MYP Biology

A concept-based approach

Years 4&5

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Introduction

The MYP biology course is inquiry based. MYP structures inquiry in sciences by developing conceptual understanding. Key concepts represent big ideas that are relevant across disciplines. Related concepts are grounded in specific disciplines and are useful for exploring key concepts in greater detail. Each chapter of this book is focused on a single related concept and one or two key concepts.

Every chapter opens with ways in which the related concept is explored in other disciplines. This structure will help to develop an interdisciplinary understanding of the concepts. After the interdisciplinary opening pages, the concepts are introduced more deeply in relation to the content of the chapter.

The objectives of MYP Science are categorized into four criteria, which contain descriptions of specific targets that are accomplished by studying this programme:

A Knowing and understanding

B Inquiring and designing

C Processing and evaluating

D Reflecting on the impacts of science

Within each chapter, we have included activities designed to promote achievement of these objectives, such as experiments and data-based questions. We also included factual, conceptual and debatable questions, and activities designed to promote development of approaches to learning skills. The summative assessment found at the end of each chapter is framed by a statement of inquiry relating the concepts addressed to one of the six global contexts, as in the MYP eAssessment.

For those students taking the eAssessment at the end of the MYP programme, the International Baccalaureate Organization provides a subject-specific topic list. Great care has been taken to ensure all topics from the list are covered within this book.

Overall, this book is meant to guide a student's exploration of biology and aid the development of specific skills that are essential for academic success and getting the most out of this educational experience. In particular, the content of this book will provide a sound foundation for the study of DP Biology, both at Standard and Higher Level.

How to use this book

To help you get the most of your book, here's an overview of its features.

Concepts, global context and statement of inquiry

The key and related concepts, the global context and the statement of inquiry used in each chapter are clearly listed on the introduction page.

Activities

A range of activities that encourage you to think further about the topics you studied, research these topic and build connections between biology and other disciplines.

Experiment

Practical activities that help you prepare for assessment criteria B & C.

ATL Skills

These Approaches to Learning sections introduce new skills or give you the opportunity to reflect on skills you might already have. They are mapped to the MYP skills clusters and are aimed at supporting you become an independent learner.

Data-based question

These questions allow you to test your factual understanding of biology, as well as study and analyse data. Data-based questions help you prepare for assessment criteria A, B & C.

1 A grey circle appears before a conceptual question.

2 A red circle appears before a debatable question.

Summative assessment

There is a summative assessment at the end of each chapter; this is structured in the same way as the eAssessment and covers all four MYP assessment criteria.

A B C D These icons indicate which criterion is assessed in that section.

Glossary

The glossary contains definitions for all the subject-specific terms emboldened in the index.

Topics overview

The MYP eAssessment subject list for Biology consists of nine broad topics:

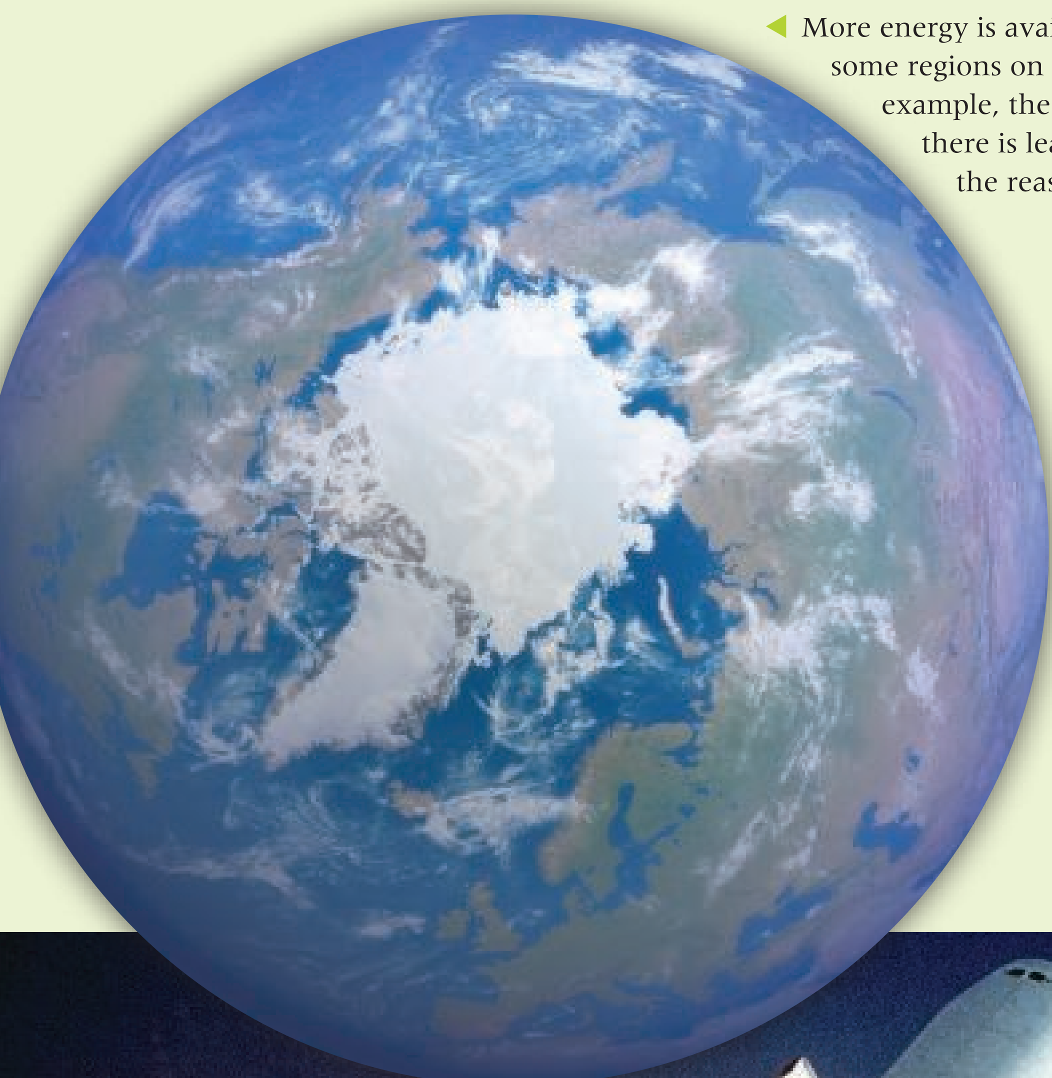
Cells	Metabolism	Interactions between organisms
Organisms	Evolution	Human interactions with environments
Processes	Interactions with environment	Biotechnology

These topics are further broken down into sub-topics and the mapping grid below gives you an overview of where these are covered within this book. It also shows you which key concept, global context and statement of inquiry guide the learning in each chapter.

