Energy and respiration (chapter 12):

- Energy in living organisms needed for:
  - Anabolic reactions:
    - Protein synthesis / DNA replication / glycogenesis / polymerisation
  - Cellular work:
    - Active transport / movement of chromosomes / sliding filaments / movement of vesicles
  - Movement
  - Maintenance of body temperature in endotherms
- Glucose is stable due to its activation energy – lowered by enzymes and raising the energy level of glucose by phosphorylation

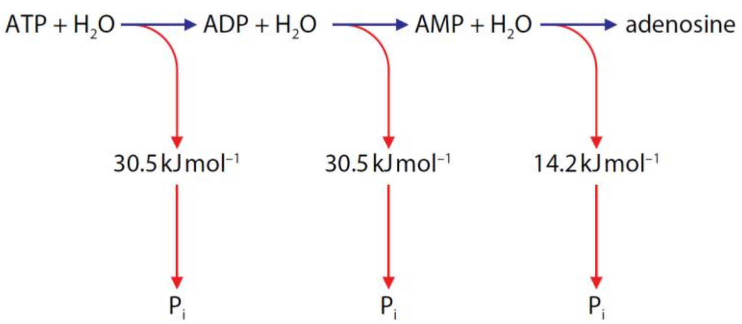


Figure 12.4 Hydrolysis of ATP (P_i is inorganic phosphate, H_3PO_4).

- These reactions are all reversible; the interconversion of ATP and ADP is given by:

$$ATP + H_2O \rightleftharpoons ADP + H_3PO_4 \pm 30.5\,kJ$$

- Features of ATP that make it suitable as the universal energy currency:
  - Loss of phosphate / hydrolysis, leads to energy release
  - Small packets of energy
  - Small / water-soluble, so can move around cell
  - Immediate energy donor
  - Acts as link between energy-yielding and energy-requiring reactions
  - High turnover
- Excess energy during transfer and reactions are converted into thermal energy

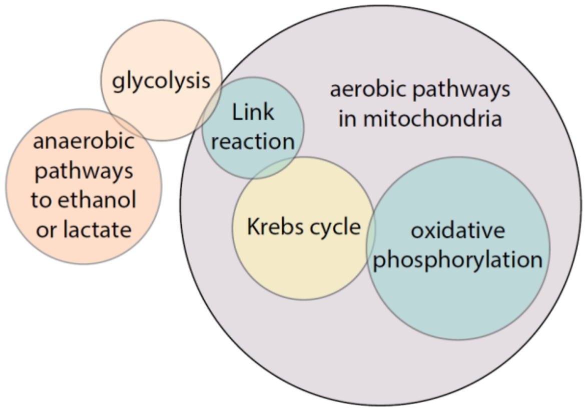


Figure 12.7 The sequence of events in respiration.

- Four stages in aerobic respiration:
- ❖ Glycolysis – cytoplasm:

- Glucose phosphorylated by ATP
- Raises energy level / overcomes activation energy to form fructose bisphosphate
- Lysis / splitting of glucose / hexose
- Breaks down to two TP (triose phosphate)
- 6C (hexose bisphosphate) into 2 × 3C (triose phosphate) which is then dehydrogenated; hydrogen transferred to NAD
- 2 reduced NAD formed from each TP
- 4 ATP produced; final net gain of 2 ATP
- Pyruvate produced

