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SENIOR FIVE TERM 2

TOPIC 5/7: TRANSFER OF HEAT

Competency: The learner investigates modes of heat transfer in nature and their application in industry and society.

Conduction

Conduction is the transfer of heat from a region of high temperature to that of low temperature without a resultant movement of the molecules of conducting material.

Mechanisms of heat conduction

(a) Metals
- The atoms of metals consist of free mobile electrons; when one end of a metal is heated, these free electrons travel at high speed and collide with other electrons and atoms. In this way heat is transferred quickly from a hot end to a cold end.
- Secondly when one end of a metal is heated atoms vibrate with high frequency and amplitude; collide with other atoms to which they give heat. Those atoms that receive heat also vibrate with high frequency and amplitude, collide and transfer their heat. In this way heat energy is transferred from one part of the metal to another.

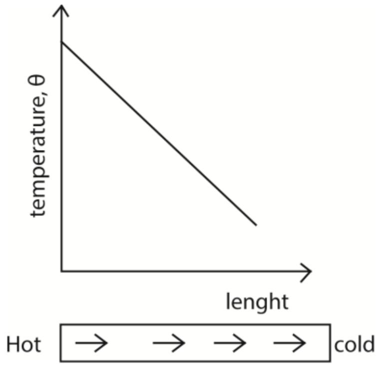
(b) Non-metals
- In non-metal heat is transferred by interatomic vibrations.
- When one end of a metal is heated atoms vibrate with high frequency and amplitude; collide with other atoms to which they give heat. Those atoms that receive heat also vibrate with high frequency and amplitude, collide and transfer their heat. In this way heat energy is transferred from one part of the metal to another

(c) Heat transfer in gases

Heat energy in gases is transferred by molecular collisions between hot and cold molecules. When a gas is heated, the fast moving molecules collide and pass on their kinetic energy to cold slower molecules.

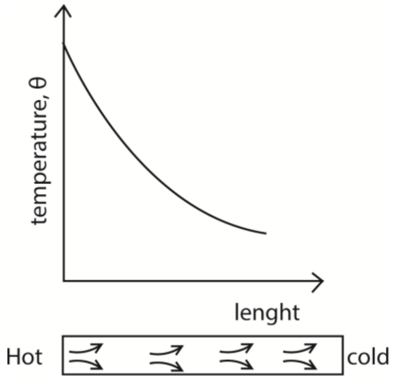
Temperature distribution along a conductor

(i) **Lagged metal**



The rate of heat flow along the bar is constant since heat loss is negligible.

(ii) **Unlagged or exposed to the surrounding**

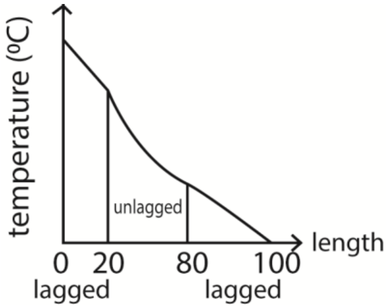


The rate of heat flow decrease with length due to heat losses

Example 1

The two ends of a metal bar of length 1.0m are perfectly lagged up to 20cm from either end. The ends of the bar maintained at 100^0C and 0^0C respectively.

(i) Sketch a graph of temperature versus distance of a bar. (02marks)



(ii) Explain the features of the graph in (b)(i)(03marks)

- In lagged portions there is constant heat flow because there is no heat loss to the surroundings
- In unlagged portion heat flow is not uniform due to heat loss to the environment.

Thermal conductivity

Thermal conductivity is the rate of heat transfer per unit cross section area per unit temperature gradient

Factors affecting the rate of heat flow

- Temperature gradient
- Cross-section area

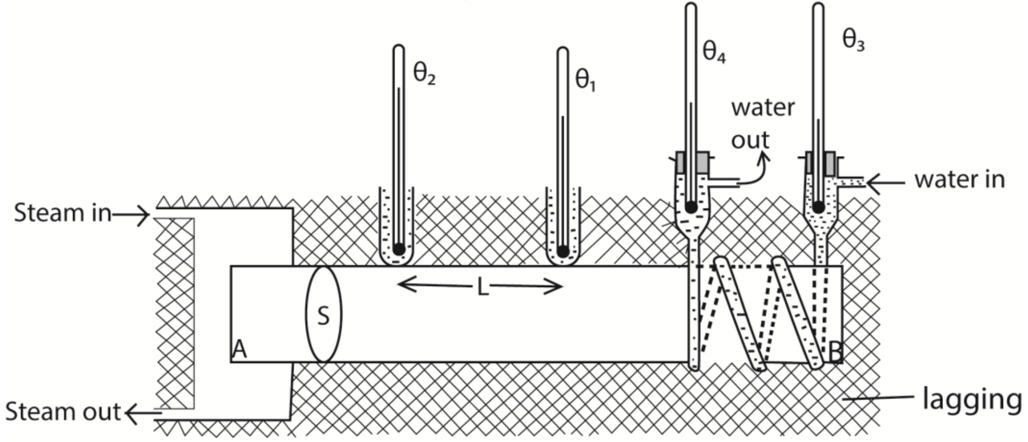
i.e. $\frac{Q}{t} = kA\left(\frac{\theta_2 - \theta_1}{L}\right)$

Measurement of thermal conductivity of a good conductor (e.g. metal)

Conditions

- Heat must flow through the specimen at measurable rate
- The temperature gradient along the specimen must be measurably steep. i.e. the specimen bar must be longer than it diameter.

Apparatus for thermal conductivity of a metal.

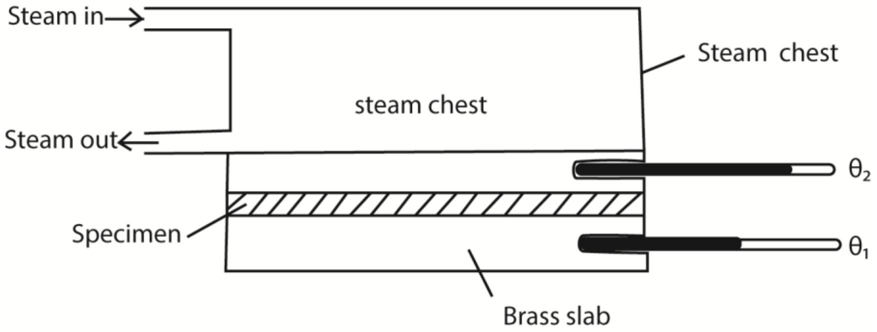


- Specimen bar AB of mean diameter, d, is heated by steam at end A and cooled by water at end B as shown above
- The lagging ensure a constant rate of heat flow
- The setup is left to run for some time until steady temperatures θ_1, θ_2, θ_3 and θ_4 are obtained.
- The rate water flow m kgs^{-1} is measured using a cylinder and stop clock.
- Cross section area A = $\frac{\pi d^2}{4}$
- The rate of heat flow is given by

$$\frac{Q}{t} = kA\left(\frac{\theta_2 - \theta_1}{L}\right) = mc_w(\theta_4 - \theta_3)$$

where k = thermal conductivity of the metal and c_w is specific heat capacity of water

