HEAT TRANSFER

Module -III

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Heat Transfer

MODULE - III

MOST IMPORTANT
OBJECTIVE TYPE QUESTIONS & ANSWERS

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MECHANICAL ENGINEERING

THERMAL RADIATION

3. Heat Transfer by Radiation

249. The ratio of the emissive power and absorptive power of all bodies is the same and is equal to the emissive power of a perfectly blackbody. This statement is known as
(a) Kirchhoff's law (b) Stefan's law
(c) Wien law (d) Planck's law

BPSC AE 2012 Paper - V
KPSC AE. 2015
HPPSC LECT. 2016

Ans : (a) : Kirchhoff's law- The ratio of the emissive power to absorptive power of all bodies is the same and is equal to the emissive power of perfectly blackbody.

$$\frac{E}{\alpha} = \text{constant}$$

$$E_b = \frac{E_1}{\alpha_1}$$

250. Which of the following is not the characteristics of Planck's black body radiation distribution
(a) As temperature increases, the peak of the curve shift towards higher wavelength
(b) Spectral emissive power varies continuously with the change in wavelength
(c) At a given wavelength, as temperature increases, emissive power also increases
(d) Total emissive power is proportional to T^4

RPSC LECTURER 16.01.2016

Ans. (a) : According to the characteristics of Planck's black body radiation distribution as temperature increases, the peak of the curve shift towards higher wavelength.

251. The total heat radiation from a black body per second per unit area is proportional to (Where T is an absolute temperature).
(a) T^4 (b) T^3
(c) T^2 (d) T

HPPSC AE 2018

Ans. (a) : Stefan Boltzmann Law–According to Stefan-Boltzmann law, the amount of Radiation emitted per unit time from an area of a black body at absolute temperature T is directly proportional to the fourth power of the temperature.

$$Q = \sigma AT^4$$

$$Q \propto T^4$$

where σ is Stefan's constant $= 5.67 \times 10^{-8} W/m^2K^4$

252. Depending on the radiation properties, a body will be opaque when,
(a) $\tau = 1; \rho = \alpha = 0$ (b) $\alpha = 0; (\tau + \rho) = 1$
(c) $\tau = 0; (\alpha + \rho) = 1$ (d) $\rho = 0; (\tau + \alpha) = 1$

TNPSC AE 2013
Nagaland PSC CTSE 2017 Paper-2

Ans. (d) : Opaque body– When no irradiation is transmitted through the body, it is called opaque body.
For opaque body

$$\rho = 0$$

so, $\alpha + \tau = 1$

Gray body– A gray body is defined as a body whose absorptivity of a surface does not vary with variation in temperature and wavelength of the incident radiation.

253. A gray body is one whose absorptivity
(a) varies with temperature
(b) varies with wavelength of incident ray
(c) varies with temperature and wavelength of incident ray
(d) does not very with either temperature or wavelength of incident ray
(e) is equal its emissivity

CGPSC AE 2014 -II
SJVN ET 2013

Ans. (d) : A gray body is one whose absorptivity does Vary with either temperature of wavelength of incident ray.

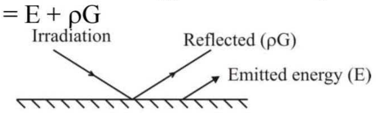
254. The total radiation leaving a surface per unit time and per unit area is called
(a) radiosity (b) shape factor
(c) radiation intensity (d) black body radiation

TNPSC 2019

Ans. (a) : Radiosity (J)- The total thermal radiation energy leaving a surface per unit time per unt area is known as radiosity.

J = Emitted energy + Reflected part of incident.

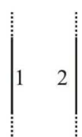
$$J = E + \rho G$$



255. What is the value of shape factor for two infinite parallel surfaces separated by a distance X ?
(a) 0 (b) Infinite
(c) 1 (d) X

TNPSC 2019
JPSC AE PRE 2019
RPSC Vice Principal ITI 2018
BPSC AE Mains 2017 Paper - V
UKPSC AE 2012 Paper–II

Ans. (c) : The infinite parallel planes with the assumption that leakage of radiation from space between them is zero.



$\therefore F_{11} + F_{12} = 1$

$\because$ Plane are flat so,

$F_{11} = 0$

$F_{12} = 1 = F_{21}$

256. A grey body is one whose absorptivity
(a) varies with temperature
(b) varies with wavelength of incident ray
(c) varies with temperature and wavelength of incident ray
(d) does not vary with temperature and wavelength of incident ray

UKPSC AE 2007 Paper -II

Ans. (d) : Gray body is hypothetical body like black body which energy diagram at every temperature and wave length just like with black body.
* Emissivity and absorptivity of gray body is necessarily bellow one, but is does not vary with temperature and wavelength of incident ray.

257. Stefan Boltzmann law is expressed as
(a) $E_b = \sigma T^4$ (b) $E_b = \sigma(\Delta T)^4$
(c) $E_b = \sigma(\Delta T)^{1.4}$ (d) $E_b = \sigma T^{1.4}$

UKPSC AE 2007 Paper -II

Ans. (a) : According to Stefan Boltzman's emissive power of black body is directly proportional to forth power of absolute temperature of body

$$E_b \propto T^4 \quad \text{or} \quad \boxed{E_b = \sigma T^4}$$

where σ =Stefan Boltzman's constant

and $\sigma = 5.67\times10^{-8}\dfrac{w}{m^2-k^4}$

258. With usual notations, for black body
(a) $\alpha = 0, \tau = 0, \rho = 1$ (b) $\alpha = 1, \tau = 0, \rho = 0$
(c) $\alpha = 1, \tau = 1, \rho = 0$ (d) None of the above

UKPSC AE 2007 Paper -II

Ans. (b) : $\alpha = 1, \tau = 0, \rho = 0$

Absorptivity (α)	Fraction of incident radiation absorbed.
Reflectivity (ρ)	Fraction of incident radiation reflected.
Transmittivity (τ)	Fraction of incident radiation transmitted.

259. Two long parallel surfaces each of emissivity 0.7 are maintained at different temperatures and accordingly have radiation heat exchange between them. It is desired to reduce 75% of the radiant heat transfer by inserting thin parallel shields of emissivity 1 on both sides. The number of shields should be:
(a) 2 (b) 1
(c) 3 (d) 4

OPSC AEE 2019 PAPER - II

Ans : (c) : Since emissivity '$\in$' of both surfaces and shield are same and equal to 0.7 Radiation shields reduces 75% of radiation so radiation exchange in presence of n shield,

$$\therefore \frac{E_1-E_2}{4} = \frac{E_1-E_2}{n+1}$$

$\therefore n = 3$

Where E_1 and E_2 are emissive power of long parallel surfaces.

260. A good approximation of the measured solar spectrum is made by
(a) black-body energy distribution
(b) Planck's energy distribution
(c) inverse square law
(d) solar constant

ESE 2019

Ans. (a) : The blackbody model with a temperature of 5900 k is a good approximation to measured solar radiation.

261. In which type of collector is solar radiation focused into the absorber from the top, rather than from the bottom ?
(a) Fresnel lens (b) Paraboloidal
(c) Concentrating (d) Compound parabolic

ESE 2020

Ans. (d) : Compound parabolic

262. A flat plate collector is 150 cm wide and 180 cm high and is oriented such that it is perpendicular to the sun rays. Its active area is 90% of the panel size. If it is in a location that receives solar insulation of 1000 W/m^2 peak, the peak power delivered to the area of the collector will be
(a) 1.23 kW (b) 2.43 kW
(c) 4.46 kW (d) 6.26 kW

ESE 2020

Ans. (b) : Area of the flat plate
$= 150\times180 = 27000\ cm^2 = 2.7\ m^2$
Solar insolation = $1000\ W/m^2 = 1000\times2.7\times0.90$
$= 2700\times0.90 = 2.43$ kW

263. A surface having high absorptance for shortwave radiation (less than 2.5 µm) and a low emittance of long-wave radiation (more than 2.5 µm), is called
(a) Absorber (b) Emitter
(c) Selective (d) Black

ESE 2020

Ans. (c) : Selective

264. A room window (consisting of a vertical sheet of plane glass) is exposed to direct sunshine at a strength of 1000 W/m^2. The window is pointing due south, While the sun is in the southwest, 30^0 above the horizon. Estimate the amount of solar energy in W/m^2 reflected by the window: Assume glass to be gray with ρ (reflectivity) = 0.08.
(a) 49 (b) 490
(c) 612.3 (d) 61.2

BHEL ET 2019

Ans. (a) : 49

265. A wave of radiation falls on a body. 35% of the radiation is reflected back. If transmissivity of the body is 0.25, then emissivity is :
(a) 0.35 (b) 0.45
(c) 0.40 (d) 0.25

BHEL ET 2019

Ans. (c) : Given– transmissivity $\tau = 0.25$
reflectivity $\beta = 0.35$
$\alpha + \beta + \tau = 1$
$\alpha + 0.35 + 0.25 = 1$
$\alpha = 1 - 0.60 = 0.40$ (according to Kirchoff's law of thermal radiation.)
$\boxed{\alpha = \in = 0.40}$

266. An electric flat-plate square heater of sides 10 cm provides 100 W power from each side. If the heater is assumed black, its temperature is approximately:
(a) 648^0 C (b) 648 K
(c) 6480 K (d) 6480^0 C

BHEL ET 2019

Ans. (b) : Area = 10 cm × 10 cm
= 100 cm^2 = 100 × 10^{-4} m^2
Q = 100 W
$\boxed{E = \in \sigma A T^4}$
for block body $\boxed{\in = 1}$
$100 = 1 \times 5.67 \times 10^{-8} \times 100 \times 10^{-4} \times T^4$
$100 = 567 \times 10^{-12} \times T^4$
$$T^4 = \frac{100}{567 \times 10^{-12}}$$
$T^4 = 0.17636 \times 10^{12}$
$$T = \sqrt[4]{0.17636 \times 10^{12}}$$
$\boxed{T = 648\ K}$

267. The rate of energy emission from unit surface area through unit solid angle, along a normal to the surface, is known as:
(a) Emissivity (b) Transmissivity
(c) Reflectivity (d) Intensity of radiation

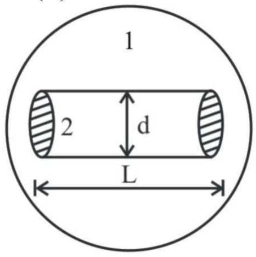
OPSC AEE 2019 PAPER - II

Ans : (d) : The rate of energy emission from unit surface area through unit solid angle, along a normal to the surface, is known as intensity of radiation.

268. At the centre of hollow sphere (Surface 1) of 2 m diameter a solid cylinder of 1 m diameter and length each is placed (Surface 2), what will be the view factor F_{11}?
(a) 0.375 (b) 1
(c) 0.625 (d) 0.75

OPSC AEE 2019 PAPER - II

Ans : (c) : Given : Diameter of sphere (D) = 1 m
Diameter of cylinder (d) = 0.5 m
Length of cylinder (L) = 0.5 m



$F_{21} = 1$
∵ (Cylinder is completely enclosed with sphere)
From reciprocity theorem
$A_1 F_{12} = A_2 F_{21}$
$$F_{12} = \frac{A_2}{A_1} F_{21} = \frac{\left(\pi d L + 2\frac{\pi}{4} d^2\right)}{4\pi\left(\frac{D}{2}\right)^2}$$
$$F_{12} = \frac{0.5 \times 0.5 + \frac{0.5 \times 0.5}{2}}{1 \times 1}$$
$F_{12} = 0.375$
According to the summation rule,
$F_{11} + F_{12} = 1$
$F_{11} = 1 - F_{12} = 1 - 0.375$
$\boxed{F_{11} = 0.625}$

269. Value of Solar constant is
(a) 1.357 kW/m^2 (b) 2.561 kW/m^2
(c) 5.61 kW/m^2 (d) 9.089 kW/m^2

Gujarat PSC AE 2019

Ans : (a) : Value of solar constant is 1.357 kW/m^2

270. In a radioactive heat transfer, a gray surface is one
(a) Which appears gray to the eye
(b) Whose emissivity is independent of wavelength
(c) Which has reflectivity equal to zero
(d) Which appears equally bright from all directions

Gujarat PSC AE 2019

Ans : (b) : In a radioactive heat transfer a gray surface is one whose emissivity is independent of wavelength.

271. Emissivity of perfectively black body is
(a) 0 (b) 1
(c) infinite (d) 0.5

Gujarat PSC AE 2019

Ans : (b) : The emissivity '$\in$' is unity for black body i.e., perfect emitter.
Absorptivity 'α' and emissivity '$\in$' are equal in value so absorptivity of black body is unity because emissivity of black body is unity.

272. Two spheres A and B of same material have radii 1 m and 4 m and temperature 4000 K and 2000 K respectively. Which one of the following statements is correct?
The energy radiated by sphere A is
(a) greater than that of sphere B
(b) less than that of sphere B
(c) equal to that of sphere B
(d) equal to double that of sphere B

Gujarat PSC AE 2019
TNPSC AE 2017

Ans : (c) : $E_{b_1} = A_1 \sigma_b T_1^4$
$E_{b_2} = A_2 \sigma_b T_2^4$
$$\frac{E_{b_1}}{E_{b_2}} = \frac{4\pi \times 1^2 \times \sigma_b \times 4000^4}{4\pi \times 4^2 \times \sigma_b \times 2000^4}$$
= 1
$\boxed{E_{b1} = E_{b2}}$

273. The thermal radiations occur in the portion of electromagnetic spectrum between the wavelengths
(a) 10^{-2} micron to 10^{-4} micron
(b) 10^{-1} micron to 10^{-2} micron
(c) 0.1 micron to 10^2 micron
(d) 10^2 micron onwards

BPSC AE Mains 2017 Paper - V
UKPSC AE 2007 Paper -II

Ans : (c) : 0.1 micron to 10^2 micron.

274. The emissive power of a black body is P. If its absolute temperature is doubled, the emissive power becomes

(a) 2P (b) 4P
(c) 8P (d) 16P

BPSC AE Mains 2017 Paper - V

Ans : (d) : As emissive power, $E \propto T^4$

So, $\frac{E_2}{E_1} = \frac{(2T)^4}{T^4}$

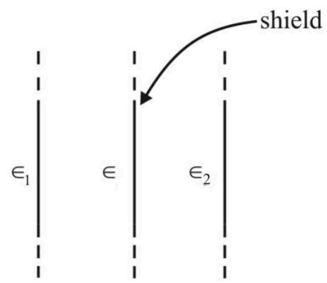
$= 16$

275. Two long parallel plates of same emissivity 0.5 are maintained at different temperatures and have radiation heat exchange between them. A radiation shield of emissivity 0.25 placed in the middle will reduce radiation heat exchange to

(a) 1 (b) $\frac{1}{4}$
(c) $\frac{3}{10}$ (d) $\frac{3}{5}$

BPSC AE Mains 2017 Paper - V
TRB Polytechnic Lecturer 2017
RPSC Vice Principal ITI 2018

Ans : (c) :



Radiation heat exchange between parallel plates

$$Q_1 = \frac{\sigma(T_1^4 - T_2^4)}{\left(\frac{1}{\in_1} + \frac{1}{\in_2} - 1\right)}$$

$\in_1 = 0.5$

$$Q_1 = \frac{\sigma(T_1^4 - T_2^4)}{3}$$

Now a radiation shield of emissivity $\in$ = 0.25 is inserted between the plates, so new radiation change.

$$Q_2 = \frac{\sigma(T_1^4 - T_2^4)}{\left(\frac{1}{0.5} + \frac{1}{0.25} - 1\right) + \left(\frac{1}{0.25} + \frac{1}{0.5} - 1\right)}$$

$$Q_2 = \frac{\sigma(T_1^4 - T_2^4)}{10}$$

$$\therefore \frac{Q_1}{Q_2} = \frac{10}{3}$$

$$\frac{Q_2}{Q_1} = \frac{3}{10}$$

276. The total emissivity power is defined as the total amount of radiation emitted by a blackbody per unit

(a) temperature (b) thickness
(c) area (d) time

BPSC AE 2012 Paper - V

Ans : (d) : The total emissivity power is defined as the total amount of radiation emitted by a blackbody per unit time.

277. The emissive power of a body depends upon its

(a) temperature
(b) wavelength
(c) physical nature
(d) all of the above

BPSC AE 2012 Paper - V

Ans : (d) : The emissive power of a body depends upon its.

- temperature
- wavelength
- physical nature

278. A perfect blackbody is one which

(a) is black in colour
(b) reflects all heat
(c) transmits all heat radiations
(d) is fully opaque

BPSC AE 2012 Paper - V

Ans : (d) : A blackbody refers to an opaque that emits thermal radiation. A perfectly black body is one that absorbs all incoming light and does not reflect any.

279. Two radiation surfaces $A_1 = 6\ m^2$ and $A_2 = 4\ m^2$ have the shape factor $F_{1-2} = 0.1$; the shape factor F_{2-1} will be :

(a) 0.18 (b) 0.15
(c) 0.12 (d) 0.10

RPSC Vice Principal ITI 2018

Ans. (b) :
By reciprocity theorem,
$A_1F_{1-2} = A_2F_{2-1}$
$6 \times 0.1 = 4 \times F_{2-1}$
$\boxed{F_{2-1} = 0.15}$

280. The wave length at which the black body emissive power reaches its maximum value at 300 K is –

(a) 9.6 µm (b) 15.5µm
(c) 5.1µm (d) 38.0µm

RPSC INSP. OF FACTORIES AND BOILER 2016

Ans : (a)
Temperature of body = 300 K
Let the wavelength of maximum amount of radiation i.e., peak emissive power wavelength is λ_{max}.
From Wien's displacement law
$T. \lambda_{max} = 2898\ \mu mK$
$\lambda_{max} = \frac{2898}{300} = 9.66\ \mu mK$

281. Two plates spaced 150 mm apart are maintained at 1000^0C & 70^0C. The heat transfer will take mainly by–

(a) convection (b) free convection
(c) forced convection (d) radiation

RPSC INSP. OF FACTORIES AND BOILER 2016

Ans : (d) $Q = \sigma(T^4 - T_\infty^4)$
At high temperature, radiation transfer will be high due to 4^{th} power of temperature.

282. 40% of incident radiant energy on the surface of thermally transparent body is reflected back, if the transmissivity of the body be 0.15 then emissivity of the surface is–
(a) 0.45 (b) 0.55
(c) 0.40 (d) 0.75

RPSC INSP. OF FACTORIES AND BOILER 2016
SJVN ET 2013

Ans : (a) Given,
$\rho = 0.4, \quad \tau = 0.15$
We know that,
$\alpha + \rho + \tau = 1$
$\alpha + 0.4 + 0.15 = 1$
$\alpha = 0.45 \qquad [\alpha = \varepsilon]$

283. Two very large parallel plates with emmisionfies 0.3 and 0.8 exchange heat. Find the percentage (%) reduction in heat transfer when a polished aluminium shield (ε = 0.04) is placed between them)
(a) 85% (b) 88%
(c) 91% (d) 93%

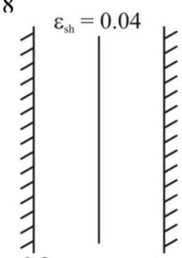
TNPSC 2019

Ans. (d) : Data given-
$\varepsilon_1 = 0.3, \varepsilon_2 = 0.8, \varepsilon_{sh} = 0.04$

$$\left[\frac{q}{A}\right]_{\text{net without shield}} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

$$= \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1}{0.3} + \frac{1}{0.8} - 1}$$

$\varepsilon_{sh} = 0.04$



$\varepsilon_1 = 0.3$ $\varepsilon_2 = 0.8$

$$\left[\frac{q}{A}\right]_{\text{without shield}} = 0.279 \times \sigma\left(T_1^4 - T_2^4\right) \text{W/m}^2$$

$$\left[\frac{q}{A}\right]_{\text{with shield}} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1}{0.3} + \frac{2}{0.04} + \frac{1}{0.8} - 2}$$

$$= 0.019 \times \sigma \times \left(T_1^4 - T_2^4\right) \text{W/m}^2$$

$$\% \text{ Reduction} = \frac{q_{\text{without}} - q_{\text{with}}}{q_{\text{without}}} \times 100\%$$

$\%$ Reduction = 93.18%

284. The emissitivities for non-metallic surfaces generally
(a) increase with increase in temperature
(b) decrease with increase in temperature
(c) increase exponentially with temperature
(d) remain constant at all temperatures

TNPSC 2019

Ans. (b) : The emissitivities for non-metallic surfaces generally decrease with increase in temperature.

285. Statement (I) : The radiation emitted by earth is of longer wavelength than that emitted by the sun.
Statement (II) : Earth is at a lower temperature than the sun.
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

JWM 2017

Ans. (a) : The radiation emitted by sun is of shorter wave length then that emitted by earth. This is because that sun has high temperature than earth.

