Chemical Principles II
Professor Dr. Arnab Mukherjee
Department of Chemistry
Indian Institute of Science Education and Research, Pune
Module 05
Lecture 30
Thermodynamic Temperature

The fact that the Carnot engine has highest efficiency working between two temperature reservoirs gives rise to something call thermodynamic temperature, so we are going to talk about that.

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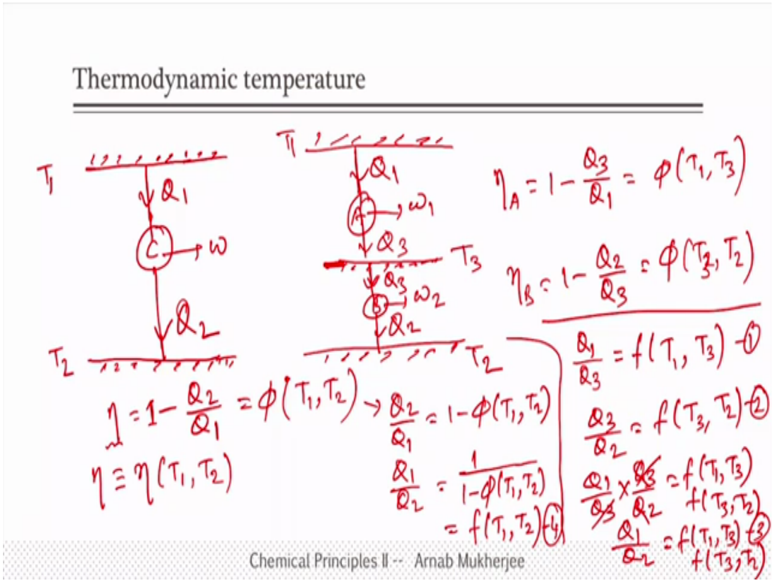

So remember that a Carnot engine working let us say between two temperature bath T 1 and T 2 where T 1 is high temperature bath and T 2 is the load temperature bath and let us say it takes in Q amount of Q 1 amount of heat does some work and throws away Q 2 amount of heat. So this particular engine will have or you can will have the efficiency as 1 minus Q 2 by Q 1, so where we know that Q 1 is the you know heat that is taken in from high temperature and Q 2 is heat that is thrown out to the low temperature.

So you see the efficiency eta which is 1 minus Q 2 by Q 1 depends on these two temperatures T 1 and T 2, right so we can say that the efficiency is basically a function of two temperatures T 1 and T 2 because nothing else is a required to define the efficiency of a Carnot engine apart from that the heat taken in and heat you know thrown to two different temperatures reservoirs.

So we can call that this is particular efficiency some function let us say phi 1 phi of T 1 and T 2, ok now let us construct another engine a combine system where two engine work simultaneously heat Q 1 is taken in from high temperature some work is being done and Q 3 is thrown to an intermediate temperature reservoir T 3, so T 3 works as temperature reservoir low temperature reservoir for the upper engines let us call that A and then same Q 3 will be taken in by another engine called B which does some other work and finally Q 2 heat is thrown to the T 2 temperature reservoir.

So what we have done is that we replace one engine by two engines in and there is a temperature reservoir in between T 1 and T 2 temperature, ok. Since the heat cannot escape it takes in and give the same amount of heat to the next engine, so now this is a combine system, now if you calculate the efficiency of engine A what we are going to get 1 minus Q 3 by Q 1 and this one is a function of T 1 and T 3, right.

Similarly, eta B which is the efficiency of the second engine is one minus Q 2 by Q 3 therefore we can say it is a function of T 2 so we are writing like first high and then low so T 3 and T 2, ok. So now you see if I consider the final you know initial and final temperature differences then efficiency of this engine let us call it C, so efficiency of engine C will be same as that of the combine efficiency of the right hand side engine, ok.

So now if I rearrange a little bit here this particular equation let us say from here if I rearrange a little bit then what I get is that Q 2 by Q 1 is equal to 1 minus phi T 1, T 2, ok we can invert it and write Q 1 by Q 2 so we are inverting just to say that heat input divided by heat output is 1 by 1 minus phi T 1 and T 2, right it is still a function of T 1 and T 2, so let us call it f T 1, T 2 now finally what we got? We got for the engines C we got Q 1 by Q 2 is equal to a function that is a function of T 1 and T 2, ok.

So you can write the same thing for above two, so from eta A we get heat input is Q 1 by Q 3 is a function of T 1 and T 3 and from eta B the engine B what we get? The input is Q 3 output is Q 2 we get f T 3, T 2. Now you see one interesting thing happens I can multiply equation 1 and equation 2, so if I multiply equation 1 and equation 2 what I am going to get Q 1 by Q 3 into Q 3 by Q 2 is equal to f T 1, T 3 multiplied by f T 3, T 2 left hand side cancels and gives us Q 1 by Q 2 is equal to product of two functions, ok.

