Cambridge AS level Biology

CODE: (9700)

Chapter 09 Gas exchanging and smoking

9.1 Gas exchange

The human gas exchange system links the circulatory system with the atmosphere. It is adapted to:

■ Clean and warm the air that enters during breathing

■ Maximise the surface area for diffusion of oxygen and carbon dioxide between the blood and atmosphere

■ Minimise the distance for this diffusion

■ Maintain adequate gradients for this diffusion.

Oxygen is essential for respiration in most organisms. In multicellular organisms like humans, cells are distant from the external environment, requiring a specialized gas exchange surface. In humans, the alveoli in the lungs provide this surface, with a large surface area of around 70 m^2 in an adult, allowing a high rate of gas exchange between oxygen and carbon dioxide molecules.

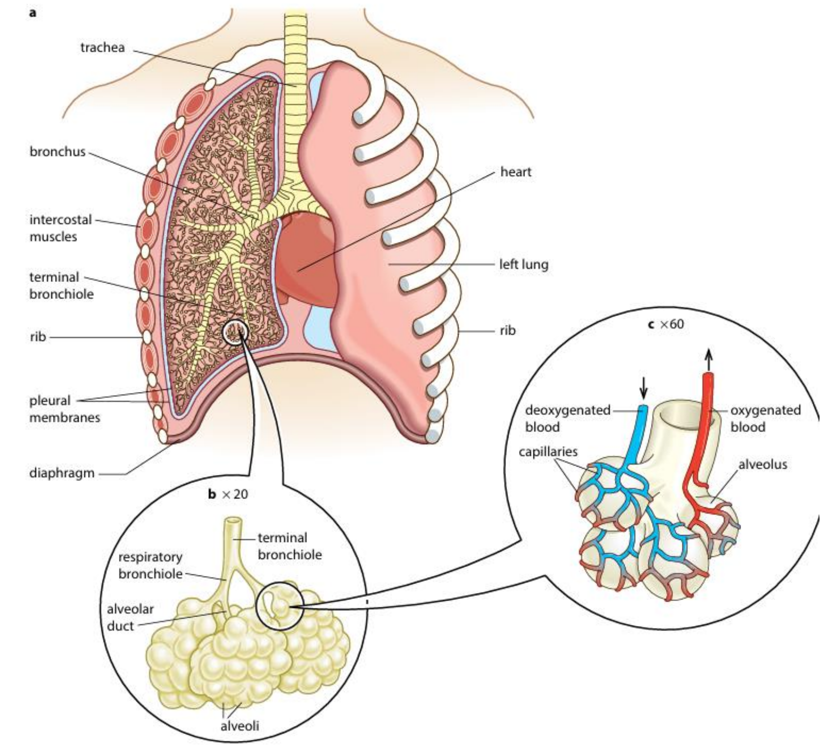


Figure 9.2 The human lungs. Air passes through **a** the trachea and bronchi to supply many branching bronchioles **b** which terminate in alveoli **c** where gas exchange occurs. A gas exchange surface of around 70 m^2 fits into the thoracic cavity, which has a capacity of about 5 dm^3.

9.2 Lungs

The lungs are in the thoracic (chest) cavity surrounded by the pleural membranes, which enclose an airtight space. This space contains a small quantity of fluid to allow friction-free movement as the lungs are ventilated by the movement of the diaphragm and ribs.

9.3 Trachea, bronchi and bronchioles

Leading from the throat to the lungs is the **trachea**. (Table 9.1) At the base of the trachea are two **bronchi** (singular: **bronchus**), which subdivide and branch extensively forming a bronchial 'tree' in each lung. Each bronchus divides many times to form smaller **bronchioles**.