Measurement of thermal conductivity of a bad conductor (e.g. glass, cork



- Glass s cut in form of a thin disc of cross section area, A and thickness, x.
- The disc is sandwiched between a steam chest and brass slab of mass, m and specific heat capacity, c.
- Steam is passed through the chest until the thermometers register steady temperatures, θ_1 and θ_2.
- Then, $\frac{\theta}{t} = kA\left(\frac{\theta_2 - \theta_1}{x}\right)$
- The glass disc is removed and brass slab is heated directly by steam chest, until its temperature is about 10^0C above θ_1.
- Steam chest is removes and the top of the glass slab is covered by the glass disc.
- The temperature of the slab is recorded at suitable time interval until its temperature is about 10^0C below θ_1.
- A graph of temperature against time is plotted and its slope s determined at θ_1

$$\frac{\theta}{t} = mcs$$

$$\therefore\ kA\left(\frac{\theta_2 - \theta_1}{x}\right) = mcs$$

$k = \frac{mcsx}{A(\theta_2 - \theta_1)}$ but A = $\frac{\pi D^2}{4}$

$$\therefore k = \frac{4mcsx}{\pi D^2(\theta_2 - \theta_1)}$$

Precautions

- Sample in a thin disc
- Faces of the disc highly polished to ensure tight uniform contacts
- A thin layer of grease is smeared on faces for good thermal contact.

Example 2

A cylindrical iron vessel with a base of diameter 15cm and thickness 0.30cm has its base coated with a thin film of soot of thickness 0.10cm. It is then filled with water at 100^{0}C and placed on a large block of ice at 0^{0}C. Calculate the initial rate at which the ice will melt (06marks) (thermal conductivity of soot=0.12Wm^{-1}K^{-1}, Thermal conductivity of iron, k = 75Wm^{-1}K^{-1})

$$\frac{Q}{t} = kA\left(\frac{\theta_2 - \theta_1}{x}\right) = k_1A\left(\frac{\theta_2 - \theta_1}{x}\right) = ml_f$$

where m is mass that melt per second and l_f = latent heat of fusion

$$\frac{Q}{t} = 75A\left(\frac{100 - \theta_1}{0.3\ x\ 10^{-2}}\right) = 0.12A\left(\frac{\theta_1 - 0}{0.1\ x\ 10^{-2}}\right)$$

$$\theta_1 = 99.52^0C$$

Also, $kA\left(\frac{\theta_2 - \theta_1}{x}\right) = ml_f$

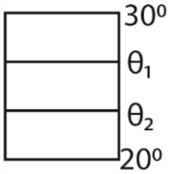
$$75\ x\ \pi\ x\ \frac{(0.15)^2}{4}\left(\frac{100 - 99.52}{0.3\ x\ 10^{-2}}\right) = m\ x\ 3.3\ x\ 10^5$$

m = 6.42 x 10^{-4}kgs^{-1}

Example 3

A window of height 1.0m and width 1.5m contains a double grazed unit consisting of two single glass panes, each of thickness 4.0mm separated by an air gap of 2.0mm. Calculate the rate at which heat is conducted through the window if the temperatures of external surfaces of glass are 20^{0}C and 30^{0}Crespectively.

[Thermal conductivities of glass and air are 0.72Wm^{-1}K^{-1} and 0.025 Wm^{-1}K^{-1} respectively] (07marks)



$$\frac{dQ}{dT} = \frac{kA(\theta_2 - \theta_1)}{L} = \text{mc x slope}$$

$$\frac{k_1A(30 - \theta_1)}{4\ x\ 10^{-3}} = \frac{k_2A(\theta_2 - \theta_1)}{2\ x\ 10^{-3}} = \frac{k_1A(\ \theta_1 - 20)}{4\ x\ 10^{-3}}$$

$$=> \theta_1 + \theta_2 = 50$$

$$\frac{0.72A(30 - \theta_1)}{4\ x\ 10^{-3}} = \frac{0.025A(\ \theta_1 - \theta_2)}{2\ x\ 10^{-3}}$$

$$\frac{0.72A(30 - \theta_1)}{4\ x\ 10^{-3}} = \frac{0.025A(\ \theta_1 - (50 - \theta_1)}{2\ x\ 10^{-3}}$$

$\theta_1 = 29.4^0C$

Hence $\frac{dQ}{dT} = \frac{0.72A(30 - 29.4)}{4\ x\ 10^{-3}}$ =162W

Example 4

Explain why heating systems based on the circulation of steam are more efficient than those based on circulation of boiling water. (02marks)

A given mass of steam gives out more energy that an equal amount of water at the same temperature because steam possesses very high specific latent heat vaporization

Convections

Convection is a process of heat transfer in fluids from a region of high temperature to a region of low temperature, due to movement of the medium.

Mechanism of heat transfer by convection

When a fluid is heated from underneath, it expands and becomes less dense than fluid above. The warm less dense fluid molecules rise to the top and the cool more dense fluid molecules from above moves downwards to take place. This process continues and circulating current of the fluid is established until the whole fluid is heated up.

Example 5

(i) What is convection?

(ii) Explain how convectionoccurs.

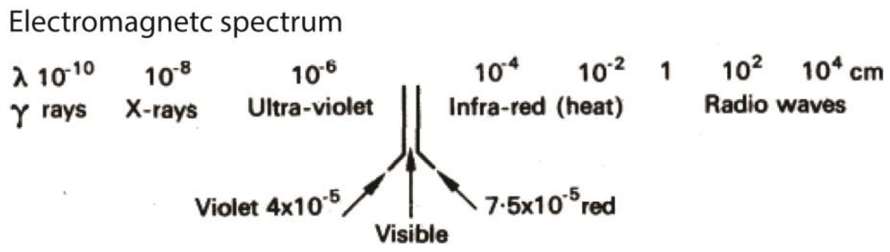
Radiation

Thermal radiation is the transfer of heat through vacuum i.e. no material medium is required for this transmission.

A black body radiation is an electromagnetic radiation emitted by a body solely due its temperature i.e. energy emitted depends on body's temperature.

Electromagnetic spectrum

Electromagnetic spectrum is the distribution of electoral magnetic radiations ranging from those of short wave length to those of longer wave length as shown below.



Infrared radiations

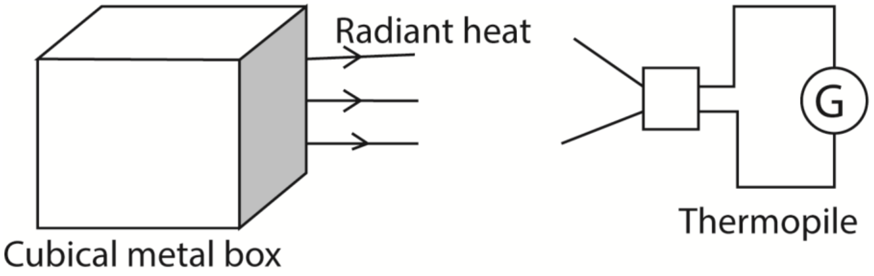
Infrared radiations are electromagnetic radiations which are converted into heat when they strike a surface.

