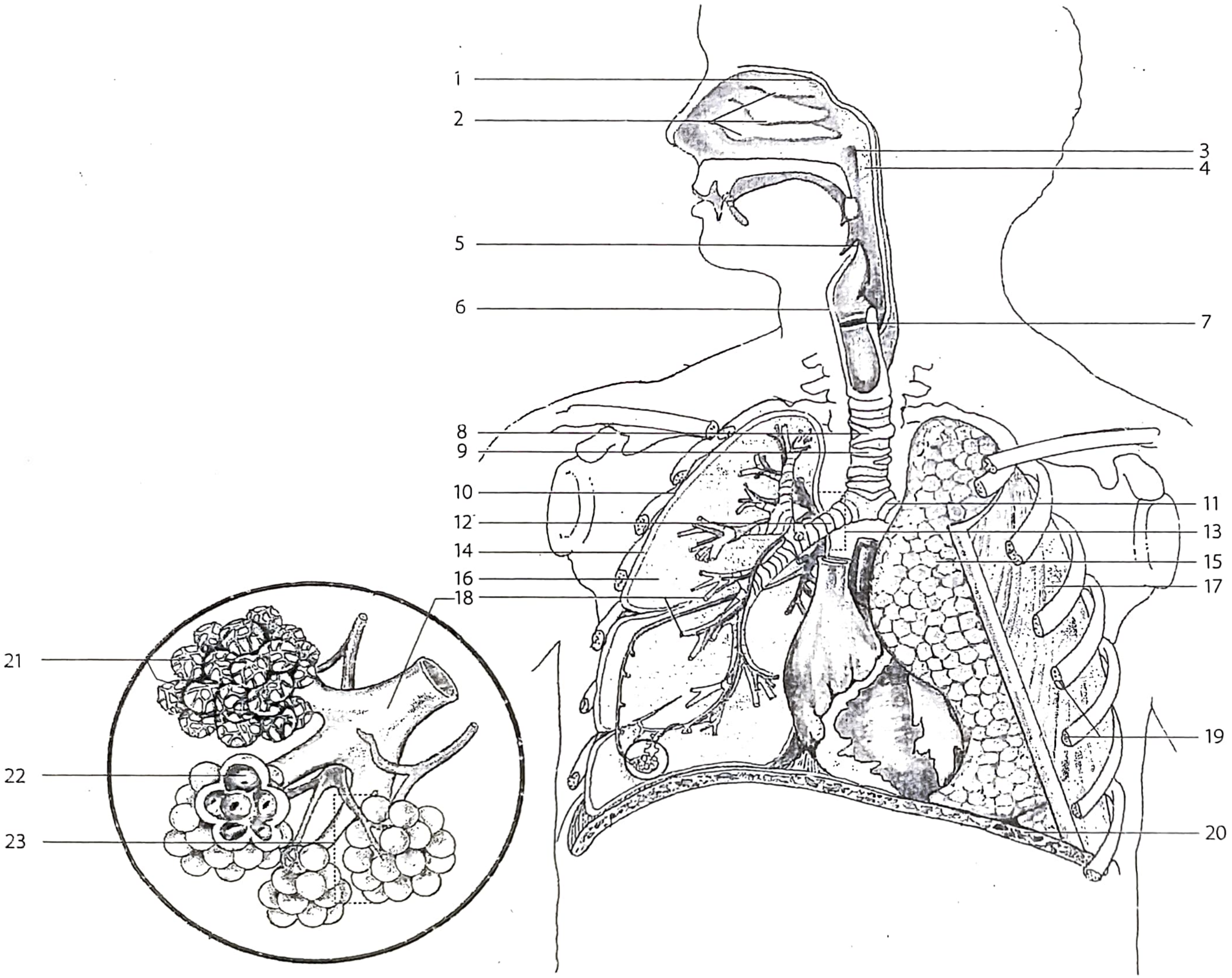
8. GASEOUS EXCHANGE

TERMINOLOGY

TERM	**DESCRIPTION**
Mucus	A slimy substance secreted by glands to protect and lubricate surfaces
Cilia	Hair-like projections on the cells lining some of the airways that sweep mucus upwards
Diffusion	Movement of molecules from a region where they are more concentrated to a region where they are less concentrated
Breathing	Ventilating the lungs by moving air in and out of them
Permeable	Can be penetrated by liquids or gases
Stomata	Small openings on a leaf through which oxygen and carbon dioxide can pass
Alveolus (Plural: Alveoli)	Air sac that allows efficient gas exchange with the blood
Surfactant	A substance that lowers the surface tension of the moist film lining the alveoli
Deoxygenated	Term used to describe blood that contains a low concentration of oxygen
Oxygenated	Term used to describe blood that contains a high concentration of oxygen
Spirometer	An instrument for measuring the amount of air entering and leaving the lungs
Sputum	A substance containing saliva mixed with mucus and other matter that is coughed up and expelled from the mouth
Allergen	A substance that causes an allergic reaction
Allergy	A condition in which a person is abnormally sensitive to a particular substance
Passive smoking	Breathing in tobacco smoke from other peoples' cigarettes
Artificial respiration	A method to start and maintain breathing once it has stopped

