PHYS 425 - w4l1

Last Time: Thermal conductivity of a gas

$$\frac{\dot{Q}}{A} = -K \frac{dT}{dx}$$

$$K = \frac{1}{3} n m c_v \bar{v} l$$

mfp $l = \dfrac{1}{\sigma_c n}$ $\qquad \sigma_c = \pi (2r)^2$

$$K = \frac{1}{3} \cancel{n} m c_v \bar{v} \frac{1}{\sigma_c \cancel{n}} = \frac{m c_v \bar{v}}{3 \sigma_c} \Rightarrow \text{const!}$$

This result is indep. of the dencity or pressure of gas!

Might have expected denser gas to better conduct heat (higher K) because there are more particles available to transfer heat.

But at higher density, have an increased collision rate between particles (reduced mfp ℓ) $\therefore$ This effect reduces heat transfer rate.

These two effects (increased no. of particles & reduce ℓ) cancel making K indep. of gas density / pressure.

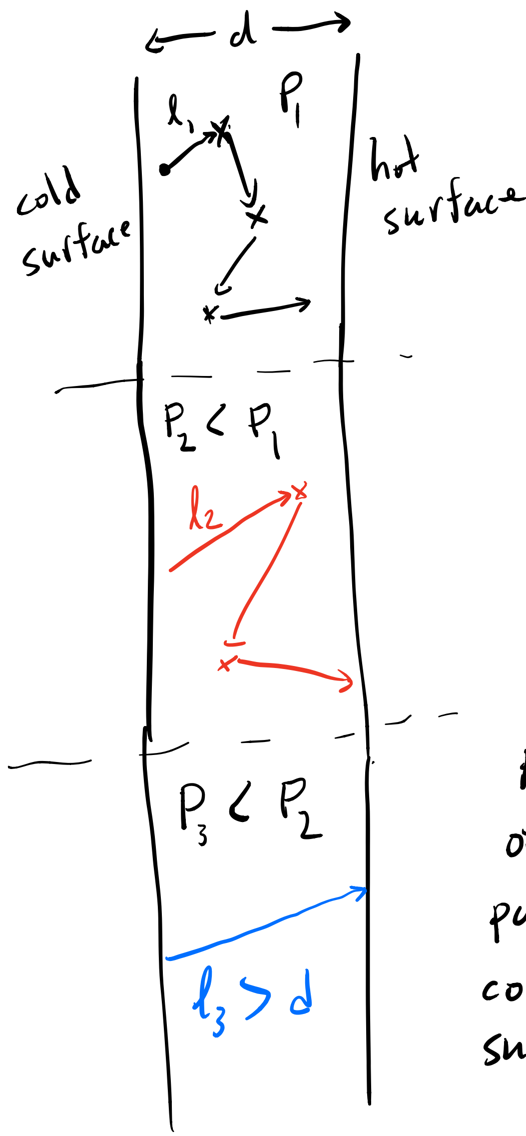
Must be something missing! K cannot continue to be indep. of n at very low pressures. What if you could (in principle) make a perfect vacuum $n \to 0$. Then must have $K \to 0$ (not remain const) as $n \to 0$.

$\Rightarrow$ no particles available to trans. heat from hot to cold surface.

Recall that mfp $\ell \propto \frac{1}{n}$

As $n \downarrow$ (low pressure)

$\ell \uparrow$.



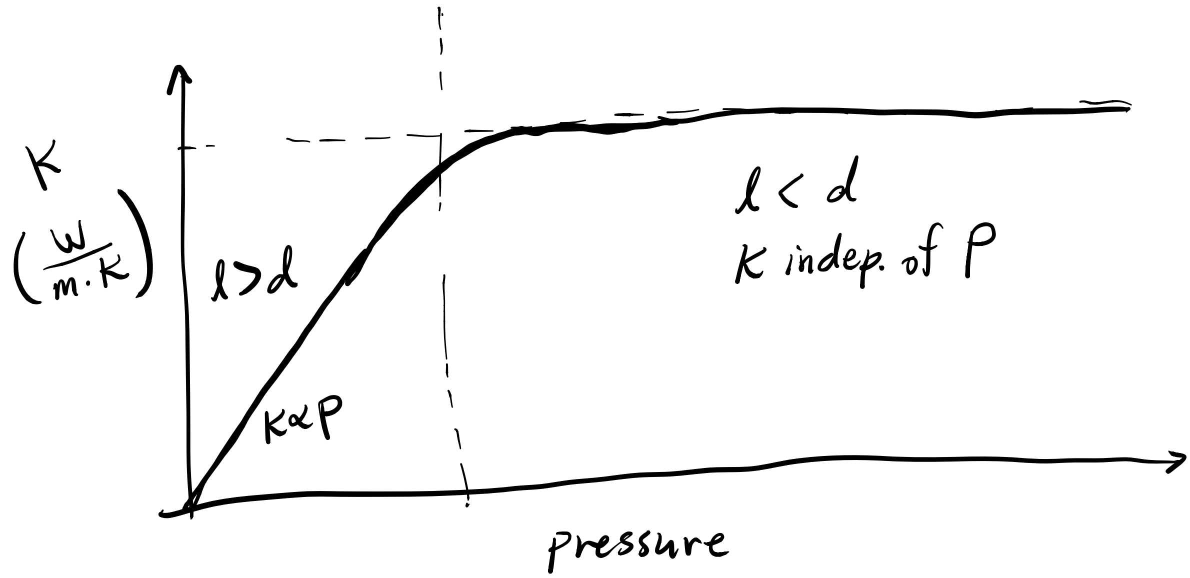
Eventually mfp ℓ get to be larger than spacing between two surfaces.

