

# ENERGY TRANSFER AND BIOGEOCHEMICAL CYCLES

## Science Key Concepts Series: Biology

**FOR USE IN:** Biology Grades 9-12, (General Science Grades 7-8 optional)  
**EDUCATIONAL ADVISOR:** Dr. O. Roger Anderson, Columbia University, Professor Natural Sciences, Teachers College; and Senior Research Scientist, Lamont-Doherty Earth Observatory

### MAJOR CONCEPTS

The Food Chain, First Law of Thermodynamics, Biogeochemical Cycles.

### EDUCATIONAL OBJECTIVES

Help the student:

- To examine energy transfer, transformation, and conservation in the food chain by observing a locust, a primary consumer, in a laboratory experiment.
- To examine, in several laboratory demonstrations, the recycling of two vital natural elements in our ecosystem: carbon, and nitrogen.
- To understand fundamental experimental design, and laboratory techniques in biology and chemistry.

### BACKGROUND INFORMATION

This video demonstrates the integration between science content (what we know about science) and science methodology (how we study science). Students will observe how a number of scientific hypotheses are investigated by carefully conceived experiments. Observing the process, through which scientific knowledge is acquired, will help students understand the nature of scientific evidence in a more meaningful way.

The supply of the materials, which make up biomass, is finite. Materials such as nitrogen and carbon are repeatedly recycled as various compounds in the air, soil and living biomass. The carbon and nitrogen cycles, keep the amount of natural carbon and nitrogen available to living organisms on Earth in equilibrium. Consequently, life on Earth is able to be sustained. Plants need nitrogen, phosphorus, potassium, and carbon/hydrogen in complex sugar molecules in relatively large amounts, and these are called macronutrients. Other nutrients, such as iron, manganese and zinc, are also recycled by the decomposition of dead remains; these are needed in much smaller amounts.

### BEFORE SHOWING THE VIDEO

It may be helpful to review with students how energy flows in the food chain. Producers (plants) obtain energy from the sun to perform photosynthesis. When plants are eaten by primary (herbivores), and secondary consumers, (carnivores and omnivores) the content of the plants is transformed into energy by the consumers to sustain their own life (respiration) and to perform other tasks. It may also be important to mention the role of decomposers, which is to break down dead organisms and waste products. Given the experiment with a locust in the video on its energy intake and uses of that energy, it may be an interesting investigation to also study how a human, a secondary consumer, takes in and spends his/her energy. As a homework exercise the evening before watching the video, ask the students to estimate the energy they receive from consuming food during dinner that evening. A handout listing the energy content of typical food items can be provided. Labels on food packaging also supply information on energy content. Students will learn how to read and interpret the labels. For comparison, an adult human male consumes on average 1,000 kilocalories (kcal) in a meal. Ask the students to suggest how they spend the calories consumed. For example, for a 70-kg human male, lying still consumes 1.3 kcal/ minute; walking 4 kcal/ minute; swimming, 8 kcal /minute and running, 15 kcal/ minute. Create a balance sheet to show that the Law of Conservation of Energy is not violated. Besides activities, how else are ingested calories accounted for? Increased weight?

Energy transformation is also an important concept. For example, the sun conforms nuclear to light energy. Plants transform light to potential energy stored in glucose. Plant eaters convert the potential energy of glucose to kinetic energy as they move. Students can create a list of all common forms of energy. Other than the ones mentioned, there are electrical energy, chemical energy, heat, work, etc. Ask students to give examples of energy transformation essentially from any one form to another. For example, a galvanic cell or battery transforms chemical to electrical energy. A mechanical engine transforms the stored chemical energy in fuel to heat and work.

### CONTENT OF THE VIDEO

**The video contains the following key concepts. To play only concepts 2 or 3, simply fast-forward to its title.**

	min: sec
1. Food Chain Energy Transfer	4:50
2. The Carbon Cycle	4:40
3. The Nitrogen Cycle	4:55

These concepts are illustrated with excellent experiments, live photography, microscopy, scanning electron very high magnification computer graphics, and clarifying positioned captions.

