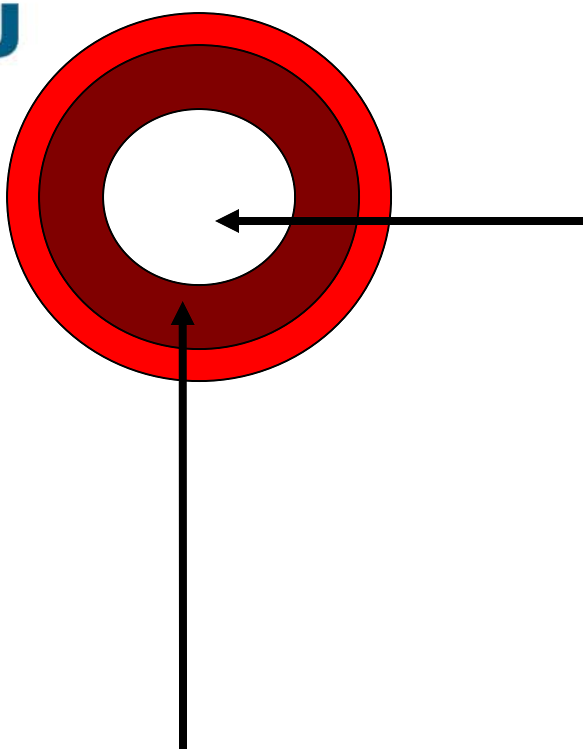
Now, let's consider the blood vessels...

Let us consider each vessel in turn to see how its shape is related to the job it has to do.

In each case we will look at a cross-section of the vessel

ARTERY





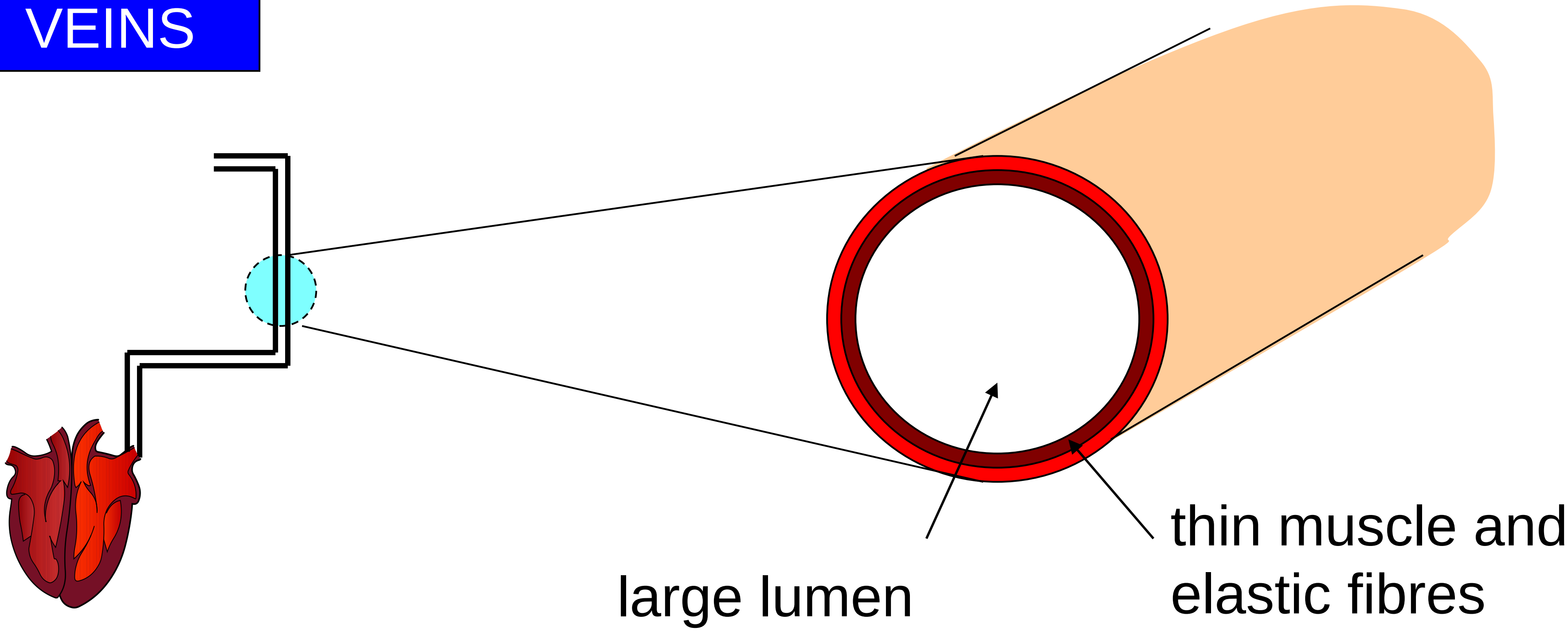
The **small lumen** means that blood will be under high pressure.

