Thermal Expansion and Calorimetry

Heat - It is a form of energy which produces the sensation of warmth.

S.I. unit - Joule

Temperature - It is the degree of hotness or coldness of a body.

Tem. scales

(1) **Celsius scale** - designed by Anders Celsius

melting pt. of ice = 0 °C

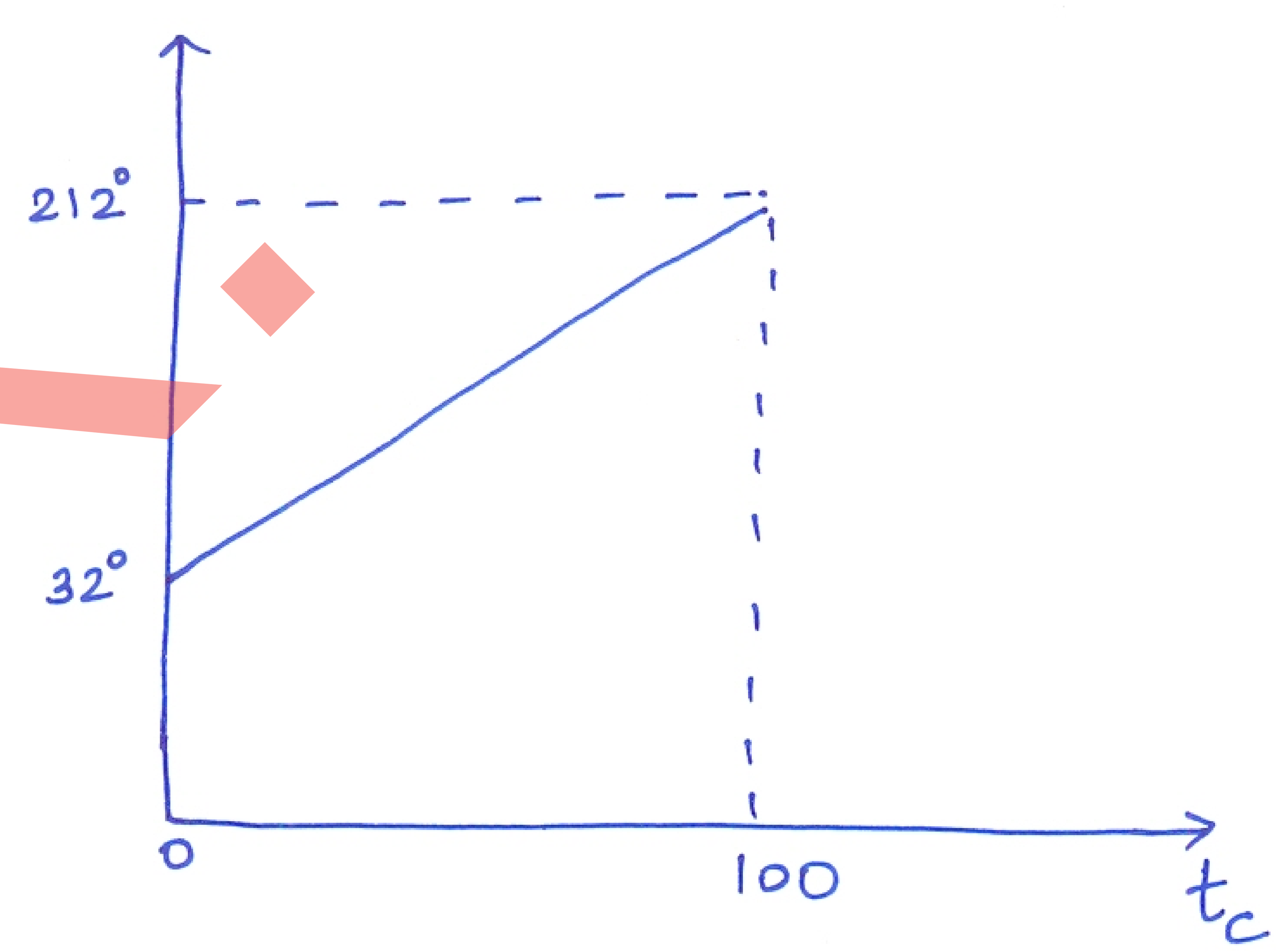
boiling pt. of water = 100 °C

(2) **Fahrenheit scale** - designed by Gabriel Fahrenheit

m.pt. of ice = 32 °F

b.pt. of water = 212 °F

* $t_c = \frac{t_F - 32}{180} \times 100$



(3) **Absolute tem. scale** - designed by Lord Kelvin

m.pt. of ice = 273.15 K

b.pt. of water = 373.15 K

* $T_K = t_c + 273.15$

Thermal expansion

The heating of solids results in their expansion, this is called thermal expansion.

