12.1 Energy

Energy

1. *outline the need for energy in living organisms, as illustrated by active transport, movement and anabolic reactions, such as those occurring in DNA replication and protein synthesis.*

Name the type of reaction that occurs when larger more complex biological molecules are made from smaller molecules.
- anabolic / condensation / polymerisation

State examples of anabolic reactions occurring in living organisms
- DNA replication / transcription
- Protein synthesis
- Lipid / triglyceride / phospholipid synthesis
- Carbohydrate / polysaccharide synthesis
- Phosphorylation

Outline examples of movement in cells that use ATP.
- muscle fibre / sarcomere contraction.
- active transport of (named) ion / molecule OR active transport (of substance) against concentration gradient.
- movement of vesicles / organelles through cytoplasm.
- exocytosis of (named) substance.
- endocytosis / phagocytosis.
- spindle fibre / chromosome / chromatid movement during mitosis / meiosis.
- cilia / flagella wafting / beating.

Name the mechanism that can maintain a higher concentration of ions inside a cell.
- Active transport

Suggest why ATP is needed for protein synthesis.
- unwinding DNA
- activating (RNA) nucleotides
- mRNA synthesis
- movement of mRNA from nucleus
- amino acid activation
- moving ribosomes along mRNA
- peptide bond formation / joining amino acids
- post translation modification

ATP

2. *describe the features of ATP that make it suitable as the universal energy currency.*
3. *state that ATP is synthesised by:*
    - *transfer of phosphate in substrate-linked reactions*
    - *chemiosmosis in membranes of mitochondria and chloroplasts*

Describe the properties of ATP that make it suitable for its role as the universal energy currency.

- water soluble: easily transported around the cell
- small molecule: easily diffuses to sites of energy use.
- ATP loses Pi / phosphate group: this hydrolysis releases energy.
- hydrolysed by ATPase: releases energy in small packets (30.5 kJ mol^{-1}); releases energy immediately for cellular processes.
- relatively stable: not broken down spontaneously.
- can be recycled / regenerated OR ATP ⇄ ADP + Pi.

Chemiosmosis = synthesis of ATP using a proton gradient across a membrane in a mitochondrion or chloroplast.

Demonstration of chemiosmosis experiment

- Mitochondria that had been isolated from cells, were kept in liquid, in glass dishes, to which ADP, Pi and other substances were added.
- The temperature, pH and water potential were kept constant.
- After a period of time, presence of ATP was checked.

a. **Contents of the dishes, and whether ATP was produced in each case:**

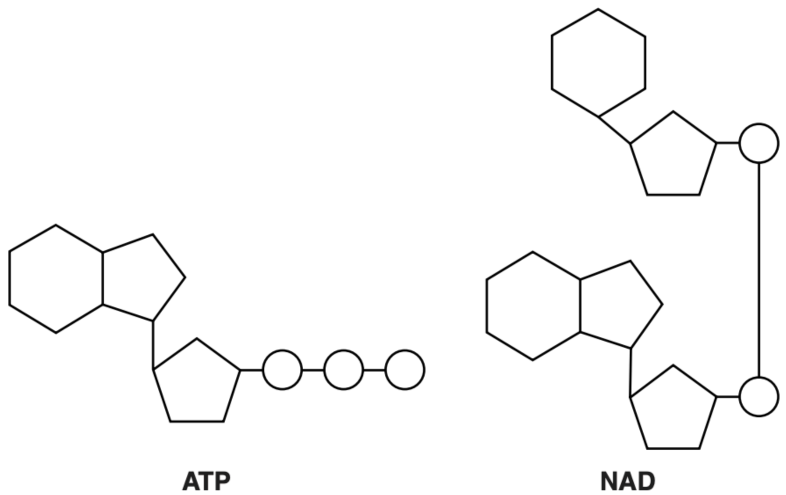
Dish contents	ATP produced
mitochondria + ADP + Pi + acetyl CoA + oxygen	✓
mitochondria + ADP + Pi + acetyl CoA	x
mitochondria + ADP + Pi + low concentration of protons (H+)	x
mitochondria + ADP + Pi + high concentration of protons (H+)	✓

b. **Explain the consequences to a mitochondrion if the water potential of the liquid in the dishes is higher than the water potential of the mitochondrial matrix.**
    - water enters (mitochondrion / matrix)
    - by osmosis / down the water potential gradient
    - membranes ruptured / mitochondrion bursts

c. **Name the enzyme used to produce ATP in chemiosmosis.**
    - ATP synth(et)ase

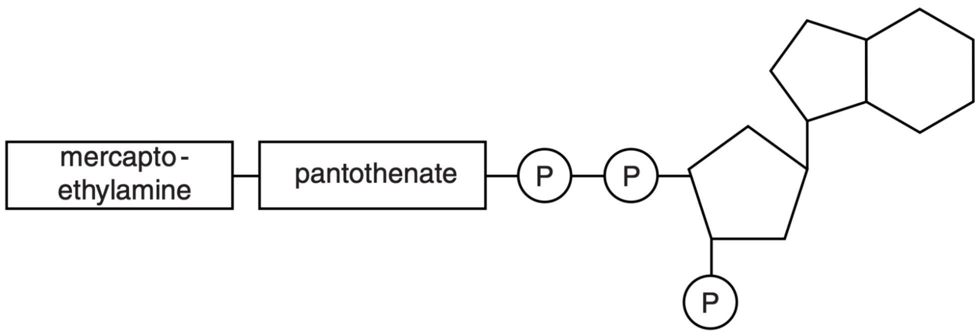
Describe how ATP is made by substrate-linked reactions.
- inorganic phosphate is added to ADP: ADP + Pi
- this forms phosphorylated compound: ATP

Name the stages in which chemiosmosis occurs in respiration and in photosynthesis.
- respiration: oxidative phosphorylation.
- photosynthesis: photophosphorylation / light dependent stage.



Compare the structures of ATP and NAD.
- both have ribose (sugars)
- ATP has 1 ribose / pentose / sugar; NAD has 2
- both have adenine / purine (base)
- NAD has nicotinamide / pyrimidine (base)
- ATP has 3 phosphates; NAD has 2

Fig. 1.1 represents the molecular structure of coenzyme A.



State the structural similarities between coenzyme A and ATP.

- three phosphates
- ribose / pentose
- adenine

ATP is synthesised from ADP and Pi in a phosphorylation reaction. State the two different ways in which this phosphorylation reaction occurs in aerobic respiration.

- substrate-linked phosphorylation / substrate level phosphorylation
- chemiosmosis / oxidative phosphorylation

Energy Values of Respiratory Substrates

4. *explain the relative energy values of carbohydrates, lipids and proteins as respiratory substrates.*

When animals exercise, they can respire substrates obtained directly from their diet, as well as respire substrates from energy stores. Suggest the benefits of obtaining most of the respiratory substrates from the diet.

- substrate immediately available to muscle cells.
- no need to break down glycogen / energy stores.
- glycogen is still available as substrate between feeds.
- AVP: e.g. for birds, cannot carry stores as need to be light to fly.

Explain why lipids have a higher energy value than carbohydrates.

- more C–H (bonds) / more reduced / more hydrogen.
- produces more reduced NAD.
- more aerobic respiration / oxidative phosphorylation / chemiosmosis / ETC
- produces more ATP per gram / molecule / unit mass.

Name the covalent bond in lipids that is hydrolysed by lipase.

- Ester

Respiratory Quotient (RQ)

5. *state that the respiratory quotient (RQ) is the ratio of the number of molecules of carbon dioxide produced to the number of molecules of oxygen taken in, as a result of respiration.*
6. *calculate RQ values of different respiratory substrates from equations for respiration.*

$$RQ = \frac{\text{molecules of carbon dioxide released}}{\text{molecules of oxygen taken in}}$$

Define the term respiratory quotient.

- volume of carbon dioxide produced ÷ volume of oxygen consumed
- per unit time

Explain why a hummingbird that has not fed for some time has an RQ value of 0.7, while a hummingbird that has fed has an RQ value of 1.0.

