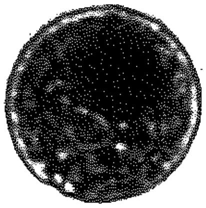
Key idea: Food chains can be put together to form food webs. The complexity of a food web depends on the number of foods chains and trophic levels involved.

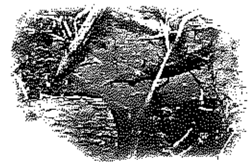
Species are assigned to trophic levels on the basis of their sources of nutrition, with the first trophic level (the producers), ultimately supporting all other (consumer) levels. Consumers are ranked according to the trophic level they occupy, although some consumers may feed at several different trophic levels. In the example of a lake ecosystem below, your task is assemble the organisms into a food web in a way that illustrates their trophic status and their relative trophic position(s).

Feeding Requirements of Lake Organisms



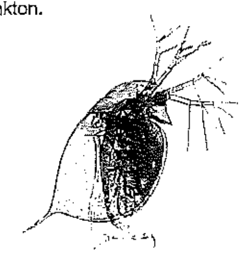
Autotrophic protists
Chlamydomonas (above), *Euglena*
Two of the many genera that form the phytoplankton.

Macrophytes (various species)
A variety of flowering aquatic plants are adapted for being submerged, free-floating, or growing at the lake margin.

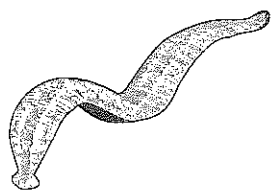


Detritus
Decaying organic matter from within the lake itself or it may be washed in from the lake margins.

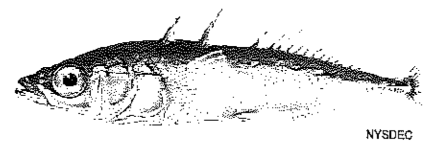
Asplanchna (planktonic rotifer)
A large, carnivorous rotifer that feeds on protozoa and young zooplankton (e.g. small *Daphnia*).



Daphnia
Small freshwater crustacean that forms part of the zooplankton. It feeds on planktonic algae by filtering them from the water with its limbs.

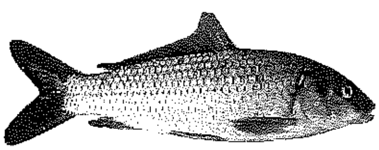


Leech (*Glossiphonia*)
Leeches are fluid feeding predators of smaller invertebrates, including rotifers, small pond snails and worms.

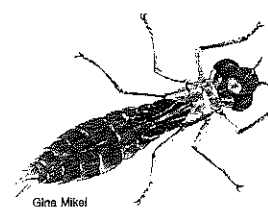


Three-spined stickleback (*Gasterosteus*)
A common fish of freshwater ponds and lakes. It feeds mainly on small invertebrates such as *Daphnia* and insect larvae.

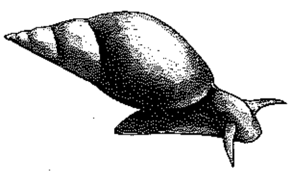
Diving beetle (*Dytiscus*)
Diving beetles feed on aquatic insect larvae and adult insects blown into the lake community. The will also eat organic detritus collected from the bottom mud.



Carp (*Cyprinus*)
A heavy bodied freshwater fish that feeds mainly on bottom living insect larvae and snails, but will also take some plant material (not algae).

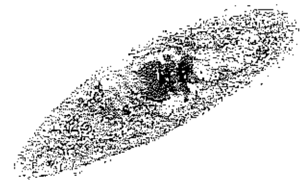


Dragonfly larva
Large aquatic insect larvae that are voracious predators of small invertebrates including *Hydra*, *Daphnia*, other insect larvae, and leeches.

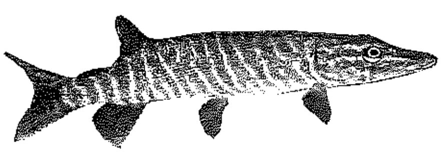


Great pond snail (*Limnaea*)
Omnivorous pond snail, eating both plant and animal material, living or dead, although the main diet is aquatic macrophytes.

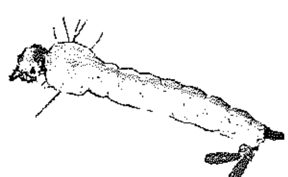
Herbivorous water beetles (e.g.*Hydrophilus*)
Feed on water plants, although the young beetle larvae are carnivorous, feeding primarily on small pond snails.