Chapter	Topics covered	Key concept	Global context	Statement of inquiry	ATL skills
1 Energy	Movement Energy transfer Cell respiration, aerobic and anaerobic respiration Food chains/webs	Change Systems	Globalization and sustainability	Humans need to find sources of energy that do not cause harmful and irreversible changes to ecosystems and the environment.	**Critical thinking skills:** Revise understanding based on new information and evidence **Thinking in context:** How can we make human energy use more sustainable?
2 Transformation	Biochemistry and enzymes Word and chemical equations Photosynthesis	Change	Scientific and technical innovations	Science is applied to mitigate the transformations associated with aging but sometimes anti-aging science is misrepresented.	**Creative thinking skills:** Generate metaphors and analogies **Communication skills:** Use a variety of organizers for writing tasks
3 Form	Cell structure Tissues Organs Systems Classification	Relationships	Identities and relationships	Relationships between organisms are revealed by similarities and differences between the myriad of forms.	**Communication skills:** Use and interpret a range of discipline-specific terms **Information literacy skills:** Understand and use technology systems **Information literacy skills:** Preview and skim videos to build understanding
4 Function	Cell functions Nutrition Digestion Receptors Senses	Systems	Orientation in space and time	Each component in a system must perform its specific function at the right time and place for the system as a whole to be successful.	**Critical thinking skills:** Making reasonable predictions **Affective skills:** Practicing resilience
5 Movement	Diffusion Osmosis Tropisms Transpiration and translocation Gas exchange Transport and circulation	Change	Fairness and development	The changes in the weather patterns caused by current economic activity may not be fair to future generations.	
6 Interaction	Nervous system Competition Pathogens/parasites Predator/prey Interdependancy	Relationships	Identities and relationships	When two or more individuals interact, they form relationships that, over time, impact and contribute to their identity.	**Creative thinking skills:** Generating analogies **Thinking in context:** What is the relationship between video games and identity? **Organization skills:** Preparing for eAssessment
7 Balance	Homeostasis Hormones Ecosystem Cycles including nutrient, carbon, nitrogen	Systems	Fairness and development	Development is only sustainable if systems remain in balance.	**Information literacy skills:** Present information in a variety of formats and platforms **Critical thinking skills:** Addressing counterclaims
8 Environment	Habitat Habitat change or destruction Pollution/ conservation	Change	Personal and cultural expression	Environments provide aesthetic benefits and influence human cultural expression, but human induced changes undermine these benefits.	**Thinking in context** **Communication skills:** Collaborate with peers and experts using a variety of digital environments and media
9 Patterns	Unity and diversity in life forms DNA Genome mapping and application Cell division Mitosis Meiosis Reproduction Life cycles	Relationships	Orientation in time and space	Observing patterns allows scientists to propose new theories that explain how the living world works.	**Creative and innovative thinking skills:** Generate a testable hypothesis **Critical thinking skills:** Evaluating evidence and arguments
10 Consequences	Inheritance and variation Natural selection Speciation and extinction Genetic modification Cloning Ethical implications	Change	Scientific and technical innovation	Scientific and technical innovations can change the impacts that we have on the world.	**Critical thinking skills:** Draw supported conclusions **Reflection skills:** Consider ethical, cultural and environmental implications
11 Evidence	Factors affecting human health Vaccination	Relationships	Scientific and technical innovation	Healthy lifestyles can be based on evidence of relationships between types of behaviour and risks of disease.	**Information literacy skills:** Finding, interpreting, judging and creating information
12 Models	Overexploitation Mitigation of adverse effects 3D tissue and organ printing Human influences	Systems	Globalization and sustainability	Methods of achieving sustainability can be developed using models that explore differences between systems.	**Critical thinking skills:** Is modelling an essential part of all research in biology? **Communication skills:** Take effective notes in class and make effective summary notes

1 Energy

Energy is invisible, but its effects are easily observed.



◀ More energy is available to living organisms in some regions on Earth than in others. For example, the poles are the regions where there is least available energy. What is the reason for this?

▼ A huge amount of energy is needed to get a space shuttle into orbit. To generate this energy, hydrogen and oxygen are used as fuel. The plumes trailing behind the shuttle are water. Hydrogen is obtained using fossil fuels formed millions of years ago out of the remains of living organisms. What is the source of the oxygen?

▲ All aspects of life rely on energy. Based on this idea, Dutch physicist and artist Theo Jensen refers to his gigantic Strandbeests as "animals" that "live" on the beach. The organisms made of plastic tubes and sheets have stomachs, muscles, wings and legs, and use wind energy to move. They can also store energy, which allows them to continue moving even when the wind is not blowing. While moving, their legs throw sand in the air, leading to the formation of dunes which protect the coasts from rising sea levels. What other impacts could these animals have on their environment? Is this a strategy that could be used in other countries too?

▲ *Hallucigenia* lived on Earth 500 million years ago. It had muscles for movement, like animals alive today. It used energy from chemicals rather than wind. How did *Hallucigenia* obtain chemical energy? How can animals still obtain the chemical energy that they need for movement despite using it for more than half a billion years?

"Over time, these skeletons have become increasingly better at surviving the elements such as storm and water and eventually I want to put these animals out in herds on the beaches, so they will live their own lives."

Theo Jensen

Key concepts: Change, Systems

Related concept: Energy

Global context: Globalization and sustainability

Introduction

Energy is what makes things happen. In physics this is stated more formally: energy is the capacity to do work. Energy cannot be created or destroyed, but it can be converted from one form to another or transferred between objects. Energy is therefore closely related to the key concept of change.

Energy for body functions comes from food. Energy for industry, transport and for homes comes from a variety of sources including oil and gas. There are major issues about where energy will come from in the future, so the global context of this chapter is globalization and sustainability.

▼ Rapeseed (*Brassica napus*) is a very versatile crop, producing vegetable oils for human consumption and for the production of biodiesel, as well as a protein-rich animal food. Could growing such crops solve the problems of energy supply in the future?

Statement of inquiry:

Humans need to find sources of energy that do not cause harmful and irreversible changes to ecosystems and the environment.

All aspects of life rely on energy:

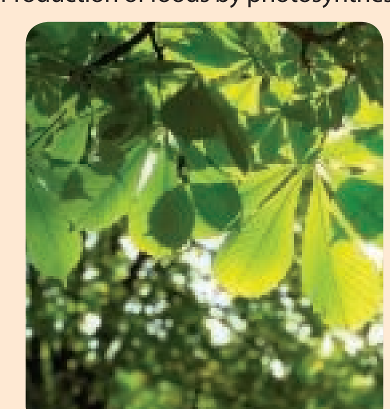
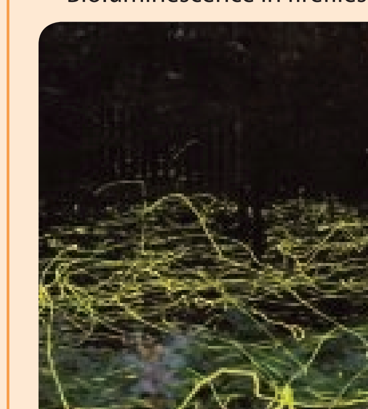
- Movement is possible because of kinetic energy. A falcon diving through the air to catch its prey and pollen grains blown by the wind have kinetic energy. Blood flowing through arteries also has kinetic energy. The concept of movement is the theme of Chapter 5.
- Atoms interacting to form molecules (chemical energy), neurons sending and receiving messages (electrochemical energy) and tissues changing shape (elastic energy) are all possible because of potential energy. Potential energy is energy that is stored and which exists because of a change in position, shape or state.
- Plant growth is possible because of a form of radiant energy: light. Other forms of radiant energy are gamma rays, microwaves and radio waves.

All the cells in living organisms, as well as the air around them, are made up of particles that may vibrate, rotate and move in random directions. This movement of particles is a source of thermal energy: the more rapid the movement, the greater the thermal energy and the higher the temperature. Heat is thermal energy that is being transferred, generally from a material with a higher temperature to materials with a lower temperature, for example, from the human body to the environment. In nature, energy is lost from all ecosystems in the form of heat.

▼ What kind of energy is needed to split firewood? What is the source of this energy? Firewood is a source of energy itself—what kind and how is it released?

Changes to the form of energy

The table gives examples of two energy transformations in biology. Draw up an expanded version of the table to include more forms of energy.

Light to chemical	**Chemical to light**
Production of foods by photosynthesis	Bioluminescence in fireflies
	

PLANTS

How do plants obtain energy?

Plants grow towards the light and do not grow well if they are deprived of light. When you walk under trees, the shade shows that leaves block some of the sunlight. These observations suggest that plants absorb light and use it as an energy source. Light energy must be changed into chemical energy inside the plant. Although this seems obvious, scientists look for evidence, usually from experiments. You can obtain evidence for the conversion of light energy into chemical energy inside plants by doing a simple experiment, using a pondweed such as *Elodea* or *Cabomba*.

Elodea releasing bubbles of oxygen

Experiment

Hypothesis

When plants convert light energy to chemical energy they produce oxygen.

Materials

A stem of *Elodea* or *Cabomba*; a clean, transparent container; tap water

Method

Fill a clean, transparent container with water. Choose a stem of *Elodea* or *Cabomba* that has plenty of leaves. Place it upside down in water and cut the end of the stem.

Observations

Bubbles of gas should emerge from the cut end of the stem and rise to the water surface.