Cartilage in the trachea and bronchi keeps these airways open and air resistance low and prevents them from collapsing or bursting as the air pressure changes during breathing. (Figure 9.3)

Warming and cleaning the air

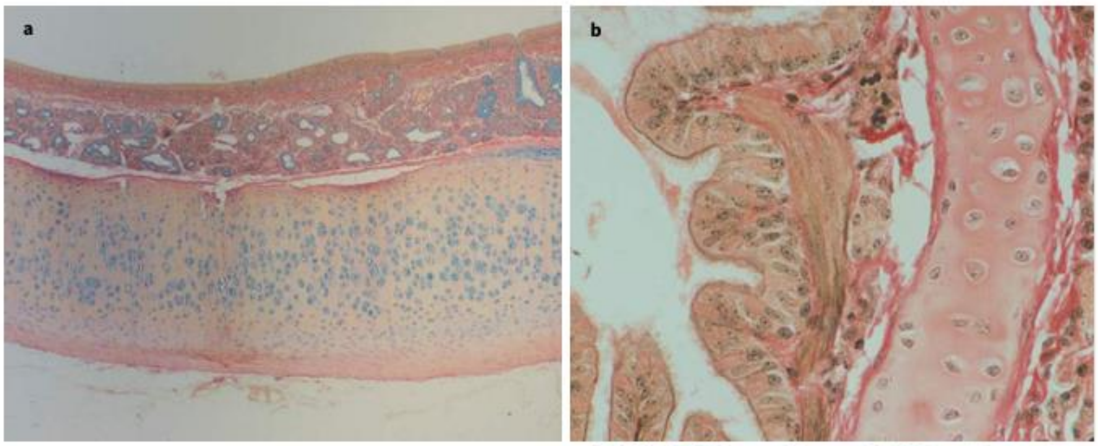
Air through the nose and trachea warms and moistens the lungs, protecting delicate surfaces from desiccation and suspended matter like dust, sand, pollen, and viruses, which can threaten lungs' function.

Particles larger than about 5–10 µm are caught on the hairs inside the nose and the **mucus** lining the nasal passages and other airways. In the trachea and bronchi, the mucus is produced by the **goblet cells** of the ciliated epithelium. The upper part of each goblet cell is swollen with **mucin** droplets which have been secreted by the cell

Phagocytic white blood cells known as **macrophages** patrol the surfaces of the airways scavenging small particles.

Airway	Number	Approximate diameter	Cartilage	Goblet cells	Smooth muscle	Cilia	Site of gas exchange
trachea	1	1.8 cm	yes	yes	yes	yes	no
bronchus	2	1.2 cm	yes	yes	yes	yes	no
terminal bronchiole	48 000	1.0 mm	no	no	yes	yes	no
respiratory bronchiole	300 000	0.5 mm	no	no	no	a few	no
alveolar duct	9×10^6	400 µm	no	no	no	no	yes
alveoli	3×10^9	250 µm	no	no	no	no	yes

Table 9.1 The structure of the airways from the trachea to the alveoli. The various airways are shown in Figure 9.2.



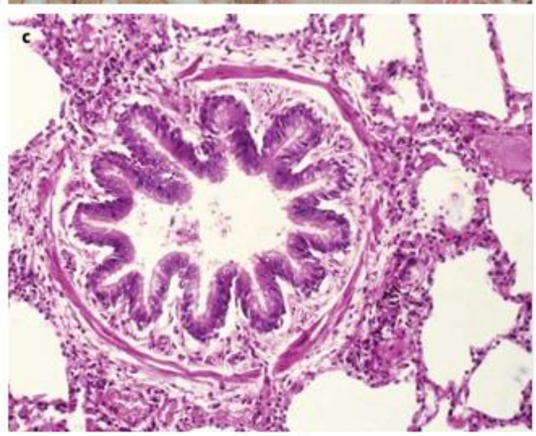


Figure 9.3

a A light micrograph of part of the trachea in transverse section (TS) (×65). The lining is comprised of ciliated epithelium which rests on a basement membrane made of protein fibres. In between the ciliated cells are goblet cells (here stained blue). Beneath the epithelium is an area of loose tissue with blood vessels and mucous glands. The trachea as a whole is supported by C-shaped rings of cartilage, a portion of which appears as the thick layer running across the bottom of the picture.

b A light micrograph of part of a bronchus in TS (×300). Between the ciliated epithelial cells, the goblet cells are stained pink. There are fewer goblet cells per cm^2 than in the trachea, and the epithelial cells are not as tall. Beneath the epithelium there are elastic fibres. Blocks of cartilage, not rings, support the bronchus, and part of one can be seen, also stained pink, stretching from the top to the bottom of the picture.

c A light micrograph of a small bronchiole in TS (×135). Surrounding the epithelium is smooth muscle. There is no cartilage. Around the bronchiole are some alveoli.