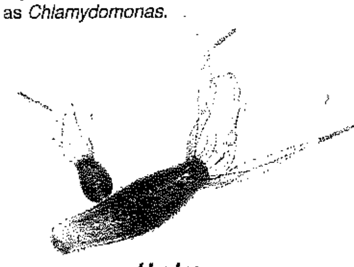
Protozan (e.g. *Paramecium*)
Ciliated protozoa such as *Paramecium* feed primarily on bacteria and microscopic green algae such as *Chlamydomonas*.



Pike (*Esox lucius*)
A top ambush predator of all smaller fish and amphibians. They are also opportunistic predators of rodents and small birds.



Mosquito larva (*Culex* spp.)
The larvae of most mosquito species, e.g. *Culex*, feed on planktonic algae and small protozoans before passing through a pupal stage and undergoing metamorphosis into adult mosquitoes.



Hydra
A small carnivorous cnidarian that captures small prey items, e.g. small *Daphnia* and insect larvae, using its stinging cells on the tentacles.

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1. From the information provided for the lake food web components on the previous page, construct **ten** different **food chains** to show the feeding relationships between the organisms. Some food chains may be shorter than others and most species will appear in more than one food chain. An example has been completed for you.

Example 1: Macrophyte → Herbivorous water beetle → Carp → Pike

(a) ______________________________

(b) ______________________________

(c) ______________________________

(d) ______________________________

(e) ______________________________

(f) ______________________________

(g) ______________________________

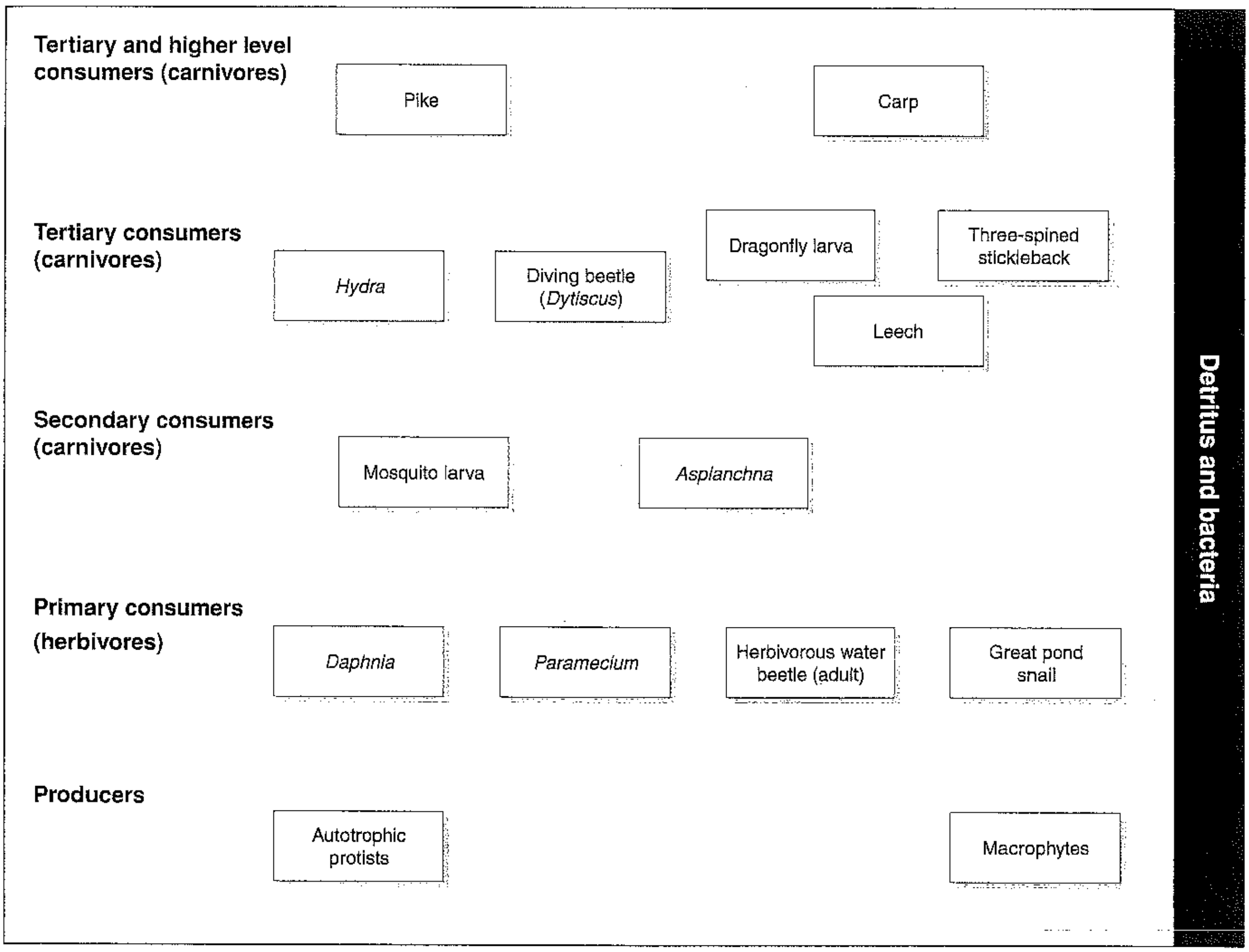
(h) ______________________________

(i) ______________________________

(j) ______________________________

2. (a) Use the food chains created above to help you to draw up a **food web** for this community. Use the information supplied to draw arrows showing the flow of **energy** between species (only energy **from** the detritus is required).

   (b) Label each species to indicate its position in the food web, i.e. its trophic level (**T1, T2, T3, T4, T5**). Where a species occupies more than one trophic level, indicate this, e.g. **T2/3**:



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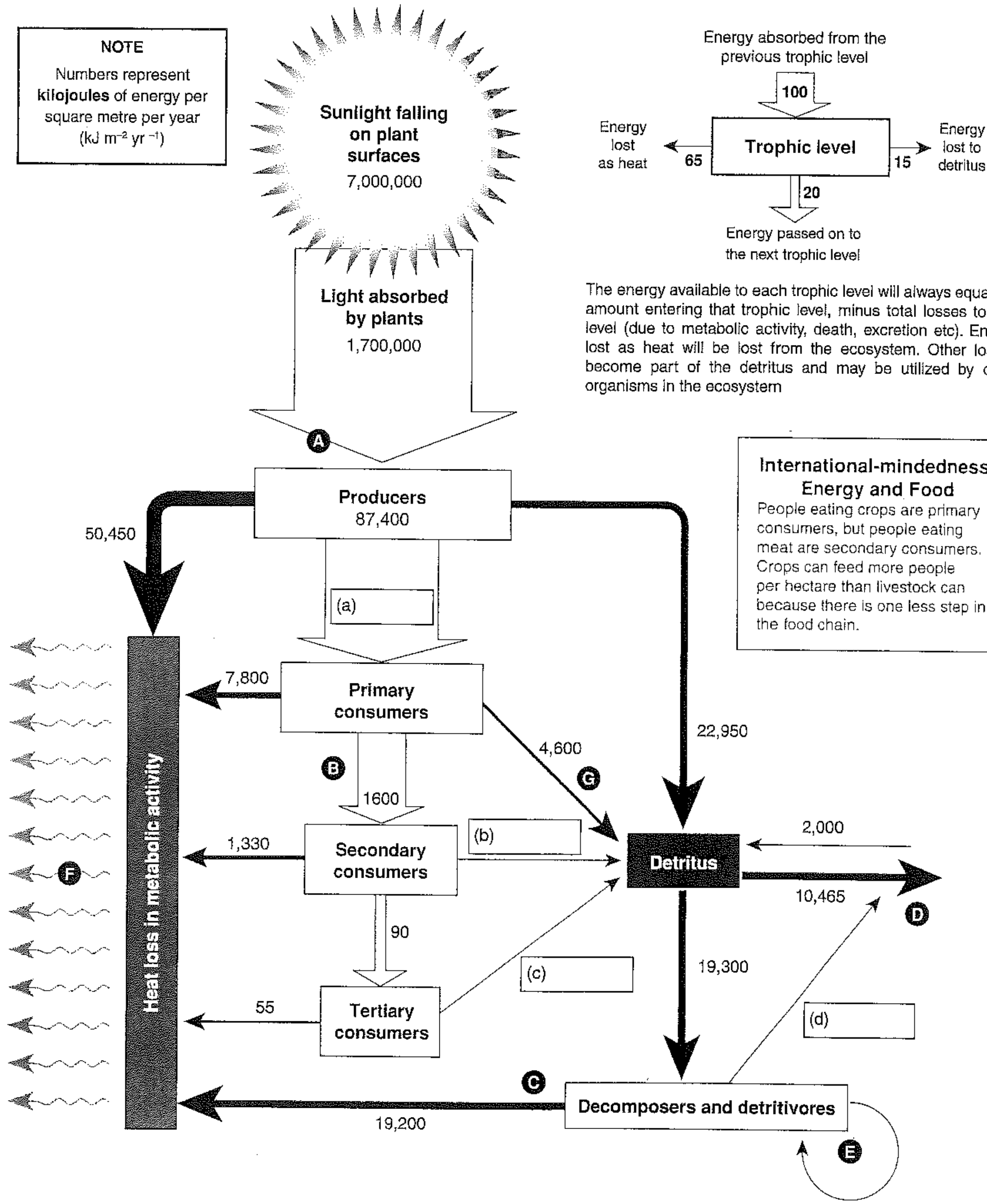
Key idea: Energy flows through an ecosystem between trophic levels. Only 5-20% of energy is transferred from one trophic level to the next.