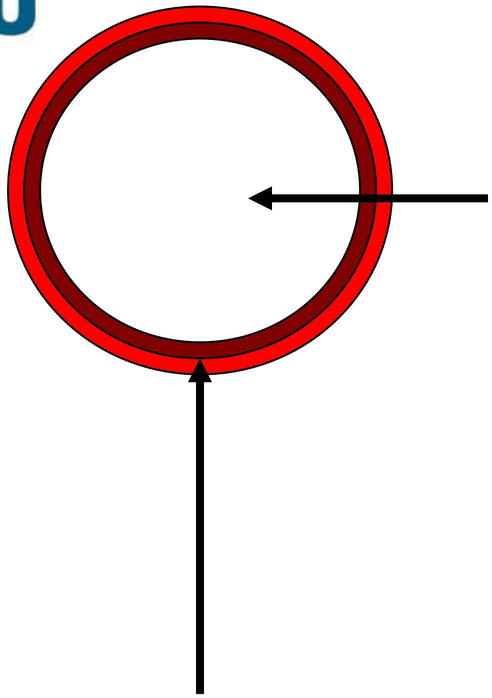
The thick fibrous wall strengthens the artery. The elastic allows the artery to ***stretch*** under pressure whilst the muscle can contract to ***push*** the blood along.

The blood flowing through an artery will be under high pressure and moving extremely fast.

There is no chance that the blood will turn around and start travelling in the opposite direction. Therefore, there are no valves present in arteries.

