A2 Biology OCR

Unit F214: Communication, Homeostasis and Energy

Module 4.1 Respiration

Notes & Questions
Outline why plants, animals and microorganisms need to respire, with reference to active transport and metabolic reactions.

- Where does the energy come from?
  - Energy originally comes from the sun and is fixed as potential energy in complex organic molecules such as glucose by photosynthesis by photoautotrophs.
  - The complex organic molecules are only potential stores of energy.
  - For their energy to be realised and used it must be converted into another form ATP.
  - The metabolic process of Respiration converts these organic molecules into ATP which is used by all living things as an energy source.
  - Respiration is essential for all life and all cells in all living things must carry out this metabolic reaction in order to stay alive.
- How does ATP keep cells alive?
  - ATP is used for all cell metabolic reactions including but not limited to:
    - Active transport
    - Mitosis
    - Meiosis
    - Endocytosis / Exocytosis
    - Secretions
    - Communication
    - Movement
    - Anabolic / Catabolic reactions

Describe, with the aid of diagrams, the structure of ATP.
- Nucleotide derivative
- Contains
  - 3 Phosphates
  - held by high energy bonds
  - Adenine
  - A nitrogenous base
  - A ribose sugar
  - Which is a pentose (5 carbon) sugar
State that ATP provides the immediate source of energy for biological processes.

- ATP is referred to as the Universal Energy Currency
  - Recognised by every cell
  - Dispatches energy in small quantities
  - Too much would waste energy
  - Too much delivered can be disruptive
  - Heavily recycled within the body (50kg used per day but only have 5g of ATP within our body at any one time)

- Below shows how much energy is released when each bond between the phosphates is hydrolysed
  - ATP + H₂O → ADP + H₂O
    - 30.6 kJ mol⁻¹
  - ADP + H₂O → AMP + H₂O
    - 30.6 kJ mol⁻¹
  - AMP + H₂O → Adenosine
    - 14.2 kJ mol⁻¹

- Below describes the processes of how energy is released and the enzyme involved.
Explain the importance of coenzymes in respiration, with reference to NAD and coenzyme A.

- **Nicotinamide Adenine Dinucleotide (NAD)**
  - Organic, non protein molecule
  - Helps dehydrogenase enzymes to carry out oxidation reactions
  - Contains 2 ribose sugars, 1 nitrogenous base adenine 2 phosphate groups and a nictinamide molecule.
  - When NAD accepts two hydrogen atoms with their electrons it becomes reduced.
  - NAD operates during Glycolysis, the link reaction, Krebs cycle and during the anaerobic ethanol and lactate pathways
  - It then acts as a reducing agent by donating electrons at the inner mitochondrial membrane during oxidative phosphorylation.

- **Co-Enzyme A**
  - Carries ethanoate groups (acetate) made from pyruvate during the link reaction onto the Kreb’s cycle
  - It can also carry acetate groups that have been made from fatty acids or from some amino acids onto Kreb’s cycle

\[ \text{Acetate} + \text{CoA} \rightarrow \text{AcetylCoA} \]
- **Flavin Adenine Dinucleotide**
- Similar to NAD
- When FAD accepts two hydrogen atoms with their electrons it becomes reduced.
- FAD operates during the Krebs cycle.
- It then acts as a reducing agent by donating electrons at the inner mitochondrial membrane during oxidative phosphorylation

Living organisms don’t have much NAD. CoA or FAD in their cells as they are recycled/regenerated.

**Explain, with the aid of diagrams and electron micrographs, how the structure of mitochondria enables them to carry out their functions.**

- **Outer membrane**
  - The outer mitochondrial membrane is smooth
  - Impermeable to H⁺ ions
  - Has pyruvate channels

- **Inner Membrane**
  - Highly folded (cristae) which provides a large surface area
    - A lot of space for embedded proteins (electron carrier proteins and ATPsynth(ase).
  - Impermeable to H⁺ ions