286. The intensity of the radiation emitted by the sun is maximum at a wavelength of 0.5 μm. Assuming the sum to a black body, the surface temperature of the sun will approximately be:
(a) 5000 K (b) 5780 K
(c) 6280 K (d) 6490 K
(e) 6600 K

CGPSC AE 2014- II

Ans. (b) : Wavelength (λ) = 0.5 μm
Surface temperature (T) = ?
We know that-
$T \times \lambda = 2898\ \mu\text{m} - \text{K}$

$$T = \frac{2898}{0.5} = 5796 = 5780 \text{ K}$$

287. For the opaque surface, which of the following reaction is correct? [Where τ = Transmissivity, α = Absorptivity, ρ = Reflectivity]
(a) $\alpha + \tau = 1, \alpha > 0, \tau > 0, \rho > 0$
(b) $\alpha = \rho = 1$
(c) $\alpha + \rho = 1, \tau = 0$
(d) $\alpha = \tau = 1$
(e) $\tau = 1, \rho = 0, \alpha = 0$

CGPSC AE 2014- II

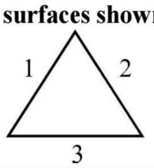
Ans. (c) : For opaque surface, transmissivity will be zero.
We know that–
$\alpha + \rho + \tau = 1$
For opaque surface $\tau = 0$ then $\alpha + \rho = 1$

288. The value of Stefan Boltzmann constant is
(a) 6.67×10^{-8} W/m^{2}K^4 (b) 5.67×10^{-8} W/m^{2}K^4
(c) 6.67×10^{-8} W/m^{4}K^2 (d) 5.67×10^{-8} W/m^{4}K^2
(e) 5.67×10^{-8} W/mK^4

CGPSC AE 2014 -II

Ans. (b) : The value of Stefan Boltzmann constant (σ) is given as $\sigma = 5.67 \times 10^{-8}$ W/m^{2}K^4

289. Consider an enclosure of three non-concave surfaces shown in Figure. The shape factor F23 is



(a) $\dfrac{A_1 + A_2 - A_3}{2A_1}$ (b) $\dfrac{A_2 + A_3 - A_1}{2A_2}$

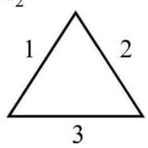
(c) $\dfrac{A_3 + A_1 - A_2}{2A_3}$ (d) $\dfrac{A_1 + A_2 + A_3}{2A_1}$

(e) $\dfrac{A_1 + A_2 + A_3}{2A_2}$

CGPSC AE 2014 -II

Ans. (b) : The shape factor F_{23} is given as

$$F_{23} = \frac{A_2 + A_3 - A_1}{2A_2}$$



290. Sun's surface at 5800 K emits radiation at a wavelength of 0.5μ. A furnace at 580°C will emit through a small opening radiation at a wavelength of nearly

(a) 10μ (b) 0.1μ

(c) 3.4μ (d) 0.01μ

(e) 5.6μ

CGPSC AE 2014 -II

Ans. (c) : According to wine's displacement law

$\lambda . T$ = Constant

$\lambda_1 \times T_1 = \lambda_2 \times T_2$

$0.5\ \mu \times 5800 = \lambda_2 \times (580+273)$

$\boxed{\lambda_2 = 3.399\mu}$

291. Soar radiation of 1200W/m² falls perpendicularly on a grey opaque surface of emissivity 0.5. If the surface temperature is 50°C and surface emissive power 600W/m², the radiosity of that surface will be

(a) 1200 W/m² (b) 300 W/m²

(c) 400 W/m² (d) 500 W/m²

(e) 600 W/m²

CGPSC AE 2014 -II

Ans. (a) : Radiosity [J] = Emitted energy per unit area per unit time + reflected part of Incident energy per unit area per unit time

$J = E + \rho.G$

$G = 1200\ W/m^2$, $\alpha = \varepsilon = 0.5$, $E = 600\ W/m^2$

For opaque surface

$\tau = 0$

$\therefore \quad \alpha + \rho + \tau = 1$

$\rho = 0.5$

then

$J = 600 + 0.5 \times 1200$

$J = 1200\ W/m^2$

292. A solid cylinder (surface 2) is located at the centre of a hollow sphere (surface 1). The diameter of the sphere is 2 m, while the cylinder has a diameter and length of 1.5 m each. The radiation configuration factor F_{11} is

(a) 0.225 (b) 0.8437

(c) 0.1562 (d) 0.4375

(e) 0.2969

CGPSC AE 2014 -II

Ans. (c) : We know that,

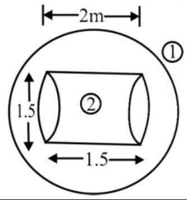
$F_{1\text{-}1} + F_{1\text{-}2} = 1$

and $A_1F_{1\text{-}2} = F_{2\text{-}1}\ A_2$ [Reciprocity theorem]

$$F_{1\text{-}2} = \frac{A_2}{A_1} = \frac{\left[\pi DL + 2\times\frac{\pi}{4}D^2\right]_2}{\left[4\pi R^2\right]_1} \qquad F_{2\text{-}1} = 1,\ F_{2\text{-}2} = 0$$

$$F_{1\text{-}2} = \frac{\left[\pi\times1.5\times1.5 + 2\times\frac{\pi}{4}\times(1.5)^2\right]}{\left[4\times\pi\times(1)^2\right]} = 0.84375$$

$F_{1\text{-}1} = 1 - 0.84375 = 0.15625$



293. If the temperature of a solid surface increases form 27°C to 627° C, its emissive power increases in the ratio:

(a) 1 : 3 (b) 1 : 9

(c) 1 : 27 (d) 1 : 81

OPSC AEE 2015 PAPER - II

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SJVN ET 2013

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Ans : (d) $T_1 = 27 + 273 = 300$ K

$T_2\ 627 + 273 = 900$ K

Emissive power (E) = σT^4 W/m²

$$\frac{E_1}{E_2} = \left(\frac{300}{900}\right)^4$$

$$\frac{E_1}{E_2} = \frac{1}{81}$$

$E_1 : E_2 = 1 : 81$

294. The temperature of a solid surface is changed for 127°C to 927°C. The emissive power shall increase in the ratio of

(a) 2 (b) 8

(c) 3 (d) 9

(e) 81

CGPSC AE 2014 -II

Ans. (e) : We know that,

$E \propto T^4$

$T_1 = 127+273 = 400K$

$T_2 = 927 +273 = 1200K$

then,

$$\frac{E_2}{E_1} = \left[\frac{T_2}{T_1}\right]^4 = \left[\frac{1200}{400}\right]^4 = [3]^4$$

$\boxed{E_2 = 81E_1}$

295. The radiation heat transfer from an inner cylindrical surface of radius r_1 and emissivity ε_1 at temperature T_1 to concentric cylinder of radius r_2, emissivity ε_2 and at temperature T_2 is proportional to-

(a) $\dfrac{T_1^4 - T_2^4}{\left[\dfrac{1}{\varepsilon_1} + \left(\dfrac{1}{\varepsilon_2} - 1\right)\left(\dfrac{r_1}{r_2}\right)\right]}$

(b) $\dfrac{T_1^4 - T_2^4}{\left[\dfrac{1}{\varepsilon_1} - \left(\dfrac{1}{\varepsilon_2} - 1\right)\left(\dfrac{r_1}{r_2}\right)\right]}$

(c) $\dfrac{T_1^4 - T_2^4}{\left[\dfrac{1}{\varepsilon_1} + \left(\dfrac{1}{\varepsilon_2} - 1\right)\left(\dfrac{r_2}{r_1}\right)\right]}$

(d) $\dfrac{\left(\dfrac{r_2}{r_1}\right)T_1^4 - T_2^4}{\dfrac{1}{\varepsilon_1} + \left(\dfrac{1}{\varepsilon_2} - 1\right)}$

RPSC AE 2018

Ans. (a) : $Q \propto \dfrac{T_1^4 - T_2^4}{\left[\dfrac{1}{\varepsilon_1} + \left(\dfrac{1}{\varepsilon_2} - 1\right)\left(\dfrac{r_1}{r_2}\right)\right]}$

296. The radiation heat transfer through large plates separated by N radiation shields becomes, when the emissivities of all surfaces are equal

(a) Q_{12}, N shields = $\dfrac{1}{N+1}Q_{12}$, no shield

(b) Q_{12}, N shields = $\dfrac{1}{N+1}Q_{12}$

(c) Q_{12}, N shields = $(N+1)Q_{12}$, no shield

(d) Q_{12}, N shields = $N(N+1)Q_{12}$, no shield

TNPSC AE 2014

Ans. (a) :

$$Q_{1-2 \text{ with N shields}} = \frac{1}{(N+1)} \times Q_{1-2 \text{ without shield}}$$

297. Radiosity (*J*) for black surface is

(a) Equivalent to emissive power E_b

(b) Greater than emissive power

(c) Less than emissive power

(d) None of the above

TNPSC AE 2014

Ans. (a) : We know that

J = Emitted energy + Reflected part of incident energy.

$J = E + \rho G$

For black body

$\rho = 0$

so, $\boxed{J = E_b}$

298. The equivalent emissivity of two parallel gray planes, whose emissivities are 0.2 and 0.5 is

(a) 0.1 (b) 0.166

(c) 0.4 (d) 2.5

TNPSC AE 2013

Ans. (b) : We know that interchanging factor for the radiation from surface 1 to surface 2

$$\varepsilon = \frac{\varepsilon_1\varepsilon_2}{\varepsilon_1 + \varepsilon_2 - \varepsilon_1\varepsilon_2}$$

$$\varepsilon = \frac{0.2 \times 0.5}{0.2 + 0.5 - 0.5 \times 0.2}$$

$$\boxed{\varepsilon = 0.166}$$

299. At thermal equilibrium, the absorptivity of a body is equal to

(a) Emissivity (b) Reflectivity

(c) Transmissivity (d) Diffusivity

TNPSC AE 2013

Ans. (a) : According to Kirchoff's Law of thermal radiation the emissivity and the absorptivity of a surface at a given temperature and wavelength are equal.

300. The value of wavelength for maximum emissive power is given by

(a) Wien's Displacement Law

(b) Fourier Law

(c) Planck's Distribution Law

(d) Kirchhoff's Law

TNPSC AE 2013

OPSC AEE 2019 PAPER - II

Ans. (a) : The value of wavelength for maximum emissive power is given by Wien's Displacement Law.

$$\lambda_{max} \propto \frac{1}{T}$$

$$\lambda_{max} T = \text{constant}$$

$$\lambda_{max} T = 2898\ \mu mk$$

301. Thermal radiation includes:

(a) Entire visible radiation and entire infrared radiation

(b) Entire visible radiation, entire infrared radiation and entire UV radiation

(c) Entire visible radiation, entire infrared radiation and some portion of UV radiation

(d) Some portion of visible radiation and entire infrared radiation

UPRVUNL AE 2016

Ans. (c) : Thermal radiation includes entire visible radiation, entire infrared radiation and some portion of UV radiation.

302. If 5 radiation shields are placed between two parallel plates, the rate of radiation heat transfer is reduced to: (ε = 1 for all surfaces)

(a) 1/10 times (b) 1/5 times

(c) 1/4 times (d) 1/6 times

UPRVUNL AE 2016

Ans. (d) :

$$(q/A)_{\text{with 'n' shields}} = \frac{1}{(n+1)}\left(\frac{q}{A}\right)_{\text{with out any shield}}$$

$$= \frac{1}{6} \text{ times}$$

303. Incident radiation of 1000 W/m^2 fall on the object. The energy absorbed by the object is 400 W/m^2 and energy transmitted is 350 W/m^2. What will be the value of reflectivity?

(a) 0.40 (b) 0.35

(c) 0.75 (d) 0.25

RPSC LECTURER 16.01.2016

Ans. (d) : Incident radiation (G) $= 1000\dfrac{W}{m^2}$

Energy absorbed by object $= 400\dfrac{W}{m^2}$

Energy transmitted $= 350\dfrac{W}{m^2}$

So, energy reflected by body $= 250\dfrac{W}{m^2}$

We know that

$$\alpha + \rho + \tau = 1$$

$$\alpha = \frac{400}{1000} = 0.4$$

$$\rho = \frac{250}{1000} = 0.25$$

$$\tau = \frac{350}{1000} = 0.35$$

304. Radiation thermal resistance may be written as (where F, A, σ are shape factor, area and Stefan-Boltzmann constant respectively)

(a) $\dfrac{1}{FA\sigma(T_1+T_2)(T_1^2+T_2^2)}$

(b) $\dfrac{1}{FA\sigma(T_1+T_2)(T_1^2-T_2^2)}$

(c) $\dfrac{1}{FA\sigma(T_1^4-T_2^4)}$

(d) $\dfrac{1}{FA\sigma(T_1^4+T_2^4)}$

RPSC LECTURER 16.01.2016

Ans. (a) : We know that

$$Q = FA\sigma(T_1^4 - T_2^4)$$

$$Q = FA\sigma(T_1^2+T_2^2)(T_1+T_2)(T_1-T_2)$$

$$Q = \frac{(T_1-T_2)}{\left[\dfrac{1}{FA\sigma(T_1^2+T_2^2)(T_1+T_2)}\right]}$$

$$Q = \frac{(T_1-T_2)}{R_{th}}$$

So,

$$R_{th} = \frac{1}{FA\sigma(T_1^2+T_2^2)(T_1+T_2)}$$

305. The degradation of plastics accelerated by

(a) Ultraviolet radiation
(b) Dampness
(c) Corrosive atmosphere
(d) None of these

SJVN ET 2013

Ans. (a) : The degradation of plastics is accelerated by ultraviolet radiation.

306. The ratio between emissive power and intensity of normal radiation is

(a) π (b) π/2
(c) 2/π (d) π/3

JPSC AE PRE 2019

Ans. (a) : The ratio between emissive power and intensity of normal radiation is π.

$$\boxed{\frac{\text{Emissive Power}}{I_b} = \pi}$$

307. The amount of radiation mainly depends on:

(a) Nature of body
(b) Temperature of body
(c) Type of surface of body
(d) All of above

SJVN ET 2013

Ans. (d) : The amount of radiation mainly depends on
• Nature of body
• Temperature of body
• Type of surface of body.

308. In what form solar energy is radiated from the Sun?

(a) Ultraviolet radiation
(b) Infrared radiation
(c) Electro-magnetic waves
(d) Transverse waves

JPSC AE PRE 2019

Ans. (c) : Electro-magnetic waves.

309. Two balls of same material and finish have their diameters in the ratio of 2 : 1 and both are heated to same temperature and allowed to cool by radiation. Rate of cooling by big ball as compared to smaller one will be

(a) 1 : 4 (b) 2 : 1
(c) 1 : 2 (d) 4 : 1

Nagaland PSC CTSE 2017 Paper-2

Ans. (d) : Use, Stefen Boltzman Law,

$$E \propto T^4$$

$$\frac{Q}{A} = \sigma T^4 \qquad \boxed{Q \propto A}$$

$$Q = \sigma T^4 A$$

$$\frac{Q_1}{Q_2} = \frac{A_1}{A_2} = \frac{d_1^2}{d_2^2} = \left(\frac{2}{1}\right)^2$$

$$\frac{Q_1}{Q_2} = \frac{4}{1}$$

$$Q_1 : Q_2 = 4 : 1$$

310. When a black body absorbs all falling radiations due to absorption, then

(a) A Black body shines
(b) The temperature of black body rises
(c) Black body radiates energy to other
(d) Black body becomes good conductor of heat

Nagaland PSC CTSE 2017 Paper-2

Ans. (a) : A surface that absorbs all radiation that falling on it. The term arises because incident visible light will be absorbed rather than reflected, therefore this surface will appear black.

311. All grey bodies obey the

(a) Stefan-boltzmann's law
(b) Planck's

(c) Kirchhoff's law
(d) Law of inertia

Nagaland PSC CTSE 2017 Paper-2

Ans. (c) : A grey bodies obey the, **Kirchhoff's Law :-** It states that, whenever a body is in thermal equilibrium with it's surrounding, its emissivity to its absorptivity.

$\boxed{\varepsilon = \propto}$

312. If the ratio of emission of a body at a given temperature is a constant for all wavelengths, the body is termed as

(a) Grey body (b) White body
(c) Qpaque body (d) Black body

Nagaland PSC CTSE 2017 Paper-2

Ans. (a) : A gray body of which the monochromatic emissivity (ε) is constant for the entire wavelength spectrum.

313. If G is irradiation and J is the radiosity, the net radiation leaving the surface is

(a) J (b) G
(c) G-J (d) J-G

Nagaland PSC CTSE 2017 Paper-2

Ans. (d) : J-G

314. An effective radiation shield should have the highest possible value of

(a) Emissivity (b) reflectivity
(c) absorptivity (d) transmissivity

Nagaland PSC CTSE 2017 Paper-2

Ans. (d) : An effective radiation shield should have the highest possible value of reflectivity. ex :- Mirror has the highest value of reflectivity.

315. For the calculation of the shape factor

(a) There should not be any intervening reflections between the surfaces
(b) There should be at least one intervening reflection between the surfaces
(c) Reflections do not affect the shape
(d) None of the above

Nagaland PSC CTSE 2017 Paper-2

Ans. (b) : There should be at least one intervening reflection between the surfaces.

316. The intensity of solar radiation is maximum at a wavelength of 0.49 μm. Assuming the Sun as a black body, what is the approximate total emissive per of Sun? [Consider Wien's displacement constant = 2890 μm-K]

(a) 6.86×10^4 kW/m^2
(b) 6.86×10^7 kW/m^2
(c) 6.86 W/m^2
(d) 6.86 kW/m^2

SJVN ET 2019

Ans. (a) :

$\lambda T = 2890 \mu mK$

$$T = \frac{2890}{0.49} = 5897.95\text{ K}$$

$E = \sigma A T^4$

$= 5.67 \times 10^{-8} \times 1 \times (5897.95)^4$

$= 6.861 \times 10^7$ W/m^2

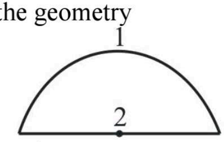
$= 6.861 \times 10^4$ kW/m^2

317. A hemispherical furnace of radius 1.0 m has a roof temperature of T_1 = 800 K and emissivity ε_1 = 0.8 . The flat floor of the furnace has a temperature T_2 = 600K and emissivity ε_2 = 0.5 . The view factor F_{12} from surface 1 to 2 will be

(a) 0.3 (b) 0.4
(c) 0.5 (d) 0.6

ESE 2019

Ans. (c) : From the geometry



$F_{21} + F_{22} = 1$

$F_{21} + 0 = 1$

$F_{21} = 1$

From reciprocity theorem

$A_1 F_{12} = A_2 F_{21}$

$$F_{12} = \frac{A_2}{A_1} F_{21}$$

$$= \frac{\pi R^2}{2\pi R^2} \times 1$$

$F_{12} = 0.5$

318. In transition boiling heat flux decreases due to which of the following?

1. Low value of film heat transfer coefficient at the surface during 100°C to 120°C surface temperature
2. Major portion of heater surface is covered by vapour film which has smaller thermal conductivity as compared to liquid
3. Nucleate boiling occurs very fast

Select the correct answer using the code given below.

(a) 1 only (b) 2 only
(c) 3 only (d) 1, 2 and 3

ESE 2019

Ans. (b) : The heat flux decreases in the transition zone of boiling because a large fraction of the heater surface is covered by a vapour film, which acts as an insulation due to the low thermal conductivity of the vapour relative to that of the liquid.

319. The temperature of a body of area 0.1 m^2 is 900 K. The wavelength for maximum monochromatic emissive power will be nearly

(a) 2.3μm (b) 3.2μm
(c) 4.1μm (d) 5.0μm

ESE 2019

Ans. (b) : From Wien's displacement law

$\lambda_{max} \cdot T = 2898$ μmk

$\lambda_{max} \cdot 900 = 2898$

$\lambda_{max} = 3.22$ μm

320. In solar flat-plate collectors, the absorber plate is painted with selective paints. The selectivity is the ratio of

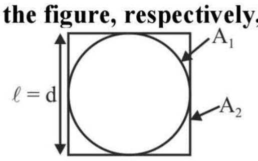
(a) Solar radiation-absorption to thermal infrared radiation-emission
(b) Solar radiation emission to thermal infrared radiation-absorption

(c) Solar radiation reflection to thermal infrared radiation-absorption
(d) Solar radiation absorption to thermal infrared radiation-reflection

ESE 2018

Ans. (a) : In solar thermal collectors, a selective surface or selective absorber is a means of increasing its operation temperature.
The selectivity is defined as the ratio of solar radiation absorption to thermal infrared radiation emission.

321. The view factors F_{12} and F_{21}, for the sphere of diameter d and a cubical box of length ℓ = d as shown in the figure, respectively, are



(a) 1 and $\frac{\pi}{3}$ (b) $\frac{\pi}{3}$ and 1
(c) 1 and $\frac{\pi}{6}$ (d) $\frac{\pi}{6}$ and 1

ESE 2017

Ans. (c) : Summation rule for sphere

$$F_{11} + F_{12} = 1$$

$$F_{12} = 1 \qquad (\because F_{11} = 0)$$

By reciprocity theorem

$$A_1F_{12} = A_2F_{21}$$

$$F_{21} = \frac{A_1}{A_2}F_{12}$$

$$F_{21} = \frac{\pi d^2}{6d^2}$$

$$F_{21} = \frac{\pi}{6}$$

322. For the radiation between two infinite parallel planes of emissivity ε_1 and ε_2 respectively, which one of the following is the expression for emissivity factor?

(a) $\varepsilon_1\varepsilon_2$ (b) $\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}$
(c) $\frac{1}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}}$ (d) $\frac{1}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1}$

MPPSC AE 2016
UKPSC AE-2013, Paper-II

Ans : (d) Emissivity factor = $\frac{1}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1}$

323. It is desired to reduce the radiation energy exchange between two infinite parallel planes by inserting radiation shields of the same emissivity. The number of shields required for 80% reduction will be:

(a) 2 (b) 3
(c) 4 (d) 5

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Ans : (c) $q_{\text{with shield}} = \frac{1}{n+1}.q_{\text{without shield}}$

$$\left(1-\frac{q_{\text{with shield}}}{q_{\text{without shield}}}\right) = 1-\frac{1}{n+1}$$

$$\left(1-\frac{4}{5}\right) = \frac{1}{n+1}$$

$$\frac{1}{5} = \frac{1}{n+1}$$

$$\boxed{n = 4}$$

324. An ideal absorber of radiation is also an ideal emitter. It is known as :

(a) Kirchhoff's law (b) Wien's law
(c) Planck's law (d) Lambert's law

OPSC AEE 2015 PAPER - II

Ans : (a) An ideal absorber of radiation is also an ideal emitter. it is known as Kirchhoff's law.
Kirchhoff's law:- The emissivity of a body is equal to its absorptivity when the body remains in thermal equilibrium with its surrounding
$\varepsilon = \alpha$ (Kirchhoff's law).
oppsc is given answer (c)

325. If ε is the emissivity of surfaces and shields and n is the number of shields, introduced between the two surfaces, then overall emissivity is given by

(a) $\frac{1}{n\varepsilon}$ (b) $\frac{1}{n(2-\varepsilon)}$
(c) $\frac{1}{(n+1)(2-\varepsilon)}$ (d) $\frac{\varepsilon}{(n+1)(2-\varepsilon)}$

BPSC Poly. Lect. 2016

Ans : (d) overall emissivity = $\frac{\varepsilon}{(n+1)(2-\varepsilon)}$

326. The temperature of a solid surface is raised from 227°C to 727°C, the emissive power of the body will change from E1 to E2 such that E2/E1 is

(a) 400 (b) 16
(c) 4000 (d) 1600

HPPSC W.S. Poly. 2016
UPPSC AE 12.04.2016 Paper-II

Ans : (b) T_1 = 227°C + 273
T_2 = 727°C + 273
T_1 = 500K
T_2 = 1000K
According to Stefan - Boltzmann law:-
$E_b = \sigma T^4$ W/m^2
σ = Stefan - Boltzmann constant
E_b = emissive power

$$\frac{(E)_1}{(E)_2} = \frac{\sigma T_1^4}{\sigma T_2^4}$$

$$\frac{(E)_1}{(E)_2} = \left(\frac{500}{1000}\right)^4$$

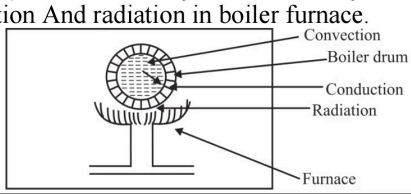
$$\frac{(E)_1}{(E)_2} = 1/16$$

E_2/E_1 = 16

327. Heat is mainly transferred by conduction, convection and radiation in :
(a) Insulated pipes carrying hot water
(b) Refrigerator freezer coil
(c) Boiler furnaces
(d) Condensation of steam in a condenser

UJVNL AE 2016
UPPSC AE 12.04.2016 Paper-II

Ans : (c) Heat is mainly, transferred by Conduction, Convection And radiation in boiler furnace.



