An understanding of energy has to start with the concept of work. Work is defined to be “the organized movement of matter against a resisting force.” Therefore, to do work, two conditions must be satisfied: something must move, and a force must resist the motion. Here are some situations in which work will be done:

a) Gravitational work: an object is lifted. The resistance is the force of gravity pulling the object downward. Note that if the object is not lifted, no work is done: when you carry something horizontally, gravity is not opposing your motion (gravity works downward, not sideways).

b) Gas expansions: a gas is allowed to expand. The resistance is the pressure exerted by the surrounding matter (usually the walls of the container).

c) Frictional work: an object is pushed along the floor. The resistance is friction, which is always opposing the motion.

d) Electrical work: a current flows through any sort of circuit. The resistance is the electrical resistance of the circuit, and the moving matter is composed of electrons.

Work is symbolized by the letter w, and it is officially defined as follows:

\[ \text{work} = \text{force} \times \text{distance} \quad \text{or} \quad w = F \times d \]

This equation can be used immediately if you know the force and distance in SI units. In that case, the units are reconciled as follows:

The SI unit of force is the newton (N), which equals a kg \( \cdot \) m/\( \text{sec}^2 \).

The SI unit of distance is the meter (m)

Therefore, the SI unit of work is given by:

\[ \text{work} = \text{force} \times \text{distance} = \text{kg} \cdot \text{m/\text{sec}^2} \times \text{m} = \text{kg} \cdot \text{m}^2/\text{sec}^2 \]

This unit is called a joule (J).

In gravitational work, the resisting force is provided by gravity and is given by the expression \( F = mg \), where \( m \) is the mass of the object (in kg) and \( g \) is the acceleration an object experiences when it is dropped (9.80 m/\( \text{sec}^2 \) in San Francisco, varying a bit if you go north or south). Therefore, the work done in lifting an object is given by \( w = mgh \), where \( h \) is the height to which the object is lifted (in meters).

**Sample Problem 4:** “A 454 g object is carried to the top of a mountain that is 1.34 kilometers high. How much work was done?”

**Answer:** neither the mass nor the height are in SI units, so we must first convert them to SI. Converting 454 g to kilograms gives \( m = 0.454 \) kg, and converting 1.34 km to meters gives \( h = 1340 \) m. Now we can calculate work:
work = 0.454 kg × 9.80 m/sec^2 × 1340 m
= 5962 kg⋅m^2/sec^2
= 5.96 × 10^3 joules

A joule is a fairly small amount of work: if you lift a 1 kilogram object 10.6 centimeters, you will do one joule of work. Therefore, large numbers are common in work calculations, and are often converted to kilojoules (kJ). One kJ = 1000 J, so the work done here is 5.96 kJ.

In expansion work, we do not normally measure force and distance. It is more convenient to measure the volume change and the resisting pressure. We can then relate these to our formula for work \((w = F \times d)\) as follows (refer to the picture below):

\[
\text{work} = \text{force} \times \Delta \text{V} = \text{area} \times \text{distance}
\]

work = force × distance \hspace{1cm} \text{(by definition)}

In this case, distance = \(\frac{\Delta \text{V}}{\text{area}}\) so...

work = force × \(\frac{\Delta \text{V}}{\text{area}}\)

pressure is defined by: \(P = \frac{\text{force}}{\text{area}}\)

so \(\text{force} = P \times \text{area}\)

which gives us: \(\text{work} = (P \times \text{area}) \times \left(\frac{\Delta \text{V}}{\text{area}}\right)\)

Canceling the area gives us:

\(\text{work} = P \times \Delta \text{V}\)

**Sample Problem 5:** “A balloon containing 1.50 L of air is heated. It expands to a final volume of 2.25 L. The pressure exerted on the balloon remains constant at 0.955 atm throughout this expansion. How much work was done by the gas?”
**Answer:** If we simply multiply the pressure and \( \Delta V \) values that we are given, we get work in units of liter-atmospheres. Although this is a legitimate unit of work, it is not normally used. There are two ways around this problem:

Option 1 (the hard way): convert the pressure and volume into SI units. The SI unit of pressure is the pascal (1 atm = 101325 Pa), and the SI unit of volume is the cubic meter (1 m\(^3\) = 10\(^3\) L).

\[
0.955 \text{ atm} \times \frac{101325 \text{ Pa}}{\text{atm}} = 9.677 \times 10^4 \text{ Pa}
\]
(Reminder: a Pa is a kg/m\( \cdot \)sec\(^2\))

\[
0.75 \text{ L} \times \frac{1 \text{ m}^3}{10^3 \text{ L}} = 7.5 \times 10^{-4} \text{ m}^3
\]

\[
w = P \times \Delta V
\]
\[
= 9.677 \times 10^4 \text{ kg/m} \cdot \text{sec}^2 \times 7.5 \times 10^{-4} \text{ m}^3
\]
\[
= 72.6 \text{ kg} \cdot \text{m}^2/\text{sec}^2
\]
\[
= 72.6 \text{ J}
\]

Option 2 (the easy way): use the fact that 1 L\cdot atm = 101.325 J!

\[
0.955 \text{ atm} \times 0.75 \text{ L} = 0.71626 \text{ L} \cdot \text{atm}
\]

\[
0.71626 \text{ L} \cdot \text{atm} \times \frac{101.325 \text{ J}}{1 \text{ L} \cdot \text{atm}} = 72.6 \text{ J}
\]

So far, we have not considered the sign of work. However, the sign plays a crucial role: we use the sign to show whether the system or the surroundings is doing the work. The convention used in chemistry is:

**When the SYSTEM does the work, the sign of w is NEGATIVE.**
**When the SURROUNDINGS do the work, the sign of w is POSITIVE.**

The signs were chosen to make the sign of work agree with the sign of the energy change: this will be discussed below. This convention may seem counter-intuitive to you, but it does make sense, as you will see.

**Sample Problem 6:** "What is the correct sign of the work in the previous example?"
Answer: The previous example involved a gas expansion, so the system (the gas) was doing the work. Therefore, the sign is negative: \( w = -72.6 \text{ J} \).

It is worth pointing out that the sign convention we have chosen changes our formula for the work in a gas expansion or compression. If we take the gas as the system, the correct form of the equation is:

\[
\text{For a gas expansion or compression: } w = -P \times \Delta V
\]

The sign of gravitational work must also agree with our convention, but this is less troublesome. If we define the system to be the object that is being lifted, then the work is positive whenever we lift the object, since we (the surroundings) are doing the work. (However, if we define ourselves to be the system, the work will be negative.)