VEINS





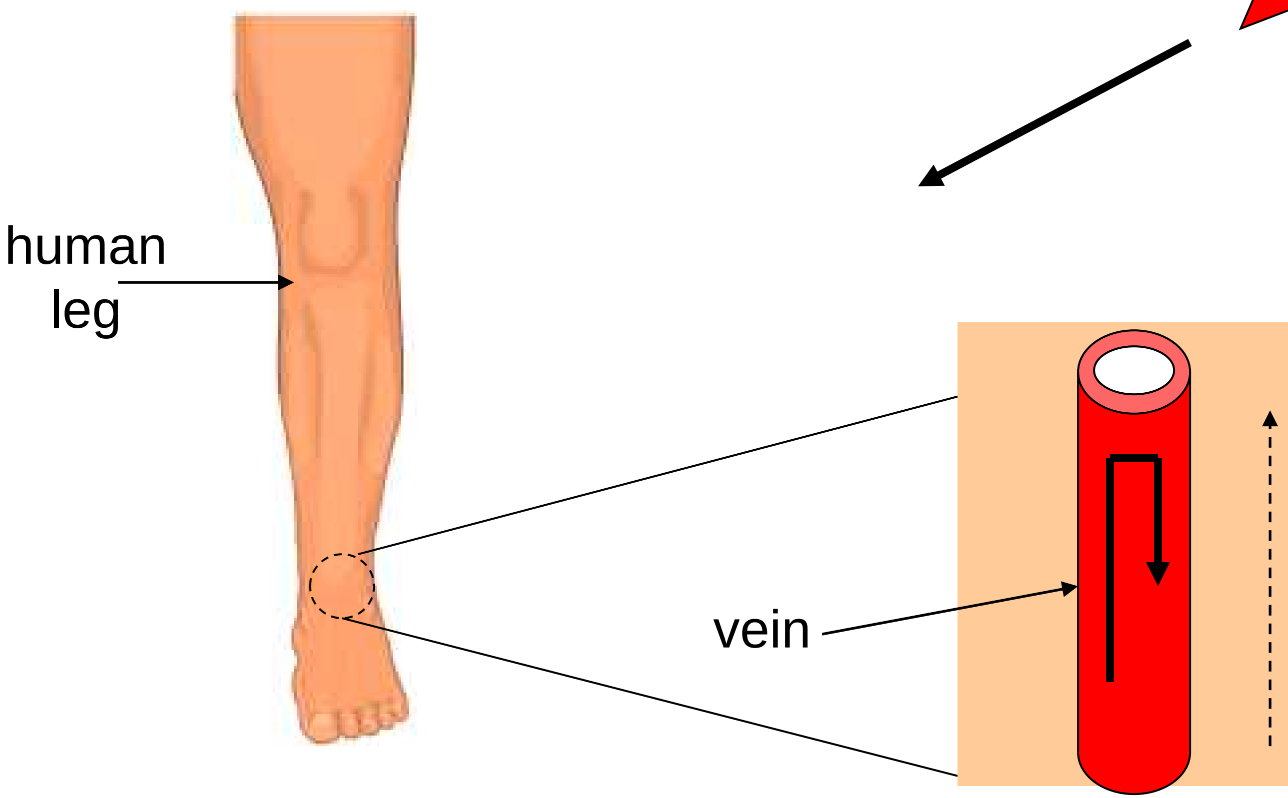
The lumen of a vein is much larger than artery. The wall is thinner as less pressure exerted on the wall.

The walls still contain elastic and muscle but there is far less present compared to the artery.

You will appreciate that the blood is flowing far less quickly through veins compared to arteries.

The veins are carrying blood back towards the heart. Materials have been exchanged and now it is running out of energy. It needs to return to the heart to receive another pump.