328. Match list-I (law) with list-II (equation) select the correct Ans.wer using the codes given below the list:

List -I	List -II
(a) stefan-Boltzmann law	1. $q = hA(T_1 - T_2)$
(b) Newton's law of cooling	2. $E = \sigma E_0$
(c) Fourier's law	3. $q = \dfrac{KA(T_1 - T_2)}{L}$
(d) Kirchoff's law	4. $q = \sigma A(T_1^4 - T_2^4)$
	5. $q = kA(T_1 - T_2)$

Code

	A	B	C	D
(a)	4	1	3	2
(b)	1	2	4	3
(c)	1	4	2	3
(d)	3	2	4	1

UJVNL AE 2016

Ans : (a)

List -I	List -I
i) stefan-Boltzmann law	$q = \sigma A(T_1^4 - T_2^4)$
ii) Newton's law of cooling	$q = hA(T_1 - T_2)$
iii) Fourier's law	$q = \dfrac{KA}{L}(T_1 - T_2)$
iv) Kirchoff's law	$E = \sigma E_0$

329. Which non-metallic body is expected to have highest value of emissivity?
(a) Iron oxide (b) Carbon
(c) Ice (d) Paper

UPPSC AE 12.04.2016 Paper-II

Ans : (c)

Material	Emissivity
Ice	0.97
Paper	0.86
Aluminum foil	0.03
Brick	0.90
Glass	0.95
Silver	0.04

330. For an opaque body sum of absorptive and reflectivity is
(a) 0 (b) 1.0
(c) less than 1.0 (d) greater than 1.0

UPPSC AE 12.04.2016 Paper-II

Ans : (b)
Absorptivity (α), Reflectivity (ρ), Transmittivity (τ)
(i) For black body
$$\alpha = 1, \quad \rho = 0, \quad \tau = 0$$
(ii) For opaque body
$$\tau = 0, \quad \alpha + \rho = 1$$
(iii) For white body
$$\rho = 1, \quad \alpha = 0, \quad \tau = 0$$

331. Terrestrial radiation has a wavelength in the range of
(a) 0.2μm to 4μm
(b) 0.2μm to 0.5μm
(c) 0.380μm to 0.760μm
(d) 0.29μm to 2.3μm

UPPSC AE 12.04.2016 Paper-II

Ans : (c) Terrestrial radiation has a wavelength in the range of 0.380μm to 0.760μm .

332. A thermal transparent body is characterised by
(a) absorptivity = 1
(b) reflectivity =1
(c) absorptivity = reflectivity =0
(d) none of the above

UKPSC AE 2012 Paper–II

Ans. (c) : absorptivity = reflectivity =0

333. Stefan-Boltzmann law is expressed as
(a) $Q = \sigma AT^4$ (b) $Q = \sigma A^2T^4$
(c) $Q = \sigma AT^2$ (d) $Q = AT^4$

UKPSC AE 2012 Paper–II

Ans. (a) : $Q = \sigma AT^4$

334. The shape factor for radiation heat transfer of a long cylinder of radius r_1 enclosed by another concentric long cylinder of radius r_2 is
(a) 0.25 (b) 0.50
(c) 0.75 (d) 1.0

UKPSC AE 2012 Paper–II

Ans. (d) : Shape factor for radiation heat transfer of a long cylinder of radius r_1 enclosed by another concentric long cylinder of radius r_2
$$\boxed{F_{12} = 1}$$

335. _____ will radiate heat to a large extent.
(a) Black polished surface
(b) White rough surface
(c) White polished surface
(d) Black rough surface

UKPSC AE 2012 Paper–II

Ans. (c) : White polished surface

336. The radiant heat transfer per unit area (W/m^2) between two plane parallel gray surfaces (emissivity = 0.9) maintained at 400 K and 300 K is
(a) 992 (b) 812
(c) 464 (d) 567

UKPSC AE 2012 Paper–II

Ans. (b) : Radiation heat transfer between parallel plate,

$$= \frac{\sigma\left(T_1^4 - T_2^4\right)}{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

$$= \frac{5.67\times10^{-8}\left(400^4 - 300^4\right)}{\left(\frac{1}{0.9} + \frac{1}{0.9} - 1\right)} = 812 \text{ W/m}^2$$

337. What is the equivalent emissivity for radiant heat exchange between a small body (emissivity = 0.4) in a very large enclosure (emissivity = 0.5) ?

(a) 0.5 (b) 0.4
(c) 0.2 (d) 0.1

UKPSC AE 2012 Paper–II

Ans. (b) : 0.4

338. For an opaque plane surface, the irradiation, radiocity and emissive power are 20,12 and 10 W/m^2 respectively. The emissivity of the surface is

(a) 0.2 (b) 0.4
(c) 0.8 (d) 1.0

UKPSC AE 2012 Paper–II

Ans. (c) : 0.8

339. The Prandtl number will be the lowest for

(a) water (b) liquid metal
(c) Aqueous solution (d) lube oil

UKPSC AE 2012 Paper–II

Ans. (b) : liquid metal

340. If one radiation shield is placed between two infinite parallel radiating plane surfaces, then the amount of heat radiated becomes

(a) one third (b) one fourth
(c) half (d) none of the above

UKPSC AE 2012 Paper–II

Ans. (c) : half

341. The opaque body is that which:-

(a) Absorbs all radiations
(b) Reflects all radiations
(c) Transmits all radiations
(d) Partly reflects and partly absorbs the radiation

UKPSC AE-2013, Paper-II

Ans. (d) : A body which partly reflects and partly absorbs the radiation is known as the opaque body.

342. According to Stefan Boltzman law the relation between the total emission from a black body per unit area and per unit time (E_b) and the absolute temperature (T) is given as:-

(a) $E_b \propto T^4$ (b) $E_b \propto T^3$
(c) $E_b \propto T^2$ (d) $E_b \propto T$

UKPSC AE-2013, Paper-II

Ans. (a) : According to Stefan Boltzman law,

$E_b \propto T^4$
$E_b = \sigma T^4$

Where, $\sigma = 5.67\times10^{-8} \frac{W}{m^2k^4}$

343. In which case the medium is not required for the transfer of heat energy:-

(a) Conduction (b) Convection
(c) Radiation (d) None of the above

UKPSC AE-2013, Paper-II

Ans. (c) :

344. The process in which heat energy is transmitted by means of electromagnetic waves is known as:-

(a) Heat conduction (b) Heat convection
(c) Heat radiation (d) None of the above

UKPSC AE-2013, Paper-II

Ans. (c) : The process in which heat energy is transmitted by means of electromagnetic waves is known as heat radiation.

345. Three radiation shields are placed between two infinite parallel plates. The emissivities of plates and shields are same. As compared to heat transfer without shields, the heat transfer with shield will become:-

(a) $\frac{1}{3}$ (b) $\frac{1}{9}$
(c) $\frac{1}{4}$ (d) None of the above

UKPSC AE-2013, Paper-II

Ans. (c) : $Q_{\text{with radiation shields}} = \frac{1}{(n+1)} Q_{\text{without radiation shields}}$

$$= \frac{1}{(3+1)} Q_{\text{without radiation shields}}$$

$$\frac{Q_{\text{with radiation shields}}}{Q_{\text{without radiation shields}}} = \frac{1}{4}$$

346. Most of the terrestrial solar radiations (received on the earth) lie within wavelength range:-

(a) 0.10μm to 0.29μm (b) 0.29μm to 2.5μm
(c) 3.8μm to 7.8μm (d) 10^2μm to 10^{10}μm

UKPSC AE-2013, Paper-II

Ans. (b) :

347. Flat plate solar collectors are used for temperature applications above ambient of about:-

(a) 20°C (b) 50°C
(c) 100°C (d) 1000°C

UKPSC AE-2013, Paper-II

Ans. (c) :

348. The intensity of solar radiation on earth is of the order of :-

(a) 1 kW/m^2 (b) 2 kW/m^2
(c) 3 kW/m^2 (d) 4 kW/m^2

UKPSC AE-2013, Paper-II

Ans. (a) :

349. Assuming the Sun to be a black body emitting radiation with maximum intensity at , the surface temperature of the sun will be:-

(a) 491.4 K (b) 4914 K
(c) 49140 K (d) 491.4° C

UKPSC AE-2013, Paper-II

Ans. (b) :

350. According to Wien's law, the wavelength corresponding to maximum energy is proportional to:-
(a) T^{-1} (b) T^{-2}
(c) T^{-3} (d) T^{-4}
UKPSC AE-2013, Paper-II

Ans. (a) : According to Wien's law
$T\lambda_{max}$ = Constant
So, $\lambda_{max} \propto T^{-1}$

351. If the ratio of emission of a body to that of a black body at a given temperature is constant for all wavelengths, the body is called:-
(a) Black body (b) Gray body
(c) White body (d) Opaque body
UKPSC AE-2013, Paper-II

Ans. (b) :

352. If a body is at thermal equilibrium, then:-
(a) Emissivity < absorptivity
(b) Emissivity > absorptivity
(c) Emissivity = absorptivity
(d) None of the above
UKPSC AE-2013, Paper-II

Ans. (c) : According to Kirchhoff's law, If a body is at thermal equilibrium,
then Emissivity = absorptivity
$\varepsilon = \alpha$ [at thermal equilibrium]

353. Which mode of heat transfer plays insignificant role in a cooling tower?
(a) Radiation (b) Evaporative cooling
(c) Convective cooling (d) All the above
UKPSC AE 2007 Paper -II

Ans. (a) : A cooling tower is a heat rejection device that rejects waste heat to the atmosphere through the cooling of a water stream to a lower temperature.
* In cooling tower, mode of heat transfer is radiation which plays insignificant rate.

354. At thermal equilibrium, the absorptivity and emissivity are
(a) unity (b) zero
(c) different (d) equal
UKPSC AE 2007 Paper -II

Ans. (d) : According to Kirchhoff's Law, the absorptivity and emissivity are equal when the body remains in thermal equilibrium with its surroundings.

$$\boxed{\epsilon = \alpha}$$

355. In case of black body
(a) Transmissivity is one
(b) Absorptivity is zero
(c) Reflectivity is one
(d) None of the above
UKPSC AE 2007 Paper -II

Ans. (d) : In case of black body absorptivity is one
(i) For black body – $\alpha = 1,\ \rho = 0,\ \tau = 0$
(ii) For perfectly white body $\alpha = 0,\ \rho = 0\ \&\ \tau = 0$
(iii) For opaque body $\alpha + \rho = 1,\ \tau = 0$
where, α = Absorptivity, ρ = Reflectivity
τ = Transmittivity

356. A radiation shield is used around thermocouples in order to measure more accurately the temperature of
(a) Solid (b) Gases
(c) Freezing liquid (d) Boiling liquid
UKPSC AE 2007 Paper -II

Ans. (b) : A thermocouple is a sensor used to measure temperature. Thermocouple consist of two wire legs made from different metals. The wire's leg are welded together at one end, creating a junction. This junction is where the temperature is measured.
A radiation shield is used around thermocouples in order to measure more accurately the temperature of gases, because its volume is not fixed or its molecules are far away.

357. On which of the following factors does not amount of radiation depend?
(a) Temperature of body
(b) Type of surface of body
(c) Nature of body
(d) All of the above
UKPSC AE 2007 Paper -II

Ans. (d) : 'Radiation' means energy released by radiating body is carried out packets of energy called "photons". There photons propagate trough space in straight paths which speed is equal to that of light.
Amount of radiation does not depend on temperature of body, type of surface of body and nature of body.

358. Which of the following property is poor for gases?
(a) Transmissivity (b) Absorptivity
(c) Reflectivity (d) All of the above
UKPSC AE 2007 Paper -II

Ans. (c) : Reflectivity

359. The temperature of sun can be measured by using
(a) Radiation pyrometer
(b) Standard thermometer
(c) Mercury thermometer
(d) None of above
UKPSC AE 2007 Paper -II

Ans. (a) : Radiation pyrometer

360. According to Wien's law the wavelength corresponding to maximum energy is proportional to
(a) T (b) T^2
(c) T^3 (d) T^4
UKPSC AE 2007 Paper -II

Ans. (a) : T

361. Planck's law holds good for
(a) Polished bodies (b) Black bodies
(c) All coloured bodies (d) None of above
UKPSC AE 2007 Paper -II

Ans. (b) : Black bodies

362. Which one of the following modes of heat transfer would take place predominantly from boiler furnace to water wall?
(a) Convection (b) Conduction
(c) Radiation
(d) Conduction and convection
UKPSC AE 2007 Paper -II

Ans. (c) : Radiation

363. Radiation heat transfer occurs at a speed of

(a) Sound (b) Light

(c) 60,000 km/hr (d) 350 m/s

UKPSC AE 2007 Paper -II

Ans. (b) : Light

364. Consider a surface at -5°C in an environment at 25°C. The maximum rate of heat that can be emitted from this surface by radiation is

(a) 0 W/m^2 (b) 155 W/m^2

(c) 293 W/m^2 (d) 354 W/m^2

TNPSC AE 2014

Ans. (b) : $T_1 = 25^oC = 273 + 25$

$= 298$ K

$T_2 = -5^oC = 268$ K

then $\frac{Q}{A} = \sigma\left(T_1^4 - T_2^4\right)$

$= 5.67 \times 10^{-8} [(298)^4 - (268)^4]$

$\frac{Q}{A} = 154.64 \frac{W}{m^2}$

365. Which pair, out of the following alternatives, is not correctly matched ?

	List – I		**List – II**
(a)	Fourier's law	–	Conduction
(b)	Newton's law of cooling	–	Convection
(c)	Stephan-Boltzman law	–	Radiation
(d)	Kirchoff's law	–	Radiation +Convection

UKPSC AE 2012 Paper–II

Ans. (d) : Kirchoff's law – Radiation +Convection

Practice Set : Level-1

1. Radiation heat transfer is characterised by :
   (a) energy transport as a result of bulk fluid motion
   (b) thermal energy transfer as vibrational energy in the lattice structure of the material
   (c) movement of discrete packets of energy as electromagnetic waves
   (d) circulation of fluid motion by buoyancy effects

2. Thermal radiations occur in the portion of electromagnetic spectrum between the wavelengths
   (a) 10^{-2} to 10^{-4} micron
   (b) 10^{-1} to 10^{-2} micron
   (c) 0.1 to 10^{2} micron
   (d) 10^{2} micron onwards

3. A perfectly black body
   (a) absorbs all the incident radiation
   (b) allows all the incident radiation to pass through it
   (c) reflects all the incident radiation
   (d) has its surface coated with lamp black or graphite

4. For a perfectly black body
   (a) absorptivity $\alpha = 1$, reflectivity $\rho = 0$ and transmissivity $\tau = 0$
   (b) $\rho = 1$ and $\alpha = \tau = 0$
   (c) $\tau = 1$ and $\alpha = \rho = 0$
   (d) $\alpha + \tau = 1$ and $\rho = 0$

5. For an absolutely white or specular body
   (a) absorptivity $\alpha = 1$, reflectivity $\rho = 0$ and transmissivity $\tau = 0$
   (b) $\rho = 1$ and $\alpha = \tau = 0$
   (c) $\tau = 1$ and $\alpha = \rho = 0$
   (d) $\alpha + \tau = 1$ and $\rho = 0$

6. For a transparent or diathermanous body
   (a) absorptivity $\alpha = 1$, reflectivity $\rho = 0$ and transmissivity $\tau = 0$
   (b) $\rho = 1$ and $\alpha = \tau = 0$
   (c) $\tau = 1$ and $\alpha = \rho = 0$
   (d) $\alpha + \tau = 1$ and $\rho = 0$

7. A diathermanous body
   (a) shines as a result of incident radiation
   (b) gets heated up as a result of absorption of incident radiation
   (c) allows all the incident radiation to pass through it
   (d) partly absorbs and partly reflects the incident radiation

8. A body which partly absorbs and partly reflects but does not allow any radiation to pass through it ($\alpha + \rho = 1$ and $\tau = 0$) is called
   (a) diathermanous (b) opaque
   (c) grey (d) specular

9. Choose the false statement :
   (a) snow is nearly black to thermal radiation
   (b) absorption of radiation occurs in a very thin layer of material near the surface
   Imp (c) transmissivity varies with wavelength of incident radiation, *i.e.*, a material may be non-transparent for a certain wavelength band and be transparent for another
   (d) most of the engineering materials have rough surfaces, and these rough surfaces give regular (specular) reflections

10. Gases have poor
    (a) absorptivity
    (b) reflectivity
    (c) transmissivity
    Imp (d) absorptivity as well as transmissivity

11. With an increase in wavelength, the monochromatic emissive power of a black body
    (a) increases
    (b) decreases
    (c) increases, reaches a maximum and then decreases
    (d) decreases, reaches a minimum and then increases

Imp

12. With an increase in the temperature of source, the wavelength at which the monochromatic emissive power is maximum
    (a) increases continuously
    (b) decreases continuously
    (c) increases, reaches a maximum and then decreases
    (d) decreases, reaches a minimum and then increases

13. Absorptivity of a body is equal to its emissivity
    (a) for a polished body
    (b) under thermal equilibrium condition
    (c) at one particular temperature
    (d) at shorter wavelengths

14. The ratio of total emissive power of body to the total emissive power of a black body at the same temperature is called
    (a) absorptivity (b) transmissivity
    (c) reflectivity (d) emissivity

15. A surface for which emissivity is constant at all temperatures and throughout the entire range of wavelength is called
(a) opaque (b) grey
(c) specular (d) diathermanous

16. Four identical pieces of copper painted with different colour of paints were heated to the same temperature and then left in the environment to cool. Which of the following paints will give fast cooling ?
(a) white (b) rough
(c) black (d) shining

17. For a grey surface
(a) emissivity is constant
(b) absorptivity equals reflectivity
(c) emissivity equals transmissivity
(d) reflectivity equals emissivity

18. What is the basic equation of radiation from which all other equations of radiation equations can be derived?
(a) Stefan-Boltzman equation
(b) Planck's equation
(c) Wien's equation
(d) Rayleigh-Jeans formula

19. The law governing the distribution of radiant energy over wavelength for a black body at fixed temperature is referred to as
(a) Planck's law (b) Wien's formula
(c) Kirchoff's law (d) Lambert's law

20. The thermal radiation propagates in the form of discrete quanta; each quanta having an energy of $E = h\nu$ where ν is the frequency of quantum. The Planck's constant h has the dimensions
(a) MLT (b) MLT^{-1}
(c) MLT^{-2} (d) ML^2T^{-1}

21. The emissivity and the absorptivity of a real surface are equal for radiation with identical temperature and wavelength. This law is referred to as
(a) Lambert's law
(b) Kirchoff's law
(c) Planck's law
(d) Wien's displacement law

Imp
16-8-18
22. A thermally transparent surface of transmissivity 0.15 receives 2000 kJ/min of radiation and reflects back 800 kJ/min out of it. The emissivity of the surface is then
(a) 0.15 (b) 0.4
(c) 0.45 (d) 0.55

23. The intensity of solar radiation on earth is
(a) 1 kW/m^2 (b) 2 kW/m^2
(c) 5 kW/m^2 (d) 10 kW/m^2

24. The relationship, $\lambda_{max} T$ = constant, between the temperature of a black body and the wavelength at which maximum value of monochromatic emissive power occurs is known as
(a) Planck's law (b) Wien's law
(c) Kirchoff's law (d) Lambert's law

25. The Stefan-Boltzman constant has units of
(a) $kcal/m^2\text{-}hr\text{-}K^4$ (b) $kcal/m\text{-}hr\text{-}K^4$
(c) $kcal/hr\text{-}K^4$ (d) $kcal/m^2\text{-}K^4$

26. The temperature of a solid surface changes from 27°C to 627°C. The emissive power changes would then conform to the ratio
(a) 6 : 1 (b) 9 : 1
(c) 27 : 1 (d) 81 : 1

27. If the temperature of a hot body is increased by 50%, the amount of radiation emitted by it would increase by nearly
(a) 50% (b) 100%
(c) 200% (d) 500%

28. The following figure 7.18 was generated from experimental data relating spectral black body emissive power to wavelength at the three temperatures T_1, T_2 and T_3 ($T_1 > T_2 > T_3$).

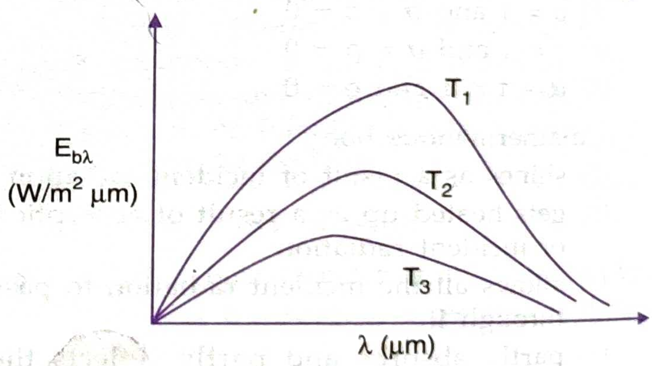


Fig. 7.18.

What conclusion can be drawn with respect to experimental data?
(a) correct because the maximum in $E_{b\lambda}$ shows the correct trend

(*b*) correct because Planck's law is satisfied

(*c*) wrong because the Stefan Boltzman law is not satisfied

(*d*) wrong because Wien's displacement law is not satisfied

29. A body at 500 K cools by radiating heat to ambient atmosphere maintained at 300 K. When the body has cooled to 400 K, the cooling rate as a percentage of original rate is about

(*a*) 31.1 (*b*) 41.5

(*c*) 50.3 (*d*) 80.4

30. For a hemisphere, the solid angle is measured in

(*a*) radian and its maximum value is π

(*b*) degree and its maximum value is 180°

(*c*) steradian and its maximum value is 2π

(*d*) steradian and its maximum value is π

31. The energy emitted (of all wavelengths) in a particular direction per unit surface area and through a unit solid angle is called

(*a*) total emissive power

(*b*) monochromatic emmissive power

(*c*) radiant flux

(*d*) intensity of radiation

32. The emissive power is multiplied with the factor .... to obtain the intensity of normal radiation for a unit surface

(*a*) $1/\sqrt{\pi}$ (*b*) $1/\pi$

(*c*) $1/2\pi$ (*d*) $\sqrt{\pi}$

33. Two spheres A and B of same material have radii 1 m and 4 m, and temperatures 4000 K and 2000 K respectively. Then the enerergy radiated by sphere A is

(*a*) greater than that of sphere B

(*b*) less than that of sphere B

(*c*) equal to that of sphere B

(*d*) two times that of sphere B

Answers :

1. (*c*)	2. (*c*)	3. (*a*)	4. (*a*)	5. (*b*)
6. (*c*)	7. (*c*)	8. (*b*)	9. (*d*)	10. (*b*)
11. (*c*)	12. (*b*)	13. (*b*)	14. (*d*)	15. (*b*)
16. (*c*)	17. (*a*)	18. (*b*)	19. (*a*)	20. (*d*)
21. (*b*)	22. (*c*)	23. (*a*)	24. (*b*)	25. (*a*)
26. (*d*)	27. (*d*)	28. (*d*)	29. (*a*)	30. (*d*)
31. (*d*)	32. (*b*)	33. (*c*)		

HINTS AND COMMENTS

9(*d*):

Rough surfaces give diffused reflections. Reflections from highly polished and smooth surfaces have regular (specular) characteristics.

16(*c*):

The emissivity of a black paint is highest (close to unity). Consequently, the emitted radiant energy will be maximum when painted black. Higher the emitted radiation, fast will be the cooling.

26(*d*):

$$\frac{E_2}{E_1} = \frac{\sigma_b A T_2^4}{\sigma_b A T_1^4}$$

$$= \left(\frac{T_2}{T_1}\right)^4 = \left(\frac{273+627}{273+27}\right)^4$$

$$= (3)^4 = 81$$

27(*d*):

$$\frac{E_2}{E_1} = \frac{\sigma_b A T_2^4}{\sigma_b A T_1^4}$$

$$= \left(\frac{T_2}{T_1}\right)^4 = (1.5)^4 = 5.06$$

The amount of radiation emitted would increase nearly by 500%.