- When not fed, lipids / fatty acids are metabolised/respired (glucose not ready available, so relies on fat reserves).
- When fed, sugar / carbohydrates are metabolised/respired (glucose readily available).

When a person exercises, power is generated.

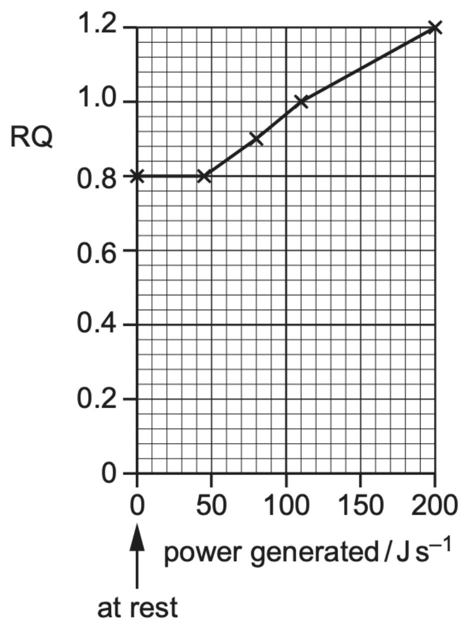
Power is measured in joules per second ($J s^{-1}$).

The power generated when a person exercises will vary depending on the type and intensity of exercise. More power is generated when the intensity of exercise increases.

An experiment was carried out to determine whether increasing the intensity of exercise in a healthy human male caused a change in the value of the respiratory quotient (RQ).

- The man had a balanced diet.
- The RQ was calculated at rest.
- He carried out exercise for the same length of time on four separate days.
- The intensity of exercise was increased over the four days, generating different powers.
- The RQ was calculated for the four different powers generated.

The results are shown in Fig. 2.1.



With reference to the figure, suggest what can be deduced from the RQ at rest.

- rest = RQ of 0.8: a mix of respiratory substrates OR lipids and carbohydrates / proteins are being respired.

With reference to the figure, suggest what can be deduced from the RQ when the power generated is 110 J s^{-1}.

- respiratory substrate used is carbohydrate / more carbohydrate respired than at rest

With reference to the figure, suggest what can be deduced from the RQ when the power generated is 200 J s^{-1}.

- anaerobic respiration is also occurring.
- reduced availability of oxygen OR increased production / release of CO2.

Investigating RQs

7. *describe and carry out investigations, using simple respirometers, to determine the RQ of germinating seeds or small invertebrates (e.g. blowfly larvae).*

12.2 Respiration

The Four Stages in Aerobic Respiration

1. *state where each of the four stages in aerobic respiration occurs in eukaryotic cells:*
   - *glycolysis in the cytoplasm*
   - *link reaction in the mitochondrial matrix*
   - *Krebs cycle in the mitochondrial matrix*
   - *oxidative phosphorylation on the inner membrane of mitochondria*

Aerobic Respiration: Glycolysis

2. *outline glycolysis as phosphorylation of glucose and the subsequent splitting of fructose 1,6-bisphosphate (6C) into two triose phosphate molecules (3C), which are then further oxidised to pyruvate (3C), with the production of ATP and reduced NAD.*
3. *explain that, when oxygen is available, pyruvate enters mitochondria to take part in the link reaction.*

Outline the stage of aerobic respiration that occurs in the cytoplasm of eukaryotic cells.

- Glycolysis
- phosphorylation of glucose
- splitting of fructose (1,6) biphosphate
- into two triose phosphate / TP
- TP oxidised / dehydrogenated to pyruvate
- net 2 ATP / 4 ATP produced
- 2 reduced NAD produced

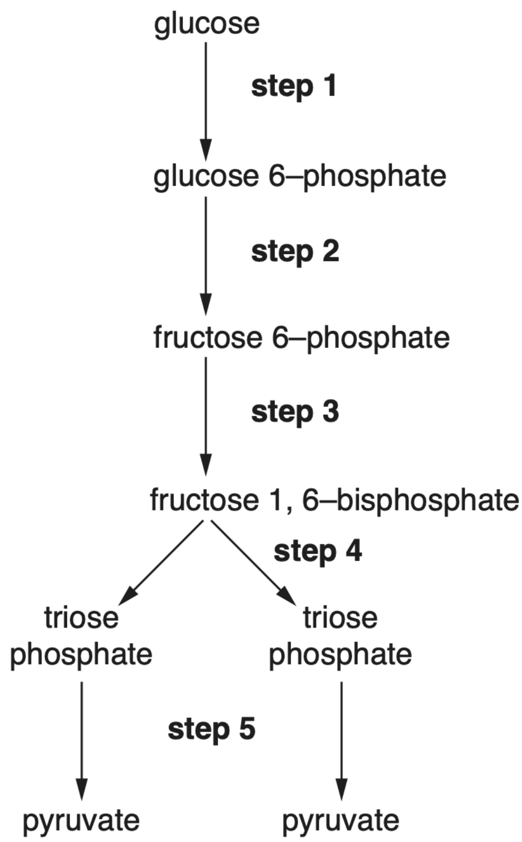
Describe and explain the use of ATP in glycolysis.

- To phosphorylate / add phosphate to glucose.
- This stops glucose leaving the cell.
- This activates / increases energy of / decreases stability of glucose.
- To make fructose (1,6) bi(s)phosphate; second phosprhylation.

Name the process by which ATP is synthesised during glycolysis.

- substrate-linked phosphorylation

Steps involved in glycolysis:



steps where phosphorylation occurs	1 AND 3
step where oxidation occurs	5
Reaction in step 5	substrate-linked phosphorylation

Aerobic Respiration: The Link Reaction

4. *describe the link reaction, including the role of coenzyme A in the transfer of acetyl (2C) groups.*

Explain what happens to pyruvate in the link reaction in aerobic respiration.
- It is decarboxylated / loses carbon dioxide.
- Is it dehydrogenated / oxidised / loses H.
- 2C / acetyl group that remains, joins coenzyme A to make acetyl coA.

Explain why the link reaction only occurs when oxygen is available.
- pyruvate converted to acetyl group / 2C group / acetyl CoA in link reaction.
- NAD needed in link reaction.
- NAD becomes reduced.
- reduced NAD goes to ETC.
- ETC / oxidative phosphorylation works if oxygen is present OR oxygen is the final electron acceptor.
- so reduced NAD is oxidised / NAD is regenerated.

The enzyme pyruvate dehydrogenase catalyses the link reaction. Pyruvate dehydrogenase is inhibited when the ratio of acetyl coenzyme A to coenzyme A increases. Suggest the importance of this inhibition.
- increase / decrease / controls rate of the link reaction.
- inhibition allows build-up of acetyl CoA to be used in the Krebs cycle.
- enzyme becomes active again when coenzyme A increases / ratio falls.
- allows more coenzyme A to enter / return to the link reaction; not enough CoA to enter the link reaction.
- example of end-product inhibition / negative feedback

Aerobic Respiration: The Krebs Cycle

5. *outline the Krebs cycle, explaining that oxaloacetate (4C) acts as an acceptor of the 2C fragment from acetyl coenzyme A to form citrate (6C), which is converted back to oxaloacetate in a series of small steps.*

6. *explain that reactions in the Krebs cycle involve decarboxylation and dehydrogenation and the reduction of the coenzymes NAD and FAD.*

Outline the main stages of the link reaction and Krebs cycle that take place in the mitochondrion.

1. pyruvate enters the mitochondrial matrix.
2. pyruvate is decarboxylated and dehydrogenated.
3. acetyl group is formed.
4. acetyl group combines with coenzyme A to form acetyl CoA.
5. acetyl CoA enters Krebs cycle.
6. acetyl CoA combines with oxaloacetate.
7. citrate is formed
8. citrate is decarboxylated and dehydrogenated
9. hydrogen atoms are accepted by NAD and FAD
10. ATP is made by substrate-linked phosphorylation
11. oxaloacetate is regenerated

State the total number of molecules of carbon dioxide removed in the link reaction and Krebs cycle for each molecule of glucose respired.

