Chapter 10 – Respiration in Humans

Subject content

Content
- human gas exchange
- aerobic respiration
- anaerobic respiration

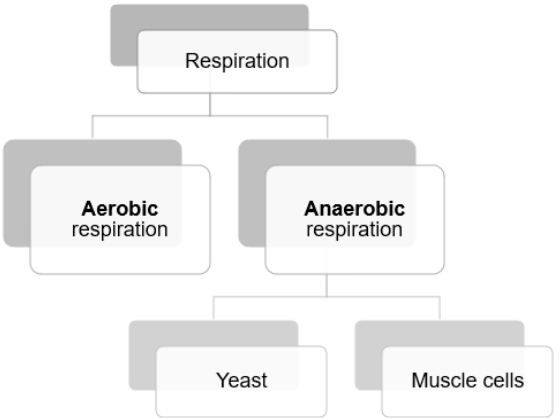
Learning outcomes
(a) identify on diagrams and name the larynx, trachea, bronchi, bronchioles, alveoli and associated capillaries
(b) state the characteristics of, and describe the role of, the exchange surface of the alveoli in gas exchange
(c) describe the removal of carbon dioxide from the lungs, including the role of the carbonic anhydrase enzyme
(d) describe the role of cilia, diaphragm, ribs and intercostal muscles in breathing
(e) describe the effect of tobacco smoke and its major toxic components – nicotine, tar and carbon monoxide, on health
(f) define and state the equation, in words and symbols, for aerobic respiration in humans
(g) define and state the equation, in words only, for anaerobic respiration in humans
(h) describe the effect of lactic acid in muscles during exercise

Use the knowledge gained in this section in new situations or to solve related problems.

Definition

Phrase	Definition
Oxidation	Chemical reaction where molecule gains oxygen / loses hydrogen
Respiration	Oxidation of food molecules with release of energy in living cells
Aerobic respiration	Oxidation of food molecules in presence of oxygen with release of large amount of energy
Anaerobic respiration	Oxidation of food molecules in absence of oxygen with release of small amount of energy
Gaseous exchange	Exchange of gases between organism & environment

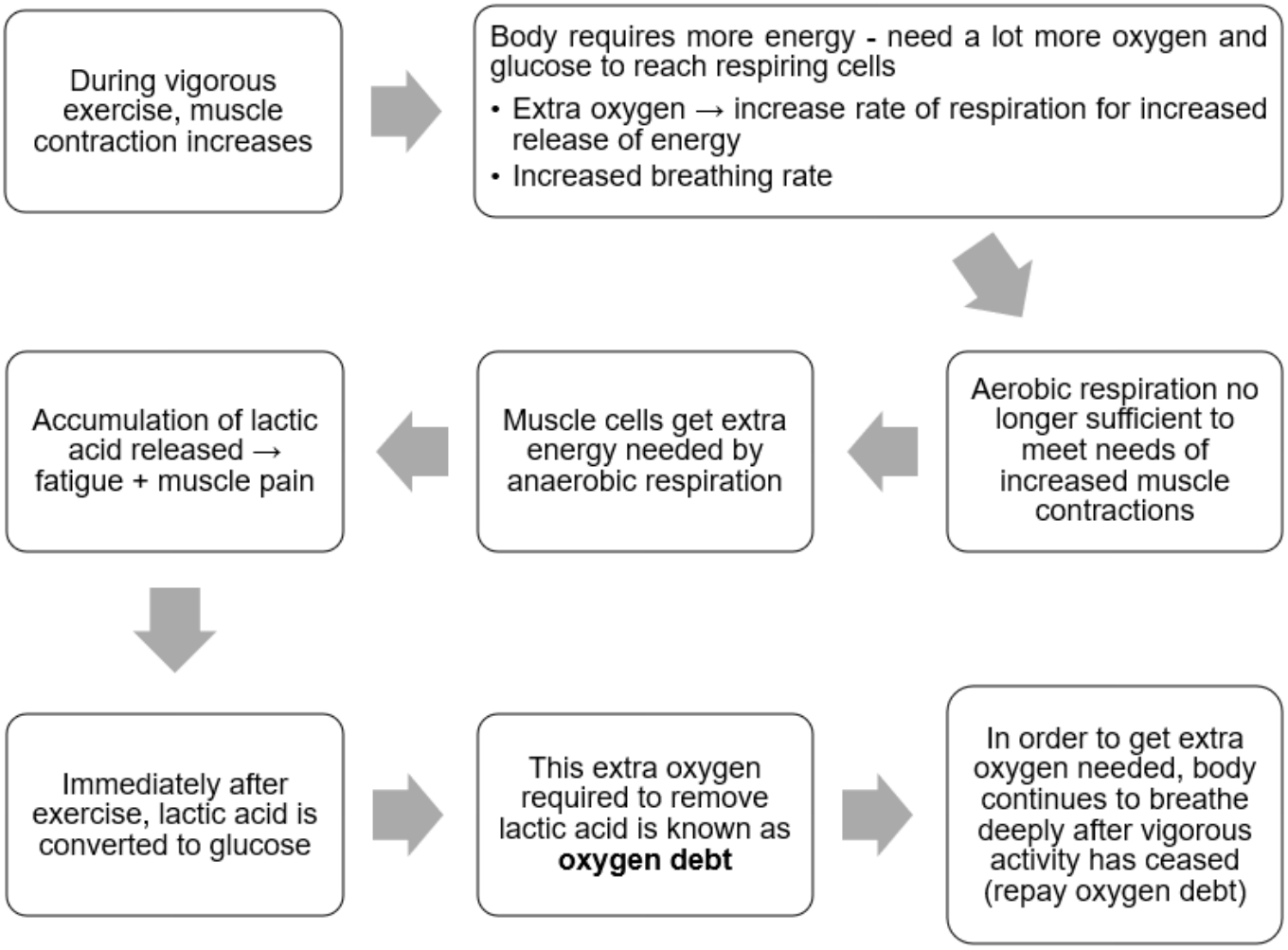
10.1 Living Things Respire



Catabolic processes:

Type	Equation	Explanation
1. **Aerobic** respiration (complex organisms)	$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ \mathbf{CO_2} + 6\ \mathbf{H_2O}$ + Energy glucose + oxygen → carbon dioxide + water + large quantity of energy	● Energy-consuming processes: 1) Synthesis of new protoplasm 2) Synthesis of proteins 3) Active transport in absorption of nutrients 4) Muscular contractions 5) Transmission of nerve impulses 6) Cell division ● Energy released as heat – keep warm
2. **Anaerobic** respiration (microorganisms)	$C_6H_{12}O_6 \rightarrow 2\ \mathbf{C_2O_5OH} + 2\ \mathbf{CO_2}$ + Energy glucose → ethanol + carbon dioxide + small quantity of energy	● **Alcoholic fermentation**: anaerobic respiration in yeast ● Little amount of energy released – inactive ○ Glucose: partially broken down ○ Ethanol produced: still contains energy
3. **Anaerobic** respiration (muscle cells)	$C_6H_{12}O_6 \rightarrow 2\ \mathbf{C_3H_6O_3}$ + Energy glucose → lactic acid + small quantity of energy	● Vigorous muscular contractions → aerobic respiration unable to release energy fast enough to meet demand ● Extra energy released through anaerobic respiration

Oxygen debt:



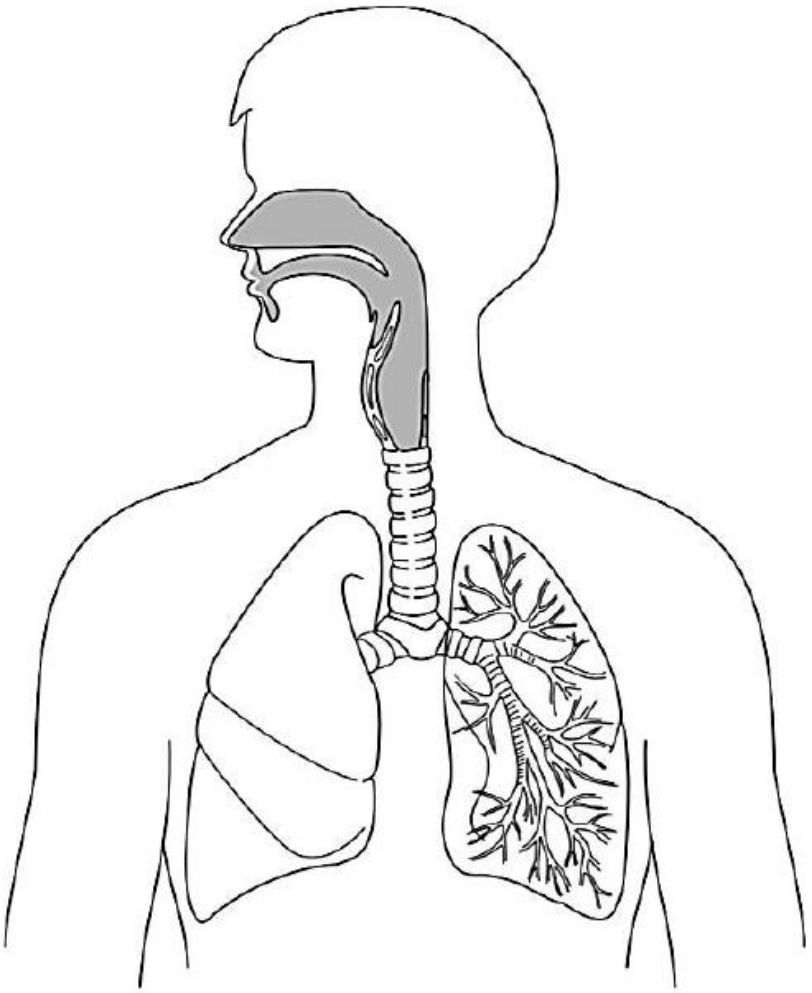
10.2 Studying Respiration

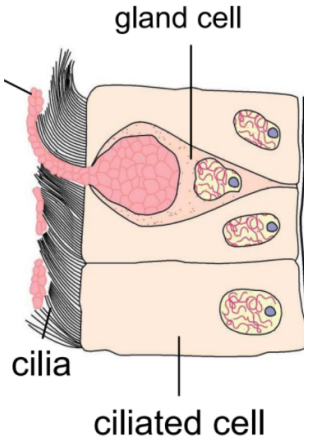
Detect respiration

Type	Detection	
	consume O_2	produce CO_2
Aerobic	✔	✔
Anaerobic (human)	✖	✖
Anaerobic (microorganisms)	✖	✔