Properties of infrared radiations

- They travel at the speed of light.
- They are reflected and refracted like light.
- When absorbed by a body the body's temperature is raised.
- Causes photo-electric emission from surfaces like Cesium.
- Affects special types of photographic plates which enable pictures to be taken in the dark.
- They are absorbed by glass but transmitted by rock salt and quartz.

Comparison of radiation ability for different surfaces

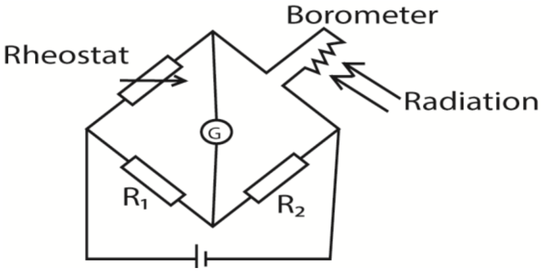
A cubical metal tank whose sides is painted; dull black, dull white and highly polished is filled with hot water and radiations from each surface are detected by a thermopile as shown below.



The galvanometer deflection is greatest when the thermopile is facing the dull black surface and least when facing a highly polished silver surface. Therefore, a polished surface is the least radiator and a black surface is the best radiator.

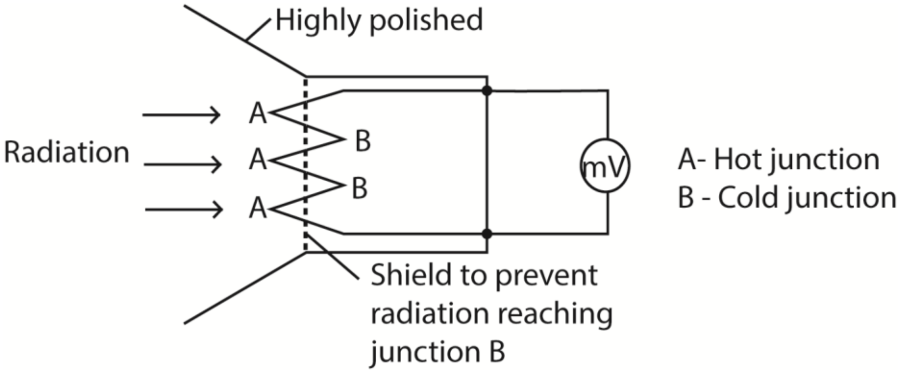
Detectors of infrared radiation

(a) Detection of infrared radiation using Barometer



The bolometer strip is connected to Wheatstone bridge circuit above. The rheostat is adjusted until the galvanometer shows no deflection. When the radiations fall on the strip, they are absorbed and its temperature raises leading to an increase in resistance. The galvanometer deflects showing the presence of radiations.

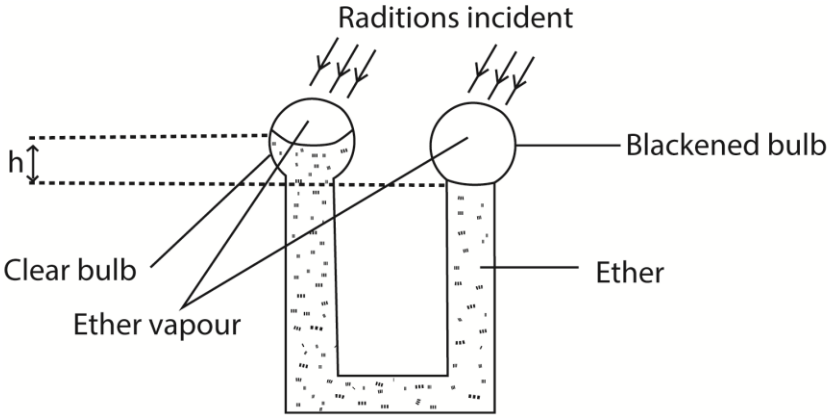
(b) Detection of infrared radiation using Thermopile



Radiation falling on junction A is absorbed and temperature rises above that of junction B. An e.m.f is generated and is measured by millivolt meter which deflects as a result.

(c) Detection of infrared radiation using the ether-thermo scope.

A blackened and clear bulbs are connected to a tube partly filled with ether i.e. each bulb contains mixture of air and ether vapour. When the arrangement is exposed to infrared radiations, more radiations are absorbed by the blackened bulb than those absorbed by the clear bulb. This raises the pressure inside the blackened bulb causing the ether liquid to be raised in the unblackened bulb as shown below.

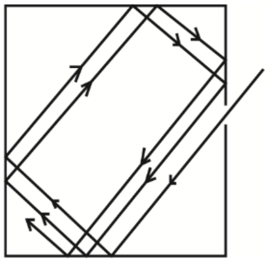


The rise h is proportional to incident radiation

Black body

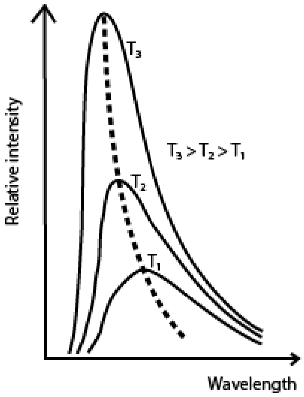
- A black body is one which absorbs all radiations incident on it and reflects or transmits none.
- The radiations emitted by a black body are called temperature radiations or black body radiations.

Approximation of black body



When radiation enters a black container through a hole, it undergoes multiple reflections. At each reflection, part of the radiation is absorbed. After several reflections, all the radiation is retained inside the container. Hence it approximates to a black body.

Distribution of black body radiation



- For every wave length, relative intensity increases as temperature is increased.
- The wavelength at which maximum intensity occur shifts to the shorter wavelength as temperature is increased.
- λ_{max} is the wavelength of radiation emitted at maximum intensity/emission of a black body at a particular temperature.

Laws of black body radiation

(a) Wien's displacement law
If λ_{max} is the wavelength of the peak of the curve for a given temperature, T then
$\lambda_{max}T$ = constant; the constant is Wien's constant = 2.9×10^{-3}mK

(b) If $E\lambda_{max}$ is the height of the peak of the curve for temperature, T, then $E\lambda_{max} \propto T^5$.

(c) The curve showing the variation of E_λ with λ at a constant temperature obeys the Plank formula; $E = \frac{C_1}{\lambda^5\left(e^{\frac{c_2}{\lambda T}}-1\right)}$ where $c_1$and c_2 are constant

Example 6

State Stefan's law. (01mark)

Stefan's law states that the total power radiated by a black body per unit surface area is proportional to the fourth power of its absolute temperature. i.e. $\frac{P}{A} \propto T^4$

If E is the total energy radiated per second per m^2 area of a black body at temperature T, then $E = \sigma T^4$. Where σ is called Stefan's constant = $5.67 \times 10^{-8} Wm^{-2}K^{-4}$.