Suggestions for further stages in your experiment:

1. Collect and test the bubbles to confirm that they are oxygen.
2. Carry out a simple test to show that light energy is needed for the production of oxygen.
3. Obtain further evidence of the need for light energy by measuring the bubbling rate at different light intensities.

Extension to your experiment

Devise a method for measuring the bubbling rate of a pondweed stem when it is placed in three different samples of water: a) tap water, b) water that has been boiled and then cooled to remove dissolved gases and c) sparkling water. Before you perform the experiment you should write a hypothesis. When you have obtained your results, you can analyse them to see whether they support your hypothesis. Do the results of this experiment change your understanding of photosynthesis?

ATL Critical thinking skills

Revise understanding based on new information and evidence

Sometimes the results of experiments support our hypothesis and reinforce our understanding, but in science it is not unusual to get surprising results. These may be due to an error in procedures, which should be found and corrected. On other occasions, the results are not in error and they show that we need to revise our understanding. The results of the extension experiment may cause you to revise your understanding of photosynthesis.

Another example of revising our understanding comes from isotope experiments. Consider the summary equation for photosynthesis:

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

This equation indicates that some of the oxygen released must come from the carbon dioxide that is used. Experiments with isotopes show that this is incorrect. The normal isotope of oxygen is ^{16}O. When plants are given water containing ^{18}O rather than ^{16}O, all the oxygen that they release is also ^{18}O rather than ^{16}O. This shows that all the oxygen produced in photosynthesis comes from the splitting of water into oxygen and hydrogen. Twelve molecules of water must be split per glucose, but six new water molecules are subsequently produced, giving the net use of six molecules shown in the equation. Clearly, photosynthesis must be a more complicated process than the summary equation suggests.

Discuss in your class the meaning of the following terms in relation to this text:

dogmatic steadfast open-minded.

How similar are leaves and solar panels?

Leaves have evolved over millions of years; solar panels have been developed by electrical engineers over recent decades. Consider how similar leaves and solar panels are by making a list of similarities and a list of differences. You could include size, shape, energy source, energy conversion and efficiency.

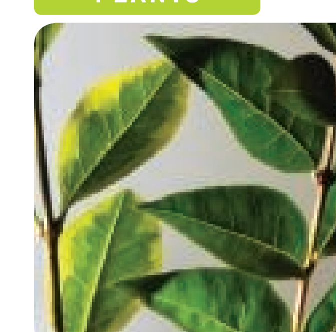
Solar panels are being installed on satellites, roof tops and increasingly in large arrays on former farmland

How do plants build up stores of energy?

PLANTS

A pigment is a chemical substance that absorbs light. Chlorophyll is the main pigment in plants and it plays an important role in absorbing energy. Chlorophyll absorbs red and blue light, but reflects green light. This is why chlorophyll, and leaves, look green.

When photons of red or blue light reach the chlorophyll, they cause particular electrons in the molecule to jump to a higher energy level. This is how light is converted into chemical energy. The high-energy electrons are very unstable, however, and they cannot store energy for more than a fraction of a second. In order for the chemical energy to be stored, the high-energy electrons must be used quickly in the production of chemical compounds such as glucose. Plant cells can only store small amounts of glucose, so when there is rapid photosynthesis they convert it to starch. This leads us to a testable hypothesis: starch is only produced by photosynthesis if there is chlorophyll in a leaf cell.



Variegated plants have chloroplasts containing the green pigment chlorophyll in some parts of the leaf but not others. Where the cells lack chloroplasts, the leaf appears yellow or white. Normal and variegated varieties of privet are shown here

The leaves of this *Coleus blumei* plant have green, white and purple areas

Experiment

Hypothesis

Starch is only produced by photosynthesis if there is chlorophyll in a leaf cell.

Method

1. Put a variegated *Pelargonium* plant in darkness for a few days.
2. Test a leaf from the plant for starch to confirm that none is present.
3. Cover part of a healthy leaf with a black card to exclude light.
4. Put the plant in bright light for a few hours.
5. Remove the leaf and test it for starch.
   - **a)** Dip the leaf into boiling water for 20 seconds to destroy all the cell membranes.
   - **b)** Put the leaf in a test tube of boiling ethanol for about two minutes to dissolve out the chlorophyll from the leaf and allow test results to be seen more clearly.
   - **c)** Rinse the leaf in water to remove the ethanol.
   - **d)** Spread the leaf on a white tile so that all of it is visible.
   - **e)** Put iodine solution over the whole of the leaf and wait for a few minutes to allow the iodine to diffuse into the cells where starch could be located.
   - **f)** Any parts of the leaf that turn black contain starch. Any parts that remain brown do not contain starch.

Analyse your results by considering the reasons for starch being present or absent from each of these regions of the leaf: green illuminated, green in darkness, white illuminated and white in darkness.

Extension to your experiment

Some leaves are either totally purple or have purple areas. Suggest a hypothesis for whether starch can be produced by photosynthesis in purple leaf cells and test your hypothesis using plants such as *Coleus blumei*. You may have to revise your understanding when you get your results, but remember that as there are many different patterns of purple leaf colour, you cannot accept or reject your hypothesis by testing just one type.

How much chemical energy is there in a seed?

Plants store energy in seeds so that when the seed germinates there is enough energy available for the early stages of growth. All seeds contain chemical energy but sunflower seeds, cashews and almonds are suitable choices for this experiment.

A simple method for measuring the chemical energy content of a seed is to burn the seed and use the heat released to increase the temperature of water. Energy is measured in joules (J). To raise one millilitre (ml) of water one degree Celsius requires 4.2 J of heat energy, so energy content of seed (J per gram of seed) = temperature rise (°C) × water volume (ml) × 4.2 J / mass of food (grams).

Seeds contain stores of chemical energy

Experiment

Method

1. Clamp a tube at an angle of about 45° with the clamp at the top of the tube.
2. Put 20 ml of water in the tube.
3. Put a thermometer into the tube and measure the temperature before burning the seed.
4. Measure the mass of a seed using an electronic balance.
5. Fix the seed onto a mounted needle and set it alight by holding it in a Bunsen burner flame.
6. When it is burning, hold the seed under the tube of water so that the flame touches the tube (see diagram).
7. When the seed has finished burning, stir the water with the thermometer and measure its temperature again.

Results

Draw up a results table to record the type of seed, its mass, the water temperature before and after burning the seed, the temperature rise and the energy content per gram of the seed.

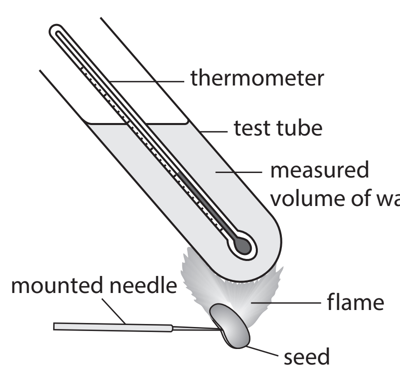
Evaluation

Dietary information on food packaging gives these values for energy content:

- sunflower seeds: 24,800 J per gram
- cashew nuts: 24,700 J per gram
- almonds: 24,500 J per gram.

Discuss the reasons for the differences between your results and the results given on food packets.

Suggest improvements to the method that you used.



Biodiesel

The seeds used in the previous experiment have relatively large amounts of chemical energy because of the oil they contain. Oil extracted from seeds is used as an alternative to diesel fuel in some parts of the world. Find out whether "biodiesel" is produced or used in your part of the world. What are the advantages and disadvantages of using biodiesel instead of fossil fuels?

▲ Biodiesel fuel pump in Spain

METABOLISM

How is energy released in cells?

Molecules such as glucose or fat contain a relatively large amount of chemical energy—more than needed for most tasks in a cell. Energy released from these food molecules is therefore used to make a large number of molecules that contain a smaller amount of energy. It is a remarkable fact that all organisms use the same molecule for storing and then supplying small packets of energy in the cell. This molecule is adenosine triphosphate (ATP). It is made by linking a phosphate group onto adenosine diphosphate (ADP). This is achieved using energy from glucose, fat or other foods. The reactions that release energy from glucose and other foods and produce ATP are called cell respiration.

