JEE MAIN | IIT JEE

Heat Transfer

Conduction & Radiation

REVISION in 60 Min

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EDUNITI

Topics to covered

Concept + PYQs

1. Modes of Heat Transfer
2. Thermal Conduction
3. Analogy with Ohm's Law
4. Interface & Junction Temperature
5. Temperature variation at Steady State
6. Equivalent Thermal Conductivity
7. Radial Heat Conduction
8. Freezing of Lake
9. Thermal Radiation
10. Stefan – Boltzmann Law
11. Newton's Law of Cooling
12. Variation of body temperature as per Newton's Law
13. Average form of Newton's Law of Cooling
14. Wien's Displacement Law

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Eduniti for Physics

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	https://youtu.be/OYjjyPIzddE
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

1. Modes of heat transfer

Conduction

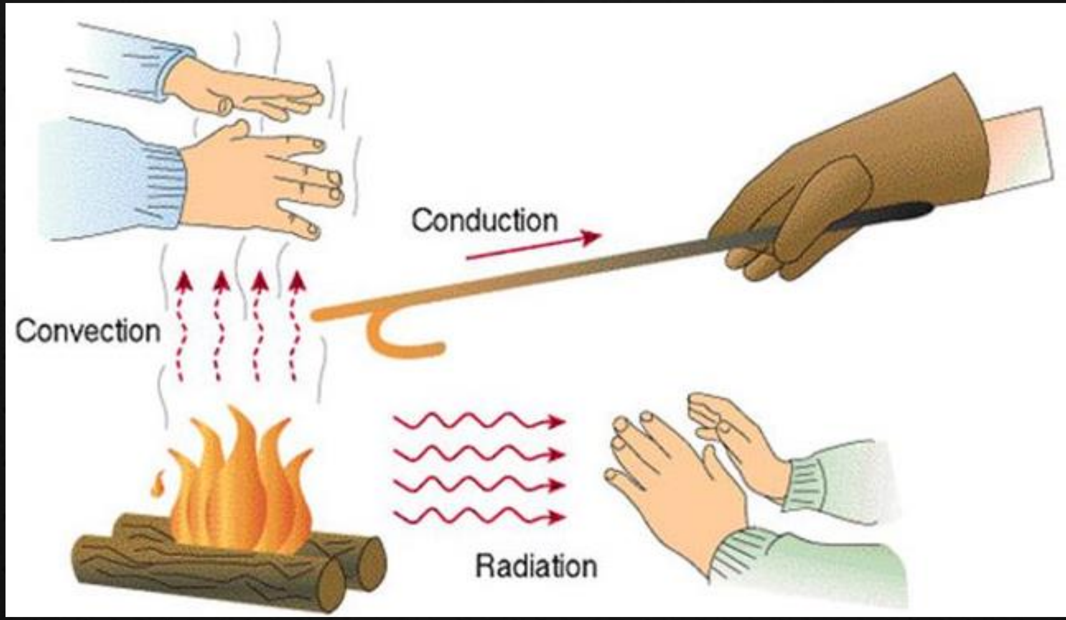
Need medium
NO particle transfer
atoms Vibrate

Convection

Need medium
Particle tranfers

Radiation

No medium
Energy transfer through Em waves



2. Thermal Conduction

If $T_1 > T_2$, at steady state

Heat current, $i = \frac{dQ}{dt} = \frac{KA(T_1 - T_2)}{L}$ {J/s}

(i) $\frac{dQ}{dt}$ is constant

(ii) K is thermal conductivity {W/m-K}

3. Analogy with Ohm's Law

$I = \frac{V_1 - V_2}{R}$

where $R = \frac{\rho L}{A}$

Similarily, $i = \frac{T_1 - T_2}{L/KA} = \frac{T_1 - T_2}{R_{th}}$

$\therefore R_{th} = \frac{L}{KA}$

Thermal Resistance

Note:
Resistance in series & parallel concept valid

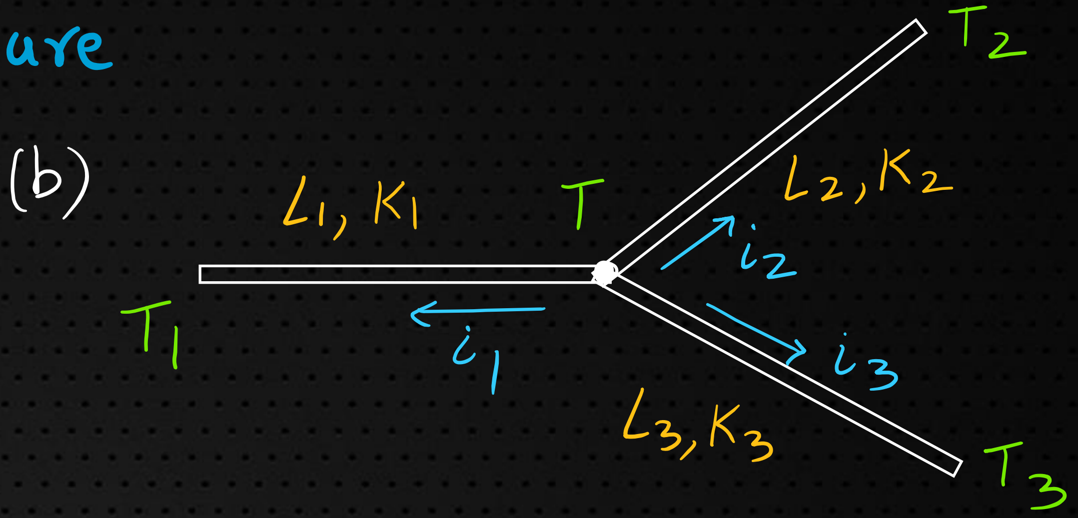
4. Interface & Junction Temperature

$\because$ i is same both rods

$$\Rightarrow \frac{T_1 - T}{L_1/K_1A} = \frac{T - T_2}{L_2/K_2A}$$

Solve for T.

$$R_1 = \frac{L_1}{K_1A}, \quad R_2 = \frac{L_2}{K_2A}$$



$$i_1 + i_2 + i_3 = 0$$

$$\Rightarrow \frac{T - T_1}{R_1} + \frac{T - T_2}{R_2} + \frac{T - T_3}{R_3} = 0$$

Where, $R_1 = \dfrac{L_1}{K_1A_1}$, $R_2 = \dfrac{L_2}{K_2A_2}$

$$R_3 = \frac{L_3}{K_3A_3}$$

... Continued

Ex 1. Two materials having coefficients of thermal conductivity '$3K$' and 'K' and thickness 'd' and '$3d$' respectively, are joined to form a slab as shown in the figure. The temperatures of the outer surfaces are 'θ_2' and 'θ_1' respectively, ($\theta_2 > \theta_1$). The temperature at the interface is

(2019 Main, 9 April II)

(a) $\dfrac{\theta_2+\theta_1}{2}$ (b) $\dfrac{\theta_1}{3}+\dfrac{2\theta_2}{3}$ (c) $\dfrac{\theta_1}{6}+\dfrac{5\theta_2}{6}$ (d) $\dfrac{\theta_1}{10}+\dfrac{9\theta_2}{10}$