- **Inter membrane Space**
  - Low pH due to build up of H⁺

- **Matrix**
  - Semi-rigid and gel like
  - Contains lots of enzymes for the link reaction and Krebs cycle
  - Contains looped mitochondrial DNA – inherited from the mother and codes for mitochondrial enzymes
  - Mitochondrial ribosomes (structurally the same to prokaryotic ribosomes) – translate the mitochondrial DNA code into enzymes
  - Contains NAD
  - Contains oxaloacetate
Mitochondria Inner Structure

- **Inner Membrane**
- **Outer Membrane**
- **Cristae**
- **Matrix**

**Figure 1**
More active = more mitochondria  
= larger mitochondria  
= more cristae

2 - 5 μm and up to 10 μm in athletes
State that glycolysis takes place in the cytoplasm.

Glycolysis – Cell Cytoplasm
Outline the process of glycolysis, beginning with the phosphorylation of glucose to hexose bisphosphate, splitting of hexose bisphosphate into two triose phosphate molecules and further oxidation to pyruvate, producing a small yield of ATP and reduced NAD.

**Products of Glycolysis per 1 molecule of glucose**

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Amount used</th>
<th>amount made</th>
<th>Net made</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ATP</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>NADH</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Pyruvate</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

- The ATP produced in glycolysis is referred to as substrate level phosphorylation as it is produced as one substrate is changed to another.
State that, during aerobic respiration in animals, pyruvate is actively transported into mitochondria.

- 2 molecules of pyruvate are made in the cytoplasm of the cell from the process of glycolysis.
- Pyruvate is then actively transported into the matrix of the mitochondria.
- Pyruvate then undergoes decarboxylation (removal of a carboxyl group) catalysed by the enzyme pyruvate decarboxylase and also oxidation (the removal of hydrogen) by the enzyme pyruvate dehydrogenase.
- The matrix of the mitochondria cannot act on glucose as it does not have the enzymes specific to respire it.

State that the link reaction takes place in the mitochondrial matrix.

Link Reaction & Krebs cycle
Outline the link reaction, with reference to decarboxylation of pyruvate to acetate and the reduction of NAD.

### Link Reaction - Matrix

Products of the Link reaction per 1 molecule of glucose

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Amount used</th>
<th>amount made</th>
<th>Net made</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyruvate</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ATP</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>NADH</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Acetyl CoA</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Explain that acetate is combined with coenzyme A to be carried to the next stage.

- Pyruvate is decarboxylised and oxidised to create acetate.
- Acetate does not exist by itself.
- It is combined with the CoEnzyme A which enables it to be carried to the next stage which is the Krebs cycle also in the matrix.
State that the Krebs cycle takes place in the mitochondrial matrix.

Outline the Krebs cycle, with reference to the formation of citrate from acetate and oxaloacetate and the reconversion of citrate to oxaloacetate.

Explain that during the Krebs cycle, decarboxylation and dehydrogenation occur, NAD and FAD are reduced and substrate level phosphorylation occurs.
Products of the Krebs per 1 molecule of glucose

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Amount used</th>
<th>amount made</th>
<th>Net made</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetyl Co A</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oxaloacetate</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ATP</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>NADH</td>
<td>0</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>FADH</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Outline the process of oxidative phosphorylation, with reference to the roles of electron carriers, oxygen and the mitochondrial cristae.

Outline the process of chemiosmosis, with reference to the electron transport chain, proton gradients and ATP synthase.

- Oxidative phosphorylation is the phosphorylation of ADP to ATP with the presence of Oxygen
- It takes place at the inner mitochondrial membrane.
- The more cristae the more membrane there is for embedded proteins, therefore the more oxidative phosphorylation, therefore the more ATP produced.
1. NADH becomes oxidise at electron carrier protein 1 giving up Hydrogen.
   - These Hydrogen atoms split into electrons and protons, with the electrons exciting electron carrier protein 1.
   - The excited electron carrier protein pumps the protons into the intermembrane space.

2. FADH becomes oxidise at electron carrier protein 2 giving up Hydrogen.
   - These Hydrogen atoms split into electrons and protons, with the electrons exciting electron carrier protein 2.
   - The protons stay in the mitochondrial matrix and will join with oxygen (the final electron acceptor).