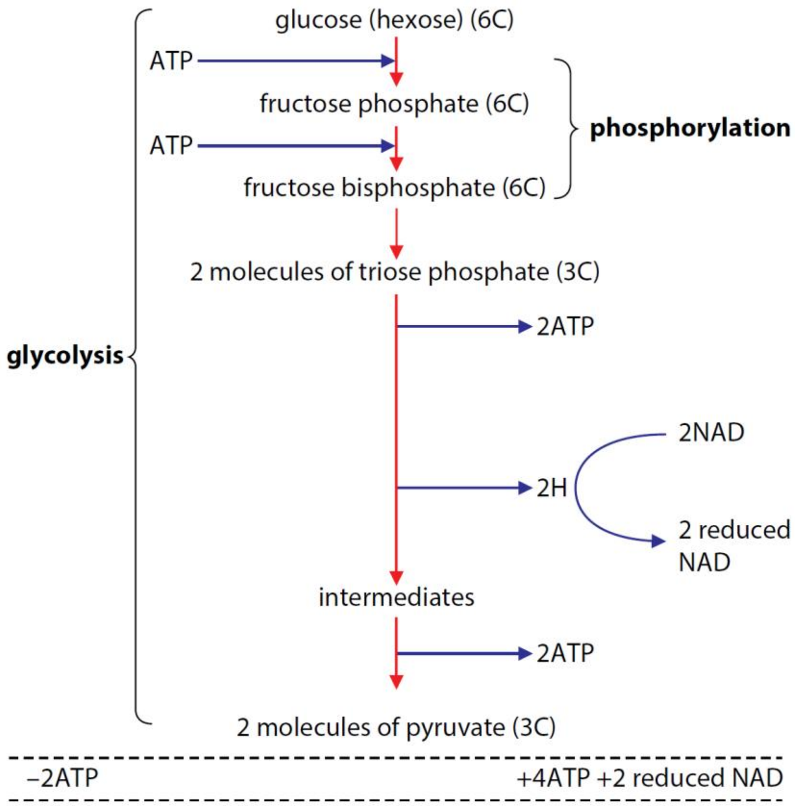


Figure 12.8 The glycolytic pathway.

- Link reaction – mitochondrial matrix:
  - Pyruvate passes by active transport from the cytoplasm through the outer and inner membranes of a mitochondrion
  - Undergoes decarboxylation, dehydrogenation (hydrogen transferred to NAD) and combined with coenzyme A (CoA) to give acetyl coenzyme A
  - Role of CoA:
    - Combines with acetyl group in the link reaction
    - Delivers acetyl group to the Krebs cycle
    - Acetyl group combines with oxaloacetate

$$\text{pyruvate} + \text{CoA} + \text{NAD} \rightleftharpoons \text{acetyl CoA} + CO_2 + \text{reduced NAD}$$

- Krebs cycle – mitochondrial matrix:
  - Reactions are catalysed by enzymes
  - Acetyl CoA combines with a four-carbon compound (oxaloacetate) to form a six-carbon compound (citrate)

- Citrate is decarboxylated and dehydrogenated – through intermediate compounds – to yield CO_2 (waste gas) and hydrogens are accepted by hydrogen carriers (NAD and FAD) to form reduced NAD and reduced FAD
- Oxaloacetate is regenerated to combine with another acetyl CoA
- Two CO_2 are produced
- One FAD and three NAD molecules are reduced
- One ATP molecule is generated (substrate-level phosphorylation)

