S K Mondal's

Heat Transfer

GATE, IES & IAS 20 Years Question Answers

Contents

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Note

If you think there should be a change in option, don't change it by yourself send me a mail at swapan_mondal_01@yahoo.co.in I will send you complete explanation.

Every effort has been made to see that there are no errors (typographical or otherwise) in the material presented. However, it is still possible that there are a few errors (serious or otherwise). I would be thankful to the readers if they are brought to my attention at the following e-mail address: swapan_mondal_01@yahoo.co.in

S K Mondal

1. Modes of Heat Transfer

OBJECTIVE QUESTIONS (GATE, IES, IAS)

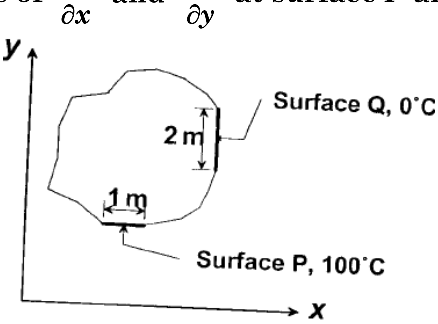
Previous 20-Years GATE Questions

Fourier's Law of Heat Conduction

GATE-1. For a given heat flow and for the same thickness, the temperature drop across the material will be maximum for [GATE-1996]
(a) Copper (b) Steel (c) Glass-wool (d) Refractory brick

GATE-2. Steady two-dimensional heat conduction takes place in the body shown in the figure below. The normal temperature gradients over surfaces *P* and *Q* can be considered to be uniform. The temperature gradient $\frac{\partial T}{\partial x}$ at surface *Q* is equal to 10 k/m. Surfaces *P* and *Q* are maintained at constant temperatures as shown in the figure, while the remaining part of the boundary is insulated. The body has a constant thermal conductivity of 0.1 W/m.K. The values of $\frac{\partial T}{\partial x}$ and $\frac{\partial T}{\partial y}$ at surface *P* are:

(a) $\frac{\partial T}{\partial x} = 20K/m, \frac{\partial T}{\partial y} = 0K/m$
(b) $\frac{\partial T}{\partial x} = 0K/m, \frac{\partial T}{\partial y} = 10K/m$
(c) $\frac{\partial T}{\partial x} = 10K/m, \frac{\partial T}{\partial y} = 10K/m$
(d) $\frac{\partial T}{\partial x} = 0K/m, \frac{\partial T}{\partial y} = 20K/m$



[GATE-2008]

GATE-3. A steel ball of mass 1kg and specific heat 0.4 kJ/kg is at a temperature of 60°C. It is dropped into 1kg water at 20°C. The final steady state temperature of water is: [GATE-1998]
(a) 23.5°C (b) 300°C (c) 35°C (d) 40°C

Thermal Conductivity of Materials

GATE-4. In descending order of magnitude, the thermal conductivity of
a. Pure iron, [GATE-2001]
b. Liquid water,
c. Saturated water vapour, and
d. Pure aluminium can be arranged as

(a) a b c d (b) b c a d (c) d a b c (d) d c b a

Previous 20-Years IES Questions

Heat Transfer by Conduction

IES-1. A copper block and an air mass block having similar dimensions are subjected to symmetrical heat transfer from one face of each block. The other face of the block will be reaching to the same temperature at a rate: [IES-2006]

(a) Faster in air block
(b) Faster in copper block
(c) Equal in air as well as copper block
(d) Cannot be predicted with the given information

Fourier's Law of Heat Conduction

IES-2. Consider the following statements: [IES-1998]

The Fourier heat conduction equation $Q = -kA\dfrac{dT}{dx}$ presumes

1. **Steady-state conditions**
2. **Constant value of thermal conductivity.**
3. **Uniform temperatures at the wall surfaces**
4. **One-dimensional heat flow.**

Of these statements:

(a) 1, 2 and 3 are correct (b) 1, 2 and 4 are correct
(c) 2, 3 and 4 are correct (d) 1, 3 and 4 are correct

IES-3. A plane wall is 25 cm thick with an area of 1 m², and has a thermal conductivity of 0.5 W/mK. If a temperature difference of 60°C is imposed across it, what is the heat flow? [IES-2005]

(a) 120W (b) 140W (c) 160W (d) 180W

IES-4. A large concrete slab 1 m thick has one dimensional temperature distribution: [IES-2009]

$$T = 4 - 10x + 20x^2 + 10x^3$$

Where T is temperature and x is distance from one face towards other face of wall. If the slab material has thermal diffusivity of 2×10^{-3} m²/hr, what is the rate of change of temperature at the other face of the wall?

(a) 0.1°C/h (b) 0.2°C/h (c) 0.3°C/h (d) 0.4°C/h

IES-5. Thermal diffusivity of a substance is: [IES-2006]

(a) Inversely proportional to thermal conductivity
(b) Directly proportional to thermal conductivity
(c) Directly proportional to the square of thermal conductivity
(d) Inversely proportional to the square of thermal conductivity

IES-6. Which one of the following expresses the thermal diffusivity of a substance in terms of thermal conductivity (k), mass density (ρ) and specific heat (c)? [IES-2006]

(a) $k^2 \rho c$ (b) $1/\rho kc$ (c) $k/\rho c$ (d) $\rho c/k^2$

IES-7. Match List-I and List-II and select the correct answer using the codes given below the lists: [IES-2001]
h_m - mass transfer coefficient,
D - molecular diffusion coefficient,
L - characteristic length dimension,
k - thermal conductivity,
ρ - density,
C_p - specific heat at constant pressure, μ- dynamic viscosity)

List-I	List-II
A. Schmidt number	**1.** $\dfrac{k}{(\rho C_p D)}$
B. Thermal diffusivity	**2.** $\dfrac{h_m L}{D}$
C. Lewis number	**3.** $\dfrac{\mu}{\rho D}$
D. Sherwood number	**4.** $\dfrac{k}{\rho C_p}$

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

IES-8. Match List-I with List-II and select the correct answer using the codes given below the lists: [IES-1996]

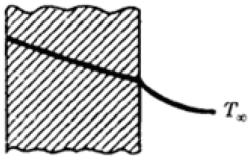
List-I	List-II
A. Momentum transfer	**1.** Thermal diffusivity
B. Mass transfer	**2.** Kinematic viscosity
C. Heat transfer	**3.** Diffusion coefficient

Codes:	**A**	**B**	**C**		**A**	**B**	**C**
(a)	2	3	1	(b)	1	3	2
(c)	3	2	1	(d)	1	2	3

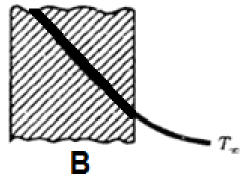
IES-9. Assertion (A): Thermal diffusivity is a dimensionless quantity.
Reason (R): In M-L-T-Q system the dimensions of thermal diffusivity are [L^2T^{-1}] [IES-1992]
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-10. A furnace is made of a red brick wall of thickness 0.5 m and conductivity 0.7 W/mK. For the same heat loss and temperature drop, this can be replaced by a layer of diatomite earth of conductivity 0.14 W/mK and thickness [IES-1993]
(a) 0.05 m (b) 0.1 m (c) 0.2 m (d) 0.5 m

IES-11. Temperature profiles for four cases are shown in the following figures and are labelled A, B, C and D.



A



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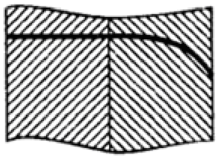
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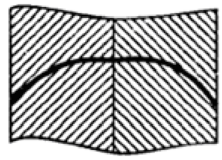

D

Match the above figures with **[IES-1998]**

1. High conductivity fluid **2. Low conductivity fluid**
3. Insulating body **4. Guard heater**

Select the correct answer using the codes given below:

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

Thermal Conductivity of Materials

IES-12. Match the following: **[IES-1992]**

	List-I		**List-II**
A.	Normal boiling point of oxygen	**1.**	1063°C
B.	Normal boiling point of sulphur	**2.**	630.5°C
C.	Normal melting point of Antimony	**3.**	444°C
D.	Normal melting point of Gold	**4.**	–182.97°C

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

IES-13. Assertion (A): The leakage heat transfer from the outside surface of a steel pipe carrying hot gases is reduced to a greater extent on providing refractory brick lining on the inside of the pipe as compared to that with brick lining on the outside. **[IES-2000]**
Reason (R): The refractory brick lining on the inside of the pipe offers a higher thermal resistance.
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-14. Assertion (A): Hydrogen cooling is used for high capacity electrical generators. **[IES-1992]**
Reason (R): Hydrogen is light and has high thermal conductivity as compared to air.
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-15. In MLT θ system (T being time and θ temperature), what is the dimension of thermal conductivity? [IES-2009]

(a) $ML^{-1}T^{-1}\theta^{-3}$ (b) $MLT^{-1}\theta^{-1}$ (c) $ML\theta^{-1}T^{-3}$ (d) $ML\theta^{-1}T^{-2}$

IES-16. Assertion (A): Cork is a good insulator. [IES-2009]
Reason (R): Good insulators are highly porous.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R individually true but R in not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-17. In which one of the following materials, is the heat energy propagation minimum due to conduction heat transfer? [IES-2008]

(a) Lead (b) Copper (c) Water (d) Air

IES-18. Assertion (A): Non-metals are having higher thermal conductivity than metals. [IES-2008]
Reason (R): Free electrons In the metals are higher than those of non metals.

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Answers with Explanation (Objective)

Previous 20-Years GATE Answers

GATE-1. Ans. (c) $Q = -kA\dfrac{dT}{dx}$

$$\frac{Qdx}{A} = -kdT \quad \therefore kdT = \text{constant} \quad \text{or } dT \propto \frac{1}{k}$$

Which one has minimum thermal conductivity that will give maximum temperature drop.

GATE-2. Ans. (d) Heat entry = Heat exit

$$(2\times B)\frac{dT}{dx} = (1\times B)\frac{dT}{dy}$$

GATE-3. Ans. (a) Heat loss by hot body = Heat gain by cold body

$$m_h c_{ph}(t_h - t_f) = m_c c_{pc}(t_f - t_c)$$

$$\text{or } 1\times 0.4\times(60 - t_f) = 1\times 4.2\times(t_f - 20) \qquad \text{or } t_f = 13.5°\text{C}$$

GATE-4. Ans. (c)

Previous 20-Years IES Answers

IES-1. Ans. (b)

IES-2. Ans. (d) Thermal conductivity may constant or variable.

IES-3. Ans. (a) $Q = kA\dfrac{dT}{dx} = 0.5\times 1\times\dfrac{60}{0.25}\text{W} = 120\,\text{W}$

IES-4. Ans. (b) $\dfrac{\partial T}{\partial x} = -10 + 40x + 30x^2 \qquad \Rightarrow \dfrac{\partial^2 T}{\partial x^2} = 40 + 60x$

$$\left.\frac{\partial^2 T}{\partial x^2}\right|_{x=1} = \frac{1}{\alpha}\frac{\partial T}{\partial \tau} \qquad \Rightarrow 40 + 60(1) = \left(\frac{1}{2\times 10^{-3}}\right)\frac{\partial T}{\partial \tau}$$

$$\Rightarrow \frac{\partial T}{\partial \tau} = (2\times 10^{-3})(100) = 0.2°\text{C/hour}$$

IES-5. Ans. (b) Thermal diffusivity $(\alpha) = \dfrac{k}{\rho c_p}; \quad \therefore \alpha \propto k$

IES-6. Ans. (c) $\alpha = \dfrac{k}{\rho c_p}$

IES-7. Ans. (d)

IES-8. Ans. (a)

IES-9. Ans. (d)

IES-10. Ans. (b) For thick place homogeneous wall, heat loss $= kA\dfrac{dt}{dx}$

$$or\left(0.7\times A\times\frac{dt}{0.5}\right)_{red\,brick}=\left(0.14\times A\frac{dt}{dx}\right)_{diatomic}\quad or\,\Delta x=0.1m\qquad [\because dt=\text{constant}]$$

IES-11. Ans. (a) Temperature slope is higher for low conducting and lower for high conducting fluid. Thus A is for 1, B for 2. Temperature profile in C is for insulator. Temperature rise is possible only for heater and as such D is for guard heater.

IES-12. Ans. (d)

IES-13. Ans. (a)

IES-14. Ans. (a) It reduces the cooling systems size.

IES-15. Ans. (c) $Q=-KA\dfrac{dT}{dx};\left(ML^2T^{-3}\right)=K\left(L^2\right)\dfrac{(\theta)}{(L)}$

$$\Rightarrow ML^2T^{-3}=K(L)(\theta)\qquad\qquad \Rightarrow K=\frac{ML^2T^{-3}}{L\theta}=\left[MLT^{-3}\theta^{-1}\right]$$

IES-16. Ans. (a)

IES-17. Ans. (d) Heat energy propagation minimum due to conduction heat transfer in case of Air as its thermal conductivity is high.

IES-18. Ans. (d) Non-metals have lower thermal conductivity and free electrons in metal higher then non metal therefore (d) is the answer.

2. One Dimensional Steady State Conduction

OBJECTIVE QUESTIONS (GATE, IES, IAS)

Previous 20-Years GATE Questions

General Heat Conduction Equation in Cartesian Coordinates

GATE-1. In a case of one dimensional heat conduction in a medium with constant properties, T is the temperature at position x, at time t. Then $\frac{\partial T}{\partial t}$ is proportional to: [GATE-2005]

(a) $\frac{T}{x}$ (b) $\frac{\partial T}{\partial x}$ (c) $\frac{\partial^2 T}{\partial x \partial t}$ (d) $\frac{\partial^2 T}{\partial x^2}$

General Heat Conduction Equation in Spherical Coordinates

GATE-2. One dimensional unsteady state heat transfer equation for a sphere with heat generation at the rate of 'q' can be written as [GATE-2004]

(a) $\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$ (b) $\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial T}{\partial r}\right)+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial}{\partial t}$

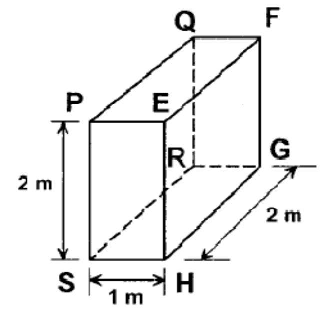
(c) $\frac{\partial^2 T}{\partial r^2}+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$ (d) $\frac{\partial^2}{\partial r^2}+(rT)+\frac{q}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$

Heat Conduction through a Plane Wall

GATE-3. A building has to be maintained at 21°C (dry bulb) and 14.5°C. The outside temperature is –23°C (dry bulb) and the internal and external surface heat transfer coefficients are 8 W/m²K and 23 W/m²K respectively. If the building wall has a thermal conductivity of 1.2 W/mK, the minimum thickness (in m) of the wall required to prevent condensation is: [GATE-2007]

(a) 0.471 (b) 0.407 (c) 0.321 (d) 0.125

GATE-4. For the three-dimensional object shown in the figure below, five faces are insulated. The sixth face (PQRS), which is not insulated, interacts thermally with the ambient, with a convective heat transfer coefficient of 10 W /m²\.K. The ambient temperature is 30°C. Heat is uniformly generated inside the object at the rate of 100 W/m³. Assuming the face PQRS to be at uniform temperature, its steady state temperature is:

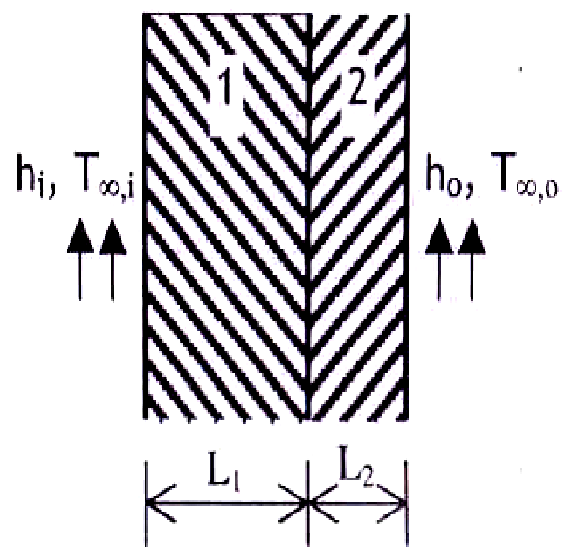


[GATE-2008]

(a) 10°C (b) 20°C (c) 30°C (d) 40°C

Heat Conduction through a Composite Wall

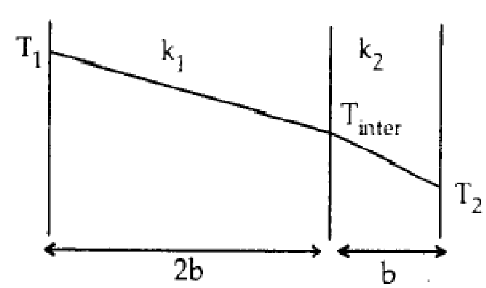
GATE-5. Consider steady-state heat conduction across the thickness in a plane composite wall (as shown in the figure) exposed to convection conditions on both sides.
Given: h_i = 20 W/m²K; h_o = 50 W/m²K; $T_{\infty.i} = 20°C$; $T_{\infty.o} = -2°C$; k_1 = 20 W/mK; k_2 = 50 W/mK; L_1 = 0.30 m and L_2 = 0.15 m. Assuming negligible contact resistance between the wall surfaces, the interface temperature, T (in °C), of the two walls will be:



[GATE-2009]

(a) – 0.50 (b) 2.75 (c) 3.75 (d) 4.50

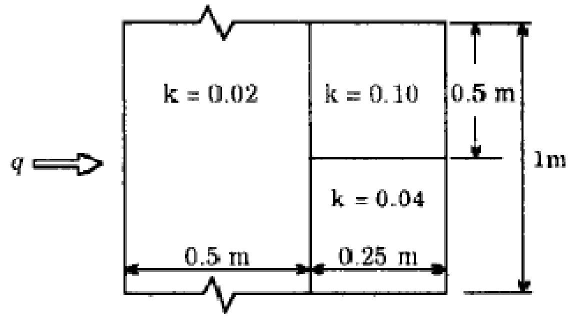
GATE-6. In a composite slab, the temperature at the interface (T_{inter}) between two materials is equal to the average of the temperatures at the two ends. Assuming steady one-dimensional heat conduction, which of the following statements is true about the respective thermal conductivities?



[GATE-2006]

(a) $2k_1 = k_2$ (b) $k_1 = k_2$ (c) $2k_1 = 3k_2$ (d) $k_1 = 2k_2$

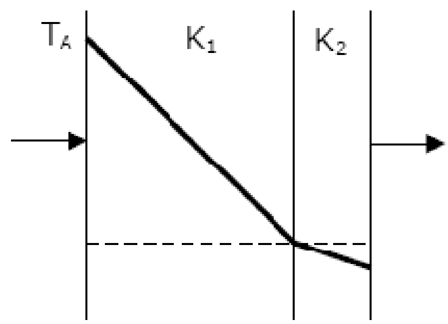
GATE-7. Heat flows through a composite slab, as shown below. The depth of the slab is 1 m. The k values are in W/mK. the overall thermal resistance in K/W is:



(a) 17. (b) 21.9
(c) 28.6 (d) 39.2

[GATE-2005]

GATE-8. The temperature variation under steady heat conduction across a composite slab of two materials with thermal conductivities *K_1* and *K_2* is shown in figure. Then, which one of the following statements holds?