- 6 ($2CO_2$ released in link reaction + $4CO_2$ released in Krebs cycle)

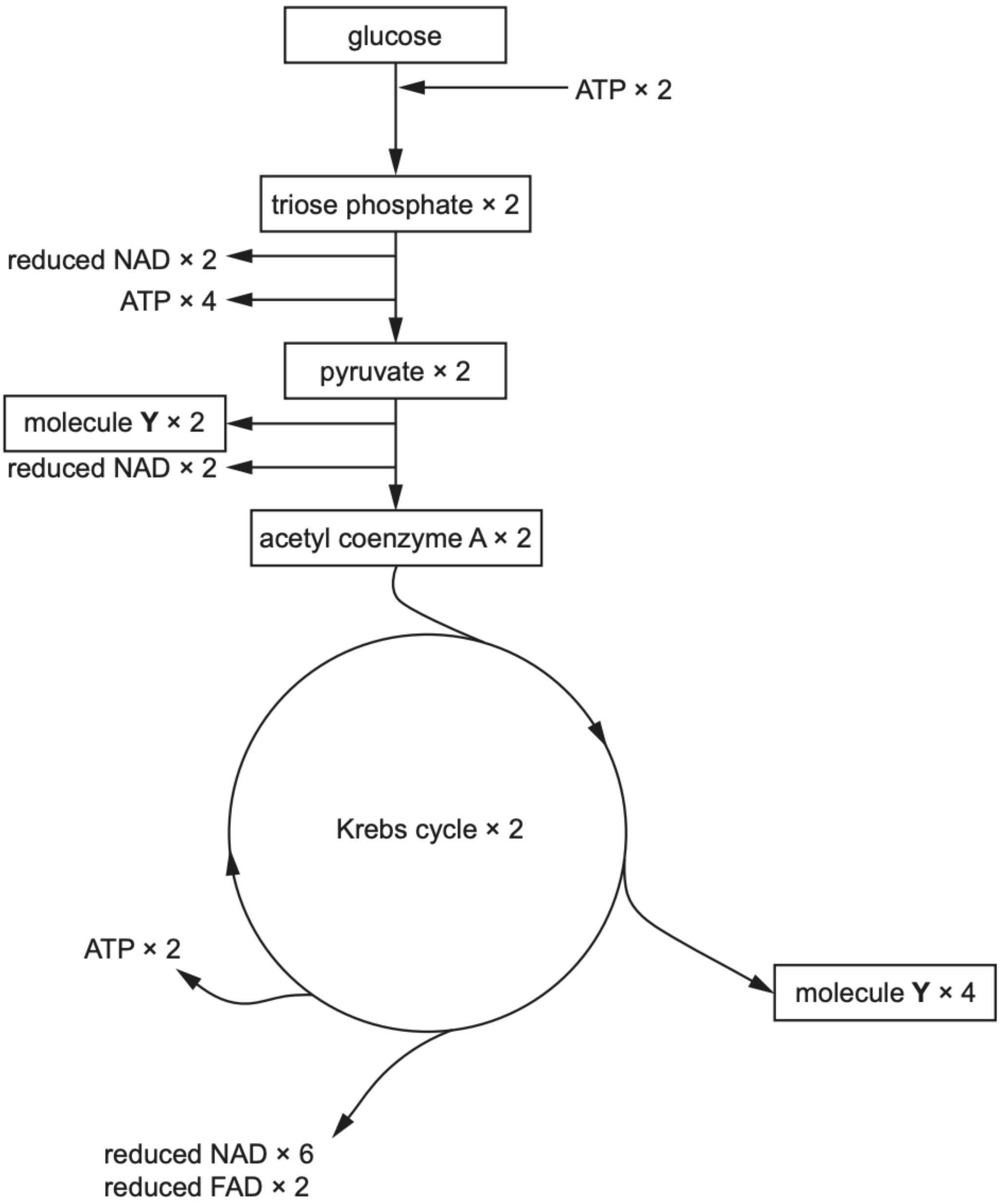
Describe the role of coenzyme A in respiration.

- combines with acetyl group / acetate formed from pyruvate.
- in link reaction.
- delivers acetyl group / acetate to the Krebs cycle.
- acetyl group / acetate combines with oxaloacetate to form citrate.

State the term used to describe the reaction that results in the production of ATP during the Krebs cycle.

- substrate-linked phosphorylation

Fig. 6.1 outlines the first three stages of respiration in aerobic conditions.



Name molecule Y

- carbon dioxide

Explain how the figure shows that glycolysis involves oxidation.

- triose phosphate dehydrogenated
- reduced NAD made / released

Aerobic Respiration: Role of NAD & FAD

7. *describe the role of NAD and FAD in transferring hydrogen to carriers in the inner mitochondrial membrane.*

Describe and explain the role NAD and FAD in aerobic respiration.

- They act as coenzymes/ cofactors.
- To dehydrogenase / in dehydrogenation in glycolysis, link reaction, and Krebs cycle.
- NAD and FAD accept H atoms during dehydrogenation, and get reduced.
- They act as hydrogen / electron carriers
- Glycolysis:
    - NAD becomes reduced (NAD → NADH)
    - so that triose phosphate becomes oxidised / dehydrogenated.
- Link reaction:
    - NAD becomes reduced.
    - so that pyruvate bnecomes oxidised / dehydrogenated for production of acetyl coenzyme A.
- Krebs cycle:
    - Both NAD and FAD become reduced.
    - to regenerate oxaloacetate.
- Oxidative phosphorylation:
    - Reduced NAD and FAD deliver hydrogen / H^+ and high energy electrons to inner mitochondrial membrane/ cristae/ ETC.
    - e– pass along ETC, releasing energy for ATP production via chemiosmosis: 2.5 / 3 ATP synthesised per reduced NAD.
    - Electron transfer drives proton pumping for ATP production / oxidative phosphorylation.
    - NAD and FAD are recycled back to their oxidised forms, releasing electrons to carries and protons into the matrix.

Outline the roles of NAD in the <u>cytoplasm</u> of a cell.

- hydrogen carrier / acceptor; gets reduced or gains H / H+ and electrons.
- acts as a coenzyme; enables dehydrogenases to work.
- glycolysis / respiration in anaerobic conditions.

At one time it was thought that the oxidative phosphorylation of:

• one molecule of reduced NAD results in the synthesis of 3 ATP molecules

• one molecule of reduced FAD results in the synthesis of 2 ATP molecules.

Modern research has shown that the actual net number of ATP molecules synthesised for each glucose molecule respired is much lower than the theoretical value.

Suggest reasons why the actual net number of ATP molecules synthesised is less than the theoretical number.

- ATP / energy used to transport pyruvate / reduced NAD / products of glycolysis into (named part of) mitochondria.
- some protons leak from intermembrane space.
- some energy lost as heat.

- glucose may not be completely broken down / some intermediates are used in different metabolic processes.
- reduced NAD may be used for other metabolic reactions.

