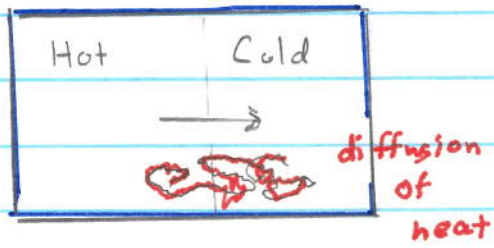
Heat and Specific Heats



- The transfer of energy, aka heat Q, from the hot to the cold

- The transfer is a diffusive process, and is very slow. It takes 1 millisec for sound to propagate across the box, but seconds or more to diffuse across the box.

- An important quantity is the heat capacity

$$C \equiv \frac{dQ}{dT} \qquad \text{so} \qquad dQ = C\,dT$$

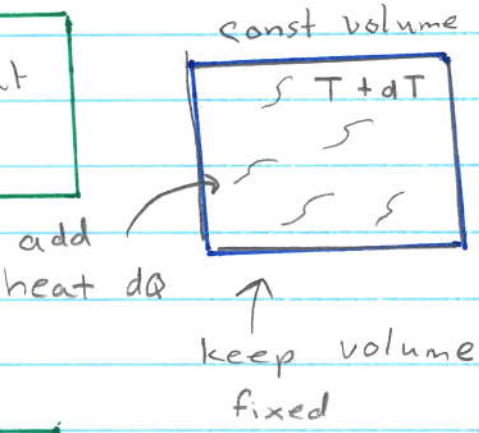
$C\,dT$ is heat required to raise dT.

- The heat capacity grows with the system size (the ocean has a large heat capacity). We usually quote the specific heat per mol or per kilo, i.e. the specific heat for 1mol of substance. The book uses $c = C/\text{Mass}$ for the specific heat per kilo

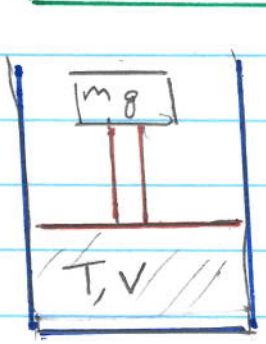
- For one mole, C is of order $R = 8.32 \frac{J}{\text{mol } ^\circ K}$

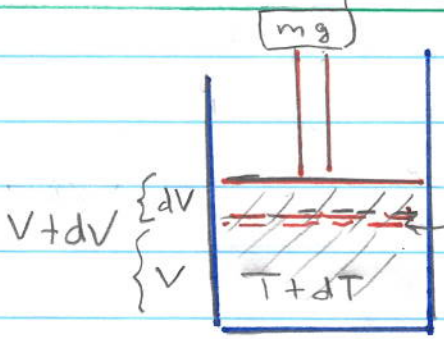
There are two kinds of specific heats

(1) $C_V = \left(\frac{dQ}{dT}\right)_V$ = specific heat at constant volume



(2) $C_p = \left(\frac{dQ}{dT}\right)_p$ = specific heat at constatnt pressure. This is easier to measure for liquids & solids.





add heat. The volume increases, but the pressure is fixed.

- We will in the next lecture derive a formula relating C_V to the change in energy with temperature (at fixed volume).

$$C_V = \left(\frac{\partial U}{\partial T}\right)_V$$ because $dU = dQ$ ← the heat added increases the energy of the gas

- So for a mono-atomic gas $U = N\frac{3}{2}k_B T$, while for diatomic gas we have $U = N\frac{5}{2}k_B T$ So we find

$$C_V = \begin{cases} \frac{3}{2}Nk_B & \text{mono-atomic} \\ \frac{5}{2}Nk_B & \text{diatomic} \end{cases}$$

$\Rightarrow$ for one mole: $N = N_A$, $N_A k_B = R$

$$C_V^{1\,mol} = \begin{cases} \frac{3}{2}R & \text{mono} \\ \frac{5}{2}R & \text{dia} \end{cases}$$

- It is clear that one needs to add more heat at constant pressure, relative to constant volume, to raise °1K, since each time you add heat at constant pressure the volume increases