Energy cannot be created or destroyed, only transformed from one form (e.g. light energy) to another (e.g. chemical energy in the bonds of molecules). This means that the flow of energy through an ecosystem can be measured. Each time energy is transferred from one trophic level to the next (by eating, defecation, etc), some energy is given out as heat to the environment, usually during cellular respiration. Living organisms cannot convert heat to other forms of energy, the amount of energy available to one trophic level is alwa less than the amount at the previous level. Potentially, v can account for the transfer of energy from its input (as sol radiation) to its release as heat from organisms, becau energy is conserved. The percentage of energy transferr from one trophic level to the next is the **trophic efficiency**. varies between 5% and 20% and measures the efficiency energy transfer. An average figure of 10% trophic efficiency often used. This is called the **ten percent rule** (below).

Energy Flow Through an Ecosystem

NOTE
Numbers represent **kilojoules** of energy per square metre per year ($kJ\ m^{-2}\ yr^{-1}$)



The energy available to each trophic level will always equal the amount entering that trophic level, minus total losses to that level (due to metabolic activity, death, excretion etc). Energy lost as heat will be lost from the ecosystem. Other losses become part of the detritus and may be utilized by other organisms in the ecosystem

International-mindedness: Energy and Food

People eating crops are primary consumers, but people eating meat are secondary consumers. Crops can feed more people per hectare than livestock can because there is one less step in the food chain.

1. Study the diagram on the previous page illustrating energy flow through a hypothetical ecosystem. Use the example at the top of the page as a guide to calculate the missing values (a)–(d) in the diagram. Note that the sum of the energy inputs always equals the sum of the energy outputs. Write your answers in the spaces provided on the diagram.

2. Identify the processes occurring at the points labelled A – G on the diagram:

   A. ______________________ E. ______________________

   B. ______________________ F. ______________________

   C. ______________________ G. ______________________

   D. ______________________

3. (a) Calculate the percentage of light energy falling on the plants that is absorbed at point A:

   Light absorbed by plants ÷ sunlight falling on plant surfaces x 100 = ______________________

   (b) What happens to the light energy that is not absorbed? ______________________

4. (a) Calculate the percentage of light energy absorbed that is actually converted (fixed) into producer energy:

   Producers ÷ light absorbed by plants x 100 = ______________________

   (b) How much light energy is absorbed but not fixed: ______________________

   (c) Account for the difference between the amount of energy absorbed and the amount actually fixed by producers:

   ____

   ____

5. Of the total amount of energy **fixed** by producers in this ecosystem (at point A) calculate:

   (a) The total amount that ended up as metabolic waste heat (in kJ): ______________________

   (b) The percentage of the energy fixed that ended up as waste heat: ______________________

6. (a) State the groups for which detritus is an energy source: ______________________

   (b) How could detritus be removed or added to an ecosystem? ______________________

   ____

7. Under certain conditions, decomposition rates can be very low or even zero, allowing detritus to accumulate:

   (a) From your knowledge of biological processes, what conditions might slow decomposition rates?