Light is the Earth's energy source. Plants are producers and animals are consumers. Food energy ingested is: added to biomass, used in respiration, or excreted as feces. Respiration provides energy for the body's activities and loses heat to the surroundings. Energy moves through a food chain from producers, the plants, to consumers: the herbivores, carnivores, and omnivores; to decomposers.

### **The Respirometer Experiment**

This experiment demonstrates how the energy transfer from plant (grass), to a primary consumer (locust) is used by the locust, and those uses are quantitatively measured. A respirometer measures the volume of oxygen consumed by the locust, from which in turn the amount of energy used in respiration can be calculated. Further calculations also measure the conversion of the energy in the grass consumed by the locust into an increased biomass of the locust, and into feces. Since 12 kJ of energy was consumed in the amount of grass eaten by the locust, and only 11 kJ were accounted for by respiration, increased biomass, and feces, the students are asked to look for faults in the design of the experiment.

### **The Carbon Cycle**

#### **Carbon In The Ecosystem**

The element carbon is a finite resource. Carbon is present in the atmosphere, living things and soil.

#### **Uptake of CO<sub>2</sub> from the atmosphere**

In an experiment, radioactive carbon dioxide is used to measure, trace, and verify the uptake of CO<sub>2</sub> by a plant from the atmosphere. The equation for the photosynthesis of radioactive carbon is given with <sup>14</sup>C.

#### **The return of CO<sub>2</sub> to the atmosphere**

Carbon passes into animals in food eaten, Both plants and animals respire and so return carbon to the air as carbon dioxide. An experiment shows the different changes in CO<sub>2</sub> levels in the air of sealed off test tubes containing a leaf, woodlice, and a combination of both. Bicarbonate indicator in the tubes measures the level of carbon dioxide in each tube over time. Questions are asked concerning the causes of the different levels of carbon dioxide remaining in the tubes.

Decomposition Nutrients including carbon return to the soil during the breakdown of dead organisms by earthworms, fungi, and bacteria. Carbon is also returned to the air when fossil fuels and forests are burned.

### **The Nitrogen Cycle**

#### **Proteins contain nitrogen**

Nitrogen is present in protein and in DNA. The nitrogen in the air is a non reactive gas which cannot be used by plants. However, nitrates are soluble nitrogen-containing compounds, which can be used by plants to make proteins.

#### **Plant nutrition**

It is demonstrated that plants grow better with more nitrates in the soil.

#### **Nitrogen cycle**

But how do nitrates get into the soil? Lightning directly converts a small amount of nitrogen gas into nitrates. The addition of inorganic fertilizer adds nitrates immediately, while organic fertilizers slowly do so after decay and several stages in which various bacteria eventually form nitrates. The nitrogen-fixing bacteria, *Rhizobium*, converts nitrogen gas directly into ammonium ions from which other bacteria form nitrates. An experiment verifies the existence of *Rhizobium* in tiny nodules on plant roots. Graphic artwork visualizes these various pathways along with the appropriate chemical symbols.

### **AFTER SHOWING THE VIDEO**

1. The sun is the source of energy for almost all life on Earth. How does the sun generate that energy? (This question is intended to raise discussion about the thermonuclear fusion reaction that takes place in the sun. It is a chain reaction that has lasted so far for some 4.5 billion years.)
2. Plants absorb energy from the sun and use it to produce their own food. How do plants do that? The emphasis looked for in the answer is the ability of chlorophyll to capture the energy of particular wavelengths in sunlight and use it to transform simple molecules of carbon dioxide and water into complex molecules of glucose. (The formula for photosynthesis would be useful here.)
3. Starting with the human digestive system, how do we extract: energy from food that we ingest? (This discussion will lead to respiration at the cellular level.)
4. Which organism is more likely to be efficient in using the energy in grass, the locust that feeds on grass, or the bird that feeds on the locust? Why? Which human uses the energy in plants more efficiently, a vegetarian, or a person that also eats meat?
5. Energy can be measured in calories or Joules. Explain what each is and how they are related.
6. It is a truism that all life is dependent on the energy of sunlight, and eventually, will yield up all of this energy as heat energy back to the universe. Explain this based on your knowledge of how energy transfer works in food webs.
7. Trace the major steps in the nitrogen cycle. Do the same for the carbon cycle. Where in those cycles do they become essential for plants, for animals?