9.4 Alveoli

At the end of the pathway between the atmosphere and the bloodstream are the **alveoli** (Figures 9.3c and 9.5). Alveolar walls contain **elastic fibres** which stretch during inspiration and recoil during expiration to help force out air. Alveoli have thin walls and blood capillaries, allowing oxygen and carbon dioxide molecules to diffuse quickly between the air and blood. To maintain a steep concentration gradient, breathing and blood movement are essential. Breathing brings fresh air with high oxygen concentration, while blood brings oxygen and carbon dioxide.

9.5 Smoking

The World Health Organization (WHO) considers smoking a disease. Until the 19th century, tobacco was primarily smoked by men. However, during World War I, smoking became fashionable for European men and women. In recent decades, countries like the UK and USA have seen a decline in smoking, while countries like China and Pakistan have seen a rise in shisha smoking.

Figure 9.4 False-colour scanning electron micrograph of the surface of the trachea, showing large numbers of cilia (yellow) and some mucus-secreting goblet cells (red) (×2600).

9.6 Tobacco smoke

Tobacco smoke contains over 4000 toxic chemicals, primarily found in the burning tip. It is composed of both mainstream and sidestream smoke, with 85% of the smoke released being sidestream. These toxic ingredients are more concentrated in sidestream smoke than mainstream smoke, exposing nearby people to the harmful effects of passive smoking.

The main components of cigarette smoke pose a threat to human health. These are:

■ Tar, which contains carcinogens (cancer-causing compounds)

■ Carbon monoxide

■ Nicotine.

In general, tar and carcinogens damage the gas exchange system, carbon monoxide and nicotine damage the cardiovascular system.

■ Tar is a mixture of compounds that settles on the lining of the airways in the lungs and stimulates a series of changes that may lead to obstructive lung diseases and lung cancer.

■ Carcinogens are cancer-causing compounds. These cause mutations in the genes that control cell division

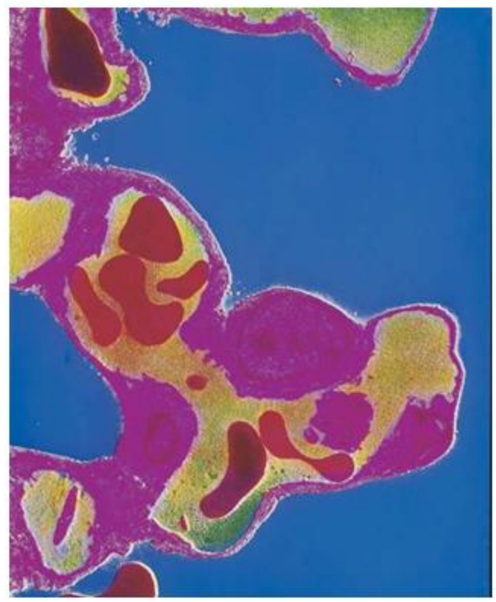


Figure 9.5 False-colour transmission electron micrograph of the lining of an alveolus. Red blood cells fill the blood capillaries (yellow), which are separated from the air (blue) by a thin layer of cells (pink) ×2100.

9.10 lung diseases

Lung diseases are a major global health issue, primarily caused by air pollution, smoking, and allergic reactions. The lungs' delicate tissue is exposed to harmful gases and particles, making every breath a struggle. Small particles, less than 2 µm in diameter, can reach alveoli and stay there, making the lungs susceptible to airborne infections like influenza and pneumonia. The slow air flow in the lungs also makes them susceptible to allergic reactions, leading to asthma.

Every disease has a characteristic set of **signs** and **symptoms**.

Chronic (long-term) **obstructive pulmonary diseases (COPD)** such as asthma, chronic **bronchitis** and **emphysema** are now common in many countries.

Chronic bronchitis

Cigarette smoke contains tar, which stimulates mucus secretion by goblet cells and mucous glands. This tar also inhibits the cleaning action of the ciliated epithelium, leading to mucus accumulation in bronchioles. This accumulation can block bronchioles, causing dirt, bacteria, and viruses to accumulate and block the airways. This leads to'smoker's cough', which tries to move mucus up the airways. Over time, damaged epithelia are replaced by scar tissue, and the smooth muscle surrounding the airways thickens, making it difficult to breathe. Infections like pneumonia can develop in the accumulated mucus, leading to chronic bronchitis.

