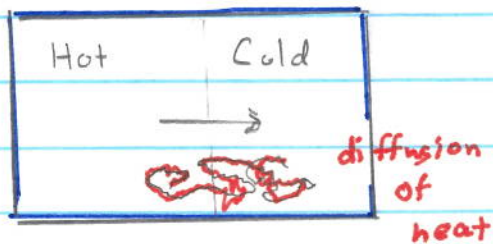


## Heat and Specific Heats



- 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 millisecond for sound to propagate across the box, but seconds or more to diffuse across the box.

- An important quantity is the heat capacity

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

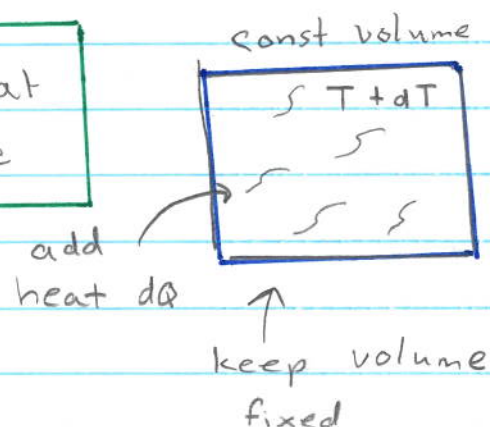
$C dT$  is heat required to raise  $dT$ .

- 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 1 mol of substance. The book uses  $c = C/\text{Mass}$  for the specific heat per kilo

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

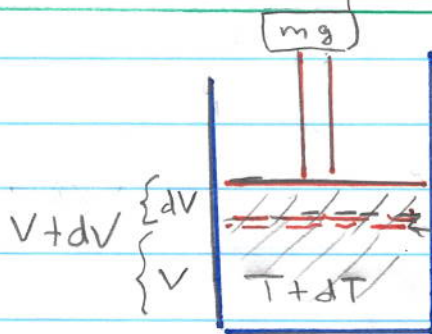
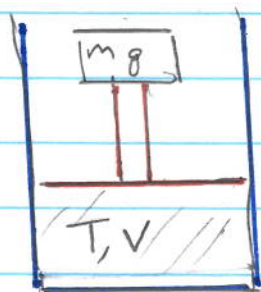
There are two kinds of specific heats

①  $C_v = \left( \frac{dQ}{dT} \right)_v = \text{specific heat at constant volume}$



②  $C_p = \left( \frac{dQ}{dT} \right)_p = \text{specific heat at constant pressure}$

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

$$C_v = \begin{cases} \frac{3}{2} N k_B & \text{mono-atomic} \\ \frac{5}{2} N k_B & \text{diatomic} \end{cases}$$

$\Rightarrow$  for one mole:

$$N = N_A$$

$$N_A k_B = R$$

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

- It is clear that one needs to add more heat at constant pressure, relative to constant volume, to raise  $1^\circ\text{K}$ , since each time you add heat at constant pressure the volume increases.

We will show in the next section for ideal gas:

$$C_p = C_v + Nk_B \quad (\text{ideal gas only})$$

So

← reflects the work done by increasing volume in const pressure case

$$C_p = \begin{cases} \frac{5}{2} Nk_B & \text{mono} \\ \frac{7}{2} Nk_B & \text{diatomic} \end{cases}$$