28(*d*):

According to Wien's displacement law $\lambda_m T$ = constant. As λ_m increases, T decreases and accordingly $E_{b\lambda}$ decreases. As such, the correct diagram relating spectral black body emissive power to wavelength would be as shown below:

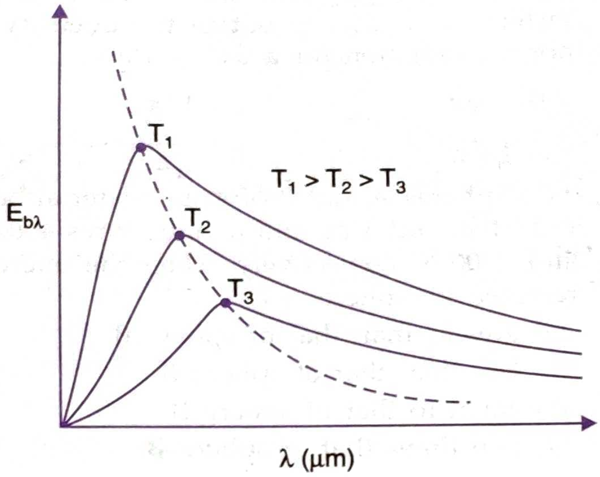


Fig. 7.19.

29(*a*):

$$\frac{Q_2}{Q_1} = \frac{T_2^4 - T_\infty^4}{T_1^4 - T_\infty^4}$$

$$= \frac{400^4 - 300^4}{500^4 - 300^4}$$

$$= 0.32 \text{ or } 32\%$$

33(*c*):

$$\frac{E_A}{E_B} = \frac{\sigma\, 4\pi\, R_A^2\, T_A^4}{\sigma\, 4\pi\, R_B^2\, T_B^4}$$

$$= \frac{R_A^2\, T_A^4}{R_B^2\, T_B^4}$$

$$= \frac{1^2 \times 4000^4}{4^2 \times 2000^4} = 1$$

As such $E_A = E_B$

Practice Set : Level- 2

1. For the same type of shapes, the value of radiation shape factor will be higher when
   (a) surfaces are more closer
   (b) surfaces are moved further apart
   (c) surfaces are smaller and held closer
   (d) surfaces are larger and held closer

2. Which of the followings is a wrong statement? The shape factor is equal to one
   (a) for any surface completely enclosed by another surface
   (b) for infinite parallel planes radiating only to each other
   (c) for a flat or convex surface with respect to itself
   (d) inner cylinder to outer cylinder of a long co-axial cylinder

3. The reciprocity theorem states that
   (a) $F_{12} = F_{21}$ (b) $A_1 F_{12} = A_2 F_{21}$
   (c) $A_1 F_{21} = A_2 F_{12}$ (d) $A_2 F_{12} = A_1 F_{21}$
   where the symbols have their usual meanings

4. Two radiating surfaces $A_1 = 6$ m^2 and $A_2 = 4$ m^2 have shape factor $F_{1\text{-}2} = 0.1$. Then the shape factor $F_{2\text{-}1}$ will be
   (a) 0.18 (b) 0.15
   (c) 0.12 (d) 0.10

5. What is the value of shape factor for two infinite parallel surfaces separated by a distance x
   (a) 0 (b) ∞
   (c) 1 (d) x

6. A hemispherical surface 1 lies over horizontal plane surface 2 such that covex portion of hemisphere is facing sky.

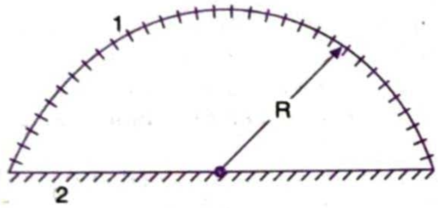


Fig. 8.56.

   What is the value of the geometrical shape factor F_{12}?
   (a) 1/4 (b) 1/2
   (c) 3/4 (d) 1/8

7. A small sphere of outer area 0.6 m^2 is totally enclosed by a large cubical hall. The shape factor of hall with respect to sphere is 0.004? What is the measure of the internal side of the hall?
   (a) 4 m (b) 5 m
   (c) 6 m (d) 10 m

8. What will be the view factor F_{21} for the geometry as shown below (sphere within a cube)?
   (a) $\frac{\pi}{2}$
   (b) $\frac{\pi}{4}$
   (c) $\frac{\pi}{3}$
   (d) $\frac{\pi}{6}$

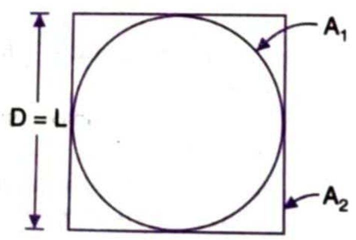


Fig. 8.57.

9. For infinite parallel planes with emissivities ϵ_1 and ϵ_2, the interchange factor for radiation from surface 1 to surface 2 is
   (a) $\epsilon_1 \epsilon_2$ (b) $\epsilon_1 + \epsilon_1$
   (c) $\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2}$ (d) $\frac{\epsilon_1 \epsilon_2}{\epsilon_1 + \epsilon_2 - \epsilon_1 \epsilon_2}$

10. Two plane parallel grey surfaces having 0.9 emissivity are maintained at 400 K and 300 K. The radiative heat transfer rate per unit area of these surfaces is about
   (a) 992 W/m^2 (b) 812 W/m^2
   (c) 567 W/m^2 (d) 464 W/m^2

11. The heat exchange between a small body having emissivity ε_1 and area A_1, and a large enclosure having emissivity ε_2 and area A_2 is given by
   $$Q_{1-2} = A_1 \varepsilon_1 \sigma (T_1^4 - T_2^4)$$
   What is the assumption for this relation?
   (a) $\varepsilon_2 = 1$
   (b) A_1 is very small as compared to A_2
   (c) $\varepsilon_2 = 0$
   (d) small body is at the centre

12. What is the equivalent emmissivity for radiant heat exchange between a small body (emissivity = 0.4) in a very large enclosure (emissivity = 0.5)?
   (a) 0.5 (b) 0.4
   (c) 0.2 (d) 0.1

13. A radiation shield should
   (a) have high transmissivity
   (b) absorb all the radiations
   (c) have high reflective power
   (d) partly absorb and partly transmit the incident radiation

imp
14. Two long parallel plates of same emissivity 0.5 are maintained at different temperatures and have radiation heat exchange between them. A radiation shield of emissivity 0.25 placed in the middle will reduce radiation heat exchange to
   imp (a) $\frac{1}{2}$ (b) $\frac{1}{4}$ (c) $\frac{3}{10}$ (d) $\frac{3}{5}$

15. A thin shield of emssivity ϵ_3 (on both sides) is placed between two infinite parallel plates of emissivities ϵ_1 and ϵ_2 and temperatures T_1 and T_2 respectively. If $\epsilon_1 = \epsilon_2 = \epsilon_3$, then the fraction radiant energy transfer without shield/with shield takes the value

(a) 0.25 (b) 0.50
(c) 0.75 (d) 1.25

16. Two long parallel surfaces, each of emissivity 0.7 are maintained at different temperatures and accordingly have radiation exchange between them. It is desired to reduce 75% of this radiant heat transfer by inserting thin parallel shields of equal emissivity 0.7 on both sides. What should be the number of shields?
(a) 1 (b) 2
(c) 3 (d) 4

17. The grey body shape factor for radiant heat exchange between a small body (emissivity 0.4) in a large enclosure (emissivity 0.5) is
(a) 0.1 (b) 0.2
(c) 0.4 (d) 0.5

18. An enclosure consists of four surfaces 1, 2, 3 and 4 The view factors for radiation heat transfer are:
$F_{11} = 0.1$; $F_{12} = 0.4$ and $F_{13} = 0.25$
The surface areas A_1 and A_4 are 4 m^2 and 2 m^2 respectively. The view factor F_{41} is
(a) 0.75 (b) 0.50
(c) 0.25 (d) 0.1

Answers :

1. (d)	2. (c)	3. (b)	4. (b)	5. (c)
6. (b)	7. (b)	8. (d)	9. (d)	10. (b)
11. (b)	12. (b)	13. (c)	14. (c)	15. (b)
16. (c)	17. (c)	18. (b)		

HINTS AND COMMENTS

2(c):

For a flat or convex surface, the shape factor with respect to itself is zero. This aspect stems from the fact that for any part of flat or convex surface, one cannot see any other part of the same surface.

15(b):

The ratio of radiant energy transfer without and with shield is given by

$$\frac{\left(\frac{1}{\epsilon_1}+\frac{1}{\epsilon_2}-1\right)}{\left(\frac{1}{\epsilon_1}+\frac{1}{\epsilon_3}-1\right)+\left(\frac{1}{\epsilon_3}+\frac{1}{\epsilon_2}-1\right)}$$

When $\epsilon_1 = \epsilon_2 = \epsilon_3$, the above fraction takes the value $\frac{1}{2}$.

16(c):

Let N be the required number of shields. When emissivities of the main radiating surfaces and those of parallel radiation shields are equal, then the rates of heat tramsfer with and without shields are prescribed by the relation

$$\frac{\text{without shields}}{\text{with shields}} = \frac{1}{N+1}$$

We are given that,

$$(Q)_{\text{shielded}} = (1 - 0.75)\,(Q)_{\text{unshielded}}$$

or $\frac{1}{N+1} = 0.25$ or $N = 3$

17(c):

$$(F_g)_{12} = \frac{1}{\frac{1-\epsilon_1}{\epsilon_1}+\frac{1}{F_{12}}+\frac{1-\epsilon_2}{\epsilon_2}\times\frac{A_1}{A_2}}$$

The configuration corresponds to a completely enclosed body, and small compared with the enclosing body. That is

$$A_1 <<< A_2 \quad \text{and} \quad F_{12} = 1$$

Hence, $$(F_g)_{12} = \frac{1}{\frac{1-\epsilon_1}{\epsilon_1}+1+0} = \epsilon_1 = 0.4$$

18(b):

$$F_{11} + F_{12} + F_{13} + F_{14} = 1$$

or $$F_{14} = 1 - (F_{11} + F_{12} + F_{13}) = 1 - (0.1 + 0.4 + 0.25) = 0.25$$

Invoking reciprocity theorem,

$$A_1 F_{14} = A_4 F_{41}$$

$$\therefore \quad F_{41} = \frac{A_1}{A_4} F_{14} = \frac{4}{2} \times 0.25 = 0.5$$

SHORT TYPE QUESTIONS & ANSWERS

ON

RADIATION HEAT TRANSFER

BIJAN KUMAR GIRI

1. Define emissive power.

Ans: The emissive power is defined as the total amount of radiation emitted by a body at a certain temperature per unit time and per unit area at all wavelengths.

Unit : W/m^2

2. Define monochromatic emissive power.

Ans: The monochromatic emissive power(E_λ) or spectral-emissive power is defined as the rate of energy radiated per unit area of the surface per unit time at a particular wavelength(λ) and temperature (T).

Unit : W/m^2 per

3. Define emissivity.

Ans: The ability of a surface of a body to emit radiation is called as emissivity(ε).

→ This property indicates how efficiently a real surface emits radiation heat flux.

→ It can also be defined as the ratio of emissive power of any normal or real body to the emissive power of a black body of equal temperature.

$$\text{Emissivity}, \varepsilon = \frac{E}{E_b}$$ ← emissive power of black body

→ Its values ranges between 0 to 1.

4. Define absorptivity(α).

Ans : Absorptivity (α) : It is a radiative properties and can be defined as the fraction of incident radiation absorbed when an incident radiation strikes on a surface.

$$\text{Absorptivity} (\alpha) = \frac{\text{Absorbed portion of radiation } (G_a)}{\text{Total incident radiation } (G)} = \frac{G_a}{G}$$

→ Its value lies in the range betn. 0 to 1.

5. Define reflectivity (ρ).

Ans: Reflectivity (ρ) : It is a radiative properties and can be defined as the fraction of incident radiation reflected back when an incident radiation strikes on a surface.

$$\text{Reflectivity} (\rho) = \frac{\text{Reflected portion of radiation } (G_r)}{\text{Total incident radiation } (G)} = \frac{G_r}{G}$$

→ Its value lies in the range betn. 0 and 1

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6. What is the condition that the radiative properties of a surface must satisfy?

Ans. The radiative properties: absorptivity (α), reflectivity (ρ) and transmittivity (τ) ~~must~~ of a surface of a body must satify the following condition:

$$\boxed{\alpha + \rho + \tau = 1}$$ i.e., conservation of energy principle.

7. Define transmittvity of a surface.

Ans: Transmissivity (τ): It is a radiative properties and can be defined as the fraction of incident radiation transmitted through the material body when an incident radiation incidents on a surface.

$$\text{Transmittivity, } \tau = \frac{\text{transmitted radiation } (G_t)}{\text{total incident radiation } (G)} = \frac{G_t}{G}$$

→ Its value lies betn 0 to 1.

8. State Stefan-Boltzmann Law of radiation.

Ans: Stefan-Boltzmann law states that the emissive-power of a black body (E_b) is directly proportional to the fourth power of the absolute temperature (T) of surface.

i.e., $E_b \propto T^4$

Or $\boxed{E_b = \sigma T^4}$, W/m^2

↑ Stefan-Boltzmann constant

and $\sigma = 5.67 \times 10^{-8}\ W/m^2\text{-}K^4$.

Kirchhoff's Law :- The law states that at any temp, the ratio of total emissive power E to the total absorptivity α is a constant for all substances which are in thermal equilibrium with their environment.

$$\boxed{\frac{E}{\alpha} = \text{constant}} \quad \text{i.e., } \frac{E_1}{\alpha_1} = \frac{E_2}{\alpha_2} = \frac{E_3}{\alpha_3} = \cdots = E_b \text{ (const)}$$

Also, $\varepsilon = \frac{E}{E_b} \Rightarrow E_b = \frac{E}{\varepsilon}$

By comparing, $\frac{E}{\varepsilon} = \frac{E}{\alpha} \Rightarrow \boxed{\varepsilon = \alpha}$

Thus, Kirchhoff's law also states that the emissivity (ε) of a body is equal to its absorptivity (α) when the body remains in thermal equilibrium with its surrounding.

Q. Define the followings :

Black body , White body , Opaque body , Gray body and Coloured body

Black body :- A blackbody is defined as a perfect emitter and absorber of radiation. At a specified temp. and wavelength, no surface can emit more energy than a black body.

→ A blackbody absorbs all incident radiation, regardless of wavelength and direction.

→ A blackbody emits radiation energy uniformly in all directions per unit area normal to direction of emission. Therefore, Blackbody is a diffuse emitter.

• The term diffuse means 'independent of direction'.

→ For a black body $\alpha = 1$ and $\rho = \tau = 0$

→ There is no such perfectly black body in nature. The term black is used, since most black coloured surfaces normally show high values of absorptivity (α) and they also absorbs all visible light rays, because of which they appear black to our eyes.

→ There are some surfaces which absorbs nearly all incident radiation, yet do not appear black (Ice, Snow, White-washed wall) $\alpha > 0.95$

→ Another Ex:- Large cavity with a small opening (Laboratory Black Body)

Opaque body :- When no incident radiation is transmitted through the body, it is called an opaque body.

→ For an opaque body, $\tau = 0$ and $\alpha + \rho = 1$

→ Glasses and liquids are considered as opaque.

White body :- If all the ~~radiation~~ incident radiation falling on a body are reflected, it is called a white body.

→ For a white body, $\rho = 1$, $\alpha = 0$ and $\tau = 0$

→ Gases such as hydrogen, oxygen and nitrogen (and their mixtures such as air) have a transmittivity (τ) of pracitally unity.

Gray body :- If the radiative properties α, ρ and τ of a body are assumed to be uniform over the entire wavelength spectrum then such a body is called gray body.

→ A gray body is also defined as one whose absorptivity (α) of a surface does not vary with temp and wavelength of the incident radiation (i.e., $\alpha = (\alpha)_\lambda$ = constant)

Coloured body :- A coloured body is one whose absorptivity (α) of a surface varies with the wavelength of radiation [$\alpha \neq (\alpha)_\lambda$].

Q. List the salient features of a black body radiation .

Solution : A black body is an ideal or hypothetical surface having the following radiation heat transfer characteristics :

(*i*) A black body absorbs all the incident radiation regardless of wavelength and direction.

(*ii*) A black body neither reflects nor transmits any amount of incident radiation.

(*iii*) For a prescribed wavelength a black body radiates the maximum energy possible at the temperature of the body.

(*iv*) The black body is a diffused emitter. This implies that the radiation emitted by a black surface is a function of wavelength and temperature but is independent of direction.

Q. Explain Planck's law of radiation .

Ans :

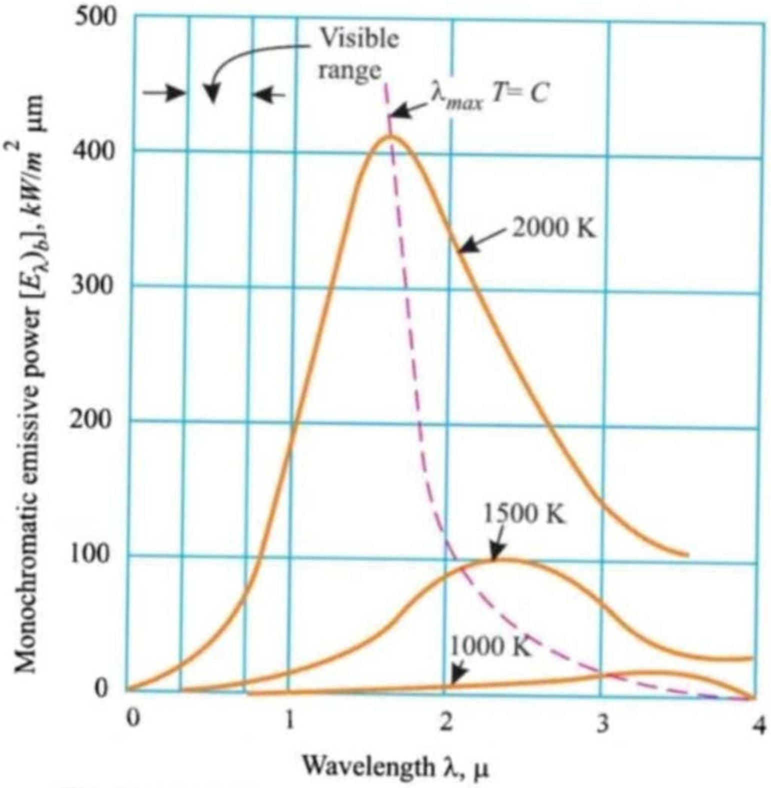


Fig. 11.6. Variation of emissive power with wavelength.

The plot shows the the following distinct characteristics of black body radiations :

1. *The energy emitted at all wavelengths increases with rise in temperature.*
2. *The peak spectral emissive power shifts towards a smaller wavelength at higher temperatures*. This shift signifies that at elevated temperature, much of the energy is emitted in a narrow band ranging on both sides of wavelength at which the monochromatic power is maximum.
3. The *area* under the monochromatic emissive power versus wavelength, at any temperature, gives *the rate of radiant energy emitted* within the wavelength interval $d\lambda$. Thus,

$$dE_b = (E_\lambda)_b \, d\lambda$$

or
$$E_b = \int_{\lambda=0}^{\lambda=\infty} (E_\lambda)_b \, d\lambda \quad \text{... over the entire range of length.}$$

This integral represents the total emissive power per unit area radiated from a black body.

Q. State Wien's displacement law.

<u>Ans : Wien's displacement law :</u>

Wien established a relationship between the temperature of a black body and the wavelength at which the maximum value of monochromatic emissive power occurs. A peak monochromatic emissive power occurs at a particular wavelength. **Wien's displacement law** *states that the product of λ_{max} and T is constant, i.e.,*

$$\lambda_{max} T = \text{constant}$$

Or , $\lambda_{max} T = 2898\ \mu mK$

This law holds true for more *real substances*; there is however some deviation in the case of a metallic conductor where the product (λ_{max} T) is found to vary with absolute temperature. It is used in *predicting a very high temperature through measurement of wavelength.*

Problem :

A small black body has a total emissive power of 4.5 kW/m². Determines its surface temperature and the wavelength of emission maximum. In which range of the spectrum does this wavelength fall ?

Solution : From Stefan Boltzman law, the rate of energy transmission from a black body is

$$E = \sigma_b T^4 ;$$

$$4.5 \times 1000 = 5.67 \times 10^{-8} T^4$$

$$\therefore \quad T = \left[\frac{4.5 \times 1000}{5.67 \times 10^{-8}}\right]^{\frac{1}{4}} = 530.77 \text{ K}$$

The wavelength of emission maximum is given by Wien's law. That is

$$\lambda_{max} T = 2.898 \times 10^{-3}$$

$$\lambda_{max} = \frac{2.898 \times 10^{-3}}{530.77}$$

$$= 5.46 \times 10^{-6} \text{ m} = 5.46 \text{ μm}$$

From Fig. 7.1, it may be seen that this wavelength falls in the infrared region of the spectrum.

Problem :

The sun emits maximum radiation at $\lambda = 0.52$ μm. Assuming the sun to be a black body, calculate the surface temperature of the sun and the emissive ability of the sun's surface at that temperature. Also determine the maximum monochromatic emissive power of the sun's surface.

Solution : From Wien's displacement law

$$T = \frac{2.898 \times 10^{-3}}{\lambda_{max}}$$

$$= \frac{2.898 \times 10^{-3}}{0.52 \times 10^{-6}} = 5573 \text{ K}$$

From Stefan's Boltzman law,

$$E = \sigma_b T^4$$

$$= 5.67 \times 10^{-8} (5573)^4$$

$$= 5.47 \times 10^{7} \text{ W/m}^2$$

Maximum monochromatic emissive power can be worked out from the relation

$$(E_\lambda)_{max} = 1.285 \times 10^{-5} T^5$$

$$= 1.285 \times 10^{-5} (5573)^5$$

$$= 6.908 \times 10^{13} \text{ W/m}^2$$

per metre wavelength

Example 11.2. *Assuming the sun to be a black body emitting radiation with maximum intensity at $\lambda = 0.49$ µm, calculate the following :*

(i) *The surface temperature of the sun, and*

(ii) *The heat flux at surface of the sun.*

Solution. *Given:* $l_{max} = 0.49$ µm

(i) **The surface temperature of the sun, *T*:**

According to Wien's displacement law,

$$\lambda_{max} T = 2898 \ \mu mK$$

$$\therefore \quad T = \frac{2898}{\lambda_{max}} = \frac{2898}{0.48} = \mathbf{5914\ K\ \ (Ans.)}$$

(ii) **The heat flux at the surface of the sun, $(E)_{sun}$:**

$$(E)_{sun} = \sigma T^4 = 5.67 \times 10^{-8}\, T^4 = 5.67 \left(\frac{T}{100}\right)^4$$

$$= 5.67 \times \left(\frac{5914}{100}\right)^4 = \mathbf{6.936 \times 10^7\ W/m^2\ (Ans.)}$$

Q. Define intensity of radiation .

Ans : **INTENSITY OF RADIATION**

When a surface element emits radiation, all of it will be intercepted by a hemispherical surface placed over the element. The **intensity of radiation** (*I*) is defined as the *rate of energy leaving a surface in a given direction per unit solid angle per unit area of the emitting surface normal to the mean direction in space.*

$$E = \pi I$$

i.e., The *total emissive power of a diffuse surface is equal to* π *times its intensity of radiation.*

Q. State Lambert's cosine law .

Ans : **LAMBERT'S COSINE LAW**

The law states that the *total emissive power* E_θ from *a radiating plane surface in any direction is directly proportional to the cosine of the angle of emission*. The angle of emission θ is the angle subtended by the normal to the radiating surface and the direction vector of emission of the receiving surface. If E_n be the total emissive power of the radiating surface in the direction of its normal, then

$$E_\theta = E_n \cos \theta$$

The above equation is true only for diffuse radiation surface. The radiation emanating from a point on a surface is termed diffused if the intensity, *I*, is constant. This law is also known as *Lambert's law of diffuse radiation.*

Q. Write the properties of a black body.

Ans :

A *black body* has the following *properties*:

(i) It absorbs all the incident radiation falling on it and does not transmit or reflect regardless of wavelength and direction.