Now this we get from here let us call that equation 3 and we already have from this equation 4 Q 1 by Q 2, now 4 and 3 we can equate.

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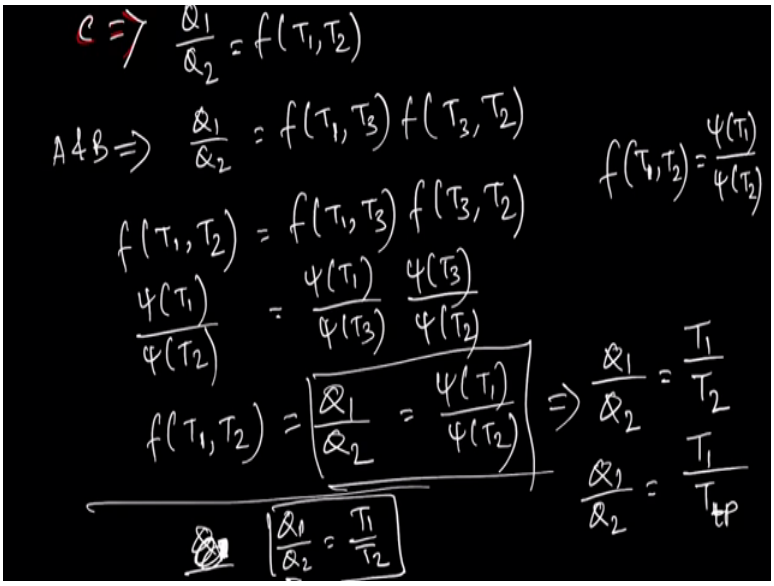

So what we have seen that from engine C we got Q 1 by Q 2 as a function of T 1, T 2 and from combine engine A and B we got Q 1 by Q 2 as f T 1, T 3 multiplied by T 3, T 2, ok so equating these two we get T 1, T 2 is a product of T 1, T 3 f T 3, T 2. Now you see somehow this product or these functions is dropping out here even though we have introduce a temperature and that is possible if this function T 1, T 2 or any two temperature is a ratio of function of these two temperatures separately, let us say if I write an I can show you.

So this can be a function of psi T 1 is a function of T 1 and this ratio is the overall function we can write the same way, you see if we write that the psi T 3 cancels out, so f is basically f which is a function of two temperatures is basically a ratio of function of individual temperatures, right. So now what we learned from here is that and where did you get this? Now what is our f T 1, T 2? Our f T 1, T 2 is nothing but Q 1 by Q 2, right and we got f T 1, T 2 as psi of T 1 by psi of T 2.

So this is the basic formulations of the thermodynamics temperature. So you see it is not exactly a temperature it is a function of temperature some function of temperature. Now kelvin used a linear function we can use some linear function with changes with T 1 and if you use a linear function or we can call this psi T 1 itself as T 1 then we can say that the ratios of heat input output is related to the ratios of two thermodynamics temperatures.

You need only need one specific point in order to determine the other temperatures, so for example if you calculate Q 1 and Q 2 for a known temperature and the known temperature typically is taken to be the temperature of triple point of water which is 273 point 16, so this is T triple point is known Q 1, Q 2 will be measured and then you can get the value of T 1, so that is we can measure the temperature given that we can calculate heat input and output.

So in real experiment as especially below 1 kelvin temperature where the gas see other the temperature that we learnt from you know zero law of thermodynamics is when we combine a property with the heat, so for example or with the temperature for example we say that how much is a value of P V when the pressure is very low and how much is a value of P V with respect to P V at triple point that will give us a major of the temperature, that is in a gas thermometer.

Similarly for other cases for solids and a other you know mercury we calculate the property by looking at the changes in the volume or changes in the pressure and things like that. Here thermodynamics temperature we are calculating the temperature by calculating the heat input and output and that is possible because Carnot engine gives us that, remember that for ideal cases we exactly know that Q 1 by Q 2 in ideal gases case we know that Q 1 by Q 2 is exactly as T 1 by T 2 that is from our normal (therm) you know temperature definition itself it gives that in ideal gas however in general for non-ideal gases also we can write the ratios of heat input output as a function of the individual temperatures.

That is kelvin actually decided you know given this kelvin scale and one can see that when one of that will go to zero then let us say you know in order for the efficiency to go to 1 the one of the temperatures to go to zero and in that the heat output will be zero there will be no heat going out, so it becomes an adiabatic step itself. So when the isothermal and adiabatic becomes equal at that point your efficiency will become 1, ok.