Modern
Day 15

Outline

I Last time

II Atmospheric pressure & the Kinetic Theory of Gases

III Temperature

IV Ideal Gas Law

V Work done by expanding gas (STEAM ENGINE)

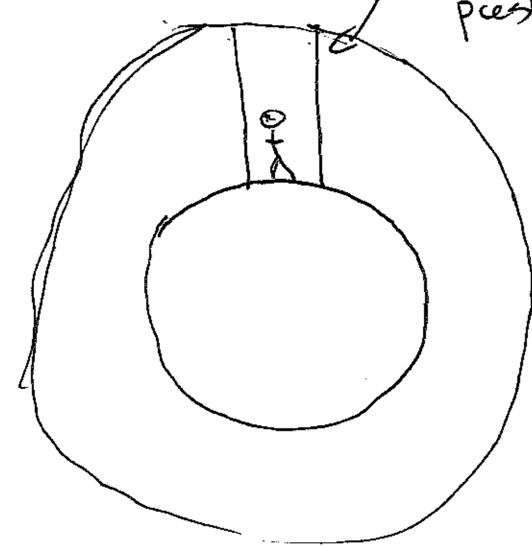
I
- studied group and phase velocity:

$$v_g = \frac{d\omega}{dk}$$

and

$$v_p = \frac{\omega}{k}$$

- Everything lets off E & M radiation. Not all visible.
- Started thinking about pressure: $P = F/A$



and found

$$\frac{dP}{dz} = \rho g$$

$$\Rightarrow P(z) = \rho g z + P(0)$$

for incompressible fluid (i.e. $\rho = \text{const.}$)

We turn now to atmospheric pressure, that is, the pressure at the surface of the Earth

For an incompressible fluid (water) ρ is independent of P. So,

$$P(z) = \rho g z + P(0)$$

$P(0)$: pressure at surface $z=0$.

<u>Compressible</u>: Need to know how density depends on pressure, the "equation of state"

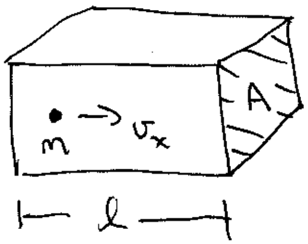
(3) <u>Atmospheric Pressure</u>

$$1 \text{ Atmosphere} = 1 \text{ atm} \approx 15 \text{ lbs/in}^2 = 1.01 \times 10^5 \text{ Pa}$$

Or use mercury: $h = 760$ mm.

(4) Kinetic theory of gases

(or: "What is pressure?")



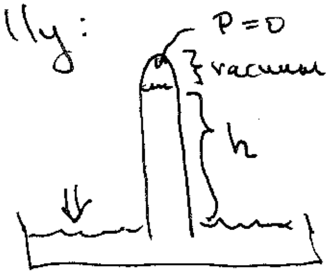
In collision with right wall, the momentum delivered is:

$$\Delta p = 2 m v_x$$

Time btwn collisions (w/ right wall): $\Delta t = \dfrac{2l}{v_x}$

Average force delivered: $F = \dfrac{\Delta p}{\Delta t} = \dfrac{2 m v_x}{2l} \cdot v_x = \dfrac{1}{l} m v_x^2$

Barometer – a tube sealed at one end, open at the other. Fill it with water and tip up vertically:



$\rho g h = 1$ atm, for water

$$h = \frac{1.01 \times 10^5 \text{ N/m}^2}{10^3 \frac{\text{kg}}{\text{m}^3}\ 10 \text{ m/s}^2} \cong 10 \text{ m} = 34 \text{ ft}$$

Then, (one molecule)

$$P = \frac{F}{A} = \frac{1}{l \cdot A} m v_x^2 = \frac{1}{V} m v_x^2$$

V ← volume

For N molecules

$$PV = N m \langle v_x^2 \rangle = \frac{1}{3} N m \langle v^2 \rangle$$

$\langle\ \rangle$ ← average

The last equality follows from

$$v^2 = v_x^2 + v_y^2 + v_z^2; \quad \langle v^2 \rangle = \underbrace{\langle v_x^2 \rangle + \langle v_y^2 \rangle + \langle v_z^2 \rangle}$$

These are equal if we ignore external influences.

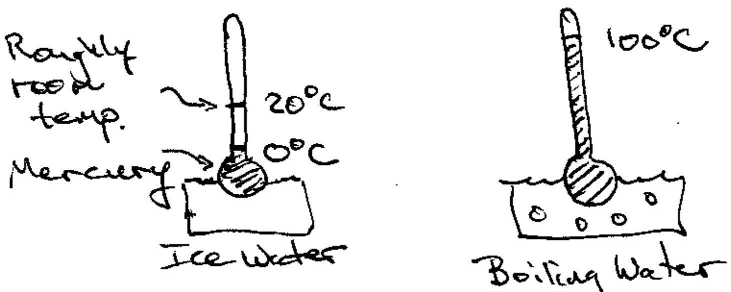
Can also write in terms of $E = \frac{1}{2} m v^2$. Get,

$$PV = \frac{2}{3} N \langle E \rangle$$

III Temperature

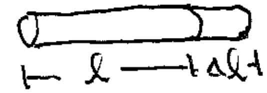
(1) Thermal Expansion

Most substances expand as temp. increases



Celsius Temp. Scale

Bar of iron; Initially at temp. T and heat up by ΔT then



The change is given by

$$\Delta l = \alpha l \Delta T$$

call α = coeff. of thermal expansion

(2) Temperature of molecular energy

What is temperature?

Temperature is a measure of the average (random) kinetic energy of the molecules in a substance.

(This is a statistical notion.)

(It also requires thermal equilibrium, so one molecule going 100 m/s is not temp., but 100 going 1 m/s is.)

(Freezing H_2O : 273 °K, Room temp. : 293° K, Boiling H_2O : 373°K)

(3) Absolute Zero: −273°C : all molecular motion ceases (not so in quantum). Kelvin temp. Scale

$$°K = °C + 273$$

(4) Boltzmann's Constant

$$\boxed{\langle E \rangle = \tfrac{3}{2} kT}$$

$\langle E \rangle$ = ave. kinetic energy molecules

k: Boltzmann's constant: 1.38×10^{-23} J/K

T: (Kelvin) Temperature