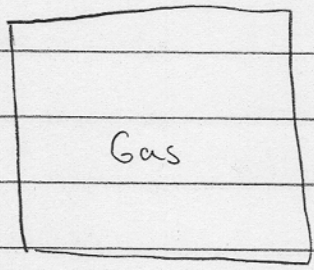
Temperature

What is it?

t_C, t_F, T — where did it come frome

• Celsius, Farenheit ~1724, Kelvin



① Characterized by constants of motio

→ E the total energy in the box

→ N the total # of part in box

② Then the other state variables

P, T, ρ are determined

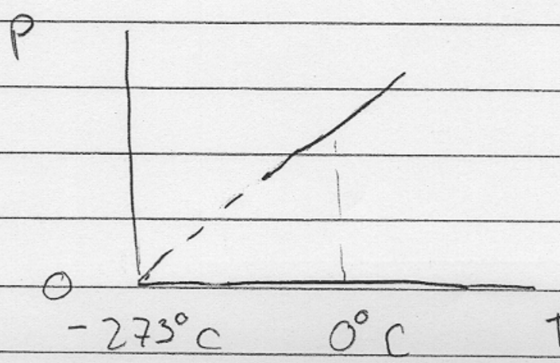
by these constants (E, N) and the properties of the gas

• In the study of dilute gases find at fixed temperatur

(Boyle) $PV = \text{constant}$ at fixed temperatur

Now keep V fixed and decrease the temperature

① P decreasa,



the special temperature -273°

where P = 0, is independen

of gas and volume

So one finds a special temperature $t_c = -273°C$ where pressure beomes zero

- Define this temperature to be zero

$$T = t_c + 273°C \rightarrow \text{(ie } T=0 \text{ is } -273°C$$

temp in Kelvin

Celsius temp

Generally want to use kelvin.

Last Time

- Temperature Scales

t_C ← Celsius

t_F ← Farenheit $\qquad t_F = \frac{9}{5} t_c + 32°F$

T ← Kelvin $\qquad T = t_c + 273°C$

ⓐ always use it when doing calcs
ⓑ Defined to be zero when pressure = 0

- Dilute Gass (Ideal Gasses)

$PV = \text{const}$ fixed T (Boyle law)

$P \propto T$ fixed V (Gay-Lussac)

$V \propto T$ fixed P (Gay-Lussac)

What is V?

→ What we really mean is the Volume for a fixed number of particles. V/N

→ Can Double the volume and double the number of particles at the same temp and get the same pressure

So

$$P\frac{V}{N} = const$$

All these are combinded to give

$$PV = N k_B T$$

Where

$$k_B = 1.38 \times 10^{-23} \ J/°K$$

Note: $k_B \sim 10^{-23}$ $N \sim 10^{23}$ $N k_B \sim 1$

Usually work with mols

1mol = 1 N_A of particles $\qquad N_A = 6.02 \times 10^{23}$

So

$$N = \underset{\text{number of moles}}{n} N_A$$

The

$$PV = n \underbrace{N_A k_B}_{\equiv R} T \qquad \text{or} \qquad \boxed{PV = nRT}$$

$$\boxed{R \equiv \text{the ideal gas const} = 8.31 \frac{J}{°K\ mol} = N_A k_B}$$

Similarly:

1 mol weighs = $\underline{M}$ ≡ molar mass

Example: $\underline{M} = 55.8g$ for iron

$$m = n\underline{M}$$

m: mass of substance

Trivia

① How much does $1N_A$ of protons weigh?
Approx 1g

② The mass of proton $\approx$ mass neutron $m_p \simeq m_n$
Electron mass is neglible $\frac{m_e}{m_p} \simeq \frac{1}{2000}$

③ Iron has 26 protons + 30 neutrons $\simeq$ 56 nucleons

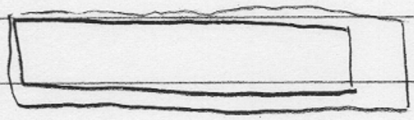
1mol of Fe weighs $\simeq$ 56 g

Problem: Volume of 1 mole at $0^\circ C$ and 1 atm?

$$PV = nRT \qquad 1\,\text{atm} = 1\,\text{bar} \approx 10^5 \frac{N}{m^2}$$

$$V = \frac{(1\,\text{mol})(8.31\,\frac{J}{\text{mol}})(273^\circ K)}{10^5 \frac{N}{m^2}} = 22.4\,L$$

