Energy

Unit: Energy, Work & Power

MA Curriculum Frameworks (2016): HS-PS3-1
MA Curriculum Frameworks (2006): 2.1, 2.2, 2.3

Mastery Objective(s): (Students will be able to...)
- Calculate the gravitational potential energy of an object.
- Calculate the kinetic energy of an object.

Success Criteria:
- Correct equation(s) are chosen for the situation.
- Variables are correctly identified and substituted correctly into equation(s).
- Algebra is correct and rounding to appropriate number of significant figures is reasonable.

Tier 2 Vocabulary: work, energy

Language Objectives:
- Explain when & why an object has potential energy.
- Explain when & why an object has kinetic energy.

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

Notes:
energy: the ability to cause macroscopic objects or microscopic particles to increase their velocity; or their ability to increase their velocity due to the effects of a force field.

In plain English, if we apply mechanical energy to a physical object, the object will either move faster (think of pushing a cart), heat up, or have the ability to suddenly move when we let go of it (think of stretching a rubber band).

Energy can be transferred from one object (or collection of objects) to another.

Energy is a “conserved” quantity in physics, which means it cannot be created or destroyed, only changed in form.

* More properly, the combination of mass and energy is conserved. Einstein’s equation states that mass can be converted to energy via the relationship $E = mc^2$.
Energy is a scalar quantity, meaning that it does not have a direction.

**kinetic energy** ($K$): the energy that 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.*

**thermal energy** (heat, $Q$): the energy that an object has because of the kinetic energy of its molecules.

Energy is measured in joules (J):

$$1 J \equiv 1 N \cdot m \equiv 1 \frac{kg \cdot m^2}{s^2}$$

Use this space for summary and/or additional notes:
Potential Energy

Potential energy is the energy that an object has because the object is in a force field. When the object is released, the force field will act on the object to cause it to gain kinetic energy.

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, isolated object cannot have potential energy.

Recall the following definition of a force field:

**force field**: a region in which an object experiences a force because of some property of that object.

- **gravitational field** (or “gravity field”): a force field in which an object experiences a force because of and proportional to its mass.
- **electric field**: a force field in which an object experiences a force because of and proportional to its electric charge.

An single, isolated object cannot have potential energy.

For example, in the coyote-anvil system pictured to the right, both the coyote and the anvil have negligible potential energy. (There is a tiny amount of gravitational attraction between them—assuming the anvil has a mass of 200 kg and the coyote has a mass of 20 kg, the gravitational attraction between them would be $3 \times 10^{-7}$ N.) However, the Earth can attract the entire coyote-anvil system toward itself.

On the other hand, in the coyote-anvil-Earth system, the anvil and the coyote each have potential energy with respect to the Earth. As the coyote and anvil fall, the potential energy changes to kinetic energy, causing both the coyote and the anvil to fall faster and faster...

Refer to Systems on page 187 and Gravity Fields on page 194 for a brief review.
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 gravitational field (equal to the acceleration due to gravity, \( \ddot{g} \), which is approximately \( 10 \frac{m}{s^2} \) near the surface of the Earth), 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 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 gravitational field.

Kinetic Energy

The kinetic energy of an object is related to its mass and velocity. Translational kinetic energy (the kinetic energy of an object or system that is moving in the xy plane) is given by the equation:

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

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 (Enthalpy)

In chemistry, chemical potential energy comes from various forces within atom and molecules, largely 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 contained in the molecules before vs. after the reaction. If energy is given off by a reaction, it is absorbed by the particles, increasing their kinetic energy, which means the temperature increases. If energy is absorbed by a reaction, that energy must come from the kinetic energy of the particles, which means the temperature decreases.

Electric Potential

Electric potential is the energy that causes electrically charged particles to move. 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.