Emphysema

Infected lungs cause phagocytes to leave the blood and line the airways, removing bacteria from the body. Phagocytes release the enzyme elastase, which destroys elastin in alveoli walls, allowing phagocytes to reach the surface and remove bacteria. This results in bronchioles collapsing during expiration, trapping air in the alveoli, which often burst. This reduces surface area for gas exchange and decreases the number of capillaries, resulting in **emphysema**, which reduces oxygen absorption into the blood.

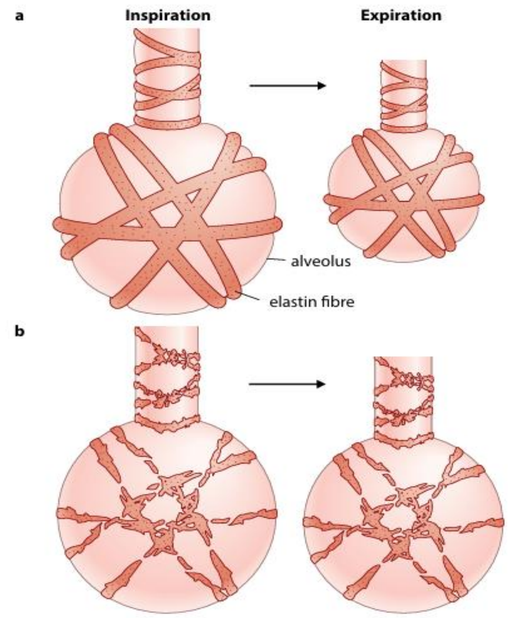


Figure 9.6 The development of emphysema. **a** Healthy alveoli partially deflate when breathing out, due to the recoil of elastin fibres. **b** Phagocytes from the blood make pathways through alveolar walls by digesting elastin and, after many years of this destruction, the alveoli do not deflate very much.

Emphysema is a lung disease caused by the loss of elastin, making it difficult to move air out of the lungs. This results in poor oxygenation and rapid breathing. As the disease progresses, lungs become more resistant to blood flow, leading to increased blood pressure in the pulmonary artery and enlargement of the right side of the heart. Severe emphysema requires continuous oxygen supply through a face mask. Chronic bronchitis and emphysema often occur together, posing a serious health risk. Recovery from COPD is not possible in older people.

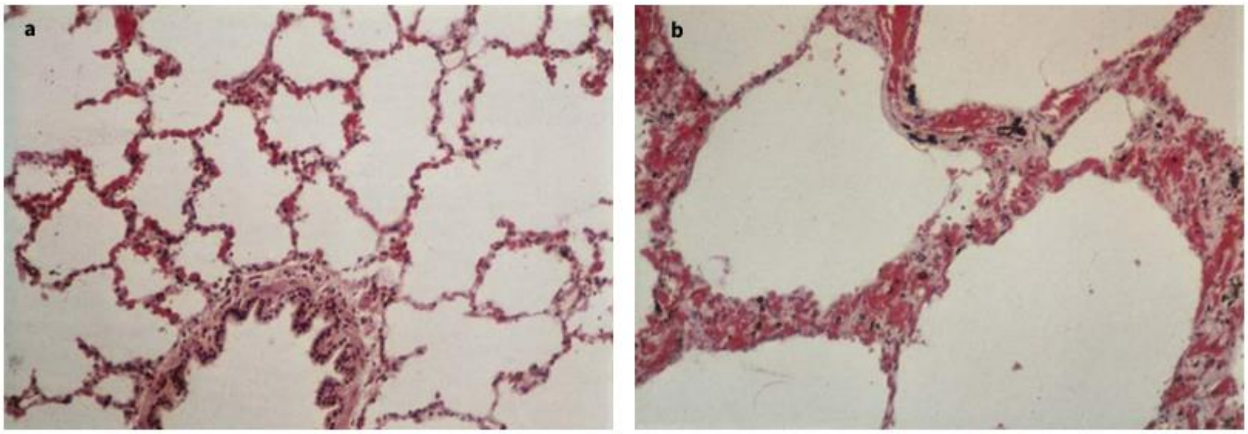


Figure 9.7 **a** Photomicrograph of normal lung tissue (×75). **b** Photomicrograph of lung tissue from a person with emphysema, showing large spaces where there should be many tiny alveoli (×75).