Types of thermal expansion

① Linear expansion (α)

Consider a solid rod of length L heated for a small tem. ΔT so that its length increases by ΔL.

It is found that

$$\Delta L \propto L \quad \& \quad \Delta L \propto \Delta T$$

$$\therefore \quad \Delta L \propto L \Delta T$$

$$\Delta L = \alpha L \Delta T$$

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

Coefficient of linear expansion

② Area Expansion (β)

Consider a solid rod having surface area A heated to ΔT tem. so that its area increases by ΔA.

It is found that

$$\Delta S \propto S \quad \& \quad \Delta S \propto \Delta T$$

$$\therefore \quad \Delta S \propto S \Delta T$$

$$\Delta S = \beta S \Delta T$$

$$\boxed{\beta = \frac{\Delta S}{S \Delta T}}$$

③ Volume expansion (γ)

$$\boxed{\gamma = \frac{\Delta V}{V \Delta T}}$$

Coefficient of volume expansion

Relation betⁿ α, β & γ

Consider a solid cube of side L, surface area of each face of cube S & volume of cube V.

Let the cube be heated by tem. ΔT.

So, ΔL - increase in length of each side of cube.

ΔS - " " area " " face " "

ΔV - " " volume " " " "

New length of each side of cube $= L + \Delta L$

" surface area " " face " " $= S + \Delta S$

" volume " cube $= V + \Delta V$

Relation betⁿ α & β

$$S = L^2$$

$$S + \Delta S = (L + \Delta L)^2$$

$$S + \beta S \Delta T = (L + \alpha L \Delta T)^2$$

$$S(1 + \beta \Delta T) = L^2 (1 + \alpha \Delta T)^2$$

$$1 + \beta \Delta T = 1 + \alpha^2 \Delta T^2 + 2\alpha \Delta T$$

$$1 + \beta \Delta T = 1 + 2\alpha \Delta T$$

$$\boxed{\alpha = \beta/2}$$

Relation betⁿ α & γ

$$V = L^3$$

$$V + \Delta V = (L + \Delta L)^3 \Rightarrow V + \gamma V \Delta T = (L + \alpha L \Delta T)^3$$

$$\cancel{V + \gamma \Delta T = L^3 (1+}$$

$$V(1 + \gamma \Delta T) = L^3 (1 + \alpha \Delta T)^3$$

$$1 + \gamma \Delta T = 1 + \alpha^3 \Delta T^3 + 3\alpha \Delta T + 3\alpha^2 \Delta T^2$$

$$1 + \gamma \Delta T = 1 + 3\alpha \Delta T$$

$$\gamma = 3\alpha$$

$$\boxed{\alpha = \gamma/3}$$

Expansion in liquids

Real expansion – only the liquid expands, not the container

$$\gamma_r = \frac{\text{real increase in volume}}{\text{original volume} \times \text{rise in tem.}}$$

Apparent expansion – both the liquid & the container expands

$$\gamma_a = \frac{\text{apparent increase in volume}}{\text{original volume} \times \text{rise in tem.}}$$