(ii) It emits maximum amount of thermal radiations at all wavelengths at any specified temperature.

(iii) It is a *diffuse emitter* (*i.e.*, the radiation emitted by a black body is independent of direction).

Problem :

Thermal radiation strikes a surface which has a reflectivity of 0.55 and a transmissivity of 0.032. The absorbed flux as measured indirectly by heating effect works out to be 95 W/m^2. Determine the rate of incident flux.

Solution : From an energy balance,

$$\alpha + \rho + \tau = 1$$

or $$\frac{Q_a}{Q_0} + \rho + \tau = 1$$

or $$\frac{Q_a}{Q_0} + 0.032 + 0.55 = 1$$

$\therefore$ Incident flux Q_0

$$= \frac{Q_a}{1-0.032-0.55}$$

$$= \frac{95}{0.418} = 227.27 \ W/m^2$$

Problem :

Consider a system of concentric spheres of radius r_1 and r_2 ($r_2 > r_1$). If $r_1 = 5$ cm, determine the radius r_2 if it is desired to have the value of shape factor F_{21} equal to 0.6.

Solution : For the configuration of concentric cylinders as depicted in, Fig.

$F_{12} = 1$

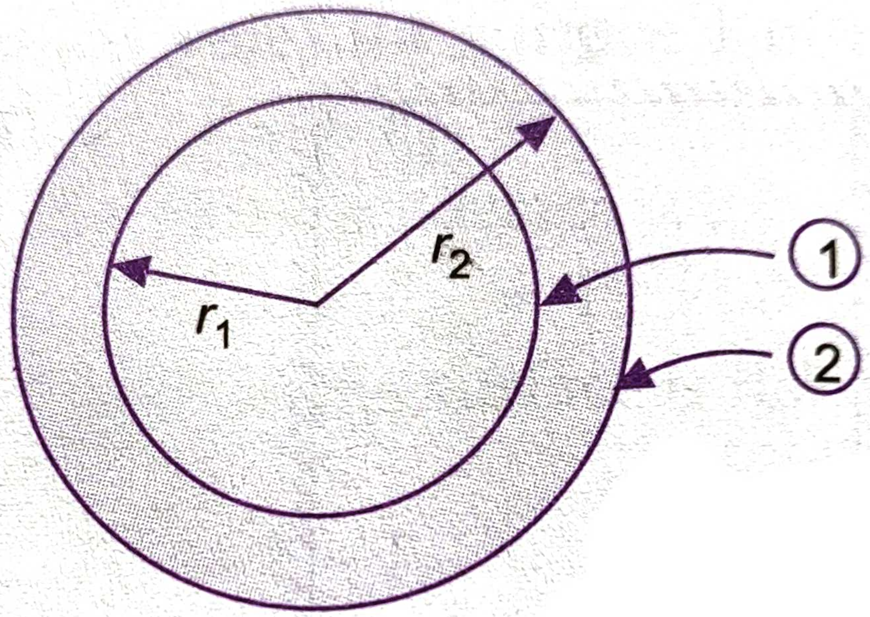


Fig.

From reciprocity theorem :

$$A_1 F_{12} = A_2 F_{21}$$

Substituting the relevent data,

$$4\pi (0.05)^2 \times 1 = 4\pi r_2^2 \times 0.6$$

$$\therefore \quad r_2 = \left[\frac{0.05^2}{0.6}\right]^{\frac{1}{2}} = 0.0645 \text{ m}$$

$$= \mathbf{6.45 \text{ cm}}$$

Q. Write short note on radiation shape factor .

Ans : *"The fraction of the radiative energy that is diffused from one surface element and strikes the other surface directly with no intervening reflections."*

The radiation shape factor is represented by the symbol F_{ij} which means the shape factor from a surface A_i to another surface A_j. Thus the radiation shape factor F_{12} of surface A_1 to surface A_2 is

$$F_{12} = \frac{\text{direct radiation from surface 1 incident upon surface 2}}{\text{total radiation from emitting surface 1}}$$

$$F_{12} = \frac{\text{directed radiation from surface-1 incident upon surface-2}}{\text{total radiation from emitting surface-1}}$$

$$= \frac{Q_{12}}{Q_1}$$

From Stefan-Boltzman law,

$$= \frac{Q_{12}}{\sigma_1 A_1 T_1^4} \qquad \left(\because Q_1 = \sigma_1 A_1 T_1^4\right)$$

$$\Rightarrow \boxed{Q_{12} = A_1 F_{12} \sigma_1 T_1^4} \quad \text{(For black body)}$$

Or, $Q_{12} = \varepsilon_1 A_1 F_{12} \sigma_1 T_1^4$ (For real surface)

Shape Factor depends upon:

1. Shape and size of surfaces
2. Orientation of surfaces w.r.t each other
3. Distance between the surfaces

Q. State reciprocity theorem .

When two bodies are exchanging radiant energy with each other, the shape factor relation is given by the eqn. (12.12) *i.e.*,

$$A_1 F_{1-2} = A_2 F_{2-1}$$

In general, $A_i F_{i-j} = A_j F_{j-i}$ ...(Reciprocity theorem)

This reciprocal relation is particularly useful when one of the shape factors is *unity*.

Q. What is the shape factor of a concave , convex and flat surface with itself ?

* A *concave surface* has a shape factor with itself because the radiant energy coming out from one part of the surface is intercepted by the another part of the same surface. *The shape factor of a surface with respect to itself is F_{l-l}.*
* For *a flat or convex surface, the shape factor with respect to itself is zero* (*i.e.*, $F_{1-1} = 0$). This is due to the fact that for any part of flat or convex surface, one *cannot see/view any other part of the same surface.*

Q. What do you mean by radiation shields ?

Ans : (i) Radiation heat transfer between two surfaces can be reduced greatly by inserting a thin, **high-reflectivity (low-emissivity)** sheet of material between the two surfaces. Such highly reflective thin plates or shells are called **radiation shields**.

(ii) The role of the radiation shield is to reduce the rate of radiation heat transfer by placing additional resistances in the path of radiation heat flow.**The lower the emissivity of the shield, the higher the resistance.**

Applications : 1. Multilayer radiation shields constructed of about 20 sheets per cm thickness separated by evacuated space are commonly used in cryogenic and space applications.

2.Radiation shields are also used in temperature measurements of fluids to reduce the error caused by the radiation effect when the temperature sensor is exposed to surfaces that are much hotter or colder than the fluid itself.

Problem :

Radiant energy with an intensity of 800 W/m² strikes a flat plate normally. The absorptivity is twice the transmissivity and thrice the reflectivity. Determine the rate of absorption, transmission and reflection of energy.

Solution : From an energy balance,

$$\alpha + \rho + \tau = 1$$

$$\text{or } \alpha + \frac{\alpha}{2} + \frac{\alpha}{3} = 1 \; ; \quad \alpha = 0.5455$$

$\therefore$ Absorption Q_a

$$= \alpha Q_0$$

$$= 0.5455 \times 800$$

$$= \mathbf{436.40} \text{ W/m}^2$$

Transmission Q_t

$$= \tau Q_0$$

$$= \frac{0.5455}{3} \times 800$$

$$= \mathbf{145.47} \text{ W/m}^2$$

Reflection Q_r

$$= \rho Q_0$$

$$= \frac{0.5455}{2} \times 800$$

$$= \mathbf{218.20} \text{ W/m}^2$$

Problem :

A furnace having inside temperature of 2250 K has a glass circular viewing of 6 cm diameter. If the transmissivity of glass is 0.08, make calculations for the heat loss from the glass window due to radiation.

Solution : The radiation heat loss from the glass window is given by

$$Q = \sigma_b A T^4 \times \tau$$

where τ is the transmissivity of glass

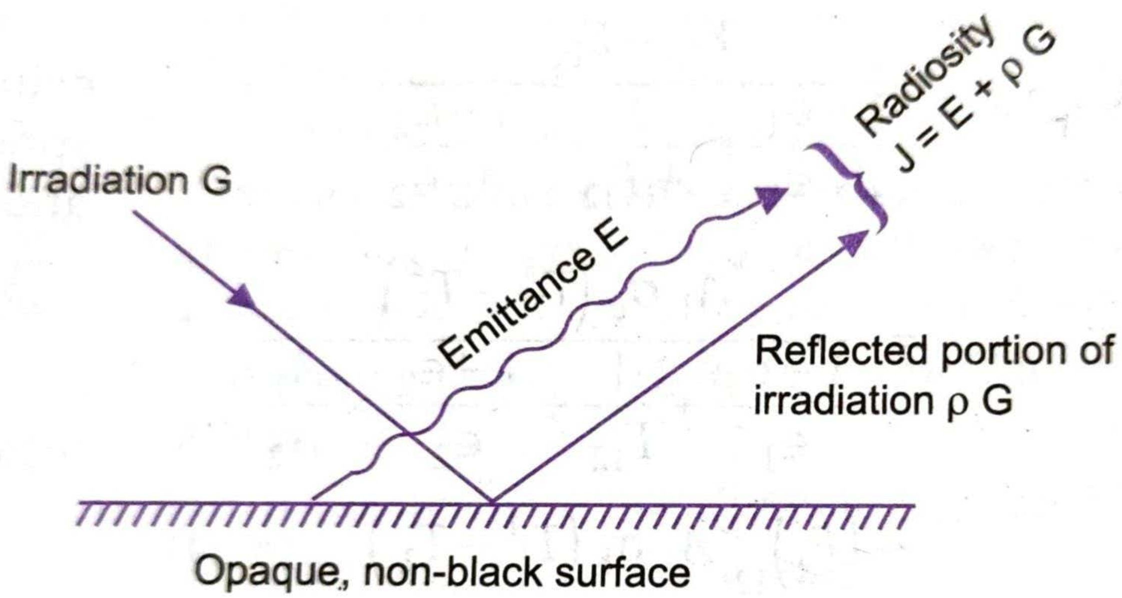
$$Q = 5.67 \times 10^{-8} \times \frac{\pi}{4} (0.06)^2 \times 2250^4 \times 0.08$$

$$= 328.53 \text{ W}$$

Q. Write short notes on Radiosity and Irradiation .

Ans : • **Radiosity** (J) indicates the total radiant energy leaving a surface per unit time per unit surface area. It comprises the original emittance from the surface plus the reflected portion of any radiation incident upon it.

• **Irradiaton** (G) denotes the total radiant energy incident upon a surface per unit time per unit area; some of it may be reflected to become a part of the radiosity of the surface.



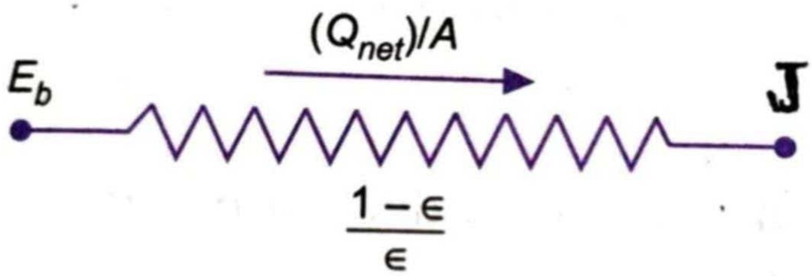
For an opaque non-black surface of constant radiation characteristics, the total radiant energy (J) leaving the surface is the sum of its original emittance (E) and the energy reflected (ρG) by it out of the irradiation (G) impinging on it. Hence

$$J = E + \rho G = \epsilon E_b + \rho G$$

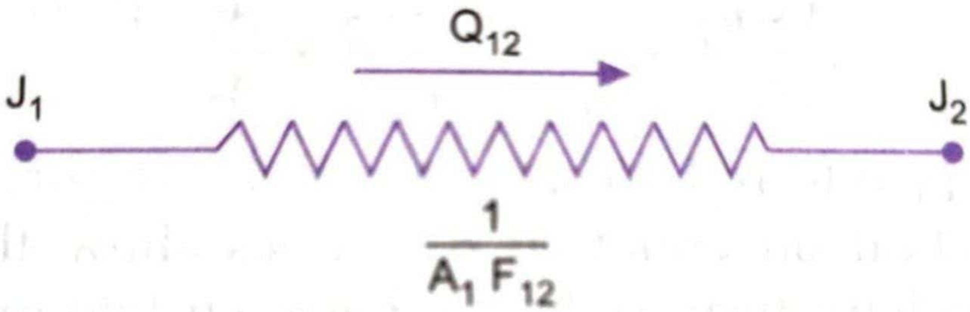
where E_b is the emissive power of a perfect black body at the same temperature.

Q. Define 'surface resistance ' and ' space resistance ' .

Surface resistance:: The term or factor $\left(\frac{1-\varepsilon}{A\varepsilon}\right)$ related to the surface properties of the radiating body is called Surface resistance to radiation heat transfer.



Space resistance: The term or factor $\left(\frac{1}{A_1F_{12}}\right)$ is called 'space resistance' and it is due to the distance betn the geometry of the radiating surfaces or bodies.



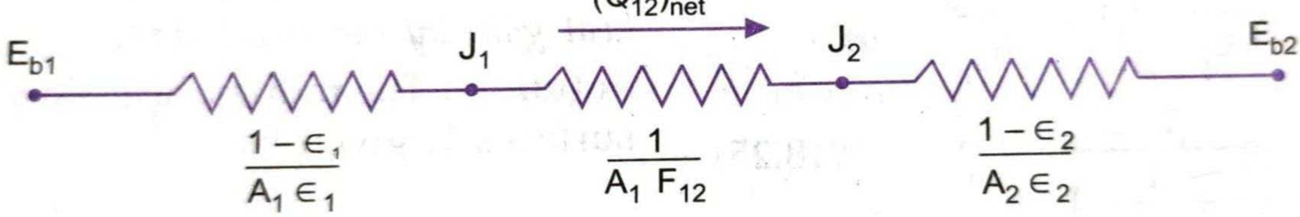


Fig. -- Electrical network representing space and surface resistance to radiation

Bijan Kumar Giri

1. What is the difference between diffusion and radiation heat transfer ?

Diffusion heat transfer is due to random molecular motion. Neighboring molecules move randomly and transfer energy between one another - however there is no bulk motion. Radiation heat transfer, on the other hand, is the transport of heat energy by electromagnetic waves. All bodies emit thermal radiation. In particular, notice that unlike diffusion, radiation heat transfer does not require a medium and is thus the only mode of heat transfer in space. The time scale for radiative heat transfer is much smaller than diffusive heat transfer.

2.Define a black surface

A black surface is defined by three criteria:

- it absorbs all radiation that is incident on it
- it emits the maximum energy possible for a given temperature and wavelength of radiation (according to Planck's law)
- the radiation emitted by a blackbody is not directional (it is a diffuse emitter)

A black surface is the perfect emitter and absorber of radiation. It is an idealized concept (no surface is exactly a black surface), and the characteristics of real surfaces are compared to that of an ideal black surface.

3.What is the range of values for the emissivity of a surface ?

The emissivity ε ranges between 0 and 1.

4.What are the conditions to be satisfied for the application of a thermal circuit ?

he problem must be a steady state, one-dimensional heat transfer problem.

5. What is a gray surface ?

.A Gray surface is defined as one for which the emissivity (ε) and the absorptivity (α) are independent of wavelength (λ).

6. What is a diffuse surface ?

A diffuse surface is defined as one for which the emissivity (ε) and the absorptivity (α) are independent of direction (θ).

7. If a surface emits 200 W at a temperature of T, how much energy will it emit at a temperature of 2T ?

Since $E \propto T^4$, a 2-fold increase of temperature brings a (2^4) = 16-fold increase in energy. Thus the surface will emit (16)(200) = 3200 W.

8. A greenhouse has an enclosure that has a high transmissivity at short wavelengths and a very low transmissivity (almost opaque) for high wavelengths. Why does a greenhouse get warmer than the surrounding air during clear days ? Will it have a similar effect during clear nights ?

Solar radiation is skewed towards shorter wavelengths. On a clear day the glass of the greenhouse admits a large proportion of the incident radiation. Inside the greenhouse, the various surfaces (plants etc.) reflect the radiation; but the reflected radiation is spectrally different, having more of a high wavelength contribution. Thus the reflected radiation is not transmitted well by the glass, and is reflected back into the greenhouse. The interior heats up due to this 'trapped' radiation. The same effect will not be seen on a clear night, since there is no solar radiation.

Example 12.21. *A hot ingot casting 25 cm (length) × 25 cm (width) × 1.8 m (height) at a temperature of 1200 K is stripped from its mould. The casting is made to stand on the end on the floor of a large foundry whose wall, floor and roof can be assumed to be at 290 K temperature. If the emissivity of casting material is 0.8, calculate the net heat exchange between the casting and the room.*

Solution. The rate of radiant heat exchange between the ingot and the room is given by

$$Q_{12} = (F_g)_{1-2} A_1 \sigma (T_1^4 - T_2^4)$$

where, A_1 = Area of the ingot = (0.25 × 0.25) + 4 × 0.25 × 1.8 = 1.8625 m^2

The configuration corresponds to a completely enclosed body, and small compared with the enclosing body, *i.e.* $A_1 << A_2$ and $F_{1-2} = 1$. Hence

$$(F_g)_{1-2} = \frac{1}{\left(\frac{1-\varepsilon_1}{\varepsilon_1}\right) + \frac{1}{F_{1-2}} + \left(\frac{1-\varepsilon_2}{\varepsilon_2}\right)\frac{A_1}{A_2}} = \frac{1}{\frac{1-\varepsilon_1}{\varepsilon_1} + 1 + 0} = \varepsilon_1 = 0.8$$

$$\therefore \quad Q_{12} = 0.8 \times 1.8625 \times 5.67 \left[\left(\frac{1200}{100}\right)^4 - \left(\frac{290}{100}\right)^4\right]$$

$$= 174586 \text{ W or } \mathbf{174.586\ kW\ (Ans.)}$$

LONG TYPE QUESTIONS & ANSWERS

ON

RADIATION HEAT TRANSFER

Bijan Kumar Giri

Problem :

A gray surface has an emissivity $\in = 0.35$ at a temperature of 550 K source. If the surface is opaque, calculate its reflectivity for a black body radiation coming from a 550 K source.

(b) A small 25 mm square hole is made in the thin-walled door of a furnace whose inside walls are at 920 K. If the emissivity of the walls is 0.72, calculate the rate at which radiant energy escapes from the furnace through the hole to the room.

Solution : The requirement that all of the radiant energy striking any surface may be accounted for is :

$$\alpha + \rho + \tau = 1$$

Here :

(*i*) $\tau = 0$ as the surface is opaque

(*ii*) $\alpha = \in = 0.35$

This is in accordance with Kirchoff's law which states that absorptivity equals emissivity under the same temperature conditions.

$\therefore$ Reflectivity ρ

$$= 1 - (\alpha + \tau)$$

$$= 1 - (0.35 + 0) = 0.65$$

Thus the surface reflects 65 percent of incident energy coming from a source at 550 K.

(*b*) The small hole acts as a black body and accordingly the rate at which radiant energy leaves the hole is

$$E = \sigma_b\, AT^4$$

$$= 5.67 \times 10^{-8} \times (0.025 \times 0.025) \times 920^4$$

$$= 25.38 \text{ watts}$$

Note: The data about the emissivity of the inside wall is not needed.

Problem :

Measurements were made of the monochromatic absorptivity and monochromatic hemispherical irradiation incident on an opaque surface, and the variation of these parameters with wavelength may be approximated by the results shown in Fig. 7.8. Determine the absorbed radiant flux, the total hemispherical absorptivity and the total reflectivity of the surface.

Solution : Incident flux

$$= 800\,(8-2) = 4800\ \text{W/m}^2$$

Absorbed radiant flux

$$= \int_0^\infty \alpha_\lambda E_\lambda \, d\lambda$$

$$= \int_2^4 (1\times 800)\,d\lambda + \int_4^8 (0.5\times 800)\,d\lambda$$

$$= 800\,(4-2) + 400\,(8-4)$$

$$= 3200\ \text{W/m}^2$$

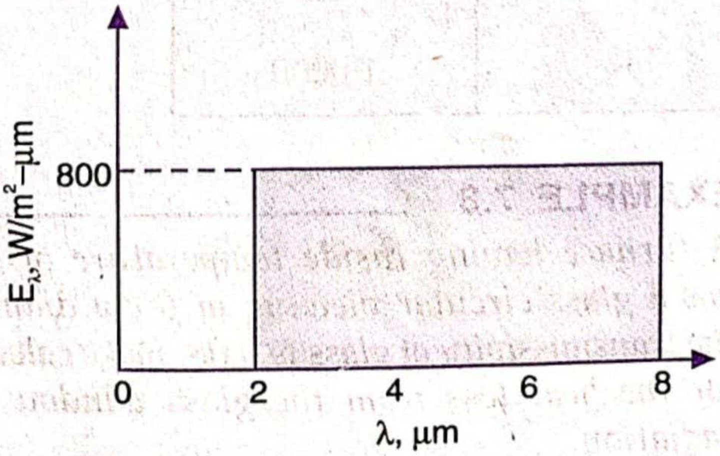
$\therefore$ Absorptivity α

$$= 3200/4800 = 0.667$$

The requirement that all the radiant energy striking any surface may be accounted for is

$$\sigma + \tau + \rho = 1$$

Here, $\tau = 0$ as the surface is opaque and therefore reflectivity of the surface is



$$\rho = 1 - \alpha$$

$$= 1 - 0.667 = 0.333$$

Example 11.1. *The effective temperature of a body having an area of 0.12 m^2 is 527°C. Calculate the following:*

(i) The total rate of energy emission,

(ii) The intensity of normal radiation, and

Solution. *Given:* $A = 0.12\ m^2$; $T = 527 + 273 = 800\ K$

(i) The total rate of energy emission, E_b:

$$E_b = \sigma A T^4 \text{ W (watts)}$$

$$= 5.67 \times 10^{-8} \times 0.12 \times (800)^4 = 5.67 \times 0.12 \times \left(\frac{800}{100}\right)^4 = \mathbf{2786.9\ W\ (Ans.)}$$

(ii) The intensity of normal radiation, I_{bn} :

$$I_{bn} = \frac{E_b}{\pi}, \quad \text{where } E_b \text{ is in W/m}^2 K^4$$

$$= \frac{\sigma T^4}{\pi} = \frac{5.67 \times \left(\frac{800}{100}\right)^4}{\pi} = \mathbf{7392.5\ W/m^2.sr\ \ (Ans.)}$$

(iii) The wavelength of maximum monochromatic emissive power, l_{max} :

From Wien's displacement law,

$$\lambda_{max} T = 2898\ \mu mK$$

or,

$$\lambda_{max} = \frac{2898}{T} = \frac{2898}{800} = \mathbf{3.622\,\mu m\ \ (Ans.)}$$

Example 11.2. *Assuming the sun to be a black body emitting radiation with maximum intensity at $\lambda = 0.49\ \mu m$, calculate the following :*

(i) The surface temperature of the sun, and

(ii) The heat flux at surface of the sun.

