16. The First Law of Thermodynamics

Introduction and Summary

The First Law of Thermodynamics is basically a statement of Conservation of Energy. The total energy of a thermodynamic system is called the Internal Energy U. A system can have its Internal Energy changed (ΔU) in two major ways:

(1) Heat Q can flow into the system from the surroundings and

(2) the system can do work W on the surroundings.

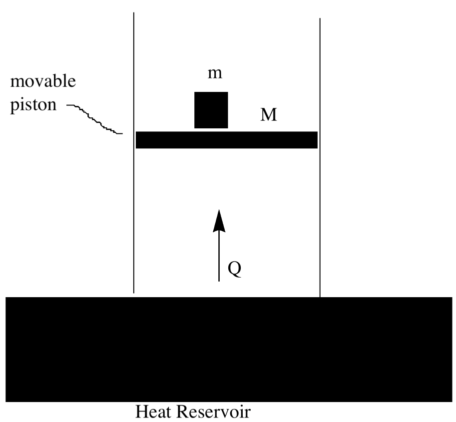
The concept of Heat Energy Q has been discussed previously in connection with Specific Heat c and the Latent Heats of fusion and vaporization at phase transitions. Here, we will focus on the Heat Q absorbed or given off by an ideal gas. Also, the Work W done by an ideal gas will be calculated. Both heat and work are energy, and it is important to understand the difference between the heat Q and the work W.

Thermodynamic Work W

Previously, we understood the concept of Mechanical Work in connection with Newton's Laws of Motion. There the focus was work done ON THE SYSTEM. For example, the work done on a mass M in raising it up a height h against gravity is W=Mgh. Thermodynamic Work is similar to Mechanical Work BUT in Thermodynamic Work the focus is on the work done BY THE SYSTEM.

Historically, Thermodynamics was developed in order to understand the work done BY heat engines like the steam engine. So when a system (like a heat engine) does work ON its surroundings, then the Thermodynamic Work is POSITIVE. (This is the opposite for Mechanical Work.) If work is done on the heat engine, the Thermodynamic Work is NEGATIVE. An example might help here.

Suppose an ideal gas like diatomic nitrogen is inside a cylinder with a movable piston on top. The piston has mass M and there is an additional mass m on top of the piston as picture below.



The gas is in contact with a heat reservoir on the bottom and heat Q flows into the gas from the reservoir because the gas is colder than the heat reservoir. By the way, a heat reservoir is so large that it can lose a quantity of heat Q and the temperature of the heat reservoir will hardly change.

The pressure of the gas is constant because the piston is movable; the piston may rise but all the while the pressure P of the gas is unchanged. (The pressure on the gas is from the mass of the piston and the mass on top of the piston together with atmospheric pressure.) Because the piston rises a distance ΔS, the volume of the gas increases $\Delta V = A\Delta S$ where A=the area of the cylindrical piston and S=the height of the cylinder of gas. The work W done by the gas is calculated using

$$\Delta W = F\,\Delta S$$

This is the same formula as in mechanics except that here the gas does positive work when the it does work on the surroundings, as in this case where the piston rises. (If the piston went downward, the work would have been done ON the gas and the work by the gas would be negative. This would happen if heat were taken out of the gas.)

Recall that the gas pressure P is defined

$$P = \frac{F}{A}$$

where A is the area of the piston and F is the force of the gas on the piston. Rearranging we get

$$F = P\,A$$

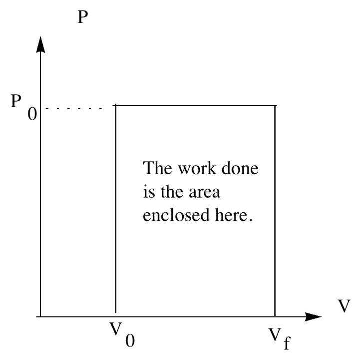
Using this in the equation for the work W we get

$$W = PA\,\Delta S$$

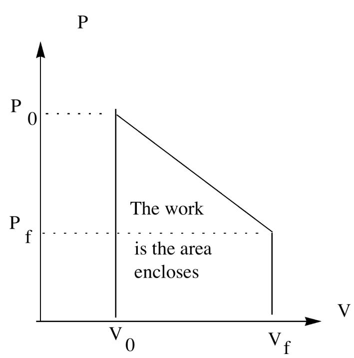
However, the change in volume of the gas is $\Delta V = A\Delta S$ so the work done by the gas is equal to

$$W = P\,\Delta V$$

For the process just described--in which heat Q enters the gas and the pressure is constant while the volume of the gas changes ΔV--the work done is $W = P\Delta V$.



More generally, we will have processes where the pressure changes and in these cases the work done can also be calculated. For example, suppose the pressure decreases linearly as indicated in the diagram below.



The work done is the sum of two areas: a rectangle and a triangle.

$W = P_f (V_f - V_0) + (1/2)(P_0 - P_f)(V_f - V_0)$

The Distinction Between Heat and Work

Suppose the piston had been made immovable while the heat entered the gas from the reservoir. Then the internal energy of the gas would have increased ΔU=Q without any work by the gas.

1. Heat is added to a system in a process where the internal energy of the system (i.e., of the gas) changes WITHOUT a change in a macroscopic parameter like volume ΔV. If heat Q flows into a system like the gas, then the internal energy of the gas system increases ΔU=Q.

2. Work is done by a system if a macroscopic parameter like volume changes. The gas does positive work when it does work on the environment; in such a case, the internal energy of the gas decreases ΔU= -PdV.

The general case is that in which work is done W=-PdV by the system and heat Q is absorbed by the system from the surroundings and this is written

$$\Delta U = Q - W$$

This is the 1st Law of Thermodynamics, which states that the internal energy of a system can change in two ways:

(1) Heat Q can flow into the system from the surroundings, in which case the internal energy of the system increases.

(2) Additionally, work W can be done by the gas system on the surroundings, in which case the internal energy of the gas system decreases by -W.

Various Kinds of Thermodynamic Processes

1. Adiabatic Process: No heat is exchanged between the system and its surroundings.
2. Isobaric Process: Constant pressure
3. Isothermal Process: Constant temperature
4. Isochoric Process: Constant volume
5. Cyclic Process: The end state of the process is the same as the beginning state