Unfortunately, this could lead to a real **Problem..**

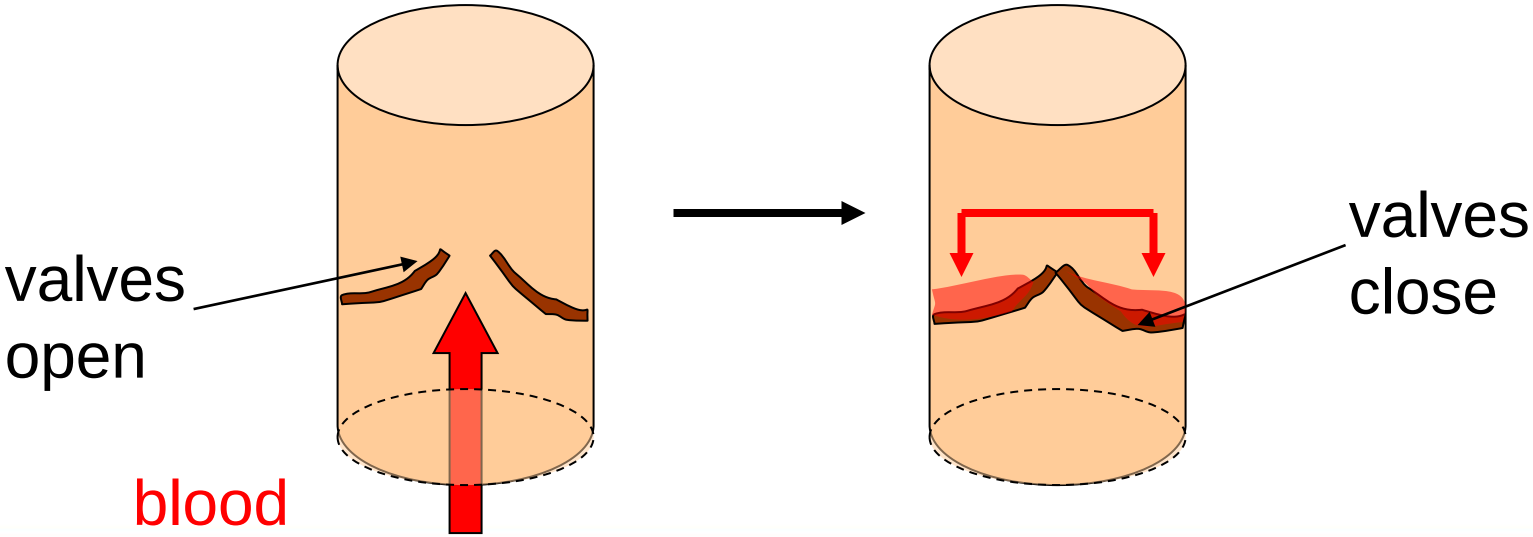


What happens if blood loses so much energy that it stops and turns around?

This situation could arise where blood is flowing against gravity. However, there is a solution to this problem. It comes in two parts.

1. Firstly, veins have valves which act to stop the blood from going in the wrong direction.

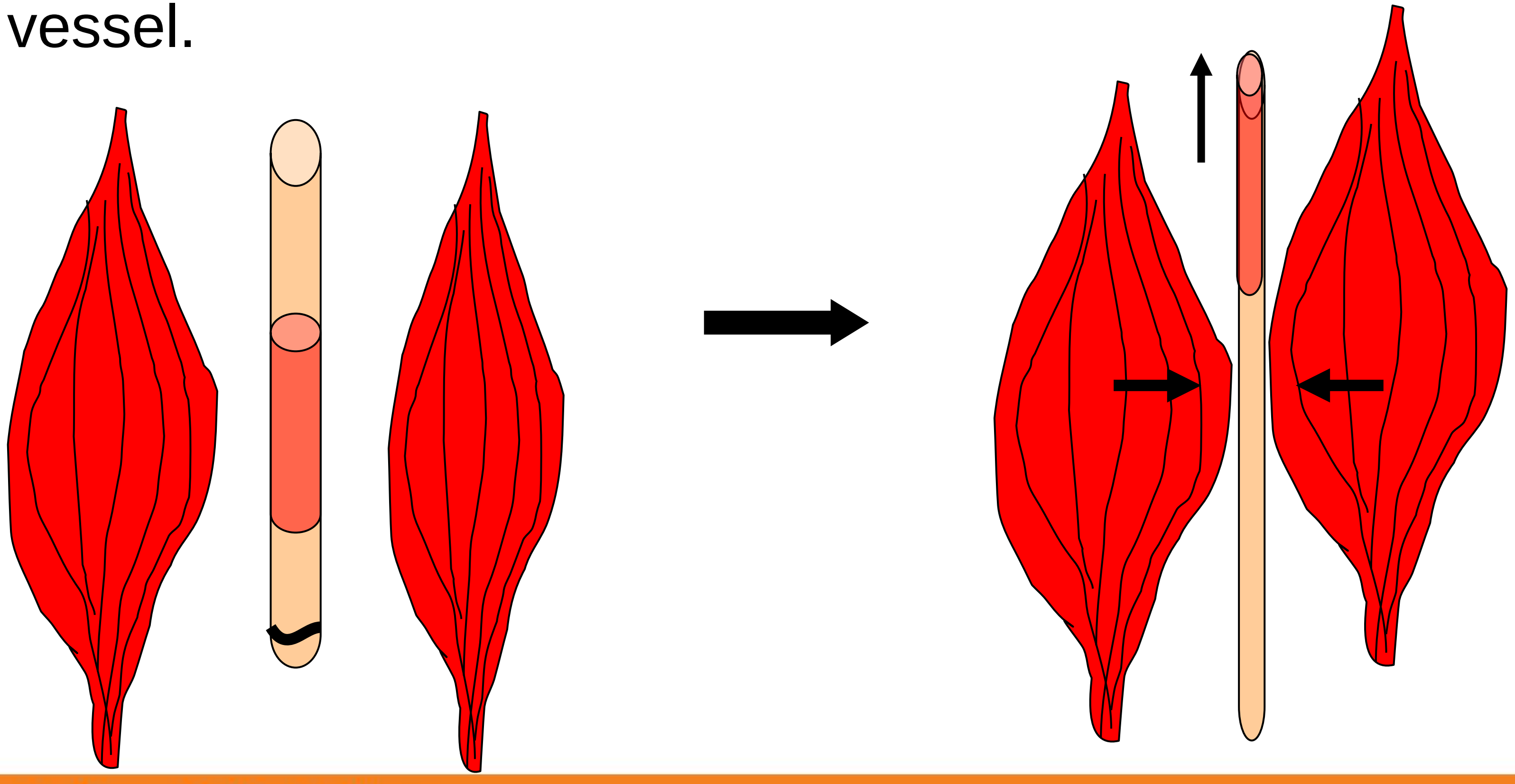
(These valves are similar to those found in the heart)