Solution. *Given:* $l_{max} = 0.49\ \mu m$

(i) The surface temperature of the sun, T:

According to Wien's displacement law,

$$\lambda_{max} T = 2898\ \mu mK$$

$\therefore$

$$T = \frac{2898}{\lambda_{max}} = \frac{2898}{0.48} = \mathbf{5914\ K\ \ (Ans.)}$$

(ii) The heat flux at the surface of the sun, $(E)_{sun}$:

$$(E)_{sun} = \sigma T^4 = 5.67 \times 10^{-8}\ T^4 = 5.67\left(\frac{T}{100}\right)^4$$

$$= 5.67 \times \left(\frac{5914}{100}\right)^4 = \mathbf{6.936 \times 10^7\ W/m^2\ (Ans.)}$$

Example 11.3. *Calculate the following for an industrial furnace in the form of a black body and emitting radiation at 2500°*C :

(i) Monochromatic emissive power at 1.2 μm length,

(ii) Wavelength at which the emission is maximum,

(iii) Maximum emissive power,

(iv) Total emissive power, and

(v) Total emissive power of the furnace if it is assumed as a real surface with emissivity equal to 0.9.

Solution. *Given* : $T = 2500 + 273 = 2773K$; $\lambda = 1.2\ \mu m$, $\varepsilon = 0.9$

(i) Monochromatic emissive power at 1.2 μm length, $(E_\lambda)_b$:

According to Planck's law,

$$(E_\lambda)_b = \frac{C_1 \lambda^{-5}}{\exp\left(\frac{C_2}{\lambda T}\right) - 1}$$

where, $C_1 = 3.742 \times 10^8$ W.μm^4/m^2 = 0.3742×10^{-15} W.m^4/m^2, and

$C_2 = 1.4388 \times 10^{-2}$ mK

Substituting the values, we get

$$(E_\lambda)_b = \frac{0.3742 \times 10^{-15} \times (1.2 \times 10^{-6})^{-5}}{\exp\left(\frac{1.4388 \times 10^{-2}}{1.2 \times 10^{-6} \times 2773}\right) - 1} = \frac{1.5 \times 10^{14}}{74.48} = \mathbf{2.014 \times 10^{12}\ W/m^2\ (Ans.)}$$

(*ii*) Wavelength at which the emission is maximum, λ_{max}:

Accodrding to Wien's displacement law,

$$\lambda_{max} = \frac{2898}{T} = \frac{2898}{2773} = \mathbf{1.045\ \mu m\ \ (Ans.)}$$

(*iii*) Maximum emissive power, $(E_{\lambda b})$max:

$$(E_{\lambda b})_{\max} = 1.285 \times 10^{-5}\, T^5 \text{ W/m}^2 \text{ per metre length} \qquad \text{[Eqn. (11.19)]}$$

$$= 1.285 \times 10^{-5} \times (2773)^5 = \mathbf{2.1 \times 10^{12}\ W/m^2\ per\ metre\ length\ (Ans.)}$$

[**Note:** At high temperature the difference between $(E_\lambda)_b$ and $(E_{\lambda b})_{max}$ is very small].

(*iv*) Total emissive power, E_b :

$$E_b = \sigma T^4 = 5.67 \times 10^{-8} (2773)^4 = 5.67\left(\frac{2773}{100}\right)^4 = \mathbf{3.352 \times 10^6\ W/m^2.\ (Ans.)}$$

(*v*) Total emissive power, E with emissivity (ε) = 0.9 :

$$E = \varepsilon\, \sigma T^4 = 0.9 \times 5.67 \left(\frac{2773}{100}\right)^4 = \mathbf{3.017 \times 10^6\ W/m^2.\ (Ans.)}$$

SHAPE FACTOR ALGEBRA AND SALIENT FEATURES OF THE SHAPE FACTOR

In order to compute the shape factor for certain geometric arrangements for which shape factors or equations are not available, the concept of shape factor as fraction of intercepted energy, and reciprocity theorem can be used. The shape factors for these geometries can be derived in terms of *known shape factors of other geometries. The interrelation between various factors is called* **shape factor algebra.**

For the calculation of shape factors for specific geometries and for the analysis of radiant heat exchange between surfaces, the following facts and properties will be useful:

1. The shape factor is purely a function of geometric parameters only.
2. When two bodies are exchanging radiant energy with each other, the shape factor relation is given by the eqn. (12.12) *i.e.*,

   $$A_1 F_{1-2} = A_2 F_{2-1}$$

   In general, $A_i F_{i-j} = A_j F_{j-I}$ ...(Reciprocity theorem)

   This reciprocal relation is particularly useful when one of the shape factors is *unity.*
3. When all the radiation emanating from a *convex surface* 1 is intercepted by the enclosing surface 2, the *shape factor of convex surface with respect to the enclosure F_{1-2} is unity.* Then in conformity with reciprocity theorem, the shape factor F_{2-1} is merely the ratio of areas.

   [*i.e.*, when surface A_1 is *entirely convex*, say a sphere, completely enclosed by A_2, then according to reciprocity relation, we have

   $$A_1 F_{1-2} = A_2 F_{2-1} \quad \text{and} \quad A_1 = A_2 F_{2-1}$$

   ($\because F_{1-2} = 1$, as surface 1 completely sees surface 2)

   or $$F_{2-1} = \frac{A_1}{A_2}$$ (*i.e.*, ratio of areas), and $F_{2-1} + F_{2-2} = 1$

   In this case, the black body radiation exchange is

   $$Q_{12} = A_1 \sigma (T_1^4 - T_2^4)$$]
4. A *concave surface* has a shape factor with itself because the radiant energy coming out from one part of the surface is intercepted by the another part of the same surface. *The shape factor of a surface with respect to itself is F_{1-1}.*
5. For *a flat or convex surface, the shape factor with respect to itself is zero* (*i.e.*, $F_{1-1} = 0$). This is due to the fact that for any part of flat or convex surface, one *cannot see/view any other part of the same surface.*

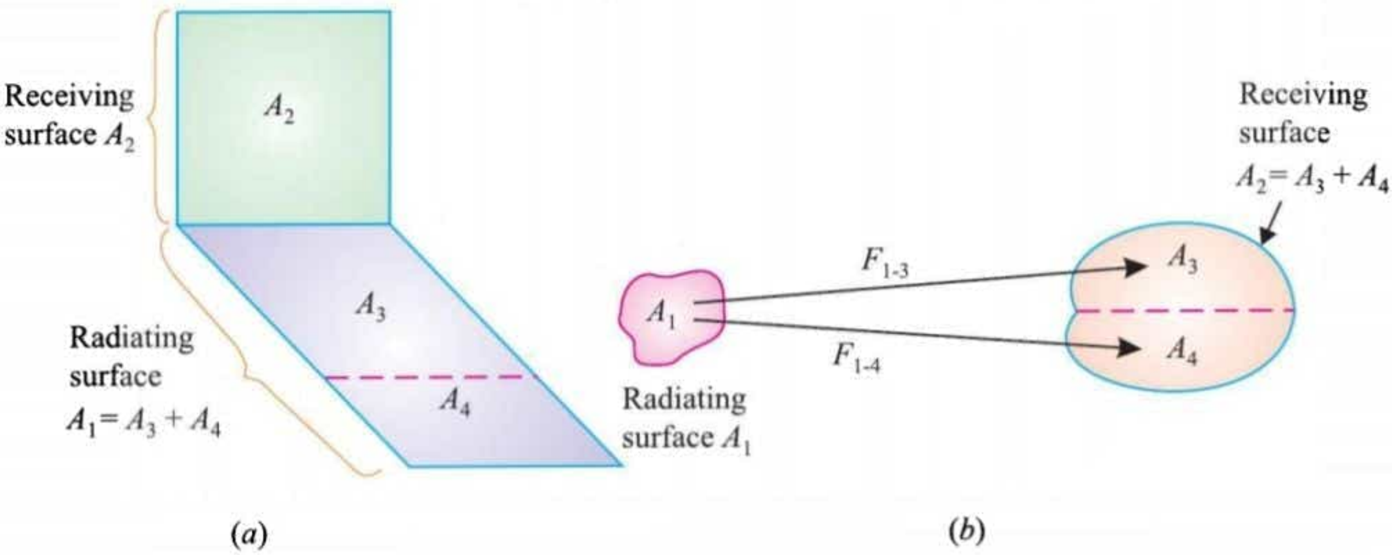


Fig. 12.5. Relation between shape factors.

6. If two surfaces A_1 and A_2 are parallel and large, radiation occurs across the gap between them so that $A_1 = A_2$ and all radiation emitted by one falls on the other; then

$$F_{1-2} = F_{2-1} = 1$$

7. If one of the two surfaces (say A_i) is divided into sub-areas A_{i1}, A_{i2}, ... A_{in}, then

$$A_i F_{i-j} = \sum A_{in} F_{in-j} \qquad \text{...(12.15)}$$

Refer to Fig. 12.5 (a) : Radiating surface A_1 has been split up into areas A_3 and A_4; we have

$$A_1 F_{1-2} = A_3 F_{3-2} + A_4 F_{4-2}$$

Evidently, $$F_{1-2} \neq F_{3-2} + F_{4-2}$$

Thus if the radiant surface is subdivided, the shape factor for that surface with respect to the receiving surface is *not equal to the sum* of the individual shape factors.

Refer to Fig. 12.5 (b): Receiving surface A_2 has been divided into subareas A_3 and A_4; we have

$$A_1 F_{1-2} = A_1 F_{1-3} + A_1 F_{1-4}$$

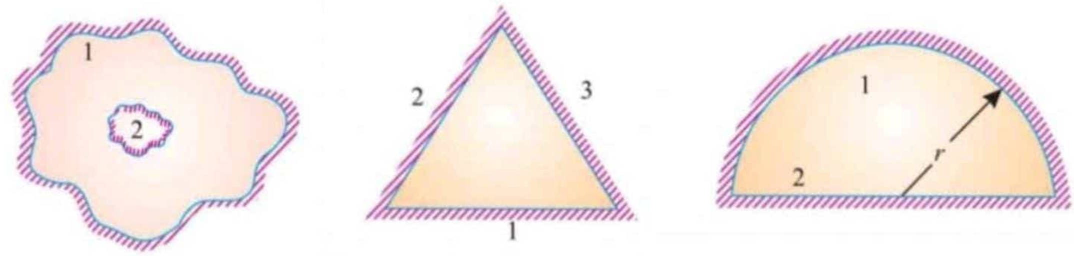
or $$F_{1-2} = F_{1-3} + F_{1-4}$$

Obviously the shape factor from a radiating surface to a subdivided receiving surface is simply the *sum of individual shape factors*.

Example 12.2. *Calculate the shape factors for the configurations shown in the Fig. 12.7.*

Solution. The shape factors can be worked out by using *summation rule*, the *reciprocity theorem* and from the *inspection of geometry.*

(*i*) *A black body inside a black enclosure:*



A black body inside a black enclosure (*i*) — A tube with cross-section of an equilateral triangle (*ii*) — Hemispherical surface and a plane surface (*iii*)

Fig. 12.7

$$F_{2-1} = 1$$ ...Because all radiation emanating from the black surface is intercepted by the enclosing surface 1.

$$F_{1-1} + F_{1-2} = 1$$ ... By *summation rule* for radiation from surface 1

$$A_1 F_{1-2} = A_2 F_{2-1}$$ ... By *reciprocity theorem*

or, $$F_{1-2} = \frac{A_2}{A_1} F_{2-1}$$

∴ $$F_{1-1} = 1 - F_{1-2} = 1 - \frac{A_2}{A_1} F_{2-1} = 1 - \frac{A_2}{A_1} \quad (\because F_{2-1} = 1)$$

Hence, $$F_{1-1} = \mathbf{1 - \frac{A_2}{A_1}} \text{ (Ans.)}$$

(*ii*) *A tube with cross-section of an equilateral triangle:*

$$F_{1-1} + F_{1-2} + F_{1-3} = 1$$ ... By summation rule

$$F_{1-1} = 0$$ ... Because the flat surface 1 *cannot see itself.*

∴ $$F_{1-2} + F_{1-3} = 1$$

$$F_{1-2} = F_{1-3} = \mathbf{0.5} \text{ (Ans.)}$$ ... By symmetry

Similarly, considering radiation from surface 2 :

$$F_{2-1} + F_{2-2} + F_{2-3} = 1$$

or, $$F_{2-1} + F_{2-3} = 1 \quad (\because F_{2-2} = 0)$$

or, $$F_{2-3} = 1 - F_{2-1}$$

$$A_1 F_{1-2} = A_2 F_{2-1}$$ ... By reciprocity theorem

or, $$F_{2-1} = \frac{A_1}{A_2} F_{1-2} = F_{1-2} \quad (\because A_1 = A_2)$$

∴ $$F_{2-3} = 1 - F_{1-2} = 1 - 0.5 = \mathbf{0.5} \text{ (Ans.)}$$

(*iii*) *Hemispherical surface and a plane surface:*

$$F_{1-1} + F_{1-2} = 1$$ ... By summation rule

$$A_1 F_{1-2} = A_2 F_{2-1}$$ ... By reciprocity theorem

or, $$F_{1-2} = \frac{A_2}{A_1} F_{2-1}$$

But, $$F_{2-1} = 1$$ ... Because all radiation emanating from the black surface 2 are interecpted by the enclosing surface 1.

∴ $$F_{1-2} = \frac{A_2}{A_1} = \frac{\pi r^2}{2 \pi r^2} = \mathbf{0.5} \text{ (Ans.)}$$

Thus in case of a hemispherical surface half the radiation falls on surface 2 and the other half is intercepted by the hemisphere itself.

Table : Geometric (F_{1-2}) and interchange (f_{1-2}) factors

S.No.	Configuration	Geometric factor (F_{1-2})	Interchange factor (f_{1-2})
1.	Infinite parallel planes	1	$\dfrac{1}{\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_2}-1}$
2.	Infinitely long concentric cylinders or concentric spheres	1	$\dfrac{1}{\dfrac{1}{\varepsilon_1}+\dfrac{A_1}{A_2}\left(\dfrac{1}{\varepsilon_2}-1\right)}$
3.	Body 1 (small) enclosed by body 2	1	ε_1
4.	Body 1(large) enclosed by body 2	1	$\dfrac{1}{\dfrac{1}{\varepsilon_1}+\dfrac{A_1}{A_2}\left(\dfrac{1}{\varepsilon_2}-1\right)}$
5.	Two rectangles with common side at right angles to each other	1	$\varepsilon_1\varepsilon_2$

Example 12.18. A *refractory material which has ε = 0.4 at 1500 K and ε = 0.43 at 1420 K is exposed to black furnace walls at 1500 K. What is the rate of gain of heat radiation per* m^2 *area?* **(M.U.)**

Solution. Taking the mean temperature and mean emissivity of the heated body, we get

$$T_2 = \frac{1420 + 1500}{2} = 1460 \text{ K}$$

$$\varepsilon_2 = \frac{0.40 + 0.43}{2} = 0.415$$

Now using the formula for parallel walls, we have

$$q = \frac{\sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} = \frac{5.67\left[\left(\frac{1500}{100}\right)^4 - \left(\frac{1460}{100}\right)^4\right]}{\frac{1}{1} + \frac{1}{0.415} - 1}$$

$$= 0.415 \times 5.67\,(15^4 - 14.6^4) = 12207 \text{ W/m}^2 = \mathbf{12.2\ kW/m^2\ (Ans.)}$$

Example 12.19. *Determine the rate of heat loss by radiation from a steel tube of outside diameter 70 mm and 3 m long at a temperature of 227° C if the tube is located within a square brick conduit of 0.3 m side and at 27° C. Take ε (steel) = 0.79 and ε (brick) = 0.93.* **(AMIE Summer, 1999; P.U., 1998)**

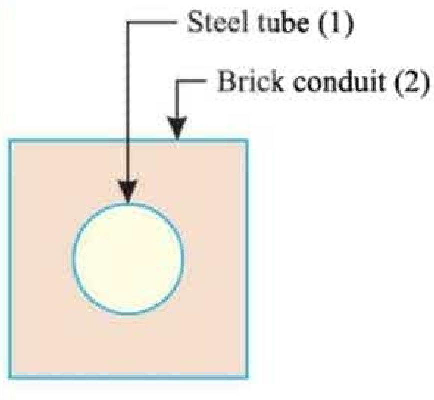


Fig. 12.31

Solution. *Given* : $d = 70$ mm $= 0.07$ m, $L = 3$m;

$T_1 = 227 + 273 = 500$ K;

$T_2 = 27 + 273 = 300$ K; $\varepsilon_1 = 0.79$; $\varepsilon_2 = 0.93$.

The rate of heat loss, Q:

The heat transfer is given by

$$Q = \frac{A_1 \sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \left(\frac{1}{\varepsilon_2} - 1\right)\frac{A_1}{A_2}} \qquad \text{...(Eqn.12.24)}$$

Now, $$\frac{A_1}{A_2} = \frac{\pi\, d\, L}{P.L} = \frac{\pi \times 0.07}{4 \times 0.3} = 0.183$$

Substituting the values in the above equation, we get

$$Q = \frac{(\pi \times 0.07 \times 3) \times 5.67\left[\left(\frac{500}{100}\right)^4 - \left(\frac{300}{100}\right)^4\right]}{\frac{1}{0.79} + \left(\frac{1}{0.93} - 1\right) \times 0.183}$$

$$= \frac{3.74\,(625 - 81)}{1.266 + 0.0138} = \mathbf{1589.7\ W\ (Ans.)}$$

Example 12.3. *Explain the meaning of the term geometric factor in relation to heat exchange by radiation. Derive an expression for the geometric factor F_{11} for the inside surface of a black hemispherical cavity of radius R with respect to itself.* **(U.P.S.C., 1994)**

Solution. • **Geometric factor** *is defined as the fraction of radiative energy that is diffused from one surface element and strikes the other surface directly with no intervening reflection.*

- The *geometric factor* depends only on the *specific geometry of the emitter and the collection surfaces.*
- The geometric factor is represented by the symbol F_{i-j} which means the shape factor from a surface A_i to another surface A_j. Thus, the geometric factor F_{1-2} of surface A_1 to surface A_2 is

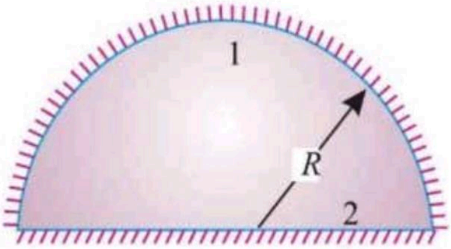


Fig. 12.8

$$F_{1-2} = \frac{\text{Direct radiation from surface 1 incident upon surface 2}}{\text{Total radiation from emitting surface}}$$

Geometric factor F_{1-1} for the inside surface of a black hemispherical cavity of radius R with respect to itself.

$$F_{1-1} = 1 - \frac{A_2}{A_1} = 1 - \frac{\pi R^2}{2\pi R^2} = 1 - \frac{1}{2} = \mathbf{0.5\ (Ans.)}$$

Example 12.31. *For a hemispherical furnace, the flat floor is at 700 K and has an emissivity of 0.5. The hemispherical roof is at 1000 K and has emissivity of 0.25. Find the net radiative heat transfer from roof to floor.*

Solution : *Given :* $T_1 = 700$ K; $\varepsilon_1 = 0.5$; $T_2 = 1000$ K; $\varepsilon_2 = 0.25$

Q_{12} (from floor to roof)

$$= \frac{A_1\, \sigma\, (T_1^4 - T_2^4)}{\left(\frac{1-\varepsilon_1}{\varepsilon_1}\right) + \frac{1}{F_{1-2}} + \left(\frac{1-\varepsilon_2}{\varepsilon_2}\right)\frac{A_1}{A_2}}$$

In this case $A_1 = \pi r^2$ and $A_2 = \frac{4\pi r^2}{2} = 2\pi r^2$

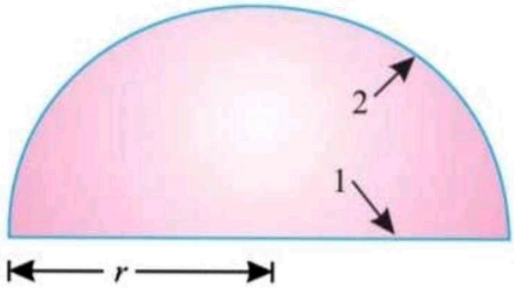


Fig. 12.38. Hemispherical furnace.

$$\therefore \qquad \frac{A_1}{A_2} = \frac{\pi r^2}{2\pi r^2} = 0.5,\ F_{1-2} = 1$$

$$\therefore \qquad Q_{12} = \frac{1 \times 5.67\left[\left(\frac{700}{100}\right)^4 - \left(\frac{1000}{100}\right)^4\right]}{\left(\frac{1-0.5}{0.5}\right) + 1 + \left(\frac{1-0.25}{0.25}\right) \times 0.5}\ \text{W/m}^2$$

$$= \frac{1 \times 5.67\ (2401 - 10000)}{3.5} = -\ 12310.4\ \text{W/m}^2$$

The –ve sign indicates that *floor gains the heat.*

$$\therefore \qquad \mathbf{Q_{12} = 12310.4\ W/m^2\ (Gain)\ (Ans.)}$$

Problem :

Determine the radiation heat flux between two closely spaced, black parallel plates radiating only to each other if their temperatures are 850 K and 425 K respectively. Recalculate the heat flux presuming that each of the parallel plates has an emissivity of 0.5. In each case, the plates have an area of 4 m^2.

Solution : The configuration factor F_{12} considers the orientation and geometry of the black radiatiing surfaces; how the two surfaces view each other and to what extent the two surfaces radiate solely to each other. The interchange factor f_{12} allows for the departure of the two surfaces from complete blackness; a function of the emissivities of the two surfaces.

For the black parallel plates radiating only to each other, F_{12} = 1 and then the radiant heat exchange is :

$$Q_{12} = F_{12} A_1 \sigma_b \left(T_1^4 - T_2^4\right)$$

$$= 1 \times 4 \times (5.67 \times 10^{-8}) \times (850^4 - 425^4)$$

$$= 10 \times 10^{-3} \text{ W}$$

For the gray surfaces, the heat exchange is :

$$Q_{12} = (F_g)_{12} A_1 \sigma_b \left(T_1^4 - T_2^4\right)$$

The gray body factor $(F_g)_{12}$ is equal to

$$(F_g)_{12} = \frac{1}{\dfrac{1-\epsilon_1}{\epsilon_1} + \dfrac{1}{F_{12}} + \dfrac{1-\epsilon_2}{\epsilon_1} \times \dfrac{A_1}{A_2}}$$

For the given configuration of parallel plates which see each other and nothing else, $F_{12} = 1$ and $A_1 = A_2$

$$(F_g)_{12} = \frac{1}{\dfrac{1-\epsilon_1}{\epsilon_1} + 1 + \dfrac{1-\epsilon_2}{\epsilon_2}}$$

$$= \frac{1}{\dfrac{1}{\epsilon_1} + \dfrac{1}{\epsilon_2} - 1}$$

$$= \frac{1}{\dfrac{1}{0.5} + \dfrac{1}{0.5} - 1} = 0.333$$

and $Q_{12} = 0.333 \times 4 \times (5.67 \times 10^{-8}) \times (850^4 - 425^4)$

$$= 37 \times 10^{-3} \text{ W}$$

It may be noted that if the emissivity of each plate is one-half of a black body, heat flux is reduced by a factor of 3.