▲ Corn has starchy seeds. The starch can be digested into sugars. Yeast can then be used to produce ethanol from the sugar by anaerobic respiration

If oxygen is used, the process is aerobic respiration. This is a long sequence of reactions, but these can be summarized in one equation:

glucose + oxygen ⟶ carbon dioxide + water
ADP → ATP

If oxygen is not available, some cells can perform anaerobic respiration, which is a shorter sequence of reactions that produces much less ATP. In some organisms, such as humans or mealworms, the summary equation for anaerobic respiration is:

glucose ⟶ lactic acid
ADP → ATP

▼ E85 is a fuel consisting of 15% gasoline and 85% ethanol

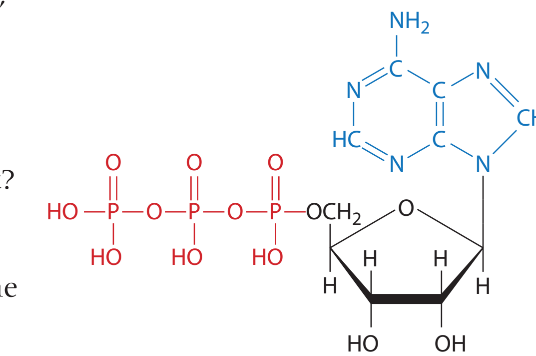
In fungi, such as yeast, and in plants the summary equation for anaerobic respiration is:

glucose ⟶ ethanol + carbon dioxide
ADP → ATP

Both these versions of anaerobic respiration produce less ATP per glucose molecule than aerobic respiration because the glucose has not been fully broken down. Ethanol and lactic acid contain chemical energy that has not been released and used to make ATP. Ethanol produced by anaerobic respiration in yeasts is used as a fuel for cars, where the remaining energy is released by combustion.

Refer to the diagram in the margin and research ATP to find out these things:

1. In the diagram of ATP, what do the letters C, H, N, O and P represent?
2. What do the single and double lines represent?
3. What are the names of each of the differently colored parts of the molecule?
4. What is removed from ATP to make **a)** ADP, **b)** AMP and **c)** adenosine?



▲ Adenosine triphosphate (ATP)

How can we measure the rate of energy release in cells?

METABOLISM

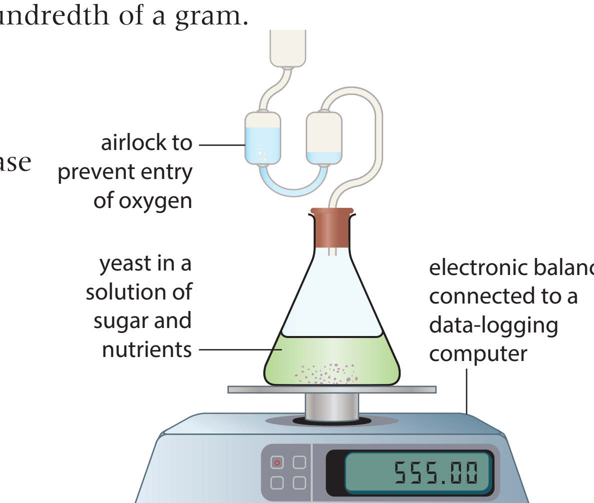
Rate means how much of something happens in a certain time. Energy is released in cells by respiration, so to find the rate of energy release, you measure the amount of respiration occurring in a period of time. The diagrams in the experiments below show methods for doing this.

Experiment

Method A

Set up the apparatus shown in the diagram and leave it running for several days. An electronic balance is needed that gives a mass reading to a hundredth of a gram.

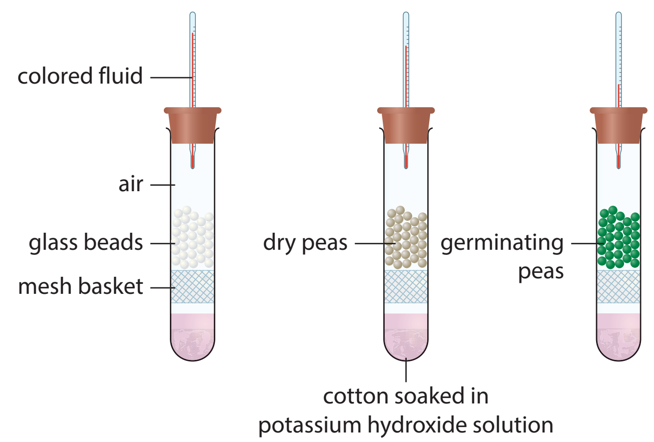
1. Explain what type of respiration the yeast cells must be carrying out.
2. The mass of the apparatus is expected to decrease steadily. What causes this loss of mass?
3. Explain these possible trends in mass loss:
   a) a gradual increase in the rate of mass loss.
   b) higher mass loss in daytime than at night.
   c) no further mass loss after a few days.
4. Suggest one advantage of recording the results with a data logger.



Experiment

Method B

Set up the three tubes shown in the diagram and place them in a hot block heater or a water bath at 30°C. When they have heated up, inject a small drop of colored fluid into the capillary tubes, near the top. If the fluid starts to move down the tube, measure how far it moves in millimetres every minute.



1. What is the purpose of the potassium hydroxide solution?
2. The fluid is expected to move downwards in the tube containing germinating peas. What causes this movement?
3. What are the correct units for measuring the rate of movement of the fluid?
4. What is the purpose of:
   a) the tube with glass beads instead of germinating peas?
   b) the tube containing the dry peas?
5. Explain how the method could be modified and improved so that the rate of energy release could be compared accurately in different types of seed.

METABOLISM

Cells on the surface of roots transfer ions such as potassium from the soil into the plant. The concentration of these ions is already much higher inside the cells than in the soil, so energy from ATP has to be used to pump the ions into the cells by active transport

What is energy needed for in cells?

Many different tasks are performed in cells using energy from ATP:

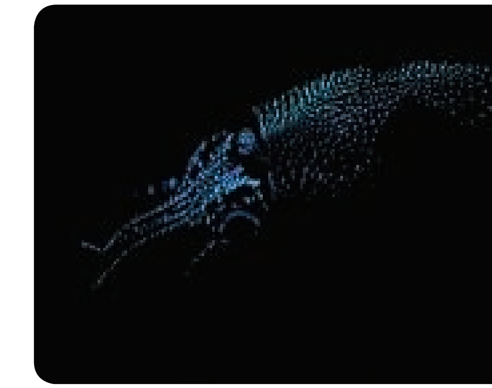
- Energy is used to transform small molecules into larger molecules such as proteins and DNA. These transformations are called anabolic reactions and are explored more fully in Chapter 2.
- ATP also provides energy for pumping ions and other particles across cell membranes from a lower to a higher concentration. This process is called active transport. Energy is changed from chemical to electrochemical during active transport.
- Energy is also required for movement. Chemical energy is changed into kinetic energy. ATP supplies energy for moving components from one part of a cell to another and also for moving the whole cell. Muscle cells in particular use considerable amounts of ATP when they are contracting. Movement is explored in Chapter 5.
- In a few species, ATP supplies energy for chemical reactions that make part of the body flash or glow, so chemical energy is changed into light.

Data-based question: Energy requirements of humans

The table shows the energy requirements of different groups of humans.

Age range (years)	Energy requirement (MJ per day)					
	Females			Males		
	Low activity level	Moderately active	Very active	Low activity level	Moderately active	Very active
1–2		3.6			4.0	
7–8	5.5	6.5	7.5	6.0	7.1	8.2
14–15	8.7	10.2	11.8	10.6	12.5	14.4
15–16	8.9	10.4	12.0	11.3	13.3	15.3
17–18	8.9	10.5	12.0	12.1	14.3	16.4

1. State two processes in human cells which require energy.
2. Suggest a reason for increasing energy requirements as boys grow older.
3. a) Calculate the percentage increase in energy requirement for a 14–15-year-old boy that stops playing computer games and starts training with a football team.
   b) Explain how the extra energy is used in the boy's body.
4. Explain what will happen in a boy's or girl's body if:
   a) they eat food each day containing more energy than their requirement
   b) they eat food each day containing less energy than their requirement.
5. a) State the trends in energy requirement as boys and girls grow from 15–16 to 17–18 years old.
   b) Suggest a reason for the different trends in boys and girls.
6. Draw a bar chart to display the energy requirements for moderately active boys and girls, for all boys or for all girls.