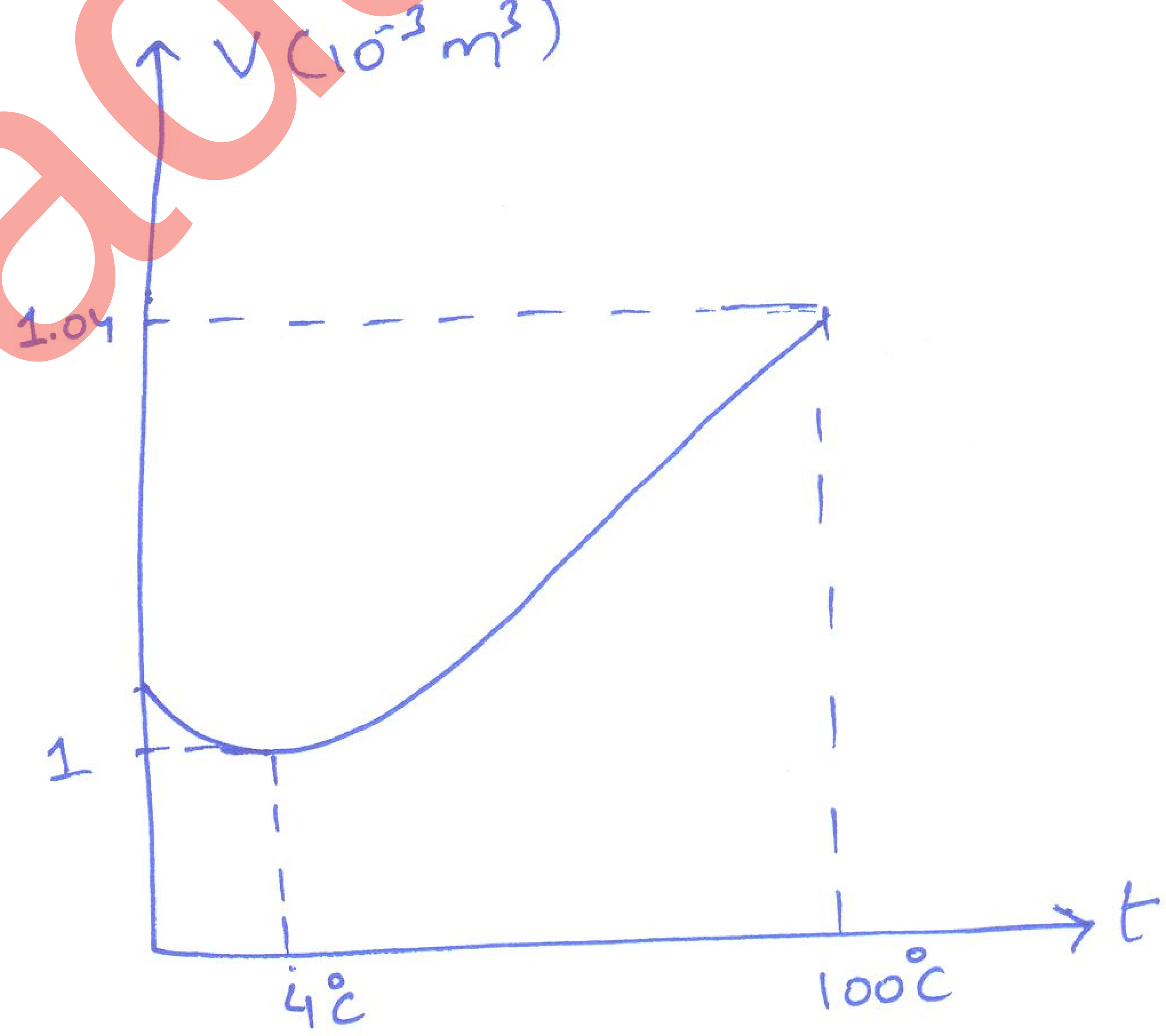
- Unit of γ_r or γ_a → $°C^{-1}$
- $\gamma_r = \gamma_a + \gamma_g$ [γ_g - coefficient of volume expansion of container]

Anamalous expansion of water

→ from 0 to 4°C : volume decreases
density increases

→ At 4°C : volume least
density max.

→ Beyond 4°C : volume increases
density decreases



- This shows water exhibits anamalous behaviour
- The anamalous expansion of water is measured by dilatometer.

Q. Explain how the anamalous expansion of water helps in the survival of aquatic life in cold winter?

Ans
- As the tem. falls, tem. of water fall ~~towards~~ to 4°C, attains max. density & sinks down.
- Warmer water present near the bottom rises up.
- Cold water at the top reaches tem. below 4°C, becomes less dense, remains on the surface & freezes.
- Tem. at bottom remains 4°C at which aquatic animals can survive.

Specific heat capacity (s)

It is the amount of heat required to raise the tem. of unit mass of a substance through one degree

$$s = \frac{\Delta Q}{m \Delta T}$$

ΔQ - amount of heat enegy

m - mass

ΔT - change in tem.