## REFERENCES

- Farish, D. J. Human Biology. M. Jones and Barlett Publishers Boston, 1993.  
Energy Balance, pp. 140 - 167
- Oxtoby, D. W., Freeman, W. A., and Block, T. F. Chemistry: Science of Change. 3<sup>rd</sup> ed. Saunders College Publishing: Philadelphia, 1998.  
Thermochemistry, pp. 410 - 449  
Nuclear Chemistry, pp. 612 - 646
- Raven, P. H., Berg, L. R., and Johnson, G. B. Environment. Updated 1995 Version. Saunders College Publishing: New York, 1995.  
Science Methodology, pp. 21 - 25  
Energy in Food Chain, pp. 40 - 57  
Biogeochemical Cycles, pp. 75 - 92
- Vander A. J., Sherman, J. H., and Luciano, D. S. Human Physiology 6<sup>th</sup> ed. McGraw-Hill: New York, 1994.  
Nutrient Content, pp. 630 - 637

## INTERNET WEB SITES FOR FURTHER INFORMATION

**Energy cycles:** Notes and graphics on the carbon cycle and the decomposition of biomass.

<http://www.swift.com/apase/charlotte/biomass.html>

**Flow of energy:** higher trophic levels: Notes for teachers on the efficiency of energy flow through trophic levels in an ecosystem. (Level: teacher) [http://www.sprl.umich.edu/GCL/paper\\_to\\_html/trophic.levels.html](http://www.sprl.umich.edu/GCL/paper_to_html/trophic.levels.html)

**Food chains and energy:** Basic notes covering a range of key terms in ecological energy systems. (Level: teacher) <http://www.sprl.umich.edu/GCL/paper-to-html/trophic.levels.html>

**Recycling of biomass, compost and organic waste:** Links to notes on the recycling of materials, with reference to the carbon and nitrogen cycles. [http://www.soton.ac.uk/~engenvir/index/enviro\\_index.html](http://www.soton.ac.uk/~engenvir/index/enviro_index.html)

**Recycling in the forest:** Description of the role of decomposers in bringing about the cycling of materials in the life of a forest. <http://www.panda.org/resources/publications/forest/forst2q2/page2-3.html>

**The nitrogen story:** Lively notes on the nitrogen cycle. [http://www.cems.umn.edu/~aiche\\_ug/history/h\\_s\\_n2.html](http://www.cems.umn.edu/~aiche_ug/history/h_s_n2.html)

**Note:** Some of these sources may be copyright protected.

## GUIDE WRITTEN BY

Alan K. Szeto, Associate in Chemistry. Columbia University and Doctor of Education Student Teachers College, Columbia University

The Science Key Concepts Series consists of 16 videos:

for Biology: Cells and Tissues, Cellular Energy and Metabolism, Energy Transfer & Biogeochemical Cycles, Homeostasis, Sensory Responses and Tropisms

for Physics: Electricity and Magnetism, The Electromagnetic Spectrum, Force and Motion, Molecular Motion, Waves

for Chemistry: Applied Chemistry, Electrochemistry, Radioactivity, Reactions and Energy Changes, Reactivity of Elements, Uses of Natural Resources

Distributed in Canada by:

**MARLIN MOTION PICTURES LTD.**

211 Watline Avenue

Mississauga ON L4Z 1P3

Phone: 905-890-1500 or 1-800-865-7617

Fax: 905-890-6550 or 1-800-203-8786

Email: [info@marlineducation.com](mailto:info@marlineducation.com)

Website: [www.marlineducation.com](http://www.marlineducation.com)