Example 7

The earth receives energy from the sun at the rate of $1.4 \times 10^3 Wm^{-2}$. If the ratio of the sun's orbit radius to the Earth's orbit radius is 216, calculate the surface temperature of the sun. (05marks)

Power radiated by the sun = $4\pi r^2 \sigma T^4$

Energy intensity = $\frac{4\pi r^2 \sigma T^4}{4\pi R^2}$

$$\therefore \frac{4\pi r^2 \sigma T^4}{4\pi R^2} = 1.4\ x\ 10^3$$

$$T^4 = \frac{1.4\ x\ 10^3}{5.7\ x\ 10^{-8}}\left(\frac{R}{r}\right)^2 = \frac{1.4\ x\ 10^3}{5.7\ x\ 10^{-8}}\ x\ 216^2$$

$$T = 5.82x\ 10^3 \text{ K}$$

Example 8

A spherical black body of radius 2.0cm at -73^0C is suspended in an evacuated enclosure whose walls are maintained at 27^0C. If the rate of exchange of thermal energy is equal to $1.85Js^{-1}$,

(i) find the value of Stefan's constant, (05marks)

$T_1 = 27 + 273 = 300K$

$T_2 = -73 + 273 = 200K$

$P = A\sigma(T_1^4 - T_2^4)$

$1.85 = 4\pi(0.02)^2\sigma(300^4 - 200^4)$

$\sigma = 5.66 \times 10^{-8} Wm^{-1}K^{-4}$

(ii) Calculate the wavelength at which the radiation emitted by the enclosure has maximum intensity (03mark)

$\lambda_{max} T = 2.9 \times 10^{-3}$

$\lambda_{max} = \frac{2.9\ x\ 10^{-3}}{300} = 9.7x\ 10^{-6}m$

Prevost's theory of heat exchange

When a body is in thermal equilibrium with its surrounding, its rate of emission of radiation to surrounding is equal to the rate of absorption of the radiation from the surrounding.

Example 9

A small blackened solid copper sphere of radius 2cm is placed in an evacuated enclosure whose wall are kept at 100^0C. Find the rate at which energy must be supplied to the sphere to keep its temperature at 127^0C. (03marks)

$$P = \sigma A(T_2^4 - T_1^4)$$

$$= \sigma 4\pi r^2(T_2^4 - T_1^4)$$

$$= 5.67 \times 10^{-8} \times 4\pi\,(2 \times 10^{-2})^2(400^4 - 372^4)$$

$$= 1.78\text{W}$$

Example 10

The energy intensity received by a spherical planet from a star is $1.4 \times 10^3\text{Wm}^{-2}$. The star is of radius 7.0×10^5km and is 14.0×10^7km from the planet.

(i) Calculate the surface temperature of the star. (04marks)

Incident energy per second (power) on a unit of planet $= \frac{4\pi r_s^2 \sigma T^4}{4\pi R^2}$

$$= \left(\frac{r_s}{R}\right)^2 \sigma T^4$$

where r_s and R are the radii of the star and the distance of the star from the planet respectively.

$$1.4 \times 10^3 = = \left(\frac{r_s}{R}\right)^2 \sigma T^4$$

$$T = \left[\frac{1.4\ x\ 10^3}{\sigma} x \left(\frac{R}{r_s}\right)^2\right]^{\frac{1}{4}} = \left[\frac{1.4\ x\ 10^3}{5.67\ x\ 10^{-8}} x \left(\frac{14\ x\ 10^{10}}{7\ x\ 10^8}\right)^2\right]^{\frac{1}{4}} = 5605.98\text{K}$$

(ii) State any assumptions you have made in (c)(i) above (01marks)

- The star is spherical
- The star radiates as a black body
- There is no heat loss to the sphere

Greenhouse effect and global warming

- When short wavelength infrared radiation from the sun pass through the water vapour and carbon dioxide in lower layers of the atmosphere, the radiation is absorbed by the earth warming it up.
- The earth re-emits this radiation (infrared) as black body radiation of long wavelength (because of low temperature) and therefore it is trapped by the water vapour and carbon dioxide in the earth's atmosphere.
- Since the radiation is prevented from escaping from the earth's atmosphere, it causes global warming.

The **quality of radiation** refers to the characteristics or properties of radiation that determine its effects and interactions with matter. Here are some key aspects of radiation quality:

1. Wavelength and Frequency:

- **Wavelength**: The distance between two consecutive peaks of a wave, determining its energy and type (e.g., infrared, ultraviolet, visible light).
- **Frequency**: The number of wave cycles per second, which is inversely related to wavelength.

2. Energy:

- **Photon Energy**: The energy of individual photons in the radiation, typically measured in electron volts (eV). Higher energy photons can cause more significant interactions with matter.

3. Intensity:

- **Radiation Intensity**: The power per unit area of the radiation, measured in watts per square meter (W/m^2). It indicates the amount of energy delivered to a surface.

4. Ionizing vs. Non-Ionizing Radiation:

- **Ionizing Radiation**: High-energy radiation that can ionize atoms and molecules, causing chemical changes (e.g., X-rays, gamma rays).
- **Non-Ionizing Radiation**: Lower-energy radiation that does not ionize atoms but can cause other effects (e.g., radio waves, microwaves).

5. Penetrating Ability:

- **Penetration Depth**: The ability of radiation to penetrate materials, depending on its energy and the type of material. For example, gamma rays have high penetration power, while alpha particles have low penetration.

6. Biological Effects:

- **Radiation Dose**: The amount of radiation absorbed by an organism, measured in grays (Gy) or sieverts (Sv). It helps assess the potential biological impact.
- **Radiation Quality Factor**: A factor used to account for the different biological effects of various types of radiation, influencing the calculation of the dose equivalent.

Understanding the quality of radiation is crucial in fields such as medical imaging, radiation therapy, and environmental protection, as it helps assess and manage the effects of radiation on health andmaterials.

Application of black body radiation

(i) Astrophysics & Astronomy

- Stars are modeled as approximate black bodies, allowing scientists to determine their **temperature, size, and age** from emitted radiation.
- The **cosmic microwave background (CMB)** is a near-perfect black body spectrum, providing evidence for the Big Bang theory.

(ii) Temperature Measurement

- Infrared thermometers and **pyrometers** use black body radiation principles to measure high temperatures without direct contact.
- Thermal imaging cameras detect emitted radiation to create heat maps, useful in medicine, engineering, and surveillance.

(iii) Quantum Physics

- Planck’s study of black body radiation solved the **ultraviolet catastrophe** and led to the birth of **quantum mechanics**, revolutionizing modern physics.

(iv) Industrial Applications

- Used in **furnace design** and material testing to understand heat transfer.
- Calibration of instruments like **spectrometers** relies on black body radiation standards.

(v) Environmental & Climate Science

- Helps model **Earth’s radiation balance**, crucial for studying climate change and greenhouse effects.

