Modern
Day 17

<u>Outline</u>

0. Last time

I. Work done by expanding gas

II Internal Energy

III Heat

IV Heat Capacity

V Discuss Exam Results

- Boltzmann

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

$k = 1.38 \times 10^{-23}$ J/K ← kelvin!

- Derived the ideal gas law

$$PV = \underset{\text{\# of molec.}}{N} \, \underset{\text{Boltzmann const.}}{k} T$$

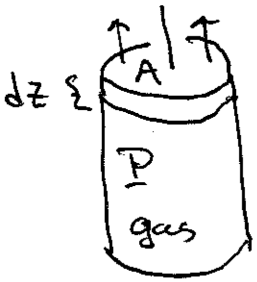
or

$$PV = \underset{\text{\# of moles}}{n} \, \underset{\text{Ideal gas const} = 8.31 \text{ J/K}}{R} T$$

1 mole = $N_A$ molecules

Avagadro's # $= N_A = 6.02 \times 10^{23}$

I How much work is done (on the outside) by an expanding gas?




$$dW = F \cdot dz = P \cdot \underbrace{A\,dz}_{dV} = P\,dV$$

$$\Rightarrow \boxed{dW = P\,dV}$$

or

$$W = \int P\,dV$$

<u>Ex 1</u>: Expansion at constant pressure

$$W = P \int dV = P(V_f - V_i)$$

<u>Ex 2</u>: <u>Ideal gas</u> expanding at constant temperature.

Can use $PV = nRT \Rightarrow P = \frac{nRT}{V}$

So,

$$W = \int P\,dV = nRT \int \frac{1}{V}\,dV$$

$$= nRT \left[ \ln(V_f) - \ln(V_i) \right]$$

$$= nRT \ln(V_f/V_i).$$

## II Internal Energy

Translational energy: $\boxed{\langle KE \rangle = \frac{3}{2} kT}$

But, kinetic energy is not the only kind a molecule can have.

Internal energy = Total thermal energy of all the molecules in sample (all forms — not just trans. kinetic energy, e.g. rotational and vibrational ...)

## Equipartition Principle:

Each "degree of freedom" (form of energy) gets, on average, the same thermal energy, in equilib. at temp. T. Counting degrees of freedom is slippery.

Trans. K.E.: 3 deg. of freedom (x,y,z)

Rotational E.: for diatomic, 2 degrees (rotation about molecular axis don't count)

Polyatomic: 3 degrees (rot about x, y, z)

Vibrational: diatomic: 2 degrees (KE+PE)

(how temp.s can also have an effect on the # of deg. of freedom you have)

At temp. T, each deg. of freedom for each molecule gets, on average,

$$\boxed{\tfrac{1}{2} kT \text{ of energy}}$$

So, $\boxed{U = N d \frac{1}{2} kT}$ ($d$ = # of deg.s of freedom)

Note: internal energy is a function of T (and amount of stuff, N). Also, we can write,

$$\boxed{U = \frac{1}{2} n R d T}$$

## III Heat

Heat = energy transferred from a hot object to a cold object by virtue of diff. of Temp.

Note: Heat is energy in <u>transit</u>.

$1^{st}$ Law of thermodynamics:

$$\Delta Q = \Delta U + \Delta W \qquad \left(\text{Conservation of energy}\right)$$

$\Delta Q$ = Heat <u>Input</u> to system

$\Delta U$ = Change in internal energy

$\Delta W$ = Work done by system on external world.

(2) For solids and liquids:

$$C = cm$$

← mass of sample ($m$)

↑ specific heat ($c$)

Specific = per unit mass

(3) Calorie: 1 calorie = amount of heat it takes to heat 1g of water $1^\circ C = 1^\circ K$, i.e.

$$C_{water} = 1 \ {cal}/{g\,^\circ C}$$

IV Heat Capacity:

(1) How much heat ($\Delta Q$) does it take to raise the temp. of a sample by $\Delta T$?

$$\Delta Q = C\Delta T, \quad C = \text{"heat capacity"}$$

depends on:
- (i) how much stuff?
- (ii) how you did it (is work done?)
- (iii) what stuff is it?

Note: $\boxed{1 \text{ cal} = 4.184 \text{ J}}$

[ Food calorie, sometimes Cal, = 1,000 cal = 1 kcal. ]

V Exam