JEE MAIN | IIT JEE

Thermal Properties

THERMAL EXPANSION & CALORIMETRY

REVISION in 55 Min

Mohit Sir, IIT Kharagpur

EDUNITI

Topics to covered

1. Temperature Scales
2. Thermal Expansion
3. Effect of Temperature on density
4. Anomalous behavior of Water
5. Expansion in Cavities / Gaps etc.
6. Apparent Expansion of Liquid (*Hg rise in Thermometer*)
7. Effect of Temperature on Pendulum Clocks (*Second's Pendulum*)
8. Thermal Stress
9. Bimetallic Strip
10. Calorimetry – Heat Exchange
11. Phase Transformation (*Graph Understanding*)
12. Water Equivalent

JOIN

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Chapter	Formulae_Concept VIDEO LINK
Unit & Dimensions	https://youtu.be/wdd-wlZF4Hk
Errors and Vectors	
Vernier Calliper	https://youtu.be/pVoN045dV8I
Screw Gauge	https://youtu.be/gYd2PtmZ0mw
Kinematics_Motion in 1d	https://youtu.be/U4NNxFaFliE
Kinematics_Motion in 2d	https://youtu.be/4_Zo5WhMf7w
Laws of Motion	https://youtu.be/7JlR8gNRQIs
Friction	https://youtu.be/Rn1bLst7eGk
Work Energy Power	https://youtu.be/kjrXoE-kDI8
Circular Motion	https://youtu.be/KnFymKHlkT0
Centre of Mass	https://youtu.be/ads35RKD618
Cons of Momentum & Collision	https://youtu.be/3f0u4L-lyyw
Rotational Motion_Moment of Inertia	https://youtu.be/9ckZdOhy3z0
Gravitation	https://youtu.be/rAj2huLVaEk
Properties of Solids	https://youtu.be/gSXxjk89l_c
Fluids Statics (Part 1)	https://youtu.be/RFKx9B9yo3M
Fluid Dynamics (Part 2)	https://youtu.be/Y717vQpUEJQ
Fluid Properties (Part 3)	https://youtu.be/V8xUWWK2oT0
Simple Harmonic Motion	https://youtu.be/RIb7ofNG09I
Thermal Properties	
Heat Transfer	
KTG	https://youtu.be/XO1tvFhIa0I
Thermodynamics	https://youtu.be/iz_kf1jRDRw
Wave Motion -Organ Pipes and Resonance Tube	https://youtu.be/fB7pfJ77za8
Wave Motion - Doppler's Effect	https://youtu.be/9-BxOaamnwg
Electrostatics	https://youtu.be/3stXbGRMcrk
Capacitors	https://youtu.be/EXEiickNUkY
Current Electricity	https://youtu.be/gm8FUfjrX18
Moving Charges and Magnetic Effect of Current	https://youtu.be/ULD2Ok1CGJk
Earth's Magnetism	https://youtu.be/a4CT5uVwAK4
Magnetic Properties	https://youtu.be/63cwdYXNlYE
EMI	https://youtu.be/puVavm_GFRM
Alternating Current	https://youtu.be/74dTY-pzM_o
Ray Optics	https://youtu.be/BhnyTWzIlBA
Wave Optics Part 1_Interference	https://youtu.be/LG5nlE8XTeI
Wave Optics Part 2_Diffraction_Polarization	https://youtu.be/ymMyyJGGqnY
Optical Instruments	https://youtu.be/OQssbDH0A4I
Electromagnetic Waves	https://youtu.be/bcVXgEkyQZY
Semiconductors_Basics + Zener Diode	https://youtu.be/_A2JomQ7-50
Semiconductors_Transistors	https://youtu.be/psDwl84Nzb0
Semiconductors_Logic Gates	https://youtu.be/pZdQAzLbFTo
Communication Systems	https://youtu.be/8NgMqK9X79Y
Modern Physics_Part 1_Atomic Physics	https://youtu.be/9VKUnE3mpHk
Modern Physics_Part 2_Photoelectric Effect	https://youtu.be/24oTQp84jrk
Modern Physics_Part 3_Dual Nature of Light	https://youtu.be/0zoR_saMAQY
Modern Physics_Part 4_Radioactivity	https://youtu.be/AdX3YBhQyog
Modern Physics_Part 5_Nuclear Physics	https://youtu.be/VDWqVahGixc
Modern Physics_Part 6_X Rays	https://youtu.be/dSHXdzX7NX0