(a) $K_1 > K_2$ (b) $K_1 = K_2$
(c) $K_1 = 0$ (d) $K_1 < K_2$

[GATE-1998]

Heat Conduction through a Composite Cylinder

GATE-9. A stainless steel tube (k_s = 19 W/mK) of 2 cm ID and 5 cm OD is insulated with 3 cm thick asbestos (k_a = 0.2 W/mK). If the temperature difference between the innermost and outermost surfaces is 600°C, the heat transfer rate per unit length is: [GATE-2004]

(a) 0.94 W/m (b) 9.44 W/m (c) 944.72 W/m (d) 9447.21 W/m

GATE-10. Two insulating materials of thermal conductivity *K* and 2*K* are available for lagging a pipe carrying a hot fluid. If the radial thickness of each material is the same. [GATE-1994]

(a) Material with higher thermal conductivity should be used for the inner layer and one with lower thermal conductivity for the outer.
(b) Material with lower thermal conductivity should be used for the inner layer and one with higher thermal conductivity for the outer.
(c) It is immaterial in which sequence the insulating materials are used.
(d) It is not possible to judge unless numerical values of dimensions are given.

Previous 20-Years IES Questions

Heat Conduction through a Plane Wall

IES-1. A wall of thickness 0.6 m has width has a normal area 1.5 m² and is made up of material of thermal conductivity 0.4 W/mK. The

temperatures on the two sides are 800°C. What is the thermal resistance of the wall? [IES-2006; 2007]

(a) 1 W/K (b) 1.8 W/K (c) 1 K/W (d) 1.8 K/W

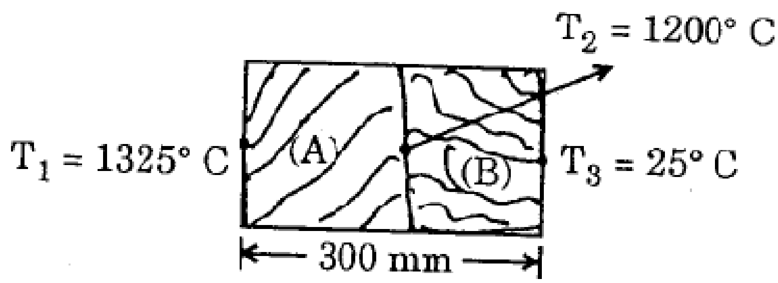
IES-2. **Two walls of same thickness and cross sectional area have thermal conductivities in the ratio 1 : 2. If same temperature difference is maintained across the two faces of both the walls, what is the ratio of heat flow Q_1/Q_2? [IES-2008]**

(a) ½ (b) 1 (c) 2 (d) 4

IES-3. **A composite wall of a furnace has 2 layers of equal thickness having thermal conductivities in the ratio of 3 : 2. What is the ratio of the temperature drop across the two layers? [IES-2008]**

(a) 2:3 (b) 3: 2 (c) 1: 2 (d) $\log_e 2 : \log_e 3$

IES-4.



A wall as shown above is made up of two layers (A) and (B). The temperatures are also shown in the sketch. The ratio of thermal conductivity of two layers is $\frac{k_A}{k_B} = 2$. [IES-2008]

What is the ratio of thickness of two layers?

(a) 0·105 (b) 0·213 (c) 0·555 (d) 0·840

IES-5. **Heat is conducted through a 10 cm thick wall at the rate of 30 W/m² when the temperature difference across the wall is 10°C. What is the thermal conductivity of the wall? [IES-2005]**

(a) 0.03 W/mK (b) 0.3 W/mK (c) 3.0 W/mK (d) 30.0 W/mK

IES-6. **A 0.5 m thick plane wall has its two surfaces kept at 300°C and 200°C. Thermal conductivity of the wall varies linearly with temperature and its values at 300°C and 200°C are 25 W/mK and 15W/mK respectively. Then the steady heat flux through the wall is: [IES-2002]**

(a) 8 kW/m² (b) 5 kW/m² (c) 4kW/m² (d) 3 kW/m²

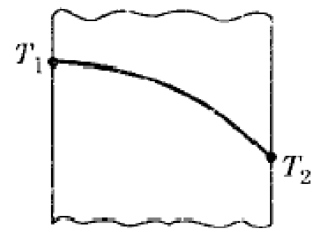
IES-7. **6.0 kJ of conduction heat transfer has to take place in 10 minutes from one end to other end of a metallic cylinder of 10 cm² cross-sectional area, length 1 meter and thermal conductivity as 100 W/mK. What is the temperature difference between the two ends of the cylindrical bar? [IES-2005]**

(a) 80°C (b) 100°C (c) 120°C (d) 160°C

IES-8. **A steel plate of thermal conductivity 50 W/m-K and thickness 10 cm passes a heat flux by conduction of 25 kW/m². If the temperature of the hot surface of the plate is 100°C, then what is the temperature of the cooler side of the plate? [IES-2009]**

(a) 30°C (b) 40°C (c) 50°C (d) 60°C

IES-9. **In a large plate, the steady temperature distribution is as shown in the given figure. If no heat is generated in the plate, the thermal conductivity 'k' will vary as (T is temperature and α is a constant)**



[IES-1997]

(a) $k_o(1+\alpha T)$ (b) $k_o(1-\alpha T)$ (c) $1+\alpha T$ (d) $1-\alpha T$

IES-10. **The temperature distribution, at a certain instant of time in a concrete slab during curing is given by $T = 3x^2 + 3x + 16$, where x is in cm and T is in K. The rate of change of temperature with time is given by (assume diffusivity to be 0.0003 cm²/s). [IES-1994]**

(a) + 0.0009 K/s (b) + 0.0048 K/s (c) – 0.0012 K/s (d) – 0.0018 K/s

Heat Conduction through a Composite Wall

IES-11. **A composite wall having three layers of thickness 0.3 m, 0.2 m and 0.1 m and of thermal conductivities 0.6, 0.4 and 0.1 W/mK, respectively, is having surface area 1 m². If the inner and outer temperatures of the composite wall are 1840 K and 340 K, respectively, what is the rate of heat transfer? [IES-2007]**

(a) 150 W (b) 1500 W (c) 75 W (d) 750 W

IES-12. **A composite wall of a furnace has 3 layers of equal thickness having thermal conductivities in the ratio of 1:2:4. What will be the temperature drop ratio across the three respective layers? [IES-2009]**

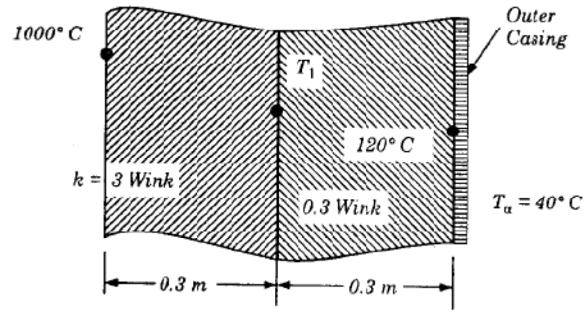
(a) 1:2:4 (b) 4:2:1 (c) 1:1:1 (d) log4:log2:log1

IES-13. **What is the heat lost per hour across a wall 4 m high, 10 m long and 115 mm thick, if the inside wall temperature is 30°C and outside ambient temperature is 10°C? Conductivity of brick wall is 1.15 W/mK, heat transfer coefficient for inside wall is 2.5 W/m²K and that for outside wall is 4 W/m²K. [IES-2009]**

(a) 3635 kJ (b) 3750 kJ (e) 3840 kJ (d) 3920 kJ

IES-14. **A furnace wall is constructed as shown in the given figure. The heat transfer coefficient across the outer casing will be:**

(a) 80 W/m^2K
(b) 40 W/m^2K
(c) 20 W/m^2K
(d) 10 W/m^2K



[IES-1999]

IES-15. **A composite wall is made of two layers of thickness σ_1 and σ_2 having thermal conductivities *K* and 2*K* and equal surface areas normal to the direction of heat flow. The outer surfaces of the composite wall are at 100°C and 200°C respectively. The heat transfer takes place only by conduction and the required surface temperature at the junction is 150°C** **[IES-2004]**

What will be the ratio of their thicknesses, $\sigma_1 : \sigma_2$?

(a) 1 : 1 (b) 2 : 1 (c) 1: 2 (d) 2 : 3

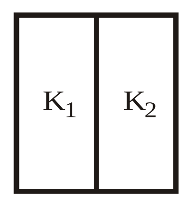
IES-16. **A composite plane wall is made up of two different materials of the same thickness and having thermal conductivities of k_1 and k_2 respectively. The equivalent thermal conductivity of the slab is:**
[IES-1992; 1993; 1997; 2000]

(a) $k_1 + k_2$ (b) $k_1 k_2$ (c) $\dfrac{k_1 + k_2}{k_1 k_2}$ (d) $\dfrac{2k_1 k_2}{k_1 + k_2}$

IES-17. **The equivalent thermal conductivity of the wall as shown in the figure is:**

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

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



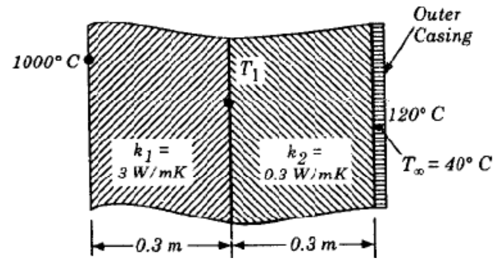
[IES-2010]

IES-18. **A composite slab has two layers of different materials having internal conductivities k_1 and k_2. If each layer has the same thickness, then what is the equivalent thermal conductivity of the slab?** **[IES-2009]**

(a) $\dfrac{k_1 k_2}{(k_1 + k_2)}$ (b) $\dfrac{k_1 k_2}{2(k_1 + k_2)}$ (c) $\dfrac{2k_1}{(k_1 + k_2)}$ (d) $\dfrac{2k_1 k_2}{(k_1 + k_2)}$

IES-19. **A furnace wall is constructed as shown in the figure. The interface temperature T_i will be:**

(a) 560°C (b) 200°C
(c) 920°C (d) 1120°C



[IES-1998]

The Overall Heat Transfer Co-efficient

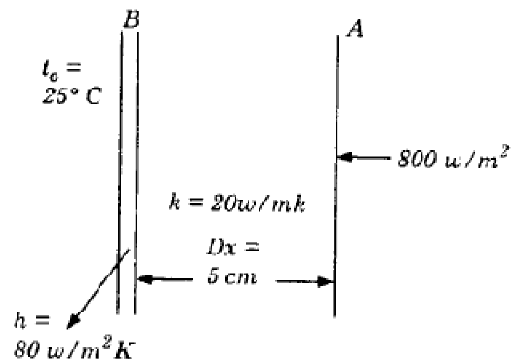
IES-20. A flat plate has thickness 5 cm, thermal conductivity 1 W/(mK), convective heat transfer coefficients on its two flat faces of 10 W/(m^2K) and 20 W/(m^2K). The overall heat transfer co-efficient for such a flat plate is: [IES-2001]

(a) 5 W/(m^2K) (b) 6.33 W/(m^2K) (c) 20 W/(m^2K) (d) 30 W/(m^2K)

IES-21. The overall heat transfer coefficient *U* for a plane composite wall of *n* layers is given by (the thickness of the i^{th} layer is t_i, thermal conductivity of the it *h* layer is k_i, convective heat transfer co-efficient is *h*) [IES-2000]

(a) $\dfrac{1}{\dfrac{1}{h_1}+\sum_{i=1}^{n}\dfrac{t_i}{k_i}+\dfrac{1}{h_n}}$ (b) $h_1+\sum_{i=1}^{n}\dfrac{t_i}{k_i}+h_n$ (c) $\dfrac{1}{h_1+\sum_{i=1}^{n}\dfrac{t_i}{k_i}+h_n}$ (d) $\dfrac{1}{h_1}+\sum_{i=1}^{n}\dfrac{t_i}{k_i}+\dfrac{1}{h_n}$

IES-22. A steel plate of thickness 5 cm and thermal conductivity 20 W/mK is subjected to a uniform heat flux of 800 W/m^2 on one surface 'A' and transfers heat by convection with a heat transfer co-efficient of 80 W/m^2K from the other surface 'B' into ambient air T_α of 25°C. The temperature of the surface 'B' transferring heat by convection is: [IES-1999]



(a) 25°C (b) 35°C (c) 45°C (d) 55°C

Logarithmic Mean Area for the Hollow Cylinder

IES-23. The heat flow equation through a cylinder of inner radius "r_1" and outer radius "r_2" is desired in the same form as that for heat flow through a plane wall. The equivalent area A_m is given by: [IES-1999]

(a) $\dfrac{A_1+A_2}{\log_e\left(\dfrac{A_2}{A_1}\right)}$ (b) $\dfrac{A_1+A_2}{2\log_e\left(\dfrac{A_2}{A_1}\right)}$ (c) $\dfrac{A_2-A_1}{2\log_e\left(\dfrac{A_2}{A_1}\right)}$ (d) $\dfrac{A_2-A_1}{\log_e\left(\dfrac{A_2}{A_1}\right)}$

**IES-24. The outer surface of a long cylinder is maintained at constant temperature. The cylinder does not have any heat source. [IES-2000]
The temperature in the cylinder will:**

(a) Increase linearly with radius (b) Decrease linearly with radius
(c) Be independent of radius (d) Vary logarithmically with radius

Heat Conduction through a Composite Cylinder

IES-25. The heat flow through a composite cylinder is given by the equation: (symbols have the usual meaning) [IES-1995]

(a) $Q = \dfrac{(T_1 - T_{n+1})2\pi L}{\sum_{n=1}^{n=n} \dfrac{1}{K_n} \log_e\left(\dfrac{r_{n+1}}{r_n}\right)}$ (b) $Q = \dfrac{4\pi(T_1 - T_{n+1})}{\sum_{n=1}^{n=n}\left[\dfrac{r_{n+1} - r_n}{K_n r_n r_{n+1}}\right]}$

(c) $Q = \dfrac{T_1 - T_{n+1}}{\dfrac{1}{A}\sum_{n=1}^{n=n}\left(\dfrac{L_n}{K_n}\right)}$ (d) $Q = \dfrac{T_1 - T_2}{\dfrac{\log_e\left(\dfrac{r_2}{r_1}\right)}{2\pi KL}}$

Heat Conduction through a Hollow Sphere

IES-26. For conduction through a spherical wall with constant thermal conductivity and with inner side temperature greater than outer wall temperature, (one dimensional heat transfer), what is the type of temperature distribution? [IES-2007]

(a) Linear (b) Parabolic (c) Hyperbolic (d) None of the above

IES-27. What is the expression for the thermal conduction resistance to heat transfer through a hollow sphere of inner radius r_1 and outer radius r_2, and thermal conductivity k? [IES-2007]

(a) $\dfrac{(r_2 - r_1)r_1 r_2}{4\pi k}$ (b) $\dfrac{4\pi k(r_2 - r_1)}{r_1 r_2}$ (c) $\dfrac{r_2 - r_1}{4\pi k r_1 r_2}$ (d) None of the above

IES-28. A solid sphere and a hollow sphere of the same material and size are heated to the same temperature and allowed to cool in the same surroundings. If the temperature difference between the body and that of the surroundings is T, then [IES-1992]

(a) Both spheres will cool at the same rate for small values of T
(b) Both spheres will cool at the same reactor small values of T
(c) The hollow sphere will cool at a faster rate for all the values of T
(d) The solid sphere will cool a faster rate for all the values of T

Logarithmic Mean Area for the Hollow Sphere

IES-29. What will be the geometric radius of heat transfer for a hollow sphere of inner and outer radii r_1 and r_2? [IES-2004]

(a) $\sqrt{r_1 r_2}$ (b) $r_2 r_1$ (c) r_2 / r_1 (d) $(r_2 - r_1)$

Heat Condition through a Composite Sphere

IES-30. A composite hollow sphere with steady internal heating is made of 2 layers of materials of equal thickness with thermal conductivities in the ratio of 1 : 2 for inner to outer layers. Ratio of inside to outside diameter is 0.8. What is ratio of temperature drop across the inner and outer layers? [IES-2005]

(a) 0.4 (b) 1.6 (c) 2 ln (0.8) (d) 2.5

IES-31. **Match List-I (Governing Equations of Heat Transfer) with List-II (Specific Cases of Heat Transfer) and select the correct answer using the code given below:** **[IES-2005]**

List-I	List-II
A. $\dfrac{d^2T}{dr^2}+\dfrac{2}{r}\dfrac{dT}{dr}=0$	**1.** Pin fin 1–D case
B. $\dfrac{\partial^2T}{\partial x^2}=\dfrac{1}{\alpha}\dfrac{\partial T}{\partial t}$	**2.** 1–D conduction in cylinder
C. $\dfrac{d^2T}{dr^2}+\dfrac{1}{r}\dfrac{dT}{dr}=0$	**3.** 1–D conduction in sphere
D. $\dfrac{d^2\theta}{dx^2}-m^2\theta=0$	**4.** Plane slab

(Symbols have their usual meaning)

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

Previous 20-Years IAS Questions

Logarithmic Mean Area for the Hollow Sphere

IAS-1. **A hollow sphere has inner and outer surface areas of 2 m² and 8 m² respectively. For a given temperature difference across the surfaces, the heat flow is to be calculated considering the material of the sphere as a plane wall of the same thickness. What is the equivalent mean area normal to the direction of heat flow?** **[IAS-2007]**

(a) 6 m² (b) 5 m² (c) 4 m² (d) None of the above

Answers with Explanation (Objective)

Previous 20-Years GATE Answers

GATE-1. Ans. (d) One dimensional, Unsteady state, without internal heat generation

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

GATE-2. Ans. (b)

GATE-3. Ans. (b)

GATE-4. Ans. (d)

GATE-5. Ans. (c) $Q = \dfrac{20+2}{\dfrac{1}{20}+\dfrac{0.30}{20}+\dfrac{0.15}{50}+\dfrac{1}{50}} = 250$

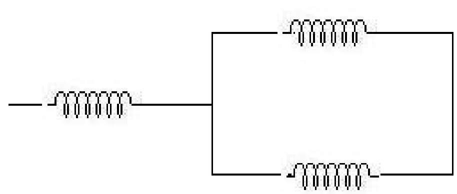
or $250 = \dfrac{20-T}{\dfrac{1}{20}+\dfrac{0.30}{20}}$ or $T = 3.75°\text{C}$

GATE-6. Ans. (d) $T_{\text{inter}} = \dfrac{T_1+T_2}{2}$

Heat flow must be same $(Q) = -k_1 A \dfrac{\left(T_1 - \dfrac{T_1+T_2}{2}\right)}{2b} = -k_2 \dfrac{\left(\dfrac{T_1+T_2}{2} - T_2\right)}{b}$

or $k_1 = 2k_2$

GATE-7. Ans. (c) Electrical circuit



Use this formula

$$R_{eq} = \frac{L_1}{K_1A_1} + \frac{1}{\dfrac{1}{\dfrac{L_2}{K_2A_2}} + \dfrac{1}{\dfrac{L_3}{K_3A_3}}}$$

GATE-8. Ans. (d) Lower the thermal conductivity greater will be the slope of the temperature distribution curve (The curve shown here is temperature distribution curve).