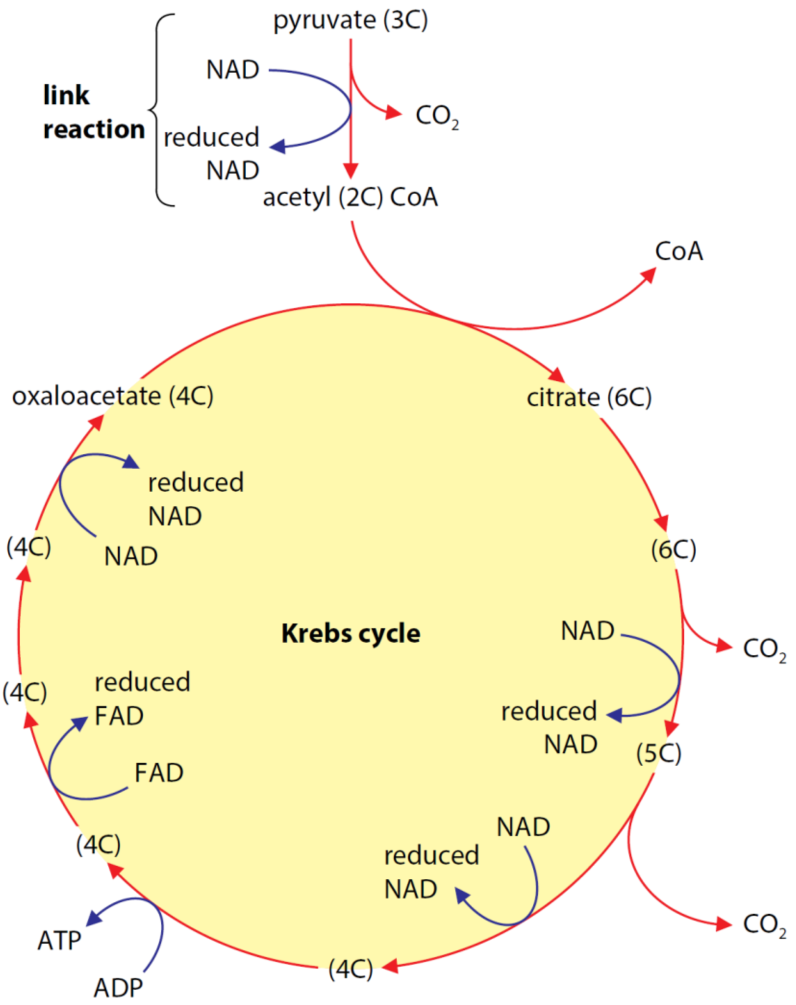


Figure 12.9 The link reaction and the Krebs cycle.

❖ Oxidative phosphorylation – inner mitochondrial membrane:
- Reduced NAD / FAD are passed to the electron transport chain (ETC) on the inner membrane of the mitochondria (cristae)
- Hydrogen released from reduced NAD / FAD and splits into electron and proton
- Electrons are passed along the electron carriers on the ETC
- Energy released from the electrons, pumps protons into the intermembrane space
- Proton gradient is set up
- Protons diffuse back through the membrane – through ATP synthase – down the potential gradient
- Oxygen acts as the final electron acceptor; acts as proton acceptor to form water; allows ETC to continue and ATP to be produced