Aerobic Respiration: Oxidative Phosphorylation

8. *explain that during oxidative phosphorylation:*
   - *hydrogen atoms split into protons and energetic electrons*
   - *energetic electrons release energy as they pass through the electron transport chain (details of carriers are not expected)*
   - *the released energy is used to transfer protons across the inner mitochondrial membrane*
   - *protons return to the mitochondrial matrix by facilitated diffusion through ATP synthase, providing energy for ATP synthesis (details of ATP synthase are not expected)*
   - *oxygen acts as the final electron acceptor to form water*

Outline the main stages of oxidative phosphorylation

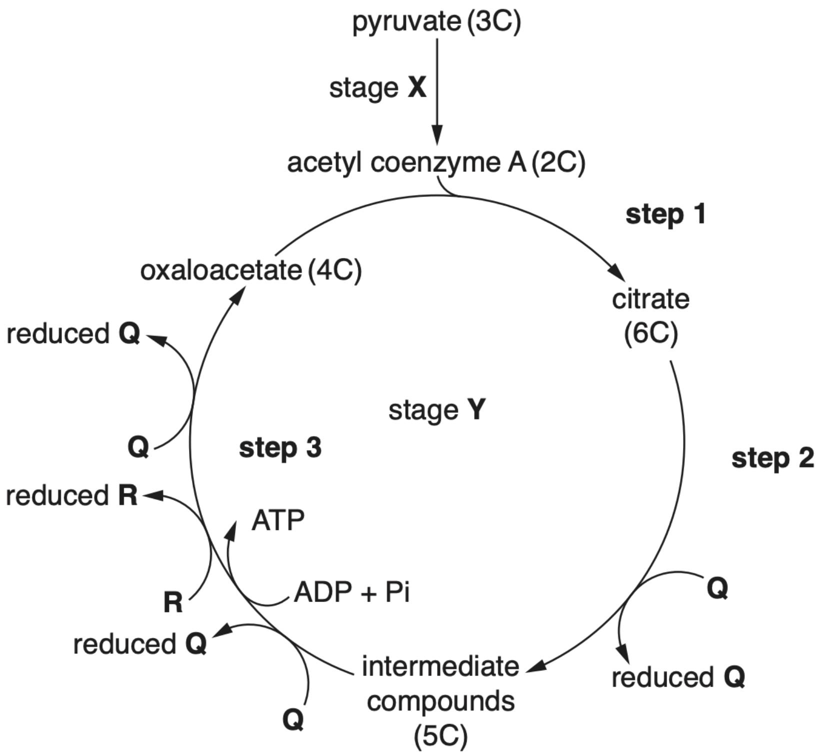
1. reduced NAD/FAD releases hydrogen atoms to cytochrome carriers.
2. hydrogen atoms split into protons and electrons.
3. electrons are passed from carrier to carrier, through ETC in inner mitochondrial membrane/ cristae.
4. electron transfer releases energy.
5. energy from electron transfer is used to pump protons into the intermembrane space.
6. a proton gradient is set up across the crista / inner membrane; high proton concentration in intermembrane space.
7. protons diffuse through the channel protein known as ATP synthase (stalked particle) into the matrix.
8. ATP synthase produces ATP from ADP and Pi; chemiosmosis.
9. protons combine with electrons and oxygen atoms to form water; oxygen acts as final electron acceptor.

	Precise location in cell
Glycolysis	Cytoplasm
Link reaction	Mitochondrial matrix
Krebs cycle	Mitochondrial matrix
Oxidative phosphorylation	Inner mitochondrial membrane/ cristae

Substrate-linked phosphorylation	Cytoplasm (glycolysis) and mitochondrial matrix (Krebs cycle)

Description	**Structure/compound involved in aerobic respiration**
Transports hydrogen atoms	NAD, FAD
Nucleotide with a purine base	NAD, FAD, ADP
Enters the Krebs cycle	Acetyl group
Produced by oxidation of triose phosphate	Pyruvate

Outline diagram showing 2 stages of aerobic respiration:



Stage X	Link reaction
Stage Y	Krebs cycle
Substance Q	NAD
Substance R	FAD

State the numbered steps in stage Y in which decarboxylation occurs.

- 2 and 3

Name the type of reaction by which ATP is made during step 3

- Substrate-linked phosphorylation

Uncontrolled cell division can lead to a cancerous tumour. Many cancer cells break down the amino acid glutamine and convert it to a 5-carbon intermediate compound, which is shown in the diagram. Suggest how the breakdown of glutamine can lead to the production of ATP in a cancer cell, other than that directly produced during step 3.

- reduced NAD / FAD to ETC
- oxidative phosphorylation / chemiosmosis

(Explanation):

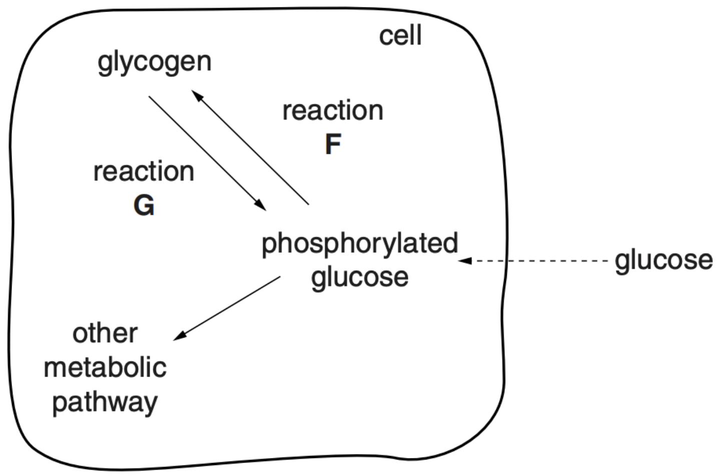
- Breakdown of glutamine produces 5-carbon intermediate that can enter Krebs cycle.
- This leads to production of reduced NAD (NADH) and reduced FAD ($FADH_2$) during Krebs cycle reactions.
- These reduced coenzymes donate high-energy electrons to the **e**lectron transport chain (ETC) in the inner mitochondrial membrane.
- Energy released as electrons pass along the ETC is used to pump protons (H^+ ions) into the intermembrane space.
- This generates a proton gradient across the membrane.
- Protons flow back through ATP synthase by chemiosmosis, driving the phosphorylation of ADP → ATP.
- This is **oxidative phosphorylation,** which produces the majority of ATP.

stage of respiration	ATP used	ATP produced
glycolysis	yes	yes
link reaction	no	no
Krebs cycle	no	yes
oxidative phosphorylation	no	yes

Describe the role of oxygen in aerobic respiration.

- Used in oxidative phosphorylation /ETC.
- Acts as the final electron acceptor.
- Acts as a proton acceptor.
- Combines to forms water.
- Allows ETC to continue by removing electrons.
- Enables continued ATP production via chemiosmosis.

Fig. 1.2 summarises the reactions that take place after glucose has entered a certain type of cell.



Suggest one type of cell in which the reactions shown in Fig. 1.2 could occur.
- liver/muscle

State the mechanism by which glucose enters the cell.
- facilitated diffusion

Name the type of reaction occurring at F and the type of reaction occurring at G.
- F: condensation / polymerisation / anabolic / glycogenesis / dephosphorylation
- G: hydrolysis / catabolic / glycogenolysis / phosphorylation

With reference to Fig. 1.2, suggest one example of an 'other metabolic pathway' for phosphorylated glucose.
- glycolysis / respiration / lipid synthesis

Structure & Function of Mitochondria

9. *describe the relationship between the structure and function of mitochondria using diagrams and electron micrographs.*

Outline the structure of a mitochondrion
- Found in eukaryotic cells.
- Bound by a double membrane.
- Outer membrane is permeable to pyruvate, which is the main product of glycolysis.
- Inner membrane is folded to form cristae, which increases surface area of the membrane.

- Embedded in the inner membrane are the carrier proteins of the electron transport chain and the protein complex responsible for ATP production = ATP synthase.
- Electron flow leads to the build-up of a large concentration of protons / hydrogen ions / H+ in the intermembrane space due to the activity of the electron transport chain.
- The matrix of the mitochondrion contains enzymes and is the site of the link reaction and the Krebs/ TCA/ citric acid cycle.

	Precise location in mitochondrion
ATP synthase	Inner mitochondrial membrane/ cristae
Krebs cycle	Mitochondrial matrix
electron transport chain	Inner mitochondrial membrane/ cristae
coenzyme A	Mitochondrial matrix
pyruvate	Mitochondrial matrix
acetyl CoA	Mitochondrial matrix
phospholipid bilayer	Inner mitochondrial membrane/ cristae
oxaloacetate	Mitochondrial matrix

Explain why it is an advantage to the cell for the inner membrane of the mitochondrion to be folded.

- increase in surface area
- more carriers / ATP synthase / ETCs
- more ATP (produced)

The inner mitochondrial membrane is the site of oxidative phosphorylation. Explain how the structure of the inner mitochondrial membrane is linked to its function.