For  
one mol  
 $N = N_A$

$$R = N_A k_B$$

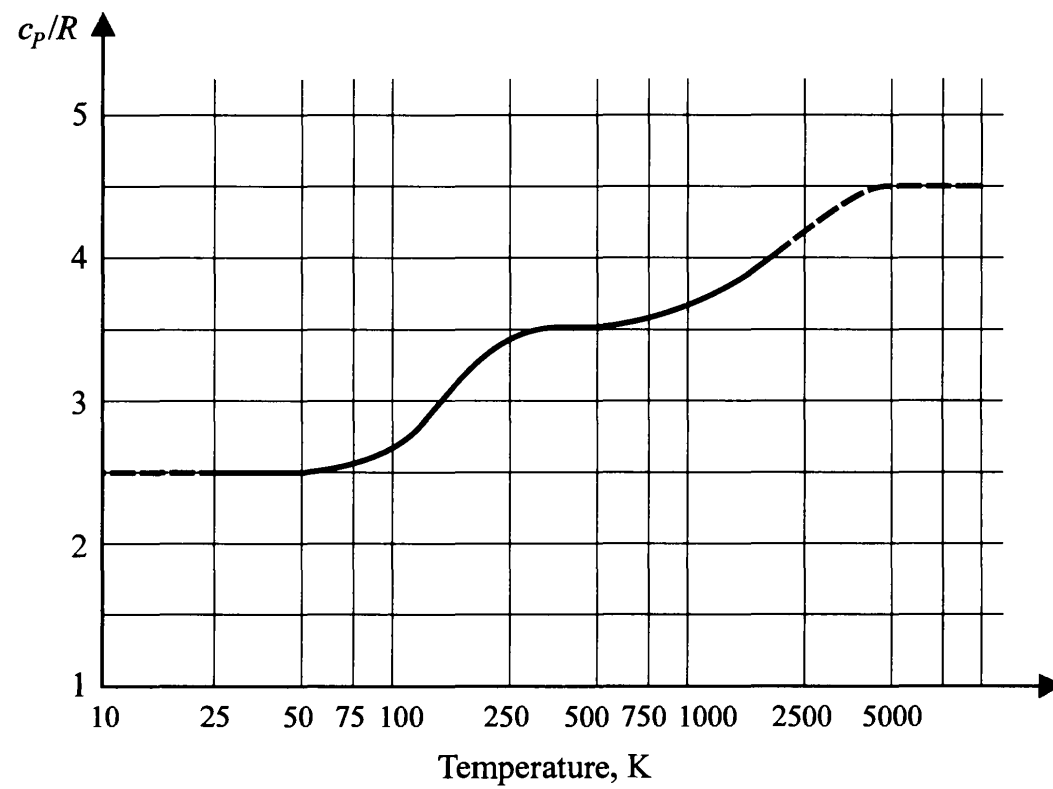
$$C_p^{\text{1 mol}} = \begin{cases} \frac{5}{2} R \\ \frac{7}{2} R \end{cases}$$

- Looking at the measured specific heats for Hydrogen gas  $\text{H}_2$  (see below) we see that at low temperatures,  $T \sim 50^\circ\text{K}$ , hydrogen is like a mono atomic gas,  $C_p = \frac{5}{2} R$ , but for room temperatures ( $\sim 290^\circ\text{K}$ ) 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.

