Heat Transfer

A layer of ice 0.15m thick has formed on the surface of a deep pond. If the temperature of the upper surface of ice is constant and equal to that of the air which -12oC , determine the time it will take for he thickness of ice to increase by 0.2mm. Given L = 80kcal /kg, ρ =910 kg/m3 and K 0.5 cal /s /m /K .

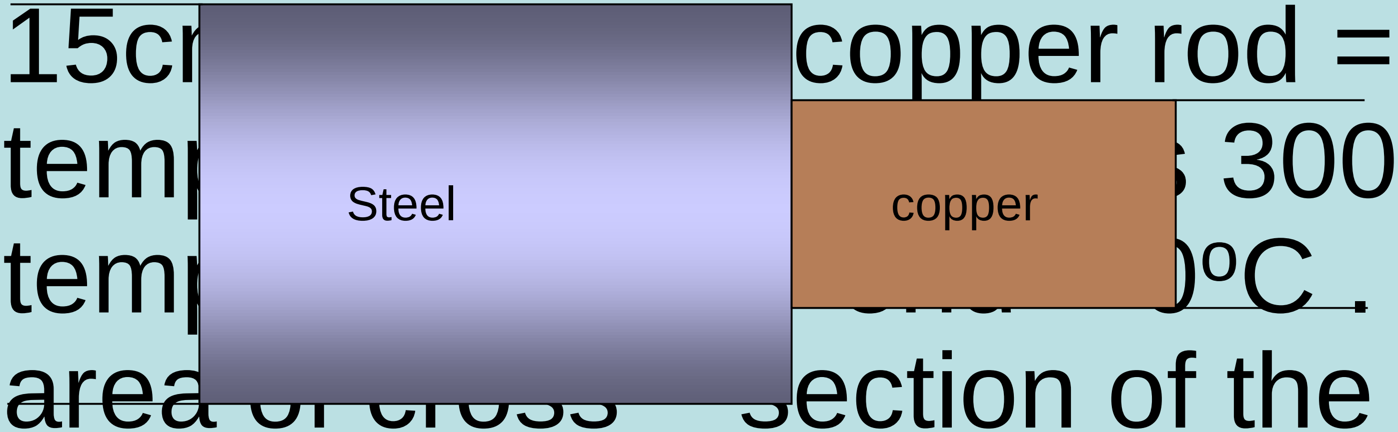
Hint: $$dt = \frac{\rho L \times dx}{KT} = 364\ s.$$

Calculate the rate of loss of heat through a glass window of are 1000cm2 and thickness 4mm when temperature inside is $37^{o}C$ and outside is $-5^{o}C$.

K = 0.0022cal/s/cm/K

Ans : 231 cal/s

What is the temp of the steel – copper junction in the steady sate of the system shown. Length of stee rod = 15c copper rod = 10cm , temp s 300°C , temp end 0°C . The area of cross section of the steel rod is twice that of the copper rod. K_{steel} = 50.2 and K_{cu} = 385 SI units.



Hint : $$\frac{K_1A_1(300 - T)}{L_1} = \frac{K_2A_2\,(T - 0)}{L_2}.$$

Radiation

Radiation

The energy emitted by a body in the form of heat by virtue of its temperature is called thermal radiation .

All bodies above absolute zero of temperature emit radiant energy .

Sun is a powerful source of radiant energy .

Properties of thermal radiation

i. EM
ii. 3×10^8 m/s
iii. IR 8000Å – 20,000Å
iv. Reflection, refraction , interference, diffraction, polarisation.

Absorptance, Reflectance and Transmittance.

Let Q – incident radiation

Q_1 – qty absorbed, Q_2- reflected,Q_3 – transmitted ($Q = Q_1+Q_2 + Q_3$)

Absorbing power or absorptance a = Q/Q_1.

Reflecting power or Reflectance r = Q/Q_2.

Transmitting power or transmittance t =Q/Q_3.

$a + r + t = 1$, if $t = 0$, $a + r = 1$

ie. poor reflectors are good absorbers and vice versa.

Absorptive powers

i) Dull copper – 13%

ii) Indian ink – 85%

iii) Shellac – 72%

iv) Lamp black – 98%

Note: a, r and t are independent of the nature of material of the body, but depend upon the wavelength of the incident radiation and the nature of the surface.

Absorptance will be different for different wavelengths corresponding to a particular wavelength is called ' monochromatic absorptance' or ' spectral absorptive power' $a_{\lambda.}$

Spectral absorptive power

For a particular λ is defined as the ratio of the heat energy absorbed in a certain time to the total heat energy incident upon it in the same time within a unit wavelength range around the wavelength λ . ie. b/w (λ-1/2) and (λ+1/2)

Fraction of energy absorbed in the **wave length range dλ** b/w (λ-d λ /2) and (λ+d λ/2) = $a_\lambda \, d\lambda$

Emissive power ‘e’

Of a body at a particular temperature is the total energy radiated per unit sec per unit area.