Example 12.24. *Calculate the heat transfer rate per m² area by radiation between the surfaces of two long cylinders having radii 100 mm and 50 mm respectively. The smaller cylinder being in the larger cylinder. The axes of the cylinders are parallel to each other and separated by a distance of 20 mm. The surfaces of inner and outer cylinders are maintained at 127° C and 27° C respectively. The emissivity of both the surfaces is 0.5.*

Assume the medium between the two cylinders is non-absorbing. **(P.U.)**

Solution. *Given*: $r_1 = 50$ mm $= 0.05$ m; $r_2 = 100$ mm $= 0.1$ m, $T_1 = 127 + 273 = 400$ K, $T_2 = 27 + 273 = 300$ K, $\varepsilon_1 = \varepsilon_2 = 0.5$.

The heat transfer between two concentric or eccentric cylinders is given by

$$(Q_{12})_{net} = \frac{A_1\,\sigma\,(T_1^4 - T_2^4)}{\left(\dfrac{1-\varepsilon_1}{\varepsilon_1}\right) + \dfrac{1}{F_{1-2}} + \left(\dfrac{1-\varepsilon_2}{\varepsilon_2}\right)\dfrac{A_1}{A_2}}$$

Here $\quad F_{1-2} = 1$ and $\dfrac{A_1}{A_2} = \dfrac{2\,\pi\,r_1\,L}{2\,\pi\,r_2\,L} = \dfrac{r_1}{r_2}$

Substituting the values, we have

$$(Q_{12})_{net} = \frac{1 \times 5.67\left[\left(\dfrac{400}{100}\right)^4 - \left(\dfrac{300}{100}\right)^4\right]}{\left(\dfrac{1-0.5}{0.5}\right) + 1 + \left(\dfrac{1-0.5}{0.5}\right)\times\dfrac{0.05}{0.1}} = \frac{992.25}{2.5} = \mathbf{396.9\ W/m^2\ (Ans.)}$$

Example 12.25. *A long cylindrical heater 25 mm in diameter is maintained at 660° C and has surface resistivity of 0.8. The heater is located in a large room whose walls are at 27° C. How much will the radiant heat transfer from the heater be reduced if it is surrounded by a 300 mm diameter radiation shield of aluminium haivng an emissivity of 0.2? What is the temperature of the shield?* **(M.U.)**

Solution. *Given:* $r_1 = \dfrac{25}{2} = 12.5$ mm $= 0.0125$ m; $r_3 = \dfrac{300}{2} = 150$ mm $= 0.15$ m; $T_1 = 660 + 273 = 933$ K; $T_2 = 27 + 273 = 300$ K; $\varepsilon_1 = 0.8$, ε_3 (shield) $= 0.2$.

Considering L is the length of the heater, the heat lost by the heater to the room is given by

$$Q = A_1\,\varepsilon_1\,\sigma\,[T_1^4 - T_2^4] \qquad ...(i)$$

where suffix '1' belongs to heater and T_2 is the room wall temperature.

$$\therefore \qquad Q = 2\,\pi\,r_1\,L \times 0.8 \times 5.67\left[\left(\frac{933}{100}\right)^4 - \left(\frac{300}{100}\right)^4\right]$$

$$= 2\,\pi \times 0.0125\,L \times 0.8 \times 5.67\,(9.33^4 - 3^4) = 0.356\,L\,(7577.5 - 81)$$

or, $$q' = \frac{Q'}{L} = 0.356\,(7577.5 - 81) = 2668.7\ \text{W} \simeq 2.67\ \text{kW/m}$$

When the cylinder is enclosed in a radiation shield then the heat flow is given by

$$Q' = \frac{A_1\,\sigma\,(T_1^4 - T_3^4)}{\dfrac{1}{\varepsilon_1} + \left(\dfrac{1}{\varepsilon_3} - 1\right)\dfrac{r_1}{r_3}} = A_3\,\varepsilon_3\,\sigma\,(T_3^4 - T_2^4)$$

as heat lost by heater to shield is further lost by shield to the room, where suffix 3′ belongs to shield.

$$q' = \frac{Q'}{L} = \frac{2\,\pi\,r_1\,\sigma\,(T_1^4 - T_3^4)}{\dfrac{1}{\varepsilon_1} + \left(\dfrac{1}{\varepsilon_3} - 1\right)\dfrac{r_1}{r_3}} = \frac{2\,\pi\,r_3\,\sigma\,(T_3^4 - T_2^4)}{\dfrac{1}{\varepsilon_3}} \qquad ...(ii)$$

From the above equation, first we have to find out the value of T_3

$$\frac{r_1\,(T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1} + \left(\frac{1}{\varepsilon_3} - 1\right)\frac{r_1}{r_3}} = \frac{r_3\,(T_3^4 - T_2^4)}{\frac{1}{\varepsilon_3}}$$

Now substituting the given values in the above equation, we get

$$\frac{0.0125\,(933^4 - T_3^4)}{\frac{1}{0.8} + \left(\frac{1}{0.2} - 1\right)\times\frac{0.0125}{0.15}} = \frac{0.15\,(T_3^4 - 300^4)}{\frac{1}{0.2}}$$

$$\frac{0.0125\,(933^4 - T_3^4)}{1.58} = 0.03\,(T_3^4 - 300^4)$$

or, $\quad 933^4 - T_3^4 = 3.792\,(T_3^4 - 300^4) = 3.792\,T_3^4 - 3.792\times 300^4$

or, $\quad 4.792\,T_3^4 = 933^4 + 3.792\times 300^4 = 300^4\,(3.792 + 93.55)$

or, $\quad T_3^4 = 20.3\times(300)^4$ or $T_3 = 636.8$ K or **363.8° C (Ans.)**

Substituting this value in eqn. (*ii*), we get

$$q' = \frac{2\pi\times 0.15\times 5.67\left[\left(\frac{636.8}{100}\right)^4 - \left(\frac{300}{100}\right)^4\right]}{\frac{1}{0.2}} = 1.0688\,(1644.4 - 81)$$

$$= 1670 \text{ W/m} = 1.67 \text{ kW/m}$$

∴ *Percentage reduction in heat flow*

$$= \frac{q - q'}{q}\times 100 = \frac{2.67 - 1.67}{2.67}\times 100 = \mathbf{37.45\%\ (Ans.)}$$

Example 12.29. *Determine heat lost by radiation per metre length of 80 mm diameter pipe at 300° C, if*

(*i*) *located in a large room with red brick walls at a temperature of 27° C;*

(*ii*) *enclosed in a 160 mm diameter red brick conduit at a temperature of 27° C.* **(P.U.)**

Take ε(pipe) = 0.79 and ε (brick conduit) = 0.93.

Solution. *Given:* $r_1 = \frac{80}{2} = 40 \text{ mm} = 0.04 \text{ m}$; $r_2 = \frac{160}{2} = 80 \text{ mm} = 0.08 \text{ m}$;

$$T_1 = 300 + 273 = 573 \text{ K}; T_2 = 27 + 273 = 300 \text{ K}, \varepsilon_1 = 0.79; \varepsilon_2 = 0.93.$$

The heat flow between two bodies is given by

$$Q_{12} = \frac{A_1 \sigma (T_1^4 - T_2^4)}{\left(\frac{1 - \varepsilon_1}{\varepsilon_1}\right) + \frac{1}{F_{1-2}} + \left(\frac{1 - \varepsilon_2}{\varepsilon_2}\right)\frac{A_1}{A_2}}$$

(*i*) If the pipe is located in a room, then

$$\mathbf{Q_{12}} = \frac{A_1 \sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1}} \text{ as } F_{1-2} = 1 \text{ and } \frac{A_1}{A_2} << 1$$

$$= A_1 \varepsilon_1 \sigma (T_1^4 - T_2^4)$$

$$= (2\pi \times 0.04 \times 1) \times 0.79 \times 5.67 \left[\left(\frac{573}{100}\right)^4 - \left(\frac{300}{100}\right)^4\right]$$

$$= 1.126 (1078 - 81) = \mathbf{1122.6 \text{ W/m (Ans.)}}$$

(*ii*) If the pipe is located in a conduit then,

$$F_{1-2} = 1 \text{ and } \frac{A_1}{A_2} = \frac{r_1}{r_2} = \frac{0.04}{0.08} = 0.5$$

$$\therefore \quad \mathbf{Q_{12}} = \frac{A_1 \sigma (T_1^4 - T_2^4)}{\left(\frac{1 - \varepsilon_1}{\varepsilon_1}\right) + 1 + \left(\frac{1 - \varepsilon_2}{\varepsilon_2}\right)\frac{A_1}{A_2}}$$

$$= \frac{2\pi \times 0.04 \times 1 \times 5.67 \left[\left(\frac{573}{100}\right)^4 - \left(\frac{300}{100}\right)^4\right]}{\left(\frac{1 - 0.79}{0.79}\right) + 1 + \left(\frac{1 - 0.93}{0.93}\right) \times 0.5} = \frac{1.126 (1078 - 81)}{1.303}$$

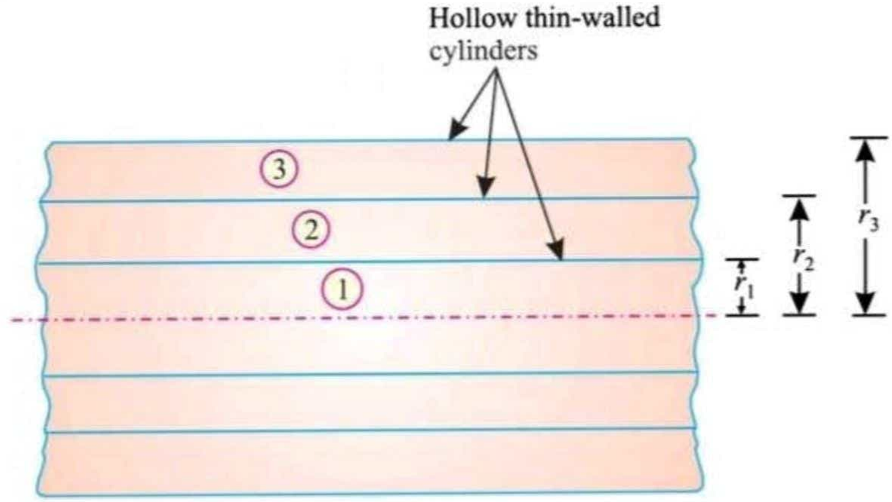
$$= \mathbf{861.5 \text{ W/m (Ans.)}}$$

Reduction in heat flow by enclosing in conduit

$$= 1122.6 - 861.5 = 261.1 \text{ W/m}$$

Example 12.27. *Three hollow thin walled cylinders having diameters 10 cm, 20 cm and 30cm are arranged concentrically. The temperatures of the innermost and outermost cylindrical surfaces are 100 K and 300 K respectively. Assuming vacuum between the annular spaces, find the steady state temperature attained by the cylindrical surface having diameter of 20 cm.*

Take $\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = 0.05$. **(M.U. 1998)**



Solution. *Given:* $r_1 = \frac{10}{2} = 5$ cm, $r_2 = \frac{20}{2} = 10$ cm, $r_3 = \frac{30}{2} = 15$ cm; $T_1 = 100$ K, $T_3 = 300$ K, $\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = 0.05$.

Temperature, T_2:

Referring to the Fig. , we can write

$$\frac{A_1\,\sigma\,(T_1^4 - T_2^4)}{\left(\frac{1-\varepsilon_1}{\varepsilon_1}\right) + \frac{1}{F_{1-2}} + \left(\frac{1-\varepsilon_2}{\varepsilon_2}\right)\frac{A_1}{A_2}} = \frac{A_2\,\sigma\,(T_2^4 - T_3^4)}{\left(\frac{1-\varepsilon_2}{\varepsilon_2}\right) + \frac{1}{F_{2-3}} + \left(\frac{1-\varepsilon_3}{\varepsilon_3}\right)\frac{A_2}{A_3}}$$

where all the areas are surface areas of the cylinders.

As $F_{1-2} = F_{2-3} = 1$ and $\varepsilon_1 = \varepsilon_2 = \varepsilon_3$ (given) $= 0.05$

$$\therefore \quad \frac{A_1\,(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \left(\frac{1}{\varepsilon_2} - 1\right)\frac{A_1}{A_2}} = \frac{A_2\,(T_2^4 - T_3^4)}{\frac{1}{\varepsilon_2} + \left(\frac{1}{\varepsilon_3} - 1\right)\frac{A_2}{A_3}} \quad \text{...(i)}$$

$$\frac{A_1}{A_2} = \frac{r_1}{r_2} = \frac{5}{10} = 0.5 \text{ and } \frac{A_2}{A_3} = \frac{r_2}{r_3} = \frac{10}{15} = 0.67$$

Substituting the values in eqn. (*i*), we get

$$\frac{2\pi r_1 L\,(T_1^4 - T_2^4)}{\frac{1}{0.05} + \left(\frac{1}{0.05} - 1\right)\times 0.5} = \frac{2\pi r_2 L\,(T_2^4 - T_3^4)}{\frac{1}{0.05} + \left(\frac{1}{0.05} - 1\right)\times 0.67}$$

$$\frac{T_1^4 - T_2^4}{20 + 19\times 0.5} = \frac{(r_2/r_1)\,(T_2^4 - T_3^4)}{20 + 19 \times 0.67}$$

$$\frac{T_1^4 - T_2^4}{29.5} = \frac{2\,(T_2^4 - T_3^4)}{32.73} = \frac{T_2^4 - T_3^4}{16.36} \qquad \left(\because \frac{r_2}{r_1} = 2\right)$$

or, $$\left(\frac{100}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4 = \frac{29.5}{16.36}\left[\left(\frac{T_2}{100}\right)^4 - \left(\frac{300}{100}\right)^4\right]$$

$$1 - x^4 = 1.8\,(x^4 - 81) \qquad \left[\text{where } x = \frac{T_2}{100}\right]$$

or, $$1 - x^4 = 1.8\,x^4 - 145.8$$

or, $$2.8\,x^4 = 146.8$$

or, $$x = \left(\frac{146.8}{2.8}\right)^{1/4} = 2.69$$

or, $$\frac{T_2}{100} = 2.69 \text{ or } \boldsymbol{T_2} = 2.69 \times 100 = \mathbf{269\ K\ (Ans.)}$$

Example 12.26. *Three thin walled infinitely long hollow cylinders of radii 5 cm, 10 cm and 15 cm are arranged concentrically as shown in Fig. 12.35. T_1 = 1000 K and T_3 = 300 K.*

Assuming $\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = 0.05$ and vacuum in the spaces between the cylinders, calculate the steady state temperature of cylindrical surface 2 and heat flow per m² area of cylinder 1.

(P.U.)

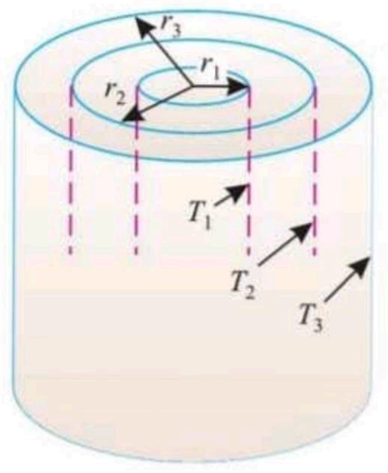


Fig. 12.35

Solution. *Given:* $r_1 = 5$ cm; $r_2 = 10$ cm; $r_3 = 15$ cm; $T_1 = 1000$ K; $T_3 = 300$ K

$$\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = 0.05.$$

For steady state heat flow,

$$Q_{12} = Q_{23}$$

or,
$$\frac{A_1\,\sigma\,(T_1^4 - T_2^4)}{\left(\frac{1-\varepsilon_1}{\varepsilon_1}\right) + \frac{1}{F_{1-2}} + \left(\frac{1-\varepsilon_2}{\varepsilon_2}\right)\frac{A_1}{A_2}} = \frac{A_2\,\sigma\,(T_2^4 - T_3^4)}{\left(\frac{1-\varepsilon_2}{\varepsilon_2}\right) + \frac{1}{F_{2-3}} + \left(\frac{1-\varepsilon_3}{\varepsilon_3}\right)\frac{A_2}{A_3}}$$

In this case $F_{1-2} = F_{2-3} = 1$; and

$$\frac{A_1}{A_2} = \frac{r_1}{r_2} = \frac{5}{10} = 0.5$$

$$\frac{A_2}{A_3} = \frac{r_2}{r_3} = \frac{10}{15} = 0.67$$

$$\therefore \quad \frac{2\,\pi\,r_1\,L\left[\left(\frac{1000}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right]}{\left(\frac{1-0.05}{0.05}\right) + 1 + \left(\frac{1-0.05}{0.05}\right)\times 0.5} = \frac{(2\,\pi\,r_2\,L\left[\left(\frac{T_2}{100}\right)^4 - \left(\frac{300}{100}\right)^4\right]}{\left(\frac{1-0.05}{0.05}\right) + 1 + \left(\frac{1-0.05}{0.05}\right)\times 0.67}$$

$$\frac{0.05\,(10000 - x^4)}{29.5} = \frac{0.1\,(x^4 - 81)}{32.73}$$

or,
$$(1000 - x^4) = \frac{29.5 \times 0.1}{32.73 \times 0.05}\,(x^4 - 81) = 1.8\,(x^4 - 81)$$

or,
$$2.8\,x^4 = 10000 - 145.8 = 9854.2$$

or,
$$x = \left(\frac{9854.2}{2.8}\right)^{1/4} = 7.7$$

or,
$$\frac{T_2}{100} = 7.7 \text{ or } T_2 = 770 \text{ K}$$

$\therefore$ Heat flow per m² area of cylinder 1,

$$Q_{12} = \frac{A_1\,\sigma\,(T_1^4 - T_2^4)}{\left(\frac{1-\varepsilon_1}{\varepsilon_1}\right) + 1 + \left(\frac{1-\varepsilon_2}{\varepsilon_2}\right)\frac{A_1}{A_2}}$$

$$Q_{12} = \frac{1 \times 5.67\left[\left(\frac{1000}{100}\right)^4 - \left(\frac{770}{100}\right)^4\right]}{\left(\frac{1-0.05}{0.05}\right) + 1 + \left(\frac{1-0.05}{0.05}\right)\times 0.5}$$

$$= \frac{5.67 \times (10000 - 3515.3)}{29.5} = \mathbf{1246.4\ W\ (Ans.)}$$

Example 12.39. *Calculate the net radiant heat exchange per m^2 area for two large parallel plates at temperatures of 427° C and 27° C respectively. ε (hot plate) = 0.9 and ε (cold plate) = 0.6.*

If a polished aluminium shield is placed between them, find the percentage reduction in the heat transfer; ε (shield) = 0.4. **(P.U.)**

Solution. *Given :* $T_1 = 427 + 273 = 700$ K; $T_2 = 27 + 273 = 300$ K; ε_1 (hot plate) = 0.9, ε_2 (cold plate) = 0.6, ε_3 (shield) = 0.4.

Net radiant heat exchange per m² area:

In the absence of radiation shield the heat flow between plates 1 and 2 is given by

$$(Q_{12})_{net} = \frac{\sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} \quad \text{...[Eqn. (12.21)]}$$

$$= \frac{5.67\left[\left(\frac{700}{100}\right)^4 - \left(\frac{300}{100}\right)^4\right]}{\frac{1}{0.9} + \frac{1}{0.6} - 1}$$

$$= \frac{13154.4}{1.777} = \mathbf{7402.6\ W.\ (Ans.)}$$

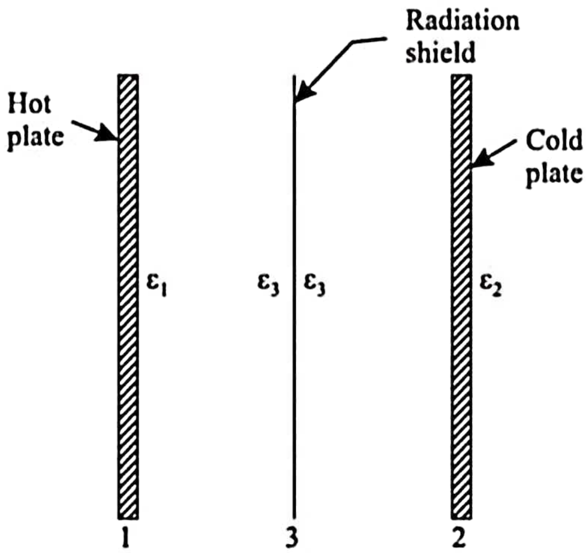


Fig. 12.47

Percentage reduction in the heat transfer flow:

When a shield is placed between the plates 1 and 2, then

$(Q_{13})_{net} = (Q_{32})_{net}$

$$\therefore \quad \frac{A\sigma (T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_3} - 1} = \frac{A\sigma (T_3^4 - T_2^4)}{\frac{1}{\varepsilon_3} + \frac{1}{\varepsilon_2} - 1}$$

$$\text{or,} \quad \frac{\left(\frac{700}{100}\right)^4 - \left(\frac{T_3}{100}\right)^4}{\frac{1}{0.9} + \frac{1}{0.4} - 1} = \frac{\left(\frac{T_3}{100}\right)^4 - \left(\frac{300}{100}\right)^4}{\frac{1}{0.4} + \frac{1}{0.6} - 1}$$

$$\text{or,} \quad \frac{2401 - x^4}{1.11 + 25 - 1} = \frac{x^4 - 81}{25 + 1.67 - 1} \qquad \left[\text{where } x = \frac{T_3}{100}\right]$$

$$\text{or,} \quad 2401 - x^4 = \frac{25.11}{25.67}(x^4 - 81) = 0.9782 = (x^4 - 81)$$

$$\text{or,} \quad 1.9782x^4 = 2480.2 \qquad \therefore x^4 = 1253.8$$

$$\text{or,} \quad x = \frac{T_3}{100} = (1253.8)^{1/4} = 5.95 \text{ or } T_3 = 595 \text{ K}$$

$$\therefore \quad (Q_{13})_{net} = \frac{\sigma (T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_3} - 1} = \frac{5.67\left[\left(\frac{700}{100}\right)^4 - \left(\frac{595}{100}\right)^4\right]}{\frac{1}{0.9} + \frac{1}{0.4} - 1}$$

$$= \frac{6507.2}{25.11} = 259.1 \text{ W}$$

$\therefore$ Reduction in heat flow due to shield

$$= (Q_{12})_{net} - (Q_{13})_{net} = 7402.6 - 259.1 = 7143.5 \text{ W}$$

$$\text{or,} \quad \text{Percentage reduction} = \frac{7143.5}{7402.6} \times 100 = \mathbf{96.5\%\ (Ans.)}$$

Example 12.40. *Determine the radiant heat exchanger in W/m² between two large parallel steel plates of emissivities 0.8 and 0.5 held at temperatures of 1000 K and 500 K respectively, if a thin copper plate of emissivity 0.1 is introduced as a radiation shield between the two plates. Use* $\sigma = 5.67 \times 10^{-8}$ *W/m² K⁴.* **(U.P.S.C., 1995)**

Solution. *Given :* $T_1 = 1000$ K; $\varepsilon_1 = 0.8$, $T_2 = 500$ K; $\varepsilon_2 = 0.5$, $\varepsilon_3 = 0.1$.