Unit → $cal.\,g^{-1}\,°C^{-1}$ or $cal.\,g^{-1}\,K^{-1}$ [As the magnitude of 1 degree is same on both Kelvin & °C scale]

Specific heat of water $= 1\ cal\ g^{-1}K^{-1}$

$= 1000\ cal\ kg^{-1}K^{-1}$

$= 1000 \times 4.18\ J\,kg^{-1}K^{-1}$

$= 4180\ J\,kg^{-1}K^{-1}$

Molar specific heat (C)

It is the amount of heat required to raise the tem. of one gram mole of the substance through a unit degree.

$$C = Ms$$

M - molecular mass

Unit → $cal.\,g\,mol^{-1}\,°C^{-1}$

*

$$s = \frac{\Delta Q}{m \Delta T}$$

$$s = \frac{\Delta Q}{n M \Delta T}$$ [$\because$ no. of moles $(n) = \frac{m \text{ (given mass)}}{M \text{ (molecular mass)}}$]

$$Ms = \frac{1}{n}\left(\frac{\Delta Q}{\Delta T}\right)$$

$$\boxed{C = \frac{1}{n}\left(\frac{\Delta Q}{\Delta T}\right)}$$

Latent heat (L)

It is the amount of heat required to change the state of unit mass of a substance from solid to liquid or liquid to gas without any change in tem.

$$L = \frac{Q}{m}$$

unit $\rightarrow$ $J\,kg^{-1}$

Specific heat of gas (c)

It is the amount of heat required to raise the tem. of 1 gm of a gas through a unit degree.

$$c = \frac{\Delta Q}{m(\Delta T)}$$

(I) Suppose a gas is enclosed in a cylinder.

(i) if the gas is compressed suddenly, $\Delta Q = 0$, $c = 0$

(ii) if the expansion is isothermal, $\Delta T = 0$, $c = \infty$

(iii) rate of expansion is slow (fall in tem. due to expansion < rise in tem. due to heat supplied)

$\Delta T = +ve$, $c = +ve$

(iv) rate of expansion very fast, $\Delta T = -ve$, $c = -ve$

Specific heat of gas

$\downarrow$ Specific heat of gas at const volume (C_v)

$\downarrow$ Specific heat of gas at constant pressure (C_p)

Molar specific heat at const. volume (C_v)

It is the amount of heat required to raise the tem. of 1 gm mole of the gas through 1K at const. volume

$$C_v = Mc_v$$

Unit $\rightarrow$ $cal.mol^{-1}K^{-1}$

* $C_p = Mc_p$

* $$\gamma = \frac{C_p}{C_v} = \frac{Mc_p}{Mc_v} = \frac{c_p}{c_v}$$

Newton's law of cooling

The rate of loss of heat of a body is directly proportional to the diff. in tem. of the body & the surroundings, provided the difference in tem. is small, not more than 40 °c.

Consider a body of mass m, specific heat 's' at tem. T be kept at a place & tem. of sullounding be T_0, where $T > T_0$

Let dQ be the amount of heat lost by the body in time dt.

Acc. to Newton's law of cooling

$$-\frac{dQ}{dt} \propto T - T_0$$

$$-\frac{dQ}{dt} = k(T - T_0)$$

$$-\frac{d(msT)}{dt} = k(T - T_0)$$

$$-ms\frac{dT}{dt} = k(T - T_0)$$

$$-\frac{dT}{dt} = \frac{k}{ms}(T - T_0)$$

$$-\frac{dT}{dt} = K(T - T_0)$$

$$\boxed{-\frac{dT}{dt} \propto (T - T_0)}$$

Newton's law of cooling also states that the rate of fall of tem. of the body is directly prop. to the temp. difference bet^n body & the sullounding, provided, the tem. diff. is not more than 40°c