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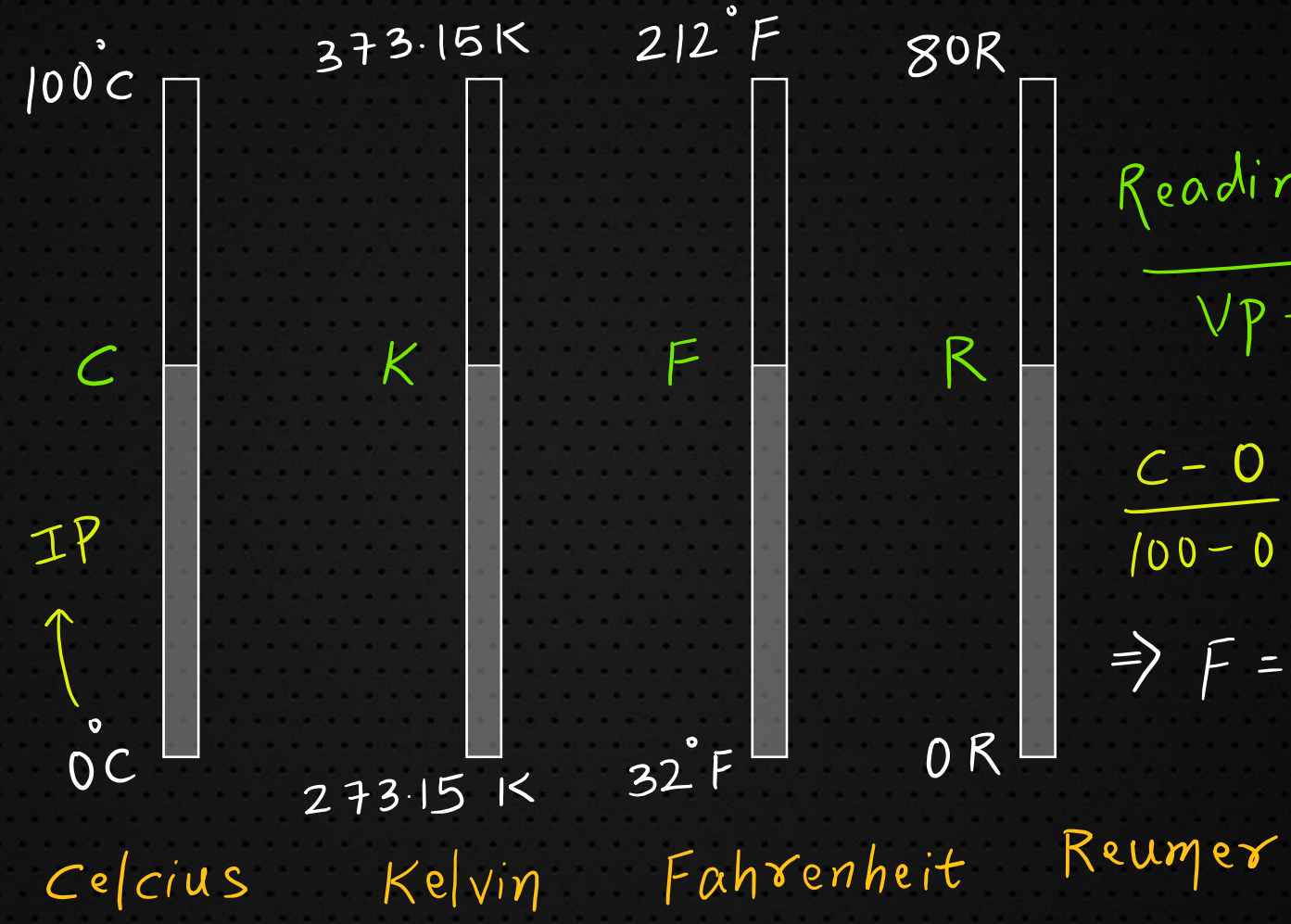
1. Temperature Scales

VP : Vapour point

IP : Ice point

(water)



Conversion Relation :

$$\frac{\text{Reading} - IP}{VP - IP} = \text{Const.}$$

$$\frac{C - 0}{100 - 0} = \frac{F - 32}{212 - 32}$$

$$\Rightarrow F = \frac{9}{5}C + 32$$

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... Continued

Ex 1. A faulty thermometer reads freezing point and boiling point of water as –5°C and 95°C respectively. What is the correct value of temperature as it reads 60°C on faulty thermometer?

(a) 60°C
(b) 65°C
(c) 64°C
(d) 62°C

... Continued

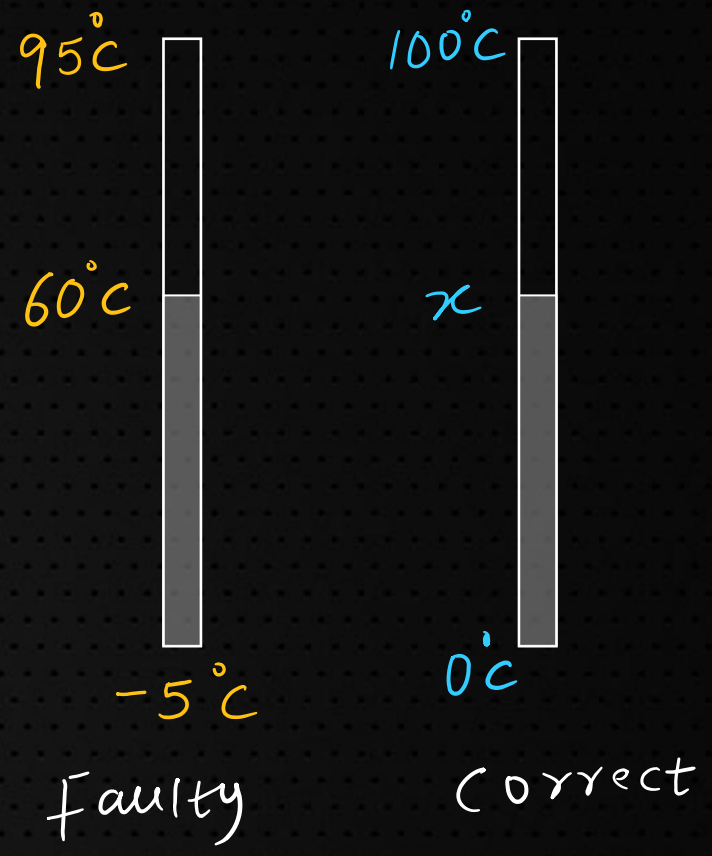
Ex 1. A faulty thermometer reads freezing point and boiling point of water as –5°C and 95°C respectively. What is the correct value of temperature as it reads 60°C on faulty thermometer?

(a) 60°C (b) 65°C
(c) 64°C (d) 62°C

Sol^n:

$$\frac{60-(-5)}{95-(-5)} = \frac{x-0}{100-0}$$

$$\Rightarrow \boxed{65 = x}$$



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2. Thermal Expansion

↳ distance between any two points ↑ due rise in temp°.