   ____

   (b) What are the consequences of this lack of decomposer activity to the energy flow? ______________________

   ____

   (c) Add an additional arrow to the diagram on the previous page to illustrate your answer: ______________________

   (d) Describe three examples of materials that have resulted from a lack of decomposer activity on detrital material:

   ____

   ____

8. The **ten percent rule** states that the total energy content of a trophic level in an ecosystem is only about one-tenth (or 10%) that of the preceding level. For each of the trophic levels in the diagram on the preceding page, determine the amount of energy passed on to the next trophic level as a percentage:

   (a) Producer to primary consumer: ______________________

   (b) Primary consumer to secondary consumer: ______________________

   (c) Secondary consumer to tertiary consumer: ______________________

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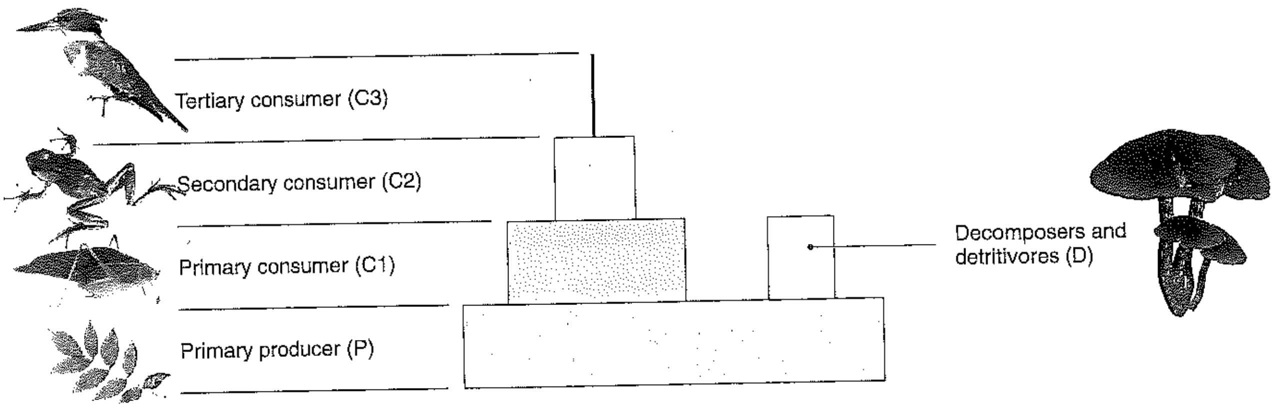
120 Ecological Pyramids

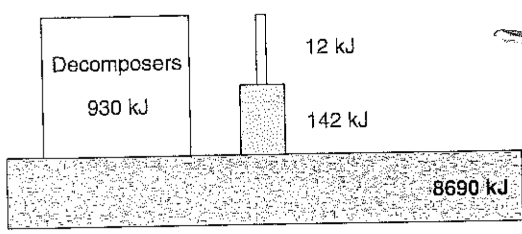
Key idea: Ecological pyramids can be used to illustrate the amount of energy at each trophic level in an ecosystem.

The energy, biomass, or numbers of organisms at each trophic level in any ecosystem can be represented by an ecological pyramid. The first trophic level is placed at the bottom of the pyramid and subsequent trophic levels are stacked on top in their 'feeding sequence'. Ecological pyramids provide a convenient model to illustrate the relationship between different trophic levels in an ecosystem. Pyramids of energy shows the energy contained within each trophic level.

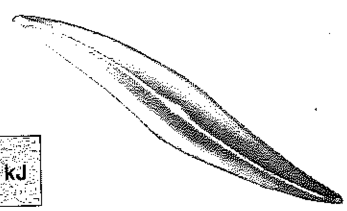


The generalized ecological pyramid pictured above shows a conventional pyramid shape, with a large base at the primary producer level, and increasingly smaller blocks at subsequent levels. Not all pyramids have this appearance. Decomposers are placed at the level of the primary consumers and off to the side because they may obtain energy from many different trophic levels and so do not fit into the conventional pyramid structure. Pyramid of biomass measures the mass of the biological material at each trophic level. They are usually similar in appearance to pyramids of energy (biomass diminishes along food chains as the energy retained in the food chain diminishes).

Pyramid of Energy for a Plankton Community



Energy



Phytoplankton (such as diatoms, left) are producers, transforming sunlight energy into the energy in the chemical bonds within organic matter (food) via photosynthesis. There are many different species of phytoplankton. They form the first trophic level in an ecological pyramid for an aquatic plankton community.

The pyramid illustrated above relates to a hypothetical plankton community. The energy at each trophic level is reduced with each progressive stage in the food chain. As a general rule, a maximum of 10% of the energy is passed on to the next level in the food chain. The remaining energy is lost due to respiration, waste, and heat.

1. Determine the **energy transfer** between trophic levels in the plankton community example in the above diagram:

   (a) Between producers and the primary consumers: ______________________

   (b) Between the primary consumers and the secondary consumers: ______________________

   (c) Why is the amount of energy transferred from the producer level to primary consumers considerably less than the expected 10% that occurs in many other communities?