The firefly squid (*Watasenia scintillans*) lives in the Western Pacific at depths where little light penetrates. It emits flashes of light from groups of light-emitting cells, using energy from ATP and an enzyme (luciferase). The flashes of light are used to attract the small fish on which it feeds.

How is thermal energy generated and lost in living organisms?

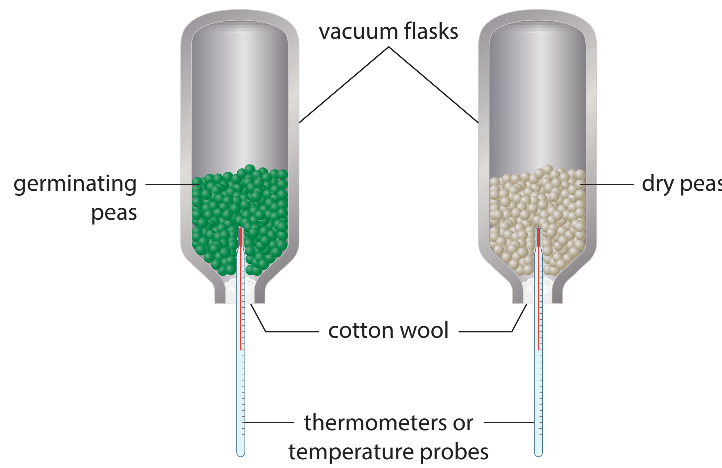
METABOLISM

Whenever energy changes from one form to another inside cells, some of it is changed into thermal energy. The energy change causes any particles involved to vibrate or move around more rapidly, so their temperature rises. Thermal energy is also generated during most chemical reactions—the products of the reaction are at a

▼ Despite cold winter weather and light clothing, these hockey players are warm, but the umpire standing behind needs more insulation

higher temperature than the reactants, because some chemical energy changes into thermal energy. For example, we experience a temperature increase when we run. Chemical energy in glucose is used to generate the kinetic energy of our moving body, but at the same time some of the chemical energy of the glucose changes to heat in our muscles.

All normal cellular activities therefore generate thermal energy. This is true for all organisms and can be demonstrated with a simple experiment using vacuum flasks and peas.

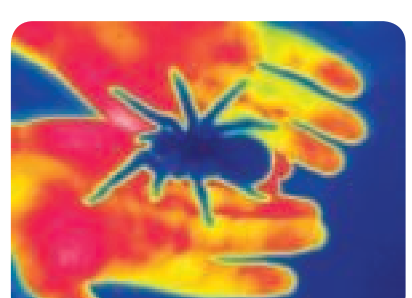


Generation of thermal energy in living organisms often makes them hotter than their surroundings. Heat passes from a hotter to a colder system, so living organisms usually lose heat to their surroundings. There are of course exceptions to this—you may be able to think of some. They are only ever temporary—all organisms generate thermal energy and eventually lose it to the environment in the form of heat.

Data-based question: Infrared photography

Some cameras can take photographs using infrared radiation instead of visible light. The images that they produce show the temperature of the subjects. This image shows a tarantula spider in a person's hands. The temperature of the dark blue areas was coolest (22.8°C or less) with increasing temperatures showing as green, yellow, orange and red (35.9°C or more).

1. How was the camera able to measure the temperature of the spider and the hands?
2. Which was losing more heat to the surroundings, the spider or the hands? Give reasons for your answer.
3. Explain the temperature difference between the palms of the hands and the fingers.
4. Was the spider losing heat to the environment or gaining heat from it? Explain your answer.

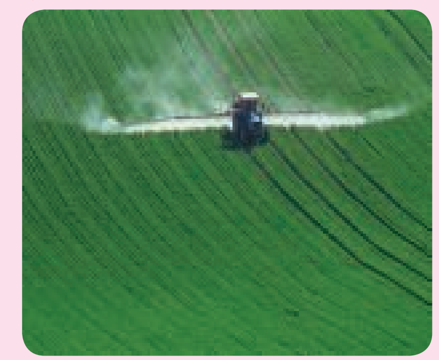


ATL Thinking in context

How can we make human energy use more sustainable?

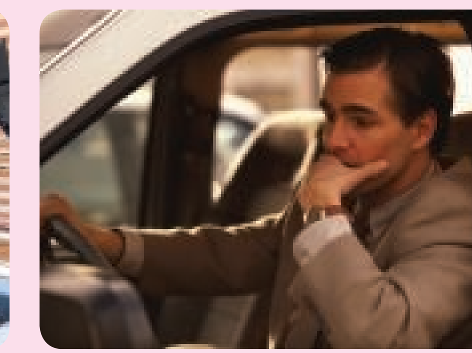
You can explore this issue by debating the answers to these questions:

1. The total energy requirements of humans on Earth are huge. What are the reasons for this?
2. Energy in food is released by respiration to fuel activities in our cells. Are there any humans living on Earth today that do not use any other energy source apart from food?
3. Is food production for humans sustainable?
4. What are the sources of energy other than food that humans use?
5. The photographs show one person exercising on a rowing machine and another commuting to work in a car. What is the source of energy in each case and what energy conversions are happening in their daily lives?
6. What can we do in our everyday lives to make human energy use more sustainable?



▲ Spraying pesticide on a food crop

▲ Exercising on a rowing machine



▲ Commuting to work

How do animals obtain energy?

ECOLOGY

Animals obtain their energy by consuming other organisms. Each cell in an animal's body is supplied with substances produced by digesting the consumed organism. These substances contain chemical energy. Fats and carbohydrates are particularly useful as sources of energy.

We can divide animals into categories according to what they consume. These are called trophic groups.

- Animals that consume plants are called primary consumers.
- Animals that consume primary consumers are called secondary consumers.
- Animals that consume secondary consumers are called tertiary consumers.
- Animals that consume dead organic matter and micro-organisms are detritivores.
- Plants are not consumers because they make their own food instead of obtaining it from other organisms. They are in a trophic group called producers.

Trophic levels

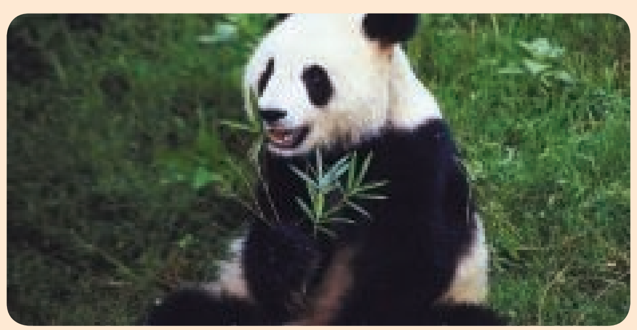
Study the photographs in the table and deduce the trophic level of each organism.


▲ Tiger


▲ Monarch butterfly caterpillar

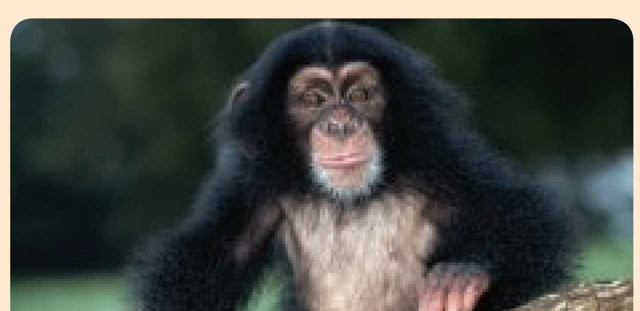

▲ Mosquito


▲ Whale shark


▲ Panda


▲ Potato aphid


▲ Dog tapeworm


▲ Chimpanzee

Interactions between species due to feeding are explored more fully in Chapter 6.

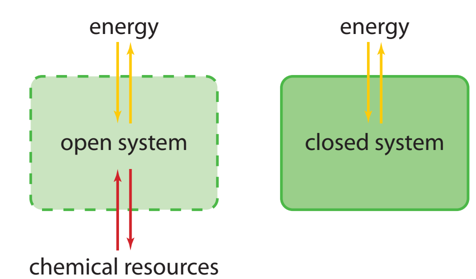
How does energy enter and leave ecosystems?

