

## 5.3: Fundamental Interactions, and Other Forms of Energy

At the most fundamental (microscopic) level, physicists today believe that there are only four (or three, depending on your perspective) basic interactions: gravity, electromagnetism, the strong nuclear interaction (responsible for holding atomic nuclei together), and the weak nuclear interaction (responsible for certain nuclear processes, such as the transmutation of a proton into a neutron<sup>7</sup> and vice-versa). In a technical sense, at the quantum level, electromagnetism and the weak nuclear interactions can be regarded as separate manifestations of a single, consistent quantum field theory, so they are sometimes referred to as “the electroweak interaction.”

All of these interactions are conservative, in the sense that for all of them one can define the equivalent of a “potential energy function” (generalized, as necessary, to conform to the requirements of quantum mechanics and relativity), so that for a system of elementary particles interacting via any one of these interactions the total kinetic plus potential energy is a constant of the motion. For gravity (which we do not really know how to “quantize” anyway!), this function immediately carries over to the macroscopic domain without any changes, as we shall see in a later chapter, and the gravitational potential energy function I introduced earlier in this chapter is an approximation to it valid near the surface of the earth (gravity is such a weak force that the gravitational interaction between any two earth-bound objects is virtually negligible, so we only have to worry about gravitational energy when one of the objects involved is the earth itself).

As for the strong and weak nuclear interactions, they are only appreciable over the scale of an atomic nucleus, so there is no question of them directly affecting any macroscopic mechanical processes. They are responsible, however, for various nuclear reactions in the course of which *nuclear energy* is, most commonly, transformed into electromagnetic energy (X- or gamma rays) and thermal energy.

All the other forms of energy one encounters at the microscopic, and even the macroscopic, level have their origin in electromagnetism. Some of them, like the electrostatic energy in a capacitor or the magnetic interaction between two permanent magnets, are straightforward enough scale-ups of their microscopic counterparts, and may allow for a potential energy description at the macroscopic level (and you will learn more about them next semester!). Many others, however, are more subtle and involve quantum mechanical effects (such as the exclusion principle) in a fundamental way.

Among the most important of these is *chemical energy*, which is an extremely important source of energy for all kinds of macroscopic processes: combustion (and explosions!), the production of electrical energy in batteries, and all the biochemical processes that power our own bodies. However, the conversion of chemical energy into macroscopic mechanical energy is almost always a dissipative process (that is, one in which some of the initial chemical energy ends up irreversibly converted into thermal energy), so it is generally impossible to describe them using a (macroscopic) potential energy function (except, possibly, for electrochemical processes, with which we will not be concerned here).

For instance, consider a chemical reaction in which some amount of chemical energy is converted into kinetic energy of the molecules forming the reaction products. Even when care is taken to “channel” the motion of the reaction products in a particular direction (for example, to push a cylinder in a combustion engine), a lot of the individual molecules will end up flying in the “wrong” direction, striking the sides of the container, etc. In other words, we end up with a lot of the chemical energy being converted into *disorganized microscopic agitation*—which is to say, *thermal energy*.

Electrostatic and quantum effects are also responsible for the elastic properties of materials, which *can* sometimes be described by macroscopic potential energy functions, at least to a first approximation (like the spring we studied earlier in the chapter). They are also responsible for the adhesive forces between surfaces that play an important role in friction, and various other kinds of what might be called “structural energies,” most of which play only a relatively small part in the energy balance where macroscopic objects are involved.

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<sup>7</sup>Plus a positron and a neutrino

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