Linear Expansion

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

$\Rightarrow L_f = L_i(1 + \alpha \Delta T)$

α → Coefficient of linear expansion

Superficial or Areal Expansion

$\Delta A = A_i \beta \Delta T$

$\Rightarrow A_f = A_i(1 + \beta \Delta T)$

$\beta = 2\alpha$

β → Coefficient of Area Expansion

Volume Expansion

$\Delta V = V_i \gamma \Delta T$

$\Rightarrow V_f = V_i(1 + \gamma \Delta T)$

$\gamma = 3\alpha$

γ → Coefficient of Volume Expansion

$\alpha : \beta : \gamma = 1 : 2 : 3$

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3. Effect of temperature on density

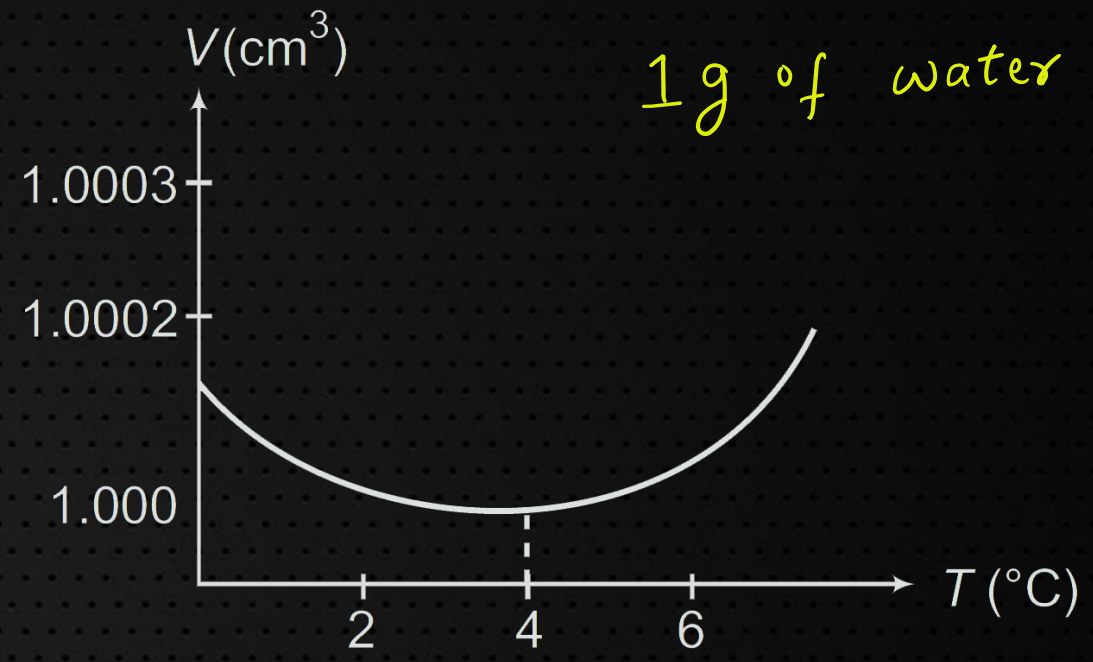
$$\rho_i = \frac{m}{V_i}, \quad \rho_f = \frac{m}{V_f} = \frac{m}{V_i(1+\gamma\Delta T)}$$

$$\Rightarrow \rho_f = \frac{\rho_i}{(1+\gamma\Delta T)}$$

If $\gamma\Delta T \ll 1 \Rightarrow \boxed{\rho_f = \rho_i(1-\gamma\Delta T)}$

4. Anomalous Expansion of Water

1 g of water



↳ This anomalous behaviour causes ice to form first at the surface of lake in cold weather

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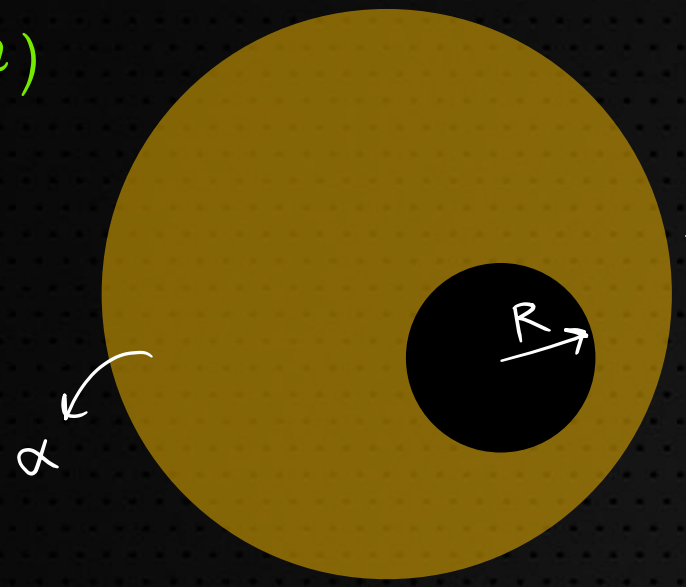
5. Expansion in Cavities/ Gaps etc.

(i)