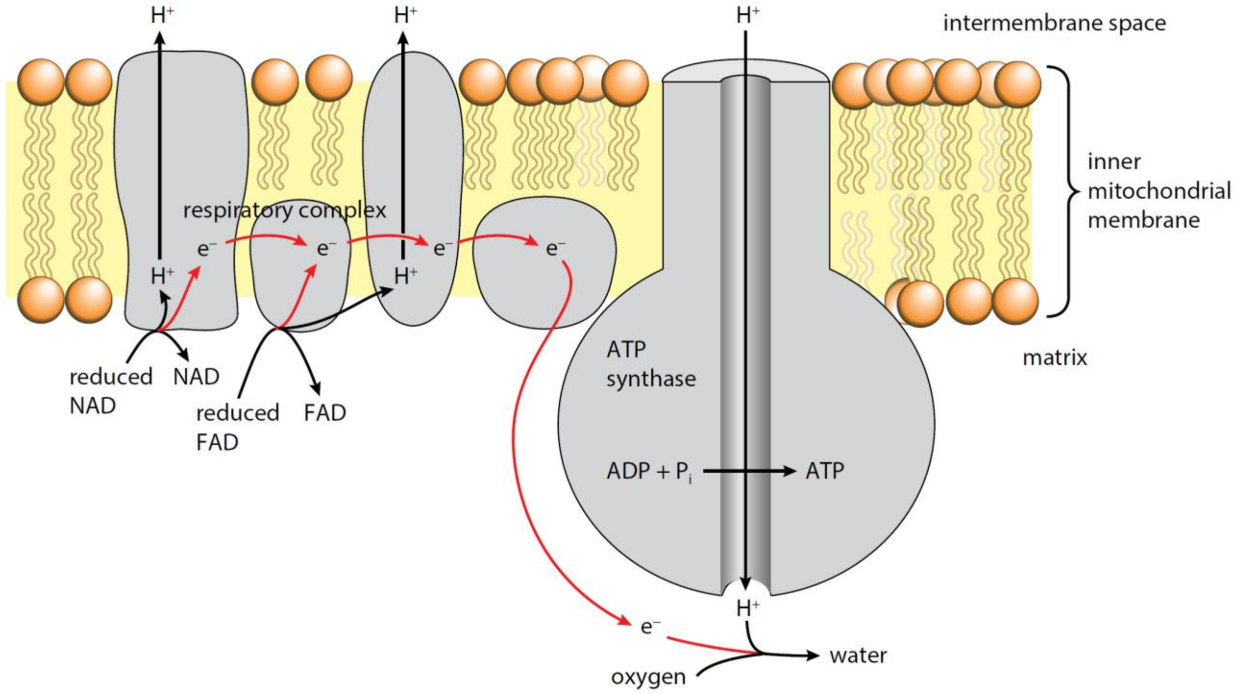


Figure 12.10 Oxidative phosphorylation: the electron transport chain.

	ATP used	ATP made	Net gain in ATP
glycolysis	−2	4	+2
link reaction	0	0	0
Krebs cycle	0	2	+2
oxidative phosphorylation	0	28	+28
Total	**−2**	**34**	**+32**

Table 12.1 Balance sheet of ATP use and synthesis for each molecule of glucose entering respiration.

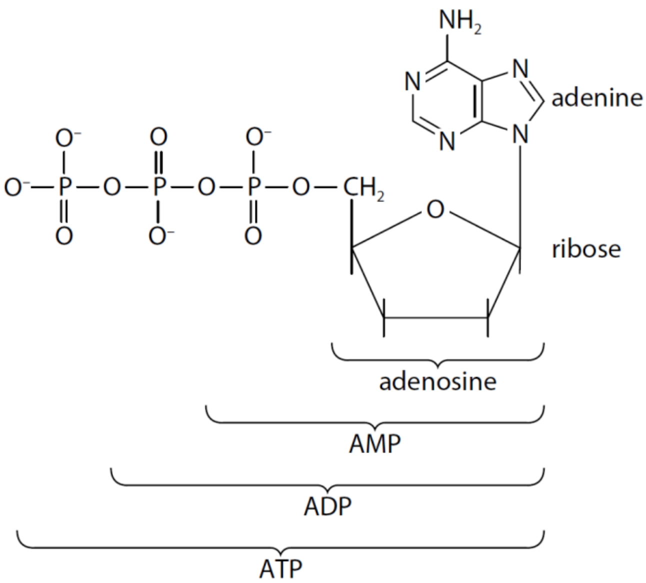
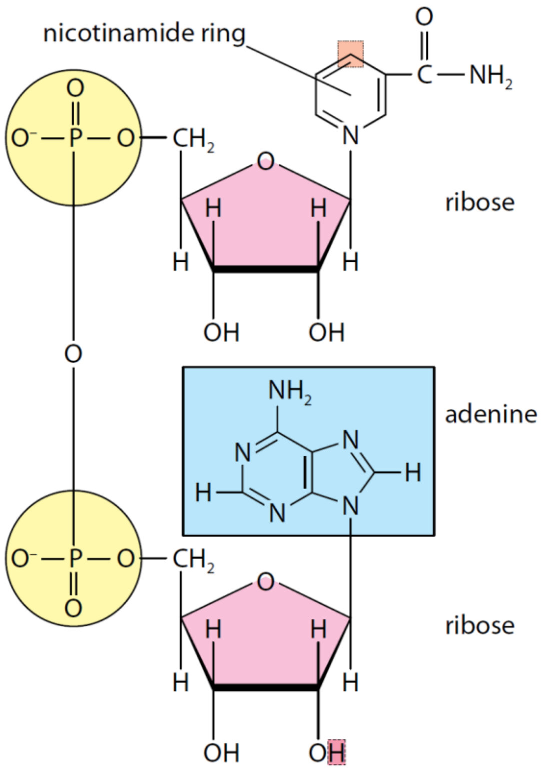


Figure 6.4 Structure of ATP.



Key

replaced by a phosphate group in NADP

site which accepts electrons

Figure 12.12 NAD (nicotinamide adenine dinucleotide).