We will show in the next section for ideal gas;

$$C_p = C_V + N k_B \qquad \text{(ideal gas only)}$$

reflects the work done by increasing volume in const pressure case

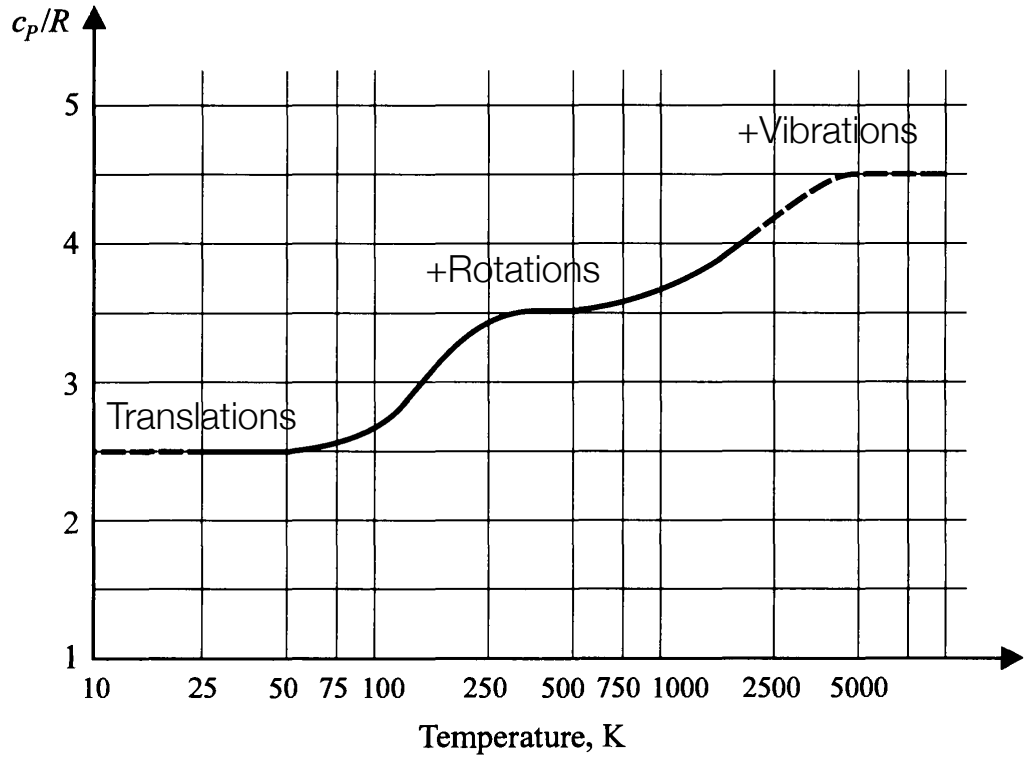
So

$$C_p = \begin{cases} \frac{5}{2} N k_B & \text{mono} \\ \frac{7}{2} N k_B & \text{diatomic} \end{cases} \Longrightarrow \text{For one mol } N = N_A,\ R = N_A k_B \Longrightarrow C_p^{1\,mol} = \begin{cases} \frac{5}{2} R \\ \frac{7}{2} R \end{cases}$$

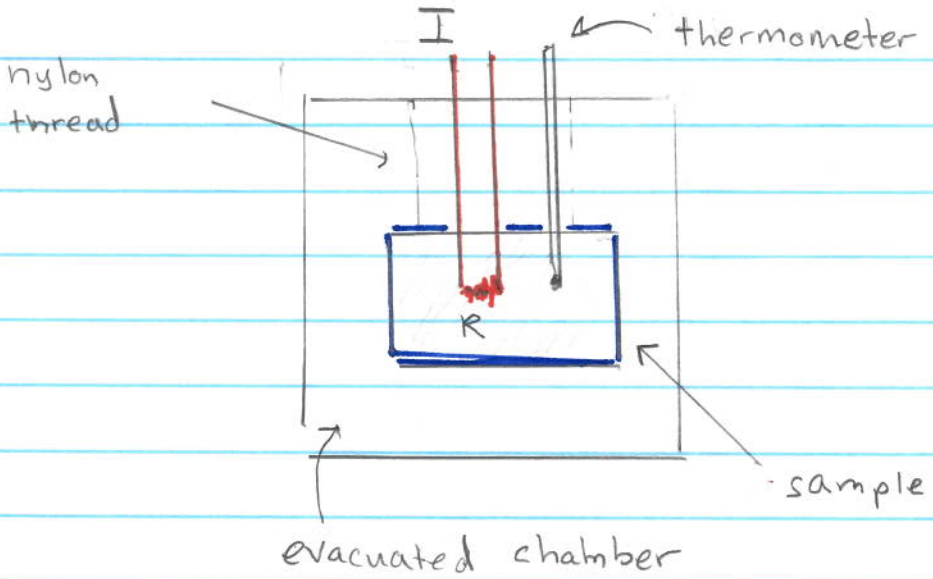
- Looking at the measured specific heats for Hydrogen gas H_2 (see below) we see that at low temperatures, $T \sim 50°K$, hydrogen is like a mono atomic gas, $C_p = \frac{5}{2} R$, but for room temperatures ($\sim 290°K$) it behaves as a diatomic gas, $C_p = \frac{7}{2} R$. At still higher temperature vibrations become important.