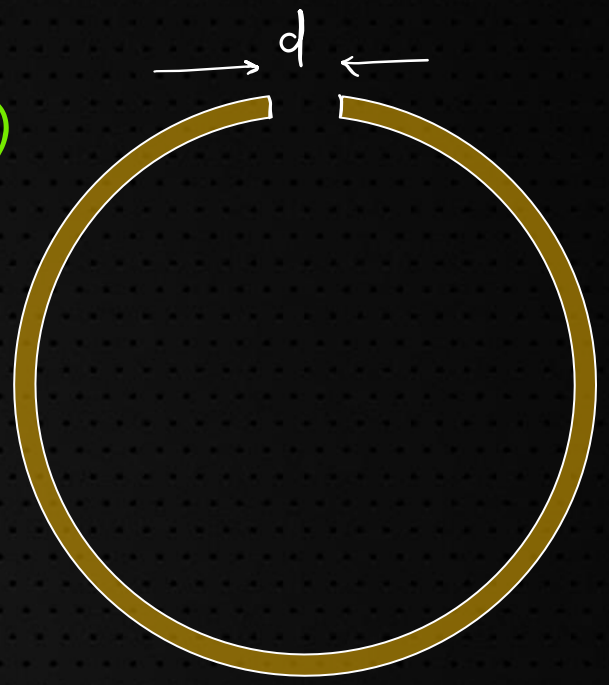
Disc, ΔT → $R_f = R(1+\alpha\Delta T)$

$A_f = \pi R^2(1+2\alpha\Delta T)$

Sphere, ΔT → $R_f = R(1+\alpha\Delta T)$

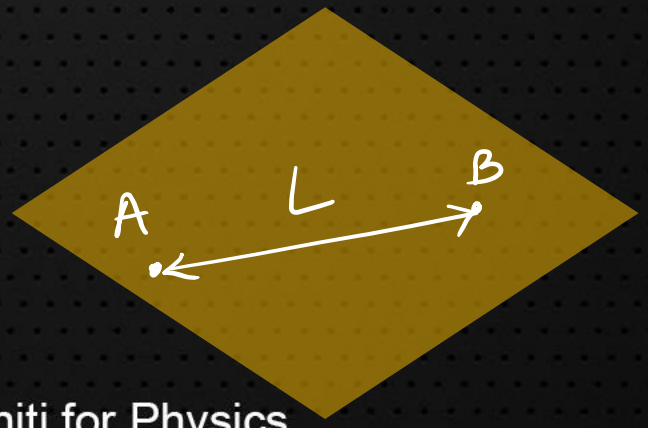
$V_f = \frac{4}{3}\pi R^3(1+3\alpha\Delta T)$

(ii)



$d_f = d(1+\alpha\Delta T)$

(iii)



$L_f = L(1+\alpha\Delta T)$

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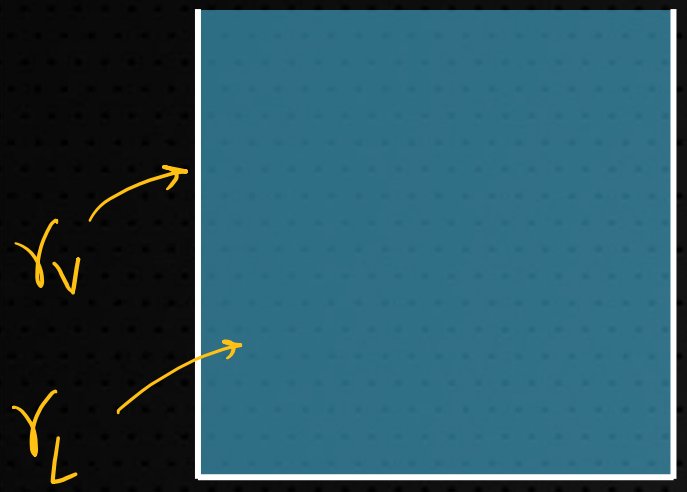
6. Apparent Expansion of Liquid



on increasing temp° (ΔT) $\Rightarrow \Delta V_V = V_0 \gamma_V \Delta T$, $\Delta V_L = V_0 \gamma_L \Delta T$

$\therefore$ Apparent Expansion, $\Delta V_{app} = V_0 \underbrace{(\gamma_L - \gamma_V)}_{\gamma_{APP}} \Delta T$

γ_{APP}

$\gamma_{APP} > 0$

$\Rightarrow \gamma_L > \gamma_V$

$\therefore$ Liquid overflow

$\gamma_{APP} = 0$

$\Rightarrow \gamma_L = \gamma_V$

$\therefore$ Liquid level same

$\gamma_{APP} < 0$

$\Rightarrow \gamma_L < \gamma_V$

$\therefore$ Liquid level falls

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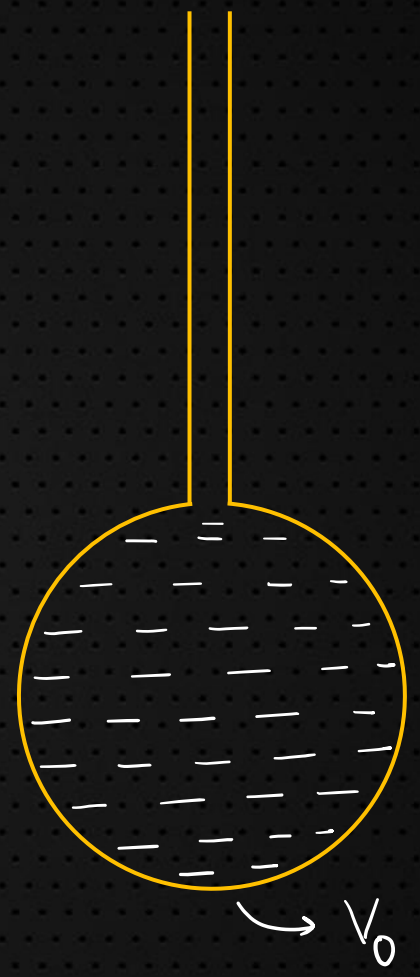
Ex2. Mercury rise in thermometer on ΔT.