... Continued

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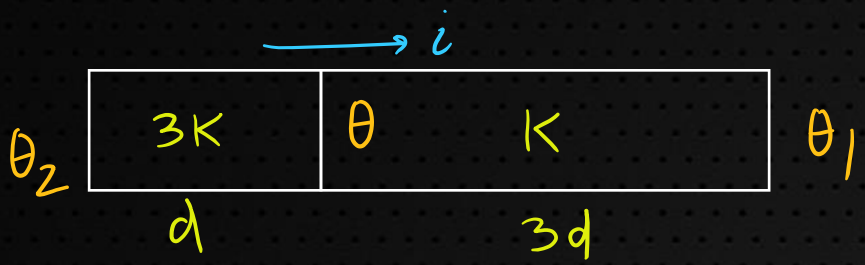
Soln:



$$\frac{\theta_2-\theta}{d/3KA} = \frac{\theta-\theta_1}{3d/KA}$$

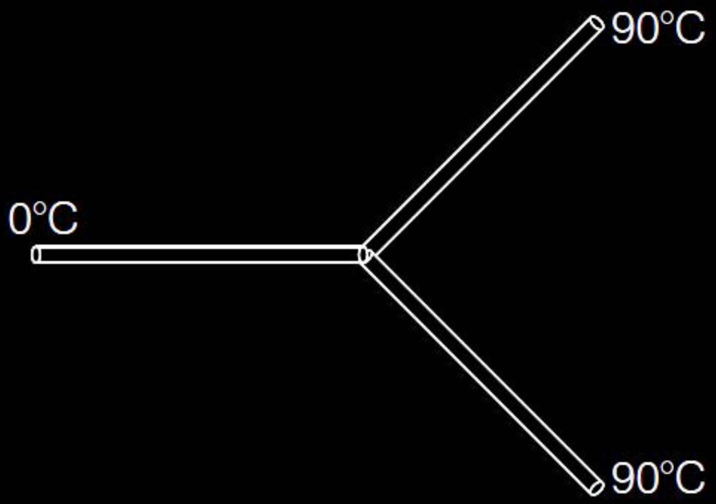
$$\Rightarrow 9(\theta_2-\theta) = \theta-\theta_1$$

$$\Rightarrow \frac{9\theta_2+\theta_1}{10} = \theta$$

$$\therefore \boxed{\theta = \frac{\theta_1}{10}+\frac{9\theta_2}{10}}$$

... Continued

Ex 2. Three rods made of the same material and having the same cross-section have been joined as shown in the figure. Each rod is of the same length. The left and right ends are kept at 0°C and 90°C respectively. The temperature of junction of the three rods will be **(2001, 2M)**



(a) 45°C
(b) 60°C
(c) 30°C
(d) 20°C

... Continued

Sol^n: $\because$ All rods identical, $R = \frac{L}{KA}$

$$\frac{T-0}{R} + \frac{T-90}{R} + \frac{T-90}{R} = 0$$

$$\Rightarrow 3T = 180$$

$$\therefore \boxed{T = 60^\circ C}$$

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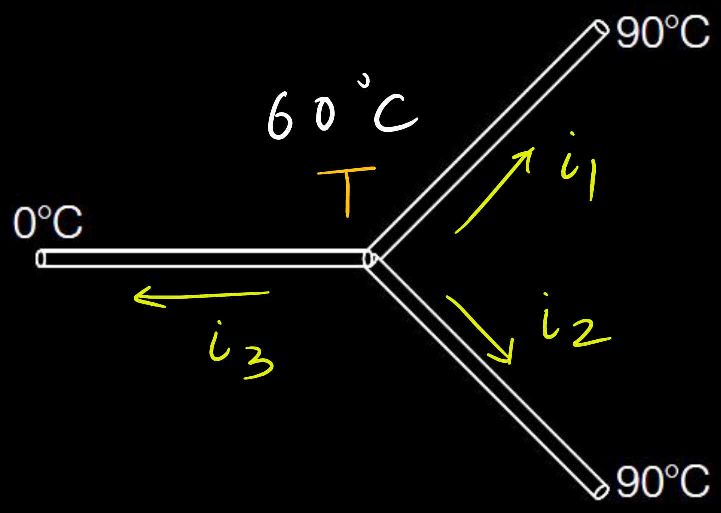

(a) 45°C
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... Continued

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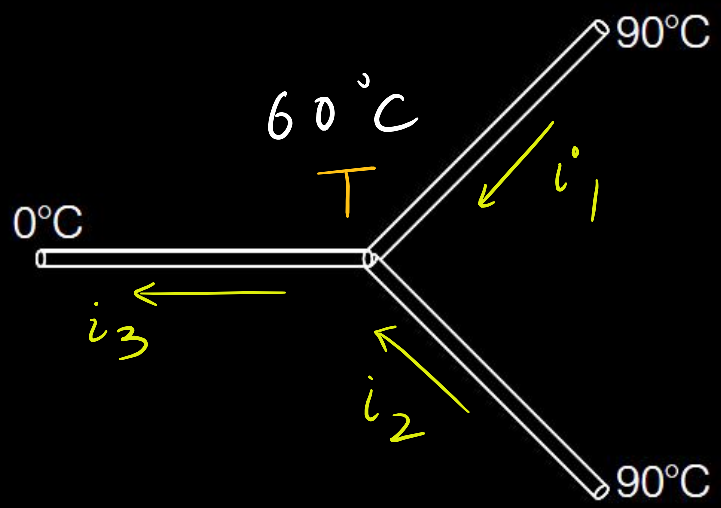

(a) 45°C (b) 60°C
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Sol^n: $\because$ All rods identical, $R = \frac{L}{KA}$

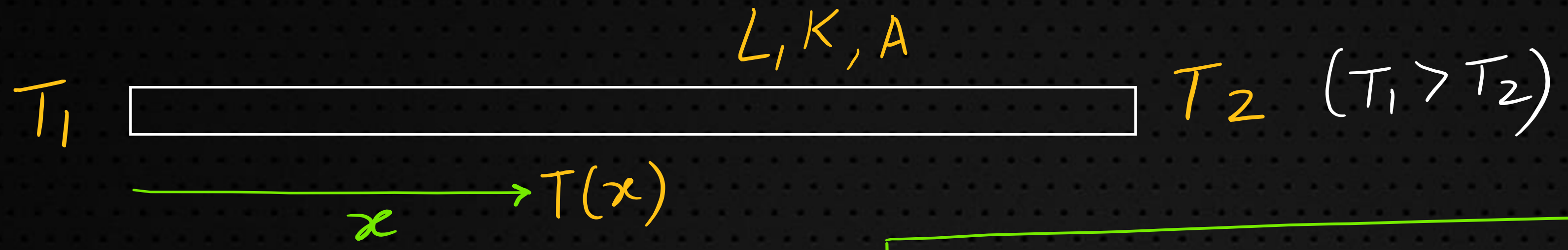
$$\frac{T-0}{R} + \frac{T-90}{R} + \frac{T-90}{R} = 0$$