You have already seen in this chapter that living organisms cannot live alone. They depend on other organisms for supplies of energy and much more. They also depend on their non-living surroundings of air, water, soil and rock. Biologists have therefore developed the concept of an ecosystem, which is an ecological system such as a lake or a forest. An ecosystem is composed of all the organisms in an area together with their non-living (abiotic) environment.

Systems are an important concept in biology. Here we introduce the concept and in the later chapters that take systems as the key concept we shall consider them more fully.

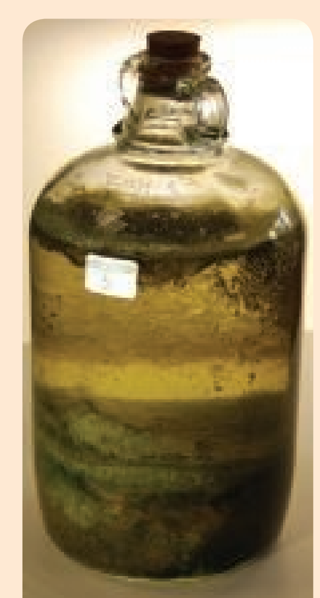
A system is a set of interacting or interdependent components. There are two main types of system:

- **Open systems** where resources can enter or exit, including both chemical substances and energy.
- **Closed systems** where energy can enter or exit, but chemical resources cannot be removed or replaced.




▲ Forest ecosystems are sustained by sunlight, but most river ecosystems are sustained by the energy in dead organic matter that enters the river

Making a mesocosm


◀ A glass jar was filled with water and mud from a pond and then sealed to create a closed system. Since then it has been kept on a sunny lab windowsill. When the photograph was taken it had been there for 18 years. Layers of differently coloured bacteria have developed including green and yellow photosynthetic types. This type of small experimental ecosystem is called a mesocosm. You could make up a mesocosm to investigate how closed systems function, but you must ensure that no organisms are harmed if you do this.

1. a) What is the only thing that has entered the mesocosm since it was set up?
   b) What is the only thing that was lost from the mesocosm?
2. Explain whether bacteria that rely on aerobic respiration for their energy could survive in the mesocosm.
3. Explain whether life could be sustained in the mesocosm for millions of years, or whether it will inevitably die out after a time.
4. Discuss whether larger organisms than bacteria could evolve in the mesocosm.

▲ Sunlight sustains shallow coral reefs, but does not penetrate far below the surface. What is the energy source there?

Most natural ecosystems are open, with some chemical substances entering and other substances leaving. In all ecosystems, living organisms generate thermal energy and cannot change this into any other more useful form of energy. You might expect the temperature of the organisms and indeed the temperature of the whole ecosystem to increase. This does not happen because the organisms lose heat to the surroundings and the ecosystem as a whole loses energy to other systems.

The amount of energy in an ecosystem will decrease and the organisms will die unless energy lost as heat is replaced by energy entering the ecosystem. In most ecosystems, energy enters as sunlight. There are also some ecosystems that are sustained by supplies of dead organic matter from other ecosystems or by inorganic chemical reactions.

Data-based question: Energy flow in a deep-water ecosystem

The diagram shows energy flow in deep water in the Bay of Quinte on the northern shore of Lake Ontario, Canada. There is little or no photosynthesis in this ecosystem. Micro-organisms feed on dead organic matter that sinks down from surface waters and that comes from organisms which defecate and die in the deep water. Detritivores feed on the micro-organisms mostly by filtering the lake water. Carnivores are larger organisms that feed on the detritivores. The numbers indicate energy flow in kilojoules per square metre per day (kJ m^{-2} day^{-1}). There are small energy losses from this ecosystem due to insect larvae maturing into flying adults and migrating from the lake. These losses are not shown on the diagram.

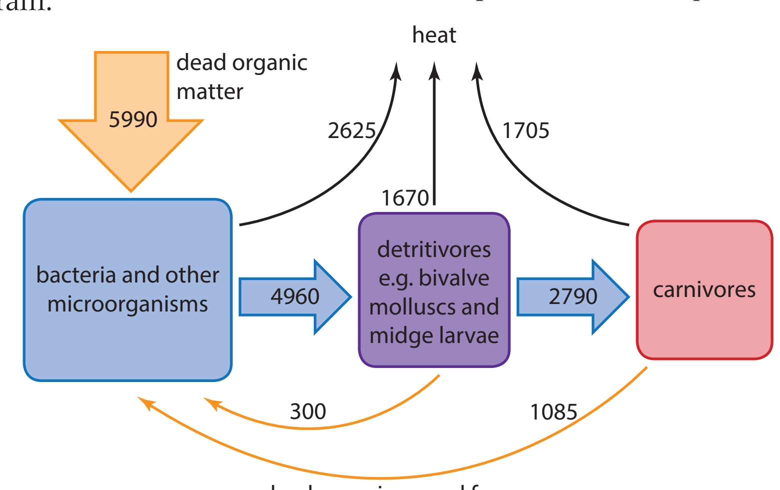
1. Suggest a reason for the lack of photosynthesis in this ecosystem.

2. State which group of organisms releases most energy in the form of heat from respiration.

3. **a)** Of the 4960 kJ of energy that the detritivores take in, 33.7% is lost as heat. Calculate the percentage of the energy taken in by carnivores that is lost from them as heat.

b) Suggest reasons for the difference in the percentage of energy taken in that is lost as heat.

4. Deduce with reasons whether this is an open or a closed system.



What prevents long food chains from developing?

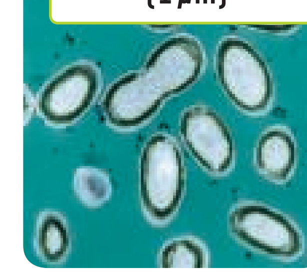
ECOLOGY

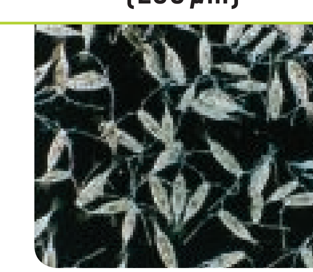
A food chain is a series of organisms, each of which feeds on the previous organism in the chain. Food chains start with a producer and continue with a primary consumer, secondary consumer and so on. When real food chains are studied, they rarely extend beyond a tertiary consumer and very little food gets beyond that stage. A terrestrial food chain is shown below:

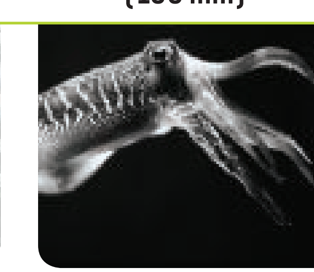
grass → zebra → lion

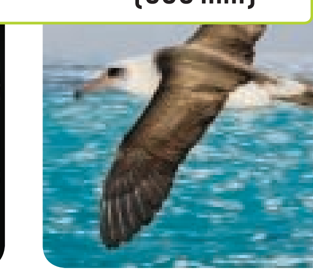
The marine food chain shown here gives the sizes and typical lengths of the organisms.

cyanobacteria (1 μm) → copepods (200 μm) → squid (100 mm) → albatross (800 mm)









To explain the reasons for food chains rarely extending beyond four stages, let us consider the lion and the zebra. The lion is dominant in the sense that it can catch and kill a zebra to obtain the chemical energy contained in its body. But the zebra has already used up much of the energy that was in the grass that it ate and this energy has been lost as heat. Less than 10% of the energy that was in the grass remains in the bodies of the zebras. Lions and other secondary consumers therefore inevitably get less energy than zebras and other primary consumers. If there are tertiary consumers in a food chain, they get even less of the energy. So, an animal can increase its supply of energy by feeding at an earlier stage in the food chain.

We could ask the question "Why don't lions increase their supply of energy by eating grass?". The answer is that they are not well adapted to do this—they are adapted instead to kill and digest prey. Zebras are far better at feeding on grass than lions and they therefore obtain much more energy from the ecosystem. Perhaps it is the zebra and not the lion that is dominant.