γ_L for Liquid

α for vessel

$\gamma_L > 3\alpha$

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... Continued

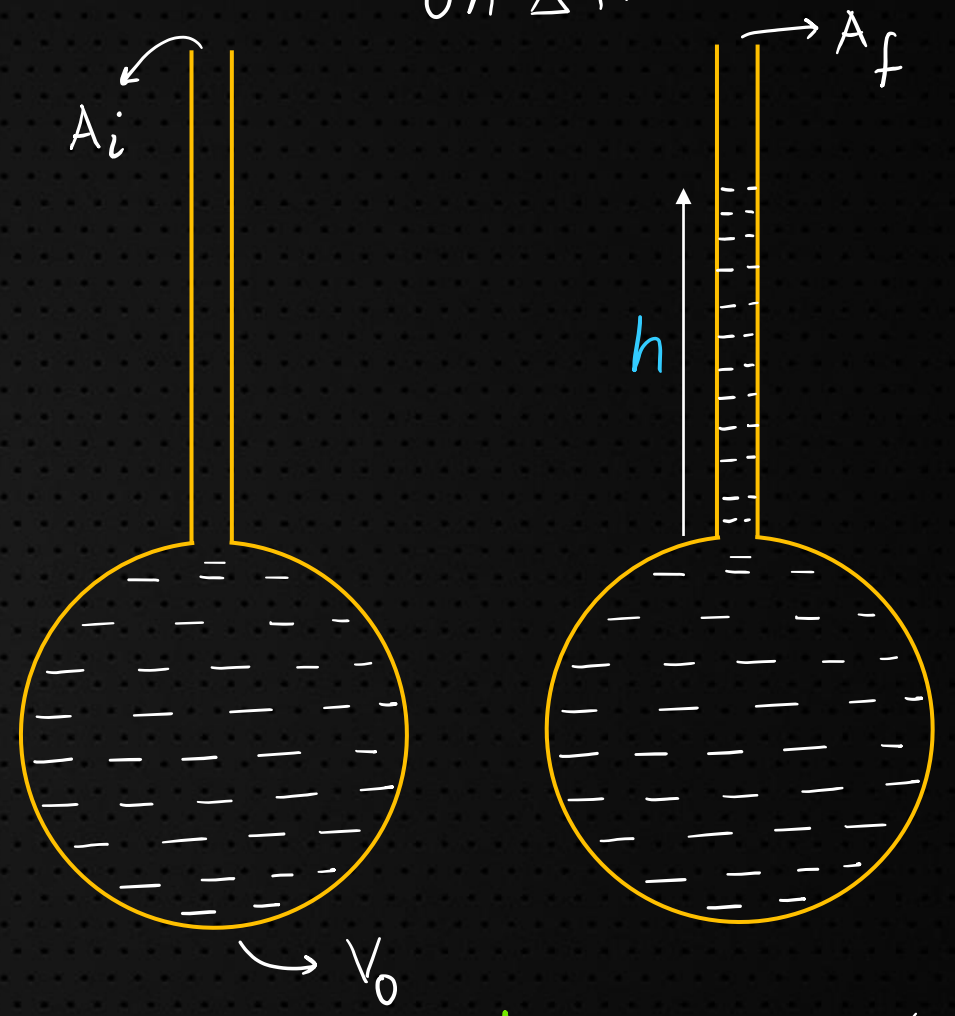
Sol^n: App ↑ in vol of liquid,

$$\Delta V = V_0(\gamma_L - 3\alpha)\Delta T$$

$$\therefore \Delta V = h \times A_f$$

$$\Rightarrow h = \frac{\Delta V}{A_f} = \frac{V_0(\gamma_L - 3\alpha)\Delta T}{A_i(1 + 2\alpha\Delta T)}$$

Ex2. Mercury rise in thermometer on ΔT.



γ_L for Liquid

α for vessel

$\gamma_L > 3\alpha$

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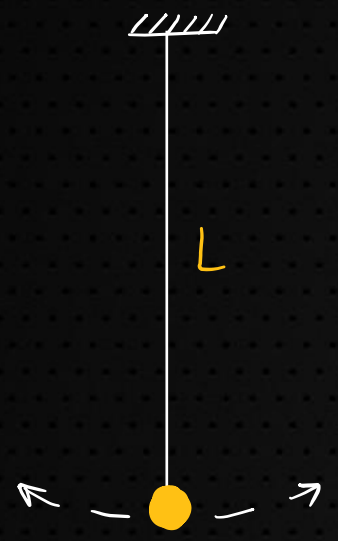
7. Effect of Temperature on Pendulum Clocks



Second's pendulum → for 1 oscillation of Pendulum, clock shows 2 sec

⇒ T of Pendulum is also 2 sec $\left\{ T = 2\pi\sqrt{\frac{L}{g}} \right.$

Temp ↑, $\Delta\theta$

⇒ $L\uparrow$ ⇒ $T\uparrow$

∴ clock becomes slow/Looses time

Temp ↓, $\Delta\theta$

⇒ $L\downarrow$ ⇒ $T\downarrow$

∴ Fast / Gain time

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... continued

NOTE:

Time Lost $= \frac{1}{2}\alpha\Delta\theta . t$

|||y for Time Gain $= \frac{1}{2}\alpha\Delta\theta . t$

{ approximation for calculation

Ex3. A pendulum clock loses 12 s a day if the temperature is 40°C and gains 4 s a day if the temperature is 20°C. The temperature at which the clock will show correct time, and the coefficient of linear expansion α of the metal of the pendulum shaft are, respectively. **(2016 Main)**

(a) 25°C, $\alpha = 1.85 \times 10^{-5}/°C$ (b) 60°C, $\alpha = 1.85 \times 10^{-4}/°C$

(c) 30°C, $\alpha = 1.85 \times 10^{-3}/°C$ (d) 55°C, $\alpha = 1.85 \times 10^{-2}/°C$

... continued

NOTE:

Time Lost $= \frac{1}{2}\alpha\Delta\theta \cdot t$

|||ly for Time Gain $= \frac{1}{2}\alpha\Delta\theta \cdot t$

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Soln:

$$12 = \frac{1}{2}\alpha(40-T)\cdot t \quad \text{— (i)}$$

$$4 = \frac{1}{2}\alpha(T-20)\cdot t \quad \text{— (ii)}$$

from (i) & (ii), we get: $\boxed{T = 25°C}$

$$12 = \frac{1}{2} \times \alpha \times 15 \times (24 \times 3600)$$

$$\Rightarrow \boxed{\alpha = 1.85 \times 10^{-5}/°C}$$

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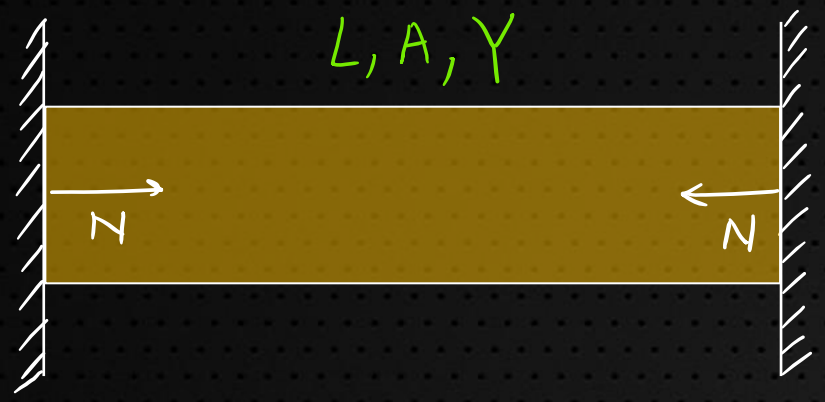
8. Effect of ΔT on Rod between walls (thermal stress)



on ↑ temp° by ΔT, $\Delta L = L\alpha\Delta T$

(ΔL is also compression by N)

$\therefore$ Thermal stress $= Y \times \frac{\Delta L}{L}$

$= \boxed{Y\alpha\Delta T}$

and, $\boxed{N = AY\alpha\Delta T}$

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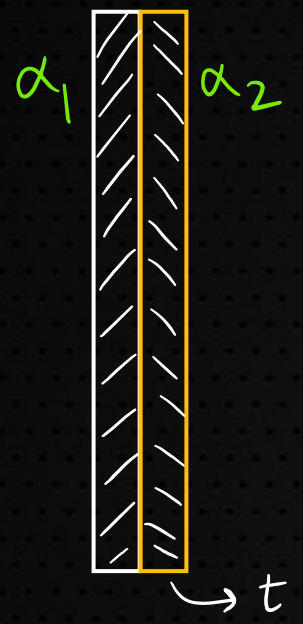
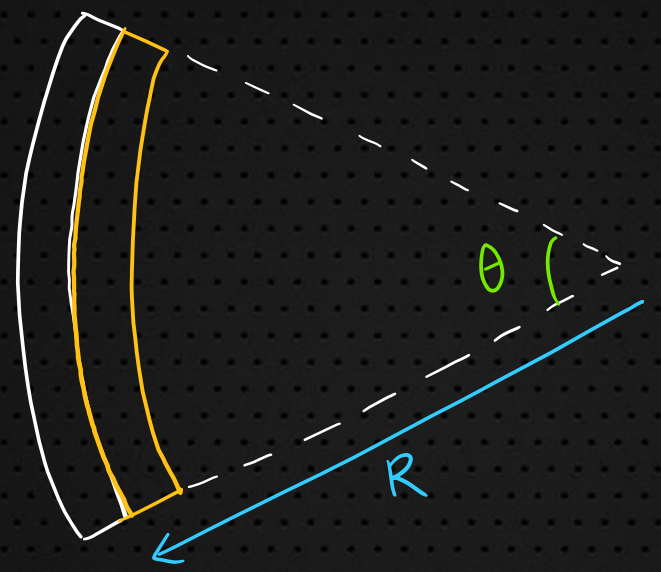
9. Bimetallic strip



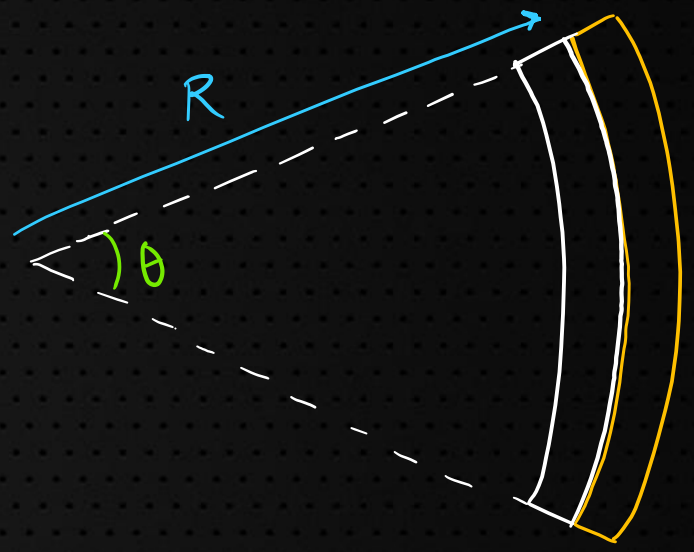
on heating by ΔT

$\alpha_1 > \alpha_2$



$$R = \frac{t}{(\alpha_1 - \alpha_2)\Delta T}$$

$\alpha_2 > \alpha_1$



$$R = \frac{t}{(\alpha_2 - \alpha_1)\Delta T}$$

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10. Calorimetry - Heat Exchange

$T_1 > T_2$

Assuming no heat lost to surrounding:

(i) Heat loss by A = Heat gain by B

$\Rightarrow m_A s_A (T_1 - T) = m_B s_B (T - T_2)$

↳ T is final temp°

↳ $s = \frac{\Delta Q}{m \Delta T}$, specific heat capacity

J/kg°C or cal/g°C

↳ 1 cal = 4.2 J

NOTE:

Heat capacity, $C = ms$

$\therefore \Delta Q = C\Delta T$

... Continued

Ex4. When 100 g of a liquid A at 100°C is added to 50 g of a liquid B at temperature 75°C, the temperature of the mixture becomes 90°C. The temperature of the mixture, if 100 g of liquid A at 100°C is added to 50 g of liquid B at 50°C will be

