Bio Factsheet

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Answering Exam Questions on Respiration

For the exam you need to be able to:

- Define the term respiration
- Describe what happens at each stage and know where they occur
- Interpret diagrams showing the stages
- Apply your knowledge of these basics to explain what is happening when a person sprints or gets cramp, for example. Year after year, examiners complain that students do not understand anaerobic respiration as well as they do aerobic.

All of the basic facts were outlined in Factsheet 12. This Factsheet concentrates on the 4 bullet points above and the types of questions that keep coming up.

Do you have any misconceptions? Here are recent comments from Chief Examiners:

- *A surprisingly large number of candidates thought that oxygen, carbon dioxide and water could be respiratory substrates.*
- *Candidates should note that mitochondria release energy during respiration rather than creating it.*
- *A common misconception is that water is used in respiration.*
- *It was not unusual to find candidates describing the passage of hydrogen or hydrogen ions down the electron transport chain.*
- *Respiration was often considered not to be necessary at rest;*

Respiration is the process by which energy is released from organic molecules. The energy is then available for all the processes that need it in a living organism.

The usual substrate (the organic substance from which energy is released) is glucose, although fats, amino acids and other substrates can be used if necessary.

The energy which is released is stored - in the short term - in molecules of ATP.

Typical Exam Question

What are the advantages of ATP as an energy storage molecule? (2 marks)

In other words: Why store energy in ATP, why not just use glucose?

Here is the actual markscheme:

ATP cannot pass out of cell;
Quickly/easily broken down (hydrolysed) / broken down in a one-step reaction / immediate source of energy;
Stores / releases small amounts of energy;
Do not credit producing energy. max 2

Each semicolon (;) indicates a separate mark. Obliques (/) indicate alternatives. So if you wrote:
" it's quick to break down, you can get the energy out immediately" **you'd end up with one mark, not two.**
The point here is that you should always try to say one more thing than there are marks and try to make quite different points rather than the same one twice.

Note how short and sharp the markscheme is –the examiners are looking for key terms & short phrases – don't waste time waffling. Finally, note the phrase they definitely won't give you a mark for **"producing/making energy"** You can't produce energy, only convert it from one form to another.

Here's the Chief Examiner's comments on student answers to this question:

Although most candidates knew that ATP is readily hydrolysed, fewer were able to give a second advantage, although good candidates knew that the energy is released in small amounts and that the molecule cannot pass out of a cell.

Glucose v ATP

One mole of glucose releases 2880 kJ of energy when burned completely in oxygen. Hydrolysis of one mole of ATP to ADP and phosphate releases 31 kJ of energy. Thus, the small "packets" of energy released from ATP make it an ideal short-term energy storage molecule.

The process of respiration can occur with oxygen (aerobic) or without oxygen (anaerobic). Aerobic respiration releases a lot more ATP than anaerobic.

In fact, for every glucose molecule which is broken down, aerobic respiration produces nineteen times as much ATP than anaerobic respiration.

Aerobic respiration

Aerobic respiration can be divided into four stages:
1. Glycolysis (G)
2. The Link reaction (LR)
3. Krebs cycle (K)
4. The electron transfer chain (ETC)

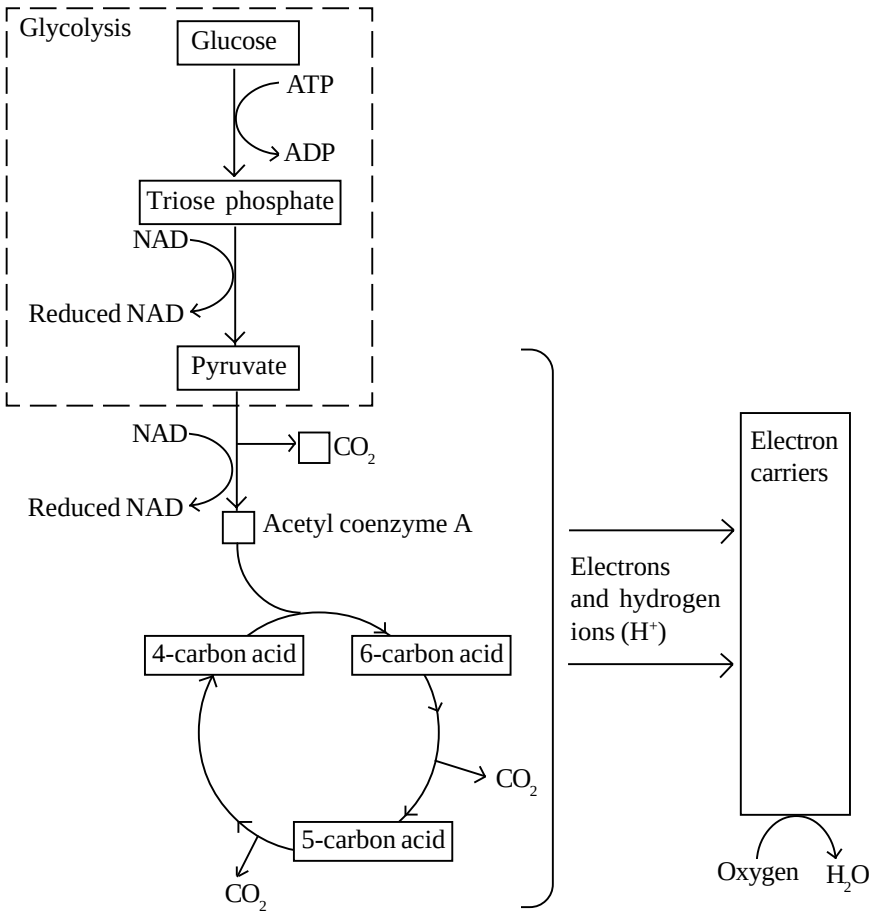
These take place in different parts of the cell (Table 1). You must learn all these facts.

