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Home Gameboard Biology Biochemistry Respiration Oxidative Phosphorylation

Oxidative Phosphorylation

A Level
P P P

Oxidative phosphorylation is the final stage of aerobic respiration.

Part A The process

During oxidative phosphorylation, NADH (reduced NAD) and $FADH_2$ (reduced FAD) are _____, releasing H^+ ions and electrons, and regenerating NAD^+ and FAD. The electrons move along a series of protein complexes embedded in the _____ called the _____. The energy released during this allows these protein complexes to actively transport H^+ ions from the mitochondrial matrix to the _____.

These H^+ ions then flow back into the mitochondrial matrix down their electrochemical gradient through a transmembrane protein called _____, providing the energy needed to synthesise ATP from ADP & Pi (inorganic phosphate). The maximum number of ATP molecules produced during this stage (per molecule of glucose) is ≈ 34, but the actual number varies depending on how much of the energy produced is used to make ATP, and how much is lost in the form of _____.

After reaching the final part of the electron transport chain, the electrons react with oxygen (the _____) and the H^+ ions to form water (H_2O).

Items:

ATP synthase **oxidised** **heat** **intermembrane space** **reduced** **cytoplasm** **final electron acceptor** **inner mitochondrial membrane** **electron transport chain** **outer mitochondrial membrane**

Part B Reactants

Which of the following molecules are **used up** during oxidative phosphorylation?

- [ ] oxygen
- [ ] water
- [ ] NAD^+
- [ ] NADH (reduced NAD)
- [ ] FAD
- [ ] $FADH_2$ (reduced FAD)
- [ ] ADP
- [ ] ATP
- [ ] carbon dioxide

Part C Products

Which of the following molecules are **produced** during oxidative phosphorylation?

- [ ] oxygen
- [ ] water
- [ ] NAD^+
- [ ] NADH (reduced NAD)
- [ ] FAD
- [ ] $FADH_2$ (reduced FAD)
- [ ] ADP
- [ ] ATP
- [ ] carbon dioxide

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Adenosine Triphosphate (ATP)

A Level
P P P

Adenosine triphosphate (ATP) is the main "energy transfer" molecule used in cells. Energy (from organic molecules in respiration, or from sunlight in photosynthesis) is used to synthesise ATP from adenosine diphosphate (ADP) and inorganic phosphate (P_i). This energy is stored within the ATP molecule and can then be released during ATP hydrolysis.

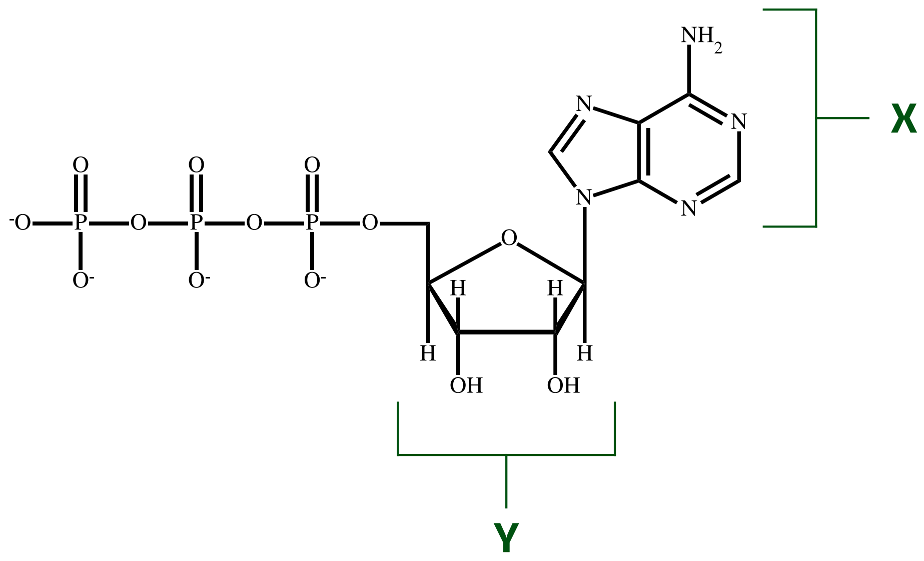

Figure 1: The molecular structure of adenosine triphosphate (ATP).