(2019 Main, 11 Jan II)

(a) 60°C (b) 80°C (c) 70°C (d) 85°C

... Continued

Ex4. When 100 g of a liquid A at 100°C is added to 50 g of a liquid B at temperature 75°C, the temperature of the mixture becomes 90°C. The temperature of the mixture, if 100 g of liquid A at 100°C is added to 50 g of liquid B at 50°C will be

(2019 Main, 11 Jan II)

(a) 60°C (b) 80°C (c) 70°C (d) 85°C

Sol^n:

100g of A, 100°C + 50g of B, 75°C

Heat Loss by A = Heat Gained by B

$\Rightarrow 100 \cdot S_A (100-90) = 50 \cdot S_B (90-75) \Rightarrow S_A = \frac{3}{4} S_B$ — (1)

100g of A, 100°C + 50g of B, 50°C

$\Rightarrow 100 \cdot S_A (100-T) = 50 \cdot S_B (T-50)$ — (2)

Put (1) in (2), $\therefore \boxed{T = 80°C}$

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11. Phase Transformation

↳ heat required to change phase, $\Delta Q = mL$ → Latent heat, J/kg or cal/g

Latent heat of fusion

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

Latent heat of Vaporisation

$L_v = Q/m$

(i) L_f for ice = 80 cal/g { By loosing 80 cal, 1g of water changes to ice at 0°c & Vice-Versa

(ii) L_v for steam = 540 cal/g

(iii) During phase change T is const.

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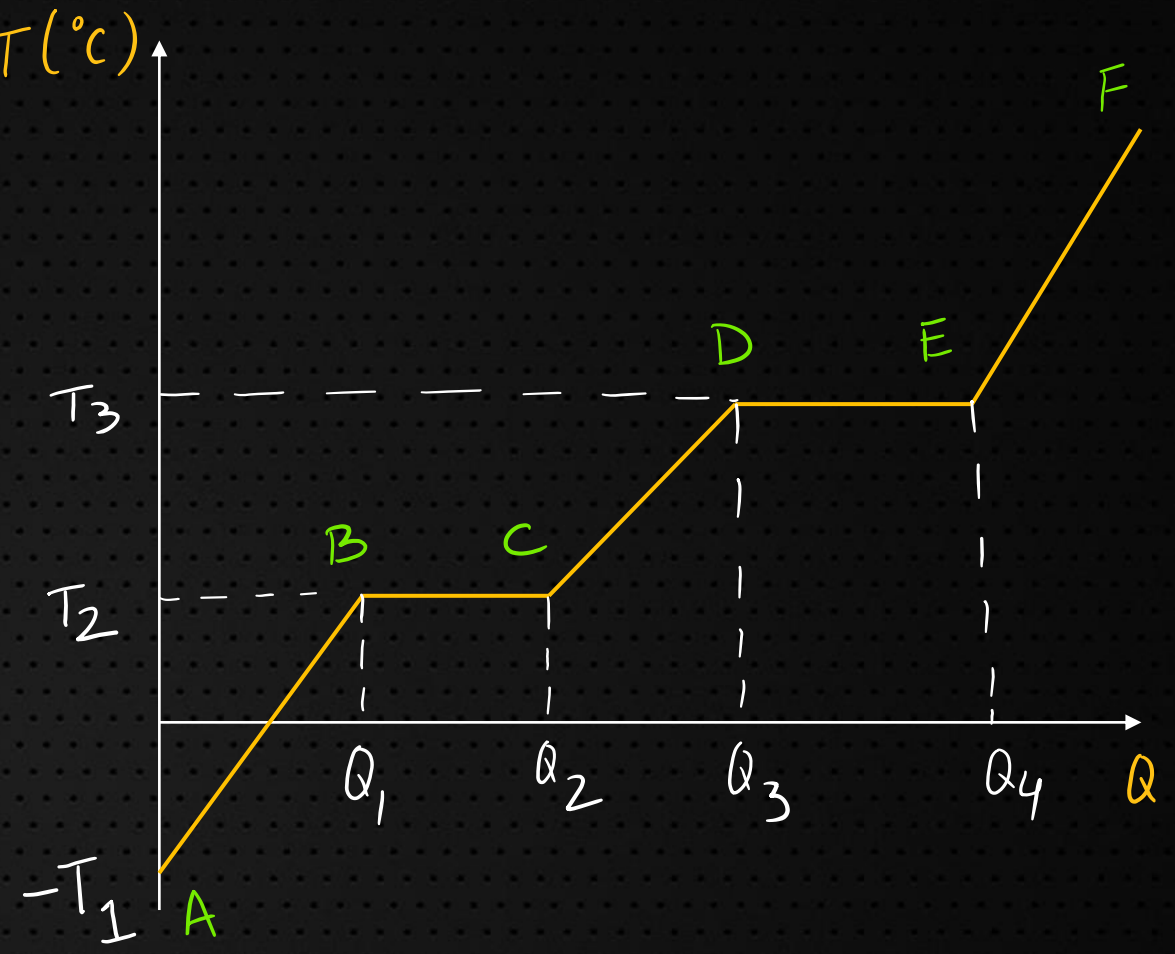
(i) AB → solid

(ii) T_2 → Melting pt.

(iii) CD → Liquid

(iv) T_3 → Boiling pt.