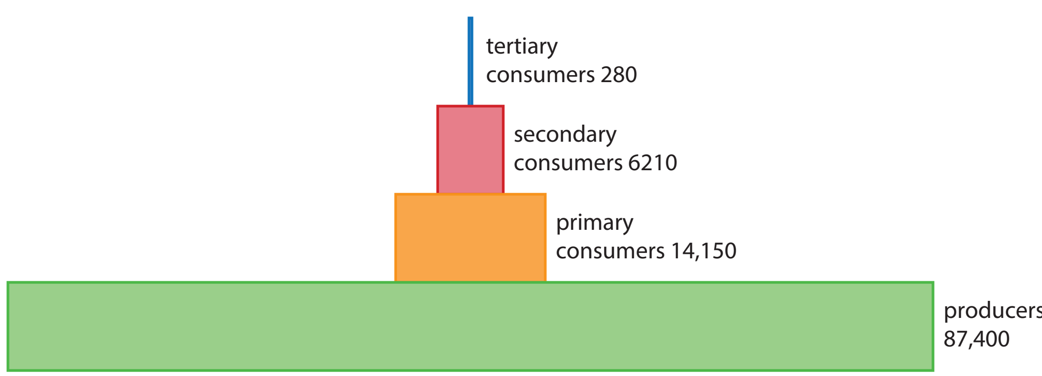
Which is my trophic level?

Humans can be primary, secondary or tertiary consumers, depending on what food we are eating. Find examples of foods that place us at each of these levels. Thinking globally, which trophic level is best for using energy efficiently, given that the human population is already higher than 7 billion?

- Select a food from this barbecue—what trophic level are you at if you eat it?

Data-based question: Pyramids of energy

The chart shows data from the Silver Springs River in Florida, USA. This type of chart is called a pyramid of energy. Each bar represents the amount of energy taken in by all the organisms in a trophic group. The units are kilojoules per square metre per year (kJ m^{-2} $year^{-1}$)



1 a) Calculate the amount of energy taken in by producers that does not pass to primary consumers.

b) Suggest two possibilities for what happens to this energy, assuming that the producers do not have more energy at the end of the year than at the start.

2 a) Of the energy taken in by primary consumers, 43.5% eventually passes to secondary consumers. Calculate the percentage of energy taken in by secondary consumers that passes to tertiary consumers.

b) Explain how energy can pass from one consumer to another.

3. There are no quaternary consumers in this ecosystem. Explain the reasons for this.

Summative assessment

Statement of inquiry

Humans need to find sources of energy that do not cause harmful and irreversible changes to ecosystems and the environment.

Introduction

This assessment is based principally on a report entitled *Oil palm plantations: threats and opportunities for tropical ecosystems*, published by the UNEP Global Environmental Alert Service (GEAS) in 2011 and available at https://na.unep.net/geas/archive/pdfs/Dec_11_Palm_Plantations.pdf To begin the assessment, read the report carefully.

Energy in ecosystems

1. Energy cannot be created or destroyed but can change from one form to another. Deduce what change happens in these cases.

   a) Rainforest is cut down and burned to clear land for oil palm plantations. [1]

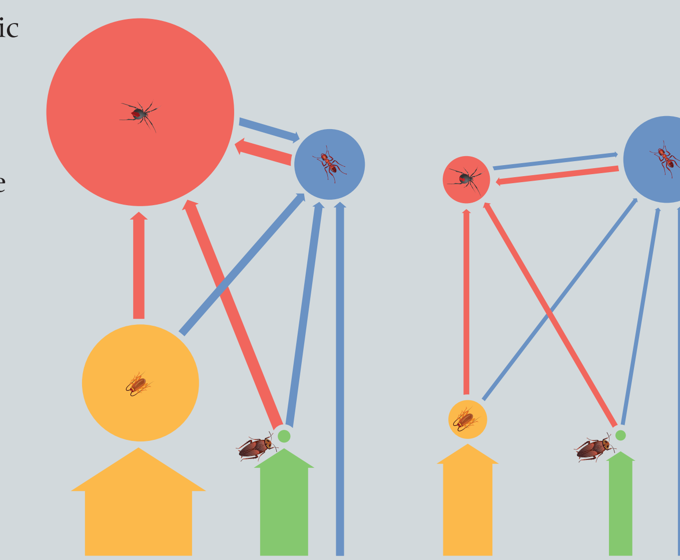
   b) Peat swamps are drained, allowing the peat to oxidize. [1]

   c) Sunlight is absorbed by palm leaves and oil is produced. [1]

   d) Palm oil is used as biodiesel in a vehicle. [1]

   e) Food containing palm oil is eaten by a person in Europe or the USA. [1]

2. The diagrams here show energy flows between trophic groups of animals in a natural rainforest (left) and an oil palm plantation (right). The animal groups are primary consumers (green), detritivores (yellow), carnivores (red) and omnivores (blue). The size of the circles indicates the biomass of the groups of animals and the width of the arrows indicates the amount of energy flowing from one group to another.



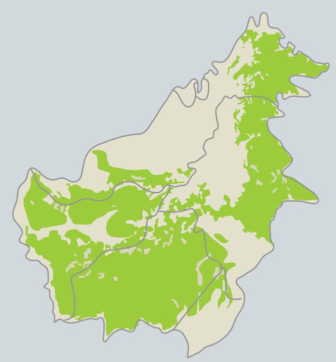
   a) Compare and contrast the source of energy for herbivores and detritivores in the natural rainforest. [2]

   b) What changes in energy flow happen when an area of natural rainforest is replaced by an oil palm plantation? [1]

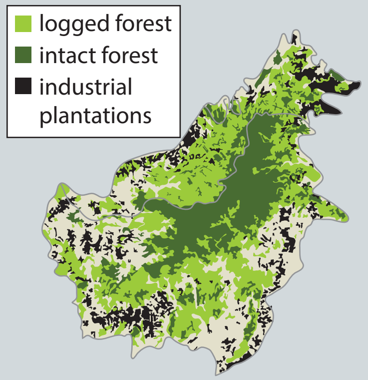
   c) State the reason for the much lower biomass of carnivores in the oil plantation than in the natural rainforest. [1]

   d) Suggest a reason for a higher biomass of omnivores in the oil palm plantation than the natural rainforest. [1]

3. One hundred years ago there were probably more than 230,000 orangutan (*Pongo pygmaeus*) in their natural tropical rainforest habitats on Borneo and Sumatra. Population estimates by the World Wide Fund for Nature in 2016 were 41,000 on Borneo and 7,500 on Sumatra. The maps here show the parts of Borneo that orangutan inhabited in 1930 and the parts of the island where there was natural intact forest, logged forest, and plantations of rubber trees and oil palms in 2010.



▲ Areas of Borneo inhabited by orangutan in 1930 (in green)
Source: The Ministry of Forestry, 2009



▲ Intact and logged forests, as well as industrial plantations in Borneo in 2010
Source: Gaveau DLA et al (2014), PLoS ONE 9(7): e101654. doi:10.1371/journal.pone.0101654

a) Analyse the information in the maps to assess whether or not:

i) orangutan originally inhabited all areas of forest on Borneo [1]

ii) plantations of rubber or palm oil have been established in areas formerly inhabited by orangutan [1]

iii) areas of intact forest remain where orangutan were living in 1930. [1]

b) Discuss whether logging or clearance of forest for plantations has had more harmful effects on orangutan. [2]

Measuring the energy content of vegetable oils

4. The table shows how much oil is produced per hectare (100 m × 100 m) when four different crops are grown and also the total global area of their production.