GATE-9. Ans. (c) $Q = \dfrac{2\pi L\left(t_i - t_f\right)}{\dfrac{\ln\left(\dfrac{r_2}{r_1}\right)}{K_A} + \dfrac{\ln\left(\dfrac{r_3}{r_2}\right)}{K_B}} = \dfrac{2\pi\times 1\times(600)}{\dfrac{\ln\left(\dfrac{0.025}{0.01}\right)}{19} + \dfrac{\ln\left(\dfrac{0.055}{0.025}\right)}{0.2}} = 944.72\,\text{W/m}$

GATE-10. Ans. (b)

Previous 20-Years IES Answers

IES-1. Ans. (c) $R = \dfrac{L}{KA} = \dfrac{0.6}{0.4 \times 1.5} = 1\ K/W$

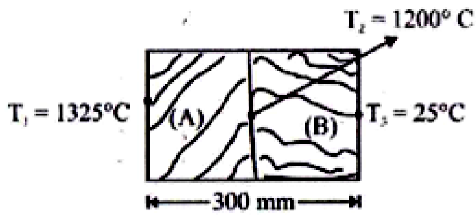
IES-2. Ans. (a) $\dfrac{Q_1}{Q_2} = \dfrac{K_1 A \dfrac{dT}{dx}}{K_2 A \dfrac{dT}{dx}}$

IES-3. Ans. (a) $\dfrac{K_1 A(\Delta T_1)}{dx} = \dfrac{K_2 A(\Delta T_2)}{dx}$

$$\Rightarrow \quad K_1(\Delta T_1) = K_2(\Delta T_2) \qquad \Rightarrow \frac{\Delta T_1}{\Delta T_2} = \frac{K_2}{K_1} = \frac{2}{3}$$

IES-4. Ans. (b) $\dfrac{k_A(1325 - 1200)}{x_A} = \dfrac{k_B(1200 - 25)}{x_B}$

$$\Rightarrow \frac{x_A}{x_B} = \frac{2 \times 125}{1175} = 0.2127 \simeq 0.213$$



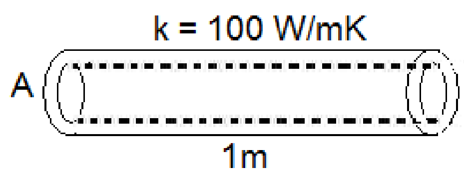
IES-5. Ans. (b) $\dot{q} = K\dfrac{dT}{dx}$ or $k = \dfrac{\dot{q}}{\left(\dfrac{dT}{dx}\right)} = \dfrac{30}{\left(\dfrac{10}{0.1}\right)} = 0.3$ W/mK

IES-6. Ans. (c) $K_{average} = \dfrac{25 + 15}{2} = 20$ [As it is varying linearly]

IES-7. Ans. (b) $\therefore\ \dot{Q} = kA\dfrac{dT}{dx}$

or $\dfrac{6000}{10 \times 60} = 100 \times \left(\dfrac{10}{10000}\right) \times \dfrac{dT}{1}$

or $dT = 100°C$

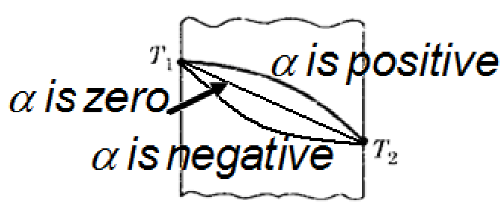


IES-8. Ans. (b) $Q = -KA\dfrac{dT}{dx} \Rightarrow \dfrac{Q}{A} = -K\dfrac{dT}{dx}$

$$\Rightarrow \quad 25 \times 10^3 = 50 \times \frac{(100 - T_2)}{(0.1)} \qquad \Rightarrow T_2 = 50°C$$

IES-9. Ans. (a) For the shape of temperature profile.

$K = k_o(1 + \alpha T)$



IES-10. Ans. (d) Use $\dfrac{d^2T}{dx^2} = \dfrac{1}{\alpha}\dfrac{dT}{d\tau}$ relation.

Temperature distribution is $T = 3x^2 + 3x + 16$, $\dfrac{dT}{dx} = 6x + 3$°K/cm²

IES-11. Ans. (d) $Q = \dfrac{t_f - t_i}{\sum \dfrac{L}{KA}} = \dfrac{1840 - 340}{\dfrac{0.3}{0.6 \times 1} + \dfrac{0.2}{0.4 \times 1} + \dfrac{0.1}{0.1 \times 1}} = 750$ W

IES-12. Ans. (b) $K_1 \Delta T_1 = K_2 \Delta T_2 = K_3 \Delta T_3 = Q$

$$\Rightarrow \Delta T_1 : \Delta T_2 : \Delta T_3 = \frac{Q}{K_1} : \frac{Q}{K_2} : \frac{Q}{K_3} = \frac{1}{1} : \frac{1}{2} : \frac{1}{4} = 4:2:1$$

IES-13. Ans. (c) Heat Loss / sec $= \dfrac{(T_1 - T_2)}{\dfrac{1}{h_1 A} + \dfrac{x}{K_1 A} + \dfrac{1}{h_2 A}} = \dfrac{(30-10)}{\dfrac{1}{40}\left(\dfrac{0.115}{1.15} + \dfrac{1}{2.5} + \dfrac{1}{4}\right)}$

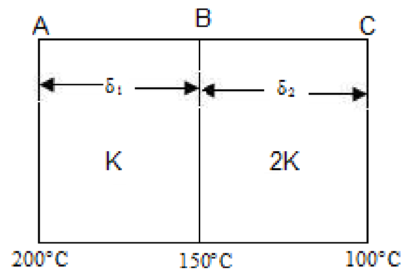
$$= \frac{40 \times 20}{(0.1 + 0.4 + 0.25)} = 1066.66 \text{ kJ/sec} = \frac{3840.000}{1000} \text{ kJ/hour} = 3840 \text{ kJ/hour}$$

IES-14. Ans. (d) For two insulating layers,

$$\frac{Q}{A} = \frac{t_1 - t_2}{\dfrac{\Delta x_1}{k_1} + \dfrac{\Delta x_2}{k_2}} = \frac{1000-120}{\dfrac{0.3}{3} + \dfrac{0.3}{0.3}} = \frac{880}{1.1} = 800$$

For outer casing, $\dfrac{Q}{A} = \dfrac{120-40}{1/h}$, or $800 \times \dfrac{1}{h}$, and $h = \dfrac{800}{80} = 10\ \text{W/m}^2\text{K}$

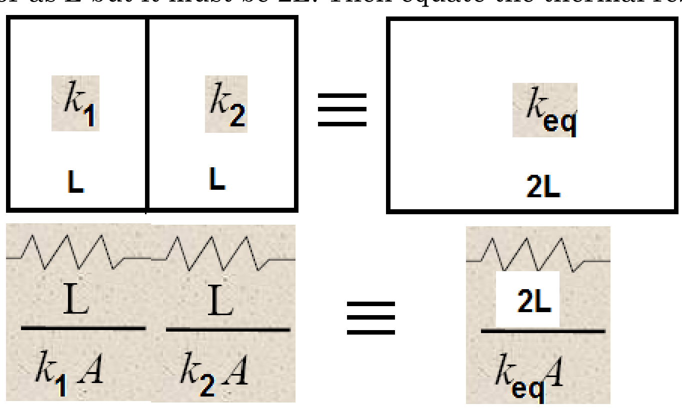
IES-15. Ans. (c) $Q_{AB} = Q_{BC}$



or $-k.A.\left(\dfrac{200-150}{\delta_1}\right) = -2kA\left(\dfrac{150-100}{\delta_2}\right)$

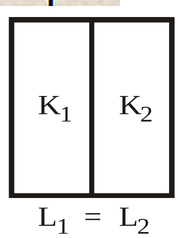
or $\dfrac{\delta_1}{\delta_2} = \dfrac{50}{2 \times 50} = \dfrac{1}{2}$

IES-16. Ans. (d) The common mistake student do is they take length of equivalent conductor as L but it must be $2L$. Then equate the thermal resistance of them.



IES-17. Ans. (c) $\dfrac{1}{K_{eq}} = \dfrac{1}{2}\left(\dfrac{1}{K_1} + \dfrac{1}{K_2}\right)$

$$K_{eq} = \frac{2K_1K_2}{K_1 + K_2}$$



IES-18. Ans. (d) Same questions [IES-1997] and [IES-2000]

IES-19. Ans. (c) For two insulating layers, $\dfrac{Q}{A} = \dfrac{t_1 - t_2}{\dfrac{\Delta x_1}{k_1} + \dfrac{\Delta x_2}{k_2}} = \dfrac{1000-120}{\dfrac{0.3}{3} + \dfrac{0.3}{0.3}} = 800$

Considering first layer, $\dfrac{Q}{A} = \dfrac{1000 - T_i}{\dfrac{0.3}{3}} = 800$, or $T_i = 1000 - 80 = 920°\text{C}$

IES-20. Ans. (a)
IES-21. Ans. (a)
IES-22. Ans. (b) $800 = \frac{t_B - t_o}{1/h} = \frac{t_B - 25}{1/80}$
IES-23. Ans. (d)
IES-24. Ans. (d)
IES-25. Ans. (a)

IES-26. Ans. (c) Temp distribution would be $\frac{t - t_1}{t_2 - t_1} = \frac{\frac{1}{r} - \frac{1}{r_1}}{\frac{1}{r_2} - \frac{1}{r_1}}$

IES-27. Ans. (c) Resistance $(R) = \frac{r_2 - r_1}{4\pi k(r_1 r_2)}$ $\because$ $Q = \frac{\Delta t}{R} = \frac{4\pi k(t_1 - t_2)}{\left(\frac{r_2 - r_1}{r_1 r_2}\right)}$

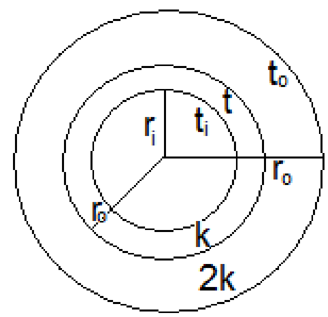
IES-28. Ans. (c)
IES-29. Ans. (a)
IES-30. Ans. (d) $r_i = 0.8\ r_o$ and $r = r_i + t = r_2 - t$

$$\Rightarrow 2r = r_i + r_o \quad \Rightarrow r = \frac{r_i + r_o}{2}$$

$$\Rightarrow r = \frac{r_i + 1.25 r_i}{2} = 1.125 r_i$$

$$\Rightarrow r = \frac{0.8 r_o + r_o}{2} = 0.9 r_o \quad \Rightarrow \frac{r_0}{r} = \frac{1}{0.9}$$

$$\therefore Q = \frac{t_i - t}{\frac{r - r_i}{4\pi k r r_i}} = \frac{t - t_o}{\frac{r_o - r}{4\pi (2k) r r_o}}$$



IES-31. Ans. (d)

Previous 20-Years IAS Answers

IAS-1. Ans. (c) $A_m = \sqrt{A_1 A_2} = \sqrt{2 \times 8} = 4\ \text{m}^2$

3. Critical Thickness of Insulation

OBJECTIVE QUESTIONS (GATE, IES, IAS)

Previous 20-Years GATE Questions

Critical Thickness of Insulation

GATE-1. A steel steam pipe 10 cm inner diameter and 11 cm outer diameter is covered with insulation having the thermal conductivity of 1 W/mK. If the convective heat transfer coefficient between the surface of insulation and the surrounding air is 8 W / m²K, then critical radius of insulation is: [GATE-2000]

(a) 10 cm (b) 11 cm (c) 12.5 cm (d) 15 cm

GATE-2. It is proposed to coat a 1 mm diameter wire with enamel paint (*k* = 0.1 W/mK) to increase heat transfer with air. If the air side heat transfer coefficient is 100 W/m²K, then optimum thickness of enamel paint should be: [GATE-1999]

(a) 0.25 mm (b) 0.5 mm (c) 1 mm (d) 2 mm

GATE-3. For a current wire of 20 mm diameter exposed to air (*h* = 20 W/m²K), maximum heat dissipation occurs when thickness of insulation (*k* = 0.5 W/mK) is: [GATE-1993; 1996]

(a) 20 mm (b) 25 mm (c) 20 mm (d) 10 mm

Heat Conduction with Heat Generation in the Nuclear Cylindrical Fuel Rod

GATE-4. Two rods, one of length *L* and the other of length 2L are made of the same material and have the same diameter. The two ends of the longer rod are maintained at 100°C. One end of the shorter rod *Is* maintained at 100°C while the other end is insulated. Both the rods are exposed to the same environment at 40°C. The temperature at the insulated end of the shorter rod is measured to be 55°C. The temperature at the mid-point of the longer rod would be: [GATE-1992]

(a) 40°C (b) 50°C (c) 55°C (d) 100°C

Previous 20-Years IES Questions

Critical Thickness of Insulation

IES-1. Upto the critical radius of insulation: [IES-1993; 2005]

(a) Added insulation increases heat loss

(b) Added insulation decreases heat loss
(c) Convection heat loss is less than conduction heat loss
(d) Heat flux decreases

IES-2. Upto the critical radius of insulation [IES-2010]
(a) Convection heat loss will be less than conduction heat loss
(b) Heat flux will decrease
(c) Added insulation will increase heat loss
(d) Added insulation will decrease heat loss

IES-3. The value of thermal conductivity of thermal insulation applied to a hollow spherical vessel containing very hot material is 0·5 W/mK. The convective heat transfer coefficient at the outer surface of insulation is 10 W/m²K.
What is the critical radius of the sphere? [IES-2008]
(a) 0·1 m (b) 0·2 m (c) 1·0 m (d) 2·0 m

IES-4. A hollow pipe of 1 cm outer diameter is to be insulated by thick cylindrical insulation having thermal conductivity 1 W/mK. The surface heat transfer coefficient on the insulation surface is 5 W/m²K. What is the minimum effective thickness of insulation for causing the reduction in heat leakage from the insulated pipe? [IES-2004]
(a) 10 cm (b) 15 cm (c) 19.5 cm (d) 20 cm

IES-5. A metal rod of 2 cm diameter has a conductivity of 40W/mK, which is to be insulated with an insulating material of conductivity of 0.1 W/m K. If the convective heat transfer coefficient with the ambient atmosphere is 5 W/m²K, the critical thickness of insulation will be: [IES-2001; 2003]
(a) 1 cm (b) 2 cm (c) 7 cm (d) 8 cm

IES-6. A copper wire of radius 0.5 mm is insulated with a sheathing of thickness 1 mm having a thermal conductivity of 0.5 W/m – K. The outside surface convective heat transfer coefficient is 10 W/m² – K. If the thickness of insulation sheathing is raised by 10 mm, then the electrical current-carrying capacity of the wire will: [IES-2000]
(a) Increase (b) Decrease
(c) Remain the same (d) Vary depending upon the electrical conductivity of the wire

IES-7. In current carrying conductors, if the radius of the conductor is less than the critical radius, then addition of electrical insulation is desirable, as [IES-1995]
(a) It reduces the heat loss from the conductor and thereby enables the conductor to carry a higher current.
(b) It increases the heat loss from the conductor and thereby enables the conductor to carry a higher current.
(c) It increases the thermal resistance of the insulation and thereby enables the conductor to carry a higher current.
(d) It reduces the thermal resistance of the insulation and thereby enables the conductor to carry a higher current.

IES-8. It is desired to increase the heat dissipation rate over the surface of an electronic device of spherical shape of 5 mm radius exposed to convection with h = 10 W/m²K by encasing it in a spherical sheath of

conductivity 0.04 W/mK, For maximum heat flow, the diameter of the sheath should be: [IES-1996]

(a) 18 mm (b) 16 mm (c) 12 mm (d) 8 mm

IES-9. What is the critical radius of insulation for a sphere equal to?
k = thermal conductivity in W/m-K [IES-2008]
h = heat transfer coefficient in W/m²K

(a) 2kh (b) 2k/h (c) k/h (d) $\sqrt{2\text{kh}}$

IES-10. Assertion (A): Addition of insulation to the inside surface of a pipe always reduces heat transfer rate and critical radius concept has no significance. [IES-1995]
Reason (R): If insulation is added to the inside surface, both surface resistance and internal resistance increase.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-11. Match List-I (Parameter) with List-II (Definition) and select the correct answer using the codes given below the lists: [IES-1995]

List-I	List-II
A. Time constant of a thermometer of radius r_o	**1.** hr_o/k_{fluid}
B. Biot number for a sphere of radius r_o	**2.** k/h
C. Critical thickness of insulation for a wire of radius r_o	**3.** hr_o/k_{solid}
D. Nusselt number for a sphere of radius r_o	**4.** $h_2\pi r_o l/\rho cV$

***Nomenclature*: h: Film heat transfer coefficient, k_{solid}: Thermal conductivity of solid, k_{fluid}: Thermal conductivity of fluid, ρ: Density, c: Specific heat, V: Volume, l: Length.**

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

IES-12. An electric cable of aluminium conductor (k = 240 W/mK) is to be insulated with rubber (k = 0.15 W/mK). The cable is to be located in air (h = 6W/m²). The critical thickness of insulation will be: [IES-1992]

(a) 25mm (b) 40 mm (c) 160 mm (d) 800 mm

IES-13. Consider the following statements: [IES-1996]

1. Under certain conditions, an increase in thickness of insulation may increase the heat loss from a heated pipe.
2. The heat loss from an insulated pipe reaches a maximum when the outside radius of insulation is equal to the ratio of thermal conductivity to the surface coefficient.
3. Small diameter tubes are invariably insulated.
4. Economic insulation is based on minimum heat loss from pipe.

Of these statements

(a) 1 and 3 are correct (b) 2 and 4 are correct
(c) 1 and 2 are correct (d) 3 and 4 are correct.

IES-14. A steam pipe is to be lined with two layers of insulating materials of different thermal conductivities. For minimum heat transfer

(a) The better insulation must be put inside **[IES-1992; 1994; 1997]**

(b) The better insulation must be put outside
(c) One could place either insulation on either side
(d) One should take into account the steam temperature before deciding as to which insulation is put where.

Heat Conduction with Internal Heat Generation

IES-15. Water jacketed copper rod "*D*" m in diameter is used to carry the current. The water, which flows continuously maintains the rod temperature at $T_i^o C$ during normal operation at "*I*" amps. The electrical resistance of the rod is known to be "*R*" Ω/m. If the coolant water ceased to be available and the heat removal diminished greatly, the rod would eventually melt. What is the time required for melting to occur if the melting point of the rod material is T_{mp}? [IES-1995]
[C_p = specific heat, ρ = density of the rod material and *L* is the length of the rod]

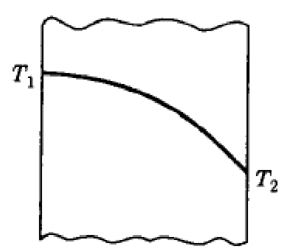
(a) $\frac{\rho(\pi D^2/4)C_p(T_{mp}-T_i)}{I^2R}$ (b) $\frac{(T_{mp}-T_i)}{\rho I^2R}$ (c) $\frac{\rho(T_{mp}-T_i)}{I^2}$ (d) $\frac{C_p(T_{mp}-T_i)}{I^2R}$

Plane Wall with Uniform Heat Generation

IES-16. A plane wall of thickness 2L has a uniform volumetric heat source q* (W/m³). It is exposed to local ambient temperature T_∞ at both the ends (x = ± L). The surface temperature T_s of the wall under steady-state condition (where h and k have their usual meanings) is given by: [IES-2001]

(a) $T_s = T_\infty + \frac{q^*L}{h}$ (b) $T_s = T_\infty + \frac{q^*L^2}{2k}$ (c) $T_s = T_\infty + \frac{q^*L^2}{h}$ (d) $T_s = T_\infty + \frac{q^*L^3}{2k}$

IES-17. The temperature variation in a large plate, as shown in the given figure, would correspond to which of the following condition (s)?
1. Unsteady heat
2. Steady-state with variation of k
3. Steady-state with heat generation



Select the correct answer using the codes given below: [IES-1998]
Codes: (a) 2 alone (b) 1 and 2 (c) 1 and 3 (d) 1, 2 and 3

IES-18. In a long cylindrical rod of radius *R* and a surface heat flux of q_o the uniform internal heat generation rate is: [IES-1998]

(a) $\frac{2q_0}{R}$ (b) $2q_0$ (c) $\frac{q_0}{R}$ (d) $\frac{q_0}{R^2}$

Previous 20-Years IAS Questions

Critical Thickness of Insulation

IAS-1. In order to substantially reduce leakage of heat from atmosphere into cold refrigerant flowing in small diameter copper tubes in a refrigerant system, the radial thickness of insulation, cylindrically wrapped around the tubes, must be: [IAS-2007]

(a) Higher than critical radius of insulation
(b) Slightly lower than critical radius of insulation
(c) Equal to the critical radius of insulation
(d) Considerably higher than critical radius of insulation

IAS-2. A copper pipe carrying refrigerant at – 200 C is covered by cylindrical insulation of thermal conductivity 0.5 W/m K. The surface heat transfer coefficient over the insulation is 50 W/m² K. The critical thickness of the insulation would be: [IAS-2001]

(a) 0.01 m (b) 0.02 m (c) 0.1 m (d) 0.15 m

Answers with Explanation (Objective)

Previous 20-Years GATE Answers

GATE-1. Ans. (c) Critical radius of insulation (r_c) = $\frac{k}{h} = \frac{1}{8}\text{ m} = 12.5\text{ cm}$

GATE-2. Ans. (b) Critical radius of insulation (r_c) = $\frac{k}{h} = \frac{0.1}{100}\text{ m} = 1\text{ mm}$

$\therefore$ Critical thickness of enamel point $= r_c - r_i = 1 - \frac{1}{2} = 0.5\text{ mm}$

GATE-3. Ans. (b) Maximum heat dissipation occurs when thickness of insulation is critical.