(v) EF → Vapour



$$Q_1 = m s_s (T_2 + T_1), \quad Q_2 - Q_1 = m L_f, \quad Q_3 - Q_2 = m s_L (T_3 - T_2)$$

$$Q_4 - Q_3 = m L_v$$

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... Continued

Ex 5. Ice at $-20°C$ is added to 50 g of water at 40°C. When the temperature of the mixture reaches 0°C, it is found that 20 g of ice is still unmelted. The amount of ice added to the water was close to (Take, specific heat of water = 4.2 J/g/°C specific heat of ice = 2.1 J/g/°C and heat of fusion of water at 0°C = 334 J/g)**(2019 Main, 11 Jan I)**

(a) 40 g (b) 50 g (c) 60 g (d) 100 g

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... Continued

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(a) 40 g (b) 50 g (c) 60 g (d) 100 g

Sol^n: M gram of Ice, $-20°C$
+
50 g of water, 40°C

$\Downarrow$

20 g of ice + $(50 + M - 20)$ g of water at 0°C.

Heat Loss by 50 g of water = Heat Gained (M gram ice to ↑ Temp° + M−20 ice to water)

$$\Rightarrow 50 \times 4.2 \times 40 = M \times 2.1 \times 20 + (M-20) \times 334$$

$$\therefore M = 40.10\,g \simeq \boxed{40\,g}$$

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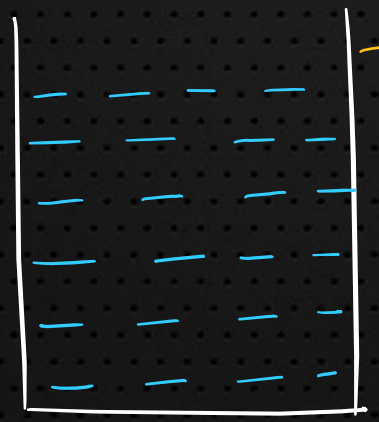
12. Water Equivalent

↳ Amount of water which requires the same amount of heat for same ΔT as that of object.

$$ms\Delta T = m_w s_w \Delta T \Rightarrow \boxed{m_w = \frac{ms}{s_w}}$$

→ W (water Equivalent)

Ex:



→ suppose water equivalent of container is 50g

⇒ Instead of Container, take 50g water

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... Continued

Ex 6. Steam at 100°C is passed into 1.1 kg of water contained in a calorimeter of water equivalent 0.02 kg at 15°C till the temperature of the calorimeter and its contents rises to 80°C. The mass of the steam condensed in kg is **(1986, 2M)**

(a) 0.130 (b) 0.065

(c) 0.260 (d) 0.135

... Continued

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(a) 0.130 (b) 0.065

(c) 0.260 (d) 0.135

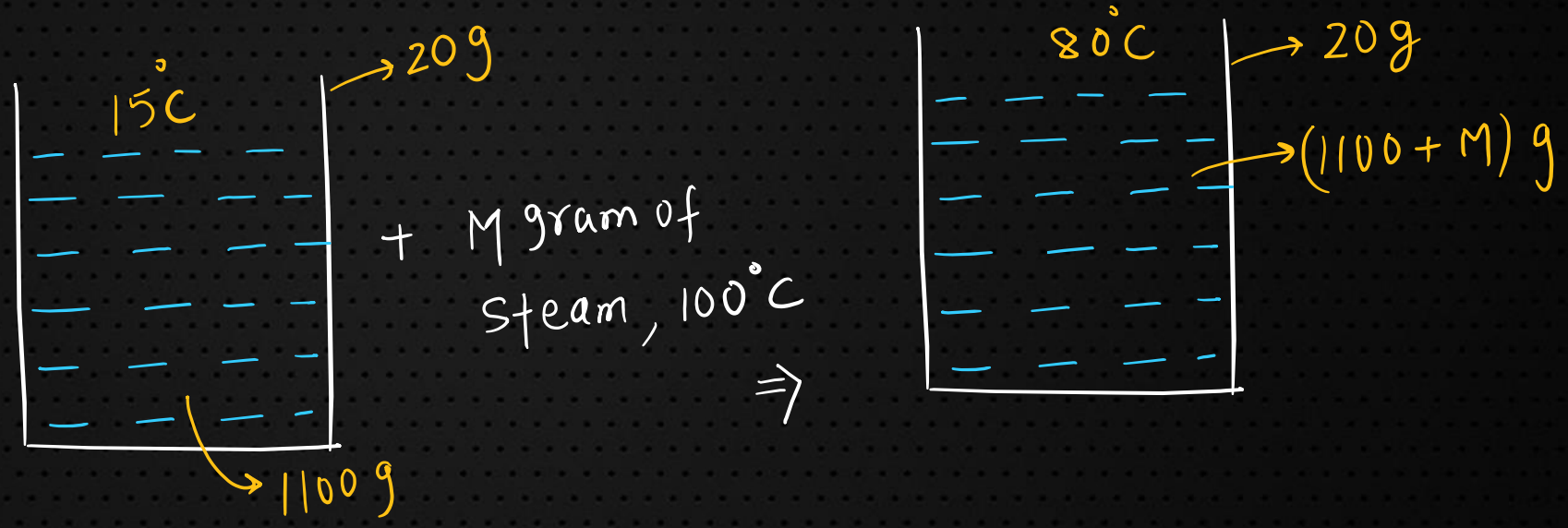
$L_V = 540$ cal/g

$S_w = 1$ cal/g°C

Sol^n: $ML_V + MS_w(100-80) = 1120 \cdot S_w \cdot (80-15)$

$\Rightarrow M = \dfrac{1120 \times 1 \times 65}{540 + 20} = 130\,g$

$\therefore \boxed{M = 0.130\ kg}$



PYQs LINKS (JEE MAIN)

2021 July	2021 August
https://bit.ly/3GUO6AF	https://youtu.be/RRcF-GJEi8A

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(Practice these Questions)

Revision Series Playlist Link https://bit.ly/3eBbib9

JEE Main PYQs Link https://bit.ly/2S54jzh Chapter wise 2021, 2020, 2018

GoldMine Link https://bit.ly/2VhOGFF

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