Figure 2.36 The human respiratory system



Key to Figure 2.36 above

1. Olfactory region – contains sensory hairs that are able to perceive chemical stimuli that will be interpreted by the olfactory region of the brain as a smell.
2. Turbinate bones – increase the internal surface area of the nasal cavity and direct the flow of air towards the pharynx.
3. Opening of Eustachian tube – allows air to move into the middle ear, via the Eustachian tube, in order to equalise the air pressure on both sides of the ear drum (tympanum).
4. Pharynx – the passage that leads from the nasal cavity and the mouth to the trachea and oesophagus.
5. Epiglottis – valve that closes the glottis when food or liquid is swallowed in order to prevent them from entering the trachea and subsequently the lungs.
6. Larynx – the 'voice box'. This is a widening of the trachea housing a cartilaginous 'voice box' containing the vocal cords.
7. Glottis – opening of the trachea from the pharynx.
8. Trachea – conducts air to and from the lungs. Lined with a mucus membrane of ciliated epithelium. Mucus traps solid particles and is then expelled by wave-like movements of the cilia to the pharynx where it is then swallowed. Any pathogens that may have been trapped in the mucus are now destroyed in the stomach.
9. C-shaped cartilaginous rings – keeps trachea open. Opening of ring is adjacent to the oesophagus allowing the oesophagus to expand as food moves down the oesophagus.
10. Pleura – double membrane surrounding the lungs that helps to prevent friction during the ventilation process.
11. Circular cartilaginous rings – used to keep the bronchi open in order to ensure an unobstructed pathway for the flow of air to and from the lungs.
12. Bronchi – left and right branch of the trachea that conduct air to and from the lungs.
13. Hilum – a triangular shaped depression in the lung surface. The structures forming the root of the lung, the bronchus, pulmonary artery, nerves, lymph vessels and pulmonary vein, enter and leave the lung at this position.
14. Interpleural cavity – fluid-filled space between the pleura. Fluid acts as a lubricant in order to prevent friction during ventilation as the ribcage and muscles slide over the lung surface.
15. Left lung – two lobes but slightly longer than right lung.
16. Right lung – three lobes but slightly shorter than left lung.
17. Intercostal muscles – responsible for the protection of the lungs and play a role in the ventilation process of the lungs.
18. Bronchioles – sub-divisions of the bronchi inside the lungs.
19. Ribs – form ribcage. Protect the lungs and heart.
20. Diaphragm – a dome-shaped muscular sheet separating the thoracic cavity from the abdominal cavity. Plays a role in the ventilation process of the lungs.
21. Capillary network – provides large surface area for external gaseous exchange to occur.
22. Alveoli – small, thin-walled, sac-like structures surrounded by a network of capillaries. The alveoli provide the surface that meets the requirements for efficient gaseous exchange.
23. Infundibulum – the expanded ends of the alveoli from which a collection of alveoli originates.

Difference between Cellular Respiration, Breathing and Gas Exchange.

Cellular Respiration

- Occurs in living plant and animal cells
- Chemical process
- Glucose is broken down to release energy (ATP) and carbon dioxide

Breathing

- Involves inhalation and exhalation
- mechanical process
- Inhalation - when air$\overset{(O_2)}{\wedge}$ is taken into the lungs
- Exhalation - removal of air$\overset{(CO_2)}{\wedge}$ from the lungs

Gas exchange $O_2 \overset{\text{diffusion}}{\rightleftarrows} CO_2$

- Occurs in the lungs and in body tissue
- Physical process involving diffusion
- Lungs : O_2 diffuses from alveoli into the blood while CO_2 diffuses from the blood into the alveoli.
- Tissue level : O_2 diffuses from the blood capillaries into the body cells, while CO_2 diffuses from the body cells into the blood capillaries.

Requirements of efficient gas exchange organs.

Requirements	In humans
1. Gas exchange surface has a large surface area to allow maximum intake of O_2 and sufficient release of CO_2.	Large number of alveoli provide the large area for exchange of gases.
2 Gas exchange surface is thin so gases can diffuse through rapidly.	Squamous epithelium of alveolus is only one cell layer thick.
3. Gas exchange surface is permeable and moist so that the gas molecules can pass through in solution.	The secretions of certain cells lining the alveoli keep the surface moist.
4. It is well ventilated to ensure constant intake of O_2 and removal of CO_2	Diaphram and intercostal muscles between ribs provide an efficient mechanism for ventilation
5. Has a good transport system such as a good blood supply close to the gas exchange surface	Alveoli are richly supplied with blood capillaries
6 It is protected to prevent drying out and damage	Thoracic cage, consisting of the ribs, sternum and vertebral column protects the lungs.

Homeostatic control of breathing

- The respiratory centre in the medulla oblongata of the human brain controls the normal, involuntary breathing rate.

