Lecture 4

A definition of heat

From our everyday experience, we know that heat is some sort of energy that transfers from hot objects to cold objects when the come in contact. For example, we get warmed while we are close to fire, that is, we feel heat transfer from fire to our body, that increases our body temperature. For now, consider temperature as a measure of "hotness or coldness", so that we can ~~see~~ say a hot body has a higher temperature from cold one. Also, temperature determines which way heat will be flowing while objects are in thermal contact. We are going to go into the details of temperature soon.

Kind of similar to fire, while one holds ice on his/her, hands, s/he feels the hands ~~to~~ becoming colder, meaning heat is leaving from our body to the ice. We then conclude and define —

"Heat is a thermal energy in transit".

This definition might seem obscure since we didn't define thermal energy. ~~To~~ We will have to wait until classical thermodynamics to provide a rigorous mathematical formulation. For now, we can provide some intuition behind it.

(i) ~~Heat~~ Experiments suggests that heat spontaneously transfers from hotter to colder body when they are in contact. However, it is possible that the opposite happens like in the refridgerator. But that doesn't happen without any cost. You have to provide energy from outside (by means of electricity). So, without this intervention, heat is always transferred from hotter to colder body.

(ii) We have to distinguish between two fundamental processes in which the temperature (as well as the internal energy) ~~is~~ of an object increases. The two fundamental processes are — (i) transfer of heat and (ii) doing work on the object (system). This work can be done in many different ways. Let us think about an example. Consider an isolated system. By isolated, we mean that no heat can enter or leave from the system. Our system is a box of water, where we have inserted a paddle turbine through a very small hole. The paddle turbine can be rotated by hand from outside, or by falling objects on the liver (like done in water based power-plants). If this happens, turbine will start rotating into the water and consequently due to stirring and friction of water with turbine blades, the ~~heat~~ temperature of the water will start to increase. The friction will cause the turbine to slow down. Consequently, the work done by the friction force will provide energy to the system and the temperature will thus increase. In this way, temperature was increased by doing some work on the system, no heat exchange with some other object was not present.

Alternatively, you could increase the temperature of the water by exactly the same amount by just putting the box of water close to some fire. Both of these processes lead to the same result, an increase of temperature of the system.

(iii) There is no meaning of heat in a body. You can't say, this body has this amount of heat, since we are defining heat to be the energy in transit. But its not just this definition, that restricts defining heat of a body. We will see with an ~~exma~~ example and reasoning. Say, you have a box full of some ideal gas. There is a piston that ~~mov~~ can move into or out of the box. If you push the piston into the box, you will do some work on the gas molecules, which will increase their kinentic energy and hence temperature. No heat exchange was involved during the process. So, even if you define that the system had Q amount of heat before, it is still Q, but we have moved to a different temperature.

Now, with careful experiment, we can increase the temperature by the same amount by transfer of heat from some hot object. Say, 50 J was transferred. Now, if Q was the amount of heat before, now it should be (Q+50) J. But the temperature is same as it was while the piston did work to increase the temperature. It would have been really nice if you could say, at 0 temperature the heat in a body is zero and as temperature increases, the heat increases by a simple relation with temperature. But sadly, this is not true, since we ~~could~~ can increase temperature without introduction of any heat exchange, which result in the same system as providing heat.

(iv) You might think rubbing your hands ~~involve friction~~, ~~that takes away~~ * generates heat, but that's a common misinterpretation of wording. Actually rubbing your hand involves friction, that takes away the kinetic energy off your hands and increases the internal energy of your hand, which increases the temperature. Similarly, if you move a box full of gas on a surface with friction, the work done by friction will transfer energy in the box and its temperature will increase. Then, there will be a temperature difference between gas and box, and heat will be exchanged, and temperature of the gas in the box will increase.

~~Thermal equilibrium~~

Heat capacity

Heat is measured in Joules (J). The rate of heat exchange has the units of watts (W). $1W = 1Js^{-1}$.

We ask the question, how much heat ~~energy~~ is needed to increase the temperature by a small amount dT.

If dQ is needed, then,

$$dQ \propto dT$$

$$\Rightarrow dQ = C\,dT$$

$$\therefore C = \frac{dQ}{dT}$$

where C is called the heat capacity. So, the change in temperature is proportional to the change in heat, but the absolute value of temperature is not proportional to absolute Q (it doesn't exists).

Heat capacity has a unit of JK^{-1}.

We can also express heat capacity per unit mass or per unit volume. If it is per unit mass, which we will encounter frequently is called the specific heat capacity, which has a unit of $J Kg^{-1} K^{-1}$. Another term is molar heat capacity, defined as the heat capacity of one mole of substance.

When we think about heat capacity of gas, there is a further complication. Our question was how much heat we need to provide for increasing the temperature by one Kelvin. But, we have two ways of doing so —

(i) We can place our gas in a sealed box and add head by placing it near a furnace. As the temperature rises, the gas will not be allowed to expand, since the volume is fixed, so its pressure will increase due to increased velocities of the molecules. This method is known as heat transfer at constant volume.

(ii) Place the gas in a chamber connected to a piston and now ~~to~~ provide heat. The piston can slide along the chamber. As temperature rises, the piston is forced out (doing work against the atmosphere and the gas is allowed to expand, keeping the pressure constant. This is known as heat transfer at constant pressure.

In either case, we are giving constraints, either keeping the volume constant ~~and~~ or pressure. So, we have to define two heat capacities —

(i) C_v: heat capacity at constant volume and

(ii) C_p: " " " pressure

$$C_v = \left(\frac{\partial Q}{\partial T}\right)_v \quad \text{and} \quad C_p = \left(\frac{\partial Q}{\partial T}\right)_p$$

We could expect C_p to be greater than C_v since some of the heat contributes to doing work on the atmosphere as the gas expands.