$$\Rightarrow \quad 3T = 180$$

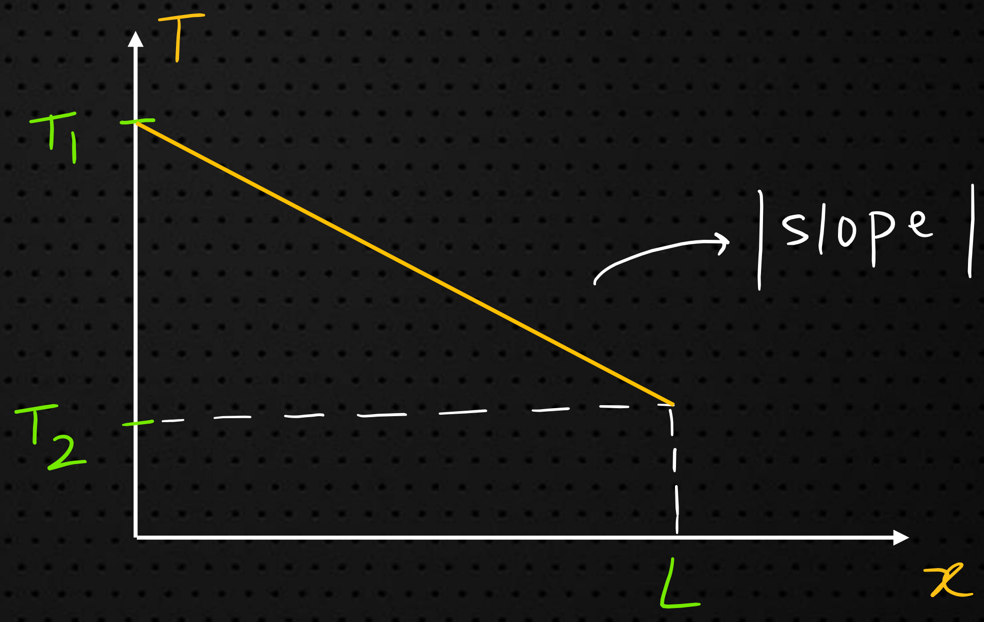
$$\therefore \quad \boxed{T = 60^\circ C}$$

$\rightarrow$ we can comment on true dir^n of Heat currents.

5. Temperature Variation at steady state



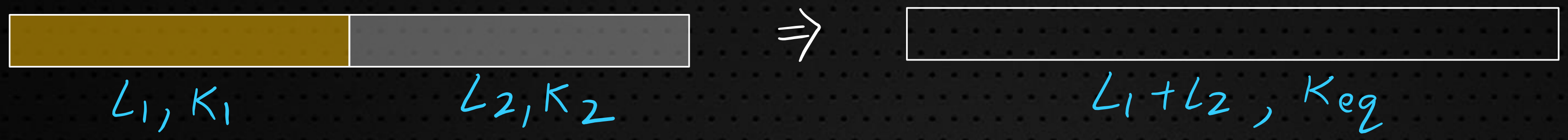
$$\frac{T_1 - T(x)}{x/KA} = \frac{T_1 - T_2}{L/KA} \Rightarrow \boxed{T(x) = -\left(\frac{T_1 - T_2}{L}\right)x + T_1}$$



$$|\text{slope}| = \frac{T_1 - T_2}{L}$$

6. Equivalent Thermal Conductivity (K_{eq})

(a) In Series



$$R_1 + R_2 = R_{eq} \Rightarrow \frac{l_1}{K_1 A} + \frac{l_2}{K_2 A} = \frac{l_1 + l_2}{K_{eq} A}$$

$$\Rightarrow K_{eq} = \frac{K_1 K_2 (l_1 + l_2)}{l_1 K_2 + l_2 K_1}$$

(b) In parallel

$A_1 + A_2$

$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{R_{eq}}$$

$$\Rightarrow \frac{K_1 A_1}{L} + \frac{K_2 A_2}{L} = \frac{K_{eq}(A_1 + A_2)}{L}$$

$$\therefore K_{eq} = \frac{K_1 A_1 + K_2 A_2}{A_1 + A_2}$$

... Continued

Ex 3. A cylinder of radius R is surrounded by a cylindrical shell of inner radius R and outer radius $2R$. The thermal conductivity of the material of the inner cylinder is K_1 and that of the outer cylinder is K_2. Assuming no loss of heat, the effective thermal conductivity of the system for heat flowing along the length of the cylinder is **(2019 Main, 12 Jan I)**

(a) $\dfrac{K_1 + K_2}{2}$

(b) $\dfrac{K_1 + 3K_2}{4}$

(c) $\dfrac{2K_1 + 3K_2}{5}$

(d) $K_1 + K_2$

... Continued

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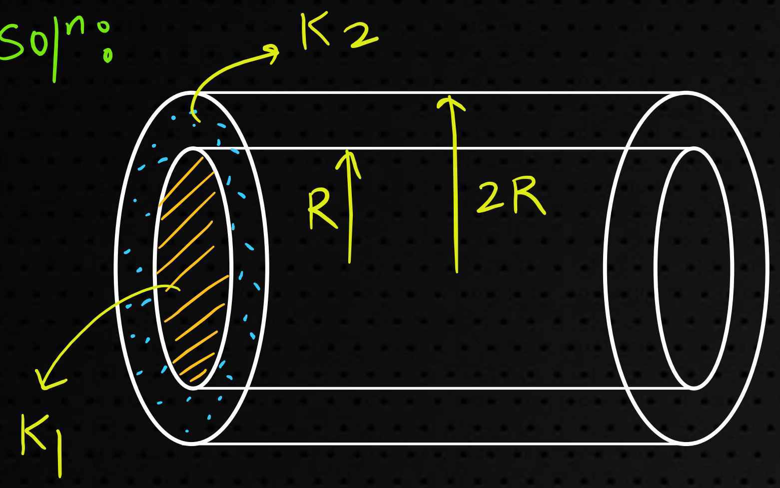
(c) $\dfrac{2K_1 + 3K_2}{5}$ (d) $K_1 + K_2$

Sol^n:

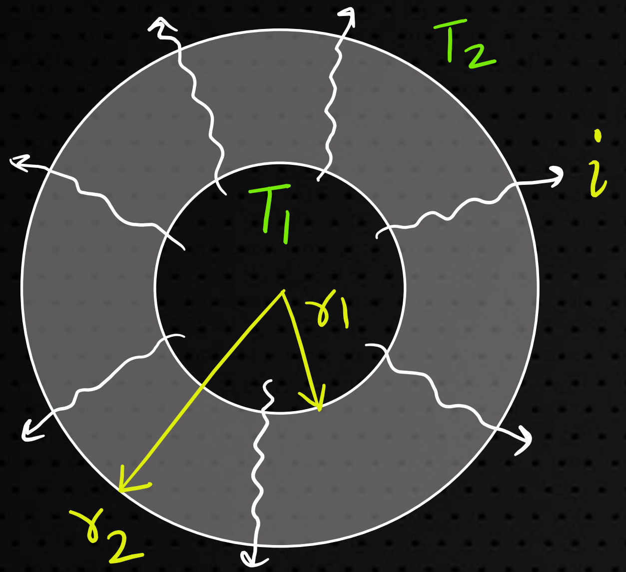


$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{R_{eq}} \Rightarrow \frac{K_1 \pi R^2}{L} + \frac{K_2 \pi (4R^2 - R^2)}{L} = \frac{K_{eq} \cdot \pi 4R^2}{L}$$

$$\Rightarrow K_1 + 3K_2 = 4K_{eq} \qquad \therefore \boxed{K_{eq} = \frac{K_1 + 3K_2}{4}}$$