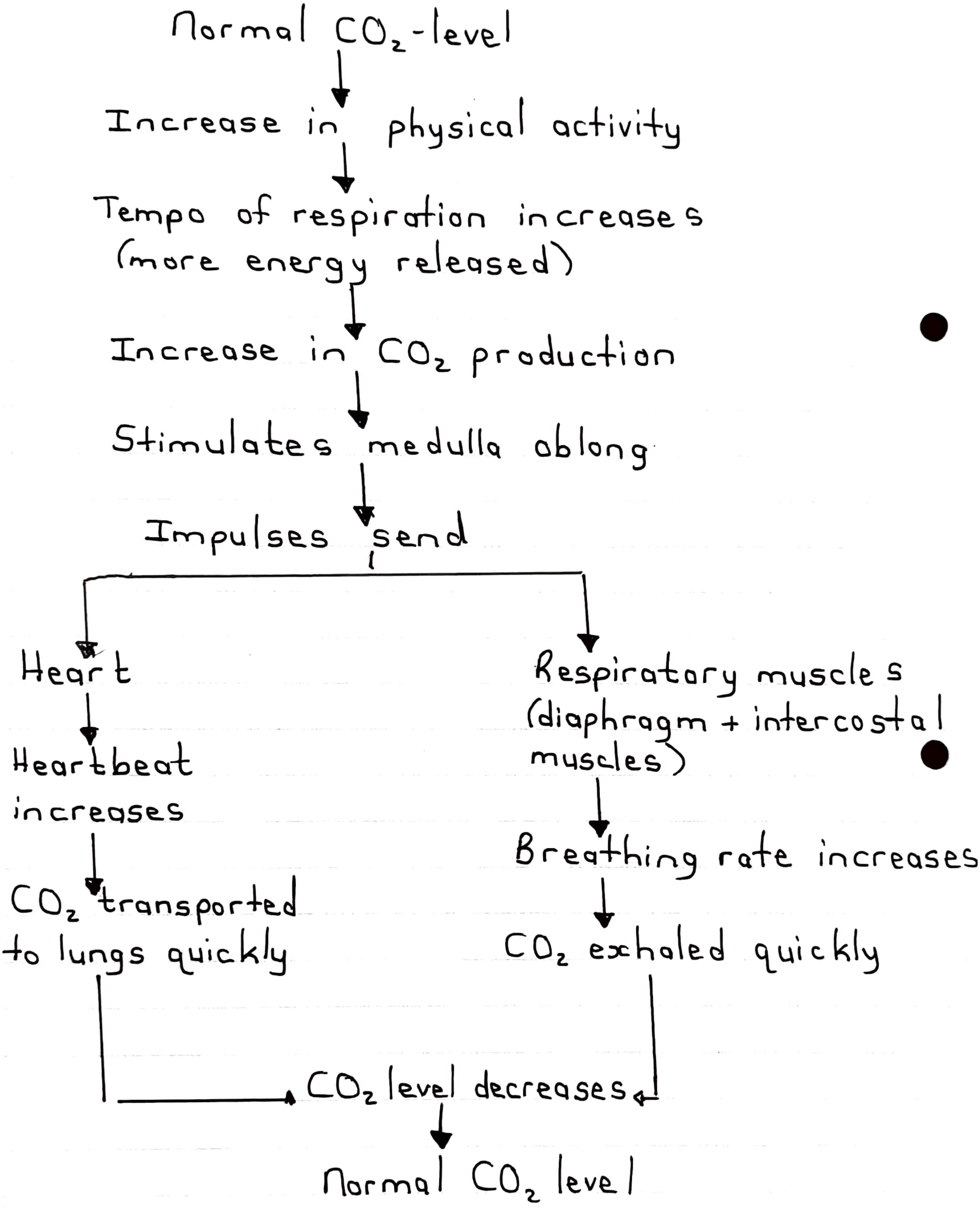
- Cells in the medulla oblongata are sensitive to changes in CO_2 level of the blood.

- Breathing rate is controlled by the amount of CO_2 in the blood.

- Adrenaline (hormone secreted by the adrenal gland) also accelerates the breathing rate.

Homeostatic control of breathing.

What happens when CO_2 level in the blood rises?

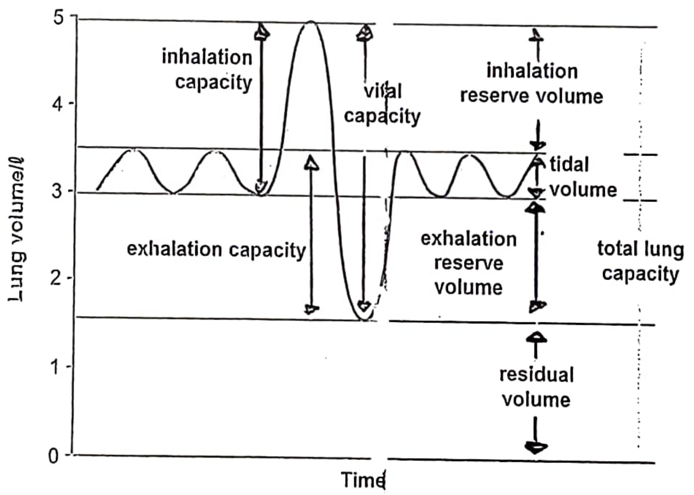


Lung capacity

= Total volume of air that the lungs can accommodate.

- Spirometer: A machine that can measure the volume of air breathed in and out of the lungs accurately over a period of time.

- The graph below shows the different volumes of air in the lungs:



- Tidal volume: The amount of air that is breathed in and out during normal breathing.
- Inhalation reserve volume: After normal inhalation it is possible to breath in additional air.
- Exhalation reserve volume: It is possible to breath out additional air after normal exhalation.
- These 2 reserve volumes as well as the tidal volume = vital capacity.

Residual volume = The volume of air that remains in your lungs when you have breathed out fully.

As volume increases, pressure decreases.

Inspiration /Inhalation Active process

- The external intercostal muscles contract, raising the rib cage upwards and outwards.
- The muscles of the diaphragm contract and the diaphragm flattens.
- The volume of the thoracic cavity increases.
- The air pressure inside the lungs decreases below the pressure of air in the atmosphere (atmospheric pressure).
- Air outside the body is at atmospheric pressure, which is higher than the pressure of the air inside the lungs. Therefore air outside the body flows into the lungs to equalise the pressure and the lungs inflate with air.

