Thermodynamics

Relates internal (heat) energy and its flow to temperature and work

Heat flows from "hot" → "cold"

Temperature = measure of "hotness" [Kelvin]

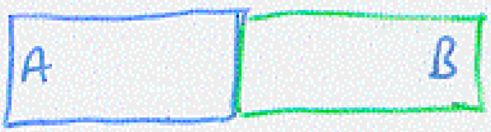
- $T = 0\ K$ ("absolute zero") when no more heat can be extracted from system

  $= 273.16\ K$ at $0°C$ ($32°F$)

"Zeroth" Law of TD:

"If two bodies are in thermal eqm. with a third, they are in thermal eqm. with each other."

i.e. if $T_C = T_A$ and $T_C = T_B$, then $T_A = T_B$



no heat flow

$T_A = T_B$

Temperature : Measurement, Defining a Scale

Zeroth law ⇒ unique temp. for any system in eqm.

Definition ⇒ If $T_A > T_B$, heat flows A ⇒ B

Can use physical properties to define a scale, but which ?

- density , pressure, electrical resistance ?

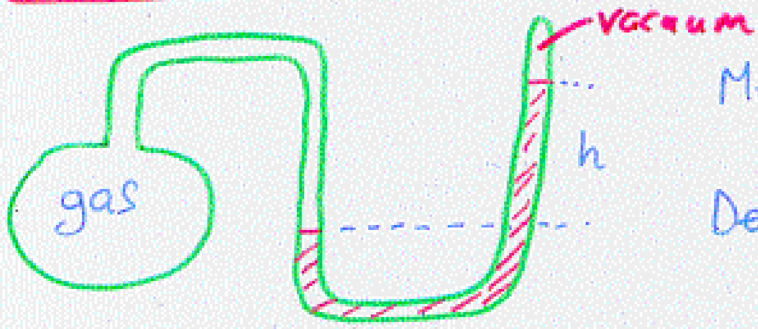
thermal expansion — gas — can go ↑ or ↓ as T ↑

We choose :

① H_2O triple-point has $T_3 \equiv 273.16\ K$

($\Rightarrow T_{boil} - T_3 = 100\ K = 100°C$)

② Constant-vol Gas Thermometer :



Measure $P = \rho g h$

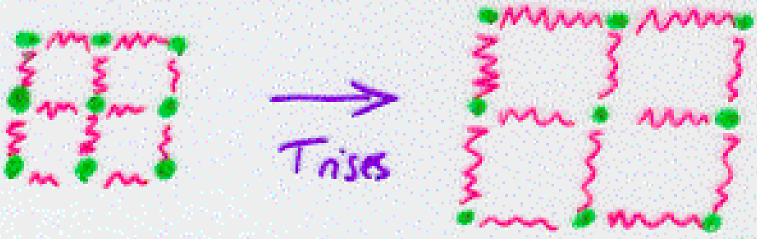
Define $T \propto P$

So $\frac{T}{T_3} = \frac{P}{P_3} \Rightarrow T = (273.16)\frac{P}{P_3}$

Good news : Any gas gives same value for T as $n \to 0$

Thermal Expansion of Solids + Liquids

- Most solids + liquids increase size as T ↑ (i.e. their density ↓)



inter-atomic distances increase as heat is absorbed

e.g. railroad tracks, dental fillings, bimetallic strip

Coefficient of linear expansion α: $\frac{\Delta L}{L} = \alpha \Delta T$

- fractional length change per Kelvin temp. change [/K]

Note: every dimension changes, e.g. hole in solid also increases in size.

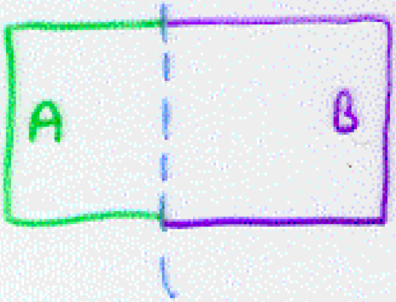
For a cube of side x, change in volume $V = x^3$

is $\frac{dV}{dT} = \frac{dV}{dx} \cdot \frac{dx}{dT} = 3x^2 \cdot \alpha x = 3\alpha V$

$\Rightarrow$ Coeff. of volume expansion $\frac{dV}{V} \equiv \beta = 3\alpha$

- fractional vol. change per Kelvin. [/K]

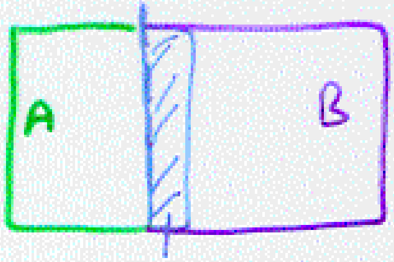
Temperature and Heat Transfer



thermal interaction
heat exchange if $T_A \neq T_B$

diathermic wall (conducts heat)

cf.



A, B push piston around
⇒ work exchanged (force moves point of app.)

piston (insulated)

Heat Capacity:

If body absorbs heat energy Q (Joule) with no change in state,

$Q = m C \Delta T$: $C \equiv$ specific heat capacity [J/kg/K]

e.g. water: $C = 4190$ J/kg/K = 1 Calorie

Example: Aluminium can, m = ~~200g~~ 100g, T = 0°C
filled with 200g water at 80°C.
– what is final temp. of mixture? ($C_{Al} = 900$ J/kg/K)

Use: Heat gained by can = Heat lost by water

$T_f(\text{can}) = T_f(\text{water})$

Heat of Transformation (L)

= heat absorbed / released for a change of state with no change in temp:

e.g. ice at 0°C → water at 0°C : $L = 333\,kJ/kg$

water at 100°C → steam at 100°C : $L = 2256\,kJ/kg$

Note: during transformation, mixture is at eqm. since $T_1 = T_2$

Example: Insulated container, 2kg ice at −5°C, heater inputs heat at 5 kW

① To bring ice to 0°C, $Q = 2\,kg \times C_{ice} \times (5°C)$

$= 2 \times 2220 \times 5 = 22.2\,kJ$. Time taken $= \frac{22.2}{5} = \underline{4.44\,s}$

② To melt ice, $Q = 2\,kg \times L_{ice} = 2 \times 333 \times 10^3 = 666\,kJ$

Time taken $= \frac{666}{5} = \underline{133.2\,s}$

③ After 180s, time to heat water from 0°C to $T_f = (180 - 133.2 - 4.44)$

$= 42.36\,s \Rightarrow$ heat input $= 5\,kW \times 42.36 = 211.8\,kJ$

$\therefore$ Final temp $T_f - 0 = \frac{\Delta Q}{C_{water}} = \frac{211.8\,kJ}{4190} = \underline{50.55°C}$