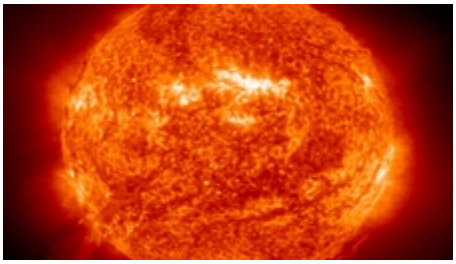
Competency 045:
Energy Transformations and Conservation of Matter and Energy



The teacher understands energy transformations and the conservation of matter and energy.

Energy exists in many forms and is defined as the ability to do work, or apply a force over a distance. Energy Story from the California Energy Commission describes energy, its ability to transform, and the kinds of energy which human consume throughout the world. Energy Systems produced by Carnegie Mellon University provides an extensive look at energy use on Earth. The sections “Energy Transformation” (page 10), “Energy and Chemical Stability” (page 18), and “Chemical Formations” (page 22) should be the main focus of your review.

Explanations of the science content behind each of the Descriptive Statements related to this competency are given in each of the following sections.

Subtopics:

- Processes that Generate Energy in the Sun (Nuclear Fusion)
- Conservation of Matter
- Sources of Electrical Energy and Energy Transformations for Human Use
- Exothermic and Endothermic Chemical Reactions
- Energy Transfer in a Variety of Situations
- The Conservation of Energy
- Applications in Life and Earth/Space Science

Processes that Generate Energy in the Sun (Nuclear Fusion)

The beginning teacher describes the processes that generate energy in the sun and other stars.

Key Concepts:

- Electromagnetic radiation produced by the sun is the major source of energy on Earth. In the sun, a process called nuclear fusion yields electromagnetic radiation. During nuclear fusion, atoms are fused together to form the nucleus of a larger atom, releasing energy in the process.
- In the sun, this reaction mainly occurs when 4 hydrogen atoms (4 protons) fuse into a helium atom (2 neutrons and 2 protons).

- Due to electromagnetic forces, protons repel each other strongly. In order to fuse them together, a tremendous amount of energy and pressure must be present to overwhelm the repulsion. Such conditions only occur at the core of the sun.
- The energy of this nuclear reaction is released as short wavelength gamma radiation in the core of the sun. However, it takes around 100,000 years before it reaches the surface at which time it has changed into longer wavelength radiation like X-rays, ultraviolet and visible light, and infrared.

Resources:

Energy of the Sun. The NASA website, The Energy of the Sun, details the history and basics of nuclear physics, the basis for the sun's energy, the different kinds of stars, and supernovas.
Energy from Nuclear Fusion. The multi-step process of nuclear fusion, which occurs in the sun, is described in an article by Jim Doyle.

Conservation of Matter

The beginning teacher applies the law of conservation of matter to analyze a variety of situations (e.g., the water cycle, food chains, decomposition, balancing chemical equations).

Key Concepts:

- In general, the amount and of matter in a closed system will remain the same, regardless of the occurrence of chemical or physical changes. (Nuclear reactions represent an exception to this statement.)
- For this reason, chemical equations must be balanced so that the number of each type of atom on either side of a reaction is the same. For example, the reaction for cellular respiration contains 6 carbon atoms, 12 hydrogen atoms, and 18 oxygen atoms on each side of the equation.
  $C_6H_{12}O_6 + 6O_2$? $6H_2O + 6CO_2$
- Even though matter is constantly shifting between different forms during the biogeochemical cycles on Earth, the amount of matter remains the same. For example, water changes from ice to liquid to gas during the water cycle, but the overall quantity of H2O on Earth stays approximately constant (the amount of water on Earth can fluctuate slightly due to various geological and biological processes).

Resources:

Chemical Equations. VisionLearning demonstrates how to balance a chemical equation and briefly discusses the conservation of matter.
Balancing Chemical Equations. The art of balancing equations in chemistry is modeled in this video from Khan Academy.

Global Carbon Cycle. Dr. Nancy Moreno explains how carbon cycles through the living and nonliving components of Earth's systems.

The Water Cycle. Earth's water is always in movement. This page from the USGS explains the process.

Sources of Electrical Energy and Energy Transformations for Human Use

The beginning teacher describes sources of electrical energy and process of energy transformation for human uses (e.g., fossil fuels, solar panels, hydroelectric plants).