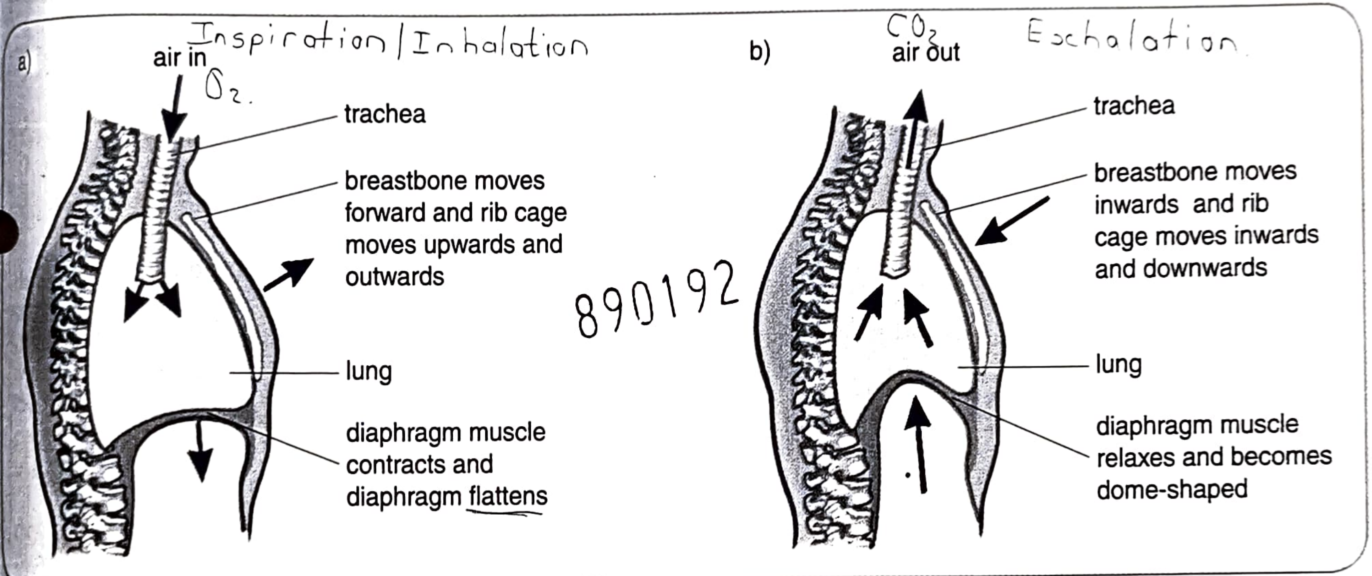


Fig. 7.12 *Changes in the volume of the thorax result in the flow of air during a) inspiration and b) expiration*

Expiration |exhalation. ① Passive process.

- ② The external intercostal muscles relax and the ③ rib cage moves inwards and downwards due to gravity.
- 4 The diaphragm relaxes and becomes dome-shaped.
- 5 The volume of the thoracic cavity decreases.
- 6 The air pressure inside the lungs increases above atmospheric pressure.
- 7 Air inside the lungs is at a higher pressure than the pressure of the air outside the body. Therefore air is forced out of the lungs into the atmosphere.

During forced breathing out, for example when holding a note during singing, the internal intercostal muscles and abdominal muscles contract. During quiet breathing, the movement of the diaphragm alone is responsible for ventilation of the lungs.

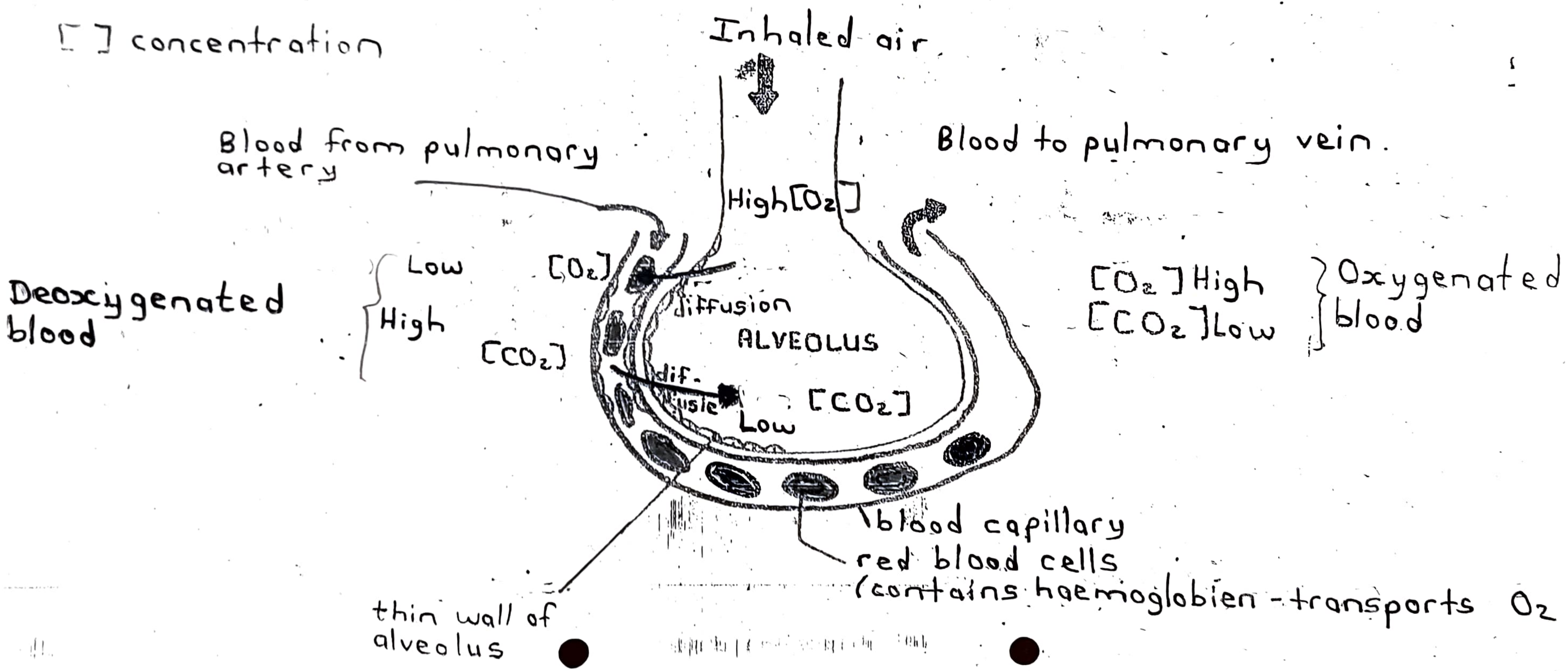
In Practical activity 3 you will make a simple model using a plastic cold drink bottle to show what happens during inspiration and expiration. In your model there will only be one 'lung'.