Part A X and Y

What is the name of the nitrogenous base labelled **X** in **Figure 1**?

What is the name of the sugar labelled **Y** in **Figure 1**?

Part B Inorganic phosphate

During respiration and photosynthesis, ATP is synthesised from ADP (adenosine diphosphate) and P_i (inorganic phosphate).

What is meant by "inorganic phosphate"?

- a single phosphate ion ($PO_4{}^{3-}$) which is not bound to anything else
- a compound consisting of one or more phosphate groups but which is not bound to anything else
- any compound that contains one or more phosphate groups
- any compound that contains one or more phosphate groups but does not contain any carbon atoms

Part C Chemical energy

Why does the hydrolysis of ATP to ADP and P_i release energy?

- ATP hydrolysis is a spontaneous reaction that requires no energy input.
- ATP is much more stable than ADP, which means that energy will be released when ATP is converted to ADP.
- The bonds between phosphate groups within ATP are "high-energy" bonds, which means they are very strong and therefore release a lot of energy when they are broken.
- During hydrolysis, water is split apart into hydrogen and oxygen. This process releases energy.
- The bonds between phosphate groups within ATP are relatively weak. The new bonds that form after hydrolysis are much stronger, which means that the reaction will release energy.
- Breaking chemical bonds is exothermic, whereas forming chemical bonds is endothermic.

Adapted with permission from OCR A Level June 2002, Science Modular Central Concepts in Biology, Question 1

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NAD and FAD

A Level

P P P

Part A Function of NAD and FAD

What is the main function of NAD^+ and FAD in aerobic respiration?

- To accept electrons from organic molecules and transfer them to the electron transport chain - where they are used to synthesise ATP.
- To act as energy transfer molecules which transfer energy by donating a phosphate group.
- To be transported across the inner mitochondrial membrane, driving an electrochemical gradient that is then used to synthesise ATP.
- To react with coenzyme A (CoA) to form acetyl CoA.
- To be broken down into smaller organic molecules in order to provide the energy needed for other reactions.
- To act as the final electron acceptors during oxidative phosphorylation.

Part B Oxidation and reduction

In the table below, match the reaction type to the equation.

Equation	Reaction type
$\mathrm{NAD^+ + H^+ + 2\,e^- \longrightarrow NADH}$	
$\mathrm{NADH \longrightarrow NAD^+ + H^+ + 2\,e^-}$	
$\mathrm{FAD + 2\,H^+ + 2\,e^- \longrightarrow FADH}$	
$\mathrm{FADH \longrightarrow FAD + 2\,H^+ + 2\,e^-}$	

Items:

oxidation **reduction**

Part C NADH and FADH2 production

Fill in the table below to give the number of molecules produced during each stage of aerobic respiration **per molecule of glucose**.

Stage	Molecule	
	NADH	$FADH_2$
Glycolysis		
Link reaction		
Krebs cycle		
Oxidative phosphorylation		

Items:

0 1 2 3 4 5 6

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STEM SMART Biology Week 33 - Respiration 2

Oxygen Levels

A Level
C C C

Liver cells are frequently used as a source of mitochondria. These cells are homogenised in a sucrose solution and the mitochondria isolated. The suspended mitochondria are then placed in an oxygen electrode where the oxygen uptake of these organelles can be measured over a given time period.

The results of one of these experiments are shown in **Figure 1**.