Revision exercise as set by global examination bodies

1. (a) State

    (i) Stefan’s law of thermal radiation (01mark)

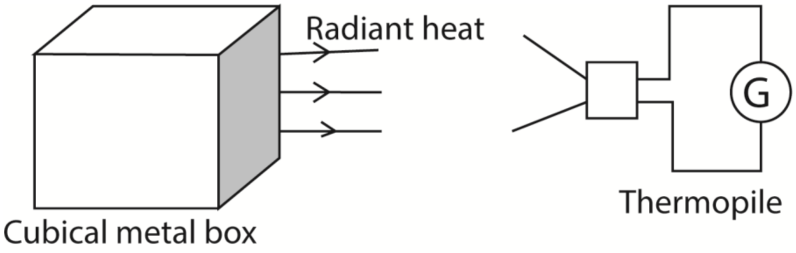
    Stefan’s law states that the total power radiated by a black body per unit surface area is proportional to the fourth power of its absolute temperature. i.e. $\frac{P}{A} \propto T^4$

    (ii) Wien’s displacement law. (01 ark)

    The wavelength λ_m at which maximum energy is radiated for temperature, T is such that $\lambda_m T$ = constant.

    (b) Describe an experiment to show the rate of heat loss from a body depends on the nature of the surface. (04marks)

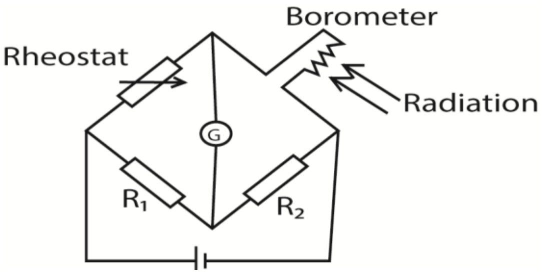
A cubical metal tank whose sides are painted; dull black, dull white and highly polished is filled with hot water and radiations from each surface are detected by a thermopile as shown below.



The galvanometer deflection is greatest when the thermopile is facing the dull black surface and least when facing a highly polished silver surface. Therefore, a polished surface is the least radiator and a black surface is the best radiator. Hence, rate of heat loss from a body depends on the nature of the surface.

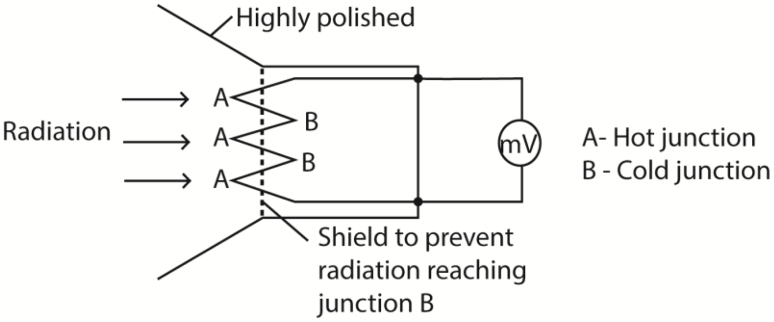
(c) (i) Describe an experiment to detect thermal radiation. (03 marks)

Using **Borometer**



The bolometer strip is connected to Wheatstone bridge circuit above. The rheostat is adjusted until the galvanometer shows no deflection. When the radiations fall on the strip, they are absorbed and its temperature rises leading to an increase in resistance. The galvanometer deflects showing the presence of radiations.

Or Using **a thermopile**

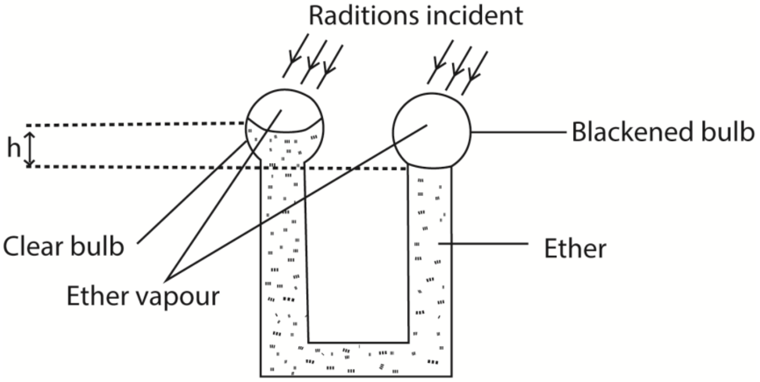


Radiation falling on junction A is absorbed and temperature rises above that of junction B. An e.m.f is generated and is measured by millivolt meter which deflects as a result.

Or

Using the ether-thermo scope.

A blackened and clear bulbs are connected to a tube partly filled with ether i.e. each bulb contains mixture of air and ether vapour. When the arrangement is exposed to infrared radiations, more radiations are absorbed by the blackened bulb than those absorbed by the clear bulb. This raises the pressure inside the blackened bulb causing the ether liquid to be raised in the unblackened bulb as shown below.



The rise h is proportional to incident radiation

(iii) Explain the mechanisn of heat transfer in fluids. (03 marks)

When a fluid is heated from underneath, it expands and becomes less dense than fluid above. The warm less dense fluid rises to the top and the cool more dense fluid from above moves downwards to take place. This process continues and circulating current of the fluid is established until the whole fluid is heated up.

(d) Explain;

(i) what is meant by a perfect black body. (01 mark)

A perfect black body is one that absorbs all the radiation incident on it, but reflects and transmits none.

(ii) what is meant by quality of radiation. (01 mark)

The **quality of radiation** refers to the characteristics (such as frequency, intensity) or properties of radiation that determine its effects and interactions with matter.

(iii) Why a black body at 1000K is red hot whereas it is white hot at 2000K. (02 mark)

Red hot: 1000K, the peak wavelength emitted by a black body falls in visible red range making the black body appear red hot.

White Hot: At 2000K, the black body produces a mixture of peak wavelengths with colors in the visible spectrum including red, yellow, green, and blue, which combine to produce white light. Thus, the black body appears white hot.

(e) The element of an electric fire with an output of 0.5kW, is a cylinder 20cm long.The element behaves as a black body and when in use its temperature is 693.5^{0}C. Calculate the diameter of the element. (04marks)

From $P = \sigma A T^4$

$= \sigma(\pi d L)T^4$

$\Rightarrow \; d = \frac{P}{\sigma \pi L T^4}$

Substitution

$$d = \frac{0.5\ x\ 10^3}{(5.67x10^{-8})\pi(20x\ 10^{-2})(693.5+273)^4}$$
$$= 0.016m$$

2. (a) (i) State any three properties of ultraviolet radiation.(03marks)
   - Produces ionization
   - Produces fluorescence
   - Affects photographic films
   - Produces photoelectric effect
   - Absorbed by glass
   - Can be polarized
   - Promotes chemical reactions

   (ii) What is a black body? (01mark)

   A black body is one that absorbs all radiations incident on it without reflecting or transmitting any.