   ____

   ____

   (d) After the producers, which trophic group has the greatest energy content? ______________________

   (e) Give a likely explanation for this: ______________________

   ____

   ____

   ____

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Data-based questions: Oxygen consumption in tobacco hornworms

Tobacco hornworms are the larvae of *Manduca sexta*. Adults of this species are moths. Larvae emerge from the eggs laid by the adult female moths. There are a series of larval stages called instars. Each instar grows and then changes into the next one by shedding its exoskeleton and developing a new larger one. The exoskeleton includes the tracheal tubes that supply oxygen to the tissues.

The graphs below (figure 12) show measurements made using a simple respirometer of the respiration rate of 3rd, 4th and 5th instar larvae. Details of the methods are given in the paper published by the biologists who carried out the research. The reference to the research is Callier V and Nijhout H F (2011) "Control of body size by oxygen supply reveals size-dependent and size-independent mechanisms of molting and metamorphosis." PNAS;108:14664–14669. This paper is freely available on the internet at http://www.pnas.org/content/108/35/14664.full.pdf+html.

Each data point on the graphs shows the body mass and respiration rate of one larva. For each instar the results have been divided into younger larvae with low to intermediate body mass and older larvae with intermediate to high body mass. The results are plotted on separate graphs. The intermediate body mass is referred to as the critical weight.

1 a) Predict, using the data in the graphs, how the respiration rate of a larva will change as it grows from moulting until it reaches the critical weight. [1]

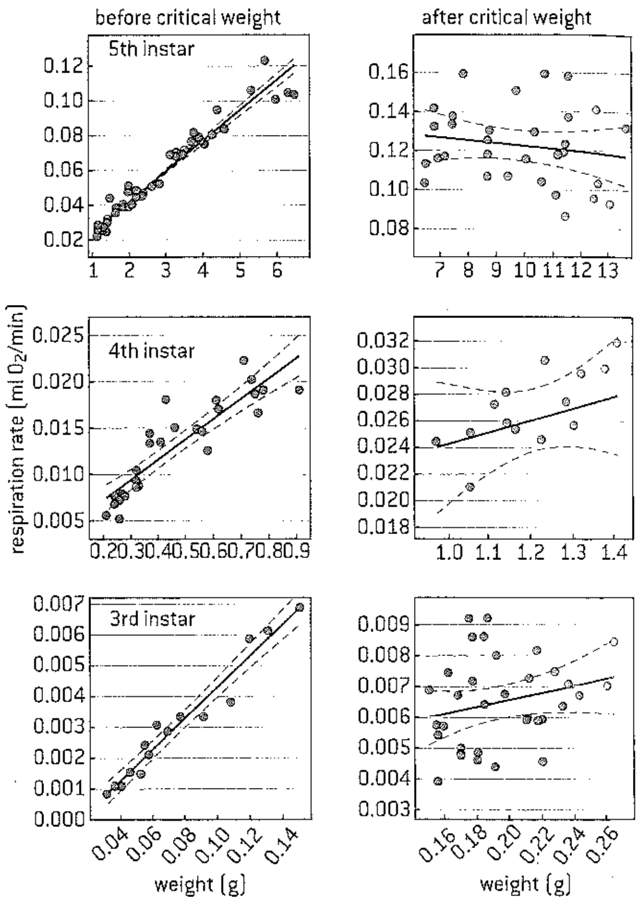
b) Explain the change in respiration rate that you have described. [2]

2 a) Discuss the trends in respiration rate in larvae above the critical weight. [2]

b) Suggest reasons for the difference in the trends between the periods below and above the critical weight. [2]

The researchers reared some tobacco hornworms in air with reduced oxygen content. They found that the instar larvae moulted at a lower body mass than larvae reared in normal air with 20% oxygen.

3 Suggest a reason for earlier moulting in larvae reared in air with reduced oxygen content. [2]



▲ Figure 12 Respiration rates of tobacco hornworms (after Callier and Nijhout, 2011)

Ethics of animal use in respirometers

Assessing the ethics of scientific research: the use of invertebrates in respirometer experiments has ethical implications.