Tabulate the differences between
a) inhalation
b) exhalation

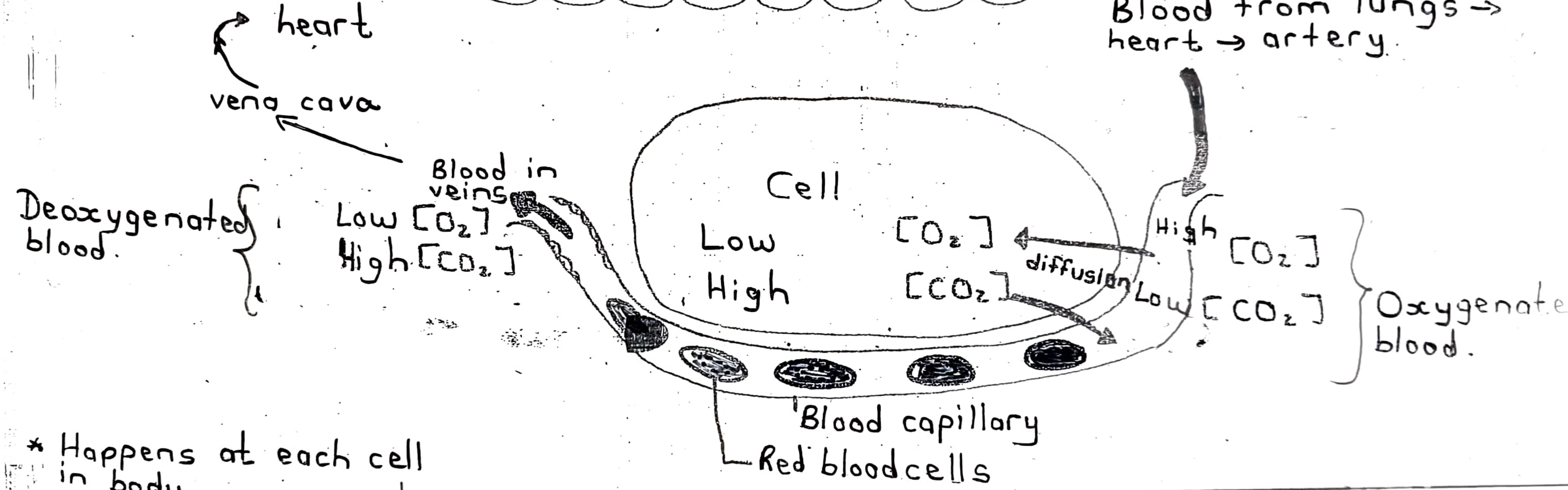
Gaseous exchange in the alveolus

Movement of O_2 and CO_2 - diffusion
High [ ] → Low [ ]

[ ] concentration



Gaseous exchange in tissues.



- Happens at each cell in body
- CO_2 - waste product (cell respiration) - must be removed
- O_2 - lungs to cells
- O_2 used for cellular respiration

Transport of O_2

1. Small amount dissolves in blood plasma
2. O_2 + haemoglobin
   ↓
   oxyhaemoglobin

Transport of CO_2

1. Dissolves in blood plasma
2. CO_2 + haemoglobien
   ↓
   carbominohaemoglobien
3. Carried as bicarbonate ions

Practical activity 3

This is a prescribed practical task.