   (b) A cylindrical metal rod with a well- insulated curved surface has one end blackened and then exposed to thermal radiation from a body at a temperature 500K. If the equilibrium temperature of the blackened end is 400K and the length of the rod is 10cm, calculate the temperature of the other end. [Thermal conductivity of the metal = 500Wm^{-1}K^{-1}] (04marks)

   Power absorbed = $\sigma A(T_2^4 - T_1^4)$

   = $5.67 \times 10^{-8}A(500^4 - 400^4)$

   = 2092.13A

   Power conducted = $\frac{Q}{t} = KA\frac{\Delta\theta}{L}$

   $= \frac{A(400-T)}{10}\ x\ 500 = 50(400-T)A$

   Power absorbed = power conducted

   $50(400-T)A$ =2092.13A

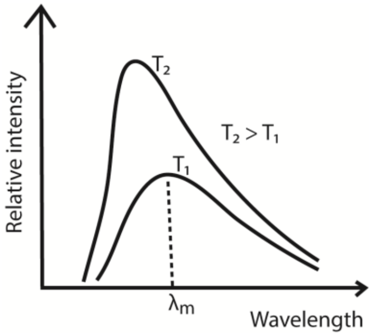
   T = 358.16K

3. (a) (i) What is meant by a black body? (02marks)

   A black body is a body that absorbs all radiations incident on it and transmits and reflects none

   (ii) Give two examples of a black body. (01mark)
   - The sun
   - Star
   - Black hole (remnants of a star after it has used up all its energy]
   - An almost enclosed blackened surface with hole/furnace with small hole

   (b) With aid of graphs describe how radiation emitted by a black body varies with wavelength for two temperatures.

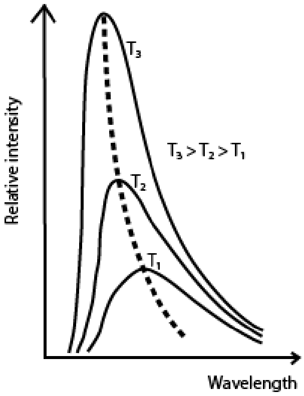


- For every wave length, relative intensity increases as temperature is increased.
- The wavelength at which maximum intensity occur shifts to the shorter wavelength as temperature is increased.
- λ_{max} is the wavelength of radiation emitted at maximum intensity/emission of a black body at a particular temperature.

4. (a)(i) Define a black body. (01mark)

   A black body is a body which absorbs all the radiations incident on it and does not reflect or transmit any.

   (ii) Sketch and explain graphs of intensity versus wavelength for three different temperatures of a black body. (03marks)

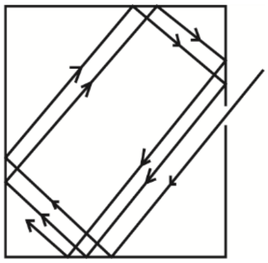


- For every wave length, relative intensity increases as temperature is increased.
- The wavelength at which maximum intensity occur shifts to the shorter wavelength as temperature is increased.
- λ_{max} is the wavelength of radiation emitted at maximum intensity/emission of a black body at a particular temperature.

5. (a) (i) What is a black body?(01marks)

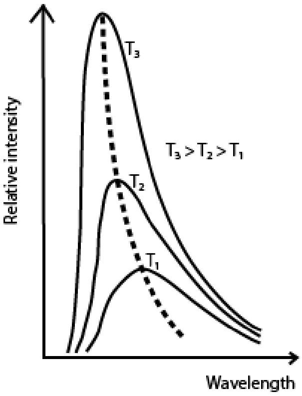
   A black body is one which absorbs all the radiation that falls upon it, and reflects or transmits none.

   (ii) Explain with the aid of a diagram how black body can be approximated. (03marks)



When radiation enters a black container through a hole, it undergoes multiple reflections. At each reflection, part of the radiation is absorbed. After several reflections, all the radiation is retained inside the container. Hence it approximates to a black body.

(iii) With the aid of sketch graphs explain the silent features of the spectral distribution of black body radiation (04 marks)



- For every wave length, relative intensity increases as temperature is increased.
- The wavelength at which maximum intensity occur shifts to the shorter wavelength as temperature is increased.
- λ_{max} is the wavelength of radiation emitted at maximum intensity/emission of a black body at a particular temperature.

(b) Give four properties of ultraviolet radiation. (02marks)

- produce ionization and florescence
- affect photographic plates
- produces photoelectric effect
- promotes chemical reaction
- can be reflected and refracted.

(c) Describe an experiment to compare the energy radiated by two surfaces at different temperatures (04marks)

- A metal cube whose sides have a variety of finishes; dull black, white, highly polished is filled with water and this water is kept boiling by a constant heat supply.
- A thermopile is made to face the various finishes of the cube at equal distances and each time the deflection on the galvanometer is noted.
- The deflection of the galvanometer is greatest when the thermopile is facing the dull-black surface and least when facing the highly polishes surface.
- This implies that the dull-black surface is a better radiator.

(d) (i) State Stefan’s law. (01mark)

Stefan’s law states that the total power radiated by a black body per unit surface area is proportional to the fourth power of its absolute temperature. i.e. $\frac{P}{A} \propto T^4$

(ii) The earth receives energy from the earth from the sun at the rate of 1.4 x 10^3Wm^{-2}. If the ratio of the earth’s orbit to the sun’s radius is 216, calculate the surface temperature of the sum. (05marks)

Power radiated by the sun = $4\pi r^2\sigma T^4$

Energy intensity = $\frac{4\pi r^2\sigma T^4}{4\pi R^2}$

$$\therefore \frac{4\pi r^2\sigma T^4}{4\pi R^2} = 1.4\ x\ 10^3$$

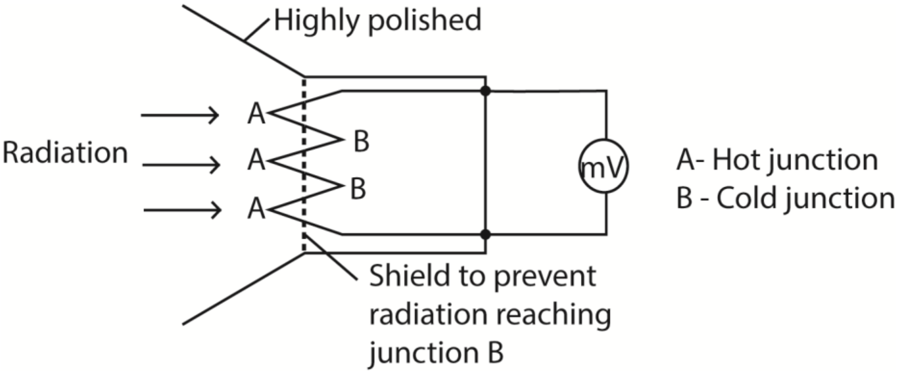
$$T^4 = \frac{1.4\ x\ 10^3}{5.7\ x\ 10^{-3}}\left(\frac{R}{r}\right)^2 = \frac{1.4\ x\ 10^3}{5.7\ x\ 10^{-3}}\ x\ 216^2$$

$$T = 5.82x\ 10^3\ \text{K}$$

6. (a) State Stefan’s law of black body radiation. (01marks)

Stefan’s law states that the energy radiated per second per unit area of black body is proportional to the fourth power of the temperature of the body in Kelvin.