Lung cancer

Tobacco smoke contains carcinogens that react with DNA in epithelial cells, leading to mutations and the development of a tumour. As the cancer spreads, it may break away and form secondary tumours. Lung cancer takes 20-30 years to develop, with most growth occurring before symptoms. Common symptoms include coughing up blood, chest pain, and difficulty breathing. Diagnosis is rare before the tumor reaches 1 cm in diameter.

Tumours in the lungs, such as that shown in Figure 9.9, are located by one of three methods:

■ Bronchoscopy, using an endoscope to allow a direct view of the lining of the bronchi (Figure 9.1)

■ Chest X-ray

■ CT scan (similar to that shown in Figure 9.8).

Lung cancers are often advanced by the time they are discovered, and treatment involves surgery, radiotherapy, and chemotherapy. Treatment depends on the type of cancer, its extent, and whether it spreads. If small and in one lung, surgery may be necessary. However, if secondary tumors exist, surgery may not cure the disease. Chemotherapy with anti-cancer drugs or radiotherapy with X-rays is used.

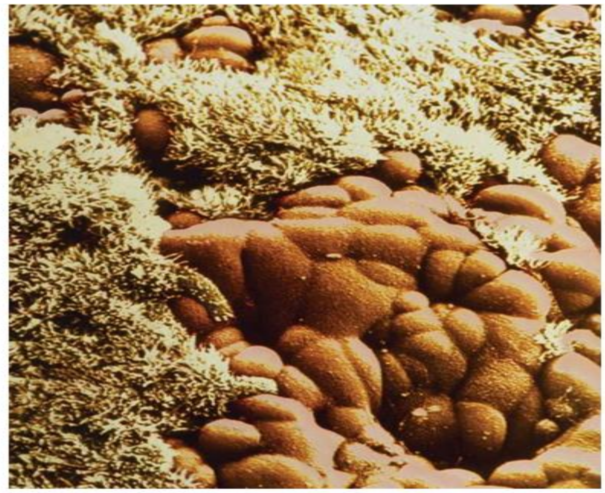


Figure 9.9 A scanning electron micrograph of a bronchial carcinoma – a cancer in a bronchus. Cancers often develop at the base of the trachea where it divides into the bronchi as this is where most of the tar is deposited. The disorganised malignant tumour cells at the bottom right are invading the normal tissue of the ciliated epithelium (×1000).

9.11 Short-term effects on the cardiovascular system

The two components of tobacco smoke that cause short term effects on the cardiovascular system are nicotine and carbon monoxide.

Nicotine

Nicotine, a drug found in tobacco, is easily absorbed by the blood and travels to the brain, stimulating the nervous system to release adrenaline, causing increased heart rate and blood pressure, and reducing oxygen supply to extremities. It is highly addictive, stimulating dopamine release, making it difficult to quit smoking.