2.

The second part of the solution has to get the blood flowing again whilst overcoming the problem of a lack of muscle in the lining of the vessel.

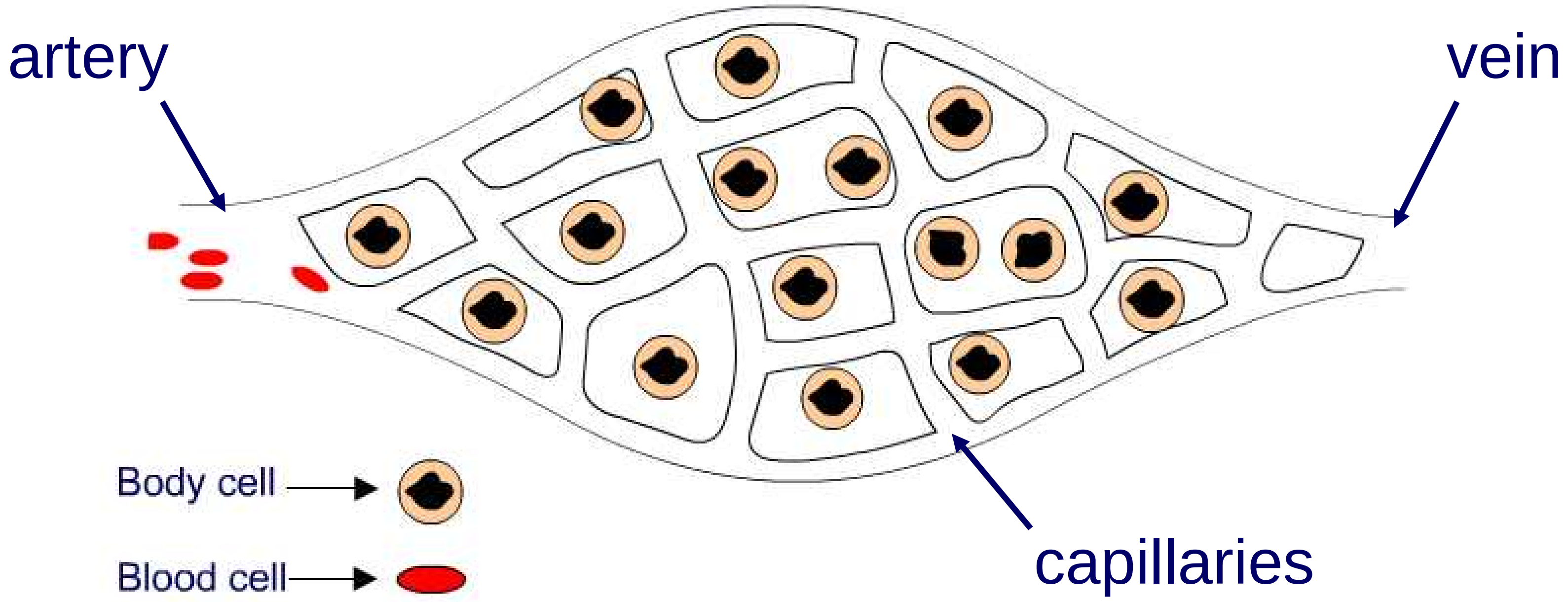
The solution comes in the form of general body muscles that surround the veins. When these muscles contract to move the body, they also squeeze the veins and push the blood along the vessel.