- inner membrane is folded / has many cristae.
- provides large surface area
- for electron carriers / electron transport chain / ETC / cytochromes
- and ATP synthase / ATP synthesis.
- it is impermeable to protons / hydrogen ions
- so allows formation of proton gradient / high concentration of protons in intermembrane space and proton pumps.
- this gradient drives ATP synthesis via ATP synthase, thus involved in oxidative phosphorylation.

Describe the role of the inner mitochondrial membrane (crista) in chemiosmosis.

- site of electron transport chain (ETC).
- as electrons pass along ETC, energy is released which moves / pumps protons / H+ from mitochondrial matrix to inter-membrane space.
- creates electrochemical / proton / H+ gradient across inner membrane.
- protons / H+ diffuse back into to matrix
- through ATP synthase / stalked particles.
- flow of protons drives phosphorylation of ADP + Pi → ATP.
- this process is called oxidative phosphorylation.

State the specific role of oxygen in the mitochondrion.

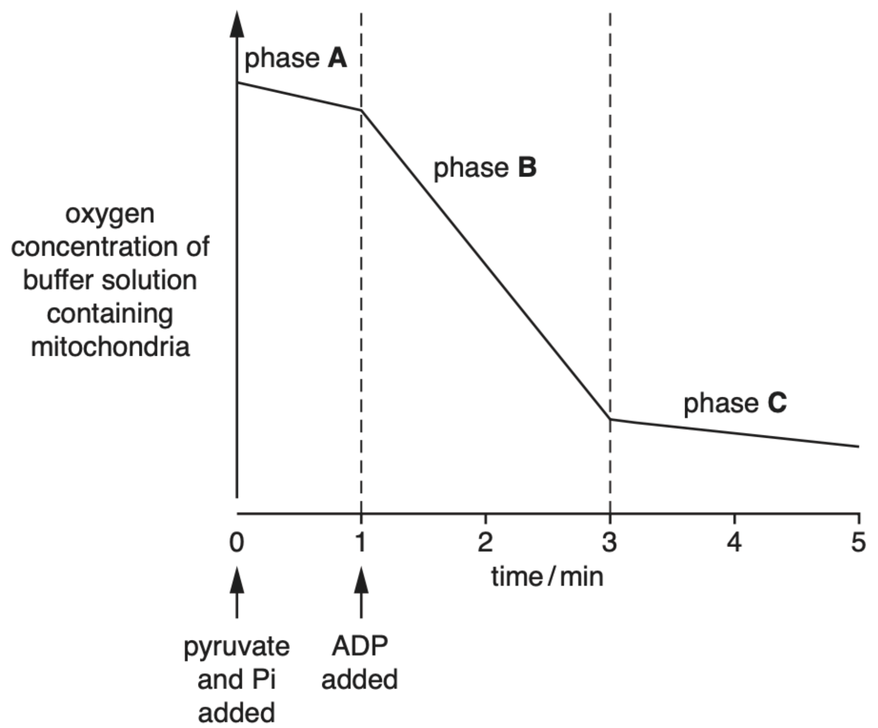
- final electron and proton acceptor (in ETC)

Graph analysis question:

Isolated mitochondria were used to investigate respiration.

- Mitochondria were extracted from respiring mammalian cells and incubated in a buffer solution.
- Pyruvate and inorganic phosphate (Pi) were added at time zero.
- ADP was added one minute later.
- The oxygen concentration of the buffer solution containing mitochondria was monitored throughout the investigation.

Results of the investigation:



a. **Suggest why the line of the graph in Fig. 7.1 is steeper during phase B than during phase A.**
    - because there is a faster rate of aerobic respiration than in phase A.
    - because in phase B ADP is present so oxygen concentration decreases faster.
    - ADP is needed for ATP synthesis.
    - oxygen is used as final electron acceptor / for oxidative phosphorylation / for aerobic respiration.

b. **Suggest why the line of the graph starts to level out in phase C.**
    - ADP / Pi / oxygen / pyruvate becomes limiting / runs out.

Suggest why heart cells have greater mean number of mitochondria per μm3 than fat cells.

- mitochondria / respiration produces ATP.
- heart / cardiac muscle cell needs more energy / ATP
- heart / cardiac muscle cell contracts / is more metabolically active.

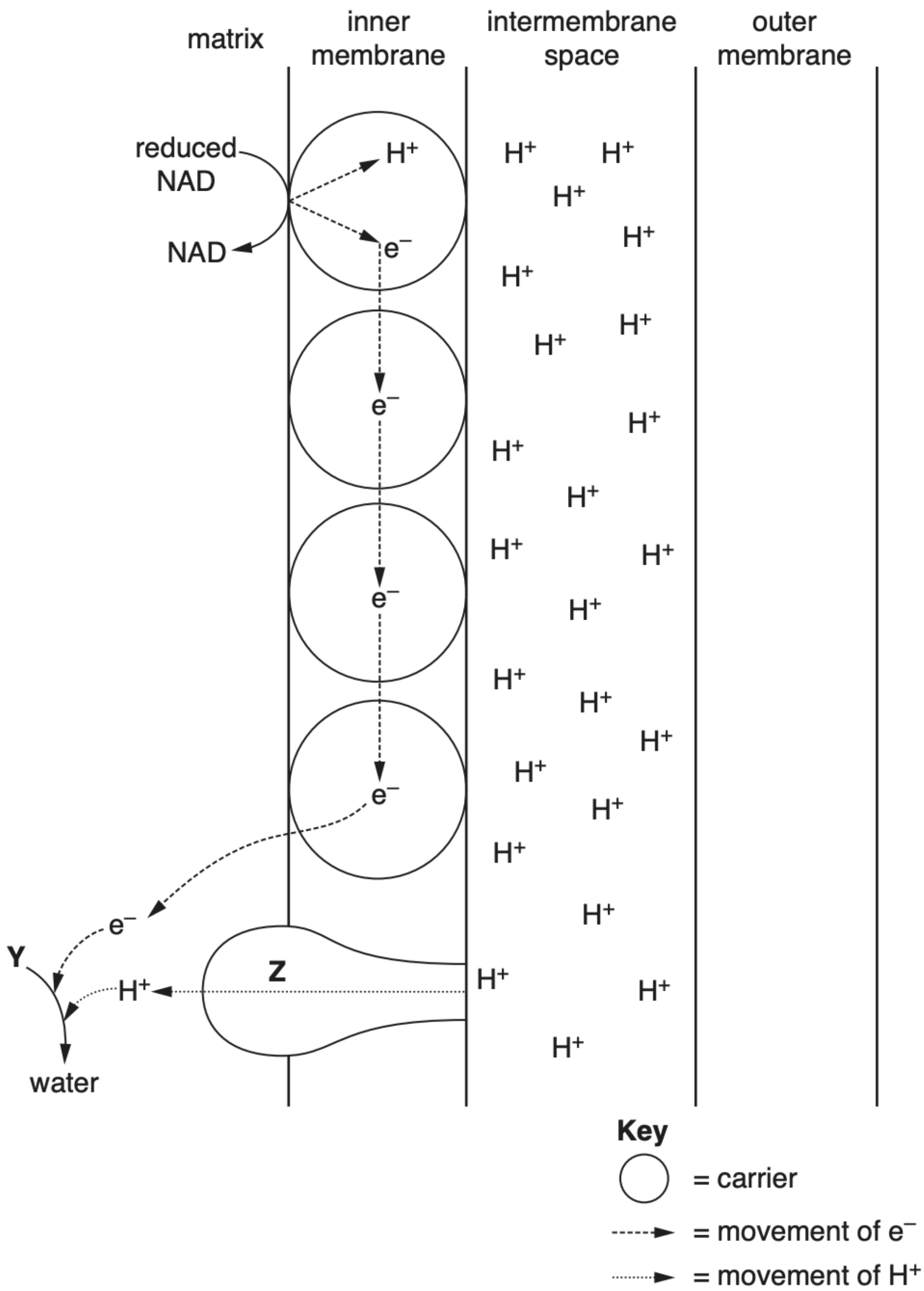
Suggest why it is difficult to compare the ability of different types of cell to respire aerobically, based only on the mean number of mitochondria per cell.