Critical radius of insulation $(r_c) = \frac{k}{h} = \frac{0.5}{20}\text{ m} = 25\text{ mm}$

Therefore thickness of insulation = $r_c - r_i = 25 - \frac{20}{2} = 15\text{ mm}$

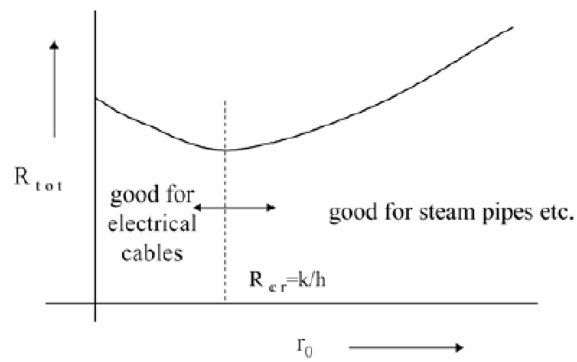
GATE-4. Ans. (c)

Previous 20-Years IES Answers

IES-1. Ans. (a)

IES-2. Ans. (c) The thickness upto which heat flow increases and after which heat flow decreases is termed as Critical thickness. In case of cylinders and spheres it is called 'Critical radius'.

IES-3. Ans. (a) Minimum q at r_o = (k/h) = r_{cr} (critical radius)



IES-4. Ans. (c) Critical radius of insulation (r_c) $= \frac{k}{h} = \frac{1}{5} = 0.2\text{ m} = 20\text{ cm}$

$\therefore$ Critical thickness of insulation $(\Delta r)_C = r_c - r_1 = 20 - 0.5 = 19.5\text{ cm}$

IES-5. Ans. (a) Critical radius of insulation $(r_c) = \frac{K}{h} = \frac{0.1}{5} = 0.02\text{ m} = 2\text{ cm}$

Critical thickness of insulation $(t) = r_c - r_1 = 2 - 1 = 1\text{ cm}$

IES-6. Ans. (a)

IES-7. Ans. (b)

IES-8. Ans. (b) The critical radius of insulation for ensuring maximum heat transfer by conduction (r) = $\frac{2k}{h} = \frac{2 \times 0.04}{10}\text{ m} = 8\text{ mm}.$ Therefore diameter should be 16 mm.

IES-9. Ans. (b) Critical radius of insulation for sphere in $\frac{2k}{h}$ and for cylinder is k/h

IES-10. Ans. (a) A and R are correct. R is right reason for A.

IES-11. Ans. (a)

IES-12. Ans. (a)

IES-13. Ans. (c)

IES-14. Ans. (a) For minimum heat transfer, the better insulation must be put inside.

IES-15. Ans. (a)

IES-16. Ans. (a)

IES-17. Ans. (a)

IES-18. Ans. (a)

Previous 20-Years IAS Answers

IAS-1. Ans. (d) At critical radius of insulation heat leakage is maximum if we add more insulation then heat leakage will reduce.

IAS-2. Ans. (a) Critical radius of insulation $\left(r_c\right) = \frac{k}{h} = \frac{0.5}{50}\,\text{m} = 0.01\,\text{m}$

4. Heat Transfer from Extended Surfaces (Fins)

OBJECTIVE QUESTIONS (GATE, IES, IAS)

Previous 20-Years GATE Questions

Heat Dissipation from a Fin Insulated at the Tip

GATE-1. A fin has 5mm diameter and 100 mm length. The thermal conductivity of fin material is 400 $Wm^{-1}K^{-1}$. One end of the fin is maintained at 130ºC and its remaining surface is exposed to ambient air at 30ºC. If the convective heat transfer coefficient is 40 $Wm^{-2}K^{-1}$, the heat loss (in W) from the fin is: [GATE-2010]

(a) 0.08 (b) 5.0 (c) 7.0 (d) 7.8

Estimation of Error in Temperature Measurement in a Thermometer Well

GATE-2. When the fluid velocity is doubled, the thermal time constant of a thermometer used for measuring the fluid temperature reduces by a factor of 2. [GATE-1994]

Previous 20-Years IES Questions

IES-1. From a metallic wall at 100°C, a metallic rod protrudes to the ambient air. The temperatures at the tip will be minimum when the rod is made of: [IES-1992]

(a) Aluminium (b) Steel (d) Copper (d) Silver

IES-2. On heat transfer surface, fins are provided [IES-2010]

(a) To increase temperature gradient so as to enhance heat transfer
(b) To increase turbulence in flow for enhancing heat transfer
(c) To increase surface are to promote the rate of heat transfer
(d) To decrease the pressure drop of the fluid

Heat Dissipation from an Infinitely Long Fin

IES-3. The temperature distribution in a stainless fin (thermal conductivity 0.17 W/cm°C) of constant cross -sectional area of 2 cm^2 and length of 1-cm, exposed to ambient of 40°C (with a surface heat transfer coefficient

of 0.0025 W/cm$^{2\,0}$C) is given by $(T - T_\infty) = 3x^2 - 5x + 6$, where T is in °C and x is in cm. If the base temperature is 100°C, then the heat dissipated by the fin surface will be: **[IES-1994]**

(a) 6.8 W (b) 3.4 W (c) 1.7 W (d) 0.17 W

Heat Dissipation from a Fin Insulated at the Tip

IES-4. The insulated tip temperature of a rectangular longitudinal fin having an excess (over ambient) root temperature of θ_o is: **[IES-2002]**

(a) $\theta_o \tan h(ml)$ (b) $\dfrac{\theta_o}{\sin h(ml)}$ (c) $\dfrac{\theta_o \tan h(ml)}{(ml)}$ (d) $\dfrac{\theta_o}{\cos h(ml)}$

IES-5. The efficiency of a pin fin with insulated tip is: **[IES-2001]**

(a) $\dfrac{\tan hmL}{(hA/kP)^{0.5}}$ (b) $\dfrac{\tan hmL}{mL}$ (c) $\dfrac{mL}{\tan hmL}$ (d) $\dfrac{(hA/kP)^{0.5}}{\tan hmL}$

IES-6. A fin of length 'l' protrudes from a surface held at temperature t_o greater than the ambient temperature t_a. The heat dissipation from the free end' of the fin is assumed to be negligible. The temperature gradient at the fin tip $\left(\dfrac{dt}{dx}\right)_{x=l}$ is: **[IES-1999]**

(a) Zero (b) $\dfrac{t_1 - t_a}{t_o - t_a}$ (c) $h(t_o - t_l)$ (d) $\dfrac{t_o - t_l}{l}$

IES-7. A fin of length l protrudes from a surface held at temperature T_o; it being higher than the ambient temperature T_a. The heat dissipation from the free end of the fin is stated to be negligibly small, What is the temperature gradient $\left(\dfrac{dT}{dx}\right)_{x=l}$ at the tip of the fin? **[IES-2008]**

(a) Zero (b) $\dfrac{T_o - T_l}{l}$ (c) $h(T_o - T_a)$ (d) $\dfrac{T_l - T_a}{T_o - T_a}$

Efficiency and Effectiveness of Fin

IES-8. Which one of the following is correct? **[IES-2008]**
The effectiveness of a fin will be maximum in an environment with

(a) Free convection (b) Forced convection
(c) Radiation (d) Convection and radiation

IES-9. Usually fins are provided to increase the rate of heat transfer. But fins also act as insulation. Which one of the following non-dimensional numbers decides this factor? **[IES-2007]**

(a) Eckert number (b) Biot number
(c) Fourier number (d) Peclet number

IES-10. Provision of fins on a given heat transfer surface will be more it there are: **[IES-1992]**

(a) Fewer number of thick fins (b) Fewer number of thin fins
(c) Large number of thin fins (d) Large number of thick fins

IES-11. Which one of the following is correct? [IES-2008]
Fins are used to increase the heat transfer from a surface by
(a) Increasing the temperature difference
(b) Increasing the effective surface area
(c) Increasing the convective heat transfer coefficient
(d) None of the above

IES-12. Fins are made as thin as possible to: [IES-2010]
(a) Reduce the total weight
(b) Accommodate more number of fins
(c) Increase the width for the same profile area
(d) Improve flow of coolant around the fin

IES-13. In order to achieve maximum heat dissipation, the fin should be designed in such a way that: [IES-2005]
(a) It should have maximum lateral surface at the root side of the fin
(b) It should have maximum lateral surface towards the tip side of the fin
(c) It should have maximum lateral surface near the centre of the fin
(d) It should have minimum lateral surface near the centre of the fin

IES-14. A finned surface consists of root or base area of 1 m^2 and fin surface area of 2 m^2. The average heat transfer coefficient for finned surface is 20 W/m^2K. Effectiveness of fins provided is 0.75. If finned surface with root or base temperature of 50°C is transferring heat to a fluid at 30°C, then rate of heat transfer is: [IES-2003]
(a) 400 W (b) 800 W (c) 1000 W (d) 1200 W

IES-15. Consider the following statements pertaining to large heat transfer rate using fins: [IES-2002]
1. Fins should be used on the side where heat transfer coefficient is small
2. Long and thick fins should be used
3. Short and thin fins should be used
4. Thermal conductivity of fin material should be large
Which of the above statements are correct?
(a) 1, 2 and 3 (b) 1, 2 and 4 (c) 2, 3 and 4 (d) 1, 3 and 4

IES-16. Assertion (A): In a liquid-to-gas heat exchanger fins are provided in the gas side. [IES-2002]
Reason (R): The gas offers less thermal resistance than liquid
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-17. Assertion (A): Nusselt number is always greater than unity.
Reason (R): Nusselt number is the ratio of two thermal resistances, one the thermal resistance which would be offered by the fluid, if it was stationary and the other, the thermal resistance associated with convective heat transfer coefficient at the surface. [IES-2001]

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-18. Extended surfaces are used to increase the rate of heat transfer. When the convective heat transfer coefficient h = mk, the addition of extended surface will: [IES-2010]
(a) Increase the rate of heat transfer
(b) Decrease the rate of heat transfer
(c) Not increase the rate of heat transfer
(d) Increase the rate of heat transfer when the length of the fin is very large

IES-19. Addition of fin to the surface increases the heat transfer if $\sqrt{hA/KP}$ is:
(a) Equal to one (b) Greater than one **[IES-1996]**
(c) Less than one (d) Greater than one but less than two

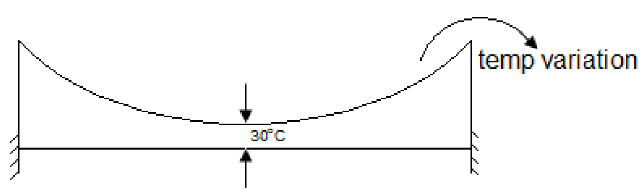
IES-20. Consider the following statements pertaining to heat transfer through fins: [IES-1996]
1. **Fins are equally effective irrespective of whether they are on the hot side or cold side of the fluid.**
2. **The temperature along the fin is variable and hence the rate of heat transfer varies along the elements of the fin.**
3. **The fins may be made of materials that have a higher thermal conductivity than the material of the wall.**
4. **Fins must be arranged at right angles to the direction of flow of the working fluid.**

Of these statements:
(a) 1 and 2 are correct (b) 2 and 4 are correct
(c) 1 and 3 are correct (d) 2 and 3 are correct.

Previous 20-Years IAS Questions

Heat Transfer from a Bar Connected to the Two Heat Sources at Different, Temperatures

IAS-1. A metallic rod of uniform diameter and length L connects two heat sources each at 500°C. The atmospheric temperature is 30°C. The temperature gradient $\frac{dT}{dL}$ at the centre of the bar will be: [IAS-2001]
(a) $\frac{500}{L/2}$ (b) $-\frac{500}{L/2}$
(c) $-\frac{470}{L/2}$ (d) Zero



Answers with Explanation (Objective)

Previous 20-Years GATE Answers

GATE-1. Ans. (b) $Q = \sqrt{h\,p\,K\,A}\;\theta_\circ \tan h(ml)$

$$m = \sqrt{\frac{hp}{KA}}; \quad P = 2\pi rl, \quad A = \frac{\pi}{4}d^2$$

Substituting we are getting

$\therefore$ Q=5 watt

GATE-2. Ans. False

Time constant by, $\Gamma = \dfrac{V.P.C}{Ah}$;

where V = Volume (m^3),
ρ = density (kg/m^3),
C = specific heat kJ/kgK,
A = Area (m^2),
h = surface film conductance W/M^2K.

When the velocity is doubled, h increases, thus τ, the time constant decreases. But it is not halved as the increase of 'h' is not two times due to the doubling of velocity.

(Since $= \dfrac{k}{\delta}$; therefore reduction of boundary layer thickness 'δ' is not linearly connected with variation in velocity).

Previous 20-Years IES Answers

IES-1. Ans. (b)

IES-2. Ans. (c) By the use of a fin, surface area is increased due to which heat flow rate increases. Increase in surface area decreases the surface convection resistance, whereas the conduction resistance increases. The decrease in convection resistance must be greater than the increase in conduction resistance in order to increase the rate of heat transfer from the surface. In practical applications of fins the surface resistance must be the controlling factor (the addition of fins might decrease the heat transfer rate under some situations).

IES-3. Ans. (b) Heat dissipated by fin surface

$$= \sqrt{\frac{hP}{kA}}\frac{t_1 - t_2}{x / kA} = \sqrt{\frac{0.0025\times 2}{0.17\times 1}} \times \frac{100-40}{1/0.17\times 2} = 3.4 \text{ W}$$

or Heat dissipated by fin surface $= h\int_0^l P dx \times \left(t - t_\alpha\right)$

IES-4. Ans. (d)

IES-5. Ans. (b)

IES-6. Ans. (a)

IES-7. Ans. (a) $hA(T_{at\ tip} - T_a) = -KA\left(\dfrac{dT}{dx}\right)_{x=l}$ = Negligibly small.

Therefore, the temperature gradient $\left(\frac{dT}{dx}\right)_{x=l}$ at the tip will be negligibly small i.e. zero.

IES-8. Ans. (a) The effectiveness of a fin can also be characterized as

$$\varepsilon_f = \frac{q_f}{q} = \frac{q_f}{hA_C\left(T_b - T_\infty\right)} = \frac{\left(T_b - T_\infty\right)/R_{t,f}}{\left(T_b - T_\infty\right)/R_{t,h}} = \frac{R_{t,h}}{R_{t,f}}$$

It is a ratio of the thermal resistance due to convection to the thermal resistance of a fin. In order to enhance heat transfer, the fin's resistance should be lower than that of the resistance due only to convection.

IES-9. Ans. (b)

IES-10. Ans. (c)

IES-11. Ans. (b)

IES-12. Ans. (b) Effectiveness (ε_{fin})

$$\boldsymbol{\varepsilon}_{\mathbf{fin}} = \frac{Q_{with\ fin}}{Q_{without\ fin}} = \sqrt{\frac{kP}{h\,A_{cs}}} = \frac{\sqrt{hPkA_{cs}}\left(t_0 - t_a\right)}{h\,A_{cs}\left(t_0 - t_a\right)}$$

If the ratio $\frac{P}{A_{cs}} is \uparrow \varepsilon_{fin} \uparrow$

IES-13. Ans. (a)

IES-14. Ans. (a) $\in = \sqrt{\frac{KP}{hA_C}} \qquad \Rightarrow \sqrt{KP} = 0.75 \times \sqrt{20 \times 1}$

$$q_{\text{fin}} = \left(\sqrt{hPKA_C}\right)\theta_0$$

$$= \sqrt{20 \times 1} \cdot \sqrt{20 \times 1} \times 0.75 \times 20$$

$$20 \times 0.75 \times 20 = 300\,W$$

$$\in = \frac{Q_{\text{fin}}}{Q_{\text{without fin}}} = \frac{300}{75} = 400\ W$$

If $\in < 1$; fins behave like insulator.

IES-15. Ans. (d)

IES-16. Ans. (c)

IES-17. Ans. (a)

IES-18. Ans. (c)

IES-19. Ans. (c) Addition of fin to the surface increases the heat transfer if $\sqrt{hA/KP}$ <<1.