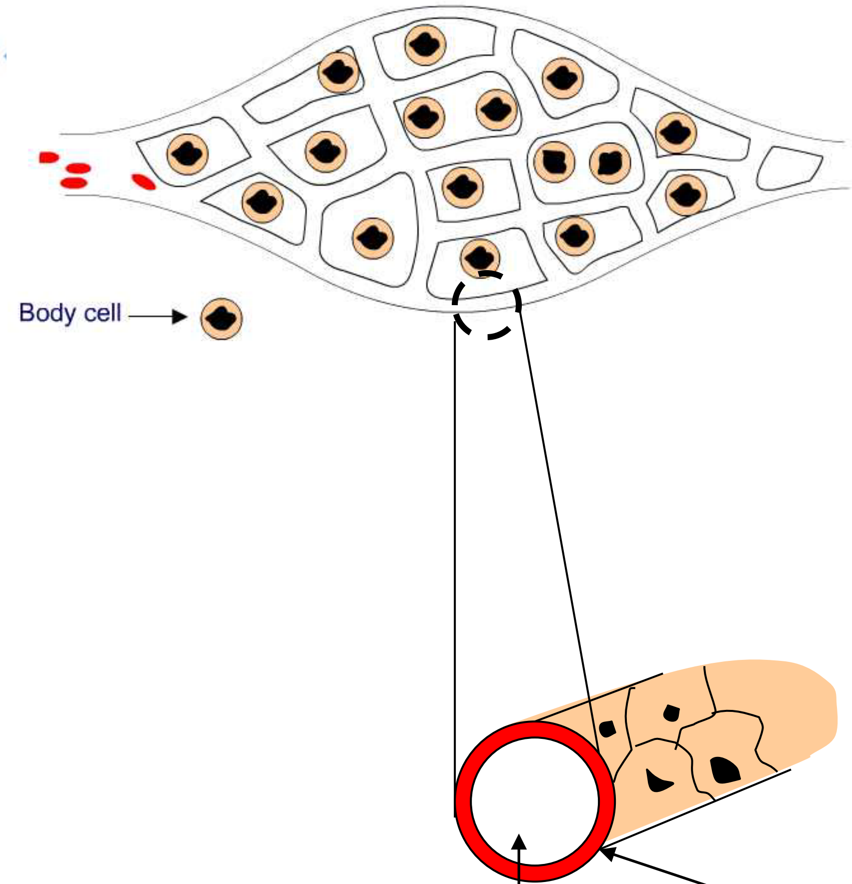


CAPILLARIES

These vessels link arteries with veins.

They are found all over the body and are essential for the exchange of materials between the blood and other body cells.