- mitochondria vary in size / in surface area of inner membrane.

Some cancer cells have different metabolic requirements from normal cells. These cancer cells obtain most of their ATP from glycolysis, even if oxygen is available. State how the glucose and oxygen requirements of these cancer cells differ from normal cells.

- cancer cells need / use more glucose.
- cancer cells need / use less oxygen.
- cancer cells get little energy / 2 ATP / small amount of ATP per glucose molecule from glycolysis.

Diagram of part of a mitochondrion showing some of the events occurring in oxidative phosphorylation:



Y	oxygen
Z	ATP synthase / ATP synthetase

a. **State sources of the reduced NAD**
   - glycolysis
   - link reaction
   - Krebs cycle

b. **With reference to the diagram, outline the role of carriers in the inner membrane**
    - splits H into electrons and H+.
    - electrons along ETC / carriers provides energy.
    - energy used to pump H+ into intermembrane space.

Explain why animals can exercise for longer when they have larger surface area of inner membrane to surface area of outer membrane ratio in mitochondria.
- larger / more inner membrane / cristae.
- more ETCs / cytochromes / ATP synthase / stalked particles.
- increased oxidative phosphorylation.
- more ATP produced.
- muscles can contract for longer / more time / without getting tired.
- During chemiosmosis, H^+ ions move down electrochemical gradient across inner membrane, through ATP synthase, driving the production of ATP from ADP + Pi.

Some effects of exposure to chemical X:

• decreased production of ATP

• increased lipid metabolism, with weight loss

• increased production of pyruvate and lactate

• excess heat energy release, causing increase in body temperature (fatal)

Chemical X increases the permeability of the inner mitochondrial membrane to protons (hydrogen ions), causing some protons to leak out into the matrix.

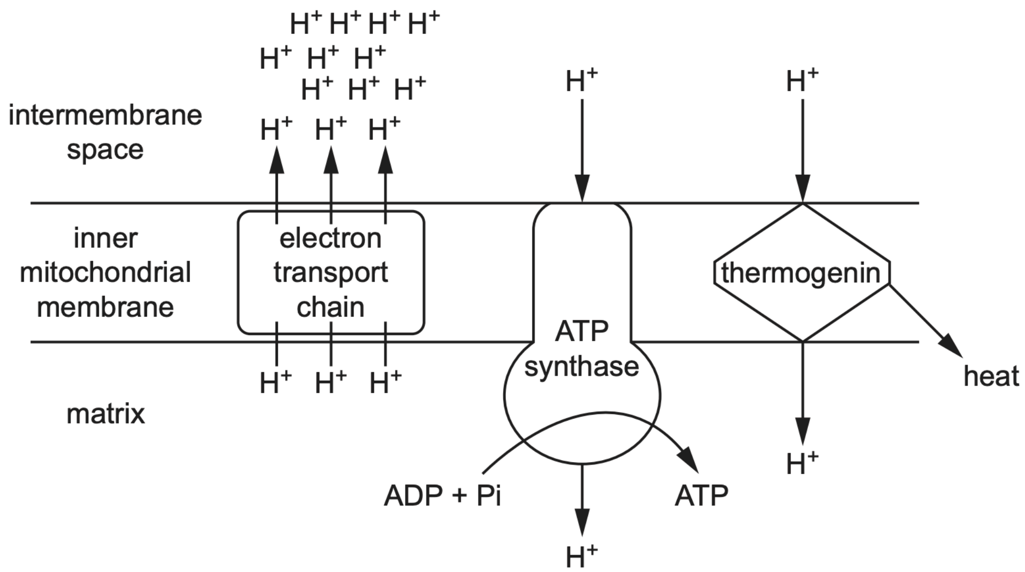
Explain the reason for each of these symptoms.

decreased production of ATP	- smaller / less steep proton gradient - fewer protons go through ATP synthase / stalked particle.
increased lipid metabolism	- use / burn / respire body fat / lipid stores - as less ATP made from glucose / food
increased production of pyruvate and lactate	- more / faster / increased rate of glycolysis - oxygen decreased / used faster / shortage - so more / increased anaerobic respiration
excess heat energy release	- energy from reduced NAD / ETC released as heat - energy not used to join ADP and Pi, so released as heat

The energy that is not converted to ATP during respiration is released as heat energy. State one homeostatic use of this heat energy in mammals.
- Thermoregulation OR maintaining constant body / core temperature

Fur seals are mammals that are adapted to live in cold temperatures. Fur seals have large quantities of a type of fat tissue known as brown adipose tissue. Brown adipose cells contain many mitochondria. These mitochondria contain a transport protein called thermogenin.

Fig. 2.1 shows the role of thermogenin in a mitochondrion of a brown adipose cell when external temperatures are cold.



With reference to the figure, describe and explain the effect of thermogenin on ATP synthesis.

- reduces ATP synthesis / less ADP reacts with Pi.
- protons diffuse through thermogenin.
- proton gradient reduced/ reduces conc of H+ in intermembrane space.
- fewer protons pass through ATP synthase.

Rotenone (insecticide) kills insects by inhibiting the transfer of electrons in the electron transport chain of the mitochondrion. Explain how it affects ATP synthesis in the mitochondrion.

- less / no energy release from electron transfer / ETC.
- less / no chemiosmosis.
- fewer / no protons move / pumped to intermembrane space.
- less steep / no proton gradient.
- fewer / no protons move / diffuse through ATP synthase.
- less / no ATP synthesised.

Suggest and explain why cardiac muscle cells have mitochondria with very large numbers of cristae.

- more cristae results in more ETC / (named) carrier proteins / ATP synthase OR more cristae results in more oxidative phosphorylation / chemiosmosis / ATP synthesis.
- because cardiac muscle must undergo continuous contractions.

Anaerobic Respiration

10. *outline respiration in anaerobic conditions in mammals (lactate fermentation) and in yeast cells (ethanol fermentation).*

Outline the stages of glycolysis and respiration in anaerobic conditions in yeast.

1. glucose is phosphorylated by ATP
2. fructose bisphosphate is formed
3. triose phosphate is dehydrogenated by NAD
4. ATP is made by substrate-linked phosphorylation
5. pyruvate is formed
6. pyruvate is decarboxylated
7. ethanal is formed
8. ethanal is reduced by alcohol dehydrogenase
9. ethanol is formed

Description	**Structure/compound involved in anaerobic respiration**
end product of glycolysis	pyruvate
cellular location of respiration in anaerobic conditions	cytoplasm
end product of respiration in anaerobic conditions in yeast cells	ethanol / carbon dioxide
compound used to reduce pyruvate	reduced NAD
end product of respiration in anaerobic conditions in muscle cells	lactate
gas released during alcoholic fermentation	carbon dioxide

Explain why a person continues to breathe deeply and at a higher rate for some time after the person has stopped exercising.

- oxygen debt (EPOC) is created.
- extra oxygen is needed to oxidise lactate to pyruvate.
- lactate is then converted back to glycogen in liver/muscles.
- oxygen is needed to re-oxygenate Hb / myoglobin.
- increased oxygen uptake supports temporarily higher metabolic rate after exercise.

Respiration in anaerobic conditions in muscle cells during vigorous exercise can create an oxygen debt. Extra oxygen is breathed in after exercise to pay back the oxygen debt. Explain ways in which the mammalian body uses this extra oxygen.

- lactate converted / oxidised
- to pyruvate / glucose / glycogen
- haemoglobin / myoglobin re-oxygenated

In anaerobic conditions, the pyruvate formed in glycolysis is converted to ethanol in yeast cells and to lactate in mammalian tissue. Compare the pathways by which pyruvate is converted to ethanol or to lactate.

<u>Similarities</u>

- reduced NAD used in both.
- NAD regenerated/glycolysis can continue in both.