Key Concepts:

- The sources of energy used by humans are the sun and its derivatives, the nuclear energy obtained from certain kinds of atoms, the gravitational pull of the moon and sun, and the heat generated from the earth's molten core and mantle.
- These sources of energy are used for transportation, heating, and electricity. Electricity in most cases is produced by generators, which are composed of coils of an electric conductor and a magnet. When either the conductor or the magnet is moved in relation to one another, the mechanical energy of this movement is converted into electric current in the conductor.
- The vast majority of energy used by humans once existed as sunlight.
    - Solar panels obviously work by sunlight, using certain materials that interact with photons to induce a flow of energized electrons (current).
    - The chemical energy in wood (burned for warmth or cooking) was produced by photosynthesis.
    - The chemical energy in fossil fuels also derives from photosynthesis that occurred thousands or even millions of years ago. Because fossil fuels take a long time to form and replenish, oil, coal, and natural gas are considered to be non-renewable resources. Fossil fuels also release greenhouse gases and contribute to climate change. They are the most widely used energy sources on Earth (82% of the energy consumed in the USA comes from fossil fuels).
    - All human food also contains chemical energy derived from photosynthesis, either directly in the form of plant-based foods (grains, fruits and vegetables), or indirectly through the consumption of animals that fed on plants or other animals (which in turn fed on plants).
    - Evaporation caused by sunlight produces water vapor, which eventually falls as rain and flows in rivers. The kinetic energy of the water flow is then used to spin a turbine in hydroelectric power plants.
    - Air, warmed by the sun, is the primary cause of wind. Warm air rises, and cooler air sinks; these movements are referred to as convection currents. Hence, wind energy is another type of solar energy.
- Nuclear energy produced by humans typically involves the fission of Uranium 235. As opposed to the fusion which occurs in the sun, fission takes place when the nucleus of a large atom breaks down into smaller nuclei. This process, along with fusion, actually violates the conservation of mass in that a small amount of matter is converted to a vast amount of energy according to Einstein's equation: $E = mc^2$. Because there is a fixed amount of Uranium 235 on our planet that is never replenished (Uranium and heavy atoms are only produced through fusion in super novas), nuclear energy is non-renewable.
- Tidal energy also can be harnessed by using a flow of water to spin a turbine. However, the tides are a result of the gravitational pull of the sun and moon, centrifugal acceleration forces, and the earth's rotation. Practical uses of this form of energy are somewhat limited by the number of areas that experience considerable tidal flow.
- Geothermal energy arises mainly from radioactive decay occurring in the earth's mantle, but friction of the circulating magma and latent heat left over from the formation of Earth also contribute to it. Earth's crust typically is cool and insulated from this heat, but in some areas where the crust is thin, heat seeps through and can be used to generate electricity.

Resources:

How Does a Generator Work? Explains how mechanical energy can be converted into electricity by a generator puts the various energy sources into a functional context. Hydroelectric Power. How do we get electricity from water? This site from the USGS eplains how hydorelectric and coal-fired plants produce electricity.

Energy. To learn more about different energy sources used by humans, their limitations, and the future of energy production in the world, click on this article from Tulane University.

Energy: Innovating to Zero. The philanthropist and entrepreneur, Bill Gates, gives a presentation on energy, our reliance on fossil fuels, the impacts this has on our planet, and the innovations that need to occur to allow humans to prosper in the future.

Exothermic and Endothermic Chemical Reactions

The beginning teacher understands exothermic and endothermic chemical reactions and their applications (e.g., hot and cold packs, energy content of food).

Key Concepts:

- Because the electrons in chemical bonds have less energy (they are in a more stable state) than free electrons, electrons release energy when they form bonds. “Bond energy” represents the amount of energy that is released when a chemical bond is formed. It also corresponds to the amount of energy necessary to break a bond.
- Exothermic reactions release energy into the environment in the form of heat, light, or sound. They occur when the bond energy of the products is more than that of the reactants.
- Endothermic reactions must absorb energy from the environment in order to take place, resulting in a cooling of the surrounding areas. These reactions occur when the bond energy of the products is less than that of the reactants.
- The digestion of food in our bodies is an example of exothermic reactions. Energy is released when the bonds in glucose (a sugar molecule) are broken. This diagram illustrates this reaction with respect to bond energy:

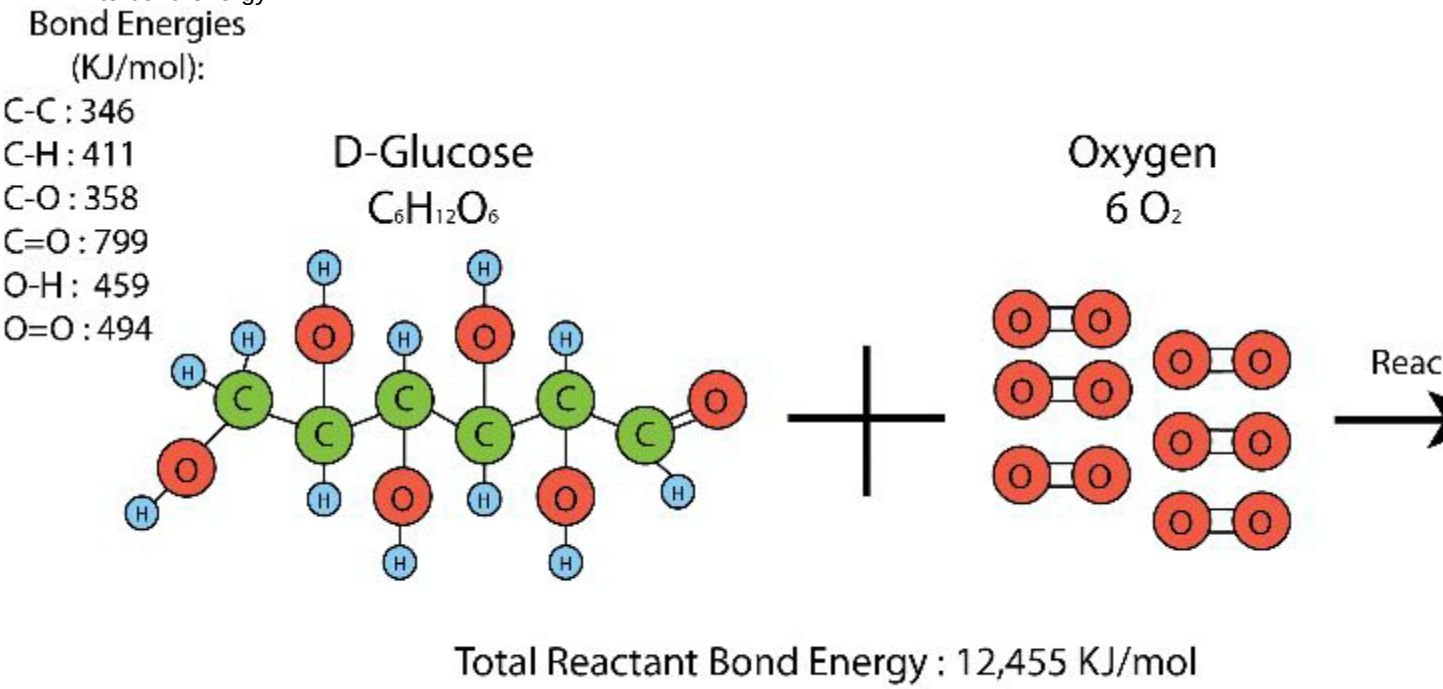


Diagram: Wikimedia Commons

Counter-intuitively, this diagram illustrates that bond energy is inversely proportional to the amount of energy possessed by the electrons in a bond. For example, C-C, C-O, and C-H bonds are the main sources of energy in a glucose molecule, because they have the lowest bond energy.

Resources:

Exothermic and Exothermic Reactions. Dr. Richard Nafshun teaches about the nature of exothermic and exothermic reactions and provides an example of each. He then explains the concept of activation energy as it relates to each type of reaction.
How Do Instant Hot and Cold Packs Work? Ask the Scientist from Michigan State University provides the answers to this question.

Energy Sources. Watch this video from K8 Science to learn about energy in foods and calories; and how to conduct a related experiment with students.

Energy Transfer in a Variety of Situations

The beginning teacher applies knowledge of the transfer of energy in a variety of situations (e.g., the production of heat, light, sound, and magnetic effects by electrical energy; the process of photosynthesis; weather processes; food webs; food energy pyramids).

Key Concepts:

- Energy exists in many different forms, but all of the forms have or potentially have the ability to apply a force over a distance. These forms of energy are interchanged constantly in the world around us.
- Some notable energy transformations are described below.
    - Electricity to heat: Heat is produced by friction when flowing electrons collide with other particles in a conductor.
    - Electricity to light: Light can be produced from electricity in a variety of ways. Incandescence refers to the heating of a conductor to the point that it glows, making it very inefficient source of light. Florescence occurs when electrons flow through a tube of gas, emitting radiation as they are incorporated into and out of the atoms of the gas.
    - Electricity and magnetism. An electromagnet is produced when electricity is run through a coil of wire. Because the electromagnet has negative and positive ends (poles), it is referred to as a magnetic dipole. The dipole produced depends on the direction in which the current is flowing through the wire (current flows from negative to positive poles). The interactions between an electromagnet and a fixed permanent magnet are the basis of how electric motors (electricity to mechanical energy) and speakers (electricity to sound vibration) work.
    - Light to chemical. Green plants absorb sunlight, which supplies the activation energy needed to synthesize (manufacture) sugar molecules. This process, called photosynthesis, is described in the following reaction:
      $6CO_2 + 6H_2O + \text{Sunlight} \rightarrow C_6H_{12}O_6 + 6O_2$
      After the reaction, the energy can travel in the form of chemical bonds (in food molecules) through a food chain to consumers, until it is broken down to do work in an organism.