IES-20. Ans. (d)

Previous 20-Years IAS Answers

IAS-1. Ans. (d)

5. One Dimensional Unsteady Conduction

OBJECTIVE QUESTIONS (GATE, IES, IAS)

Previous 20-Years GATE Questions

Heat Conduction in Solids having Infinite Thermal Conductivity (Negligible internal Resistance-Lumped Parameter Analysis)

GATE-1. The value of Biot number is very small (less than 0.01) when **[GATE-2002]**
(a) The convective resistance of the fluid is negligible
(b) The conductive resistance of the fluid is negligible
(c) The conductive resistance of the solid is negligible
(d) None of these

GATE-2. A small copper ball of 5 mm diameter at 500 K is dropped into an oil bath whose temperature is 300 K. The thermal conductivity of copper is 400 W/mK, its density 9000 kg/m^3 and its specific heat 385 J/kg.K.1f the heat transfer coefficient is 250 W/m^{2}K and lumped analysis is assumed to be valid, the rate of fall of the temperature of the ball at the beginning of cooling will be, in K/s. **[GATE-2005]**
(a) 8.7 (b) 13.9 (c) 17.3 (d) 27.7

GATE-3. A spherical thermocouple junction of diameter 0.706 mm is to be used for the measurement of temperature of a gas stream. The convective heat transfer co-efficient on the bead surface is 400 W/m^{2}K. Thermophysical properties of thermocouple material are k = 20 W/mK, C =400 J/kg, K and ρ = 8500 kg/m^3. If the thermocouple initially at 30°C is placed in a hot stream of 300°C, then time taken by the bead to reach 298°C, is: **[GATE-2004]**
(a) 2.35 s (b) 4.9 s (c) 14.7 s (d) 29.4 s

Previous 20-Years IES Questions

Heat Conduction in Solids having Infinite Thermal Conductivity (Negligible internal Resistance-Lumped Parameter Analysis)

IES-1. Assertion (A): Lumped capacity analysis of unsteady heat conduction assumes a constant uniform temperature throughout a solid body.
Reason (R): The surface convection resistance is very large compared with the internal conduction resistance. [IES-2010]

IES-2. The ratio $\dfrac{\text{Internal conduction resistance}}{\text{Surface convection resistance}}$ is known as [IES-1992]
(a) Grashoff number (b) Biot number
(c) Stanton number (b) Prandtl number

IES-3. Which one of the following statements is correct? [IES-2004]
The curve for unsteady state cooling or heating of bodies
(a) Parabolic curve asymptotic to time axis
(b) Exponential curve asymptotic to time axis
(c) Exponential curve asymptotic both to time and temperature axis
(d) Hyperbolic curve asymptotic both to time and temperature axis

IES-4. Assertion (A): In lumped heat capacity systems the temperature gradient within the system is negligible [IES-2004]
Reason (R): In analysis of lumped capacity systems the thermal conductivity of the system material is considered very high irrespective of the size of the system
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-5. A solid copper ball of mass 500 grams, when quenched in a water bath at 30°C, cools from 530°C to 430°C in 10 seconds. What will be the temperature of the ball after the next 10 seconds? [IES-1997]
(a) 300°C (b) 320°C
(c) 350°C (d) Not determinable for want of sufficient data

Time Constant and Response of — Temperature Measuring Instruments

IES-6. A thermocouple in a thermo-well measures the temperature of hot gas flowing through the pipe. For the most accurate measurement of temperature, the thermo-well should be made of: [IES-1997]
(a) Steel (b) Brass (c) Copper (d) Aluminium

Transient Heat Conduction in Semi-infinite Solids *(h or Hj 4.5. 30~5 00)*

IES-7. Heisler charts are used to determine transient heat flow rate and temperature distribution when: [IES-2005]

(a) Solids possess infinitely large thermal conductivity
(b) Internal conduction resistance is small and convective resistance is large
(c) Internal conduction resistance is large and the convective resistance is small
(d) Both conduction and convention resistance are almost of equal significance

Previous 20-Years IAS Questions

Time Constant and Response of — Temperature Measuring Instruments

IAS-1. Assertion (A): During the temperature measurement of hot gas in a duct that has relatively cool walls, the temperature indicated by the thermometer will be lower than the true hot gas temperature.

Reason(R): The sensing tip of thermometer receives energy from the hot gas and loses heat to the duct walls. [IAS-2000]

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Answers with Explanation (Objective)

Previous 20-Years GATE Answers

GATE-1. Ans. (c)

GATE-2. Ans. (c)

$$\text{Charactaristic length}\,(L_c) = \frac{V}{A_s} = \frac{\frac{4}{3}\pi r^3}{4\pi r^2} = \frac{r}{3} = \frac{0.005/2}{3} = 8.3333\times10^{-4}\,\text{m}$$

$$\text{Thermal diffusivity, } \alpha = \frac{k}{\rho c_p} = \frac{400}{9000\times385} = 1.1544\times10^{-4}$$

$$\text{Fourier number } (F_o) = \frac{\alpha\tau}{L_c^2} = 166\tau$$

$$\text{Biot number } (B_i) = \frac{hL_c}{k} = \frac{250\times8.3333\times10^{-4}}{400} = 5.208\times10^{-4}$$

Then,

$$\frac{\theta}{\theta_i} = \frac{T-T_a}{T_i-T_a} = e^{-B_i\times F_o} \quad or \quad \frac{T-300}{500-300} = e^{-166\tau\times5.208\times10^{-4}}$$

$$\text{or } \ln(T-300) - \ln 200 = -0.08646\,\tau$$

$$\text{or } \frac{1}{(T-300)}\frac{dT}{d\tau} = -0.08646 \quad \text{or} \quad \left(\frac{dT}{d\tau}\right)_{T\approx500K} = -0.08646\times(500-300) = -17.3\,\text{K/s}$$

GATE-3. Ans. (b) Characteristic length (L_c) = $\frac{V}{A} = \frac{\frac{4}{3}\pi r^3}{4\pi r^2} = \frac{r}{3} = 0.11767\times10^{-3}$ m

$$\text{Biot number } (B_i) = \frac{hL_c}{k} = \frac{400\times(0.11767\times10^{-3})}{20} = 2.3533\times10^{-3}$$

As $B_i < 0.1$ the lumped heat capacity approach can be used

$$\alpha = \frac{k}{\rho c_p} = \frac{20}{8500\times400} = 5.882\times10^{-6}\ \text{m}^2/\text{s}$$

$$\text{Fourier number } (F_o) = \frac{\alpha\tau}{L_c^2} = 425\,\tau$$

$$\frac{\theta}{\theta_i} = e^{-F_o.B_i} \qquad \text{or } F_o.B_i = \ln\left(\frac{\theta}{\theta_i}\right)$$

$$\text{or } 425\tau\times2.3533\times10^{-3} = \ln\left(\frac{300-30}{300-298}\right) \qquad \text{or } \tau = 4.9\,s$$

Previous 20-Years IES Answers

IES-1. Ans. (a)
IES-2. Ans. (b)
IES-3. Ans. (b) $\dfrac{Q}{Q_o} = e^{-B_i \times F_o}$

IES-4. Ans. (a) If Biot number (B_i) = $\dfrac{hL_c}{k} = \dfrac{h}{k}.\left(\dfrac{V}{A_s}\right) < 0.1$ then use lumped heat capacity approach. It depends on size.

IES-5. Ans. (c) In first 10 seconds, temperature is fallen by 100°C. In next 10 seconds fall will be less than 100°C.

∴ 350°C appears correct solution.

You don't need following lengthy calculations (remember calculators are not allowed in IES objective tests).
This is the case of unsteady state heat conduction.
T_t = Fluid temperature
T_o = Initial temperature
T = Temperature after elapsing time 't'
Heat transferred = Change in internal energy

$$hA\left(T - T_t\right) = -mC_p\left(\frac{dT}{dt}\right)$$

This is derived to

$$\frac{\theta}{\theta_o} = \theta^{-\frac{hAt}{\rho C_p}} \quad \text{or} \quad \frac{T - T_\infty}{T_o - T_\infty} = e^{\frac{-hA}{\rho C_p V}t}$$

$$\text{or} \quad \frac{430 - 30}{530 - 30} = 0.8 = e^{\frac{-hA}{\rho C_p V}t} \; (t = 10\,\text{sec})$$

After 20 sec $(2t)$:

$$\frac{T - 30}{530 - 30} = e^{\frac{-hA}{\rho C_p V}(2t)} = \left[e^{\frac{-hA}{\rho C_p V}t}\right]^2 \quad \text{or} \quad \frac{T - 30}{500} = (0.8)^2 = 0.64$$

$\therefore \; T = 350°\text{C}$

IES-6. Ans. (a)
IES-7. Ans. (d)

Previous 20-Years IAS Answers

IAS-1. Ans. (a)

6. Free & Forced Convection

OBJECTIVE QUESTIONS (GATE, IES, IAS)

Previous 20-Years GATE Questions

GATE-1. A coolant fluid at 30°C flows over a heated flat plate maintained at a constant temperature of 100°C. The boundary layer temperature distribution at a given location on the plate may be approximated as $T = 30 + 70\exp(-y)$ where y (in m) is the distance normal to the plate and T is in °C. If thermal conductivity of the fluid is 1.0 W/mK, the local convective heat transfer coefficient (in W/m²K) at that location will be: [GATE-2009]

(a) 0.2 (b) 1 (c) 5 (d) 10

GATE-2. The properties of mercury at 300 K are: density = 13529 kg/m³, specific heat at constant pressure = 0.1393 kJ/kg-K, dynamic viscosity = 0.1523 × 10^{-2} N.s/m² and thermal conductivity = 8.540 W/mK. The Prandtl number of the mercury at 300 K is: [GATE-2002]

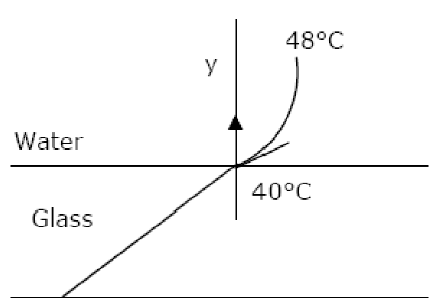
(a) 0.0248 (b) 2.48 (c) 24.8 (d) 248

GATE-3. The average heat transfer coefficient on a thin hot vertical plate suspended in still air can be determined from observations of the change in plate temperature with time as it cools. Assume the plate temperature to be uniform at any instant of time and radiation heat exchange with the surroundings negligible. The ambient temperature is 25°C, the plate has a total surface area of 0.1 m² and a mass of 4 kg. The specific heat of the plate material is 2.5 kJ/kgK. The convective heat transfer coefficient in W/m²K, at the instant when the plate temperature is 225°C and the change in plate temperature with time $dT/dt = -0.02$ K/s, is: [GATE-2007]

(a) 200 (b) 20 (c) 15 (d) 10

Data for Q4–Q5 are given below. Solve the problems and choose correct answers.

Heat is being transferred by convection from water at 48°C to a glass plate whose surface that is exposed to the water is at 40°C. The thermal conductivity of water is 0.6 W/mK and the thermal conductivity of glass is 1.2 W/mK. The spatial gradient of temperature in the water at the water-glass interface is dT/dy =1 × 10^4 K/m.



[GATE-2003]

GATE-4. The value of the temperature gradient in the glass at the water-glass interface in k/m is:
(a) -2×10^4 (b) 0.0 (c) 0.5×10^4 (d) 2×10^4

GATE-5. The heat transfer coefficient h in W/m²K is:
(a) 0.0 (b) 4.8 (c) 6 (d) 750

GATE-6. If velocity of water inside a smooth tube is doubled, then turbulent flow heat transfer coefficient between the water and the tube will:
(a) Remain unchanged **[GATE-1999]**
(b) Increase to double its value
(c) Increase but will not reach double its value
(d) Increase to more than double its value

Previous 20-Years IES Questions

IES-1. A sphere, a cube and a thin circular plate, all made of same material and having same mass are initially heated to a temperature of 250°C and then left in air at room temperature for cooling. Then, which one of the following is correct? [IES-2008]
(a) All will be cooled at the same rate
(b) Circular plate will be cooled at lowest rate
(c) Sphere will be cooled faster
(d) Cube will be cooled faster than sphere but slower than circular plate

IES-2. A thin flat plate 2 m by 2 m is hanging freely in air. The temperature of the surroundings is 25°C. Solar radiation is falling on one side of the rate at the rate of 500 W/m². The temperature of the plate will remain constant at 30°C, if the convective heat transfer coefficient (in W/m² °C) is: [IES-1993]
(a) 25 (b) 50 (c) 100 (d) 200

IES-3. Air at 20°C blows over a hot plate of 50 × 60 cm made of carbon steel maintained at 220°C. The convective heat transfer coefficient is 25 W/m²K. What will be the heat loss from the plate? [IES-2009]
(a) 1500W (b) 2500 W (c) 3000 W (d) 4000 W

IES-4. For calculation of heat transfer by natural convection from a horizontal cylinder, what is the characteristic length in Grashof Number? [IES-2007]
(a) Diameter of the cylinder
(b) Length of the cylinder
(c) Circumference of the base of the cylinder
(d) Half the circumference of the base of the cylinder

IES-5. Assertion (A): For the similar conditions the values of convection heat transfer coefficients are more in forced convection than in free convection. [IES-2009]

Reason (R): In case of forced convection system the movement of fluid is by means of external agency.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R individually true but R in not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-6. Assertion (A): A slab of finite thickness heated on one side and held horizontal will lose more heat per unit time to the cooler air if the hot surface faces upwards when compared with the case where the hot surface faces downwards. [IES-1996]
Reason (R): When the hot surface faces upwards, convection takes place easily whereas when the hot surface faces downwards, heat transfer is mainly by conduction through air.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-7. For the fully developed laminar flow and heat transfer in a uniformly heated long circular tube, if the flow velocity is doubled and the tube diameter is halved, the heat transfer coefficient will be: [IES-2000]

(a) Double of the original value (b) Half of the original value
(c) Same as before (d) Four times of the original value

IES-8. Assertion (A): According to Reynolds analogy for Prandtl number equal to unity, Stanton number is equal to one half of the friction factor.
Reason (R): If thermal diffusivity is equal to kinematic viscosity, the velocity and the temperature distribution in the flow will be the same.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false **[IES-2001]**
(d) A is false but R is true

IES-9. The Nusselt number is related to Reynolds number in laminar and turbulent flows respectively as [IES-2000]

(a) $Re^{-1/2}$ and $Re^{0.8}$ (b) $Re^{1/2}$ and $Re^{0.8}$ (c) $Re^{-1/2}$ and $Re^{-0.8}$ (d) $Re^{1/2}$ and $Re^{-0.8}$

IES-10. In respect of free convection over a vertical flat plate the Nusselt number varies with Grashof number 'Gr' as [IES-2000]

(a) Gr and $Gr^{1/4}$ for laminar and turbulent flows respectively
(b) $Gr^{1/2}$ and $Gr^{1/3}$ for laminar and turbulent flows respectively
(c) $Gr^{1/4}$ and $Gr^{1/3}$ for laminar and turbulent flows respectively
(d) $Gr^{1/3}$ and $Gr^{1/4}$ for laminar and turbulent flows respectively

IES-11. Heat is lost from a 100 mm diameter steam pipe placed horizontally in ambient at 30°C. If the Nusselt number is 25 and thermal conductivity of air is 0.03 W/mK, then the heat transfer co-efficient will be: [IES-1999]

(a) 7.5 W/m²K (b) 16.2 W/m²K (c) 25.2 W/m² K (d) 30 W/m²K

IES-12. Match List-I (Non-dimensional number) with List-II (Application) and select the correct answer using the code given below the lists:

List-I List-II [IES 2007]

A. Grashof number
B. Stanton number
C. Sherwood number
D. Fourier number

1. Mass transfer
2. Unsteady state heat conduction
3. Free convection
4. Forced convection

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

IES-13. Match List-I (Type of heat transfer) with List-II (Governing dimensionless parameter) and select the correct answer: [IES-2002]

List-I	**List-II**
A. Forced convection	**1.** Reynolds, Grashof and Prandtl number
B. Natural convection	**2.** Reynolds and Prandtl number
C. Combined free and forced convection	**3.** Fourier modulus and Biot number
D. Unsteady conduction with convection at surface	**4.** Prandtl number and Grashof number

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

IES-14. Match List-I (Phenomenon) with List-II (Associated dimensionless parameter) and select the correct answer using the code given below the lists: [IES-2006]

List-I	**List-II**
A. Transient conduction	**1.** Reynolds number
B. Forced convection	**2.** Grashoff number
C. Mass transfer	**3.** Biot number
D. Natural convection	**4.** Mach number
	5. Sherwood number

Codes:	**A**	**B**	**C**	**D**		**A**	**B**	**C**	**D**
(a)	3	2	5	1	(b)	5	1	4	2
(c)	3	1	5	2	(d)	5	2	4	1

IES-15. Match List-I (Process) with List-II (Predominant parameter associated with the flow) and select the correct answer: [IES-2004]

List-I	**List-II**
A. Transient conduction	**1.** Sherwood Number
B. Mass transfer	**2.** Mach Number
C. Forced convection	**3.** Biot Number
D. Free convection	**4.** Grashof Number
	5. Reynolds number

Codes:	**A**	**B**	**C**	**D**		**A**	**B**	**C**	**D**
(a)	1	3	5	4	(b)	3	1	2	5
(c)	3	1	5	4	(d)	1	3	2	5

IES-16. Which one of the following non-dimensional numbers is used for transition from laminar to turbulent flow in free convection? [IES-2007]

(a) Reynolds number (b) Grashof number
(c) Peclet number (d) Rayleigh number

IES-17. Match List-I (Process) with List-II (Predominant parameter associated with the process) and select the correct answer using the codes given below the lists: [IES-2003]

List-I		**List-II**	
A.	Mass transfer	**1.**	Reynolds Number
B.	Forced convection	**2.**	Sherwood Number
C.	Free convection	**3.**	Mach Number
D.	Transient conduction	**4.**	Biot Number
		5.	Grashoff Number

Codes:	**A**	**B**	**C**	**D**		**A**	**B**	**C**	**D**
(a)	5	1	2	3	(b)	2	1	5	4
(c)	4	2	1	3	(d)	2	3	5	4

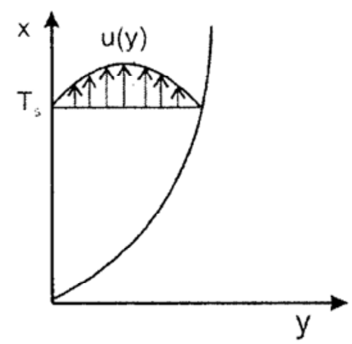
IES-18. In free convection heat transfer transition from laminar to turbulent flow is governed by the critical value of the [IES-1992]

(a) Reynolds number
(b) Grashoff's number
(c) Reynolds number, Grashoff number
(d) Prandtl number, Grashoff number

IES-19. Nusselt number for fully developed turbulent flow in a pipe is given by $N_u = CR_e^a P_r^b$. The values of a and b are: [IES-2001]

(a) $a = 0.5$ and $b = 0.33$ for heating and cooling both
(b) $a = 0.5$ and $b = 0.4$ for heating and $b = 0.3$ for cooling
(c) $a = 0.8$ and $b = 0.4$ for heating and $b = 0.3$ for cooling
(d) $a = 0.8$ and $b = 0.3$ for heating and $b = 0.4$ for cooling

IES-20. For natural convective flow over a vertical flat plate as shown in the given figure, the governing differential equation for momentum is:



$$\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = g\beta(T - T_\infty) + y\frac{\partial^2 u}{\partial y^2}$$

If equation is non-dimensionalized by $U = \dfrac{u}{U_\infty}$, $X = \dfrac{x}{L}$, $Y = \dfrac{y}{L}$ **and** $\theta = \dfrac{T - T_\infty}{T_s - T_\infty}$

then the term $g\beta(T - T_\infty)$, is equal to: [IES-2001]

(a) Grashof number
(b) Prandtl number
(c) Rayleigh number
(d) $\dfrac{\text{Grashof number}}{(\text{Reynolds number})^2}$

IES-21. Which one of the following numbers represents the ratio of kinematic viscosity to the thermal diffusivity? [IES-2005]

(a) Grashoff number
(b) Prandtl number
(c) Mach number
(d) Nusselt number

IES-22. Nusselt number for a pipe flow heat transfer coefficient is given by the equation Nu_D = 4.36. Which one of the following combinations of conditions does exactly apply for use of this equation? [IES-2004]

(a) Laminar flow and constant wall temperature
(b) Turbulent flow and constant wall heat flux
(c) Turbulent flow and constant wall temperature
(d) Laminar flow and constant wall heat flux

IES-23. For steady, uniform flow through pipes with constant heat flux supplied to the wall, what is the value of Nusselt number? [IES-2007]
(a) 48/11 (b) 11/48 (c) 24/11 (d) 11/24

