The First Law of Thermodynamics

Skills to Develop

- Develop applications of the First Law of Thermodynamics
- Calculate internal energy and elaborate on the results

The **First Law of Thermodynamics** is equivalent to the law of conservation of energy, which was described previously here. However, instead of describing a system in which energy changes form (KE to PE and back) but the total amount doesn't change, now we will describe a system in which energy can move in and out. The 2 ways it can do this are work and heat.

Imagine we have a system that is approximately isolated, like a thermos of water, and we do work on it in various ways. First we use the energy from a falling weight to mix it very vigorously, and we see what happens to the temperature of the system. Then we run some electric current through a resistor dipped in the system, and see what happens to the temperature of the system. And we observe that the same amount of work always raises the temperature the same amount. If we do the same experiments on a cup of water that isn't isolated like the thermos (but is otherwise the same), we find that the temperature doesn't increase as much when we do the same amount of work without the insulating thermos. As the system got warmer, some energy moved from the system to the surroundings. Without the thermos, heat leaves the system when it gets warmer than the surroundings, so we have to do more work to get the same increase in temperature.

Energy is the capacity to do work. Any system can do work. Perhaps it can heat a gas, causing it to expand against a force, or fall, compressing a spring, etc. But an isolated system's capacity to do work won't change. For instance, if we use a system to do work, then wait a long time, the system won't regain its original ability to do work. More concretely, if we use a falling weight to do some other work, like lifting another weight or driving a motor, the weight won't be able to do more work until we lift it to its original height. It won't float back up by itself, ready to fall again. If we use a very hot block of metal to boil water and drive motors, the block will get cooler. And if we leave it isolated and wait, it won't heat back up again by itself so we can boil more water. The capacity of a system to do work is called its **internal energy**. The internal energy of a system can change if work is done on or by the system, or if heat enters or leaves the system. If no work is done and no heat flows, then the internal energy of the system can't change. We can write this as an equation:

$$\Delta E = q + w \tag{1}$$

where ΔE is the change in internal energy (some people use U instead), q is heat, and w is work. Heat q is positive when it flows into the system, and negative when it flows out. Work w is positive when it is done to the system and negative when it is done by the system. (Actually, some people use the opposite signs for work, in which case the equation is E=q-w) This should make sense. The internal energy of the system increases when we put energy in; it decreases when we take energy out.

Molecularly, internal energy means all the kinetic and potential energy of each particle in the system. Internal energy is a state function, like temperature and pressure. Work and heat are not state functions: they depend on processes. You can't look at an object and determine how much work or heat it has because that doesn't make sense, but you can measure what its temperature is, what its volume is, and what its internal energy is.

Outside Links

- Khan Academy: First Law of Thermodynamics (18 min)
- Khan Academy: More on Internal Energy (14 min)
- Khan Academy: Work from Expansion (13 min)
- CrashCourse Chemistry: Energy and Chemistry (9 min)

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