- Comparison between the structures of ATP and NAD:
  - Both have ribose sugars
  - ATP has 1 ribose, while NAD has 2
  - Both have adenine base
  - NAD has nicotinamide base
  - ATP has three phosphates
- Function of NAD in the cytoplasm of a cell:
  - Acts as a hydrogen carrier
  - Acts as a coenzyme / enables dehydrogenases to work
  - Used in glycolysis / anaerobic respirations
- Anaerobic respiration:
- ❖ Alcoholic fermentation (conversion of glucose to ethanol):
  - In various microorganisms (e.g. yeast) and in some plant tissues
  - The hydrogen from reduced NAD is passed to ethanol (CH_3CHO); releasing the NAD and allows glycolysis to continue
  - Pyruvate is decarboxylated into ethanal, which gets reduced to ethanol (C_2H_5OH) by the enzyme ethanol dehydrogenase
  - Irreversible reaction
  - NAD regenerated, hence glycolysis can continue
- ❖ Lactic fermentation (conversion of glucose to lactate):
  - In mammalian muscles when deprived of oxygen
  - Pyruvate and reduced NAD formed by glycolysis
  - Pyruvate is decarboxylated by pyruvate decarboxylase into ethanal – which acts as a hydrogen acceptor from reduced NAD
  - NAD regenerated, hence glycolysis can continue
  - Reversible reaction

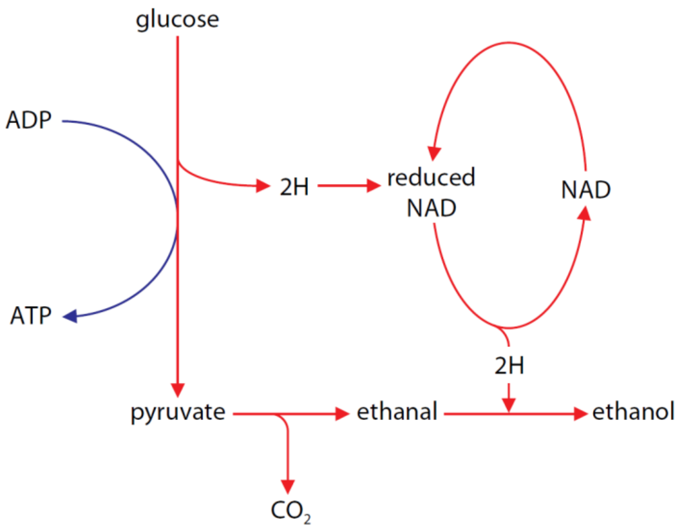


Figure 12.15 Alcoholic fermentation.

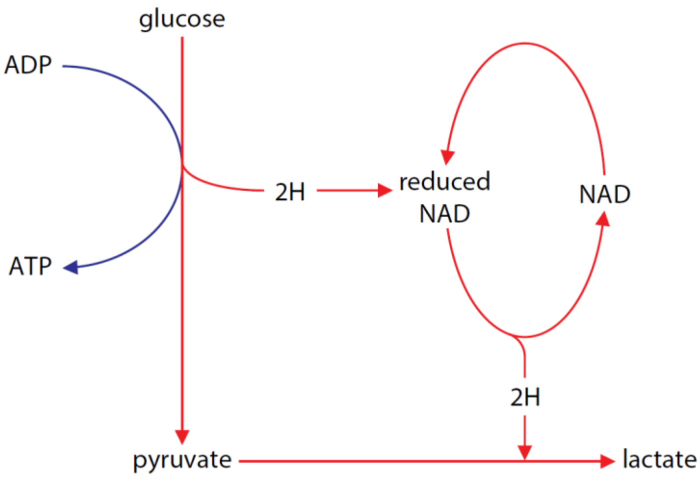


Figure 12.16 Lactic fermentation.