IES-24. A fluid of thermal conductivity 1.0 W/m-K flows in fully developed flow with Reynolds number of 1500 through a pipe of diameter 10 cm. The heat transfer coefficient for uniform heat flux and uniform wall temperature boundary conditions are, respectively. [IES-2002]
(a) 36.57 and $43.64 \frac{\text{W}}{\text{m}^2\text{K}}$ (b) 43.64 and $36.57 \frac{\text{W}}{\text{m}^2\text{K}}$
(c) $43.64 \frac{\text{W}}{\text{m}^2\text{K}}$ for both the cases (d) $36.57 \frac{\text{W}}{\text{m}^2\text{K}}$ for both the cases

IES-25. Which one of the following statements is correct? [IES-2004]
The non-dimensional parameter known as Stanton number (St) is used in
(a) Forced convection heat transfer in flow over flat plate
(b) Condensation heat transfer with laminar film layer
(c) Natural convection heat transfer over flat plate
(d) Unsteady heat transfer from bodies in which internal temperature gradients cannot be neglected

IES-26. A 320 cm high vertical pipe at 150°C wall temperature is in a room with still air at 10°C. This pipe supplies heat at the rate of 8 kW into the room air by natural convection. Assuming laminar flow, the height of the pipe needed to supply 1 kW only is: [IES-2002]
(a) 10 cm (b) 20 cm (c) 40 cm (d) 80 cm

IES-27. Natural convection heat transfer coefficients over surface of a vertical pipe and vertical flat plate for same height and fluid are equal. What is/are the possible reasons for this? [IES-2008]
1. Same height 2. Both vertical
3. Same fluid 4. Same fluid flow pattern
Select the correct answer using the code given below:
(a) 1 only (b) 1 and 2 (c) 3 and 4 (d) 4 only

IES-28. The average Nusselt number in laminar natural convection from a vertical wall at 180°C with still air at 20°C is found to be 48. If the wall temperature becomes 30°C, all other parameters remaining same, the average Nusselt number will be: [IES-2002]
(a) 8 (b) 16 (c) 24 (d) 32

IES-29. For fully-developed turbulent flow in a pipe with heating, the Nusselt number N_u, varies with Reynolds number R_e and Prandtl number P_r as [IES-2003]
(a) $R_e^{0.5} P_r^{\frac{1}{3}}$ (b) $R_e^{0.8} P_r^{0.2}$ (c) $R_e^{0.8} P_r^{0.4}$ (d) $R_e^{0.8} P_r^{0.3}$

IES-30. For laminar flow over a flat plate, the local heat transfer coefficient 'h_x' varies as $x^{-1/2}$, where x is the distance from the leading edge (x = 0) of the plate. The ratio of the average coefficient 'h_a' between the leading

edge and some location '*A*' at $x = x$ on the plate to the local heat transfer coefficient 'h_x' at *A* is: [IES-1999]

(a) 1 (b) 2 (c) 4 (d) 8

IES-31. When there is a flow of fluid over a flat plate of length '*L*', the average heat transfer coefficient is given by (Nu_x = Local Nusselt number; other symbols have the usual meaning) [IES-1997]

(a) $\int_0^L h_x dx$ (b) $\frac{d}{dx}(h_x)$ (c) $\frac{1}{L}\int_0^L h_x dx$ (d) $\frac{k}{L}\int_0^L Nu_x dx$

IES-32. In the case of turbulent flow through a horizontal isothermal cylinder of diameter '*D*', free convection heat transfer coefficient from the cylinder will: [IES-1997]

(a) Be independent of diameter (b) Vary as $D^{3/4}$
(c) Vary as $D^{1/4}$ (d) Vary as $D^{1/2}$

IES-33. Match List-I (Dimensionless quantity) with List-II (Application) and select the correct answer using the codes given below the lists:

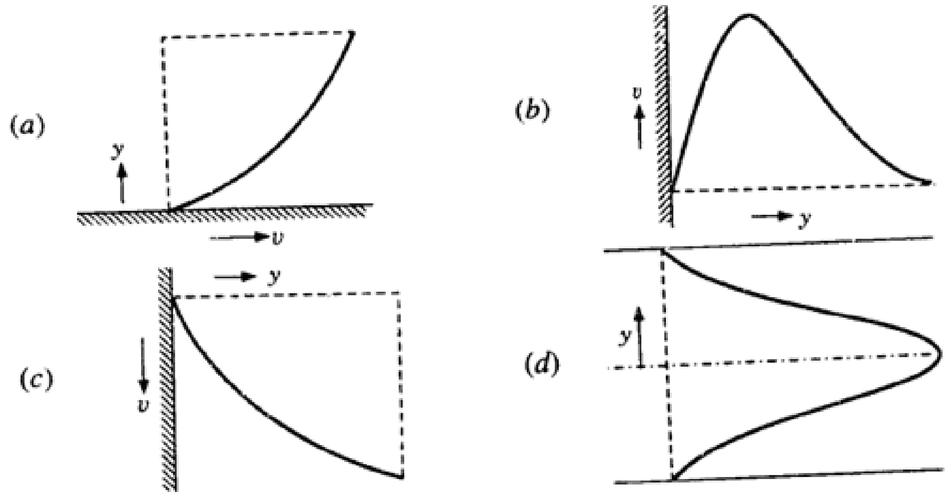
	List-I		**List-II** **[IES-1993]**
A.	Stanton number	**1.**	Natural convection for ideal gases
B.	Grashof number	**2.**	Mass transfer
C.	Peclet number	**3.**	Forced convection
D.	Schmidt number	**4.**	Forced convection for small Prandtl number

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

IES-34. Assertion (A): All analyses of heat transfer in turbulent flow must eventually rely on experimental data. [IES-2000]
Reason (R): The eddy properties vary across the boundary layer and no adequate theory is available to predict their behaviour.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-35.



Match the velocity profiles labelled A, B, C and D with the following situations: [IES-1998]

1. Natural convection **2. Condensation**
3. Forced convection **4. Bulk viscosity ≠ wall viscosity**
5. Flow in pipe entrance

Select the correct answer using the codes given below:

Codes:	A	B	C	D		A	B	C	D
(a)	3	2	1	5	(b)	1	4	2	3
(c)	3	2	1	4	(d)	2	1	5	3

IES-36. Consider the following statements: [IES-1997]
If a surface is pock-marked with a number of cavities, then as compared to a smooth surface.

1. Radiation will increase **2. Nucleate boiling will increase**
3. Conduction will increase **4. Convection will increase**

Of these statements:
(a) 1, 2 and 3 are correct (b) 1, 2 and 4 are correct
(c) 1, 3 and 4 are correct (d) 2, 3 and 4 are correct

IES-37. A cube at high temperature is immersed in a constant temperature bath. It loses heat from its top, bottom and side surfaces with heat transfer coefficient of h_1, h_2 and h_3 respectively. The average heat transfer coefficient for the cube is: [IES-1996]

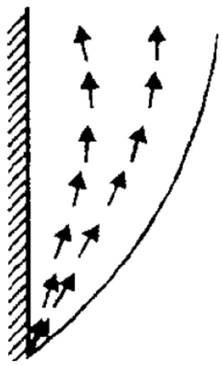
(a) $h_1 + h_3 + h_3$ (b) $\left(h_1 h_3 h_3\right)^{1/3}$ (c) $\frac{1}{h_1} + \frac{1}{h_2} + \frac{1}{h_3}$ (d) None of the above

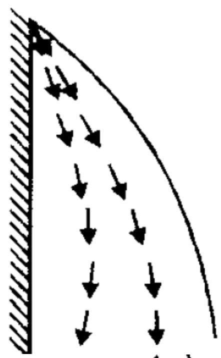
IES-38. Assertion (A): When heat is transferred from a cylinder in cross flow to an air stream, the local heat transfer coefficient at the forward stagnation point is large. [IES-1995]
Reason (R): Due to separation of the boundary layer eddies continuously sweep the surface close to the forward stagnation point.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-39. Match List-I (Flow pattern) with List-II (Situation) and select the correct answer using the codes given below the lists: [IES-1995]

List-I

A. 

B. 

C. 

D. 

List-II

1. Heated horizontal plate

2. Cooled horizontal plate

3. Heated vertical plate

4. Cooled vertical plate

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

IES-40. Consider a hydrodynamically fully developed flow of cold air through a heated pipe of radius r_o. The velocity and temperature distributions in the radial direction are given by $u(r)$ and $T(r)$ respectively. If u_m, is the mean velocity at any section of the pipe, then the bulk-mean temperature at that section is given by: [IES-1994]

(a) $\int_0^{r_o} u(r)T(r)r^2 dr$ (b) $\int_0^{r_o} \frac{u(r)}{3r}\frac{T(r)}{2r}dr$

(c) $\frac{4\int_0^{r_o} u(r)T(r)dr}{2\pi r_o^3}$ (d) $\frac{2}{u_m r_o^2}\int_0^{r_o} u(r)T(r)rdr$

IES-41. The velocity and temperature distribution in a pipe flow are given by $u(r)$ and $T(r)$. If u_m is the mean velocity at any section of the pipe, the bulk mean temperature at that section is: [IES-2003]

(a) $\int_0^{r_0} u(r)T(r)r^2 dr$
(b) $\int_0^{r_0} \frac{u(r)}{3r}\frac{T(r)}{2r} dr$
(c) $\int_0^{r_0} \frac{u(r)T(r)}{2\pi r_0^3} dr$
(d) $\frac{2}{u_m r_0^2}\int_0^{r_0} u(r)T(r)r dr$

IES-42. The ratio of energy transferred by convection to that by conduction is called **[IES-1992]**
(a) Stanton number
(b) Nusselt number
(c) Biot number
(d) Preclet number

IES-43. Free convection flow depends on all of the following EXCEPT
(a) Density
(b) Coefficient of viscosity **[IES-1992]**
(c) Gravitational force
(d) Velocity

Answers with Explanation (Objective)

Previous 20-Years GATE Answers

GATE-1. Ans. (b)

Given $T = 30 + 70\,e^{-y}$ or $\left(\dfrac{dT}{dy}\right)_{at\,y=0} = 0 + 70 \times e^{-y}.(-1) = -70$

We know that

$$-k_f\left(\frac{dT}{dy}\right)_{at\,y=0} = h\left(T_s - T_\infty\right) \quad \text{or} \quad h = \frac{70\times 1}{(100-30)} = 1$$

GATE-2. Ans. (a) $P_r = \dfrac{\mu C_p}{k} = \dfrac{0.1523\times 10^{-2}\times(0.1393\times 1000)}{8.540} = 0.0248$

GATE-3. Ans. (d) $Q = mc_p\dfrac{dT}{dt} = hA\left(t - t_s\right)$

or $4\times\left(2.5\times 10^{3}\right)\times 0.02 = h\times 0.1\times(225-25)$

GATE-4. Ans. (c) $K_w = 0.6\,\text{W/mK}; \quad K_G = 1.2\ \text{W/mK}$

The spatial gradient of temperature in water at the water-glass interface

$$= \left(\frac{dT}{dy}\right)_w = 1\times 10^4\ \text{K/m}$$

At Water glass interface,

$$Q = K_w\left(\frac{dT}{dy}\right)_w = K_G\left(\frac{dT}{dy}\right)_G \quad \text{or} \quad \left(\frac{dT}{dy}\right)_G = \frac{K_w}{K_G}\left(\frac{dT}{dy}\right)_w = \frac{0.6}{1.2}\times 10^4 = 0.5\times 10^4\ \text{K/m}$$

GATE-5. Ans. (d) Heat transfer per unit area $q = h\,(T_f - T_i)$

$$\text{or} \quad h = \frac{q}{T_f - T_i} = \frac{K_w\left(\dfrac{dT}{dy}\right)_w}{T_f - T_i} = \frac{0.6\times 10^4}{(48-40)} = 750\,\text{W/m}^2\text{K}$$

GATE-6. Ans. (c) $\bar{h} = 0.023\dfrac{k}{D}(\text{Re})^{0.8}(\text{Pr})^{\frac{1}{3}} = 0.023\dfrac{k}{D}\left(\dfrac{\rho VD}{\mu}\right)^{0.8}\left(\dfrac{\mu c_p}{k}\right)^{\frac{1}{3}}$

So $\bar{h} \propto v^{0.8}$ and $Q \propto \bar{h}$. Therefore $\dfrac{Q_2}{Q_1} = \left(\dfrac{v_2}{v_1}\right)^{0.8} = 2^{0.8} = 1.74$

Previous 20-Years IES Answers

IES-1. Ans. (d)

IES-2. Ans. (b) Heat transfer by convection $Q = hA\Delta t$

or $500\times(2\times 2) = 2\times\left\{h\times(2\times 2)\times(30-25)\right\}$ or $h = 50\,\text{W/m}^2\,°\text{C}$

IES-3. Ans. (a) Convective Heat Loss will take place from the one side of the plate since it is written that air blows over the hot plate

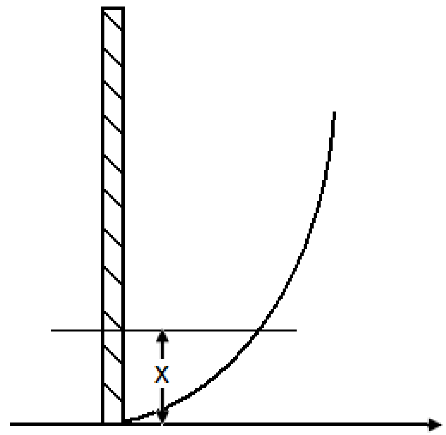
$\therefore \quad Q = hA\left(T_1 - T_2\right) = 25\times(0.5\times 0.6)(220-20) = 25\times(0.3)(200) = 1500\,\text{W}$

IES-4. Ans. (a) Characteristic length used in the correlation relates to the distance over which the boundary layer is allowed to grow. In the case of a vertical flat plate this will be x or L, in the case of a vertical cylinder this will also be x or L; in the case of a horizontal cylinder, the length will be d.

For a vertical plate

Vertical Distance 'x'

$$Gr_x = \frac{\beta g \Delta T x^3}{\upsilon^2}$$



Characteristic length

(i) Horizontal plate = $\dfrac{\text{Surface Area}}{\text{Perimeter of the plate}}$

(ii) Horizontal Cylinder
L = Outside diameter

(iii) Vertical Cylinder
L = height

IES-5. Ans. (a) A free convection flow field is a self-sustained flow driven by the presence of a temperature gradient (as opposed to a forced convection flow where external means are used to provide the flow). As a result of the temperature difference, the density field is not uniform also. Buoyancy will induce a flow current due to the gravitational field and the variation in the density field. In general, a free convection heat transfer is usually much smaller compared to a forced convection heat transfer.

IES-6. Ans. (a) Both A and R are true, and R is correct explanation for A

IES-7. Ans. (a) Reynolds Analogy: There is strong relationship between the dynamic boundary layer and the thermal boundary layer. Reynold's noted the strong correlation and found that fluid friction and convection coefficient could be related.

***Conclusion from Reynold's analogy*:** Knowing the frictional drag, we know the Nusselt number. If the drag coefficient is increased, say through increased wall roughness, then the convective coefficient will increase. If the wall friction is decreased, the convective co-efficient is decreased. For Turbulent Flow following relation may be used $Nu_x = C\left(\text{Re}_x\right)^{0.8}\left(\text{Pr}\right)^{\frac{1}{3}}$.

IES-8. Ans. (d)

IES-9. Ans. (b)

IES-10. Ans. (c)

IES-11. Ans. (a) $\dfrac{hl}{k} = N_u$, or $\text{h} = \dfrac{25 \times 0.03}{0.1} = 7.5\,\text{W/m}^2\text{K}$

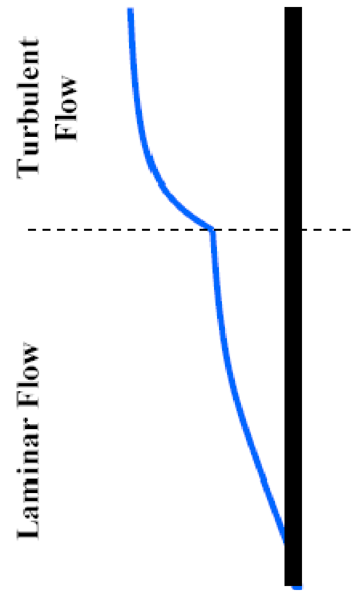
IES-12. Ans. (b)

IES-13. Ans. (c)

IES-14. Ans. (c)

IES-15. Ans. (c)

IES-16. Ans. (d) Laminar to Turbulent Transition: Just as for forced convection, a boundary layer will form for free convection. The insulating film will be relatively thin toward the leading edge of the surface resulting in a relatively high convection coefficient. At a Rayleigh number of about 10^9 the flow over a flat plate will transition to a turbulent pattern. The increased turbulence inside the boundary layer will enhance heat transfer leading to relative high convection coefficients, much like forced convection.



$Ra < 10^9$ Laminar flow [Vertical flat plate]

$Ra > 10^9$ Turbulent flow [Vertical flat plate]

IES-17. Ans. (b)

IES-18. Ans. (d)

IES-19. Ans. (c) Fully developed turbulent flow inside tubes (internal diameter D):

Dittus-Boelter Equation:

$$\text{Nusselt number, } Nu_D = \left(\frac{h_c D}{k_f}\right) = 0.023\ \text{Re}_D^{0.8}\ \text{Pr}^n$$

where, n = 0.4 for heating ($T_w > T_f$) and n = 0.3 for cooling ($T_w < T_f$).

IES-20. Ans. (d) $\dfrac{\text{Grashof number}}{(\text{Re})^2}$; gives dimensionless number which signifies whether flow is forced or free connection.

$$\frac{\text{Gr}}{\text{Re}^2} << 1; \quad \text{Forced convection}$$

$$\frac{\text{Gr}}{\text{Re}^2} >> 1; \quad \text{Natural convection}$$

IES-21. Ans. (b)

IES-22. Ans. (d)

IES-23. Ans. (a)

IES-24. Ans. (b) For uniform heat flux: $Nu_D = \dfrac{hD}{k} = 4.36$

For uniform wall temperature: $Nu_D = \dfrac{hD}{k} = 3.66$

$$\frac{k}{D} = \frac{1}{0.1} = 10$$

IES-25. Ans. (a)

IES-26. Ans. (b) For vertical pipe characteristic dimension is the length of the pipe.

For laminar flow $\mathrm{Nu} = (\mathrm{Gr.Pr})^{1/4}$

h become independent of length

$$\frac{q_1}{q_2} = \frac{h_1 A\Delta T}{h_2 A\Delta T} \quad \Rightarrow \frac{8}{1} = \frac{L_1}{L_2} \qquad \Rightarrow L_2 = 40\,\text{cm}$$

IES-27. Ans. (d) Same height, both vertical and same fluid everything

IES-28. Ans. (c) $\dfrac{Nu_2}{Nu_1} = \dfrac{\Delta t_2}{\Delta t_1} = \dfrac{60}{160}$ or $Nu_2 = 24$

IES-29. Ans. (c)

IES-30. Ans. (b) Here at $x = 0,\ h_o = h$, and at $x = x,\ h_x = \dfrac{h}{\sqrt{x}}$

$$\text{Average coefficient } = \frac{1}{x}\int_0^x \frac{h}{\sqrt{x}}\,dx = \frac{2h}{\sqrt{x}}$$

$$\text{Therefore ratio } = \frac{\frac{2h}{\sqrt{x}}}{\frac{h}{\sqrt{x}}} = 2$$

IES-31. Ans. (c)

IES-32. Ans. (a)

IES-33. Ans. (b) The correct matching for various dimensionless quantities is provided by code (b)

IES-34. Ans. (a)

IES-35. Ans. (a) It provides right matching

IES-36. Ans. (b) If coefficient of friction is increased radiation will decrease.