Construct a model to show how the human breathing system works

You will need:

- a large empty plastic cold drink bottle with screw-on lid
- plastic drinking straw
- balloon
- modelling clay
- plastic bag
- masking tape
- elastic band
- piece of string
- pair of scissors
- sharp nail

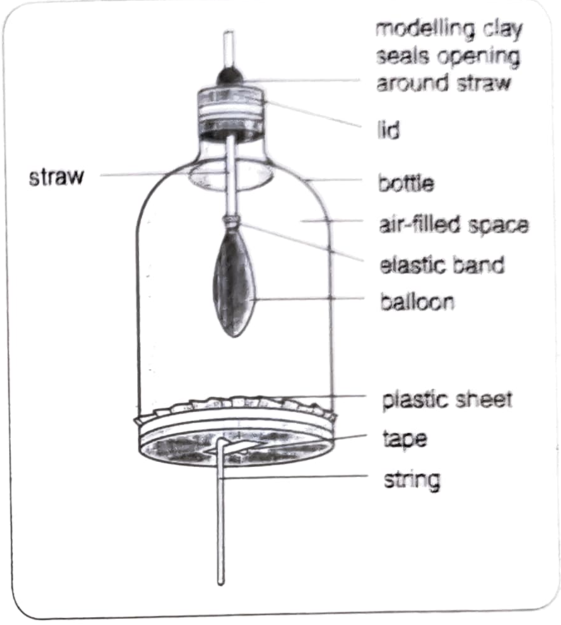


Fig. 7.13 Model of the human breathing system

Method

1. Use a pair of scissors to cut off the base of the cold drink bottle.
2. Use the nail to make a hole in the lid just large enough for the plastic straw to fit through. Make sure that the lid is screwed tightly onto the bottle.
3. Use an elastic band to tie the balloon to one end of the straw. Push the other end of the straw through the hole in the lid. Press modelling clay around the straw on top of the lid to make an airtight seal.
4. Cut the plastic bag in a circular shape large enough to cover the bottom of the bottle. Stretch the plastic sheet tightly across the bottom of the bottle. Tape the plastic sheet to the side of the bottle to hold it securely and make the bottle airtight. Tape a piece of string to the centre of the plastic sheet, allowing a short piece to hang downwards.
5. Use the string to pull the sheet of plastic downwards. Then push the sheet of plastic upwards into the bottle. Notice what happens to the balloon in each case.

Questions

1. What does the movement of the plastic sheet represent? (1)
2. What happened to the balloon when the plastic sheet moved a) down and b) up? Why did the balloon change shape? (5)
3. What parts of the thorax in a human are represented by the following in your model: straw, balloon, bottle, air-filled space, plastic sheet, piece of string? (6)
4. Describe the ways in which your model is a poor representation of the structure of the thorax and the mechanism of breathing. (6)

Practical activity 4

This is a prescribed practical task.

Demonstrate that expired air contains carbon dioxide

Task 1: Demonstrate that the air you breathe out contains carbon dioxide
Limewater can be used as an indicator for carbon dioxide. Limewater turns from clear to milky when carbon dioxide dissolves in it.

You will need:
- a beaker/container
- clear limewater
- plastic straw

Method
1. Half fill a beaker/container with clear limewater.
2. Gently exhale through the straw into the limewater until the limewater changes colour.

Question
How were you able to tell that the air you breathed out contains carbon dioxide? (1)

This part of the practical task is optional.

Task 2: Interpret the results of an investigation.
A learner set up the apparatus as in Figure 7.16 to determine whether expired air contains more carbon dioxide than inspired air.
1. The learner closed tap B and opened tap A. He placed his lips over the end of the rubber tubing and breathed in several times.
2. The learner then closed tap A and opened tap B. He placed his lips over the end of the rubber tubing and breathed out several times, the same number of breaths as in step 1.
3. He noticed that when he breathed in, bubbles appeared in flask A. When he breathed out, bubbles appeared in flask B.
4. The learner continued breathing in and out through the rubber tubing until the limewater in one of the flasks turned milky. He found that the limewater in flask B turned milky first.

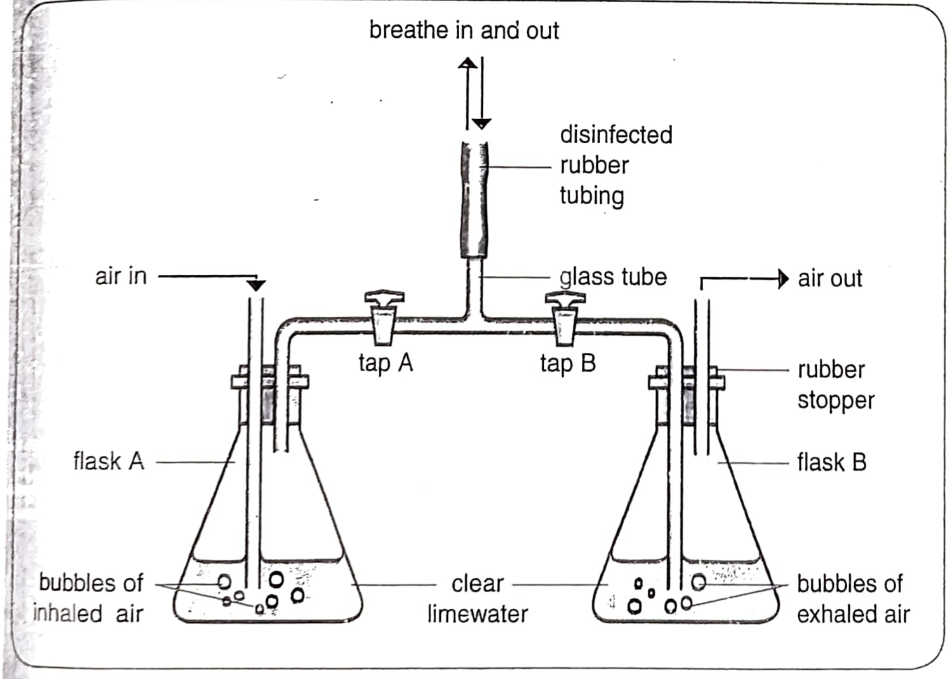


Fig. 7.16 Experimental setup

Questions
1. Write down a hypothesis for the investigation. (1)
2. Which flask is testing the carbon dioxide content of a) inspired air and b) expired air? (2)
3. What caused the limewater in flask B to turn milky? (1)
4. Explain what the results of the investigation indicate about the amount of carbon dioxide in inspired and expired air. (3)

