Energy and Matter*

In common usage, **matter** is anything that has both mass and volume (takes up space). A more rigorous definition is used in science: matter is what atoms and molecules are made of. Matter commonly is said to come in four states (phases); solid, liquid, gas and plasma.

Energy can be defined as the capacity for doing work. It exists in many different forms and can be transferred from one place to another by the processes of conduction, convection and radiation. Some of the more important forms of energy include: heat energy, electromagnetic radiation, and chemical energy. **Heat** is defined as energy in the process of being transferred from one object to another because of the temperature difference between them. Temperature variation across space can be generated by a number of different processes. **Chemical energy** comes in many different forms. However, the most important form, as it relates to this course, is the chemical energy generated by life in various types of organic molecules through the process of photosynthesis. **Potential energy**, as the name implies, is energy that has not yet been used, thus the term potential. **Kinetic energy** is energy in use (or motion). A tank of gasoline has a certain potential energy that is converted into kinetic energy by the engine.

All physical objects in our universe are constructed of matter. At the atomic level, matter can be made up of one single element type or it can be the chemical combination of a number of different elements called compounds. Life can synthesize and organize matter into complex organic molecules and structures like cells and organs.

Einstein suggested that matter and energy are related to each other at the atomic level. Energy and matter are also associated to each other at much larger scales of nature. The laws of thermodynamics describe some of the associations between energy and matter as they relate to the Universe.

The **first law of thermodynamics** is often called the **Law of Conservation of Energy**. This law suggests that **energy** can be transferred from one system to another in many forms. Also, it can not be *created* or *destroyed*. Thus, the total amount of energy available in the Universe is constant.

$$E=mc^2$$

In the equation above, energy (E) is equal to matter (m) times the square of a constant (**c**). Einstein suggested that energy and matter are interchangeable. His equation also suggests that the quantity of energy and matter in the Universe is fixed.

The second law of thermodynamics predicts that entropy of an isolated system always increases with time. **Entropy** is the measure of the disorder or randomness of energy and matter in a system. Heat cannot be transfer from a colder to a hotter body. As a result of this fact of thermodynamics, natural processes that involve energy transfer must have one direction, and all natural processes are irreversible. Because of the second law of thermodynamics both energy and matter in the Universe are becoming less useful as time goes on.

The Sun is the major source of energy for biotic and abiotic systems on the Earth. The Sun creates large amounts of electromagnetic radiation through atomic fusion. This solar energy travels through space decreasing in intensity with distance from the Sun. Only a small percentage of this energy emitted by the Sun is intercepted and received by the Earth. The amount of energy available at the various locations on the Earth's surface is controlled by a number of geometric and astronomical factors.

Study Questions

1. What is energy?
2. What forms does energy come in?
3. How do the three mechanisms of conduction, convection and radiation move energy from one place to another?
4. Outline the laws of thermodynamics.
5. Why is this statement true? The most important form of chemical energy, as it relates to this course, is the chemical energy generated by life in various types of organic molecules through the process of photosynthesis.

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* Adapted from Pidwirny, M. (2006). "Laws of Thermodynamics." *Fundamentals of Physical Geography*, 2nd Ed.