7. Radial Heat Conduction

(a)

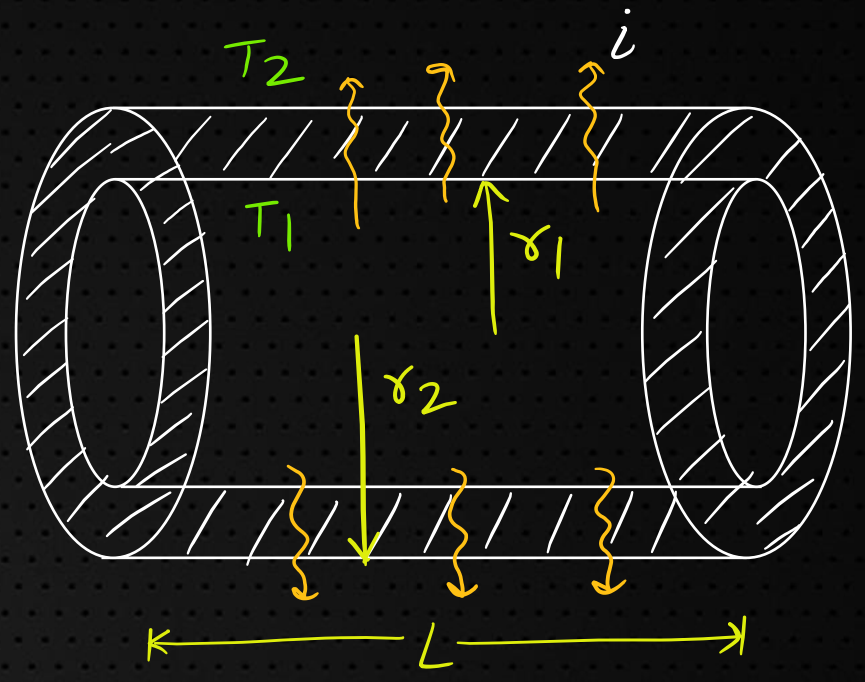


spherical shell

$$i = \frac{T_1 - T_2}{R_{th}}$$

$$R_{th} = \frac{r_2 - r_1}{4\pi K r_1 r_2}$$

(b)



Cylindrical shell

$$i = \frac{T_1 - T_2}{R_{th}}$$

$$R_{th} = \frac{\ln(r_2/r_1)}{2\pi K L}$$

https://youtu.be/RRcF-GJEi8A

→ Q5

Click for Detail sol^n

Ex4. Two thin metallic spherical shells of radii r_1 and r_2 ($r_1 < r_2$) are placed with their centres coinciding. A material of thermal conductivity K is filled in the space between the shells. The inner shell is maintained at temperature θ_1 and the outer shell at temperature $\theta_2(\theta_1<\theta_2)$. The rate at which heat flows radially through the material is :-

(1) $\dfrac{4\pi K r_1 r_2(\theta_2-\theta_1)}{r_2-r_1}$

(2) $\dfrac{\pi r_1 r_2(\theta_2-\theta_1)}{r_2-r_1}$

(3) $\dfrac{K(\theta_2-\theta_1)}{r_2-r_1}$

(4) $\dfrac{K(\theta_2-\theta_1)(r_2-r_1)}{4\pi r_1 r_2}$

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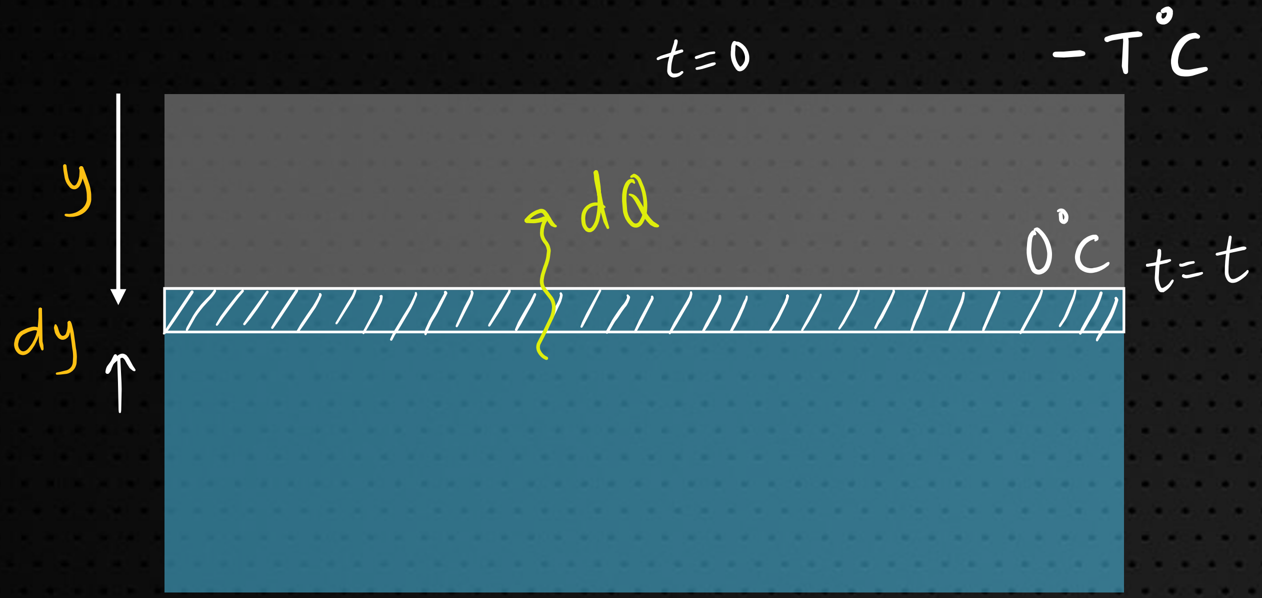
8. Freezing of Lake (time taken to freez depth y)



(i) at $t=0$ Lake starts to freez from top.

(ii) at time t 'y' depth freezes

(iii) In next dt time dy freezes by loosing dQ heat.