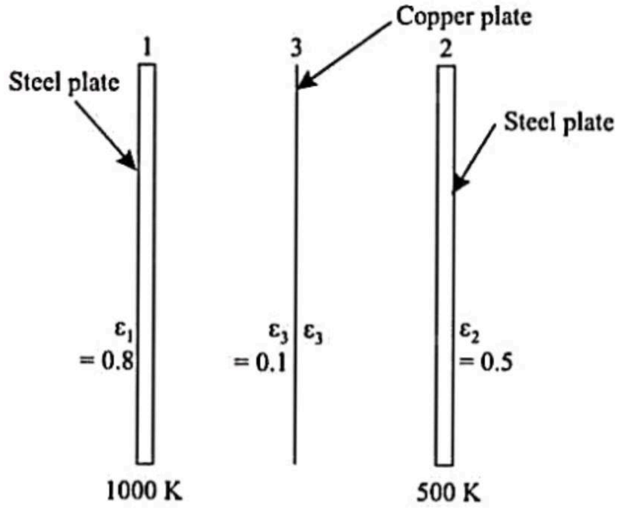


Fig. 12.48

Radiant heat exchange in W/m², $(Q_{12})_{net}$:

We know that,
$$(Q_{12})_{net} = \frac{A\sigma(T_1^4 - T_2^4)}{\left[\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1\right]+\left[\frac{1}{\varepsilon_3}+\frac{1}{\varepsilon_2}-1\right]} \quad \text{...[Eqn. (12.54)]}$$

For $A = 1$ m², we have

$$(Q_{12})_{net} = \frac{5.67\left[\left(\frac{1000}{100}\right)^4 - \left(\frac{500}{100}\right)^4\right]}{\left[\frac{1}{0.8}+\frac{1}{0.1}-1\right]+\left[\frac{1}{0.1}+\frac{1}{0.5}-1\right]}$$

$$= \frac{5.67\,(10000 - 625)}{(12.5 + 10 - 1) + (10 + 2 - 1)} = \mathbf{2501.5\ W/m^2\ (Ans.)}$$

Example 12.41. *Consider two large parallel plates one at* $t_1 = 727°C$ *with emissivity* $\varepsilon_1 = 0.8$ *and other at* $t_2 = 227°C$ *with emissivity* $\varepsilon_2 = 0.4$. *An aluminium radiation shield with an emissivity,* $\varepsilon_s = 0.05$ *on both sides is placed between the plates. Calculate the percentage reduction in heat transfer rate between the two plates as a result of the shield.*

Use $\sigma = 5.67 \times 10^{-8}$ *W/m² K⁴.* **(GATE, 1995)**

Solution. *Given :* $T_1 = t_1 + 273°C = 727 + 273 = 1000$ K; $\varepsilon_1 = 0.8$;
$T_2 = t_2 + 273°C = 227 + 273 = 500$ K; $\varepsilon_2 = 0.4$;
$\varepsilon_s = \varepsilon_3 = 0.05$; $\sigma = 5.67 \times 10^{-8}$ W/m² K⁴.

Without shield,
$$Q \text{ (per unit area)} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1}$$

$$= \frac{5.67\left[\left(\frac{1000}{100}\right)^4 - \left(\frac{500}{100}\right)^4\right]}{\frac{1}{0.8}+\frac{1}{0.4}-1} = \frac{53156}{2.75} = 19329 \text{ W}$$

Without shield,
$$(Q_{13})_{net} = (Q_{32})_{net}$$

$$\frac{A\,\sigma\,(T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_3} - 1} = \frac{A\,\sigma\,(T_3^4 - T_2^4)}{\frac{1}{\varepsilon_3} + \frac{1}{\varepsilon_2} - 1}$$

or, $$\frac{\left(\frac{1000}{100}\right)^4 - \left(\frac{T_3}{100}\right)^4}{\frac{1}{0.8} + \frac{1}{0.05} - 1} = \frac{\left(\frac{T_3}{100}\right)^4 - \left(\frac{500}{100}\right)^4}{\frac{1}{0.05} + \frac{1}{0.4} - 1}$$

$$\frac{10000 - x^4}{1.25 + 20 - 1} = \frac{x^4 - 625}{20 + 2.5 - 1}$$

or, $$10000 - x^4 = \frac{20.25}{21.5}(x^4 - 625)$$

or, $$10000 - x^4 = 0.942\,(x^4 - 625)$$
$$= 0.942\,x^4 - 588.75$$

or, $$1.942\,x^4 = 10588.75 \text{ or } x = 8.59$$

$\therefore$ $$T_3 = 100 \times 8.59 = 859 \text{ K}$$

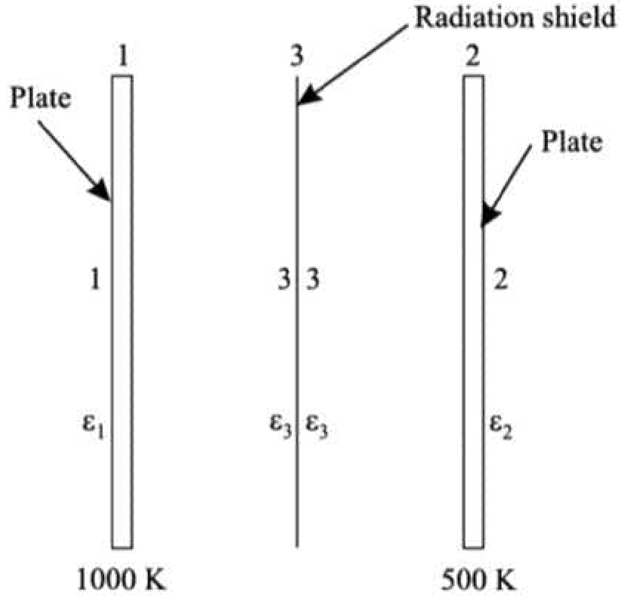


Fig. 12.49

$$(Q_{13})_{net}\text{ (per unit area)} = \frac{\left(\frac{1000}{100}\right)^4 - \left(\frac{859}{100}\right)^4}{\frac{1}{0.8} + \frac{1}{0.05} - 1} = \frac{4555.3}{20.25} = 224.9 \text{ W}$$

$\therefore$ Reduction in heat flow due to shield

$$(Q_{12})_{net} - (Q_{13})_{net} = 19329 - 224.9 = 19104.1 \text{ W}$$

$\therefore$ **Percentage reduction in heat transfer**

$$= \frac{19104.1}{19329} \times 100 = \mathbf{98.84\%} \quad \textbf{(Ans.)}$$

Example 12.42. *The large parallel plates with emissivities 0.3 and 0.8 exchange heat. Find the percentage reduction when a polished aluminium shield of emissivity 0.04 is placed between them. Use the method of electrical analogy.* **(P.U. Winter, 1997)**

Solution. *Given:* $\varepsilon_1 = 0.3$; $\varepsilon_2 = 0.8$; $\varepsilon_3 = 0.04$

Consider all resistances (surface resistances and space resistances) per unit surface area.

For steady state heat flow,

$$\frac{E_{b1} - E_{b3}}{\left(\frac{1-\varepsilon_1}{\varepsilon_1}\right) + 1 + \left(\frac{1-\varepsilon_3}{\varepsilon_3}\right)} = \frac{E_{b3} - E_{b2}}{\left(\frac{1-\varepsilon_3}{\varepsilon_3}\right) + 1 + \left(\frac{1-\varepsilon_2}{\varepsilon_2}\right)}$$

[$\because A_1 = A_2 = A_3 = 1\text{m}^2$ and $F_{1-3}, F_{3-2} = 1$]

or, $$\frac{\sigma\,(T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_3} - 1} = \frac{\sigma\,(T_3^4 - T_2^4)}{\frac{1}{\varepsilon_3} + \frac{1}{\varepsilon_2} - 1}$$

or, $$\frac{T_1^4 - T_3^4}{\frac{1}{0.3} + \frac{1}{0.04} - 1} = \frac{T_3^4 - T_2^4}{\frac{1}{0.04} + \frac{1}{0.8} - 1}$$

or, $$\frac{T_1^4 - T_3^4}{27.33} = \frac{T_3^4 - T_2^4}{25.25}$$

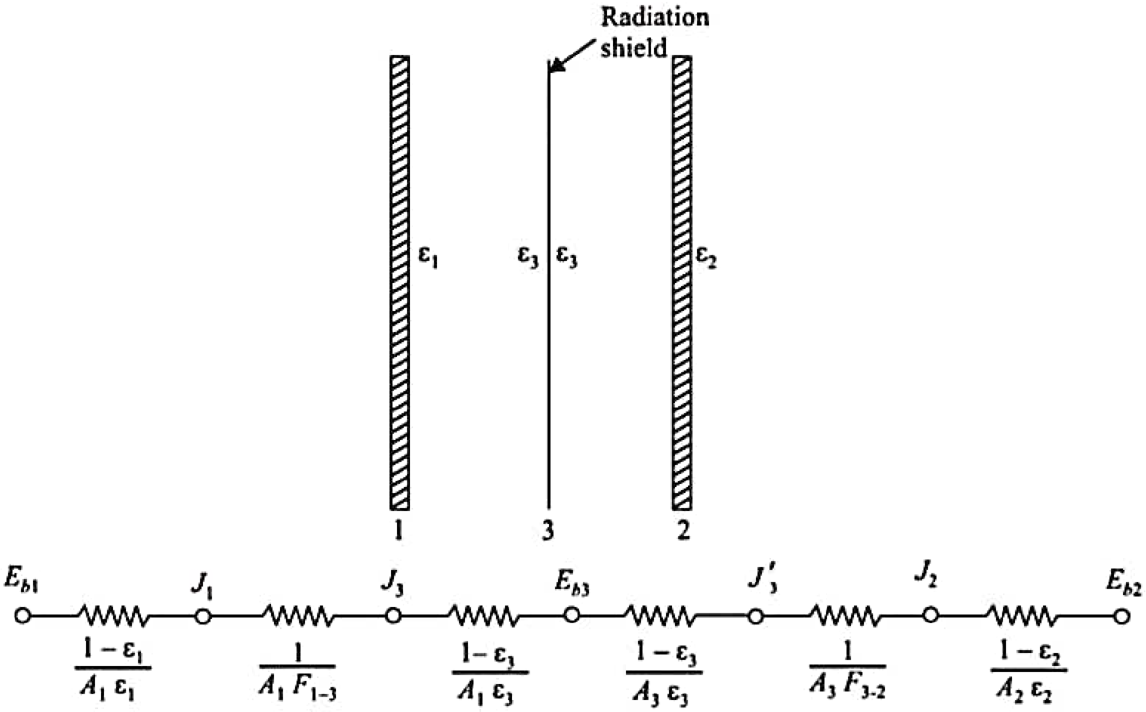


Fig. 12.50

or, $$T_1^4 - T_3^4 = \frac{27.33}{25.25}(T_3^4 - T_2^4)$$

$$= 1.08\,(T_3^4 - T_2^4) = 1.08\,T_3^4 - 1.08\,T_2^4$$

or, $$2.08\,T_3^4 = T_1^4 + 1.08\,T_2^4$$

or, $$T_3^4 = \frac{1}{2.08}(T_1^4 + 1.08\,T_2^4) = 0.48\,(T_1^4 + 1.08\,T_2^4) \qquad ...(i)$$

Q_{12} (heat flow without shield)

$$= \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{0.3} + \frac{1}{0.8} - 1} = \frac{\sigma(T_1^4 - T_2^4)}{3.58} \qquad ...(ii)$$

Q_{13} (heat flow with shield)

$$= \frac{\sigma(T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_3} - 1} = \frac{\sigma(T_1^4 - T_3^4)}{\frac{1}{0.3} + \frac{1}{0.04} - 1} = \frac{\sigma(T_1^4 - T_3^4)}{27.33} \qquad ...(iii)$$

∴ *Percentage reduction in heat flow due to shield*

$$= \frac{Q_{12} - Q_{13}}{Q_{12}}$$

$$= 1 - \frac{Q_{13}}{Q_{12}} = 1 - \frac{\sigma(T_1^4 - T_3^4)/27.33}{\sigma(T_1^4 - T_2^4)/3.58}$$

$$= 1 - \frac{3.58}{27.33}\left[\frac{T_1^4 - T_3^4}{T_1^4 - T_2^4}\right]$$

$$= 1 - 0.131\left[\frac{T_1^4 - 0.48\,(T_1^4 + 1.08\,T_2^4)}{T_1^4 - T_2^4}\right]$$

$$= 1 - 0.131 \left[\frac{T_1^4 - 0.48\, T_1^4 - 0.52\, T_2^4}{T_1^4 - T_2^4} \right]$$

$$= 1 - 0.131 \left[\frac{0.52\, (T_1^4 - T_2^4)}{(T_1^4 - T_2^4)} \right]$$

$$= 1 - 0.131 \times 0.52 = \mathbf{0.932 \text{ or } 93.2\% \text{ (Ans.)}}$$

Example 12.43. *Two large parallel plates with ε = 0.5 each, are maintained at different temperatures and are exchanging heat only by radiation. Two equally large radiation shields with surface emissivity 0.05 are introduced in parallel to the plates. Find the percentage reduction in net radiative heat transfer.* **(M.U.)**

Solution. *Given:* $\varepsilon_p = 0.5$; $\varepsilon_s = 0.05$

Consider all resistances per unit surface area.

(*i*) When shields are not used:

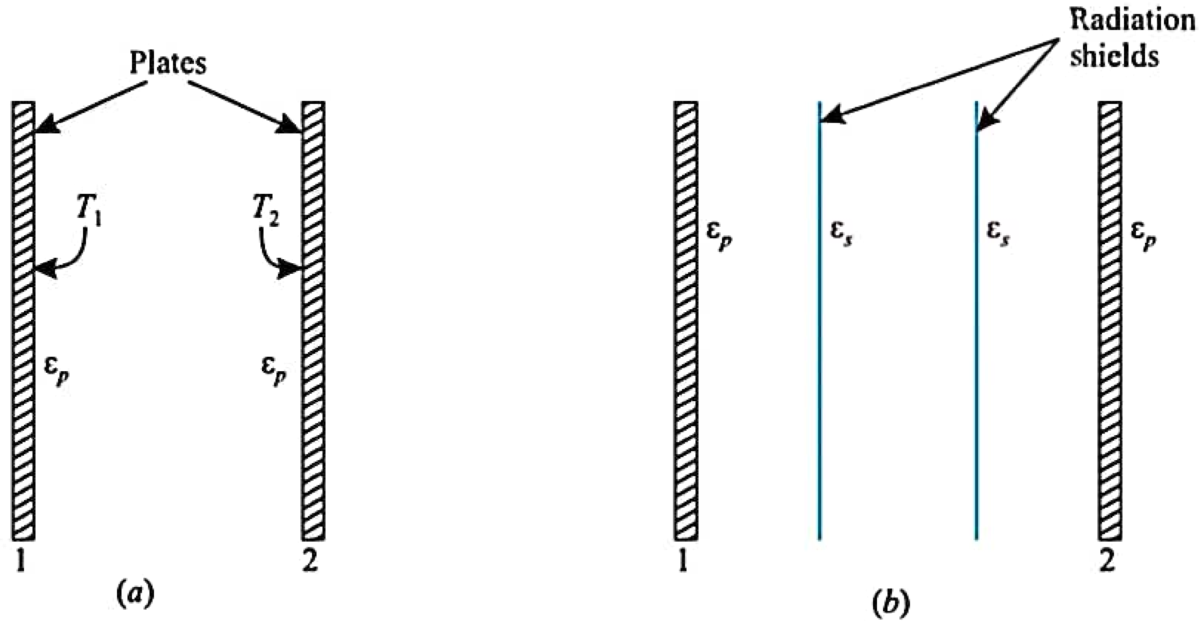


Fig. 12.51

$$(Q)_{without\ shields} = \frac{\sigma\,(T_1^4 - T_2^4)}{\left(\dfrac{1-\varepsilon_p}{\varepsilon_p}\right) + 1 + \left(\dfrac{1-\varepsilon_p}{\varepsilon_p}\right)} = \frac{\sigma\,(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_p} + \dfrac{1}{\varepsilon_p} - 1}$$

$$= \frac{C}{\dfrac{1}{0.5} + \dfrac{1}{0.5} - 1} = 0.33\,C \text{ [where } C = \sigma\,(T_1^4 - T_2^4)]$$

(*ii*) When shields are used :

$$(Q)_{with\ shields} = \frac{\sigma\,(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_p} + \dfrac{1}{\varepsilon_p} + 2\left[\dfrac{1}{\varepsilon_s} + \dfrac{1}{\varepsilon_s}\right] - (2+1)} \qquad \text{...[Eqn. 12.62]}$$

$$= \frac{\sigma\,(T_1^4 - T_2^4)}{\dfrac{2}{\varepsilon_p} + \dfrac{4}{\varepsilon_s} - 3}$$

$$= \frac{C}{\dfrac{2}{0.5} + \dfrac{4}{0.05} - 3} = \frac{C}{81} = 0.012345\ C$$

$\therefore$ Percentage reduction in heat flow $= \left(\dfrac{(Q)_{without\ shields} - (Q)_{with\ shields}}{(Q)_{without\ shields}} \right) \times 100$

$$= \left[1 - \frac{(Q)_{with\ shields}}{(Q)_{without\ shields}} \right] \times 100 = 1 - \frac{0.012345\ C}{0.33\ C}$$

= **96.26% (Ans.)**

Example 12.44. *Consider two large parallel plates, one at 1000 K with emissivity 0.8 and other is at 300 K having emissivity 0.6. A radiation shield is placed between them. The shield has emissivity as 0.1 on the side facing hot plate and 0.3 on the side facing cold plate. Calculate percentage reduction in radiation heat transfer as a result of radiation shield.* **(P.U. 2000)**

Solution. *Given :* $T_1 = 1000$ K, $\varepsilon_1 = 0.8$, $T_2 = 300$ K, $\varepsilon_2 = 0.6$, $\varepsilon_{3h} = 0.1$, $\varepsilon_{3c} = 0.3$.

(*a*) The heat transfer per m² area between two parallel plates by radiation is given by

$$Q = \frac{\sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} = \frac{5.67 \left[\left(\frac{1000}{100} \right)^4 - \left(\frac{300}{100} \right)^4 \right]}{\frac{1}{0.8} + \frac{1}{0.6} - 1}$$

$$= \frac{5.67\ (10^4 - 3^4)}{1.25 + 1.67 - 1} = 29292 \text{ W/m}^2 \text{ or } 29.292 \text{ kW/m}^2$$

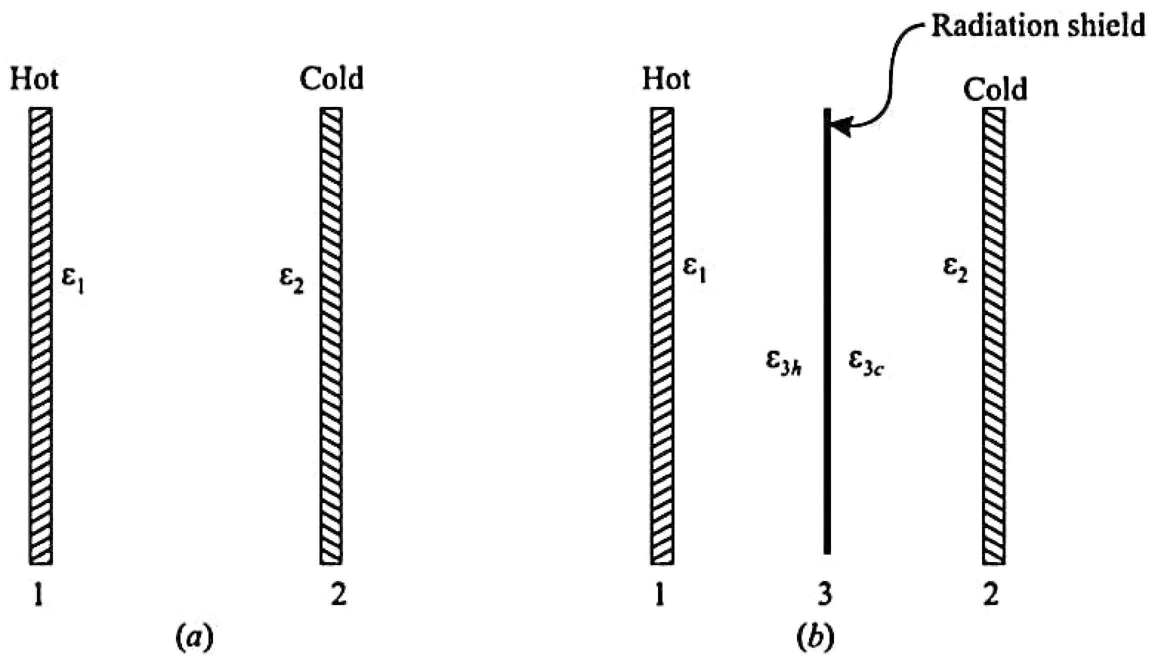


Fig. 12.52

(*b*) When a radiation shield is kept between two plates, then for thermal equilibrium, we can write

$$Q' = \frac{\sigma (T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_{3h}} - 1} = \frac{\sigma (T_3^4 - T_2^4)}{\frac{1}{\varepsilon_{3c}} + \frac{1}{\varepsilon_2} - 1} \qquad ...(1)$$

where T_3 is the temperature of the shield and ε_{3h} and ε_{3c} are the emissivities of the shield towards hot plate surface and cold plate surface.

Substituting the given values in eqn. (1), we get

$$\frac{\left(\frac{1000}{100} \right)^4 - \left(\frac{T_3}{100} \right)^4}{\frac{1}{0.8} + \frac{1}{0.1} - 1} = \frac{\left(\frac{T}{100} \right)^4 - \left(\frac{300}{100} \right)^4}{\frac{1}{0.3} + \frac{1}{0.6} - 1}$$

$$\frac{(10)^4 - x^4}{1.25 + 10 - 1} = \frac{x^4 - (3)^4}{3.33 + 1.67 - 1} \qquad \text{where } x = \frac{T_3}{100}$$

$$\frac{10000 - x^4}{10.25} = \frac{x^4 - 81}{4}$$

or, $$(10000 - x^4) = \frac{10.25}{4}(x^4 - 81) = 2.56\,x^4 - 207.36$$

or, $$3.56\,x^4 = 10207.36$$

or, $$x = \frac{T_3}{100} = \left(\frac{10207.36}{3.56}\right)^{1/4} = 7.32$$

or, $$T_3 = 732\text{ K}$$

The heat flow per m^2 area when shield is located is given by

$$Q' = \frac{\sigma\,(T_1^4 - T_3^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_{3h}} - 1} = \frac{5.67\left[\left(\frac{1000}{100}\right)^4 - \left(\frac{732}{100}\right)^4\right]}{\frac{1}{0.8} + \frac{1}{0.1} - 1}$$

$$= \frac{5.67\,(10^4 - 7.32^4)}{1.25 + 10 - 1} = \frac{5.67\,(10000 - 2871)}{10.25}$$

$$= 3943.5\text{ W/m}^2 \text{ or } 3.943\text{ kW/m}^2$$

∴ Percentage reduction in heat flow

$$= \frac{Q - Q'}{Q} \times 100$$

$$= \frac{29.292 - 3.943}{29.292} \times 100 = \mathbf{86.54\%\ (Ans.)}$$