Table 1. Summary box of cellular respiration

Stage	Site	Oxygen Needed?	What Happens?
Glycolysis	Cytoplasm	No	Glucose is converted to pyruvic acid. Hydrogen is removed and is passed to the electron carriers.
Link Reaction	Matrix of Mitochondria	Yes	Pyruvate enters mitochondrion, is decarboxylated, dehydrogenated and combines with coenzyme A to give acetyl coenzyme A. The hydrogen which is removed is passed to the electron carriers.
Kreb's Cycle	Matrix of Mitochondria	Yes	A cyclical series of reactions during which hydrogen is passed to the electron carriers, carbon dioxide is removed and the starting reagents are regenerated.
ETC.	Crista of Inner Membrane of Mitochondria	Yes	The hydrogen from glycolysis and Kreb's cycle is split to release electrons. These pass through carriers and generate ATP. The hydrogen reforms and is combined with oxygen to release water.

Typical Exam Questions ask you to label diagrams of these stages

Make sure that you can draw this out from memory in seconds! **Fig 1**



Typical Questions:

1. Mark on the diagram one stage where ATP is used/produced. The initial conversion of glucose to triose phosphate actually uses ATP – ironic, you might think, given that the whole point of respiration is to *produce* ATP. But the addition of phosphate to glucose (its phosphorylation) increases its reactivity, so making the first stage of glycolysis faster. ATP is produced in glycolysis, Krebs and the electron transfer chain (ETC).

2. The CO_2 and the Acetyl coenzyme A might be marked on with letters –X and Y – and you have to identify them.

3. What happens to the electrons and hydrogen ions at the end of the ETC? (they are converted into water).

4. Why can't Krebs and the ETC occur if there is no oxygen? (without oxygen there would be no way of disposing of the hydrogen ions –these would lower the pH, possibly denaturing enzymes).

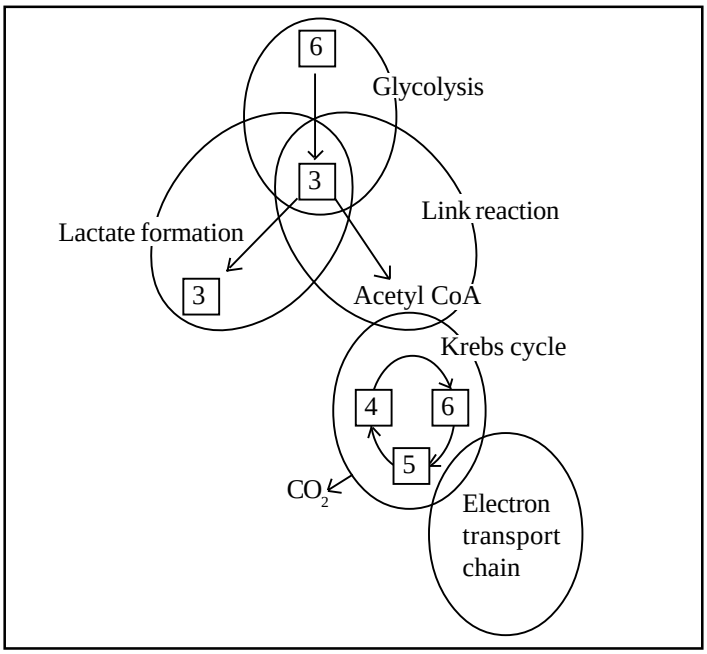
5. What might the ATP be used for in a named cell – eg liver cell? (protein synthesis, DNA synthesis, glycogen synthesis, active transport, cell division, mitosis).

Extract: Chief Examiner's Report
In describing the fate of the electrons and hydrogen ions released from the electron transfer system, many insisted on giving irrelevant details about oxidative phosphorylation and electron transfer

The stages of respiration can be shown in many ways. Examiners sometimes use unusual diagrams to test that you haven't simply memorised a common diagram but haven't really got a clue what is going on!

