Prelab: Energy and calometry

Read Feynman Lectures on Physics, Book I, Section 4-1. Online here:
http://www.feynmanlectures.caltech.edu/I_04.html

Energy is a little strange because it's an abstract concept, but it is useful because any process in nature conserves energy, i. e., the **total energy never changes**. However, different processes convert different forms of energy into each other. Some of the most common forms of energy are:

- **Kinetic energy**: the energy of motion. If you have an object of mass m going at a velocity v, its kinetic energy can be worked out as:

$$E_{\text{kin}} = \frac{1}{2}mv^2$$

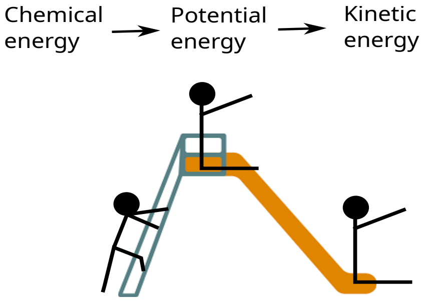
- **Gravitational (potential) energy**: the energy associated with an object being at a higher place, and thus having the "potential" of falling down. For a mass m, at an elevation h, with a strength of gravity g, it's given by:

$$E_{\text{pot}} = mgh$$

- **Chemical energy**: The energy stored and released by gasoline, the energy stored in a battery as well as the energy from food.

(If you look at these equations and compare it with the respective terms in the Bernoulli principle, they look very similar, except that the mass m is replaced by the density ρ)

These forms of energy already gives us one of the simplest examples in the conservation of energy. Suppose you want to go down a slide. First we convert chemical energy (the energy stored in our body) to potential energy by climbing up the ladder, and then we convert the potential energy to kinetic energy by sliding down.



The nice thing about this is that we can actually use conservation of energy to calculate our velocity at the bottom of the slide given the height of the slide:

$$mgh = \frac{1}{2}mv^2$$

$$v = \sqrt{2gh}$$

The remarkable thing here is that we did not need to know anything about the angle of the slide, how fast we accelerated downwards, or how long it took us to slide downwards: the only thing we needed to know is that energy must be conserved and therefore all the potential energy must be converted to kinetic energy once we reach the bottom. Amazing, isn't it?

This SI unit of energy is the **Joule** (**J**), however thermal energy is often measured in **calories** (**cal**). 1000 calories is a kcal, which is the unit commonly used for the energy content of **food**: "counting calories" really means counting kcal.

Calometry

Here are some more forms of energy:

- **Thermal energy** (**heat**): the energy due to the temperature-induced vibrations in the atoms. So it's kinetic energy again, just on a smaller scale! How much heat is stored at a certain temperature depends on the substance (this is why hot milk gets cold sooner than hot tea). We call this the **specific heat** C of a substance. For a mass m at temperature T, the thermal energy is then given by:[1]

  $$E_{\text{th}} = CmT$$

- **Electrostatic energy**: The energy on charges due to voltage. Given a voltage V and charge Q, the electrostatic energy is given by:

  $$E_{\text{el}} = QV$$

  (Remember that we learned voltage was potential energy per charge? This is just the opposite direction).

Let's consider an example. You probably know that when a warmer object comes in contact with a cooler one, the warmer will cool (and the cooler will warm up) until the temperatures are equal – we say the two objects come to thermal equilibrium or equilibrate. So dropping a hot brass cube into water will warm up the water as energy is transferred from the cube to the cooler water.

So: how much hotter? Well, we know that the brass cube **lost** some thermal energy, because it cooled down from T_1 to T_2:

$$E_{\text{th,lost}} = C_{\text{brass}} m_{\text{cube}} (T_1 - T_2)$$

so the same thermal energy will be **gaind** by the water, which will heat up from T_{room} to T_2:

$$E_{\text{th,gained}} = m_{\text{water}} C_{\text{water}} (T_2 - T_{\text{room}}).$$

Here is another one: let's use electricity to heat up water. As with us sliding down a slide losing potential energy, the electron are losing electrostatic energy by going from – to + in the battery. The total amount of electrons is given by current I multiplied by time t: $Q = It$ (remember that current is flow of charge per time), so the total energy lost in the process is given by:

$$E_{\text{el,lost}} = QV = IVt,$$

Again, that energy has to go somewhere, and it goes to whatever we are heating up (resistor, water):

$$E_{\text{th,gained}} = Cm(T_2 - T_1)$$

This is in fact very similar to our slide example: potential energy converted to kinetic energy (heat).

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[1] *This equation is a little simplified, but it will work for our purposes.*

Power

Let's look at the equation for energy lost through a circuit again:

$$E_{\text{el,lost}} = IVt$$

It is useful to define the rate at which energy is lost, i.e., how much energy is lost in a certain amount of time. This is known as **power** (***P***). In other words:

$$(\text{energy lost}) = (\text{power}) \times (\text{time})$$

$$E = Pt$$

Looking at above equation, the electrical power is given by the product of voltage and current:

$$P = IV$$

The SI unit of power is the **Watt** (**W**), which is the same as Joule/second (J/s) or Volt times Ampere (VA).

You might have heard of kilowatt-hours (kWh), which is what US electric companies use to bill you. We now understand that this is a unit of energy, because it is power (kilowatt) times time (hour). In fact, one can work out that 1 kWh = 2.6 MJ . (Mega-Joules)