3. The electrons from electron carrier protein 1 combine with those in electron carrier 2 from FADH.
   - The reasons is the electron carrier protein 2 has a stronger affinity for the electrons from electron carrier protein 1.
   - This makes sure that electron carrier protein 1 continues to split hydrogen from NADH.

4. Electron carrier protein 3 has an even stronger affinity for the electrons than electron carrier protein 1 or 2.
   - As electron carrier protein 3 accepts the electrons it becomes excited and pumps protons into the intermembrane space.
4.4.1

- Electron carrier protein 4 has an even stronger affinity for the electrons than electron carrier protein 1, 2 or 3.
- As electron carrier protein 4 accepts the electrons it becomes excited and pumps protons into the intermembrane space.

- Oxygen has the strongest affinity for the electrons than electron carrier protein 1, 2, 3 or 4.
- Oxygen is known as the final electron acceptor.
- The electrons combine with the protons from the hydrogen donated by FAD to form hydrogen at the oxygen forming water.

- The intermembrane space has a build up of protons generate a concentration gradient.
- The protons decrease the pH of the intermembrane space.

- The protons move down their concentration gradient by a process called chemiosmosis.
- As they do so they generate a proton motif force which turns ATP synthetase.

- ATP synthetase phosphorylates ADP to ATP.
State that oxygen is the final electron acceptor in aerobic respiration.

- Oxygen is said to be the final electron acceptor
- It pulls the electrons from electron carrier protein 4 in the electron transport chain
- It also collects the $\text{H}^+$ ions that have moved into the matrix via chemiosmosis.
- The $\text{H}^+$ and $e^-$ recombine to form $\text{H}_2$ and with the oxygen water is formed.
- This is why we must breathe in oxygen and breathe out water vapour.
- ATP production at the inner mitochondrial matrix is called oxidative phosphorylation because it is the phosphorylation of ADP to ATP using the presence of oxygen.

Evaluate the experimental evidence for the theory of chemiosmosis.

- Chemiosmosis is the diffusion of $\text{H}^+$ through a partially permeable membrane.
- It generates a proton motif force which turns the head unit of the enzyme ATPsynth(ase)ase which generates ATP.
- Evidence
  - ATP was not produced if the mushroom shaped head unit of ATPsynth(ase)ase was removed in intact mitochondria
  - ATP was not produced in the presence of Oligomycin, an antibiotic, now known to inhibit the flow of protons through ATPsynth(ase)ase
  - The potential difference was -200mV in the matrix compared to the intermembrane space
  - The intermembrane space had a low pH.
Explain why the theoretical maximum yield of ATP per molecule of glucose is rarely, if ever, achieved in aerobic respiration.

- The theoretical maximum energy yield from glucose is 2870kJ/Mol$^{-1}$
- 1 ATP = 30.6kJ
- Therefore 1 Mol of glucose should yield nearly 94 ATP molecules
- The reality = 30 ATP molecules
- Where is the 60 ATPs worth of energy?
- It is released as thermal energy = maintains a core body temperature thus allowing enzyme-controlled reactions to proceed under optimal conditions

Explain why anaerobic respiration produces a much lower yield of ATP than aerobic respiration.

- Anaerobic respiration occurs when there is no oxygen as the final electron acceptor.
- This means that the electron transport chain slows and stops
- There is no oxidative phosphorylation
- Therefore there is no ATP produced
- No recycling of NAD so the krebs cycle, link reaction stops as they all require NAD.
- This means there is also no substrate level phosphorylation
- Therefore there is no ATP produced
- If only there was a way to at least recycle the NAD we could make a little ATP from substrate level phosphorylation.
- Well this is exactly what happens in anaerobic respiration
- There are two types of anaerobic respiration