Spectral emissive power or monochromatic emittance e_λ

Of a body for a particular λ is defined as the quantity of radiant energy emitted per sec per unit area of the surface within **unit wavelength range** around the wavelength λ .

ie. b/w (λ-1/2) and (λ+1/2)

Energy radiated in the **wave length range dλ** b/w (λ-d λ /2) and (λ+d λ/2) = e_λ dλ

Radiant emittance or emissive power ‘e’

Radiant emittance e is the total energy emitted by a body /sec / unit area for all possible wavelengths ranging from 0 to infinity .

$e = \int e_\lambda \, d\lambda$ limit 0 to inifinity

Emissivity ε

Is the ratio of the emissive power of a body to the emissive power of a black body at the same temp.

Emissivity $\varepsilon = e/E$

Emissive power $e = \varepsilon E$

Intensity of the radiation

Is defined as the amount of heat energy falling /sec/ unit area held at right angles to the radiation .

$I \ \alpha \ 1/r^2$. inverse square law.

Intensity also depends on the strength of the source.

Spectral intensity I_λ

Is defined as the amount of heat energy incident /sec/ unit area held at right angles to the radiation in a unit wave length range around λ.

Black body

A perfectly black body is one which absorbs completely the radiations of all wavelengths falling on it hence appears black. (r = t = 0 , a = 1)

Not possible in practice.

Lamb black or plantinum black are aproximate = absorb nearly 98%.

Fery Black body – double walled hollow sphere having

Black body (full or total)radiation

Radiation emitted by a perfectly black body, when it is heated to a suitably high temperature is called black body radiation. (contains all possible wavelengths).

Prevost’s theory of Heat exchange

i. All bodies above OK emit heat to the surroundings and gain heat from the surroundings at all times.

ii. The amount of radiation emitted increases with temperature.

iii. Rate of emission depends on the temperature of body and nature of surface.

Prevost’s theory of Heat exchange

iv. Rate of emission is not affected by the surroundings.

v. Continuous exchange of heat b/w body and surroundings.

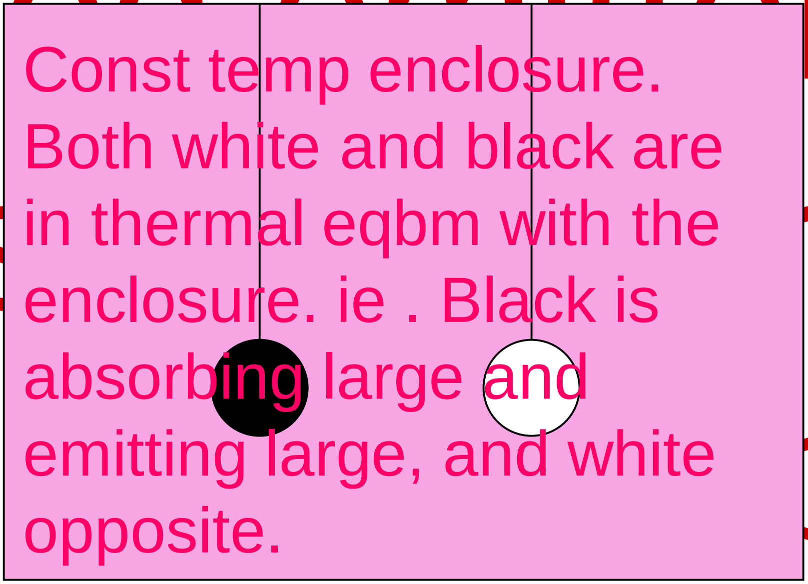
vi. Fall or rise in temperature of a body is the net result of exchange of heat between the body and the surroundings.

A body is in thermal equilibrium with its surroundings. Is it static or dynamic equilibrium . Defend.

Dynamic.

Continuous exchange of heat is going on.

Good absorbers are Good emitters Poor abs re Poor em plain.



Const temp enclosure. Both white and black are in thermal eqbm with the enclosure. ie . Black is absorbing large and emitting large, and white opposite.

Prevost’s theory – dynamic eqbm

Kirchhoff’s Law

At any given temperature , the ratio of the emissive power to the absorptive power corresponding to a certain wavelength is constant for all bodies and this constant is equal to the emissive power of a perfectly black body at the same temperature and corresponding to the same wavelength.

Kirchhoff's Law - Proof

Consider a uniformly heated enclosure maintained at temp T.

dQ – amount of heat having wavelength b/w λ and $\lambda+d\lambda$ incident on a **unit surface area** /s.

Energy absorbed = $a_\lambda\, dQ$

Energy reflected or transmitted

$$= \quad dQ - a_\lambda\, dQ \quad = dQ\,(1 - a_\lambda)$$

Energy emitted /s in the wavelength range λ and $\lambda + d\lambda$ $= e_\lambda d\lambda$

Total energy coming from the body /sec/unit area(λ and $\lambda + d\lambda$) $= dQ\,(1 - a_\lambda) + e_\lambda d\lambda$

Body and enclosure are in thermal eqbm.
ie. heat coming from body = heat incident.

$$dQ\,(1 - a_\lambda) + e_\lambda d\lambda = dQ$$

$$e_\lambda d\lambda = a_\lambda dQ$$ (general eqn)

For black body $E_\lambda d\lambda = dQ$ $(a_\lambda = 1)$

Ratio gives $e_\lambda / E_\lambda = a_\lambda$

$$e_\lambda / a_\lambda = E_\lambda$$ Kirchhoff's law.