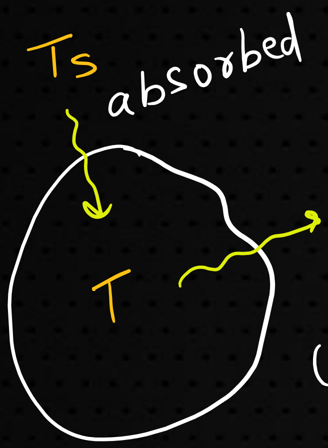
$$\frac{dQ}{dt} = \frac{KA}{y}\cdot T \Rightarrow dm\cdot L_f = \frac{KA}{y}\cdot T\cdot dt$$

$$\Rightarrow \rho A dy \cdot L_f = \frac{KA}{y}\cdot T\cdot dt \Rightarrow \frac{\rho L_f}{KT}\int_0^y y\,dy = \int_0^t dt$$

$$\therefore \boxed{t = \frac{\rho L_f}{2KT}\cdot y^2}$$

9. Thermal Radiation

Prevost Theory



Radiated (If $T > 0K$)

(i) $T > T_s$

$\Rightarrow$ Radiated > absorbed

& vice-versa

(ii) $T = T_s$

$\Rightarrow$ Radiated = absorbed

Kirchoff's Law

Good emitter are also good absorber

$(e = a < 1)$

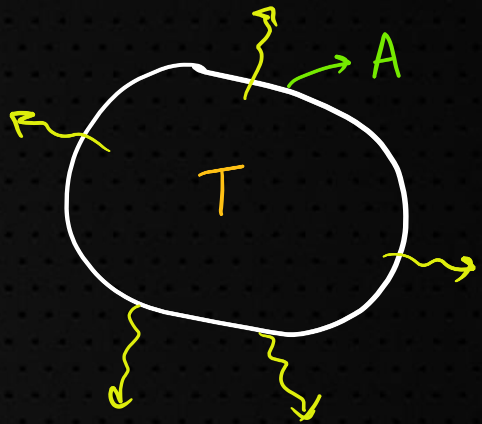
e → emissivity

a → absorpitivity

For BLACK Body

$e = a = 1$

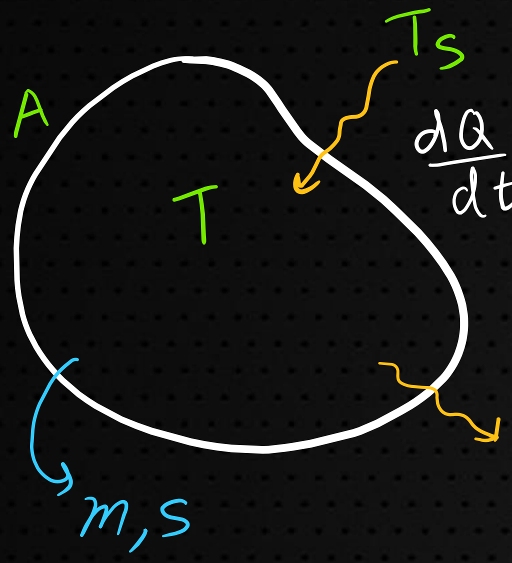
Stefan's Law



$$\frac{dQ}{dt} = \sigma A T^4$$

↳ rate of heat transfer for Black-Body

10. Stefan-Boltzmann Law



$$\frac{dQ}{dt} = \sigma e A T_s^4$$

$$\frac{dQ}{dt} = \sigma e A T^4$$

Net rate of heat loss by body

$$\frac{dQ}{dt} = \sigma e A (T^4 - T_s^4) \quad , \quad T > T_s$$

$\sigma \rightarrow$ Stefan-Boltzmann Const.

Rate of Cooling

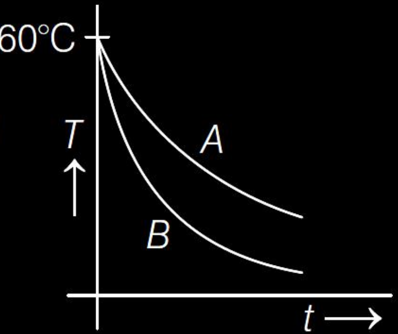
$$\Delta Q = ms\Delta T \Rightarrow \frac{dQ}{dt} = -ms\frac{dT}{dt} \quad \left\{ \begin{array}{l} -\text{ve} \\ \text{as} \\ T\downarrow \end{array} \right.$$

$$\Rightarrow \frac{dT}{dt} = -\frac{\sigma e A}{ms}(T^4 - T_s^4)$$

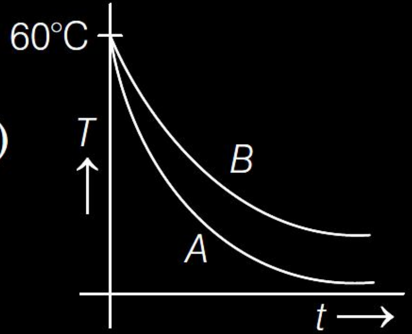
... Continued

Ex 5. Two identical beakers A and B contain equal volumes of two different liquids at 60°C each and left to cool down. Liquid in A has density of $8 \times 10^2 \, kg/m^3$ and specific heat of $2000 \, J \, kg^{-1} K^{-1}$ while liquid in B has density of $10^3 \, kg \, m^{-3}$ and specific heat of $4000 \, J \, kg^{-1} K^{-1}$. Which of the following best describes their temperature *versus* time graph schematically? (Assume the emissivity of both the beakers to be the same) **(2019 Main, 8 April I)**

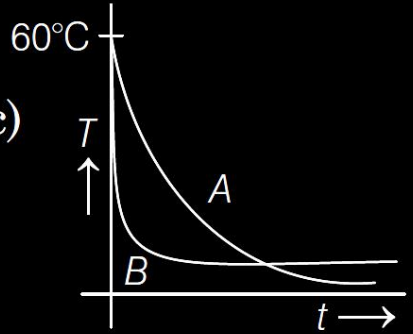
(a)



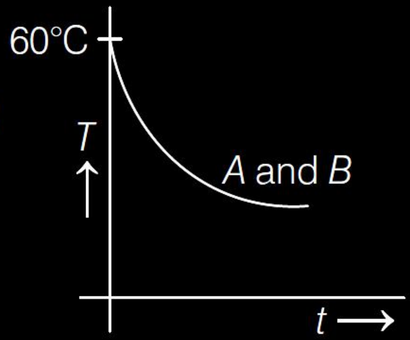
(b)



(c)



(d)



... Continued

Ex 5.

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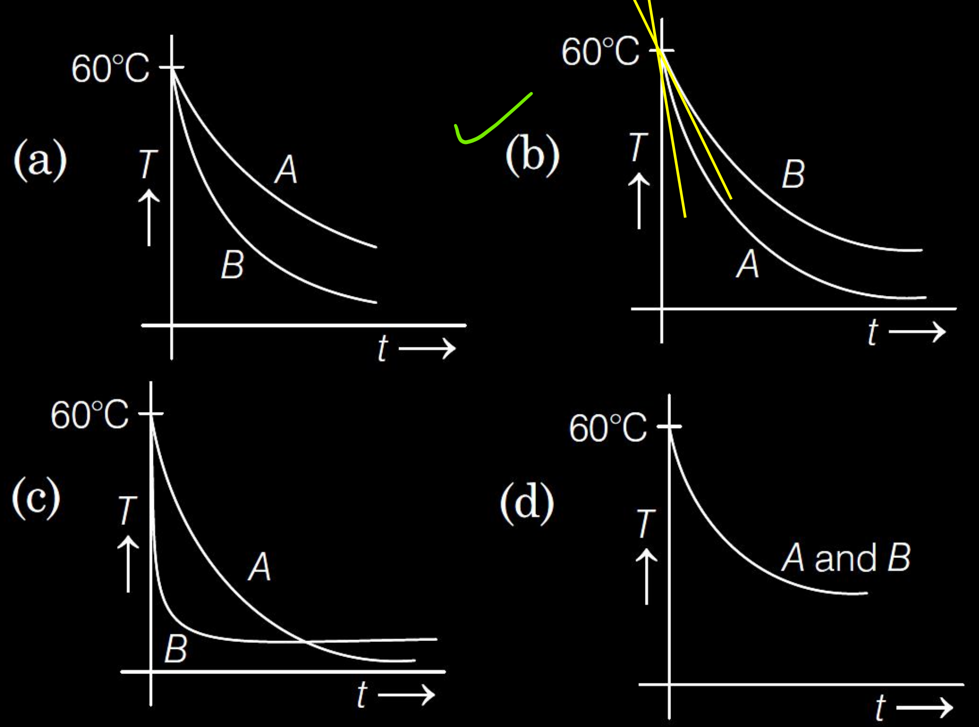