In Practical activity 4 you discovered that there is more carbon dioxide in expired air than in inspired air, but you did not discover how much. Table 7.2 compares the actual gas content of inspired and expired air.

Table 7.2 Gas content of inspired and expired air

Component	**Inspired air**	**Expired air**
Oxygen	21%	16%
Carbon dioxide	0,04%	4%
Nitrogen and inert gases	78%	78%
Water vapour	Variable	Higher than in inspired air

- Draw a pie chart to show the gas content of inspired air.
- Draw a pie chart to show the gas content of expired air.

Classroom activity 2

Use the data in Table 7.2 and your knowledge of gas exchange to answer the following questions:

1. What is the difference in the percentage of oxygen between inspired and expired air? (1)
2. Explain why there is less oxygen in expired air than in inspired air. (2)
3. What is the difference in the percentage of carbon dioxide between inspired and expired air? (1)
4. Explain why there is more carbon dioxide in expired than in inspired air. (2)
5. Explain why the percentage of nitrogen and inert gases is the same in inspired and expired air. (2)
6. Explain why there is usually more water vapour in expired air than in inspired air. (2)
7. In what other ways, not shown in the table, could inspired air be different from expired air? (2)

Classroom activity 3

Look at the spirometer tracing in Figure 7.18. It shows the breathing pattern of a female learner measured over a period of 60 seconds.

1. For the first 30 seconds the learner was sitting quietly. How many breaths did she take in 30 seconds? What was her breathing rate per minute at rest? How much air did she breathe in/out with each breath? (4)
2. During the next 30 seconds, the learner's breathing pattern changed. Describe the changes in her breathing pattern. How much air did she exhale in these 30 seconds? (3)
3. Table 7.3 shows the results of an experiment in which an adult male breathed in air containing different amounts of carbon dioxide.

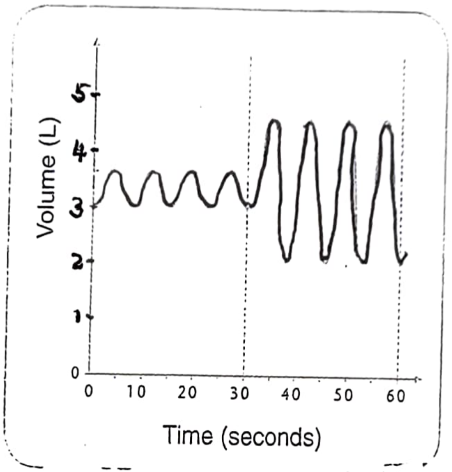


Fig. 7.18 A spirometer tracing

Table 7.3 Results of an experiment to investigate the effect of carbon dioxide content on the rate and volume of breathing

Carbon dioxide in inspired air (%)	0,04	0,80	2,00	3,00	6,00
Number of breaths per minute	14	14	15	15	28
Volume of air per breath (cm³)	520	740	860	1 220	2 100

a) What is the normal percentage of CO_2 in the air? (1)

b) At 0,04% CO_2 in the inspired air, what is the man's (i) breathing rate and (ii) depth of breathing? (2)

c) At 6% CO_2 in the inspired air, what is the man's (i) breathing rate and (ii) depth of breathing? (2)

d) Calculate the amount of air that the man breathes in per minute when he breathes in air that contains (i) 0,04% CO_2 and (ii) 6% CO_2. (4)

e) What conclusions can you draw from the information given in the table? (5)

Questions on gaseous exchange

1. Give the correct word or term for each of the following:
   a) gas exchange organs of a fish
   b) the main form in which carbon dioxide is transported in the blood
   c) the part of the human brain that controls the breathing rate
   d) a lung disease in which the walls of the alveoli break down and lose elasticity
   e) the pores through which gases enter or leave a leaf
   f) a physical process in humans in which air is taken into and released from the body
   g) a procedure in which air is introduced into the lungs of a person who has stopped breathing so that they can breathe again
   h) the pigment in human blood that carries oxygen
   i) the tissue lining the trachea
   j) a domed, muscular sheet separating the abdominal and thoracic cavity. (10)
2. Some animals can breathe through their skins.
   a) Give one example of an animal that uses its skin for gas exchange. (1)
   b) Why do humans not use their skin for gas exchange? (3)
3. Explain why:
   a) the breathing rate increases during exercise (4)
   b) it is possible to keep a person alive by using exhaled air during mouth-to-mouth resuscitation (2)
   c) people who live permanently at high altitudes have more red blood cells in their blood than people who live at low altitudes. (2)
4. Study Figure 7.29.
   a) Provide labels for parts A–G. (7)
   b) Explain two ways in which the structure labelled A is suited to its function. (4)
   c) Describe the role of the parts labelled B, C and E in inspiration. (6)
5. Figure 7.30 represents gas exchange across an alveolus. The arrow X indicates the direction of blood flow. Look at the diagram and then answer the questions that follow.
   a) Where would you find a structure like this? (1)
   b) Is the blood that enters at X oxygenated or deoxygenated? (1)
   c) What are the gases that move as indicated by A and B? (2)
   d) Provide labels for C–G. (5)
   e) How is a red blood cell well suited to the transport of oxygen? (2)