IES-37. Ans. (d) $Q = \left(h_1 A\Delta T + h_2 A\Delta T + h_3 A\Delta T\right)$

$$Q = h_{av} \times 6\,A\Delta T; \qquad \therefore\ h_{av} = \frac{h_1 + h_2 + 4h_3}{6}$$

IES-38. Ans. (b)

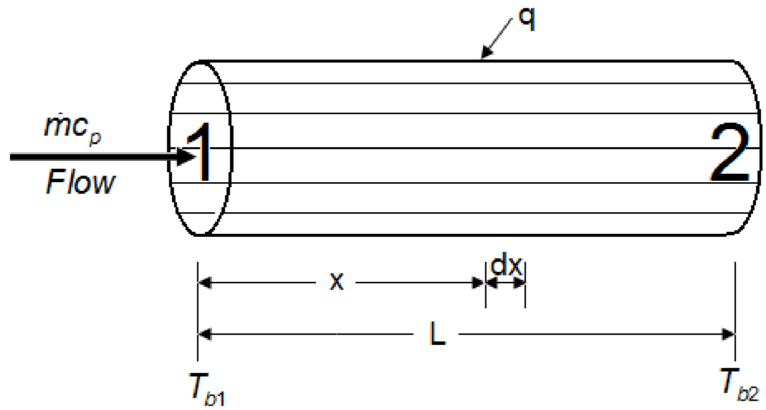
IES-39. Ans. (b)

IES-40. Ans. (d) Bulk-mean temperature =

$$\frac{\text{Total thermal energy crossing a sectionpipe in unit time}}{\text{Heat capacity offluid crossing same section in unit time}}$$

$$= \frac{\int_0^{r_o} u(r)T(r)r\,dr}{u_m \int_0^{r_o} r\,dr} = \frac{2}{u_m r_o^2}\int_0^{r_o} u(r)T(r)r\,dr$$

IES-41. Ans. (d) Bulk temperature



$$Q = \dot{m}c_p\left(T_{b2} - T_{b1}\right)$$

$$dQ = \dot{m}c_p dT_b = h\left\{2\pi r dr\left(T_w - T_b\right)\right\}$$

- The bulk temperature represents energy average or 'mixing cup' conditions.
- The total energy 'exchange' in a tube flow can be expressed in terms of a bulk temperature difference.

IES-42. Ans. (b)

IES-43. Ans. (d) $Gr_x = \dfrac{\beta g \Delta T x^3}{\upsilon^2}$

7. Boiling and Condensation

OBJECTIVE QUESTIONS (GATE, IES, IAS)

Previous 20-Years IES Questions

IES-1. Consider the following phenomena: [IES-1997]
1. Boiling **2. Free convection in air**
3. Forced convection **4. Conduction in air**
Their correct sequence in increasing order of heat transfer coefficient is:
(a) 4, 2, 3, 1 (b) 4, 1, 3, 2 (c) 4, 3, 2, 1 (d) 3, 4, 1, 2

IES-2. Consider the following statements regarding condensation heat transfer: [IES-1996]
1. For a single tube, horizontal position is preferred over vertical position for better heat transfer.
2. Heat transfer coefficient decreases if the vapour stream moves at high velocity.
3. Condensation of steam on an oily surface is dropwise.
4. Condensation of pure benzene vapour is always dropwise.
Of these statements
(a) 1 and 2 are correct (b) 2 and 4 are correct
(c) 1 and 3 are correct (d) 3 and 4 are correct.

IES-3. When all the conditions are identical, in the case of flow through pipes with heat transfer, the velocity profiles will be identical for: [IES-1997]
(a) Liquid heating and liquid cooling (b) Gas heating and gas cooling
(c) Liquid heating and gas cooling (d) Heating and cooling of any fluid

IES-4. Drop wise condensation usually occurs on [IES-1992]
(a) Glazed surface (b) Smooth surface (c) Oily surface (d) Coated surface

Factors Affecting Nucleate Boiling

IES-5. Consider the following statements regarding nucleate boiling:
1. The temperature of the surface is greater than the saturation temperature of the liquid. [IES-1995]
2. Bubbles are created by the expansion of entrapped gas or vapour at small cavities in the surface.
3. The temperature is greater than that of film boiling.
4. The heat transfer from the surface to the liquid is greater than that in film boiling.
Of these correct statements are:
(a) 1, 2 and 4 (b) 1 and 3 (c) 1, 2 and 3 (d) 2, 3 and 4

From the above curve it is clear that the temperature in nucleate boiling is less than that of film boiling. Statement 3 is wrong. Statement "4" The heat transfer from the surface to the liquid is greater than that in film boiling is correct.

IES-6. The burnout heat flux in the nucleate boiling regime is a function of which of the following properties? [IES-1993]

1. Heat of evaporation 2. Temperature difference
3. Density of vapour 4. Density of liquid
5. Vapour-liquid surface tension

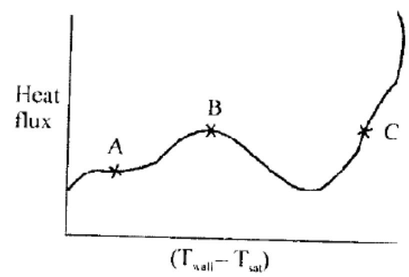
Select the correct answer using the codes given below:

Codes: (a) 1, 2, 4 and 5 (b) 1, 2, 3 and 5 (c) 1, 3, 4 and 5 (d) 2, 3 and 4

Nucleate Pool Boiling

IES-7. The given figure shows a pool-boiling curve. Consider the following statements in this regard: [IES-1993]

1. Onset of nucleation causes a marked change in slope.
2. At the point B, heat transfer coefficient is the maximum.
3. In an electrically heated wire submerged in the liquid, film heating is difficult to achieve.
4. Beyond the point C, radiation becomes significant



Of these statements:

(a) 1, 2 and 4 are correct (b) 1, 3 and 4 are correct
(c) 2, 3 and 4 are correct (d) 1, 2 and 3 are correct

IES-8. Assertion (A): If the heat fluxes in pool boiling over a horizontal surface is increased above the critical heat flux, the temperature difference between the surface and liquid decreases sharply. [IES-2003]
Reason (R): With increasing heat flux beyond the value corresponding to the critical heat flux, a stage is reached when the rate of formation of bubbles is so high that they start to coalesce and blanket the surface with a vapour film.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Film Pool Boiling

IES-9. In spite of large heat transfer coefficients in boiling liquids, fins are used advantageously when the entire surface is exposed to: [IES-1994]

(a) Nucleate boiling (b) Film boiling
(c) Transition boiling (d) All modes of boiling

IES-10. When a liquid flows through a tube with sub-cooled or saturated boiling, what is the process known? [IES-2009]

(a) Pool boiling (b) Bulk boiling
(c) Convection boiling (d) Forced convection boiling

Condensation Heat Transfer

IES-11. For film-wise condensation on a vertical plane, the film thickness δ and heat transfer coefficient *h* vary with distance *x* from the leading edge as [IES-2010]

(a) δ decreases, h increases
(b) Both δ and h increase
(c) δ increases, h decreases
(d) Both δ and h decrease

IES-12. Saturated steam is allowed to condense over a vertical flat surface and the condensate film flows down the surface. The local heat transfer coefficient for condensation [IES-1999]

(a) Remains constant at all locations of the surface
(b) Decreases with increasing distance from the top of the surface
(c) Increases with increasing thickness of condensate film
(d) Increases with decreasing temperature differential between the surface and vapour

IES-13. Consider the following statements: [IES-1998]

1. If a condensing liquid does not wet a surface drop wise, then condensation will take place on it.
2. Drop wise condensation gives a higher heat transfer rate than film-wise condensation.
3. Reynolds number of condensing liquid is based on its mass flow rate.
4. Suitable coating or vapour additive is used to promote film-wise condensation.

Of these statements:

(a) 1 and 2 are correct
(b) 2, 3 and 4 are correct
(c) 4 alone is correct
(d) 1, 2 and 3 are correct

IES-14. Assertion (A): Even though dropwise condensation is more efficient, surface condensers are designed on the assumption of film wise condensation as a matter of practice. [IES-1995]
Reason (R): Dropwise condensation can be maintained with the use of promoters like oleic acid.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-15. Assertion (A): Drop-wise condensation is associated with higher heat transfer rate as compared to the heat transfer rate in film condensation. [IES-2009]
Reason (R): In drop condensation there is free surface through which direct heat transfer takes place.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R individually true but R in not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-16. Assertion (A): The rate of condensation over a rusty surface is less than that over a polished surface. [IES-1993]

Reason (R): The polished surface promotes drop wise condensation which does not wet the surface.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-17. Consider the following statements: [IES-1997]
The effect of fouling in a water-cooled steam condenser is that it
1. **Reduces the heat transfer coefficient of water.**
2. **Reduces the overall heat transfer coefficient.**
3. **Reduces the area available for heat transfer.**
4. **Increases the pressure drop of water**

Of these statements:

(a) 1, 2 and 4 are correct
(b) 2, 3 and 4 are correct
(c) 2 and 4 are correct
(d) 1 and 3 are correct

Answers with Explanation (Objective)

Previous 20-Years IES Answers

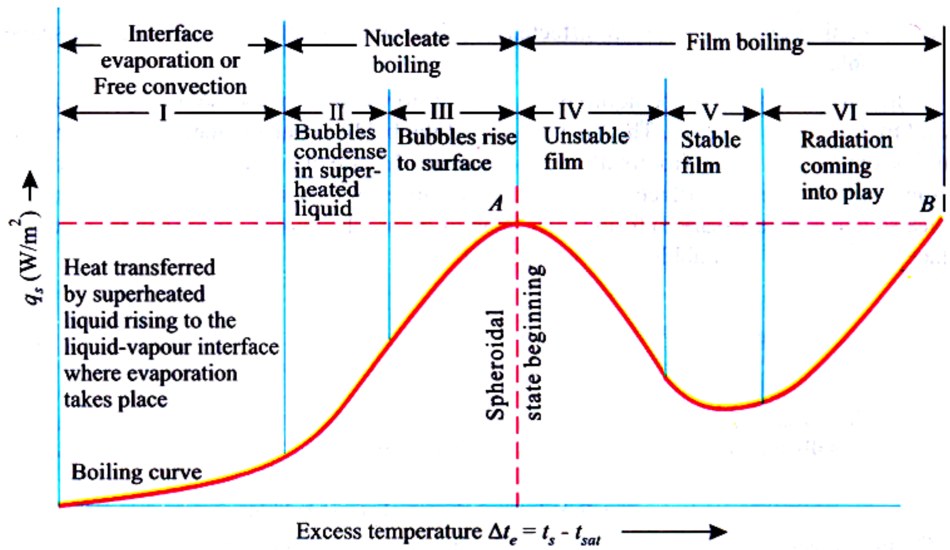
IES-1. Ans. (a) Air being insulator, heat transfer by conduction is least. Next is free convection, followed by forced convection. Boiling has maximum heat transfer

IES-2. Ans. (c)

IES-3. Ans. (a) The velocity profile for flow through pipes with heat transfer is identical for liquid heating and liquid cooling.

IES-4. Ans. (c)

IES-5. Ans. (a)



IES-6. Ans. (c) $q_{sc} = 0.18(\rho_v)^{1/2} h_{fg}[g\sigma(\rho_l - \rho_v)]^{1/4}$

IES-7. Ans. (c)

IES-8. Ans. (d) The temperature difference between the surface and liquid increases sharply.

IES-9. Ans. (b)

IES-10. Ans. (d) Pool Boiling: Liquid motion is due to natural convection and bubble-induced mixing.

Forced Convection Boiling: Fluid motion is induced by external means, as well as by bubble-induced mixing.

Saturated Boiling: Liquid temperature is slightly larger than saturation temperature.

Sub-cooled Boiling: Liquid temperature is less than saturation temperature.

Bulk Boiling: As system temperature increase or system pressure drops, the bulk fluid can reach saturation conditions. At this point, the bubbles entering the coolant channel will not collapse. The bubbles will tend to join together and form bigger steam bubbles. This phenomenon is referred to as bulk boiling bulk. Boiling can provide adequate heat transfer provide that the system bubbles are carried away from the heat transfer surface and the surface continually wetted with liquids water. When this cannot occur film boiling results. So the answer must not be Bulk boiling.

IES-11. Ans. (c) $\delta(x) = \left[\dfrac{4x\, K_1 (T_{sat} - T_w)\, \upsilon_1}{h_{fg}\, g(\rho_1 - \rho_V)}\right]^{\frac{1}{4}}$ $\therefore$ $\delta \infty x^{1/4}$

$$h(x) = \left[\frac{h_{fg} \times g(\rho_l - \rho_V)\, K_l^3}{4x\,(T_{sat} - T_w)\,\upsilon_l}\right]^{\frac{1}{4}} \qquad \therefore \qquad h(x) \propto \left(\frac{1}{x}\right)^{\frac{1}{4}}$$

IES-12. Ans. (b) $h_x\ \alpha\, x^{-1/4}$

IES-13. Ans. (d) 1. If a condensing liquid does not wet a surface drop wise, then drop-wise condensation will take place on it.

4. Suitable coating or vapour additive is used to promote drop-wise condensation.

IES-14. Ans. (b) A and R are true. R is not correct reason for A.

IES-15. Ans. (a)

IES-16. Ans. (a) Both A and R are true and R provides satisfactory explanation for A.

IES-17. Ans. (b) The pipe surface gets coated with deposited impurities and scale gets formed due the chemical reaction between pipe material and the fluids. This coating has very low thermal conductivity and hence results in high thermal resistance. Pressure will be affected.

8. Heat Exchangers

OBJECTIVE QUESTIONS (GATE, IES, IAS)

Previous 20-Years GATE Questions

Types of Heat Exchangers

GATE-1. In a counter flow heat exchanger, for the hot fluid the heat capacity = 2 kJ/kg K, mass flow rate = 5 kg/s, inlet temperature = 150°C, outlet temperature = 100°C. For the cold fluid, heat capacity = 4 kJ/kg K, mass flow rate = 10 kg/s, inlet temperature = 20°C. Neglecting heat transfer to the surroundings, the outlet temperature of the cold fluid in °C is: [GATE-2003]

(a) 7.5 (b) 32.5 (c) 45.5 (d) 70.0

Logarithmic Mean Temperature Difference (LMTD)

GATE-2. In a condenser, water enters at 30°C and flows at the rate 1500 kg/hr. The condensing steam is at a temperature of 120°C and cooling water leaves the condenser at 80°C. Specific heat of water is 4.187 kJ/kg K. If the overall heat transfer coefficient is 2000 W/m^{2}K, then heat transfer area is: [GATE-2004]

(a) 0.707 m^2 (b) 7.07 m^2 (c) 70.7 m^2 (d) 141.4 m^2

GATE-3. The logarithmic mean temperature difference (LMTD) of a counterflow heat exchanger is 20°C. The cold fluid enters at 20°C and the hot fluid enters at 100°C. Mass fl0w rate of the cold fluid is twice that of the hot fluid. Specific heat at constant pressure of the hot fluid is twice that of the cold fluid. The exit temperature of the cold fluid [GATE-2008]

(a) is 40°C (b) is 60°C (c) is 80°C (d) Cannot be determined

GATE-4. In a counter flow heat exchanger, hot fluid enters at 60°C and cold fluid leaves at 30°C. Mass flow rate of the hot fluid is 1 kg/s and that of the cold fluid is 2 kg/s. Specific heat of the hot fluid is 10 kJ/kgK and that of the cold fluid is 5 kJ/kgK. The Log Mean Temperature Difference (*LMTD*) for the heat exchanger in °C is: [GATE-2007]

(a) 15 (b) 30 (c) 35 (d) 45

GATE-5. Hot oil is cooled from 80 to 50°C in an oil cooler which uses air as the coolant. The air temperature rises from 30 to 40°C. The designer uses a *LMTD* value of 26°C. The type of heat exchanger is: [GATE-2005]

(a) Parallel flow (b) Double pipe (c) Counter flow (d) Cross flow

GATE-6. For the same inlet and outlet temperatures of hot and cold fluids, the Log Mean Temperature Difference (*LMTD*) is: [GATE-2002]

(a) Greater for parallel flow heat exchanger than for counter flow heat exchanger.
(b) Greater for counter flow heat exchanger than for parallel flow heat exchanger.
(c) Same for both parallel and counter flow heat exchangers.
(d) Dependent on the properties of the fluids.

GATE-7. Air enters a counter flow heat exchanger at 70°C and leaves at 40°C. Water enters at 30°C and leaves at 50°C. The LMTD in degree C is: [GATE-2000]

(a) 5.65 (b) 4.43 (c) 19.52 (d) 20.17

Heat Exchanger Effectiveness and Number of Transfer Units (NTU)

GATE-8. In a certain heat exchanger, both the fluids have identical mass flow rate-specific heat product. The hot fluid enters at 76°C and leaves at 47°C and the cold fluid entering at 26°C leaves at 55°C. The effectiveness of the heat exchanger is: [GATE-1997]

GATE-9. In a parallel flow heat exchanger operating under steady state, the heat capacity rates (product of specific heat at constant pressure and mass flow rate) of the hot and cold fluid are equal. The hot fluid, flowing at 1 kg/s with C_p = 4 kJ/kgK, enters the heat exchanger at 102°C while the cold fluid has an inlet temperature of 15°C. The overall heat transfer coefficient for the heat exchanger is estimated to be 1 kW/m²K and the corresponding heat transfer surface area is 5 m². Neglect heat transfer between the heat exchanger and the ambient. The heat exchanger is characterized by the following relation: $2\varepsilon = 1 - \exp(-2\text{NTU})$. [GATE-2009]

The exit temperature (in °C) for - the cold fluid is:

(a) 45 (b) 55 (c) 65 (d) 75

Previous 20-Years IES Questions

Types of Heat Exchangers

IES-1. Air can be best heated by steam in a heat exchanger of [IES-2006]

(a) Plate type
(b) Double pipe type with fins on steam side
(c) Double pipe type with fins on air side
(d) Shell and tube type

IES-2. Which one of the following heat exchangers gives parallel straight line pattern of temperature distribution for both cold and hot fluid?