<u>Differences</u>

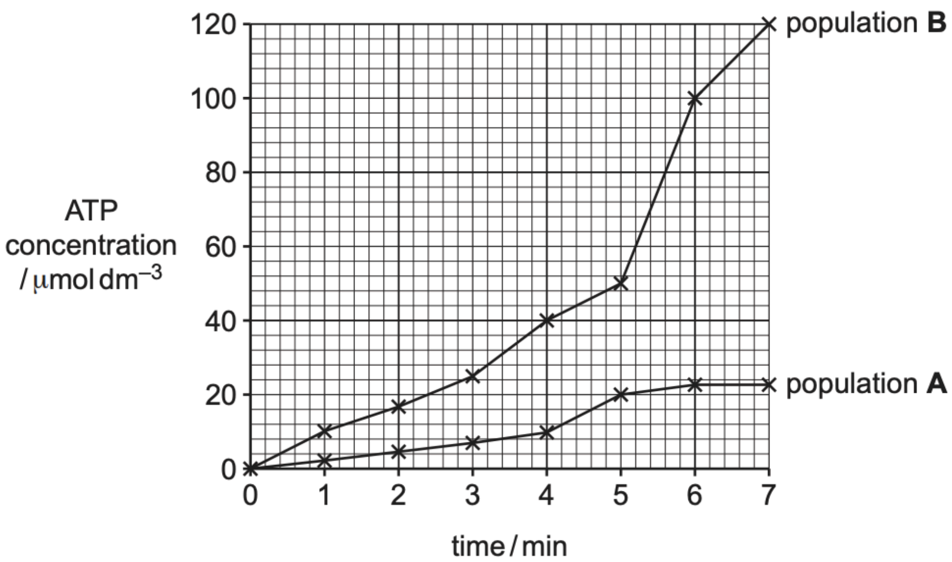
yeast/ethanol	**mammalian tissue/lactate**
decarboxylation	no decarboxylation
irreversible	reversible
two steps: pyruvate → ethanal → ethanol	one step: pyruvate→lactate
ethanal accepts H	pyruvate accepts H
ethanol dehydrogenase	lactate dehydrogenase

In an experiment on respiration, two different populations of yeast cells were used: **A** and **B**.

- Yeast cells in population **A** had no mitochondria in their cells.
- Yeast cells in population **B** did have mitochondria in their cells.

Both populations were provided with glucose in solution and the concentration of ATP was measured every minute for seven minutes.

Fig. 7.1 shows the results of the experiment.



Describe and explain the difference in results between population A and population B, as shown in the graph.

- population B produces more ATP than population A.
- production of ATP increases at a higher rate for population B than for population A.
- paired data quote.
- population B carries out glycolysis / substrate-linked phosphorylation and oxidative phosphorylation.
- population A carries out only glycolysis / respiration in anaerobic conditions / ethanol fermentation / substrate-linked phosphorylation OR population A cannot carry out oxidative phosphorylation.

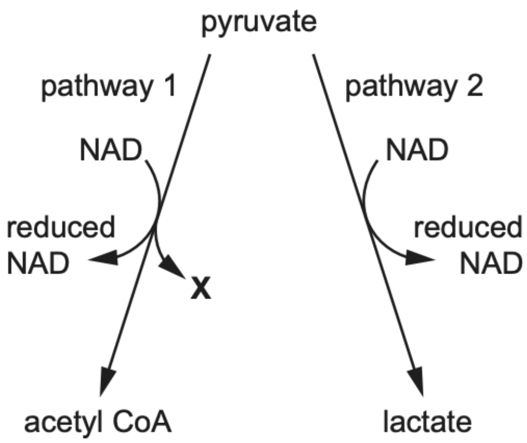
Energy Yield: Aerobic & Anaerobic Respiration

11. *explain why the energy yield from respiration in aerobic conditions is much greater than the energy yield from respiration in anaerobic conditions (a detailed account of the total yield of ATP from the aerobic respiration of glucose is not expected).*

Explain why respiration of glucose in anaerobic conditions produces less ATP than in aerobic conditions.

- Only glycolysis/ conversion of glucose into pyruvate occurs.
- Only produces 2 molecules of ATP, net per molecule of glucose.
- Oxygen is not available as the final electron acceptor.
- So pyruvate does not enter mitochondria.
- Electron transport chain/chemiosmosis/ oxidative phosphorylation/ Krebs cycle/ link reaction does not occur.
- Electron transport chain/chemiosmosis/ oxidative phosphorylation produce most ATP is produced in aerobic conditions.
- Only substrate-linked phosphorylation occurs (in glycolysis).
- No additional substrate-linked phosphorylation from Krebs cycle.
- Pyruvate is converted into lactate (OR ethanol in case of yeast)
- Lactate is still energy-rich (OR ethanol in case of yeast)

2 possible pathways for further metabolism of pyruvate:



State the condition under which pyruvate would be metabolised along pathway 2.

- anaerobic conditions / no oxygen available / little oxygen available

Name compound X

- Carbon dioxide

Name the two types of reaction that are involved in pathway 1.

- dehydrogenation
- decarboxylation

Suggest a cell in a mammal that cannot carry out pathway 1. Give a reason for your answer.

- Red blood cell / erythrocyte
- because it has no mitochondria

Anaerobic Adaptation of Rice

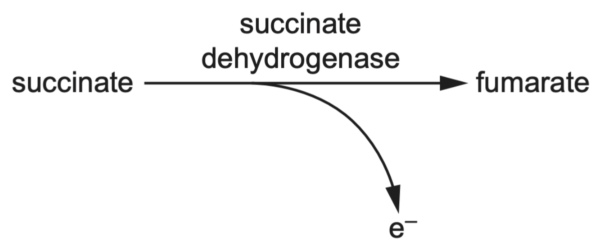
12. *explain how rice is adapted to grow with its roots submerged in water, limited to the development of aerenchyma in roots, ethanol fermentation in roots and faster growth of stems.*

Explain how rice is adapted to grow with its roots submerged in water.
- low concentration of oxygen in water.
- rice plants have aerenchyma.
- gases diffuse (through aerenchyma) down to root cells.
- allows aerobic respiration.
- some leaves trap air underwater due to ridges on leaves.
- ethanol is produced from respiration under anaerobic conditions.
- root cells can tolerate ethanol.
- root cells produce ethanol dehydrogenase (to break down ethanol).
- some varieties of rice have high rate of respiration under anaerobic conditions to generate more ATP.

Aerobic Respiration: Effect of Temperature & Substrate Concentration

13. *describe and carry out investigations using redox indicators, including DCPIP and methylene blue, to determine the effects of temperature and substrate concentration on the rate of respiration of yeast.*
14. *describe and carry out investigations using simple respirometers to determine the effect of temperature on the rate of respiration.*

Activity of succinate dehydrogenase (an enzyme in Krebs cycle) is used as a measure of the rate of respiration in the mitochondria.

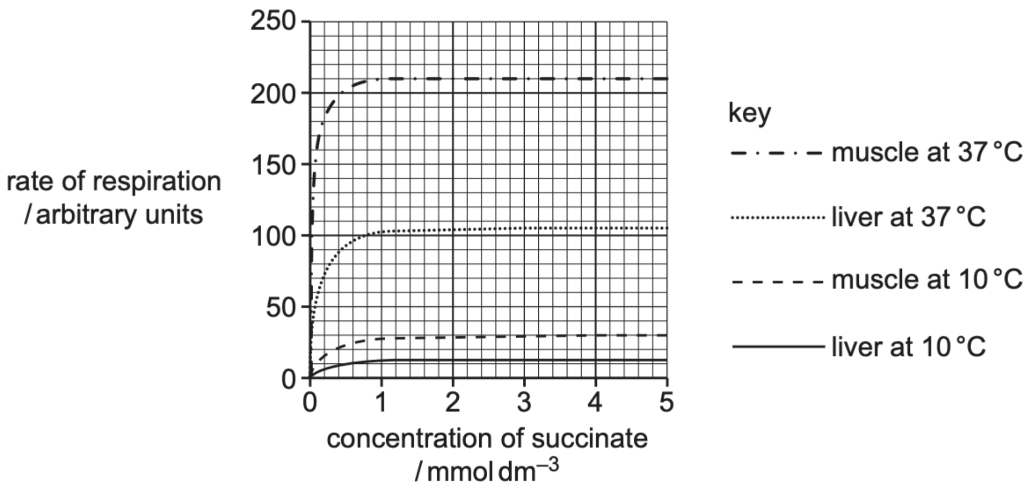


Activity of succinate dehydrogenase can be measured using a redox indicator. Name a redox indicator and explain why this indicator can be used to measure the activity of succinate dehydrogenase.
- DCPIP / methylene blue.
- changes colour / blue to colourless when reduced / accepts electrons from succinate.