Fig 2 summarises the stages of respiration in an animal cell. The boxes show the number of carbon atoms in various molecules or ions.

Fig 2. Stages of respiration



Typically, you might be asked to write in the number of carbon atoms in the boxes, show where ATP or CO_2 is produced and identify some of the molecules such as pyruvate or acetyl coenzyme A.

Extract: Chief Examiner's report
"While most candidates were able to identify acetyl coenzyme A, a significant minority thought it was acetylcholine"

Know your oxidation & reduction

Learn the following definitions:

- Oxidation is the addition of oxygen or the loss of hydrogen or electrons
- Reduction is the loss of oxygen or the addition of hydrogen or electons

Try to use these terms in your answers, they may get you quick marks.

Typical Exam Question

Describe how oxidation takes place in glycolysis and in the Krebs cycle.

Answer

removal of hydrogen/dehydrogenation;
by enzymes/dehydrogenases;
H accepted by NAD/reduced NAD formed;
in Krebs cycle, FAD (used as well);

Mention the enzymes: as well as dehydrogenase enzymes (to remove the hydrogen) there must also be decarboxylase enzymes in Krebs (to remove the CO_2). These enzymes are proteins and that is why, in cells that are adapted for rapid respiration, we see lots of ribosomes. Synoptic questions like to test your ability to link topics like cell structure, enzymes and metabolism.

Anaerobic respiration

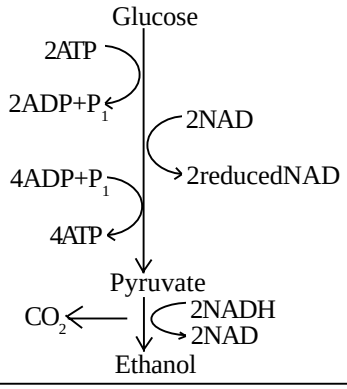
In the exam you may be asked about what happens during anaerobic respiration in yeast cells and in mammalian cells.

In anaerobic respiration glucose is broken down into pyruvate. Without oxygen being available, the pyruvate cannot be broken down any further and it cannot enter the Link Reaction. What happens next to the pyruvate depends upon the organism:

1. In yeast, pyruvate is decarboxylated to produce ethanal. Ethanal then accepts the hydrogen from NAD and forms ethanol. This releases the NAD to be reused in glycolysis. The conversion of pyruvic acid to ethanol with the release of carbon dioxide is called **alcoholic fermentation**.
2. In mammals, the pyruvate accepts the hydrogen from NAD and is reduced to lactate. The NAD is then available for further use in glycolysis. If oxygen later becomes available, the lactate is reoxidised. Since anaerobic respiration only involves glycolysis, only the 2 ATP produced in glycolysis are formed.

Fig 3 summarises the process of anaerobic respiration in yeast cells.

Fig 3



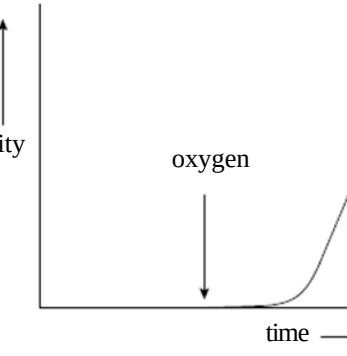
Typically, exam questions might ask you to:

- Calculate the net yield of ATP from this process. You can see that 2 molecules were used up and that 4 were produced; hence the net yield is 2 molecules;
- Describe how NAD is regenerated in anaerobic respiration in yeast cells. The reduced NAD (ie the NAD with hydrogen attached) donates H ions to pyruvate. This reduces the pyruvate and forms ethanol;

Now that we understand aerobic and anaerobic respiration we can look at Questions that ask you to think about both at the same time!

Animal cells are added to a flask that contains a culture medium containing glucose labelled with radioactive carbon atoms. Initially, conditions in the flask are anaerobic. Later, oxygen is bubbled through the medium. Samples of gas produced by the cells were tested for radioactivity at regular intervals. The results are shown in Fig 4.

Fig 4



Typically you will be asked to explain these results

The first thing to do is look closely at the graph. No gas was given off and no radioactivity was detected until oxygen was added. What were the cells doing before oxygen was added?