- **Lactate fermentation Pathway**
  - Occurs in animals
  - Pyruvate becomes reduced by accepting hydrogen from NADH converting it to lactate.
  - This is catalysed by an enzyme lactate dehydrogenase (as it is reversible)
  - This allows a small amount of NAD to be recycled
  - This allows a small amount of ATP to be produced from substrate level phosphorylation during the final stages of glycolysis
  - 2 ATP molecules are made in stead of the usual 30 per 1 glucose molecule
  - This is reversible and so the full potential of ATP can be realised when oxygen concentration rise again
- **Alcoholic fermentation Pathway**
  - Occurs in fungi and bacteria
  - Pyruvate becomes decarboxylated to ethanal through the removal of a carboxyl group
  - This is catalysed by an enzyme pyruvate decarboxylase
  - Ethanal then becomes reduced by accepting hydrogen from NADH converting it to ethanol.
  - This is catalysed by an enzyme ethanol dehydrogenase (as it is reversible)
  - This allows a small amount of NAD to be recycled
  - This allows a small amount of ATP to be produced from substrate level phosphorylation during the final stages of glycolysis
  - 2 ATP molecules are made instead of the usual 30 per 1 glucose molecule
  - This is not reversible.
Compare and contrast anaerobic respiration in mammals and in yeast.

<table>
<thead>
<tr>
<th></th>
<th>Yeast</th>
<th>Mammals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen acceptor</td>
<td>Ethanol</td>
<td>Pyruvate</td>
</tr>
<tr>
<td>Is carbon dioxide produced</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Is ATP produced</td>
<td>A little</td>
<td>A little</td>
</tr>
<tr>
<td>Is NAD reoxidised</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>End products</td>
<td>Ethanol and carbon dioxide</td>
<td>Lactate</td>
</tr>
<tr>
<td>Enzymes involved</td>
<td>Pyruvate decarboxylase,</td>
<td>Lactate dehydrogenase</td>
</tr>
<tr>
<td></td>
<td>ethanol dehydrogenase</td>
<td></td>
</tr>
</tbody>
</table>

Define the term *respiratory substrate*.

- An organic substance that can be used for respiration
- Carbohydrates is the primary respiratory substrate
- Protein would be regarded as the respiratory substrate that is only used if no others are available = Last resort!!!
- This is because protein is extremely valuable as most of human body is protein.
- Fats and proteins can only be respired under aerobic conditions as they are converted to stages in the link reaction or the krebs cycle and so required oxygen as they can only yield ATP from oxidative phosphorylation.
Explain the difference in relative energy values of carbohydrate, lipid and protein respiratory substrates.

<table>
<thead>
<tr>
<th>Respiratory substrate</th>
<th>Mean value/ kJ g(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate</td>
<td>15.8</td>
</tr>
<tr>
<td>Lipid</td>
<td>39.4</td>
</tr>
<tr>
<td>Protein</td>
<td>17.0</td>
</tr>
</tbody>
</table>

- **Respiration of Fats - Beta-oxidation Pathway**

- Respiration of Proteins = last Resort!!!
  - Excess amino acids undergo deamination as outlined in the excretion unit and then the ornithine cycle.
  - The remainder of the molecule is converted into glycogen or fat.
  - When under extreme starvation, exercise or fasting protein from muscles can be hydrolysed to amino acids and then respired.
  - Amino acids are converted to:
    - Pyruvate and enter the link reaction
    - Acetate and enter the krebs cycle.
Respiratory Quotient (RQ)

\[
RQ = \frac{\text{Volume of carbon dioxide produced}}{\text{Volume of Oxygen consumed}}
\]

Carbohydrates \( RQ = 1.0 \)
Proteins \( RQ = 0.9 \)
Lipids \( RQ = 0.7 \)
1. All organisms require energy in order to remain alive. Plants use solar energy to combine water and carbon dioxide into complex organic molecules. Both plants and animals then break down organic molecules in respiration. Energy released in this process is used in the formation of ATP.

Describe the structure of ATP.
............................................................................................................................................
............................................................................................................................................
............................................................................................................................................
............................................................................................................................................
............................................................................................................................................
............................................................................................................................................
[Total: 4 marks]

2. The figure below is a diagram of a section through a mitochondrion.

In each case, state the letter which indicates the site of:

the Krebs cycle  .................
oxidative phosphorylation  .................
decarboxylation  .................