Oil crop	Average oil yield (kg ha^{-1} $year^{-1}$)	Planted area (million hectares)
Soybean	400	94.15
Sunflower	460	23.91
Rapeseed (canola)	680	27.22
Oil palm	3620	10.55

The yield of oil palm crops in kilograms per hectare is much higher than the other three crops, but to determine whether the energy yield per hectare is higher, the energy content of the different oils is needed.

a) Suggest a testable hypothesis for the relative amount of energy in palm oil and one other oil from the table. [2]

b) Design an experiment to test your hypothesis by measuring the energy content of the two oils. This should include:

i) the types of oil that you will test [2]

ii) how you will measure the energy content of the oil [5]

iii) details of the variables you must keep constant in the experiment [3]

iv) risks and how you will minimize them. [3]

Analysis and evaluation

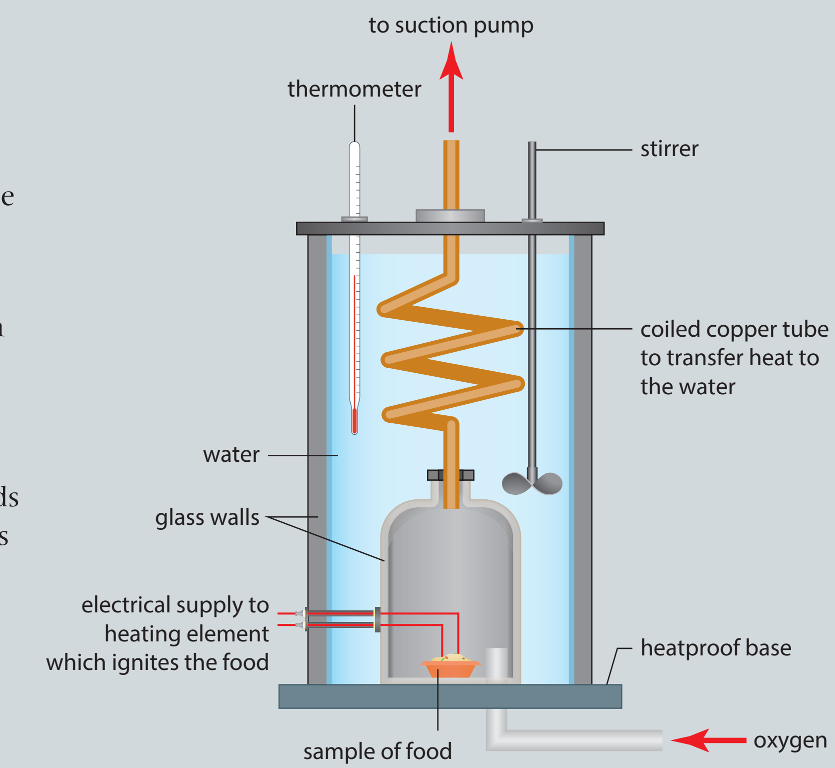
5. a) Present the results of your experiment to measure the energy content of oils in a clear and detailed results table. Remember to include row and column headings and SI units for quantitative variables. [3]

b) Display the results using a suitable type of graph or chart. [3]

c) Use calculations to evaluate the energy yields per hectare of palm oil and the other crop that you have investigated. [3]

d) Suggest scientific reasons for the differences in energy yield between the crops. [3]

e) The diagram shows a food calorimeter which is designed to measure the energy content of foods accurately. Suggest how it improves on your method in three ways. [3]



Sustainability of palm oil production

The article here was posted online in 2015 at http://theconversation.com/palm-oil-scourge-of-the-earth-or-wonder-crop-42165.
It was written by Denis J Murphy, who is Professor of Biotechnology at the University of South Wales, where he is an independent researcher and advisor to organizations that include the Food and Agriculture Organization of the United Nations and the Malaysian Palm Oil Board.

Read the passage and then answer the questions below.

Palm oil: scourge of the earth, or wonder crop?

If you happen to mention palm oil to most people outside of Asia you are unlikely to get a particularly positive reaction. Over recent years, media coverage of palm oil has typically included images of displaced orangutan and burning, degraded tropical forests. There has been a feeling that palm oil is an evil that needs to be stopped. Indeed, in some of the richer countries there have been attempts to organize consumer boycotts of palm oil products ranging from cosmetics to chocolate. Examples include France, the United Kingdom and Australia. But there is another story about palm oil that is much less frequently heard, especially in richer countries. This is a story about an ancient and bountiful African tree whose fruits provide a wholesome, vitamin-rich oil that feeds 2 billion to 3 billion people in 150 countries every day.

The oil palm tree has been cultivated as a source of food and fibre by people in western Africa for as much as 4,000 years and was harvested by our hunter gatherer ancestors for tens of millennia. Palm oil is a uniquely productive crop. On a per hectare basis, oil palm trees are 6–10 times more efficient at producing oil than temperate oilseed crops such as rapeseed (canola), soybean, olive and sunflower. The trees also have a productive lifetime of around 30 years. Soil in oil palm plantations is rich in organic content and is less disrupted compared to temperate, annual oil crops where highly destructive annual ploughing of the soil is required.

In 2014, the total estimated global production of palm oil was almost 70 million tonnes (Mt). Over 85% is exported from Indonesia and Malaysia, mostly to India and China, where the fruit oil is used in food, including as a cooking or salad oil, and in a wide range of processed food products. If oilseed crops were to replace palm oil, it would require at least 50 million additional hectares of prime farmland just to produce the same amount of edible oil.

The seed oil from palm is rich in lauric acid, a critical component in many cosmetics and cleaning products. Much of this type of palm oil is exported to Europe where it is used in toothpaste, washing up liquids, shower gels and laundry detergents. The only viable alternative oil that is rich in lauric acid comes from coconut, but the oil yield of this plant is less than 10% of palm oil. To completely substitute coconut for palm oil would require cultivating ten times as much tropical land. This is rarely realized by consumers who choose to use products containing coconut oil instead of palm oil.

Another misconception is that palm oil is overwhelmingly a "big business" crop. In fact, there are about 3 million smallholder growers, nearly all of whom farm individual family-owned plots. In Indonesia, which is the largest palm oil producing country, smallholder plots account for 40% of the total crop area. I have recently returned from a fact-finding visit to Sarawak where we saw some of the innovative ways that local people are growing oil palm alongside other crops.

Over the past year or so the pendulum of informed opinion has started to swing away from a simplistic view of palm oil as an unmitigated environmental scourge and towards a more nuanced approach that recognizes the genuine pros and cons of this bountiful tropical crop. One of the most encouraging developments has been the establishment of a reasonably robust and independent body to certify the environmental and social credentials of palm oil. The Roundtable on Sustainable Palm Oil, or RSPO, has a vision to "transform the markets by making sustainable palm oil the norm". The RSPO has over 2,000 members globally that represent 40% of the palm oil industry, covering all sectors of the supply chain.

There is also an increasingly active international research effort aimed at understanding the ecological and environmental impact of oil palm compared to other habitats such as rainforests and rapeseed or soybean farms. One example of this research is a recent analysis of tropical peat soils, some of which have been targeted for oil palm cultivation. When improperly farmed these soils can release large amounts of CO_2 and grow poor crops. But the analysis found some of types of peat can readily support oil palm crops without high CO_2 emissions, while others should be left un-farmed and conserved. They conclude that rather than a blanket-ban on farming peat soils, decisions should be made on a case-by-case basis depending on the type of peat.

Another study did a more rigorous life cycle assessment of oil crops, which is a measure of their overall environmental impact and found the overall ecological impact of palm oil is comparable, and sometimes superior to temperate crops. Two other studies examine the potential impact of land use and climate change on biodiversity in Borneo where a great deal of oil palm planting has occurred. The conclusions include the need to establish nature reserves in upland areas where climate change will be less severe and to improve connections between reserves and plantations with wildlife corridors.

There are undoubtedly many significant challenges facing oil palm, and further encroachment onto sensitive native forest areas should be minimized and eventually halted. But palm oil is also a uniquely efficient edible crop that is essential for food security in Africa and Asia. By working together as an international community that includes scientists, farmers, processors and consumers we aim to develop solutions to many of the problems faced by oil palm. Hopefully this will soon enable palm oil to regain its rightful place as one of the stars in the pantheon of global crops.

6. List examples mentioned in the article of science helping to address problems caused by palm oil production. [5]

7. Denis Murphy gives a strong argument in support of palm oil production. Write a counter-argument based on the harm that palm oil production has caused to tropical ecosystems in South-East Asia. Apply scientific language effectively in your argument. [5]

8. There are links in the online version of this article to the sources of information used, which are scientific papers published in journals. Explain the importance of giving sources of information. [5]