- The structure of the mitochondrion is related to its function:
  - Double membrane
  - Inner membrane is folded / cristae has a large surface area; has ATP synthase / stalked particles; has carrier proteins / cytochromes for the site of ETC / chemiosmosis
  - Mitochondrial matrix contains enzymes; is the site of link reaction and the Krebs cycle

- Outer membrane has protein carriers for pyruvate and reduced NAD
- Intermembrane space has low pH due to high concentration of protons from ETC, creating a proton gradient between intermembrane space and matrix, resulting to the synthesis of ATP

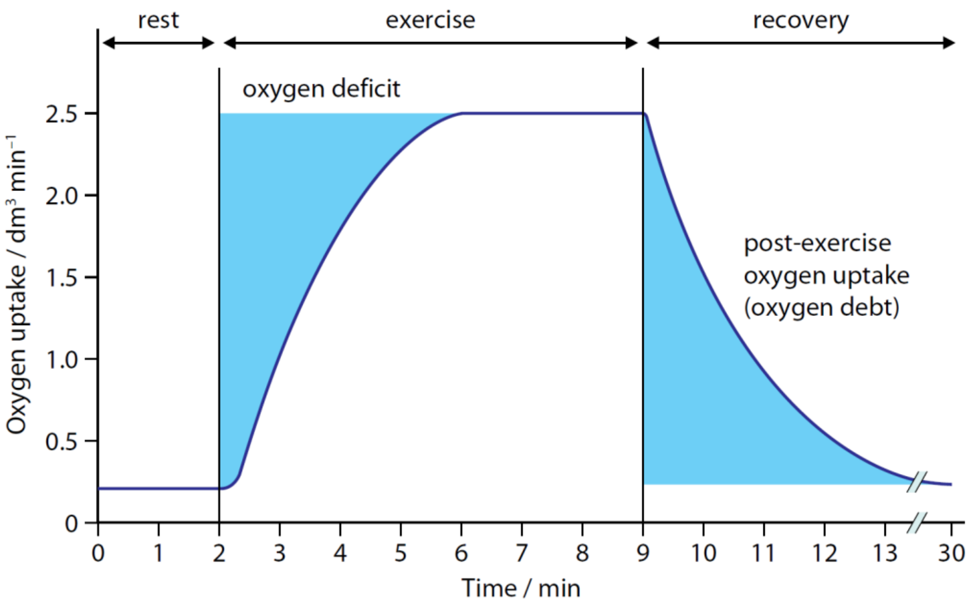


Figure 12.17 Oxygen uptake before, during and after strenuous exercise.

- The post-exercise uptake of extra oxygen is called the oxygen debt
- Respiratory substrates:
- Most energy liberated in aerobic respiration comes from the oxidation of hydrogen to water, hence the greater the number of hydrogens in the structure the greater the energy value
- The energy value of a substrate us determined by burning a known mass of the substance in oxygen in a **calorimeter**, where the energy liberated can be determined from the rise in temperature of a known mass of water in the calorimeter

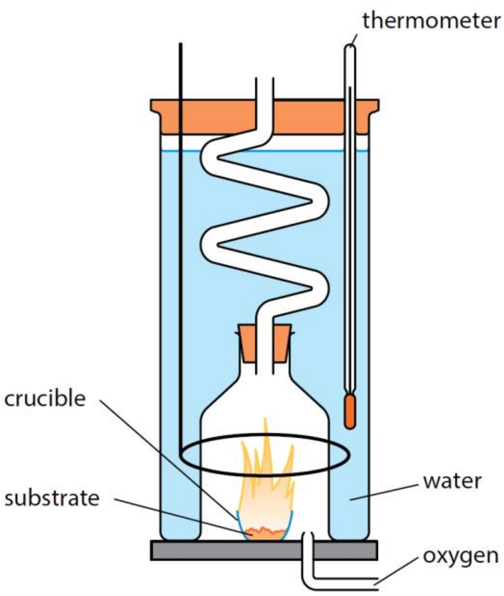


Figure 12.18 A simple calorimeter in which the energy value of a respiratory substrate can be measured.