When this happens, particles scatter not b/c of collisions w/ other particles, but b/c of collisions w/ the two surfaces.

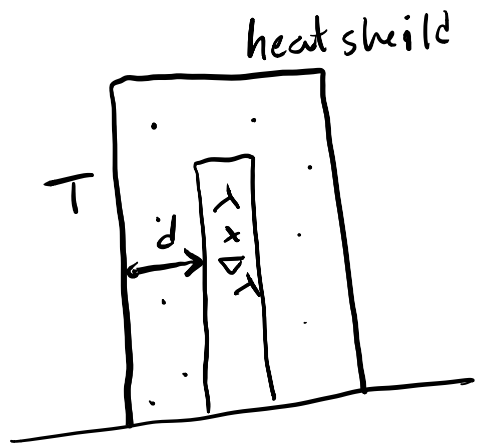
In our calculation of K, replace $\ell \to d$

When $\ell > d$ it is called the Knudsen Condition

$$K \approx \frac{1}{3} n m c_v \bar{v} d \Rightarrow K \propto n \propto P$$



Eg. If spacing between two surfaces at diff. temps in a "vacuum" is 1 cm, at which pressure will thermal conductivity of residual gas start to decrease?



require

$$d = l = \frac{1}{\sigma_c n}$$

$$n = \frac{N}{V} = \frac{P}{k_B T}$$

$$\therefore\ d = \frac{1}{\sigma_c}\frac{k_B T}{P}$$

or $$P = \frac{k_B T}{d\,\sigma_c}$$

say $T = 10\,K \leftarrow$

$\sigma_c = \pi(2r)^2$

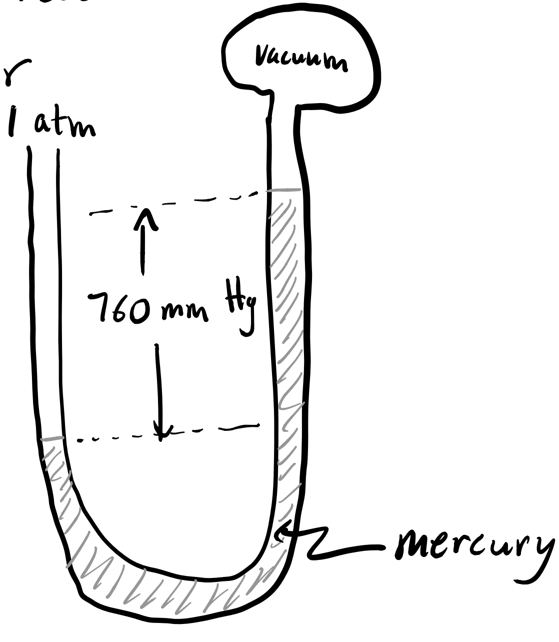
$r = 1.5\,\text{Å}$

$d = 1\,cm$

get $P \approx \underline{50\,mPa} = 5\times10^{-7}\,atm!$

Commonly used pressure unit in low-temp physics is a Torr

$1\,\text{Torr} = 1\,\text{mm Hg}$



$760\,\text{Torr} = 1\,atm$

$= 101325\,Pa$

So $50\,\text{mPa} = 3.8\times10^{-4}\,\text{Torr} = 0.38\,\text{mTorr}$

Typical mechanical pump found in most physics labs can achieve pressures of $\sim 10\,\text{mTorr}$.

→ not enough to reduce thermal conductivity of residual gas!

→ require better pump

- bigger mechanical pump
- turbo pump
- diffusion pumps

⋮