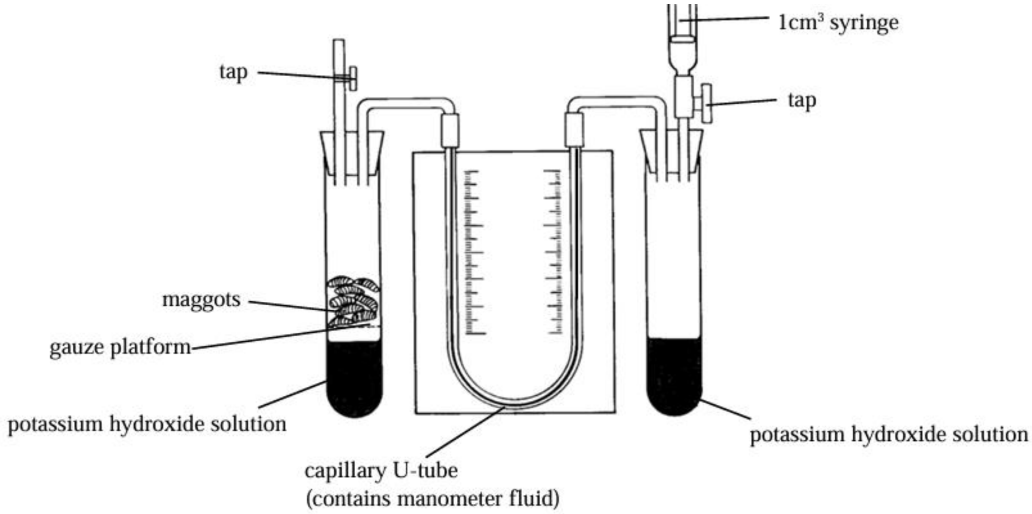
Carbon monoxide

Carbon monoxide diffuses into the lungs and red blood cells, forming carboxyhaemoglobin, causing less oxygen supply to the heart muscle. Long-term smokers risk their cardiovascular system, as damage to artery walls may lead to fatty tissue build-up and reduced blood flow. Short-term effects are reversible in non-smokers, while long-term effects are more severe.

Coronary heart disease (CHD) and **stroke** may be the result. These diseases are a major cause of death and disability. They are responsible for 20% of all deaths worldwide and up to 50% of deaths in developed countries. **Cardiovascular diseases** are multifactorial, meaning that many factors contribute to the development of these diseases.

Revision questions

(1) The diagram shows a simple respirometer set up by a student. Potassium hydroxide solution absorbs carbon dioxide.



(a)Describe how the apparatus was used to measure the oxygen consumption of the maggots

(b)The student then modified the apparatus and conducted a second investigation to measure the volume of carbon dioxide produced by the maggots.

(i) What modification would the student have made?

(ii) Explain how the student would have measured the carbon dioxide production of the maggots

(2) The table shows the composition of inspired, expired and alveolar air in humans. Figures are in volumes %.

Gas	Inspired air	Expired air	Alveolar air
Oxygen	20.7	14.6	13.2
Carbon dioxide	0.04	3.8	5.0
Nitrogen	78.0	75.4	75.6
Water vapour	1.3	6.2	6.2

(a)With reference to the figures in the table, explain the differences between the percentages of oxygen in inspired, expired and alveolar air.

(b)Explain the difference between the percentage of nitrogen in inspired air and expired air

(c)Why is the water vapour content of expired air higher than that of inspired air?

(d)(i) Describe two effects of smoking on gas exchange in the alveoli

(ii) Long term smoking may result in bronchitis and emphysema. How would the figures in the table alter in emphysema?

(3) The graph below shows the volumes of air breathed in and out by a human at rest and during exercise.

(a)What names are given to the volumes A, B and C?

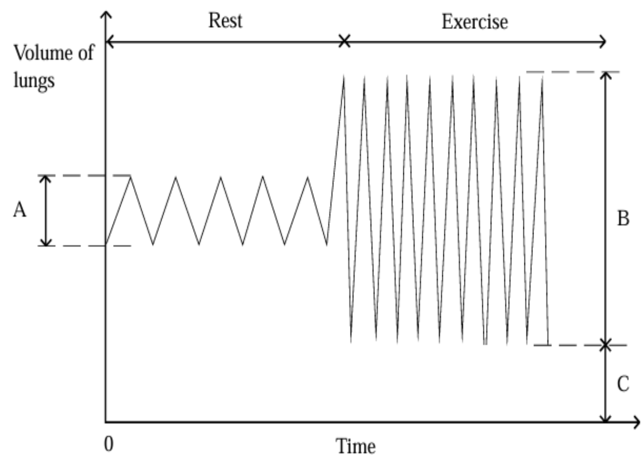
(b)(i) What changes occur to the breathing pattern during exercise?

(ii) Chemoreceptors in the body are involved in the regulation of breathing rate. What chemical are they sensitive to?

(iii) Name two sites of these chemoreceptors in the body.

(c)(i) The inspiratory and expiratory control centres are in the brain. In which part of the brain are they?

(ii) With reference to the intercostal muscles, diaphragm and ribs describe the process of inspiration in a human



(4) (a)(i) Respiratory surfaces generally need to be large in relation to the size of the organism. Explain why this is so.
(ii) Explain why the cell surface area of Amoeba is adequate as a respiratory surface but many larger organisms have evolved complex respiratory surfaces to gain more surface area.

(iii) List three features, other than large surface area, that are required by efficient respiratory surfaces in animals. 1
(b)(i) Name the respiratory surfaces of the following organisms:

an earthworm...