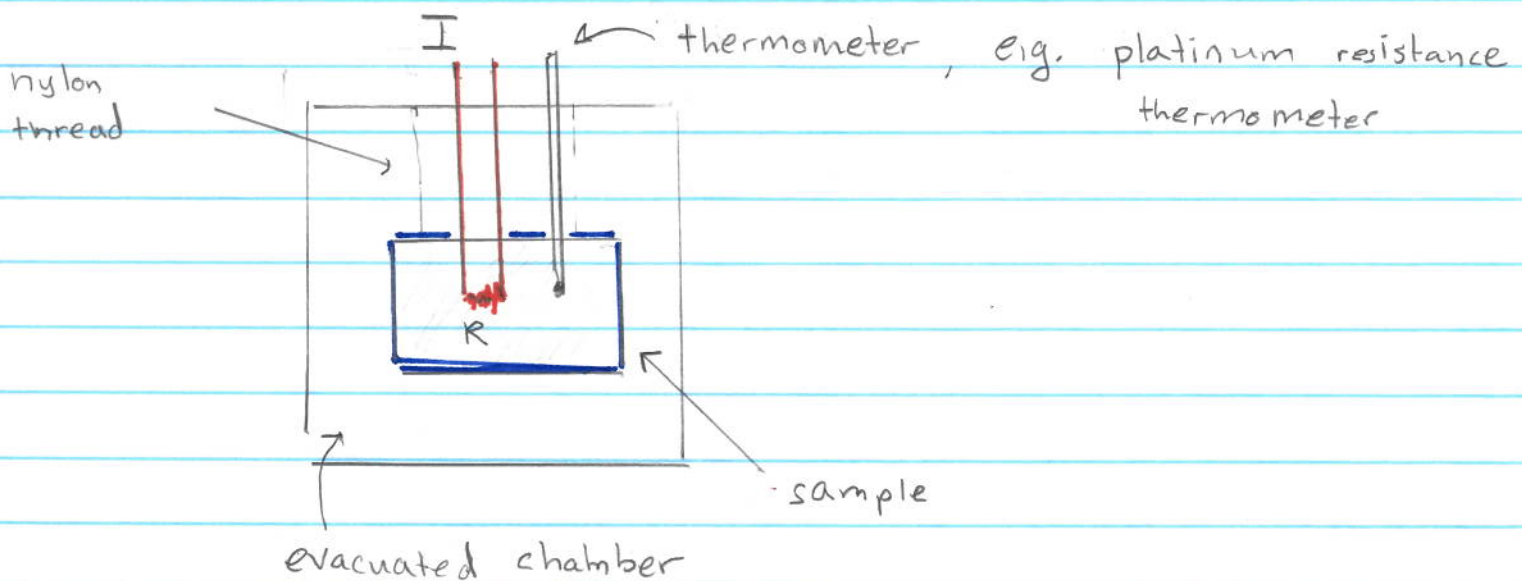
## Specific Heat of $H_2$

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- 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  $\Delta t$ . The power dissipated is  $P = I^2 R$  so the heat delivered is

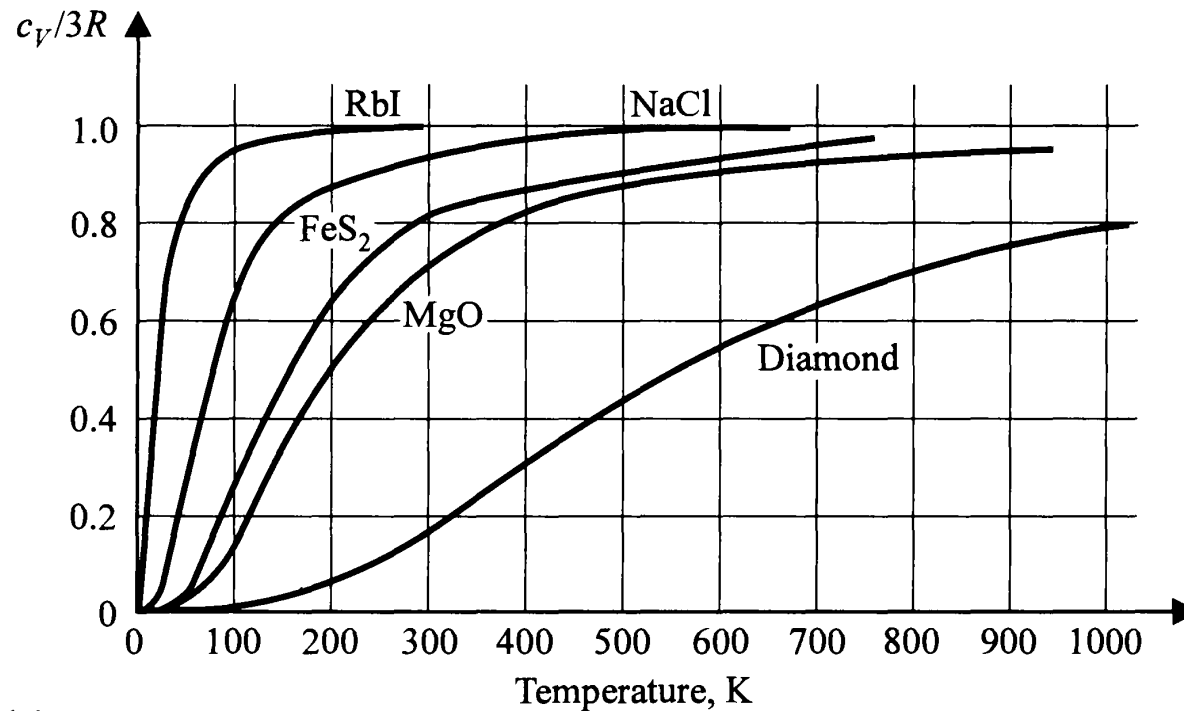
$$\Delta Q = I^2 R \Delta t$$

And then measure  $\Delta T$ . 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  $C_p$  approaches  $3R$  at high temperatures but is smaller at low temperatures.

The graph is actually for  $C_v$  and not  $C_p$ . There is a general method to convert  $C_v$  to  $C_p$ . 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)



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