Anaerobic respiration (human) → difficult to detect

10.3 Gas Exchange in Humans





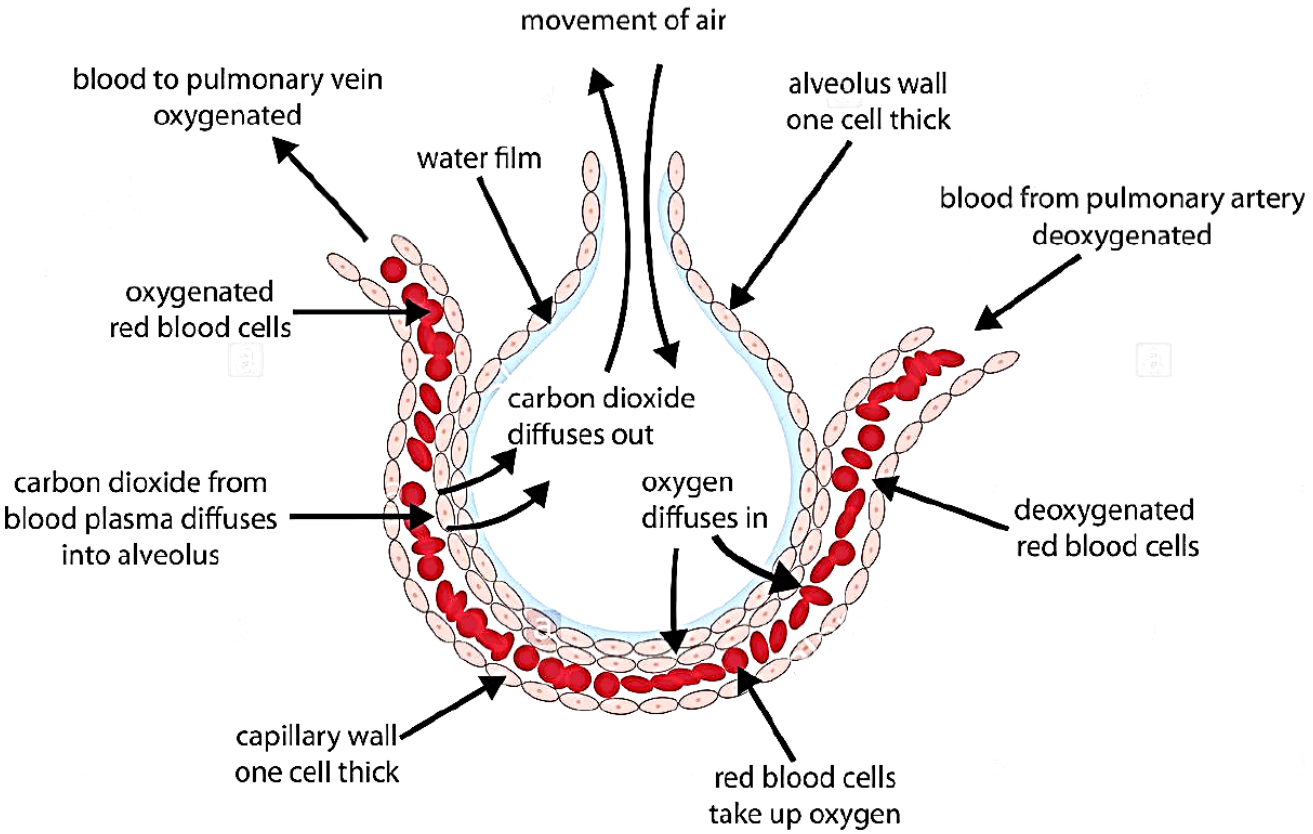
Pathway of air:

<table>
<tr><th>Organ</th><th>Function</th><th>Structure</th></tr>
<tr><td>1. Nostrils
2. Nasal passage</td><td>Air enters through 2 external nostrils
1) Walls – <u>fringe of hairs</u>
2) Nasal passages – lined with <u>moist mucous membrane</u></td><td>Breathing<table><tr><th>Advantage</th><th>Part of nose</th></tr><tr><td>1) Dust + foreign particles + bacteria trapped</td><td>Hairs in nostril
Mucus on mucous membrane</td></tr><tr><td>2) Air warmed and moistened</td><td>Nasal passages</td></tr><tr><td>3) Harmful chemicals detected</td><td>Mucous membrane (sensory cells)</td></tr></table></td></tr>
<tr><td>3. Pharynx</td><td>Common passageway for air + food</td><td></td></tr>
<tr><td>4. Larynx</td><td>Air passes into larynx → glottis (opening) → trachea</td><td></td></tr>
<tr><td>5. Trachea</td><td>• Supported by C-shaped rings of cartilage
• Keep lumen of trachea open</td><td>Epithelium<table><tr><th>Types</th><th>Function</th></tr><tr><td>1) Gland cells</td><td>Secrete mucus – trap dust particles & bacteria</td></tr><tr><td>2) Ciliated cells</td><td>Contain cilia – sweep dust-trapped mucus up trachea</td></tr></table></td></tr>
<tr><td>6. Bronchi</td><td>• Trachea divides → 2 bronchi</td><td></td></tr>
<tr><td>7. Bronchioles</td><td>• Bronchus branches repeatedly
• End in clusters of alveoli</td><td></td></tr>
<tr><td>8. Alveoli</td><td>Adaptations (below)</td><td></td></tr>
</table>

Adaptations of alveoli:

Adaptation	Description	Effect
1. **Numerous** alveoli	Large surface area	increase rate of diffusion
2. Alveolar **wall one cell thick**	Short diffusion distance for gases	faster rate of diffusion
3. Thin film of **moisture** covers alveolar wall	Oxygen dissolve	
4. Alveolar walls richly supplied with **blood capillaries**	Blood carried away quickly and continuously	maintain concentration gradient of gases between blood and air in alveoli

Gaseous exchange → **diffusion**



Gaseous exchange

- Occurs by diffusion

Concentration	Alveolar air	Blood enter lungs
O_2	high	low
CO_2	low	high

- Concentration gradient for O_2 & CO_2 between blood and alveolar air
  - O_2 : alveolar air → blood capillaries
  - CO_2 : blood capillaries → alveolar air
- Maintain diffusion gradient of gases:

Reason	Movement	
	O_2	CO_2
1. Continuous flow of blood through capillary	blood moved away	blood brought to alveoli
2. Movement of air in and out of alveoli	air brought in	removed from alveoli

Absorption of oxygen into lungs

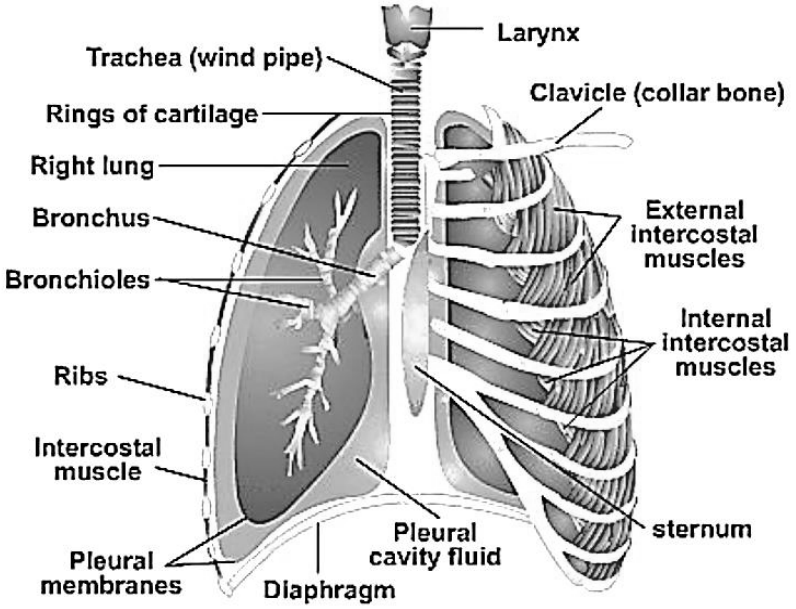
- One cell thick alveolar wall that separates blood capillaries from alveolar air is permeable to oxygen & carbon dioxide
- Alveolar air: high concentration of oxygen than blood

Removal of carbon dioxide from lungs

Tissue cells	Lungs
$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + \mathbf{HCO_3^-}$	$H^+ + HCO_3^- \rightarrow H_2CO_3 \rightarrow \mathbf{CO_2} + H_2O$
• Aerobic respiration → large amount of CO_2 • Blood pass through tissues via blood capillaries, carbon dioxide diffuse → blood → RBC (blood: • RBC: $CO_2 + H_2O \rightarrow H_2CO_3$ (catalysed by carbonic anhydrase) • H2CO3 → HCO_3^- ions (diffuse out of RBC)	• HCO_3^- ions diffuse into RBC → H_2CO_3 • H_2CO_3 → carbon dioxide + water • CO_2 diffuse out of blood capillaries into alveoli → expelled when breathing out

10.4 Breathing Mechanism in Humans

Thoracic cavity



Thoracic cavity

- **chest wall** supported by ribs
- ribs - attached dorsally to (at the back) **vertebral column** (backbone)
  attached ventrally (in front) to **sternum**
- 12 pairs of ribs (first 10 are attached to sternum)
- 2 sets of antagonistic muscles - **external and internal intercostal muscles**
- thorax separated from abdomen by **diaphragm**

Inspiration and expiration:

		Inspiration	Expiration
Diaphragm muscles		Contract	Relax
Diaphragm		Flatten	Arch upwards
Intercostal muscles	External	Contract	Relax
	Internal	Relax	Contract
Ribs		Move upwards and outwards	Move downwards and inwards
Sternum		Move up and forward	Move back down
Volume of thoracic cavity		Increase	Decrease
Lungs		Expand	Compressed
Volume of lungs		Increase	Decrease
Pressure in lungs		Decrease	Increase
Higher pressure		Atmospheric pressure	Pressure within lungs
Movement of air		Atmospheric air – forced in from exterior environment → lungs	Air within lungs – forced out from lungs → exterior environment

Compositions of inspired and expired air

Differences

Component	Inspired air	Expired air
Oxygen	21%	16.4%
Carbon dioxide	0.03%	4%
Nitrogen (same)	78%	78%
Water vapour	Variable (rarely saturated)	Saturated
Temperature	Variable	Body temperature (37℃)
Dust particles	Variable (usually present)	Little if any

Stimulus for breathing

High concentration of carbon dioxide in blood / alveolar air

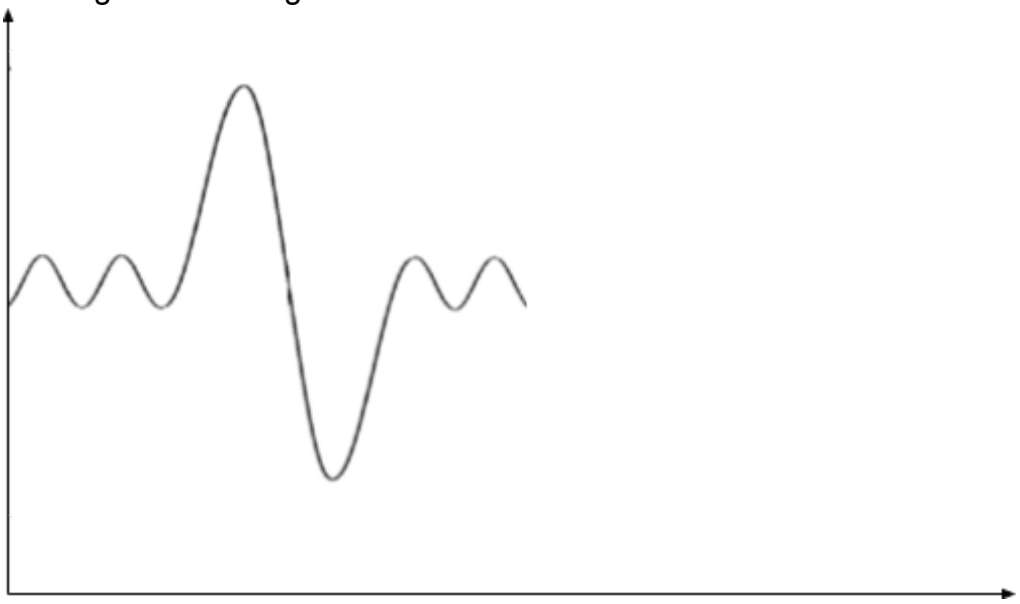
- Concentration of carbon dioxide in lungs is low → breathing movements do not occur
- Blood carbon dioxide concentration levels increase, chemoreceptors (receptors to detect chemical stimuli)

