13.1 The Concept of Energy and Conservation of Energy

The transformation of energy is a powerful concept that enables us to describe a vast number of processes:

> Falling water releases stored *gravitational potential energy*, which can become the *kinetic energy* associated with a *coherent motion* of matter. The harnessed *mechanical energy* can be used to spin turbines and alternators, doing *work* to generate *electrical energy*, transmitted to consumers along power lines. When you use any electrical device, the electrical energy is transformed into other forms of energy. In a refrigerator, electrical energy is used to compress a gas into a liquid. During the compression, some of the internal energy of the gas is transferred to the *random motion* of molecules in the outside environment. The liquid flows from a high-pressure region into a low-pressure region where the liquid evaporates. During the evaporation, the liquid absorbs energy from the *random motion* of molecules inside of the refrigerator. The gas returns to the compressor.
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> "Human beings transform the stored chemical energy of food into various forms necessary for the maintenance of the functions of the various organ system, tissues and cells in the body."[2] A person can do work on their surroundings – for example, by pedaling a bicycle – and transfer energy to the surroundings in the form of increasing random motion of air molecules, by using this catabolic energy.
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> Burning gasoline in car engines converts *chemical energy*, stored in the molecular bonds of the constituent molecules of gasoline, into coherent (ordered) motion of the molecules that constitute a piston. With the use of gearing and tire/road friction, this motion is converted into kinetic energy of the car; the automobile moves.

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[2] George B. Benedek and Felix M.H. Villars, *Physics with Illustrative Examples from Medicine and Biology, Volume 1: Mechanics,* Addison-Wesley, Reading, 1973, p. 115-6.

Stretching or compressing a spring stores *elastic potential energy* that can be released as kinetic energy.

The process of vision begins with stored *atomic energy* released as electromagnetic radiation (light), which is detected by exciting photoreceptors in the eye, releasing chemical energy.

When a proton fuses with deuterium (a hydrogen atom with a neutron and proton for a nucleus), helium-three is formed (with a nucleus of two protons and one neutron) along with radiant energy in the form of photons. The combined *internal energy* of the proton and deuterium are greater than the internal energy of the helium-three. This difference in internal energy is carried away by the photons as light energy.

There are many such processes involving different forms of energy: kinetic energy, gravitational energy, thermal energy, elastic energy, electrical energy, chemical energy, electromagnetic energy, nuclear energy and more. The total energy is always conserved in these processes, although different forms of energy are converted into others.

Any physical process can be characterized by two states, initial and final, between which energy transformations can occur. Each form of energy E_j, where "j" is an arbitrary label identifying one of the N forms of energy, may undergo a change during this transformation,

$$\Delta E_j \equiv E_{\text{final},j} - E_{\text{initial},j}\,. \tag{13.1.1}$$

Conservation of energy means that the sum of these changes is zero,

$$\Delta E_1 + \Delta E_2 + \cdots + \Delta E_N = \sum_{j=1}^{N} \Delta E_j = 0\,. \tag{13.1.2}$$

Two important points emerge from this idea. First, we are interested primarily in changes in energy and so we search for relations that describe how each form of energy changes. Second, we must account for all the ways energy can change. If we observe a process, and the sum of the changes in energy is not zero, either our expressions for energy are incorrect, or there is a new type of change of energy that we had not previously discovered. This is our first example of the importance of conservation laws in describing physical processes, as energy is a key quantity conserved in all physical processes. If we can quantify the changes of different forms of energy, we have a very powerful tool to understand nature.

We will begin our analysis of conservation of energy by considering processes involving only a few forms of changing energy. We will make assumptions that greatly simplify our description of these processes. At first we shall only consider processes acting on bodies in which the atoms move in a coherent fashion, ignoring processes in which energy is transferred into the random motion of atoms. Thus we will initially ignore the effects of friction. We shall then treat processes involving friction between consider rigid bodies. We will later return to processes in which there is an energy transfer resulting in an increase or decrease in random motion when we study the First Law of Thermodynamics.

Energy is always conserved but we often prefer to restrict our attention to a set of objects that we define to be our *system*. The rest of the universe acts as the *surroundings*. We illustrate this division of system and surroundings in Figure 13.1.

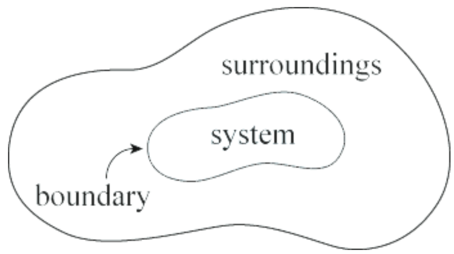

Figure 13.1 A diagram of a system and its surroundings with boundary

Because energy is conserved, any energy that leaves the system must cross through the boundary and enter the surroundings. Consider any physical process in which energy transformations occur between initial and final states. We assert that

when a system and its surroundings undergo a transition from an initial state to a final state, the change in energy is zero,

$$\Delta E = \Delta E_{\text{system}} + \Delta E_{\text{surroundings}} = 0\,. \tag{13.1.3}$$

Eq. (13.1.3) is called ***conservation of energy*** and is our operating definition for energy. We will sometime refer to Eq. (13.1.3) as the *energy principle*. In any physical application, we first identify our system and surroundings, and then attempt to quantify changes in energy. In order to do this, we need to identify every type of change of energy in every possible physical process. When there is no change in energy in the surroundings then the system is called a ***closed system***, and consequently the energy of a closed system is constant.

$$\Delta E_{\text{system}} = 0, \qquad (\text{closed system})\,. \tag{13.1.4}$$

If we add up all known changes in energy in the system and surroundings and do not arrive at a zero sum, we have an open scientific problem. By searching for the missing changes in energy, we may uncover some new physical phenomenon. Recently, one of the most exciting open problems in cosmology is the apparent acceleration of the expansion of the universe, which has been attributed to *dark energy* that resides in space itself, an energy type without a clearly known source.[3]

[3] http://www-supernova.lbl.gov/~evlinder/sci.html