

At the end of lecture 24, I gave you the DEFs of a heat engine and of a heat pump, or refrigerator. They are both CYCLIC DEVICES, meaning that each periodically returns to its initial conditions, repeating the same process over and over. The HEAT ENGINE takes heat from a hot reservoir, does useful work, and exhausts waste heat to a cold reservoir. The HEAT PUMP uses external work to remove heat from a cold reservoir and exhaust heat to a hot reservoir. You learned to draw ENERGY-TRANSFER DIAGRAMS (our book calls these "schematic representations") for both kinds of devices. Before starting this reading, make sure that you can draw an energy-transfer diagram for both a heat engine and a heat pump (you can find the book's versions in Figure 15.12 and 15.13 on pages 427-428, but the ones we drew in lecture are more informative -- if you rely on the book's diagrams, remember that "what goes in, must come out").

Also, at the end of required reading 24, I made a formal statement of the 2nd Law of Thermodynamics. Before beginning this reading, see if you can write down that law in your own words. Then check against my version at the end of reading 24 or the book's version on page 426. Finally, check your understanding (CYU) of both energy-transfer diagrams and the 2nd Law by doing CYU 3 at the top of page 433 in our textbook.

I will begin lecture 25 by proving that the "best possible" heat engines and heat pumps are reversible; by "best possible", I mean the most efficient heat engines (biggest e) and the heat pumps with the highest coefficients of performance (COP 's). You will see that, if the 2nd Law holds, then the best e for a heat engine, and the best COP for a heat pump, are both for reversible devices.

Next, we would like to find an expression for the e of a reversible heat pump or the COP of a reversible heat pump. In order to do so we need one last definition (last DEF of the year - but it is tough one):

DEF The ENTROPY (S) of a system of particles is a measure of the disorder of that system. The CHANGE IN ENTROPY (ΔS) is given by

$$\Delta S \equiv \sum_{\text{all } \Delta Q\text{'s}} \frac{\Delta Q}{T_{K,\Delta Q}} \quad \text{units are J/K}$$

where $\sum \Delta Q = Q$, the total heat transferred, and

$T_{K,\Delta Q}$ is the T_K at which each ΔQ was transferred.

How would this DEF work for an arbitrary process in which the total heat flow was an amount Q ? First, you must divide the total Q up into a bunch of little ΔQ 's, for example, a millijoule (mJ) each. Then you have to imagine the transfer of each of the ΔQ 's, one at a time. Let $T_{K,1}$ be the temperature at which the first of the ΔQ 's is transferred; the little ΔQ would change the temperature of our gas by an amount $\Delta T_K = \Delta Q/nC$, where n is the number of moles of our gas and C is the molar specific heat of our gas for this process. OK, now we are ready for the next ΔQ ; it would be transferred at a new temperature of $T_{K,1} + \Delta T_K$. So for the first two little ΔQ 's, the total ΔS would be

$$\Delta S \equiv \sum_{\text{all } \Delta Q\text{'s}} \frac{\Delta Q}{T_{K,\Delta Q}} = \frac{\Delta Q}{T_{K,1}} + \frac{\Delta Q}{T_{K,1} + \Delta T_K}$$

You would have to keep going this way until the entire Q was transferred.

This is so hard that we won't try to do it for any process except for our two processes which can be reversible, the isothermal process and the adiabatic process. For the adiabatic process, there is NO heat flow, so the $\Delta S_{\text{adiabatic}}$ MUST be zero. For the isothermal process, the temperature doesn't change, so all the little ΔQ 's are transferred at the same temperature, therefore

$$\Delta S_{\text{isothermal}} = \frac{Q}{T_K}$$

where T_K is the Kelvin temperature and Q is the heat flow during the process. This result follows directly from our DEF of the change in entropy.

So now I have described the most important uses (for us) of our DEF of the change in entropy; during lecture I will use these results to find an expression for the e of a reversible heat engine (one that uses only the isothermal and slow adiabatic processes). But I hope you are still asking the question, "How is this DEF related to the concept of disorder in our system of particles?" It is certainly NOT obvious in any way how Q/T_K indicates the change in disorder of our gas during an isothermal process. During lecture, I will take the time to consider two or three isothermal processes, and hopefully help you to see how Q/T_K IS a measure of of the change in disorder of the system of particles which composes our ideal gas. Also, note that only change in entropy has been defined; it IS possible define entropy directly, but that DEF is even tougher to grasp than this one. You do need to realize however that the entropy S of our gas can only depend upon the variables P , V , T_K , and n ; if those values are unchanged then S must also be unchanged.

Finally, our logic will lead us to an interesting restatement of the 2nd Law:

SECOND LAW OF THERMODYNAMICS

For any process, the change in entropy of the UNIVERSE is ≥ 0 .

Only for a perfectly reversible process is $\Delta S_{universe} = 0$.

In other words, the disorder of the Universe, or of any closed system, can never decrease! Increasing order in one little piece of the Universe MUST be accompanied by a greater increase in disorder somewhere else. It is this law, that in physics, separates past from future and indicates the direction of time's arrow. If we make a closed system and measure its total energy, momentum, and angular momentum, then we can go away and return any number of years later; the values of energy, momentum, and angular momentum will be the same as before. But the entropy of the system must have increased.