Thermodynamics
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Lecture 06
Work - Part I

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In the last class, we looked at inexact and exact differentials. In this class, we are going to look at the concept of work. This word is quite familiar with us. We have looked at this in mechanics, where for example, we define work as the force into the displacement in the direction of the force. Mathematically, that would be $\int F ds$, where ds is a small displacement and F is the force in the direction of the displacement.

In thermodynamics, our way of looking at work is slightly different. We know that power is rate of doing work, which is a definition which we are going to use in both mechanics and thermodynamics. But, for work itself, our definition in thermodynamics deals with energy. We look at work as an energy interaction between a system and its surroundings. We defined the system earlier as the mass which we are interested in and the surroundings as anything else which is external to the system.

We are going to look at work as an energy interaction. We have not yet defined what energy is. We will formally define it when we go on to the first law. It may seem like a chicken and egg thing, where we define energy in terms of work and work in terms of energy.

- Work is said to be done by a system, during a given operation, if the sole effect, external to the system could be reduced to the raising of a weight through a distance

  – 'Sole effect' means one and only effect
  – 'external to the system' refers to the fact that work is an interaction between system and surroundings,
  – 'could be reduced to raising of a weight' work interaction may not necessarily result in raising of a weight in the surroundings

We say that work is said to be done by a system during a given operation, if the sole effect, external to the system, could be reduced to the raising of a weight through a distance. We are not interested in what happens inside the system during the operation. We are only interested in what happens outside the system.

This emphasizes that work is interaction between a system and its surroundings. There does not actually have to be a weight which is raised. Whatever is being done by the system on its surroundings can be thought of as raising a weight.
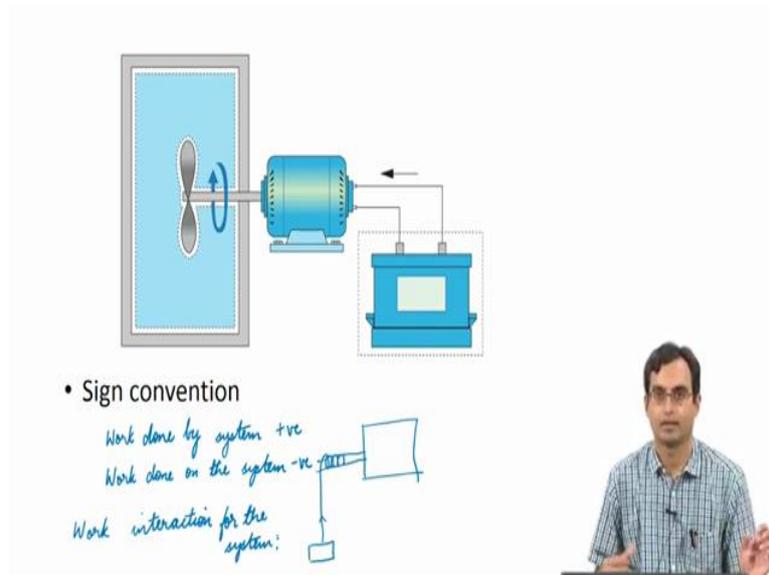
Figure 1

In Fig. 1, there are at least two systems which are marked by the dotted lines. One is a battery, and second is gas surrounding a paddle wheel which is confined inside a box. There is also a third system which is a motor. The battery is connected to the motor. The motor is connected to a paddle wheel. The paddle wheel is rotating inside a gas.

As the circuit is turned on, there is energy flow from the battery. The battery makes the motor run. When the motor runs, the shaft spins. The fan rotates and the gas inside the box is rotated. This definitely does not look like there is any 'raising of a weight'. However, we can attach a weight to a string and the string can be wound around the shaft. Instead of a fan, we now have a weight. When the motor spins the shaft, the weight gets raised. Instead of rotating/circulating the gas inside the box, the motor is now raising a weight. Hence, the work is being done by the battery on the gas (we assume that all the components in Fig. 1 are ideal so that there are no losses (e.g. friction).)

In this case, the battery, which is connected to the shaft, which is connected to the fan, is essentially doing work on the gas, because it is reducible to the 'raising of a weight' external to the system (battery in this case).

We have a sign convention with respect to work. Not everybody agrees on the sign convention. Different books use different sign conventions.

Work done is positive if it is done by the system on its surroundings. The work done is negative if it is done on the system by the surroundings. This is the sign convention we are going to use throughout the course.