Suggest why carbon dioxide is transported in the blood mainly as hydrogen carbonate ions and not as carbonic acid.

- hydrogen carbonate ions prevents decrease in blood pH
- CO_2 + H_2O, catalysed by carbonic anhydrase = carbonic acid; carbonic acid dissociates into hydrogen carboncate ions (HCO_3^-) and H^+ ions, so it acts as a buffer system.

Graph analysis question:



a. **Describe the trends shown**
    - rate of respiration increases as succinate concentration increases, up to 1.0 mmol dm^{-3} OR maximum rate at 1.0 mmol dm^{-3}.
    - rate of respiration higher at 37 °C than at 10 °C, in liver and muscle.
    - rate of respiration higher in muscle than in liver, at both temperatures.
    - comparative data quote to support mp2 or mp3.

b. **Explain the difference in the rates of respiration between liver at 37 °C and muscle at 37 °C.**
    - respiration produces ATP
    - muscle needs more energy / ATP
    - muscle contracts / is more metabolically active
    - AVP: e.g. shivering to maintain body temperature

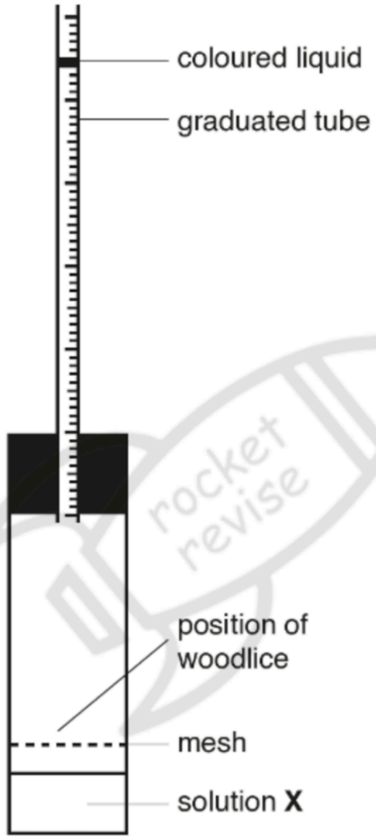
c. **When body temperature is 10˚C, muscle tissue uses more energy than liver tissue. Suggest one reason for this.**
    - muscle is contracted / generates heat / is more metabolically active

A respirometer can be used to measure the respiration rate of small invertebrates such as the common woodlouse, *Oniscus asellus*.

Fig. 8.1 shows a common woodlouse.

Fig. 8.1

Fig. 8.2 shows a respirometer.



Name solution X and state its role in the use of a respirometer.

- potassium hydroxide / sodium hydroxide solution
- absorbs carbon dioxide

A respirometer can be used to measure the effect of temperature on the rate of respiration of organisms. Suggest one factor that would need to be taken into account when using woodlice rather than germinating seeds.

- must not raise temperature too high for animals.
- woodlice have movement / activity.

As respiration takes place, oxygen is used by the woodlice and the coloured liquid moves down the graduated tube. Name the stage of aerobic respiration where oxygen is used.

- oxidative phosphorylation

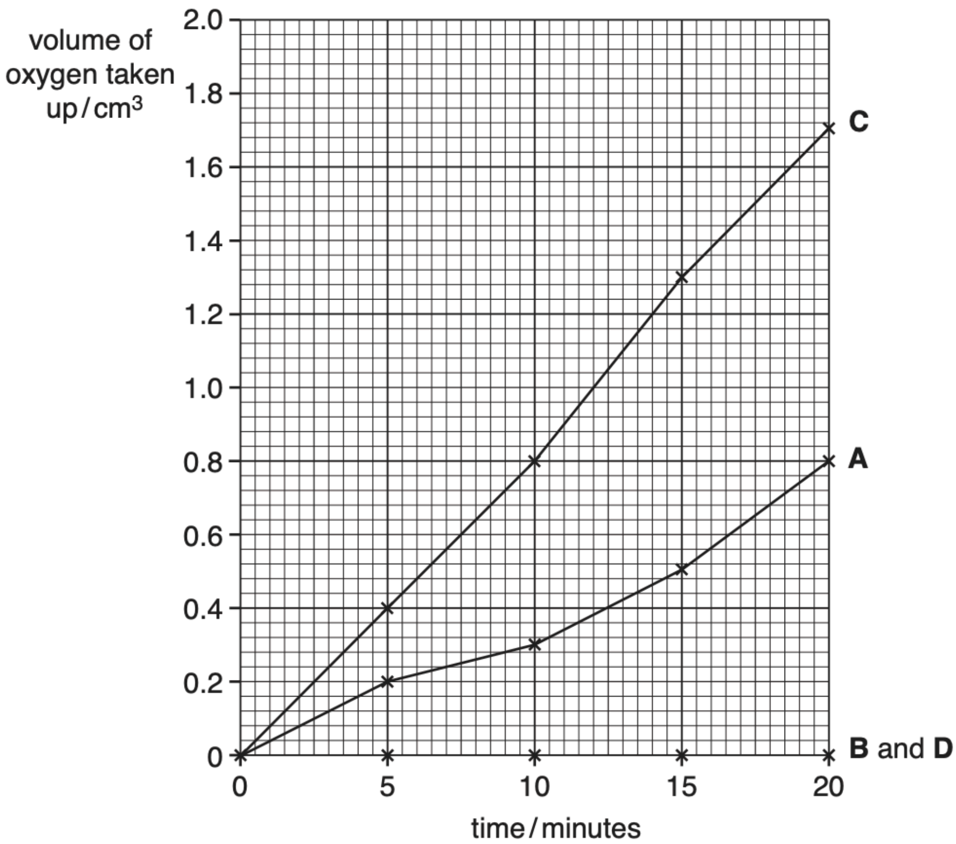
Respirometers, as shown in Fig. 8.1, were used to investigate the effect of temperature on the rate of respiration of germinating pea seeds.

Four respirometers, **A**, **B**, **C** and **D** were set up:

- **A** and **B** in a water-bath maintained at 10 °C.
- **C** and **D** in a water-bath maintained at 25 °C.
- **A** and **C** each contained 30 germinating pea seeds.
- **B** and **D** each contained glass beads with a total volume equivalent to 30 pea seeds.

- The respirometers were left in the water-baths for 10 minutes.
- In each respirometer the position of the coloured liquid in the graduated tube was then marked (time 0 minutes).
- After 5 minutes the distance moved by the coloured liquid was measured.
- The volume of oxygen taken up was calculated for each respirometer.
- This was repeated after 10, 15 and 20 minutes.

Fig. 8.2 shows the results of the experiment.



Suggest why the respirometers were left for 10 minutes before measurements were Made.

- equilibration/ acclimatising / adjusting

Suggest why respirometers B and D were used in this investigation.

- act as a control
- control eliminates effects of variables other than the independent variable / temperature.
- changes in A and C are due to seeds /respiration.

Explain why there is an increased rate of respiration of germinating pea seeds between 10 °C and 25 °C.

- at 25°C there is increased kinetic energy.
- enzymes are involved, and enzymes/substrates/molecules move faster.
- more collisions between enzyme and substrate.
- more ESCs formed.

Suggest why carrying out the experiment with germinating seeds at 50 °C could result in a lower rate of respiration than at 25 °C.

- enzymes denatured.
- change in active site (shape)/H bonds break.