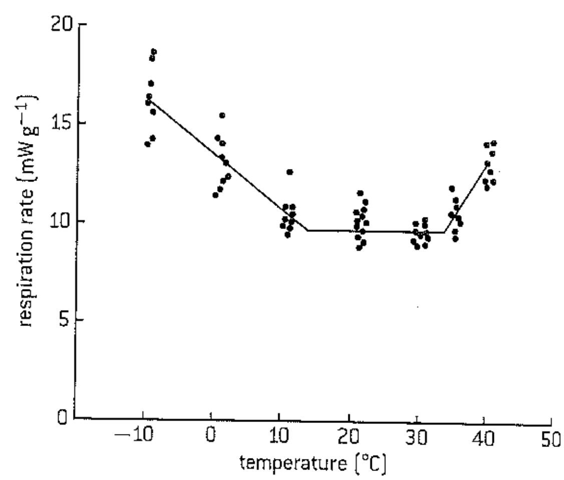
It is important for all scientists to assess the ethics of their research. There has been intense debate about the ethics of using animals in experiments. When discussing ethical issues, do we consider the consequences such as benefits to students who are learning science? Do we consider intentions? For example, if the animals are harmed unintentionally does that change

All cells can produce ATP by cell respiration. In this process carbon compounds such as carbohydrates and lipids are oxidized. These oxidation reactions are exothermic and the energy released is used in endothermic reactions to make ATP. So cell respiration transfers chemical energy from glucose and other carbon compounds to ATP. The reason for doing this is that the chemical energy in carbon compounds such as glucose is not immediately usable by the cell, but the chemical energy in ATP can be used directly for many different activities.

The second law of thermodynamics states that energy transformations are never 100% efficient. Not all of the energy from the oxidation of carbon compounds in cell respiration is transferred to ATP. The remainder is converted to heat. Some heat is also produced when ATP is used in cell activities. Muscles warm up when they contract for example. Energy from ATP may reside for a time in large molecules when they have been synthesized, such as DNA and proteins, but when these molecules are eventually digested the energy is released as heat.

Data-based questions

Figure 5 shows the results of an experiment in which yellow-billed magpies *(Pica nuttalli)* were put in a cage in which the temperature could be controlled. The birds' rate of respiration was measured at seven different temperatures, from −10 °C to +40 °C. Between −10 °C and 30 °C the magpies maintained constant body temperature, but above 30 °C body temperature increased.



▲ Figure 5 Cell respiration rates at different temperatures in yellow-billed magpies

a) Describe the relationship between external temperature and respiration rate in yellow-billed magpies. [3]

b) Explain the change in respiration rate as temperature drops from +10 °C to −10 °C. [3]

c) Suggest a reason for the change in respiration rate as temperature increased from 30 °C to 40 °C. [2]

d) Suggest two reasons for the variation in respiration rate between the birds at each temperature. [2]

Heat energy in ecosystems

Living organisms cannot convert heat to other forms of energy.

Living organisms can perform various energy conversions:

- Light energy to chemical energy in photosynthesis.
- Chemical energy to kinetic energy in muscle contraction.
- Chemical energy to electrical energy in nerve cells.
- Chemical energy to heat energy in heat-generating adipose tissue.

They cannot convert heat energy into any other form of energy.

Release of carbon dioxide from cell respiration

Carbon dioxide is produced by respiration and diffuses out of organisms into water or the atmosphere.

Carbon dioxide is a waste product of aerobic cell respiration. It is produced in all cells that carry out aerobic cell respiration. These can be grouped according to trophic level of the organism:

- non-photosynthetic cells in producers for example root cells in plants
- animal cells
- saprotrophs such as fungi that decompose dead organic matter.

Carbon dioxide produced by respiration diffuses out of cells and passes into the atmosphere or water that surrounds these organisms.

Data-based questions: Data-logging pH in an aquarium

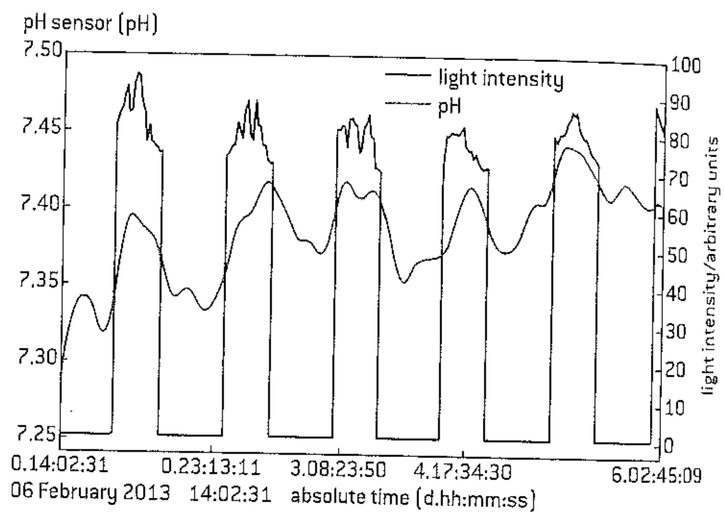
Figure 2 shows the pH and light intensity in an aquarium containing a varied community of organisms including pondweeds, newts and other animals. The data was obtained by data logging using a pH electrode and a light meter. The aquarium was illuminated artificially to give a 24-hour cycle of light and dark using a lamp controlled by a timer.