Resources:

Energy Transformations. Answers to commonly asked questions about energy, including examples of energy transformation.
How Do Speakers Work? The speaker is an example of a electromagnet/permanent magent interaction which produces sound vibrations relative to the frequency of the AC current passing through the electromagnet.

Energy, Ecosystems and the Atmsophere. Dr. Nancy Moreno talks about energy from the sun and how it enters the food chain through plants.

Energy Transformations. Quiz yourself on the content you've learned about energy transformation using the following resource from McGraw-Hill Education.

The Conservation of Energy

The beginning teacher applies the law of conservation of energy to analyze a variety of physical phenomena (e.g., specific heat, nuclear reactions, efficiency of simple machines).

Key Concepts:

- The law of the conservation of energy states that the total amount of energy in an isolated system remains constant, despite the energy transformations that take place.
- Specific heat refers to the amount of heat required to raise the temperature of one gram of a material by one degree Celsius. Calorimetry is a method used to measure the quantity of energy transformed in a system based on the temperature change and specific heat of its components. For example, one can measure how much energy is released by a chemical reaction occurring in water by measuring the temperature change of the water and container holding the water. This calculation works because total energy of the system stays the same despite the chemical/heat energy transformation.
- All machines waste energy when they convert one energy type to another. The amount of useful work done divided by the amount of energy put in is called efficiency (Work output / Energy input = Efficiency). Typically the energy is wasted in the form of heat due to friction.
- Energy also is conserved during collisions. When two objects collide, they both start off with kinetic energy, and bounce off each other with either the same amount of or less kinetic energy. Any reduction of kinetic energy is due to heat generation from the friction of impact.
- Nuclear reactions actually violate both the conservation of energy and matter. Einstein's famous "E = mc2" equation shows that matter can be annihilated to create energy and vice versa. This discovery led to refinement of these laws into the "law of conservation of mass-energy."

Resources:

Conservation of Energy. Energy is one of the physical quantities that is conserved in our universe. This page from the Franklin Institute Science Museum gives an overview of the topic.
Energy Efficiency. The Electropaedia website discusses the efficiencies of various kinds of electrical generators. The same principles apply to simple machines.

Momentum and Collisions, from the University of New South Wales, goes into greater detail on the conservation of momentum and energy in elastic (kinetic energy is conserved) and inelastic (kinetic energy is converted to heat) collisions.

Applications in Life and Earth/Space Science

The beginning teacher understands applications of energy transformations and the conservation of matter and energy in life and earth/space science.

Key Concepts:

- Sunlight is the main energy source for life on Earth. Green plants and other organisms, such as blue-green bacteria, capture energy from sunlight and use it to form chemical bonds in sugar molecules. This process is called photosynthesis. All other organisms rely on energy captured by photosynthetic organisms.
- A few kinds of organisms can use energy stored in inorganic chemical compounds, such as the chemical energy that is present in the minerals found in water of hot springs or undersea vents.
- Organisms that can produce complex organic molecules from simple inorganic molecules using energy from light or inorganic chemical reactions are referred to as producers or autotrophs.
- Organisms that rely on other organisms for their energy and food supply are called consumers or heterotrophs. There are many kinds of consumers. Herbivores eat only plants; carnivores eat other animals; detritivores (such as mites, earthworms and snails) feed on plant and animal remains;

decomposers (such as bacteria and fungi) further break down and digest dead plant and animal materials.

- The energy and matter stored by producers is passed from organism to organism through series of steps called a food chain. In most ecosystems, feeding relationships are more complex and are best represented as a food web. Each step in a food web is called a trophic level. Only about 10% of the total available energy is transferred from on trophic level to the next; the rest of the energy becomes unavailable as heat.
- Matter continuously is recycled between living and nonliving components of the Earth. Living organisms transform matter, but do not use it up. Chemicals that form the building blocks of the bodies of living organisms are referred to as nutrients. Every living organism needs nutrients to carry out essential life functions. Nutrients are passed among organisms and the environment through biogeochemical cycles.

Resources:

Energy, Ecosystems and the Atmsophere. Dr. Nancy Moreno talks about energy from the sun and how it enters the food chain through plants.
Autotroph. National Geographic Education explains the critical role of autotrophs, also known as producers, in food chains.

Energy Cycle in Living Things. Good overview of the energy cycle for life, which is fueled by the sun.

Bio-Geo-Chemical Cycles. Geography4Kids offers an easy-to-understand summary of the biological, geological and chemical processes that enable life to exist on Earth.