Overbreathing (hyperventilation)

- Take in more air than needed
- Carbon dioxide concentration in body is reduced

Breathing in and out

Volume of gas in the lungs

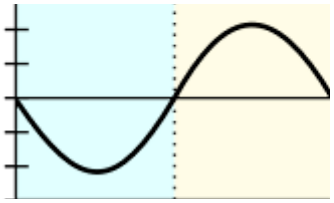
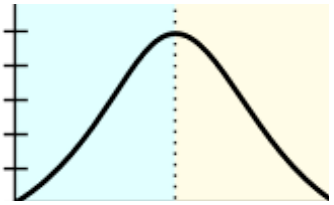


Tidal air: volume of air changed in every breathing cycle
Complemental air: additional volume of air when taking deep breath
Supplemental air:

Vital capacity = tidal air + complemental air + supplemental air

Supplemental air: some air left

Graphs → pressure change and volume change

Pressure change	Volume change
	

10.5 Effects of Tobacco Smoke on Human Health

Chemicals in tobacco smoke

Chemical	Properties	Effects
1. **Nicotine** (addictive)	• Cause secretion of adrenaline (hormone) • Blood clot easily	• Increase heartbeat rate & blood pressure • Increase risk of blood clots in arteries → coronary heart disease
2. **Carbon monoxide**	• Combine with haemoglobin → carboxyhaemoglobin • Increases rate of fatty deposits on inner arterial wall → coronary heart disease	• Reduce ability of blood to carry oxygen • Narrow lumen of arteries → increase blood pressure
3. **Tar**	• Uncontrolled cell division • Paralyse cilia	• Increases risk of lung cancer • Dust particles trapped in mucus (lining air passages) cannot be removed → chronic bronchitis + emphysema
4. **Irritants**	• Paralyse cilia	• Dust particles trapped in mucus …

Diseases caused by tobacco smoke

Disease	Effect on lungs	Symptoms
1. **Chronic bronchitis**	• Epithelium lining of air passage → **inflamed** • Excessive **mucus** secreted by epithelium • Cilia paralysed (cannot remove mucus + dust particles) • Air passages blocked	• Difficulty in breathing • Persistent coughing (clear air passages to breathe) • Risk of lung infections
2. **Emphysema**	• **Partition walls** between alveoli break down (persistent violent coughing) → decrease SA for gaseous exchange • Lungs **lose elasticity** → inflated with air	• Difficulty in breathing • Wheezing and severe breathlessness
3. **Lung cancer**	• **Uncontrolled division** of cells → tissue outgrowths / lumps	

Chronic obstructive lung disease: chronic bronchitis + emphysema

Typical questions

Multiple choice questions

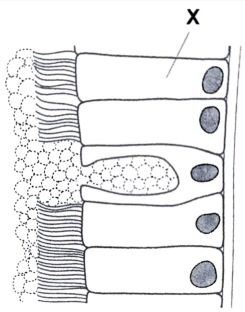
1 Some effects of smoking are listed.

1 causes uncontrollable cell division
2 increases heart rate
3 increases mucus production
4 is addictive
5 reduces the amount of oxygen in the blood

Which effects are caused by nicotine? (N2013/P1/Q19)

A 1 and 3
B 2 and 4
C 1, 2 and 5
D 3, 4 and 5

2 The diagram shows part of the lining of the human trachea.



What is the function of cell X? (N2016/P1/Q17)

A exchange of gases
B movement of mucus
C phagocytosis
D secretion of mucus

3 Some effects of smoking tobacco are listed.

1 causes bronchitis
2 increases alertness
3 increases blood pressure
4 increases heart rate
5 increases mucus production
6 causes uncontrolled cell division

Which effects are caused by tar? (N2016/P1/Q19)

A 1, 2 and 3
B 1, 5 and 6
C 2, 4 and 6
D 3, 4 and 5

4 Some effects of smoking are listed.

1 paralyses cilia
2 increases heart rate
3 increases mucus production
4 is addictive
5 reduces the amount of oxygen in the blood

Which effects are caused by nicotine? (N2017/P1/Q17)

A 1, 2 and 5
B 1 and 3
C 2 and 4
D 3, 4 and 5

5 Some processes occurring in the human body are listed.

1 cell division
2 contraction of the heart muscle
3 diffusion of oxygen from alveoli into blood
4 maintaining a constant body temperature
5 movement of carbon dioxide from plasma to alveoli

Which processes do **not** involve the use of energy from respiration? (N2018/P1/Q17)

A 1 and 4
B 2 and 5
C 3 and 5
D 3 only

6 What describes the role of carbonic anhydrase in the removal of carbon dioxide from the body? (N2018/P1/Q19)

A It causes red blood cells to absorb carbon dioxide.
B It causes the formation of hydrogencarbonate ions in the red blood cells.
C It decreases the diffusion of carbon dioxide through the alveolar membrane.
D It decreases the release of carbon dioxide from mitochondria.