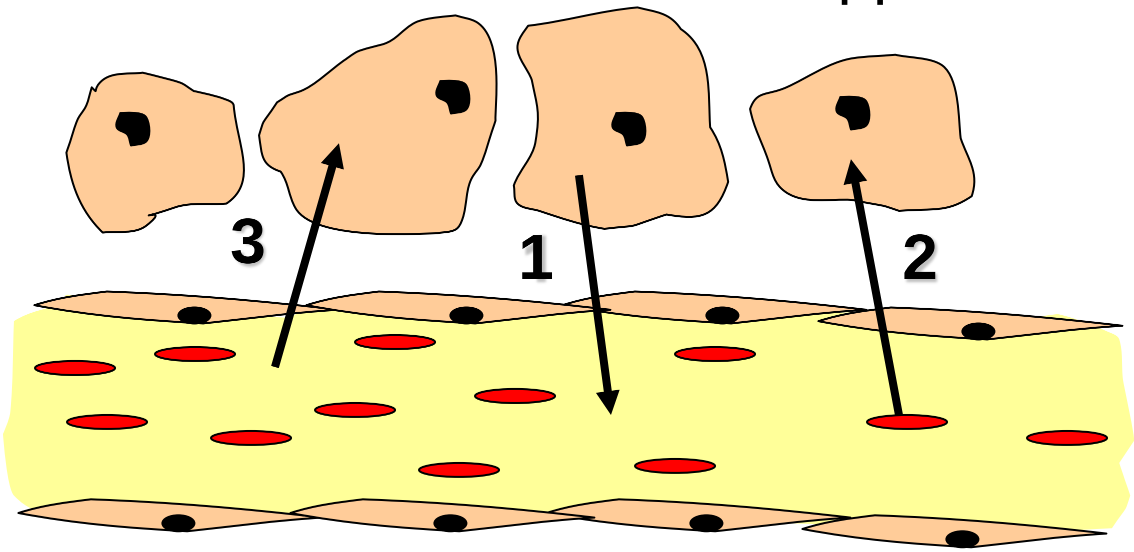
Capillaries are so small that they can only be seen using a microscope.

A collection of capillaries is known as a capillary bed.

The wall of a capillary is only one cell thick!

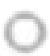
very narrow lumen

Substances can diffuse across the lining of the capillary. This allows useful substances which are dissolved within the blood to move into surrounding cells whilst cellular waste moves in the opposite direction.