- Typical energy values:

Respiratory substrate	Energy density / kJ g^{-1}
carbohydrate	15.8
lipid	39.4
protein	17.0

- Lipids have a higher energy value than carbohydrates due to the higher number of C-H bonds, hence yields more reduced NAD, so produces more ATP per gram, thus more aerobic respiration / oxidative phosphorylation / chemiosmosis; fats can only be broken down aerobically
- Respiratory quotient:
  - Shows the substrate used in respiration and whether or not anaerobic respiration is occurring
  - Step:
    - Ratio of volume or moles of CO2 produced to O2 in the same time

$$RQ = \frac{\text{volume of carbon dioxide given out in unit time}}{\text{volume of oxygen taken in in unit time}}$$

$$RQ = \frac{\text{moles or molecules of carbon dioxide given out}}{\text{moles or molecules of oxygen taken in}}$$

- For the aerobic respiration of glucose:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

$$RQ = \frac{CO_2}{O_2} = \frac{6}{6} = 1.0$$

- For the aerobic respiration of fatty acid oleic acid:

$$C_{18}H_{34}O_2 + 25.5O_2 \rightarrow 18CO_2 + 17H_2O + \text{energy}$$

$$RQ = \frac{CO_2}{O_2} = \frac{18}{25.5} = 0.7$$

- Typical respiratory quotients for the aerobic respiration of different substrates:

Respiratory substrate	Respiratory quotient (RQ)
carbohydrate	1.0
lipid	0.7
protein	0.9

- For anaerobic respiration (e.g. alcoholic fermentation):

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + \text{energy}$$

$$RQ = \frac{CO_2}{O_2} = \frac{2}{0} = \infty$$

- Or yields a high value (> 1.0), as some of the respiration might still be aerobic
- No RQ can be calculated for muscle cells using lactate pathway, as no CO_2 is produced:

$$\text{glucose } (C_6H_{12}O_6) \rightarrow 2 \text{ lactic acid } (C_3H_6O_3) + \text{energy}$$

- E.g. question:

An investigation into the RQ values of germinating maize seeds was carried out.

- A sample of maize seeds was soaked in water for one hour.
- The mean RQ value of some of the seeds was then calculated and the remaining seeds were then planted in soil.
- After 12 hours, the mean RQ value of some of the planted seeds was calculated.
- The remaining seeds were allowed to germinate and grow into seedlings.
- After 21 days, the mean RQ value of some of the seedlings was calculated.

Table 7.2 shows the results of the investigation.

Table 7.2

stage of germination and growth	mean RQ
seeds soaked in water	5.6
seeds after 12 hours in the soil	0.8
seedlings after 21 days	1.0

Suggest an explanation for each of the RQ values shown in Table 7.2.

seeds soaked in water

1 little / no, oxygen (in water) ;

2 (mostly) anaerobic respiration ;

seeds after 12 hours in the soil

3 (more) aerobic respiration / less anaerobic respiration ;

4 mixture of substrates ; e.g. 2 of carbohydrates, proteins and lipids

seedlings after 21 days

5 aerobic respiration ;

6 substrate is, glucose / carbohydrate ;

7 ref. to presence of leaves / photosynthesis ; [max 6]

The pH of the blood of an athlete decreases during a race and returns to its normal level after the race. The decrease in the pH of the blood is caused by the presence of waste products that have been excreted by cells during respiration.

Name the waste products that are excreted **and** describe what occurs to these products to help return the pH of the blood back to a normal level.

....

1. lactate (produced) ; **A** lactic acid
2. (lactate) taken to liver ;
3. converted to pyruvate ;
4. (pyruvate) converted to, glucose / glycogen ;
5. carbon dioxide (produced) ;
6. *ref. to* carbon dioxide / pH, receptors ;
7. (carbon dioxide) goes into alveoli ;
8. increased breathing (rate) ;
9. *ref. to* haemoglobin acts as a buffer for carbon dioxide ;