7 Some changes in the concentrations of chemicals in contracting muscles are listed.

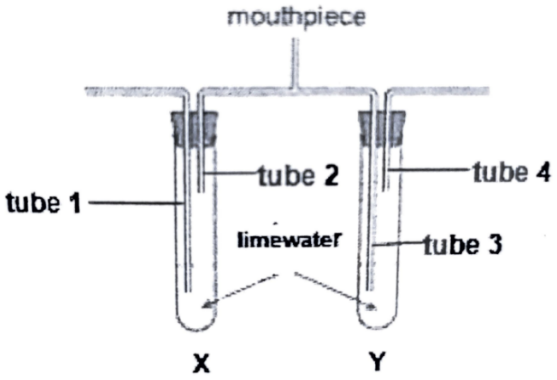
1 decrease in glucose
2 decrease in oxygen
3 increase in amino acid
4 increase in carbon dioxide

Which changes lead to lactic acid production? (N2015/P1/Q19)

A 1 and 2
B 1 and 3
C 2 only
D 4 only

Structured questions

1 The diagram below shows the apparatus used to investigate the air we breathe in and out.



With reference to the table below, compare and account for the differences in the time for limewater to change in the two test tubes. [3]

	Time for limewater to change	
	During normal breathing	**After exercise**
Test tube X	25 min	12 min
Test tube Y	4 min	2 min

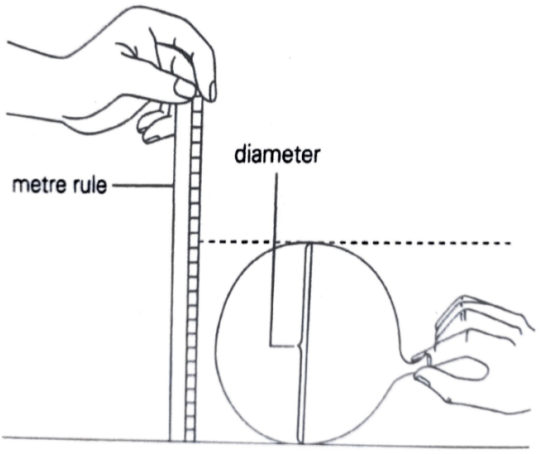
Desc: Overall, test tube X takes a longer time for limewater to change than test tube Y.

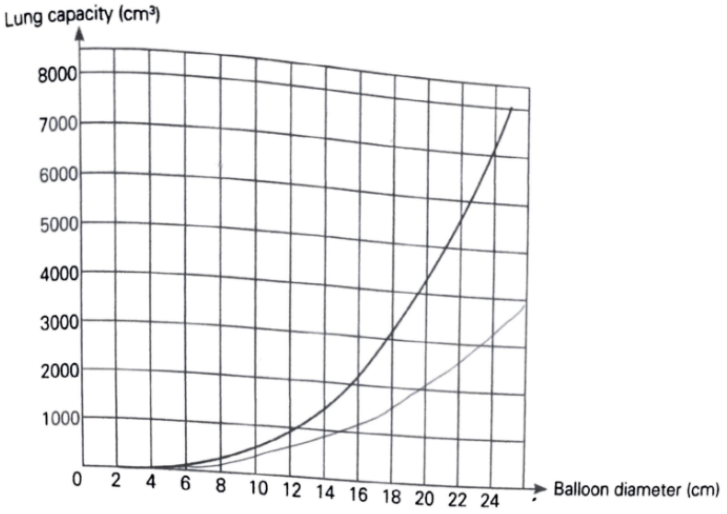
Expl: This is because inhaled air passing through limewater in test tube X contains a lower concentration of carbon dioxide than exhaled air passing through limewater in test tube Y. This leads to less amount of carbon dioxide reacting with limewater per unit time, thus rate of formation of calcium carbonate which turns limewater cloudy is low, resulting in longer time for limewater to change.

Desc: For both test tubes, time taken for limewater to change after exercise is shorter than that required during normal breathing.

Expl: After exercising, breathing rate remains at a high level to repay oxygen debt. Oxygen is taken in and carbon dioxide is expelled out at a faster rate for increased cellular respiration. Thus, higher concentration of carbon dioxide passes through limewater per unit time, which shortens the time required for limewater to turn cloudy.

2 A simple experiment to measure out lung capacity can be done with a common balloon and a metre rule, The subject is asked to inhale and exhale into the balloon. By comparing the diameters of the balloon with the graph shown on the next page, one can estimate the lung capacity during inhalation and exhalation.





(a) Explain the factor that might affect the balloon diameter and hence shift the graph above either to the left or to the right. [2]

Temperature affects balloon diameter when temperature increases, air in balloon expands, increasing the volume of air in the balloon thus increasing balloon diameter. The graph should be shifted to the right.

(b) What is the difference between the lung capacity of an athlete and a non-athlete? [1]

The athlete has a larger lung capacity than the non-athlete.

(c) What causes the difference mentioned in (b) especially during training and competitions? [3]

During training and competitions, athletes require more energy to carry out increased muscle contractions. Their breathing rate increases to take in more oxygen for a higher rate of cellular respiration which releases more energy. Thus, athletes have greater lung capacity.