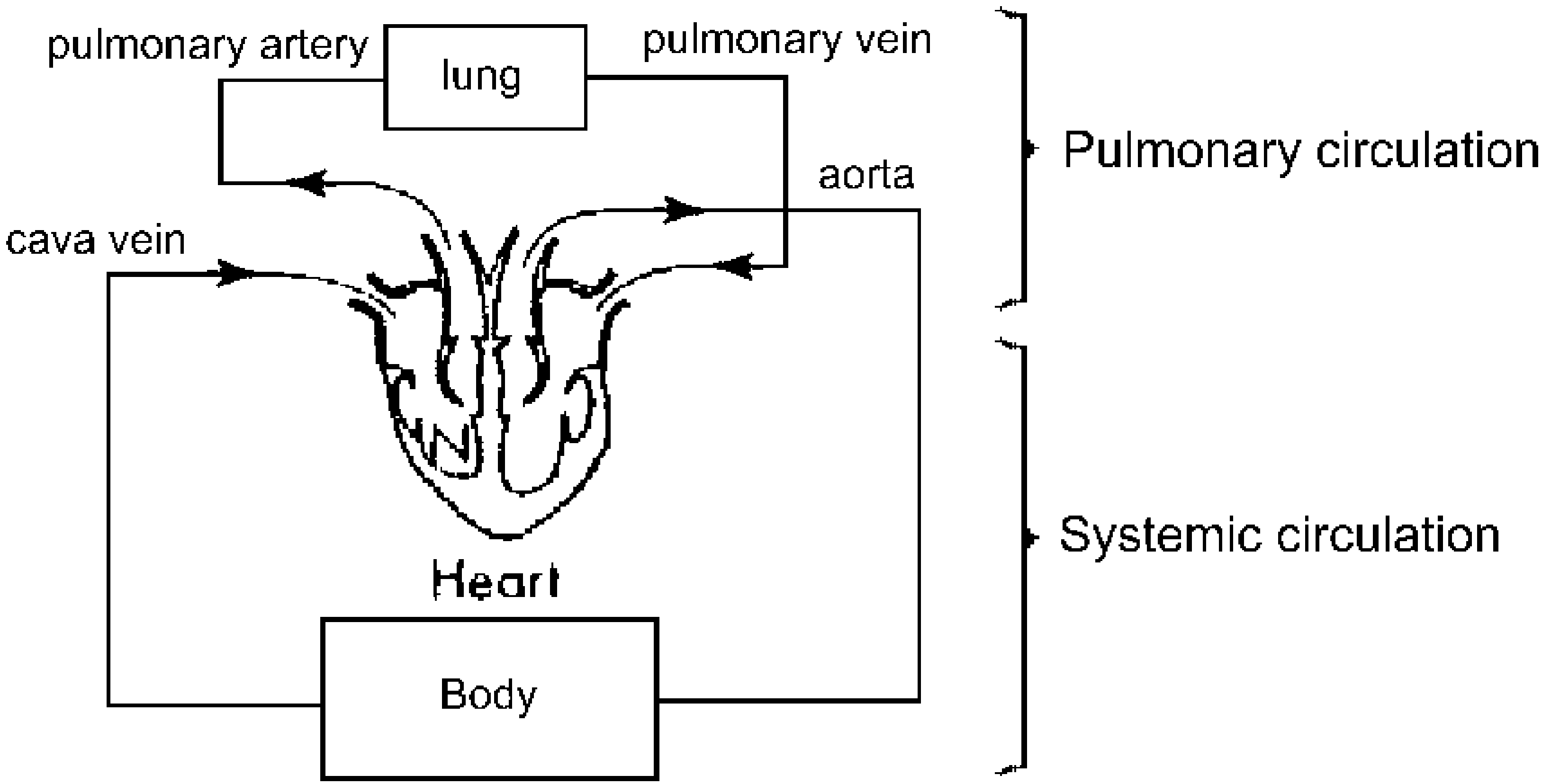


The exchange of materials between the blood and the body can only occur through capillaries.

Blood vessels

Blood vessel	Function	Characteristics
		
		
		

Path of blood flow in the circulatory system.



Multiple choice section Q8

Which vessel does **blood arriving** at the lungs come from?

A) coronary vein

C) aorta

B) pulmonary vein

D) pulmonary artery

Drag the words to fill in the gaps in the sentences.

1. Blood vessels carry ______ around the ______ .
2. There are 3 main types of blood ______
3. The first are ______ which carry blood away from the ______
4. The second are ______ which carry blood back to the heart
5. The last ones are the smallest and these are called ______
6. Capillaries ______ arteries to veins
7. Capillaries are so ______ that things can pass into and out of them
8. When things pass out of capillaries, they pass into the body ______

link | vessel | blood | capillaries | thin

body | arteries | cells | heart | veins

?

Drag the characteristics of each blood vessel to the correct place in the table.

Carries blood to the heart

Blood flows at medium pressure

The vessel wall is one cell thick

Takes blood away from the heart

Contains low oxygen levels

Blood flows at high pressure

Connects veins to arteries

Contains high oxygen levels

Carries blood between the cells

Artery	Vein	Capillary

?

FS2053 Chapter 5 - Learning outcomes

Pressure, fluids, gases and breathing

By the end of the lesson, you should be able to:

- Explain the gas laws and their application to the behaviour of gases in different conditions.
- Define pressure, pascal principle and explain its significance in various contexts.
- Describe the process of breathing.
- Differentiate between lung volume and understand their relevance to respiratory physiology.
- Understand the function of blood pressure and blood vessels in the human body, including arteries, veins, and capillaries.

The End! – **Questions?**

Next Topic:

Sound and hearing