1 Explain the changes in light intensity during the experiment. [2]

2 Determine how many days the data logging covers. [2]

3 a) Deduce the trend in pH in the light. [1]

b) Explain this trend. [2]



▲ Figure 2

4 a) Deduce the trend in pH in darkness. [1]

b) Explain this trend. [2]

Methanogenesis

Methane is produced from organic matter in anaerobic conditions by methanogenic archaeans and some diffuses into the atmosphere.

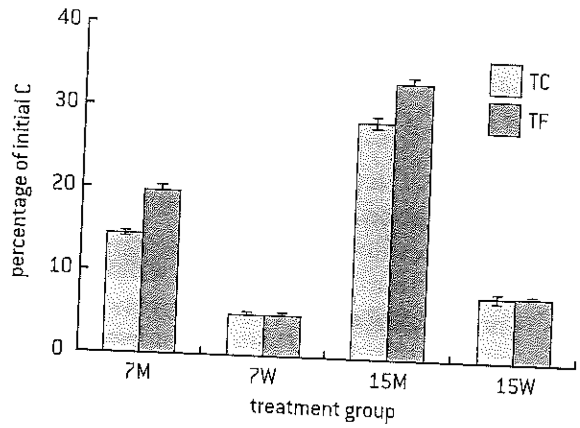
In 1776 Alessandro Volta collected bubbles of gas emerging from mud in a reed bed on the margins of Lake Maggiore in Italy, and found that it was inflammable. He had discovered methane, though Volta did not give it this name. Methane is produced widely in anaerobic environments, as it is a waste product of a type of anaerobic respiration.

Three different groups of anaerobic prokaryotes are involved.

1 Bacteria that convert organic matter into a mixture of organic acids, alcohol, hydrogen and carbon dioxide.

Data-based questions: Release of carbon from tundra soils

Soils in tundra ecosystems typically contain large amounts of carbon in the form of peat. This accumulates because of low rates of decomposition of dead plant organic matter by saprotrophs. To investigate this, ecologists collected samples of soil from areas of tussock vegetation near Toolik Lake in Alaska. Some of the areas had been fertilized with nitrogen and phosphorus every year for the previous eight years (TF) and some had not (TC). The soils were incubated for 100-day periods at either 7 or 15°C. Some samples were kept moist and others were saturated with water (W). The initial carbon content of the soils was measured and the amount of carbon dioxide given off dur the experiment was monitored. The bar chart ir figure 5 shows the results.



▲ Figure 5

1 a) State the effect of increasing the temperature of the soils on the rate of release of carbon.

b) Explain the reasons for this effect.

2 a) Compare the rates of release of carbon i moist soils with those in soils saturated with water. [

b) Suggest reasons for the differences. [

3 Outline the effects of fertilizers on rates of release of carbon from the soils. [.

4 Discuss whether differences in temperature, amount of water in the soil or amount of fertilizer have the greatest impact on the release of carbon. [:

Large quantities of partially decomposed organic matter have accumulated in some ecosystems and become compressed to form a d brown acidic material called peat. About 3% of the Earth's land surfac is covered by peat and as the depth is ten metres or more in some plac the total quantities of this material are immense.

Fossilized organic matter

Partially decomposed organic matter from past geologic eras was converted into oil and gas in porous rocks or into coal.

▲ Figure 6 Coal at a power station

Carbon and some compounds of carbon are chemically very stable and can remain unchanged in rocks for hundreds of millions of years. Ther are large deposits of carbon from past geological eras. These deposits ar the result of incomplete decomposition of organic matter and its burial in sediments that became rock.

- Coal is formed when deposits of peat are buried under other sediments. The peat is compressed and heated, gradually turning int coal. Large coal deposits were formed during the Pennsylvanian sub period of the Carboniferous. There was a cycle of sea level rises and falls; coastal swamps formed as the level fell and were destroyed and buried when the level rose and the sea spread inland. Each cycle has left a seam of coal.