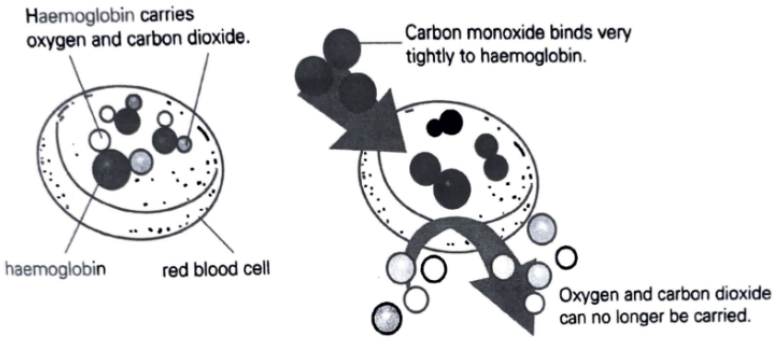
(d) Why is it important, in terms of carbon dioxide concentration in blood, for breathing rates and heart rates to be adjusted during athletic activities? [3]

When the breathing rate increases during athletic activities, more carbon dioxide is expelled out and removed through the lungs. An increased heart rate also helps to transport carbon dioxide in blood out of the cells. These actions keep the carbon dioxide concentration and also pH in the blood at safe levels.

(e) For whom do you suggest lung capacity might be a critical factor in his / her success? [1]

Scuba diver

3 Both oxygen and carbon dioxide combine readily with haemoglobin in the manner shown below.



(a) What are the two compounds formed by oxygen and carbon monoxide with haemoglobin? [2]

Oxyhaemoglobin, carboxyhaemoglobin.

(b) Suggest two reasons, with a brief explanation, why binding between carbon monoxide and haemoglobin affects oxygen uptake in red blood cells. [4]

Carbon monoxide and haemoglobin bind reversibly to form carboxyhaemoglobin. This reduces the ability of blood to transport oxygen to oxygen-poor tissues as carboxyhaemoglobin will not be broken down into carbon dioxide and haemoglobin. This is because they bond together to form very strong and stable bonding. There is an insufficient amount of haemoglobin in red blood cells to bind reversibly with oxygen to form oxyhaemoglobin due to the limited quantity of haemoglobin passing through alveoli at normal blood flow. This reduces the amount of oxygen transported to tissue cells per unit time, thus oxygen intake in red blood cells is reduced.

(c) Discuss three effects that carbon monoxide will have as a result of what happens in (b). [3]

Since oxygen uptake in red blood cells is reduced, thus less amount of oxygen is transported to tissue cells, leading to a lower rate of aerobic respiration in respiring cells which releases smaller quantities of energy. This may cause tiredness, fatigue and shortness of breath. Muscles may die or be damaged due to a lack of oxygen for respiration. If cardiac muscles die, this may lead to a heart attack.

4 The figure below shows a section of an alveolus and a capillary in the lungs. (N2018/P2/A4)

(a) Describe how the alveolus is adapted for the exchange of gases. [3]

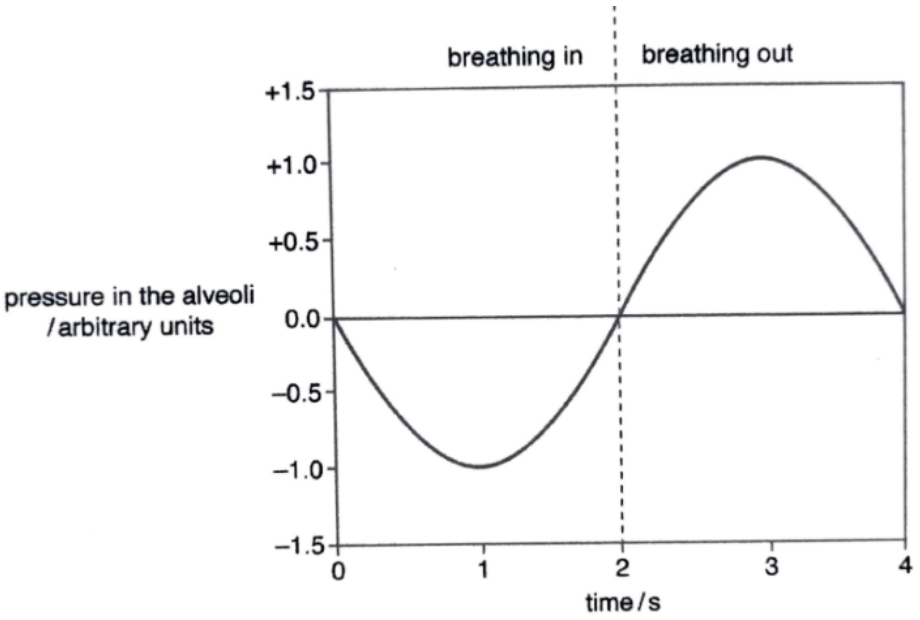
The alveoli in the lungs are one-cell thick and very thin. There are numerous alveoli in the lungs. Together, they provide a very large surface area for the exchange of gases to take place. The inner wall of each alveolus has a film of moisture on it, which allows the gases to dissolve before diffusing. Each alveolus is surrounded by a network of capillaries. These capillaries are also one-cell thick and very thin. As a result, the exchange surface of the alveoli speeds up the diffusion of oxygen and carbon dioxide between the alveoli and the capillaries.