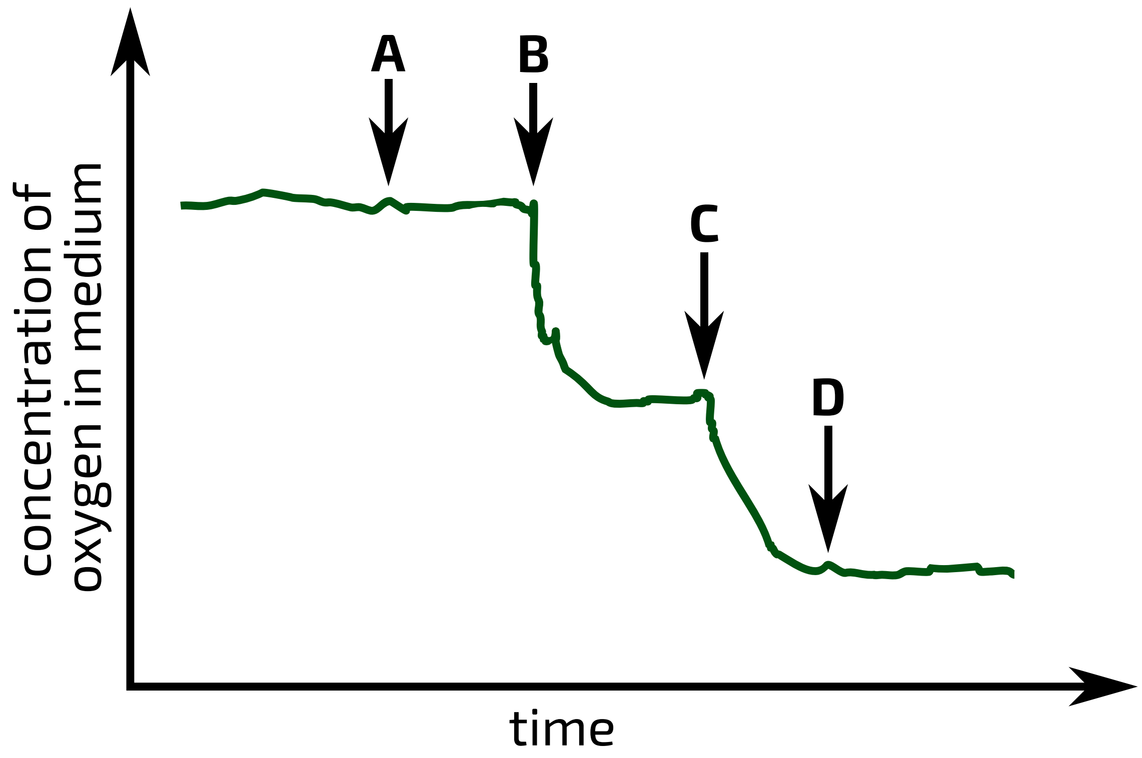

Figure 1: Oxygen concentration over time in a medium containing isolated mitochondria. At point A, glucose was added. At points B, C, and D, equal quantities of ADP were added.

Part A A to B

Which of the following explains the results between points A and B? Select all that apply.

- [ ] There is not enough oxygen present for aerobic respiration to occur.
- [ ] There is not enough glucose present for aerobic respiration to occur.
- [ ] The mitochondria are carrying out the process of fermentation, so the oxygen concentration remains constant during this period.
- [ ] Not enough ADP is present for the later stages of aerobic respiration to occur.
- [ ] Photosynthesis and respiration are occurring at equal rates, so the oxygen concentration remains constant during this period.
- [ ] The earlier stages of aerobic respiration do not use up oxygen, so the oxygen concentration remains constant during this period.

Part B B to C

Which of the following explains the results between points B and C? Select all that apply.

- [ ] The decrease in oxygen concentration slows down as ADP is used up (in making ATP).
- [ ] The rate of aerobic respiration slows down as oxygen begins to run out.
- [ ] Oxidative phosphorylation is occurring during this period, so the oxygen concentration decreases.
- [ ] The decrease in oxygen concentration slows down as glucose is used up.
- [ ] The rate of photosynthesis increases until the rate of oxygen production is equal to the rate of oxygen loss.
- [ ] Glycolysis is occurring during this period, so the oxygen concentration decreases.

Part C D onwards

Which of the following explains the results from point D onwards? Select all that apply.

- [ ] Only glycolysis is occurring from point D onwards, so the oxygen concentration remains constant.
- [ ] Not enough ADP is present for respiration to occur.
- [ ] All of the oxygen has been used up, so aerobic respiration cannot proceed.
- [ ] All of the glucose has been used up, so respiration cannot proceed.
- [ ] The lactic acid produced by the mitochondria has changed the pH of the solution such that the respiratory enzymes can no longer function.
- [ ] The rate of photosynthesis increased between points C and D, resulting in oxygen levels being kept constant.

