Energy

Unit: Work, Energy & Momentum

NGSS Standards: HS-PS3-1

MA Curriculum Frameworks (2006): 2.1, 2.2, 2.3


Knowledge/Understanding Goals:
- define energy
- conservation of energy
- work-energy theorem

Skills:
- calculate gravitational potential energy
- calculate kinetic energy

Language Objectives:
- Understand and correctly use the terms “energy,” “kinetic energy,” and “potential energy.”
- Accurately describe and apply the concepts described in this section using appropriate academic language.
- Set up and solve word problems involving energy and the conservation of energy.

Labs, Activities & Demonstrations:
- “Happy” and “sad” balls.
- Popper.

Notes:
- energy: the ability to do work

Use this space for summary and/or additional notes.
Energy is a scalar quantity that exists in several forms, including:

**kinetic energy** \( (K) \): the energy an object has because of its motion.

**potential energy** \( (U) \) the unrealized energy that an object has because of its position, temperature, chemical reactions that could occur, etc.

In mechanics, kinetic energy usually refers to the energy of an object because of its mass and velocity. Potential energy usually refers to an object’s position, and the ability of the force of gravity to cause it to move.

**heat** \( (Q) \): the energy an object has because of the kinetic energy of its molecules.

**work** \( (W) \): the amount of change in the energy of one or more objects. \( W = \Delta E \)

**electrical work** \( (W) \): the work done by applying an electric current over a period of time.

Energy is measured in Joules \( (J) \):

\[
1 \text{ J} \equiv 1 \text{ N \cdot m} \equiv 1 \frac{\text{kg \cdot m}^2}{\text{s}^2}
\]

**Systems and Potential Energy**

A *system* is a collection of objects for the purpose of describing the interaction of objects within vs. outside of that collection. The *surroundings* is all of the objects outside of the system (“everything else”).

Potential energy is a property of the energy relationship between two objects within a system, because of a field that can change the relationship between two or more objects within the system. A single object cannot have potential energy.

**Gravitational Potential Energy**

As discussed earlier, a gravity field is a region (near a massive object like the Earth) in which the force of gravity acts on all objects that have mass. Gravitational potential energy is the work that the gravity field has the potential to do on the object because of its mass.
The gravitational potential energy of an object is determined by the strength of the gravitational field, the mass of the object, and the object’s distance above the ground (height, which is the distance over which the force of gravity is able to do work on the object).

\[ U_g = F_g h = mgh \]

(Remember that \( g \) is the strength of the gravity field near the surface of the Earth, which is equal to \( 10 \, \text{m/s}^2 \), the acceleration due to gravity on Earth.

Although most physicists use the above equation for potential energy, the AP formula sheet uses the variable “\( y \)” for height and “\( \Delta y \)” for “difference in height,” which gives the following representation of the same formula:

\[ U_g = mg \Delta y \]

Remember that gravitational potential energy exists only when there are two or more objects in a system, and at least one of the objects has a significant gravity field. For example, if an anvil is sitting on top of a cliff, the anvil has gravitational potential energy relative to the Earth, provided that the anvil and the Earth are both part of the system. (We would call this “the anvil-Earth system”.)

**Kinetic Energy**

The translational (linear) kinetic energy of an object is related to its mass and velocity:

\[ K = \frac{1}{2}mv^2 \]

Note that a single object can have kinetic energy. An entire system can also have kinetic energy if the center of mass of the system is moving (has nonzero mass and velocity).

Kinetic energy exists both in linear systems and rotating systems. The above equation is for translational kinetic energy; rotational kinetic energy will be discussed in a separate topic.

**Mechanical Energy**

Mechanical energy is gravitational potential energy plus kinetic energy. Because potential energy and kinetic energy are easily interconverted, it is convenient to have a term that represents the combination of the two.
Heat
Kinetic energy is both a macroscopic property of a large object (i.e., something that is at least large enough to see), and a microscopic property of the individual particles (atoms or molecules) that make up an object. Heat is the macroscopic energy that an object has due to the combined kinetic energies of its individual particles.

As we will see when we study thermal physics, temperature is the average microscopic kinetic energy of the individual particles that an object is made of. (Macroscopic) kinetic energy can be converted into heat if the kinetic energy of a macroscopic object is turned into the individual kinetic energies of the molecules of that object and/or some other object. This can occur via friction or via a collision.

Chemical Potential Energy
In chemistry, chemical potential energy comes from the electromagnetic forces attracting the atoms in a chemical bond. The energy absorbed or given off in a chemical reaction is the difference between the energies of those bonds before vs. after the reaction. If energy is given off, it is absorbed by the particles, increasing their kinetic energy, which means the temperature increases. If energy is absorbed, that energy must come from the kinetic energy of the particles, which means the temperature decreases.

Electric Potential
Electric potential is the energy that moves electric charges, enabling them to do work. The energy for this must ultimately come from some other source, such as chemical potential (i.e., a battery), mechanical energy (i.e., a generator), etc.