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- Displacement work
- Mode of work involved when system boundary sweeps a volume while interacting with its surroundings – volume swept may be against the surroundings or against the system itself depending upon whether system does the work or not.
- This can be evaluated only for a quasi-static process (without magnetic, gravity or electric forces)

There are various forms of work. One of them is the displacement work. This is the work involved when the system boundary sweeps a volume while interacting with its surroundings. It can be visualized using a piston-cylinder arrangement.

Assume that the piston is frictionless and free to move. When the piston moves, the volume inside the cylinder (control volume) increases or decreases. As the piston moves, it sweeps a volume, which may be against the surroundings or against a system. If the piston moves upwards (or outwards), then the volume of the control volume (or a system) increases. Then we say that the work done is positive. The system increases its volume at the cost of its surroundings. It is positive for the system and negative for the surroundings. If the piston moves downwards (or inwards), it reduces the volume of the system. Then, the work would be negative. The work can be evaluated only for a quasi-static process which will be defined later.

We usually neglect magnetic, gravitational and electric forces in the analysis of the systems we are going to look at. However, gravity forces may play important role in a few cases.
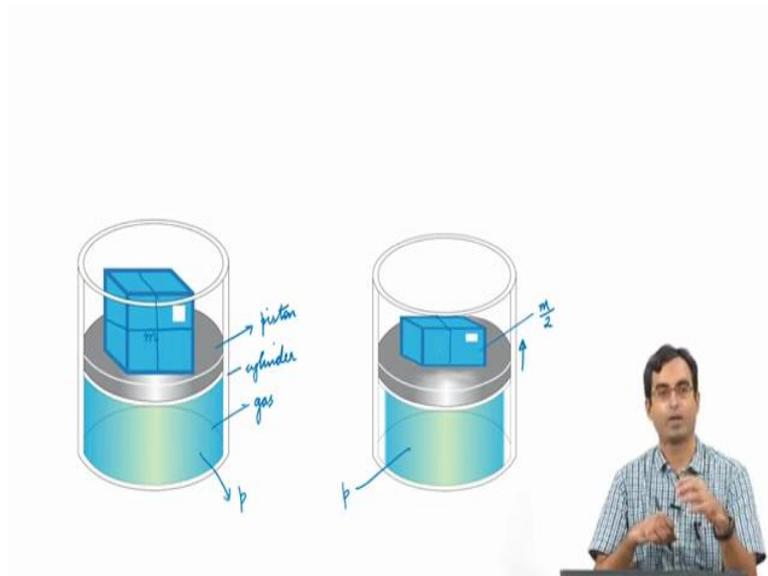
Figure 2

Work is done when there is interaction between the system and the surroundings, and the sole effect external to the system is reducible to lifting of a weight.

Consider a piston-cylinder arrangement shown in Fig. 2. The system consists of gas inside this arrangement. (A common example of a piston-cylinder would be a plastic medical syringe.). The arrangement is assumed to be frictionless and, the piston is assumed to be massless (the mass of the piston is negligible compared to whatever we are going to deal with).

There is a big block siting on the piston. This block has some mass. So, the pressure inside must be high because, the block is sitting on the piston, and the system is in equilibrium.

If the block is removed suddenly from the top of the piston, the piston moves up until the pressure inside becomes equal to atmospheric pressure (outside pressure is atmospheric pressure). The gas inside expands and the volume of the system increases. The cylinder is tall enough that the piston does not jump out.

However, during this upward movement of the piston, no weight is raised (neglecting the mass of air outside or assuming that the experiment was carried out in vacuum).

Work is done only if there is raising of a weight external to the system. In this experiment, no weight is raised. Hence, the work done by the system must be close to 0 (ignoring the atmospheric pressure around or assuming that the experiment was carried out in vacuum).

Now, cut the block into two. Remove one of the blocks suddenly. The piston moves up raising the weight of other block and stops when the system reaches new equilibrium. In this case, work is done by the system because there is raising of a weight by the system.

What would happen if we cut the block into smaller and smaller pieces (or infinitesimally small pieces) and remove each piece one by one?

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Every time a piece is removed from the top of the piston, it moves up slightly raising the weight of the remaining pieces and the system attains a new equilibrium. In this case, the system is not far from the equilibrium. As a piece is removed, there is a slight imbalance between the forces inside and outside, and the piston moves up to balance the forces again. The process is slow. There is always a resistance to the movement of the piston. The work is done by the system as there is raising of weight. This kind of a process is called as a quasi-static process or a fully-resisted process or a near-equilibrium process. In this process, the system is never far away from the equilibrium. Since the system is almost always at equilibrium in such a process, its properties can be measured (the properties of a system can be measured only when it is in equilibrium). Since the properties of a system can be measured, work done by the system can be calculated.