[Total 3 marks]
3. Aerobic respiration may be summarised by the following equation:

\[ C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \]

Although carbon dioxide and water are products of aerobic respiration, the equation is an over-simplification of the process.

State and explain one way in which this equation is an over-simplification.

...........................................................................................................................................
...........................................................................................................................................
...........................................................................................................................................
...........................................................................................................................................

[Total 2 marks]

4. The following figure is an outline of the glycolytic pathway.

\[ \text{glucose} \rightarrow \text{fructose 1,6 bisphosphate} \rightarrow \text{triose phosphate} \rightarrow \text{pyruvate} \]
With reference to the figure, state the letter, A, B or C, in the glycolytic pathway where the following processes occur.

- phosphorylation using ATP ..........................................
- dehydrogenation .........................................................
- formation of ATP ........................................................
- splitting of a hexose .....................................................

[Total 4 marks]

5. The figure below represents the first stage of respiration.

(i) Name the stage represented by the figure above.

............................................................................................................ [1]
(ii) State precisely where in the cell this stage takes place.

...................................................................................................................................................... [1]

(iii) Identify the compounds D, E and F.

D ..........................................................................................................................................................

E ..........................................................................................................................................................

F ..........................................................................................................................................................

[3]

[Total 5 marks]
6. Below is an outline diagram of the Krebs cycle. A two carbon acetyl group enters the cycle by combining with a molecule of oxaloacetate. A molecule of citrate is formed which is decarboxylated and dehydrogenated to regenerate the oxaloacetate.

(a) (i) Explain the following terms:

   - **decarboxylation** .................................................................
   - **dehydrogenation** .................................................................

(ii) State the letters of the individual steps in the cycle where decarboxylation is taking place.

   ................................................................................................................

(b) ATP is made directly by substrate level phosphorylation in the Krebs cycle.

   State the number of ATP molecules that are made directly **per 'turn'** of the cycle.

   ................................................................................................................
(c) The diagram also shows that fatty acids can be converted into acetyl CoA units by a process known as \( \beta \)-oxidation. Both this process and the Krebs cycle require NAD. The Krebs cycle also requires FAD. The hydrogen atoms released in \( \beta \)-oxidation and the breakdown of acetyl CoA in the Krebs cycle reduce the NAD and FAD molecules.

(i) State the number of reduced NAD and reduced FAD molecules that are formed in the Krebs cycle from one molecule of acetyl CoA.

- reduced NAD
- reduced FAD

(ii) State where the reduced NAD and reduced FAD molecules are reoxidised and describe what happens to the hydrogen atoms.

- ..............................................................
- ..............................................................
- ..............................................................
- ..............................................................
- ..............................................................
- ..............................................................
- ..............................................................
- ..............................................................
- ..............................................................
- ..............................................................
- ..............................................................
- ..............................................................
- ..............................................................
- ..............................................................
- ..............................................................

- [2]
- [4]
(d) The liver is responsible for producing enzymes which detoxify alcohol by breaking it down into smaller units. This breakdown by enzymes uses NAD. This means that other reactions that use NAD are less likely to take place. The build up of fats in the liver is one of the first signs of liver damage due to excessive alcohol intake.

Using the information in the diagram above, explain why the build up of fats occurs in the liver of an individual who consumes large amounts of alcohol.

..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................

[3]  
[Total: 13 marks]
7. **In anaerobic** conditions, compound F does not proceed to the link reaction.

Describe the fate of compound F during anaerobic respiration in an animal cell and explain the importance of this reaction.

............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................
............................................................................................................................................................

[Total 5 marks]
8. Below is a diagram of a respirometer. A respirometer can be used to measure the oxygen uptake of living organisms.

Describe how the apparatus shown in the diagram could be used to determine the rate of respiration of the bread mould, *Mucor*.

................................................................................................................................................
................................................................................................................................................
................................................................................................................................................
................................................................................................................................................
................................................................................................................................................
................................................................................................................................................
................................................................................................................................................
................................................................................................................................................
................................................................................................................................................
[Total 4 marks]