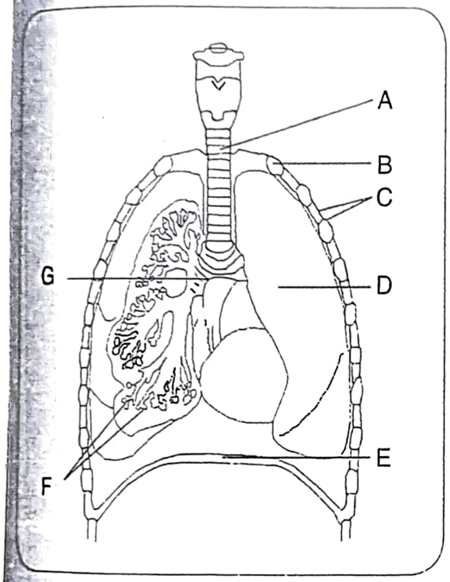


Fig. 7.29 Diagram of the human breathing system

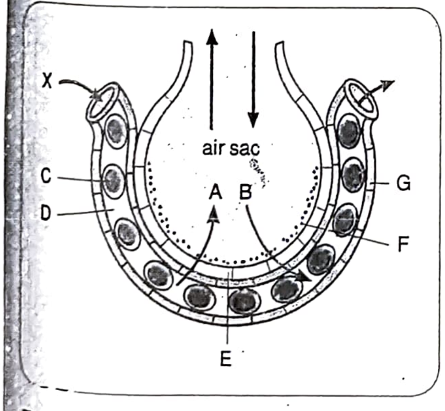


Fig. 7.30 Gas exchange across an alveolus

f) A concentration gradient of oxygen must be maintained between the air in the alveolus and the blood in the capillary.
   (i) What is meant by a concentration gradient? (1)
   (ii) Why is it necessary to maintain a concentration gradient of oxygen? (2)
   (iii) How is the concentration gradient of oxygen maintained? (4)

g) Write down three features of alveoli that make them efficient gas exchange structures. (3)

6. The graph in Figure 7.31 shows the results of an investigation into the annual number of deaths from lung cancer of male smokers over the age of 60, according to the age when they started smoking. The men in Group A smoked 10 to 20 cigarettes per day. The men in Group B smoked 21 to 40 cigarettes per day.

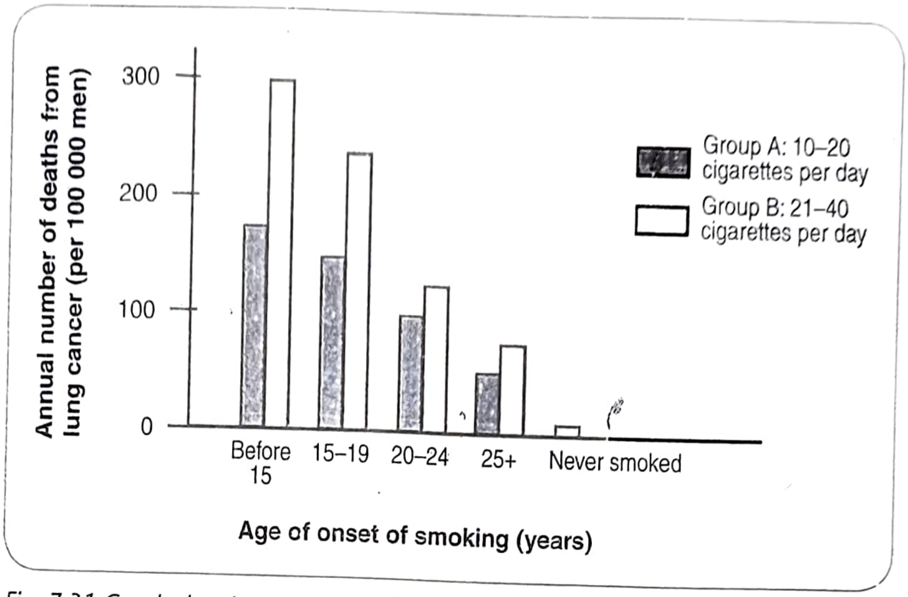


Fig. 7.31 Graph showing annual number of deaths due to lung cancer amongst men

a) Study the graph and draw up a table to summarise the results of the investigation as shown in the graph. (8)

b) Answer the following questions:
   (i) Use the graph to determine the annual number of deaths from lung cancer of the men who started to smoke at 17 and continued smoking about 20 cigarettes a day. (2)
   (ii) How does increasing the number of cigarettes smoked per day affect the annual number of deaths from lung cancer? (1)
   (iii) How does starting to smoke earlier in life affect the annual number of deaths from lung cancer? (1)
   (iv) Do the results of the investigation support the hypothesis that people who smoke are more likely to die of lung cancer? Explain your answer. (3)
   (v) Name two other respiratory diseases caused by cigarette smoke. (2)