Sol^n: $\dfrac{dT}{dt} = -\dfrac{\sigma e A}{ms}\left(T^4 - T_s^4\right)$

$\dfrac{dT}{dt} = -\dfrac{\sigma e A}{\rho V s}\left(T^4 - T_s^4\right)$ $\left\{\begin{array}{l}\sigma, e, A, V \\ \text{Const.}\end{array}\right.$

$\therefore \left|\dfrac{dT}{dt}\right| \propto \dfrac{1}{\rho s}$

$\rho s|_A = 16\times10^5$

$\rho s|_B = 40\times10^5$

$\Rightarrow \left.\dfrac{dT}{dt}\right|_A > \left.\dfrac{dT}{dt}\right|_B$

↳ cooling of A is faster

11. Newton's Law of Cooling

↳ Applicable if T is close to T_s $\left(T - T_s = \Delta T \text{ or } T = T_s + \Delta T\right)$

$$\frac{dT}{dt} = -\frac{\sigma e A}{ms}\left[(T_s + \Delta T)^4 - T_s^4\right] = -\frac{\sigma e A}{ms} \cdot T_s^4 \left[\left(1 + \frac{\Delta T}{T_s}\right)^4 - 1\right]$$

$\because \Delta T$ is small

$(1+x)^n \simeq 1 + nx$

$$\Rightarrow \frac{dT}{dt} = -\frac{\sigma e A}{ms} \cdot T_s^4 \left(1 + 4\frac{\Delta T}{T_s} - 1\right)$$

$$\Rightarrow \frac{dT}{dt} = -\frac{4\sigma e A}{ms} T_s^3 \Delta T \Rightarrow \frac{dT}{dt} = -\frac{4\sigma e A T_s^3}{ms}(T - T_s)$$

$$\Downarrow$$

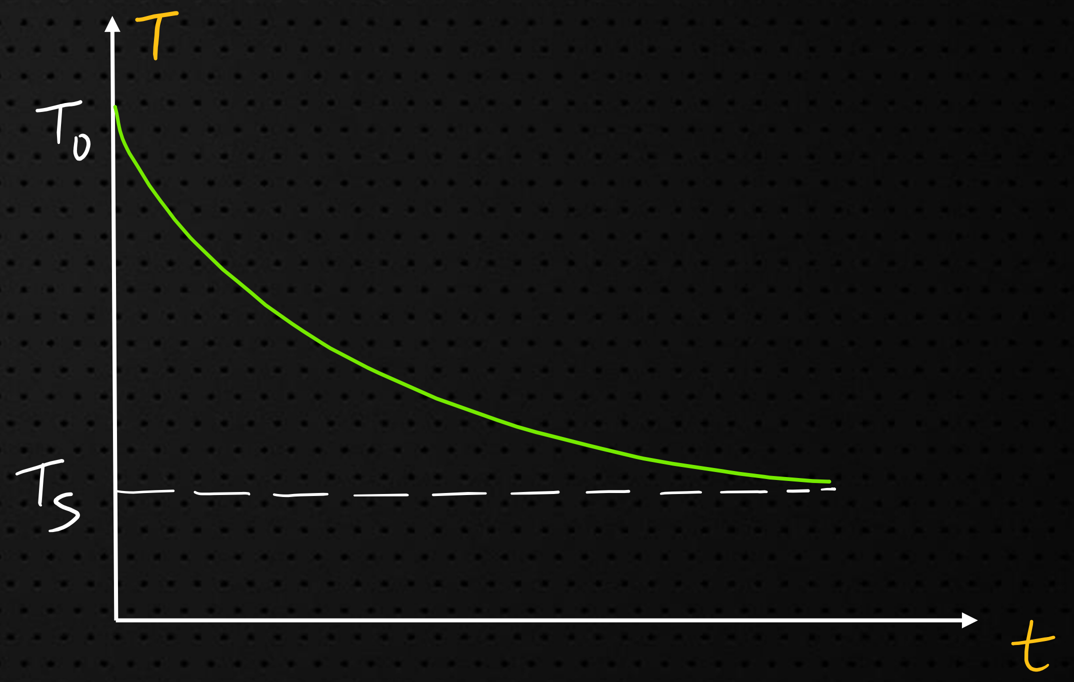
$$\frac{dT}{dt} \propto (T - T_s)$$

12. Variation of body temp° as per Newton's Law

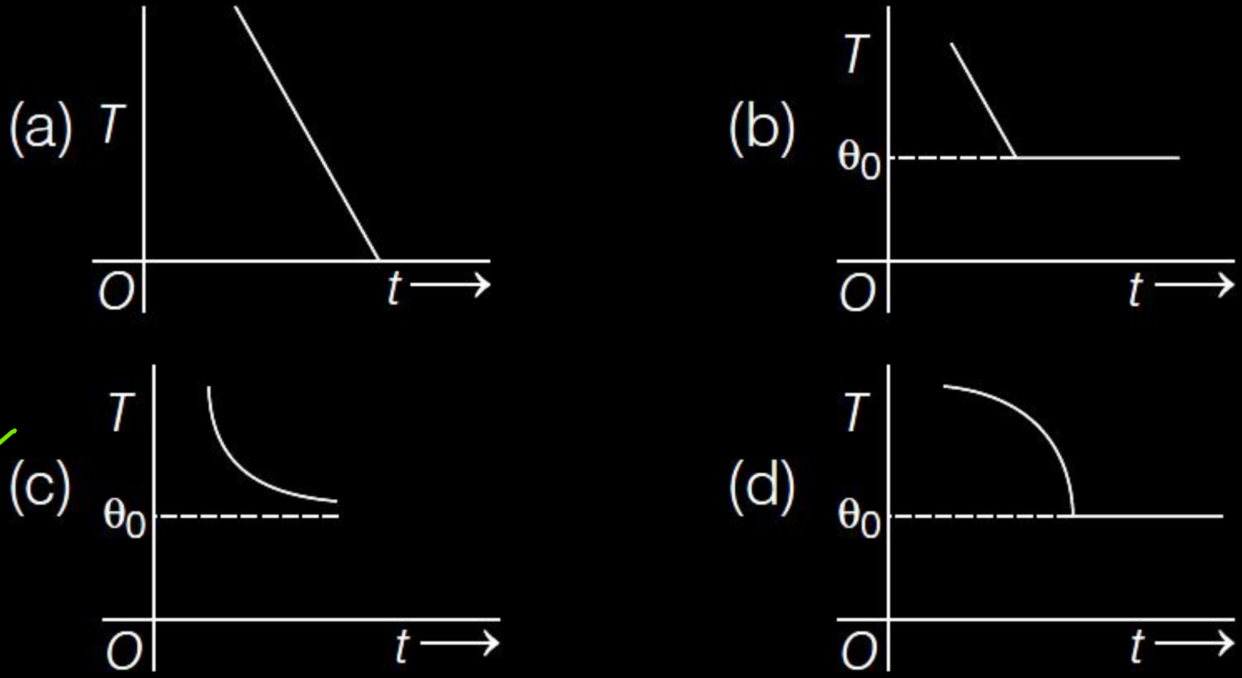
$$\frac{dT}{dt} = -\frac{4\sigma e A T_s^3}{ms}(T - T_s) \quad \text{or} \quad \frac{dT}{dt} = -C(T - T_s) \quad \left\{ C = \frac{4\sigma e A T_s^3}{ms} \right.$$