(b) Briefly describe how a thermopile can be used to detect thermal radiation. (05marks)



Radiation falling on junction A is absorbed and temperature rises above that of junction B. An e.m.f is generated and is measured by millivolt meter which deflects as a result.

(c) Explain the temperature distribution along

(i) a perfectly lagged metal bar (02marks)

When a metal is fully lagged, no heat is lost to the surroundings. The rate of heat flow along the metal bar is the same making the fall in temperature along the bar is uniform,

(ii) an unlagged metal bar. (02marks)

For a fully unlagged metal, heat lost to the surroundings. The rate of heat flow along the bar is not the same. Hence temperature gradient along the bar decreases with distance from the hot end to the cold end.

(d) The wall of a furnace is constructed with two layers. The inner layer is made of bricks of thickness 10.0cm and thermal conductivity 0.8 $Wm^{-1}K^{-1}$ and the outer layer is made of material of thickness 10.0 cm and thermal conductivity 1.6 $Wm^{-1}K^{-1}$.
The temperatures of the inner and outer surfaces ate 600^0C and 460^0C respectively.

(i) Explain why in steady state, the rate of thermal energy transfer must be the same in both layers. (01mark)

Rate of the thermal energy transfer is the same because no heat is lost transverse to the direction of heat flow.

(ii) Calculate the rate of heat flow per square meter through the wall. (05marks)

$$\frac{Q}{t} = kA\left(\frac{\theta_2 - \theta_1}{l}\right)$$

$$\frac{0.8A(600 - \theta)}{10\ x\ 10^{-2}} = \frac{1.6A(\theta - 460)}{10\ x\ 10^{-2}}$$

$$\theta = 506.7^0$$

$$\frac{QIt}{A} = \frac{0.8A(600 - 506.7)}{10\ x\ 10^{-2}} = 746.4Wm^{-2}$$

(e) Explain the greenhouse effect and how it is related to global warming. (04marks)

Short wavelength radiation from the sun passes through glass of green house. This is absorbed by plants and soil leading to increase in temperature. Plants and soil reradiate long wavelength radiations which cannot penetrate the glass and trapped in the greenhouse leading to higher temperature inside the greenhouse.

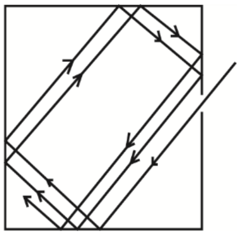
Water vapour, carbon dioxide, CFC and other greenhouse gases exhibit the same selective absorption effect in the temperature, making the earth to high temperature by absorbing short wavelength radiation.

The earth reradiates long wavelength radiation which is absorbed by the layers of greenhouse gases. This leads to increased temperature over the earth and after a long time may lead to global warming.

7. (a)(i) What is meant by a black body? (01mark)

A black body is one that absorbs all the radiations incident on it, reflects none and transmits none.

(ii) Describe how a black body can be approximated in practice. (04marks)

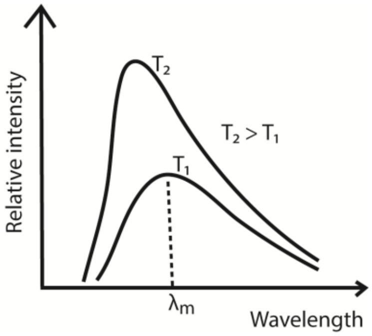


When radiation enters a black container through a hole, it undergoes multiple reflections. At each reflection, part of the radiation is absorbed. After several reflections, all the radiation is retained inside the container. Hence it approximates to a black body.

(b) (i) State Prevost's theory of heat exchange. (01mark)

A body at constant temperature is in of dynamic equilibrium with its surroundings. The rate of radiation being equal to the rate of absorption.

(ii) Sketch the variation with wavelength of the intensity of radiation emitted by a black body at two different temperatures. (01mark)



- For every wave length, relative intensity increases as temperature is increased.
- The wavelength at which maximum intensity occur shifts to the shorter wavelength as temperature is increased.
- λ_{max} is the wavelength of radiation emitted at maximum intensity/emission of a black body at a particular temperature.

(c) A cube of side 1.0cm has a grey surface that emits 50% of the radiation emitted by a black body at the same temperature. If the cube's temperature is 700^0C, calculate the power radiated by the cube. (03marks)

$P = \sigma A T^4$

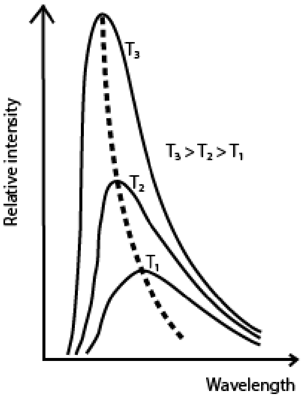
T = 700 + 273 = 973K

$\therefore P = 0.5 \times 5.67 \times 10^{-8} \times (6 \times 10^{-4}) \times 973^4 = 15.25W$

8. (i) What is meant by a black body? (01mark)

A black body is one that absorbs all incident radiations on it, transmits and reflects none.

(ii) Sketch curves showing the spectral distribution of energy radiated by a black body at three different temperatures. (02marks)



(iii) Describe the main features of the curves you have drawn in (d)(ii) (02marks)

- For every wave length, relative intensity increases as temperature is increased.
- The wavelength at which maximum intensity occur shifts to the shorter wavelength as temperature is increased.
- λ_{max} is the wavelength of radiation emitted at maximum intensity/emission of a black body at a particular temperature.

(iv) A small blackened solid copper sphere of radius 2cm is placed in an evacuated enclosure whose wall are kept at 100^{0}C. Find the rate at which energy must be supplied to the sphere to keep its temperature at 127^{0}C. (03marks)

$P = \sigma A(T_2^4 - T_1^4)$

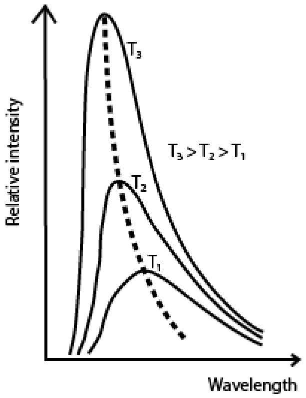
$= \sigma 4\pi r^2(T_2^4 - T_1^4)$

$= 5.67 \times 10^{-8} \times 4\pi (2 \times 10^{-2})^2(400^4 - 372^4)$

$= 1.78W$

9. (a) (i) State the laws of black body radiation (02marks)
    - The wavelength λ_m at which maximum energy is radiated for temperature, T is such that $\lambda_m T$ = constant. (Wien's displacement law)
    - If $E_{\lambda m}$ is the height of the peak of the curve for a temperature T, then $E_{\lambda m} \propto T^6$
    - The total energy radiated per square meter per second by a black body at temperature, T, is proportional to T^4 (Stefan's Boltzmann law)

(ii) Sketch the variation of intensity with wavelength in a black for different temperatures. (03marks)

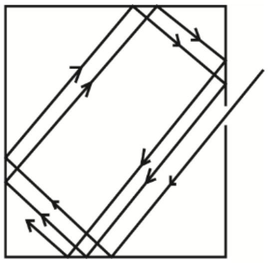


- For every wave length, relative intensity increases as temperature is increased.
- The wavelength at which maximum intensity occur shifts to the shorter wavelength as temperature is increased.
- λ_{max} is the wavelength of radiation emitted at maximum intensity/emission of a black body at a particular temperature.