(b) A person is only able to produce low levels of carbonic anhydrase. Suggest and explain the effect of this deficiency on gas exchange in this person. [3]

Carbonic anhydrase, an enzyme present in red blood cells, catalyses the reaction of carbon dioxide with water to form carbonic acid. The carbonic acid is then converted into hydrogencarbonate ions which are carried by the blood plasma to the lungs. In the lungs, the hydrogencarbonate ions diffuse back into red blood cells and are converted back into carbonic acid. Carbonic anhydrase then converts carbonic acid back into carbon dioxide

and water. The carbon dioxide diffuses out of the blood capillaries and into the alveoli. It is excreted from the human body when a person exhales. Thus, a person who is only able to produce low levels of carbonic anhydrase has difficulty removing carbon dioxide from his blood and may suffer from hyperventilation / breathe excessively as a high concentration of carbon dioxide in the blood stimulates breathing.

(c) The graph below shows the change in pressure in the alveoli during one breath.



(i) With reference to the figure above, describe the pressure in the alveoli when breathing in. [2]

From 0 s to 1 s, the pressure in alveoli decreases from 0.0 arbitrary units to -1.0 arbitrary units.
From 1 s to 2 s, the pressure in alveoli increases from -1.0 arbitrary units to 0.0 arbitrary units.

(ii) Describe how the structures in the body change the volume of the lungs when breathing in. [3]

When breathing in, external intercostal muscles contract, internal intercostal muscles relax and the diaphragm contracts. The rib cage swings outwards and upwards, increasing thoracic volume and pressure within the thoracic cavity drops. Since the pressure outside is higher than the pressure within the thoracic cavity, the air is forced into the lungs.

5 (N2014/P2/B10 EITHER)

(a) Explain how air is made to enter the lungs. [6]

During inhalation, diaphragm muscles contract and the diaphragm flattens. External intercostal muscles contract while internal intercostal muscles relax. The rib cage swings outwards and upwards. Thoracic volume increases, causing a drop in pressure within the thoracic cavity. Since pressure outside is higher than the pressure within the thoracic cavity, air rushed into the lungs.

(b) Describe how a molecule of oxygen present in the air breathed in reaches a muscle cell in the wall of the left atrium. [4]

A molecule of oxygen dissolves in a thin film of moisture lining the alveolar wall. It diffuses across the thin alveolar wall into surrounding blood capillaries. In the blood, the oxygen molecule moves into a red blood cell and combines with haemoglobin to form oxyhaemoglobin. The blood is then transported from the lungs to the heart via the pulmonary vein. Blood from the pulmonary vein enters the left atrium which contracts to pump the blood to the left ventricle. The left ventricle then contracts to pump blood to the aorta. The aorta branches into coronary arteries in the left atrium. Haemoglobin releases the oxygen molecule which then moves into the muscle cell in the wall of the left atrium.

6 Describe how any two named toxic components of tobacco smoke may affect health. [6]
(N2015/P2/B9a)

Name	**Effect**
Nicotine	Nicotine is addictive and causes the release of adrenaline, which increases the blood pressure and heart rate of smokers. It also causes blood to clot easily and increases the risk of blood clotting in blood vessels.
Carbon monoxide	Carbon monoxide combines with haemoglobin irreversibly and reduces the ability of red blood cells to transport oxygen. Inhaling high amounts of carbon monoxide can cause death. It also damages the lining of blood vessels. Carbon monoxide may also cause fatty substances to be deposited faster on the inner walls of the arteries. This may cause an increase in the blood pressure of smokers.
Tar	Tar contains carcinogens which cause the cells in the lungs to divide uncontrollable, thus resulting in lung cancer. It also paralyses the cilia lining the air passages and reduces the efficiency of gaseous exchange.

7 Explain why the oxygen used increases as the level of exercise increases. [4]
(N2012/P2/B8d)

As the level of exercise increases, body muscles require more energy to carry out more vigorous exercise. Energy is obtained when muscle cells carry out respiration. During respiration, food substances such as glucose are oxidised to release energy stored in them for cells to use.
There are two forms of respiration: aerobic respiration and anaerobic respiration. During aerobic respiration, oxygen is required and a large amount of energy is released. During anaerobic respiration, oxygen is not required but only a small amount of energy is released and lactic acid is produced. To supply the large amount of energy needed for vigorous muscular contractions, the muscle cells respire aerobically and need more oxygen, thus the oxygen used increases as the level of exercise increases.

8 (N2016/P2/B10 EITHER)

(a) Describe the similarities and differences between aerobic and anaerobic respiration in humans. [5]

Both aerobic and anaerobic respiration in humans release the energy stored in food substances such as glucose for the cells to use.
During aerobic respiration, oxygen is required and a large amount of energy is released.
During anaerobic respiration, oxygen is not required but only a small amount of energy is released.
During aerobic respiration, carbon dioxide and water are produced but during aerobic respiration, lactic acid is produced.
The level of energy released during aerobic respiration is more than that of anaerobic respiration and the level of fatigue produced during aerobic respiration is less than that of anaerobic respiration. Thus, muscle cells usually carry out aerobic respiration first, followed by anaerobic respiration.

(b) State the circumstances under which anaerobic respiration occurs in humans and the effects of the process on muscle cells. [5]

When muscle cells are not able to meet the energy demands of the body through aerobic respiration alone and there is a lack of oxygen, muscle cells will carry out anaerobic respiration. For example, during a sprint race, athletes have to run very fast in a short period of time. Their muscle cells have a sudden and very high demand for oxygen.

However, their breathing rate and heart rate are not fast enough to supply the oxygen needed for aerobic respiration by the muscle cells. Thus, muscle cells respire anaerobically to get more energy for the muscles. During anaerobic respiration, lactic acid is built up in muscle cells and an oxygen debt is incurred. Lactic acid causes fatigue and muscle pain. The lactic acid which has accumulated during anaerobic respiration needs to be removed. Oxygen is needed to oxidise the lactic acid to glucose in the liver.