$$\Rightarrow \int_{T_0}^{T} \frac{dT}{T - T_s} = -C\int_0^t dt \quad \Rightarrow \boxed{T = T_s + (T_0 - T_s)e^{-Ct}}$$

T_0 is bodies temp° at $t = 0$



Ex6. If a piece of metal is heated to temperature θ and then allowed to cool in a room which is at temperature θ_0. The graph between the temperature T of the metal and time t will be closed to **(2013 Main)**



13. Average form of Newton's Law of Cooling

↳ If body cools from T_2 to T_1 in time t,

$$\frac{T_2 - T_1}{t} = c\left(\frac{T_2 + T_1}{2} - T_s\right)$$

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Ex7. In 5 minutes, a body cools from 75°C to 65°C at room temperature of 25°C. The temperature of body at the end of next 5 minutes is ________ °C.

13. Average form of Newton's Law of Cooling

↳ If body cools from T_2 to T_1 in time t,

$$\frac{T_2 - T_1}{t} = c\left(\frac{T_2 + T_1}{2} - T_s\right)$$

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Ex 7. In 5 minutes, a body cools from 75°C to 65°C at room temperature of 25°C. The temperature of body at the end of next 5 minutes is ________ °C.

Sol^n:

$$\frac{75 - 65}{5} = c\left(\frac{75 + 65}{2} - 25\right) \Rightarrow c = \frac{2}{45}$$

$$\frac{65 - T}{5} = \frac{2}{45}\left(\frac{65 + T}{2} - 25\right) \Rightarrow \boxed{T = 57^\circ C} \text{ Ans.}$$

14. Wien's Displacement Law

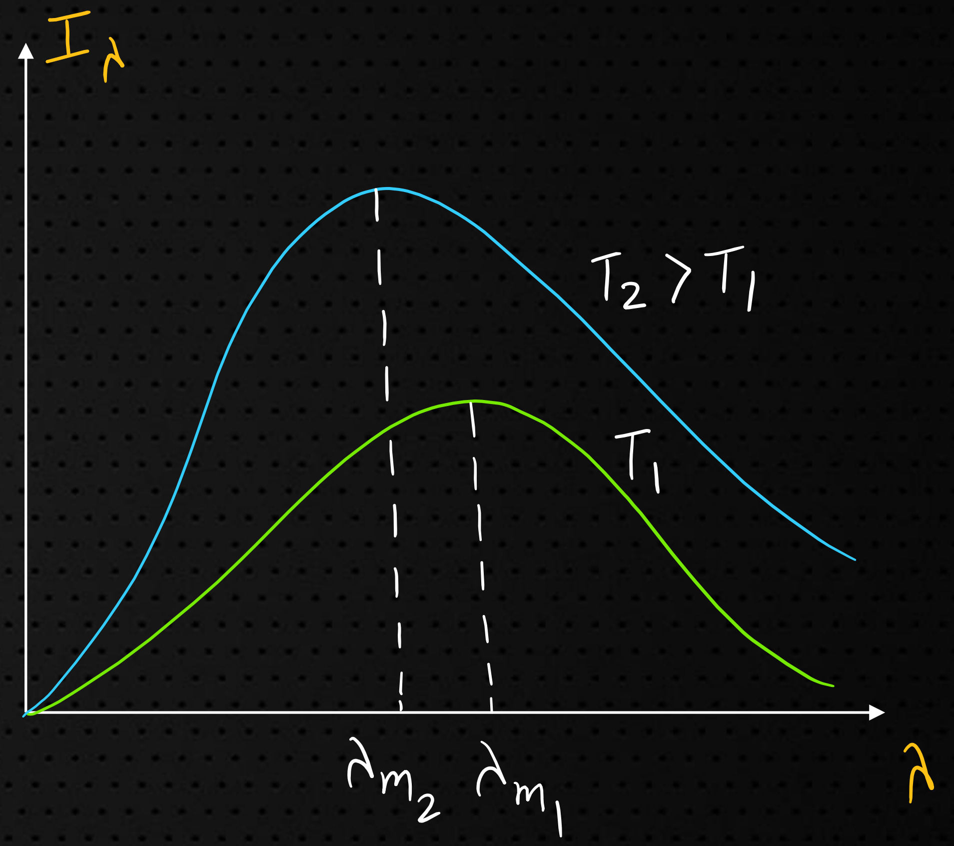
↳ Energy distribution curve of black body radiation

(i) For a Given T of body, Various wavelength is emitted.

(ii) $\lambda_m \propto \frac{1}{T} \Rightarrow \lambda_m T = b$

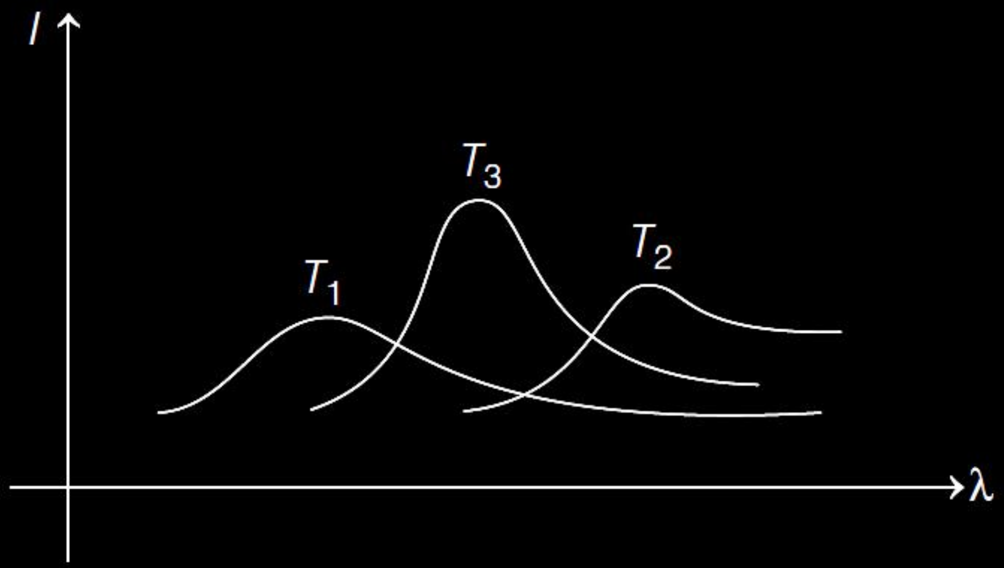
↳ Wien's Const.