(b) (i) What is a perfectly black body? (01marks)

A perfect black body is one that absorbs all the radiation incident on it, but reflects and transmits none.

(ii) How can a perfectly black body be approximated in reality? (04marks)



When radiation enters a black container through a hole, it undergoes multiple reflections. At each reflection, part of the radiation is absorbed. After several reflections, all the radiation is retained inside the container. Hence it approximates to a black body.

(c)(i) The energy intensity received by a spherical planet from a star is $1.4 \times 10^3 Wm^{-2}$. The star is of radius 7.0×10^5km and is 14.0×10^7km from the planet.

(i) Calculate the surface temperature of the star. (04marks)

Incident energy per second (power) on a unit of planet = $\frac{4\pi r_s^2 \sigma T^4}{4\pi R^2}$

$$= \left(\frac{r_s}{R}\right)^2 \sigma T^4$$

where r_s and R are the radii of the star and the distance of the star from the planet respectively.

$$1.4 \times 10^3 = = \left(\frac{r_s}{R}\right)^2 \sigma T^4$$

$$T = \left[\frac{1.4 \, x \, 10^3}{\sigma} \, x \, \left(\frac{R}{r_s}\right)^2\right]^{\frac{1}{4}} = \left[\frac{1.4 \, x \, 10^3}{5.67 \, x \, 10^{-8}} \, x \, \left(\frac{14 \, x \, 10^{10}}{7 \, x \, 10^8}\right)^2\right]^{\frac{1}{4}} = 5605.98K$$

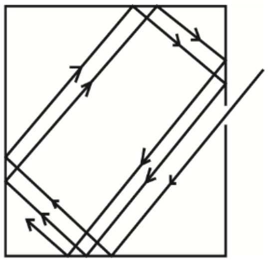
(ii) State any assumptions you have made in (c)(i) above (01marks)

- The star is spherical
- The star radiates as a black body
- There is no heat loss to the sphere

10. (a) What is meant by black body? (01mark)

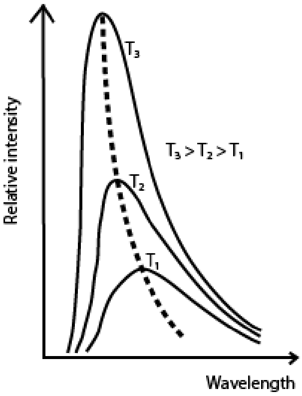
A black body is one that absorbs all incident radiation, but reflects and transmits none.

(b) Describe how an approximate black body can be realized in practice. (02marks)



When radiation enters a black container through a hole, it undergoes multiple reflections. At each reflection, part of the radiation is absorbed. After several reflections, all the radiation is retained inside the container. Hence it approximates to a black body.

(c)(i) Draw sketch graphs to show how variation of relative intensity of black body radiation with wavelength for three different temperatures. (02marks)



(iii) Describe the features of the sketch in (c)(i) above. (03marks)

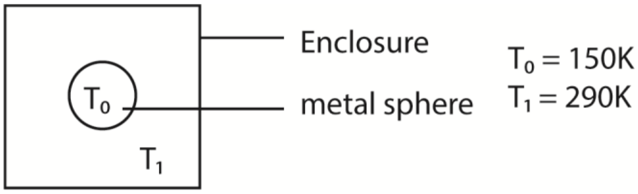
As temperature increases, the intensity increases. The intensity of shorter wavelengths increases more rapidly. The wavelength of the most intense radiation decreases as temperature increases.

(d)(i) State Stefan's law (01mark)

Stefan's law states that the total power radiated by a black body is directly proportional to the fourth power of its absolute temperature.

(ii) A solid copper sphere of diameter 10 mm and temperature of 150K is placed in an enclosure maintained at a temperature of 290K. Calculate, stating assumptions made, the initial rate of rise of temperature of the sphere.

[Density of copper = 8.93 x 10^3kgm^{-3}, specific heat capacity of copper = 3.7 x 10^2JkgK^{-1}) (07marks)

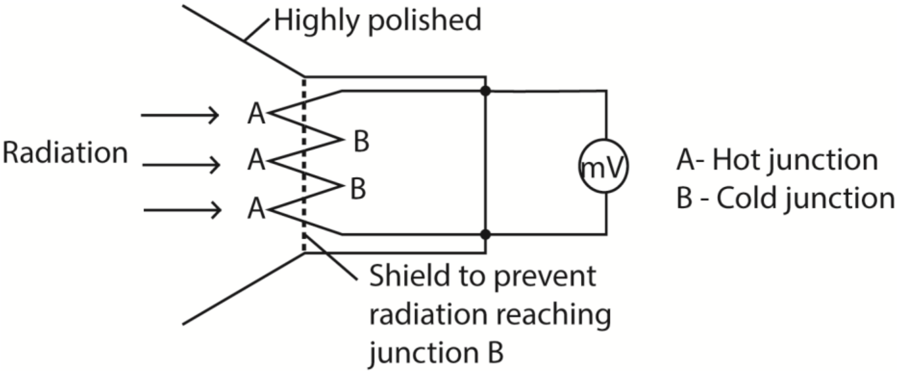


Power radiated by the sphere = $4\pi r^2\sigma T_0^4$
Power absorbed by the sphere =$4\pi r^2\sigma T_1^4$
Net power absorbed, P = $4\pi r^2\sigma(T_1^4 - T_0^4)$
But also, P = $mc\frac{d\theta}{dt} = \frac{4}{3}\pi r^3\rho c\frac{d\theta}{dt}$
At equilibrium

$$\frac{4}{3}\pi r^3\rho c\frac{d\theta}{dt} = 4\pi r^2\sigma(T_1^4 - T_0^4)$$

$$\frac{d\theta}{dt} = \frac{3\sigma}{\rho cr}(T_1^4 - T_0^4) = \frac{3 \ x \ 5.67 \ x \ 10^{-8}}{8.93 \ x \ 10^3 \ x \ 3.7 \ x \ 10^2 \ x \ 5 \ x \ 10^{-3}} = 0.068Ks^{-1}$$

(e) With the aid of a labelled diagram, describe how a thermopile can be used to determine infrared radiation. (04marks)



Radiation falling on junction A is absorbed and temperature rises above that of junction B. An e.m.f is generated and is measured by millivolt meter which deflects as a result.

Thank you
Dr. Bbosa Science