Adapted with permission from OCR A Level June 2003, Science Modular Central Concepts in Biology, Question 3

Gameboard:

STEM SMART Biology Week 33 - Respiration 2

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Home Gameboard Biology Biochemistry Respiration Respiratory Quotients

Respiratory Quotients

A Level

P P P

The respiratory quotient (RQ) of a respiratory substrate is the number of $\mathrm{CO_2}$ molecules produced divided by the number of $\mathrm{O_2}$ molecules consumed during the aerobic respiration of one molecule of substrate, i.e.

$$\text{RQ} = \frac{\mathrm{CO_2}\text{ produced}}{\mathrm{O_2}\text{ consumed}}$$

Because the respiratory quotient differs between different respiratory substrates, it is possible to estimate the relative proportions of macronutrients being metabolised by measuring an individual's $\mathrm{CO_2}$ production and $\mathrm{O_2}$ consumption.

Part A Carbohydrates

Carbohydrates are the main type of respiratory substrate. Larger carbohydrates (polysaccharides) are broken down into glucose, which can then enter the glycolysis pathway.

Balance the equation below to calculate the respiratory quotient of glucose.

$$\mathrm{C_6H_{12}O_6} + \mathrm{O_2} \longrightarrow \mathrm{CO_2} + \mathrm{H_2O}$$

What is the respiratory quotient of glucose?

Part B Fats

Carbohydrates are not the only type of respiratory substrate. Fats (triglycerides) are also used in aerobic respiration, after being broken down into glycerol and fatty acids. Glycerol can then enter the glycolysis pathway (after being converted into one of the intermediate molecules), and fatty acids can enter Krebs cycle (after being converted into acetyl CoA).

Balance the equation below to calculate the respiratory quotient of a particular fatty acid.

$$C_{18}H_{36}O_2 + O_2 \longrightarrow CO_2 + H_2O$$

What is the respiratory quotient of this fatty acid? Give your answer to 2 decimal places.

Part C Energy storage

Cells store energy in the form of triglycerides and polysaccharide carbohydrates.

What is the name of the energy-storage carbohydrate found in plant cells?

What is the name of the energy-storage carbohydrate in animal cells?

Adapted with permission from CIE, A Level, November 2005, Paper 4, Question 3

Gameboard:

STEM SMART Biology Week 33 - Respiration 2

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Respiration Summary

A Level
P P P

Part A Respiration processes

Match the processes and cellular locations to the descriptions in the table below.

Process	Description	Location
	NADH and $FADH_2$ are oxidised and the energy released is used to produce ATP. Water is also produced.	
	Pyruvate is reduced to lactate or ethanol in order to regenerate NAD^+ from NADH.	
	Pyruvate is used to make acetyl CoA. NADH and CO_2 are produced.	
	Glucose is broken down into two pyruvate molecules. NADH and ATP are produced.	
	Acetyl CoA goes through a series of reactions. NADH, $FADH_2$, ATP, and CO_2 are produced	

Items:

inner mitochondrial membrane **mitochondrial matrix** **cytoplasm** **Krebs cycle** **the link reaction** **fermentation** **oxidative phosphorylation** **glycolysis**

Part B Molecule functions in aerobic respiration

Match the molecules to the functions in the table below.

Molecule	Function
	respiratory substrates
	electron carriers (accept electrons from organic molecules and donate them to the electron transport chain)
	final electron acceptor (accepts electrons from the electron transport chain)
	primary energy transfer molecule
	reacts with oxaloacetate (4C) to form citrate (6C) and restart the Krebs cycle

Items:

ATP **oxygen** **carbohydrates** **NAD^+ and FAD** **acetyl CoA**

Part C Aerobic and anaerobic respiration

Which of the following processes are involved in **aerobic** respiration of glucose?

- [ ] glycolysis
- [ ] fermentation
- [ ] the link reaction
- [ ] Krebs cycle
- [ ] oxidative phosphorylation

Which of the following processes are involved in **anaerobic** respiration of glucose?

- [ ] glycolysis
- [ ] fermentation
- [ ] the link reaction
- [ ] Krebs cycle
- [ ] oxidative phosphorylation

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