Temp and Expansion:



ΔL

$$\frac{\Delta L}{L} = \alpha\, \Delta T$$

At constant Pressure:

Coefficient of expansion

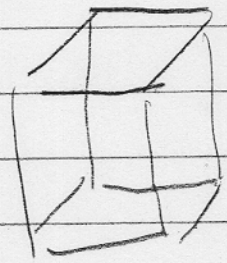
$$\frac{\Delta L}{L} \sim 10^{-5} \text{ per degree}$$

$$L_{\text{road}} \sim 30\,m \qquad \Delta T \sim 20^\circ \qquad \Delta L \sim 0.5\,cm$$

For volume expansion

$$\frac{\Delta V}{V} = \beta \, \Delta T$$

Now:



$$V = L^3$$

$$\Delta V = 3 L^2 \, \Delta L$$

$$\frac{\Delta V}{V} = 3 \frac{\Delta L}{L} = \underbrace{3\alpha}_{\beta} \Delta T$$

So

$$\beta \simeq 3\alpha$$

Heat

- To raise the temperature of a body we have to add energy. Thermal energy is known as heat transferred from one system to another
  - i.e. the kinetic and potential energies of all the molecules, and light

$$\Delta Q \propto \Delta T$$

specific heat of a body

If you have a lot of stuff it takes a lot of heat

$$\Delta Q = m c_p \Delta T$$ at constant pressure

specific heat per mass

$c_{water} = 4190 \frac{J}{kg\,°C}$ 1 cal $\simeq 4.184$ J

Also write:

specific Heat per mol

$$\Delta Q = n C_p \Delta T$$ $C_{H_2O} = 75.4$ J/mol °K

number of moles

Comments

① Now

$$\Delta Q = \overbrace{m}^{nM} c_p \, \Delta T = \overbrace{n M c_p}^{C_p} \, \Delta T$$

Compare

$M c_p = C_p$ Too easy!

② Since in $\underset{\text{Change in temp in K}}{\Delta T} = \underset{\text{Change in temp in °C}}{\Delta t}$

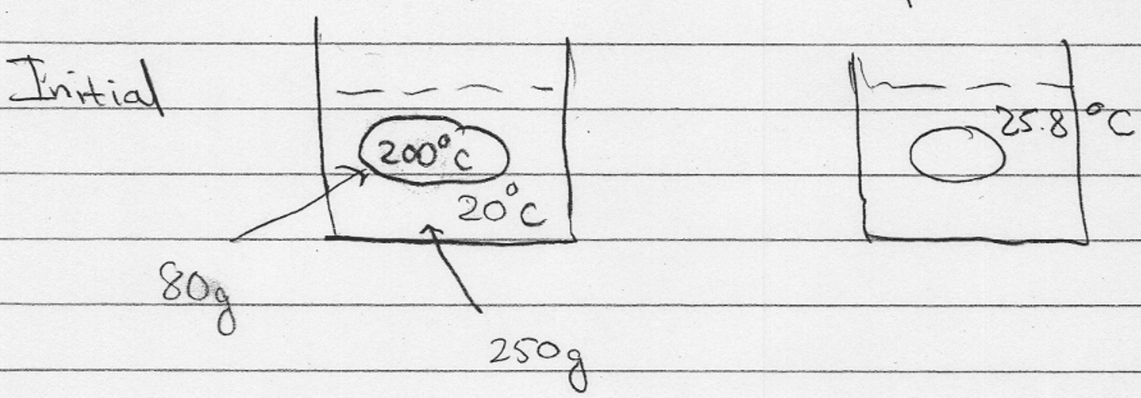
$Q = m c_p \Delta T$

$Q = m c_p \Delta t$

ie. can use celsius in working these probs

Example: determining the specific heat of steel.