Now, $\dfrac{dT}{T-T_0} = -K\,dt$

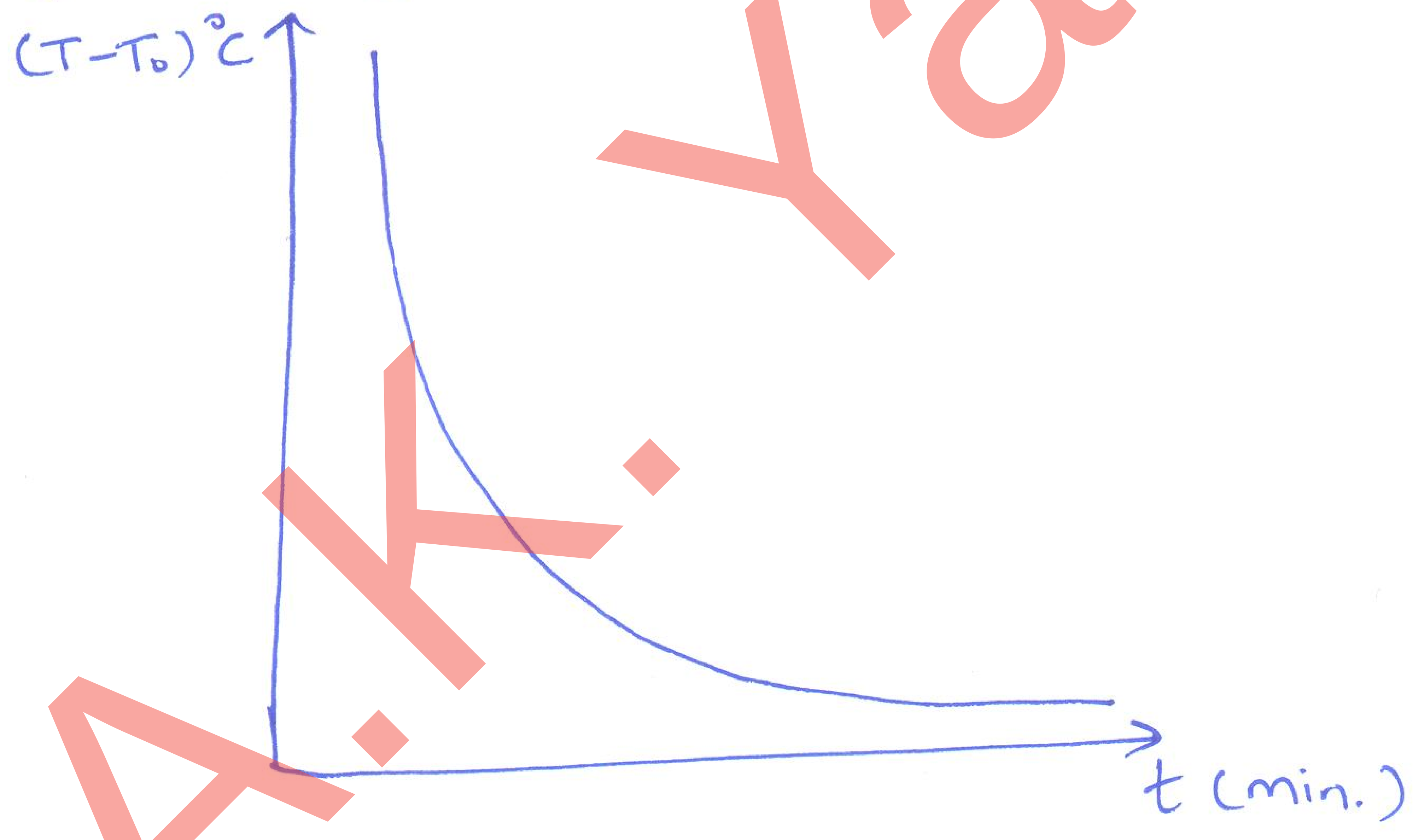
$$\log_e (T-T_0) = -Kt + c$$

This eqⁿ is similar to eqⁿ of straight line $y = mx + c$ so, Newton's law of cooling can be proved if the graph betⁿ $\log_e(T-T_0)$ & t is a straight line

Q if T is the mean tem. of the body acting betⁿ temperature T_1 & T_2 then $T = \dfrac{T_1+T_2}{2}$

$$\therefore \boxed{\frac{dT}{dt} = -K\left[\frac{T_1+T_2}{T} - T_0\right]}$$

Q. Plot the graph betⁿ tem. difference & time for Newton's law of cooling.



Reflectance, Absorptance & Transmittance

Reflectance (r) or reflecting power of a body

It is the ratio of the amount of thermal radiations reflected by a body in a given time to the total amount of thermal radiations incident on the body in the same time.

$$r = \frac{Q_1 \text{ (amount of thermal radiation reflected)}}{Q \text{ (amount of thermal radiation incident)}}$$