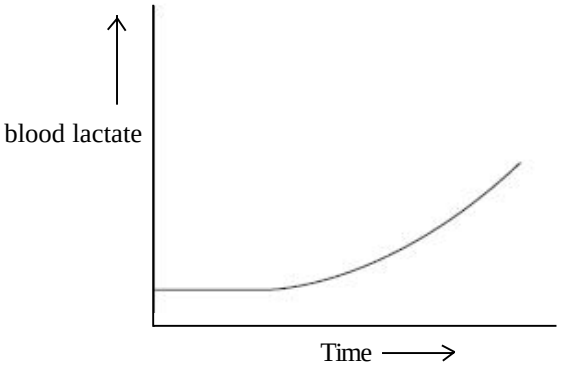
They were respiring anaerobically. When oxygen was added, the Link Reaction and Krebs cycle could begin. During the Link Reaction and Krebs CO_2 is released and this was radioactive as the C in the CO_2 came from the radioactive glucose.

Extract: Chief Examiner's report

Many candidates wrongly stated that respiration could not take place until oxygen was present. Better candidates appreciated that glycolysis occurs in the absence of oxygen but does not produce carbon dioxide.

Practice Questions

1. A student ran on a treadmill at a constant speed. The concentration of lactate in her blood was measured at regular intervals. The graph shows the results.



   (a) Explain the shape of the curve (3)
   (b) What happens to the lactate when she stopped running?(2)

2. A sprinter is exhausted after running a 100 m sprint. A marathon runner is exhausted after running for 4 hours in a marathon.
   (a) State the process by which each runner obtains their ATP
      (i) Sprinter (ii) Marathon runner:
   (b) Explain why each runner experiences muscle fatigue.
      (i) Sprinter (ii) Marathon runner
   (c) Outline how an athlete may develop an oxygen debt (3)

3. Outline the process of the anaerobic breakdown of glucose in yeast. (4)

4. (a) When glucose is respired what happens to the energy which is not incorporated into ATP? (1)
   (b) Water is a waste product of aerobic respiration. Describe how water is formed at the end of aerobic respiration. (2)
   (c) Each mole of glucose respired aerobically produces 38 moles of ATP. When one mole of glucose is respired anaerobically, only 2 moles of ATP are produced. Explain why less energy is released in anaerobic respiration (1)
   (d) Explain why a world-class sprinter does not need to breathe in during a 100 m sprint. (1)

Answers

1. (a) high energy requirement/ATP required;
   not enough oxygen for aerobic respiration;
   anaerobic respiration occurs;
   which produces lactate;
   lactate/curve rises as oxygen debt increases;
   (b) lactate is oxidised / converted to pyruvate;
   broken down to release energy/glucose/glycogen synthesised;
   in liver/muscles;

Athletes

Often, the examiners will test your knowledge of anaerobic respiration in questions about muscles, exercise and athletes.

Typical Exam Question

Human skeletal muscle can respire both aerobically and anaerobically. Describe what happens to pyruvate in anaerobic conditions.

Answer

- It is reduced by hydrogen supplied by reduced NAD and converted into lactate
- This "frees up" NAD allowing glycolysis to continue
- This lactate (or lactic acid) causes pain
- The lactate is a potential source of energy
- It is taken to the liver
- In the liver some of it is converted back into glucose
- This conversion requires oxygen (ie the lactate is oxidised)
- This is why you carry on breathing hard after you stop vigorous exercise
- Your body is getting the extra oxygen it needs to convert the lactic acid
- This shortfall of oxygen is known as the oxygen debt.

Extract: Chief Examiner's report

Candidates were frequently confused. Many did not restrict their answer to human skeletal muscle, as required – hence, 'alcohol' and 'carbon dioxide' were often given as the products of anaerobic respiration. Better candidates knew that NAD was used up in glycolysis and that it could be regenerated from reduced NAD by reducing pyruvate to lactate, thus enabling glycolysis to continue. Many did realise that anaerobic respiration meant that at least some energy could be released even if oxygen were in short supply.

Many candidates did not appreciate that lactate represents a valuable energy resource. Many merely referred to the lactate being 'got rid of', or suggested that it was 'hydrolysed', often confusing this with the formation of hydrogen ions.

2. (a) (i) *sprinter*: anaerobic respiration;
      (ii) marathon runner: aerobic respiration;
   (b) (i) lactic acid accumulates in the sprinter;
      (ii) the carbohydrate stores are depleted in the muscles of the marathon runner;
   (c) lactic acid is produced from pyruvate during anaerobic respiration;
   oxygen debt is the oxygen needed to break down the lactic acid in the liver;
   continued deep breathing is needed after exercise to replace the oxygen;
   lactic acid is converted to pyruvate in the liver;
3 glycolysis produces pyruvate;
   pyruvate is decarboxylated to produce ethanal.
   ethanal then accepts the hydrogen from NAD and forms ethanol;
   This releases the NAD to be reused in glycolysis;
   The conversion of pyruvic acid to ethanol = alcoholic fermentation;
4 (a) converted into heat;
   (b) oxygen is terminal/final electron acceptor;
      combines with electron and hydrogen (to form water);
   (c) glucose only partly broken down / only broken down to lactate;
   (d) Almost all energy required can be obtained from anaerobic respiration;

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