We will work on explaining the transitions in this course.

Specific Heat of H_2



- We can measure specific heats of solids as follows. Take a solid sample. Embed a resistor R in the sample!



- Turn on a current for a time Δt. The power dissipated is $P = I^2 R$ so the heat delivered is

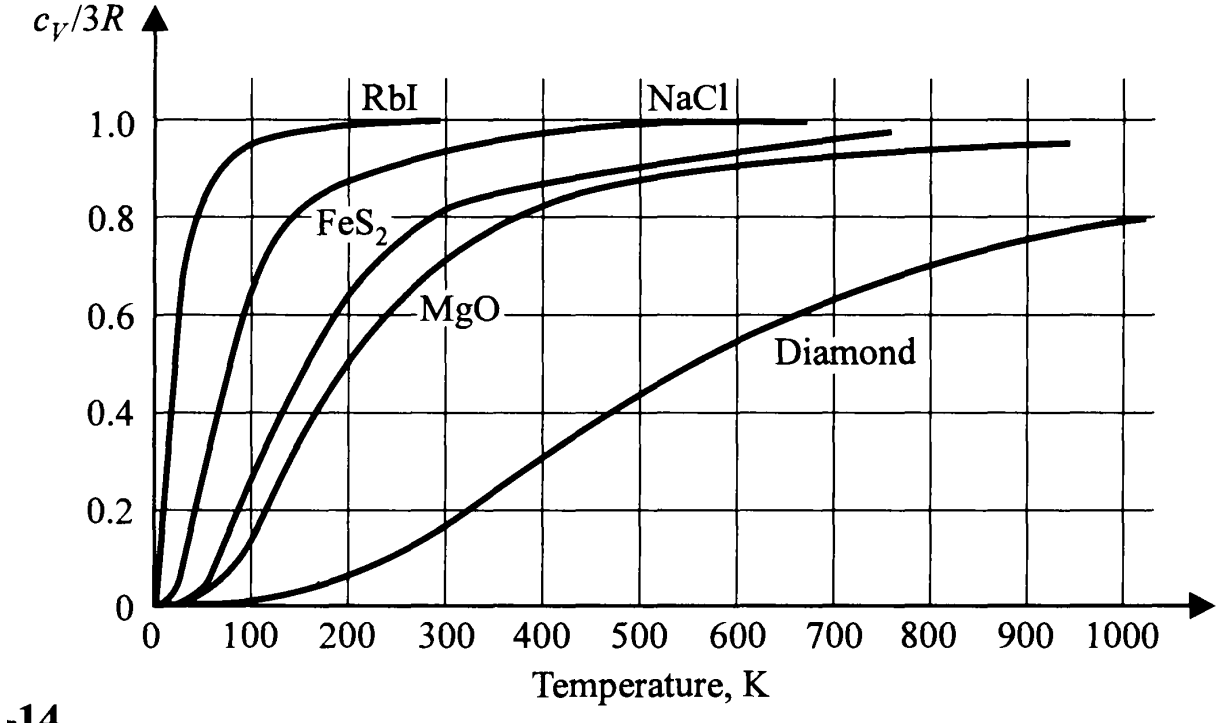
$$\Delta Q = I^2 R \, \Delta t$$

And then measure ΔT. This is $C_p = \Delta Q / \Delta T$ since the sample will expand.

- The figure below shows the specific heat per mole for various substances. We see that C_V approaches $3R$ at high temperatures but is smaller at low temperatures.

The gaph is actually for Cv and not Cp. There is a general method to convert Cv to Cp. For solids and most liquids they are nearly equal, but for gasses they are quite different.

Specific Heats of Solids: (Taken from Zemansky and Dittman)



It is not an exaggeration to say that the goal of the course is to explain these curves!