37A: The First Law of Thermodynamics

> *We use the symbol U to represent internal energy. That is the same symbol that we used to represent the mechanical potential energy of an object. Do not confuse the two different quantities with each other. In problems, questions, and discussion, the context will tell you whether the U represents internal energy or it represents mechanical potential energy.*

We end this physics textbook as we began the physics part of it (Chapter 1 was a mathematics review), with a discussion of conservation of energy. Back in Chapter 2, the focus was on the conservation of mechanical energy; here we focus our attention on thermal energy.

In the case of a deformable system, it is possible to do some net work on the system without causing its mechanical kinetic energy $\frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$ to change (where m is the mass of the system, v is the speed of the center of mass of the system, I is the moment of inertia of the system, and ω is the magnitude of the angular velocity of the system). Examples of such work would be: the bending of a coat hanger, the stretching of a rubber band, the squeezing of a lump of clay, the compression of a gas, and the stirring of a fluid.

When you do work on something, you transfer energy to that something. For instance, consider a case in which you push on a cart that is initially at rest. Within your body, you convert chemical potential energy into mechanical energy, which, by pushing the cart, you give to the cart. After you have been pushing on it for a while, the cart is moving, meaning that it has some kinetic energy. So, in the end, the cart has some kinetic energy that was originally chemical potential energy stored in you. Energy has been transferred from you to the cart.

In the case of the cart, what happens to the energy that you transfer to the cart is clear. But how about the case of a deformable system whose center of mass stays put? When you do work on such a system, you transfer energy to that system. So what happens to the energy?

Experimentally, we find that the energy becomes part of the internal energy of the system. The internal energy of the system increases by an amount that is equal to the work done on the system.

This increase in the internal energy can be an increase in the internal potential energy, an increase in the internal kinetic energy, or both. An increase in the internal kinetic energy would manifest itself as an increase in temperature.

Doing work on a system represents the second way, which we have considered, of causing an increase in the internal energy of the system. The other way was for heat to flow into the system. The fact that doing work on a system and/or having heat flow into that system will increase the internal energy of that system, is represented, in equation form, by:

$$\Delta U = Q + W_{IN}$$

which we copy here for your convenience:

$$\Delta U = Q + W_{IN} \tag{37A.1}$$

In this equation, ΔU is the change in the internal energy of the system, Q is the amount of heat that flows into the system, and W_{IN} is the amount of work that is done on the system. This equation is referred to as the First Law of Thermodynamics. Chemists typically write it without the subscript IN on the symbol W representing the work done on the system. (The subscript IN is there to remind us that the W_{IN} represents a transfer of energy into the system. In the chemistry convention, it is understood that W represents the work done on the system—no subscript is necessary.)

Historically, physicists and engineers have studied and developed thermodynamics with the goal of building a better heat engine, a device, such as a steam engine, designed to produce work from heat. That is, a device for which heat goes in and work comes out. It is probably for this reason that physicists and engineers almost always write the first law as:

$$\Delta U = Q - W \tag{37A.2}$$

where the symbol W represents the amount of work done by the system on the external world. (This is just the opposite of the chemistry convention.) Because this is a physics course, this $(\Delta U = Q - W)$ is the form in which the first law appears on your formula sheet. I suggest making the first law as explicit as possible by writing it as $\Delta U = Q_{IN} - W_{OUT}$ or, better yet:

$$\Delta U = Q_{IN} + W_{IN} \tag{37A.3}$$

In this form, the equation is saying that you can increase the internal energy of a system by causing heat to flow into that system and/or by doing work on that system. Note that any one of the quantities in the equation can be negative. A negative value of Q_{IN} means that heat actually flows out of the system. A negative value of W_{IN} means that work is actually done by the system on the surroundings. Finally, a negative value of ΔU means that the internal energy of the system decreases.

Again, the real tip here is to use subscripts and common sense. Write the First Law of Thermodynamics in a manner consistent with the facts that heat or work into a system will increase the internal energy of the system, and heat or work out of the system will decrease the internal energy of the system.