max 5

- The respiration of glucose in anaerobic conditions – oxygen is not available as a final electron acceptor, hence oxidative phosphorylation on the ETC, where most ATP are produced – produces less ATP than in aerobic conditions as only glycolysis (substrate-linked phosphorylation) occurs (only produces a net gain of 2 ATP); pyruvate converted to lactate which is energy rich
- Oxygen debt is needed to convert lactate to pyruvate in the liver cells, re-oxygenate haemoglobin, and to meet demands of continued increased in metabolic rate
- Adaptations of rice to grow with its roots submerged in water in terms of tolerance to ethanol from respiration in anaerobic conditions and the presence of aerenchyma:
  - Aerenchyma in stem and roots which help oxygen to, move / diffuse, to the roots ;
  - Shallow roots
  - Air film trapped on underwater leaves
  - Has fast internode growth
  - Modified growth regulated by gibberellin
  - Anaerobic respiration underwater
  - Tolerance to high ethanol concentration
  - Ethanol dehydrogenase switched on in anaerobic conditions
  - Carbohydrates conserved
- Respirometers:
  - To measure rate of oxygen consumption during respiration
  - CO_2 produced absorbed by concentrated solution of KOH / NaOH
  - Oxygen consumption in unit time read through the level of the manometer fluid against the scale, decrease or increase
  - Changes in temperature and pressure alter the volume of air in the apparatus, hence needed to be kept constant (e.g. electronic water bath & a control tube – with equal volume of inert material to the volume of the organisms to compensate for changes in pressure)
  - Can be used to measure the RQ of an organism done by noting down the found oxygen consumptions; set up with the same controls, but with no CO_2 absorbing chemicals
- DCPIP / methylene blue – investigating the rate of respiration using a redox dye:

- Turns from blue to colourless; the rate of change from blue to colourless is a measure of the rate of respiration; can be used to investigate effects of temperature / different substrate concentrations

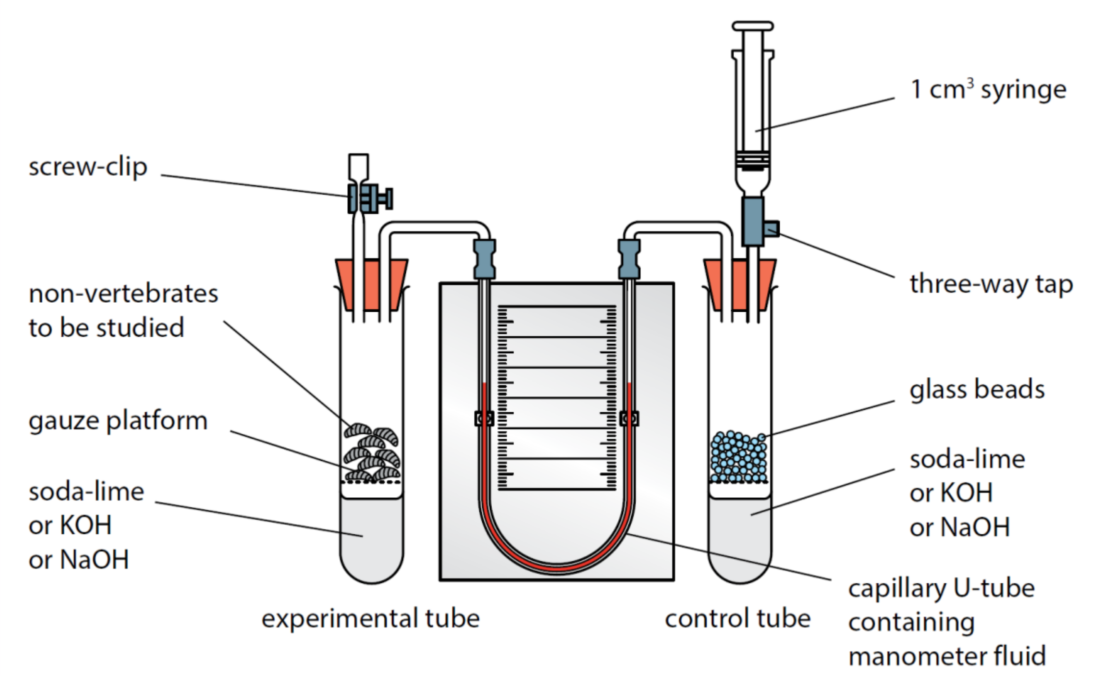


Figure 12.19 A respirometer.