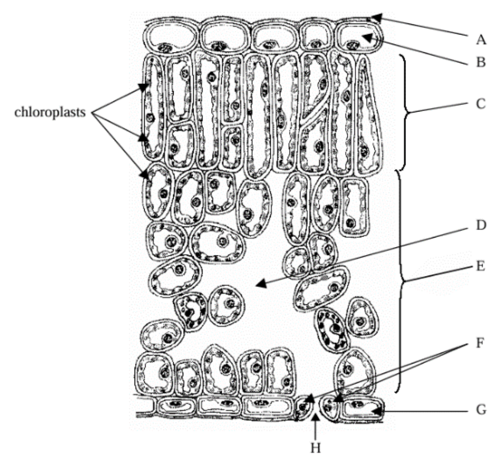
an insect..

a bony fish...

a mammal...

(ii) Describe how the respiratory surface of mammals is suited to efficient gas exchange

(5) The drawing below shows the structure of a dicotyledonous leaf in vertical section.



(a)(i) Name structures A to F.

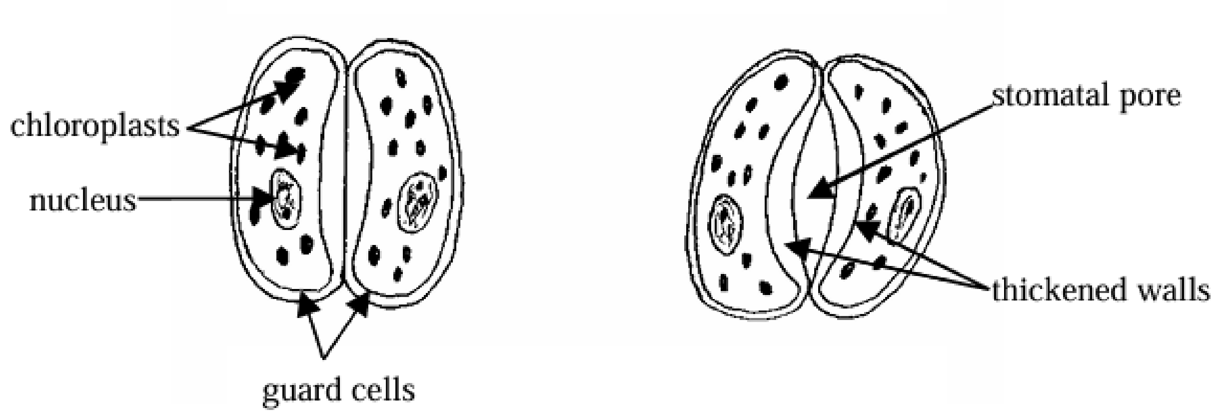
(ii) Why is gaseous exchange important in the leaf?

(iii) Gas exchange surfaces should have large surface areas, be moist and be thin. How are these conditions met in the leaf?

(b)Describe the mechanism of stomatal opening and closing

(c) Read through the following passage about breathing movements in humans and then fill in the spaces with the most appropriate word or words.
During inspiration the diaphragm .... changing from a .... shape to a .... shape. At the same time the ....muscles contract and the .... muscles relax. This pulls the ribcage upwards and outwards which .... the volume of the thorax. .... pressure in the .... cavity means that the lungs must increase in volume, thus .... the pressure in the .... where gaseous exchange occurs, so that air rushes in through the nasal passages and .... tree to equilibrate the pressure. During expiration the diaphragm and .... muscles relax and the .... muscles contract.

(6) The drawings below show a stoma in surface view in closed and open state.



(a)(i) When do the stomata:

1. release most water vapour

2. take up carbon dioxide.

3. take up oxygen?

(ii) Suggest and explain why guard cells contain chloroplasts whereas the surrounding epidermal cells do not.

(b)The guard cells possess a potassium pump which takes up potassium ions from the surrounding accessory cells during light periods. Suggest an explanation for this.

(c) Explain the significance of the pressure changes in the lungs and pleural cavities during,

(i) inspiration.

(ii) expiration.

(7) Distinguish between each of the following pairs: (a) Minute respiratory volume and vital capacity.

(b) Insect tracheae and tracheoles.

(c) Spiracles and stomata.

(d) Gill filaments and gill lamellae.

(e) Spongy mesophyll and palisade mesophyll.