2.8×10^{-3} m-K



... Continued

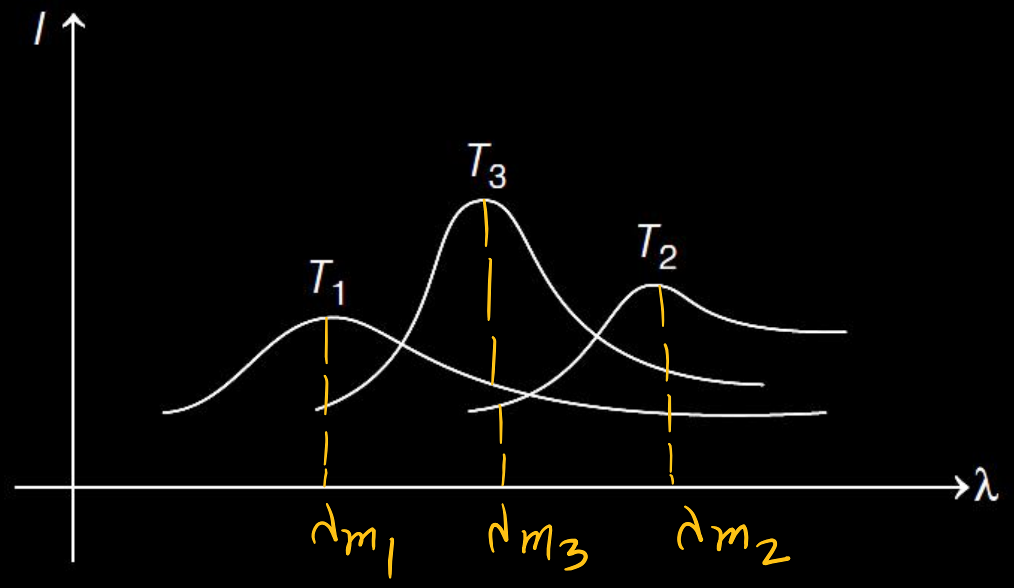
Ex 8. The plots of intensity *versus* wavelength for three black bodies at temperatures T_1, T_2 and T_3 respectively are as shown. Their temperatures are such that **(2000, 2M)**



(a) $T_1 > T_2 > T_3$
(b) $T_1 > T_3 > T_2$
(c) $T_2 > T_3 > T_1$
(d) $T_3 > T_2 > T_1$

... Continued

Ex 8. The plots of intensity *versus* wavelength for three black bodies at temperatures T_1, T_2 and T_3 respectively are as shown. Their temperatures are such that **(2000, 2M)**



(a) $T_1 > T_2 > T_3$ (b) $T_1 > T_3 > T_2$
(c) $T_2 > T_3 > T_1$ (d) $T_3 > T_2 > T_1$

Sol^n: $\lambda_m T = b \Rightarrow T \propto \frac{1}{\lambda_m}$

$\Rightarrow T_1 > T_3 > T_2$

... Continued

Ex9. Parallel rays of light of intensity $I = 912\ \text{Wm}^{-2}$ are incident on a spherical black body kept in surroundings of temperature 300 K. Take Stefan constant $\sigma = 5.7 \times 10^{-8}\ \text{Wm}^{-2}\ \text{K}^{-4}$ and assume that the energy exchange with the surroundings is only through radiation. The final steady state temperature of the black body is close to **(2014 Main)**

(a) 330 K (b) 660 K

(c) 990 K (d) 1550

... Continued

Ex9. Parallel rays of light of intensity $I = 912\ \mathrm{Wm^{-2}}$ are incident on a spherical black body kept in surroundings of temperature 300 K. Take Stefan constant $\sigma = 5.7 \times 10^{-8}\ \mathrm{Wm^{-2}\ K^{-4}}$ and assume that the energy exchange with the surroundings is only through radiation. The final steady state temperature of the black body is close to **(2014 Main)**

(a) 330 K (b) 660 K

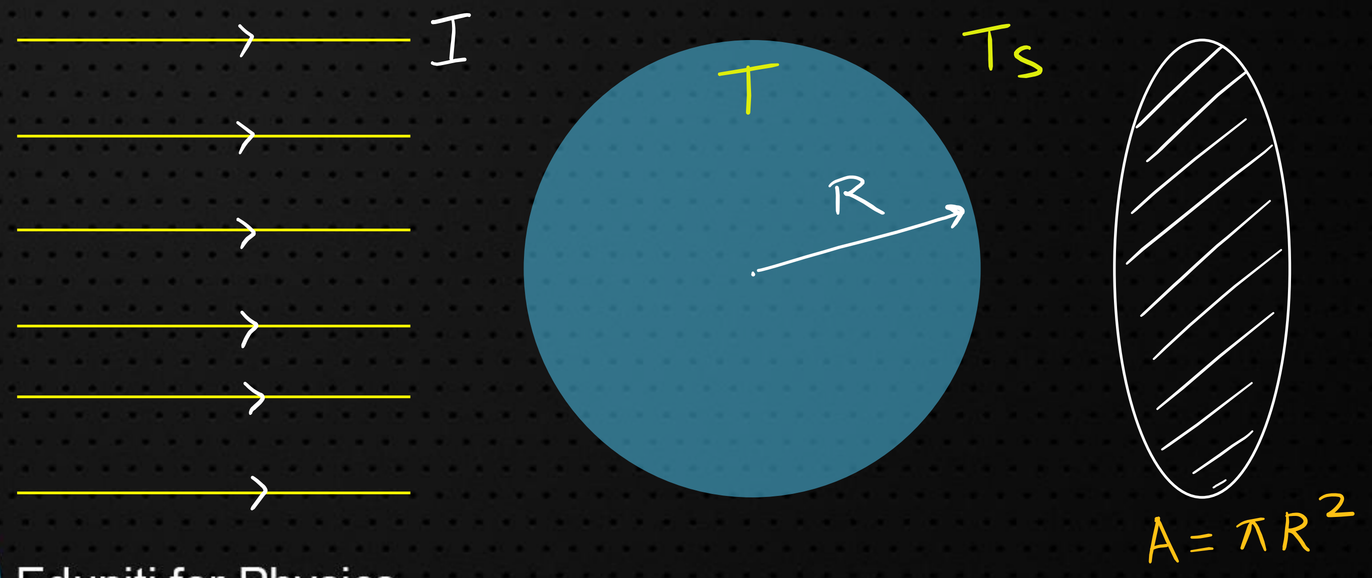
(c) 990 K (d) 1550

Sol^n: At steady T is const

$\Rightarrow$ Energy incident/s = Energy radiated/s

$\Rightarrow 912 \times \pi R^2 = \sigma \cdot 4\pi R^2 (T^4 - 300^4)$

$\therefore T = 100\sqrt{11} \approx \boxed{330\,K}$



PYQs LINKS (JEE MAIN)

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

CLICK

(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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