A steel ball of mass $80g = m_s$ has an initial temp of $200°C$ is placed in a bucket of water of $m_w = 250g$. the final temp is $25.8°C = T_f$ (neglect the cup)



Sol: No energy is added:

$$\Delta Q_w + \Delta Q_s = 0$$

$\Delta Q_s = -\Delta Q_w$ ← heat to

$$m_s c_s \Delta T_s = - m_w c_w \Delta T_w$$

$$c_s = \frac{- m_w c_w \Delta T_w}{m_s \Delta T_s}$$

$\Delta T_w = 5.8 °K$

$\Delta T_s = -174.2 °K$

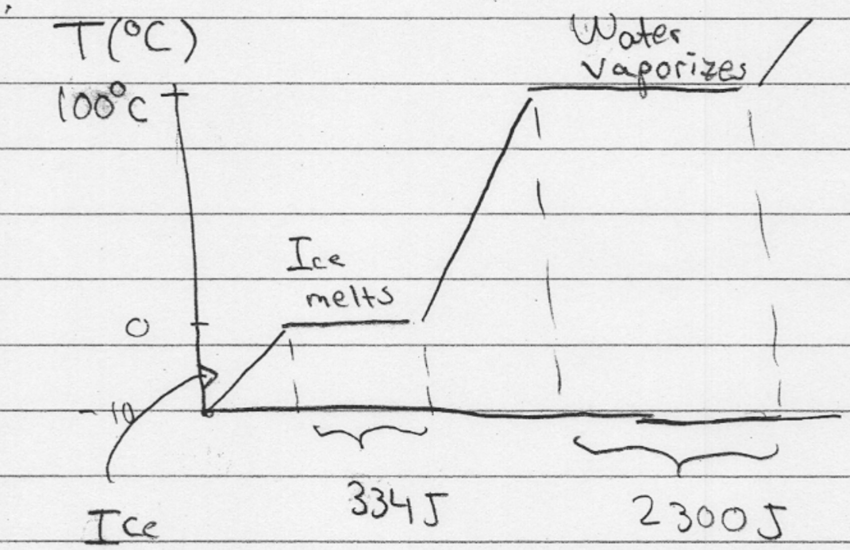
$c_s = 436 \frac{J}{kg °C}$

$c_w = 4190 J$

10 tens smaller than H_2O!

Latent Heat

Sometimes adding energy does not change the temperature ($\sim KE$) but rather changes the structure ($\sim PE$) of the material



1 Kg of H_2O

$$\Delta Q = mL$$

Latent heat of fusion $\simeq 334 \, J/kg$

heat required to melt

mass

$$\Delta Q_{Vaporize} = mL$$

Latent Heat of Vaporization $\simeq 2300 \, J/kg$ for water to steam

Example

A $\overset{m_1}{\curlyvee}$=2kg-chunk of ice at -10°C is added to $m_2 \simeq$ 5kg of liquid water at 15°C. What is the final temp?

Possible Outcomes:

- Ice could partially melt after rising to 0°C, leaving ice-water mix at 0°C
- Ice could completely melt and the T could rise above 0°C

Sol

- The heat needed to raise ice to 0°C

$$Q_1 = m_i c_i \Delta T_1 = 4.4 \times 10^4 \text{ J}$$

$c_i = 2200 \frac{J}{kg \, °K}$ = specific heat of ice

$\Delta T = 10° K$ from $-10 \leftrightarrow 0$

$m_i = 2kg$

- The heat required to melt the ice:

$$Q_2 = m_i L_i = (2kg)(334 \, J/kg) \simeq 668 \text{ J}$$

- Finally the heat taken away from the water to lower it to zero $0^\circ C$

$$\Delta Q = m_w c_w \Delta T = -3.14 \times 10^5 J$$

$$m_w = 5kg \quad c_w = 4190 \frac{J}{kg} \quad \Delta T = -15^\circ C$$

So since

$|Q_3| > (Q_1 + Q_2)$ the water will have enough energy to melt the ice and raise its temp. To find the final temp we have

$\Delta Q = 0 \leftarrow$ No heat inflow

$$\underbrace{Q_1 + Q_2 + m_i c_w (t_f - 0^\circ)}_{\text{heat into ice}} + \underbrace{m_w c_w (t_f - 15^\circ)}_{\text{heat into water}} = 0$$

$$(m_i c_w + m_w c_w) t_f = \cancel{m_i c_w 0^\circ C}^{\,0} + \underbrace{m_w c_w 15^\circ C}_{<0} - (Q_1 + Q_2)$$

$$t_f = \frac{0 + m_w c_w 15^\circ C - (Q_1 + Q_2)}{m_i c_w + m_w c_w}$$

$$t_f \simeq 9.2^\circ C$$