(a) Parallel-flow with unequal heat capacities **[IES-2001]**
(b) Counter-flow with equal heat capacities
(c) Parallel-flow with equal heat capacities
(d) Counter-flow with unequal heat capacities

IES-3. For a balanced counter-flow heat exchanger, the temperature profiles of the two fluids are: [IES-2010]

(a) Parallel and non-linear
(b) Parallel and linear
(c) Linear but non-parallel
(d) Divergent from one another

IES-4. Match List-I (Heat exchanger process) with List-II (Temperature area diagram) and select the correct answer: [IES-2004]

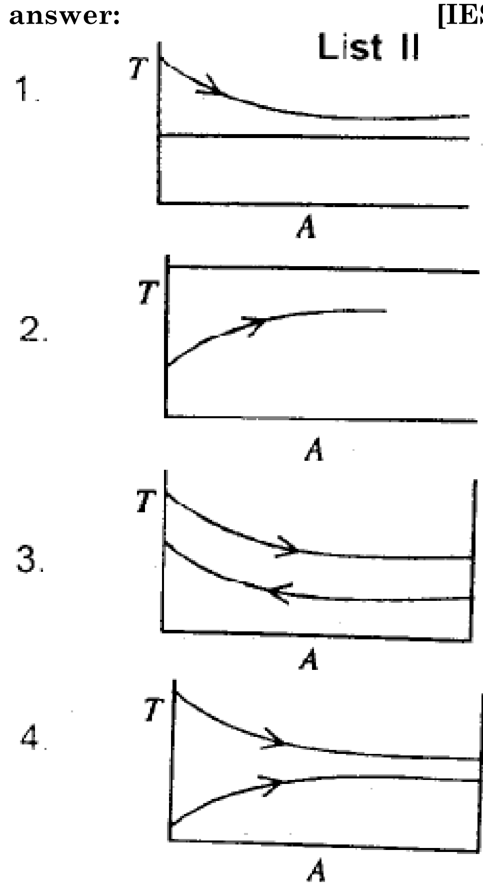
List-I

A. Counter flow sensible heating

B. Parallel flow sensible heating

C. Evaporating

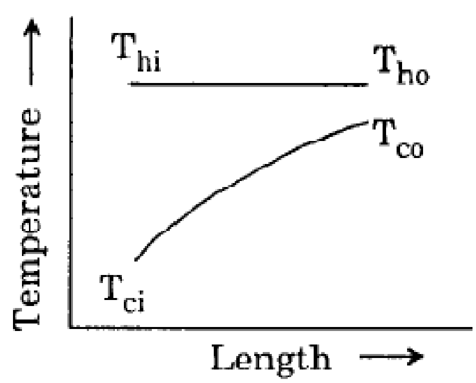
D. Condensing



Codes:	A	B	C	D		A	B	C	D
(a)	3	4	1	2	(b)	3	2	5	1
(c)	4	3	2	5	(d)	4	2	1	5

IES-5. The temperature distribution curve for a heat exchanger as shown in the figure above (with usual notations) refers to which one of the following?

(a) Tubular parallel flow heat exchanger
(b) Tube in tube counter flow heat exchanger
(c) Boiler
(d) Condenser



[IES-2008]

IES-6. Consider the following statements: [IES-1997]

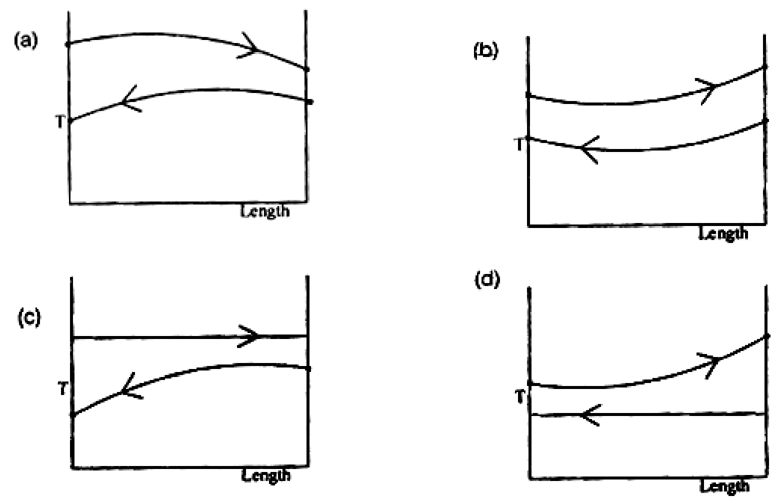
The flow configuration in a heat exchanger, whether counterflow or otherwise, will NOT matter if:

1. **A liquid is evaporating**
2. **A vapour is condensing**
3. **Mass flow rate of one of the fluids is far greater**

Of these statements:

(a) 1 and 2 are correct (b) 1 and 3 are correct
(c) 2 and 3 are correct (d) 1, 2 and 3 are correct

IES-7. Which one of the following diagrams correctly shows the temperature distribution for a gas-to-gas counterflow heat exchanger?



[IES-1994; 1997]

IES-8. Match List-I with List-II and select the correct answer using the codes given below the lists: **[IES-1995]**

List-I	List-II
A. Regenerative heat exchanger	**1.** Water cooling tower
B. Direct contact heat exchanger	**2.** Lungstrom air heater
C. Conduction through a cylindrical wall	**3.** Hyperbolic curve
D. Conduction through a spherical wall	**4.** Logarithmic curve

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

IES-9. Match List-I (Application) with List-II (Type of heat exchanger) and select the correct answer using the code given below the lists:[IES-2008]

List-I	List-II
A. Gas to liquid	**1.** Compact
B. Space vehicle	**2.** Shell and Tube
C. Condenser	**3.** Finned tube
D. Air pre-heater	**4.** Regenerative

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

IES-10. Match List-I with List-II and select the correct answer **[IES-1994]**

List-I	List-II
A. Number of transfer units	**1.** Recuperative type heat exchanger
B. Periodic flow heat exchanger	**2.** Regenerator type heat exchanger

C. Chemical additive				**3.**	A measure of the heat exchanger size
D. Deposition on heat exchanger surface				**4.**	Prolongs drop-wise condensation
				5.	Fouling factor

Codes:

	A	B	C	D		A	B	C	D
(a)	3	2	5	4	(b)	2	1	4	5
(c)	3	2	4	5	(d)	3	1	5	4

IES-11. Consider the following statements: [IES-1994]
In a shell and tube heat exchanger, baffles are provided on the shell side to:
1. **Prevent the stagnation of shell side fluid**
2. **Improve heat transfer**
3. **Provide support for tubes**

Select the correct answer using the codes given below:
(a) 1, 2, 3 and 4 (b) 1, 2 and 3 (c) 1 and 2 (d) 2 and 3

IES-12. In a heat exchanger, the hot liquid enters with a temperature of 180ºC and leaves at 160ºC. The cooling fluid enters at 30ºC and leaves at 110ºC. The capacity ratio of the heat exchanger is: [IES-2010]
(a) 0.25 (b) 0.40 (c) 0.50 (d) 0.55

Logarithmic Mean Temperature Difference (LMTD)

IES-13. Assertion (A): It is not possible to determine LMTD in a counter flow heat exchanger with equal heat capacity rates of hot and cold fluids.
Reason (R): Because the temperature difference is invariant along the length of the heat exchanger. [IES-2002]
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-14. Assertion (A): A counter flow heat exchanger is thermodynamically more efficient than the parallel flow type. [IES-2003]
Reason (R): A counter flow heat exchanger has a lower LMTD for the same temperature conditions.
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-15. In a counter-flow heat exchanger, the hot fluid is cooled from 110°C to 80°C by a cold fluid which gets heated from 30°C to 60°C. LMTD for the heat exchanger is: [IES-2001]
(a) 20°C (b) 30°C (c) 50°C (d) 80°C

IES-16. Assertion (A): The LMTD for counter flow is larger than that of parallel flow for a given temperature of inlet and outlet. [IES-1998]
Reason (R): The definition of LMTD is the same for both counter flow and parallel flow.
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A

(c) A is true but R is false
(d) A is false but R is true

IES-17. A counter flow heat exchanger is used to heat water from 20°C to 80°C by using hot exhaust gas entering at 140°C and leaving at 80°C. The log mean temperature difference for the heat exchanger is: [IES-1996]
(a) 80°C (b) 60°C
(c) 110°C (d) Not determinable as zero/zero is involved

IES-18. For evaporators and condensers, for the given conditions, the logarithmic mean temperature difference (LMTD) for parallel flow is:
(a) Equal to that for counter flow **[IES-1993]**
(b) Greater than that for counter flow
(c) Smaller than that for counter flow
(d) Very much smaller than that for counter flow

IES-19. In a counter flow heat exchanger, cold fluid enters at 30°C and leaves at 50°C, whereas the enters at 150°C and leaves at l30°C. The mean temperature difference for this case is: [IES-1994]
(a) Indeterminate (b) 20°C (c) 80°C (d) 100°C

IES-20. A designer chooses the values of fluid flow ranges and specific heats in such a manner that the heat capacities of the two fluids are equal. A hot fluid enters the counter flow heat exchanger at 100°C and leaves at 60°C. The cold fluid enters the heat exchanger at 40°C. The mean temperature difference between the two fluids is: [IES-1993]
(a) (100 +60 + 40)/3°C (b) 60°C (c) 40°C (d) 20°C

Overall Heat Transfer Co-efficient

IES-21. Given the following data, [IES-1993]
Inside heat transfer coefficient = 25 W/m^{2}K
Outside heat transfer coefficient = 25 W/m^{2}K
Thermal conductivity of bricks (15 cm thick) = 0.15 W/mK,
The overall heat transfer coefficient (in W/m^{2}K) will be closer to the
(a) Inverse of heat transfer coefficient
(b) Heat transfer coefficient
(c) Thermal conductivity of bricks
(d) Heat transfer coefficient based on the thermal conductivity of the bricks alone

Heat Exchanger Effectiveness and Number of Transfer Units (NTU)

IES-22. The 'NTU' (Number of Transfer Units) in a heat exchanger is given by which one of the following? [IES-2008]
(a) $\frac{UA}{C_{\min}}$ (b) $\frac{UA}{C_{\max}}$ (c) $\frac{UA}{E}$ (d) $\frac{C_{\max}}{C_{\min}}$

U = Overall heat transfer coefficient C = Heat capacity
E = Effectiveness A = Heat exchange area

IES-23. When t_{c1} and t_{c2} are the temperatures of cold fluid at entry and exit respectively and t_{h1} and t_{h2} are the temperatures of hot fluid at entry and exit point, and cold fluid has lower heat capacity rate as compared to hot fluid, then effectiveness of the heat exchanger is given by: [IES-1992]

(a) $\frac{t_{c1}-t_{c2}}{t_{h1}-t_{c1}}$ (b) $\frac{t_{h2}-t_{h1}}{t_{c2}-t_{h1}}$ (c) $\frac{t_{h1}-t_{h2}}{t_{h2}-t_{c1}}$ (d) $\frac{t_{c2}-t_{c1}}{t_{h1}-t_{c1}}$

IES-24. In a parallel flow gas turbine recuperator, the maximum effectiveness is: [IES-1992]

(a) 100% (b) 75% (c) 50% (b) Between 25% and 45%

IES-25. In a heat exchanger with one fluid evaporating or condensing the surface area required is least in [IES-1992]

(a) Parallel flow (b) Counter flow
(c) Cross flow (d) Same in all above

IES-26. The equation of effectiveness $\varepsilon = 1 - e^{-NTU}$ for a heat exchanger is valid in the case of: [IES-2006]

(a) Boiler and condenser for parallel now
(b) Boiler and condenser for counter flow
(c) Boiler and condenser for both parallel flow and counter flow
(d) Gas turbine for both parallel now and counter flow

IES-27. The equation of effectiveness $\varepsilon = 1 - e^{-NTU}$ of a heat exchanger is valid (NTU is number or transfer units) in the case of: [IES-2000]

(a) Boiler and condenser for parallel flow
(b) Boiler and condenser for counter flow
(c) Boiler and condenser for both parallel flow and counter flow
(d) Gas turbine for both parallel flow and counter flow

IES-28. After expansion from a gas turbine, the hot exhaust gases are used to heat the compressed air from a compressor with the help of a cross flow compact heat exchanger of 0.8 effectiveness. What is the number of transfer units of the heat exchanger? [IES-2005]

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

IES-29. In a balanced counter flow heat exchanger with $M_h C_h = M_c C_c$, the NTU is equal to 1.0. What is the effectiveness of the heat exchanger? [IES-2009]

(a) 0.5 (b) 1.5 (c) 0.33 (d) 0.2

IES-30. In a counter flow heat exchanger, the product of specific heat and mass flow rate is same for the hot and cold fluids. If NTU is equal to 0.5, then the effectiveness of the heat exchanger is: [IES-2001]

(a) 1.0 (b) 0.5 (c) 0.33 (d) 0.2

IES-31. Match List-I with List-II and select the correct answer using the codes given below the Lists (Notations have their usual meanings): [IES-2000]

List-I		**List-II**	
A.	Fin	**1.**	$\frac{UA}{C_{\min}}$
B.	Heat exchanger	**2.**	$\frac{x}{2\sqrt{\alpha\tau}}$
C.	Transient conduction	**3.**	$\sqrt{\frac{hp}{kA}}$
D.	Heisler chart	**4.**	hl/k

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

IES-32. A cross-flow type air-heater has an area of 50 m². The overall heat transfer coefficient is 100 W/m²K and heat capacity of both hot and cold stream is 1000 W/K. The value of NTU is: [IES-1999]

(a) 1000 (b) 500 (c) 5 (d) 0.2

IES-33. A counter flow shell - and - tube exchanger is used to heat water with hot exhaust gases. The water (C_p = 4180 J/kg°C) flows at a rate of 2 kg/s while the exhaust gas (1030 J/kg°C) flows at the rate of 5.25 kg/s. If the heat transfer surface area is 32.5 m² and the overall heat transfer coefficient is 200 W/m²°C, what is the NTU for the heat exchanger? [IES-1995]

(a) 1.2 (b) 2.4 (c) 4.5 (d) 8.6

IES-34. A heat exchanger with heat transfer surface area *A* and overall heat transfer coefficient *U* handles two fluids of heat capacities C_1, and C_2, such that $C_1 > C_2$. The NTU of the heat exchanger is given by: [IES-1996]

(a) AU/C_2 (b) $e^{\{AU/C_2\}}$ (c) $e^{\{AU/C_1\}}$ (d) AU/C_1

IES-35. A heat exchanger with heat transfer surface area *A* and overall heat transfer co-efficient *U* handles two fluids of heat capacities C_{max} and C_{min}. The parameter NTU (number of transfer units) used in the analysis of heat exchanger is specified as [IES-1993]

(a) $\frac{AC_{\min}}{U}$ (b) $\frac{U}{AC_{\min}}$ (c) $UAC_{\min}$ (d) $\frac{UA}{C_{\min}}$

IES-36. ε-NTU method is particularly useful in thermal design of heat exchangers when [IES-1993]

(a) The outlet temperature of the fluid streams is not known as a priori
(b) Outlet temperature of the fluid streams is known as a priori
(c) The outlet temperature of the hot fluid streams is known but that of the cold fluid streams is not known as a priori
(d) Inlet temperatures of the fluid streams are known as a priori

Heat Pipe

IES-37. Heat pipe is widely used now-a-days because [IES-1995]

(a) It acts as an insulator
(b) It acts as conductor and insulator
(c) It acts as a superconductor
(d) It acts as a fin

IES-38. Assertion (A): Thermal conductance of heat pipe is several hundred times that of the best available metal conductor under identical conditions. [IES-2000]

Reason (R): The value of latent heat is far greater than that of specific heat.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Answers with Explanation (Objective)

Previous 20-Years GATE Answers

GATE-1. Ans. (b) Let temperature t°C

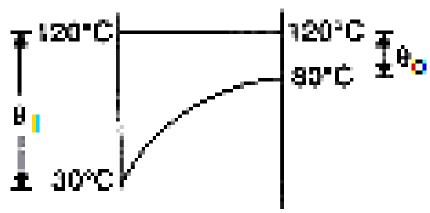
Heat loss by hot water = heat gain by cold water

$$\dot{m}_h c_{ph}\left(t_{h1}-t_{h2}\right)=\dot{m}_c c_{pc}\left(t_{c2}-t_{c1}\right)$$

or $5\times 2\times\left(150-100\right)=10\times 4\times\left(t-20\right)$

or $t=32.5°\text{C}$

GATE-2. Ans. (a) $\theta_i=120-30=90$



$$\theta_o=120-80=40$$

$$LMTD=\frac{\theta_i-\theta_o}{\ln\left(\dfrac{\theta_i}{\theta_o}\right)}=\frac{90-40}{\ln\left(\dfrac{90}{40}\right)}=61.66°\text{C}$$

$$\dot{Q}=\dot{m}c_p\left(t_{c2}-t_{c1}\right)=UA\left(LMTD\right)$$

$$\text{or } A=\frac{\left(\dfrac{1500}{3600}\right)\times 4.187\times 10^3\times\left(80-30\right)}{2000\times 61.66}$$

$$=0.707\,\text{m}^2$$

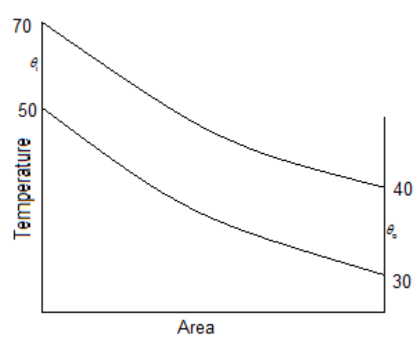
GATE-3. Ans (c) As $m_h c_h = m_c c_c$. Therefore exit temp. = 100 – $LMTD$ = 100 – 20 =80°C.

GATE-4. Ans. (b)

GATE-5. Ans. (d)

GATE-6. Ans. (b)

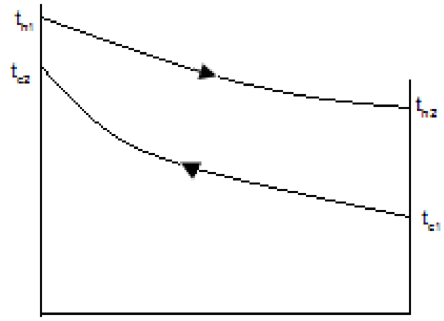
GATE-7. Ans. (b) $\theta_i=70-50=20$



$$\theta_o=40-30=10$$

$$LMTD=\frac{\theta_i-\theta_o}{\ln\left(\dfrac{\theta_i}{\theta_o}\right)}=\frac{20-10}{\ln\left(\dfrac{20}{10}\right)}=14.43°$$

GATE-8. Ans. (b)



$$\text{Effectiveness}(\varepsilon)=\frac{Q}{Q_{\max}}=\frac{t_{c2}-t_{c1}}{t_{h1}-t_{c1}}$$

$$=\frac{55-26}{76-26}=0.58$$

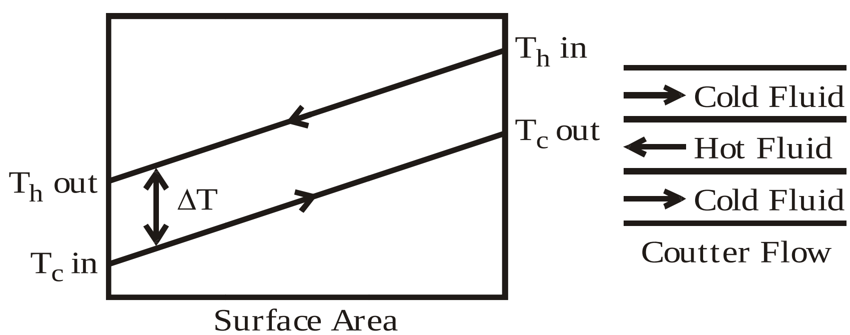
GATE-9. Ans. (b) $\varepsilon=\dfrac{1-e^{-NTU}}{2}$

and $\quad NTU=\dfrac{UA}{C_{\min}}\quad=\dfrac{1000\times 5}{4000\times 1}=1.25$

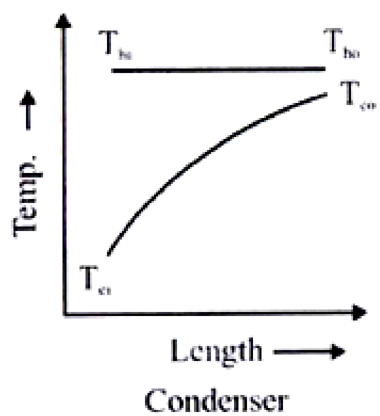
or $\quad \varepsilon=0.459=\dfrac{t_{h1}-t_{h2}}{t_{h1}-t_{c1}}=\dfrac{t_{c2}-t_{c1}}{t_{h1}-t_{c1}}=\dfrac{t_{c2}-15}{102-15}\quad\Rightarrow t_{c2}=55$

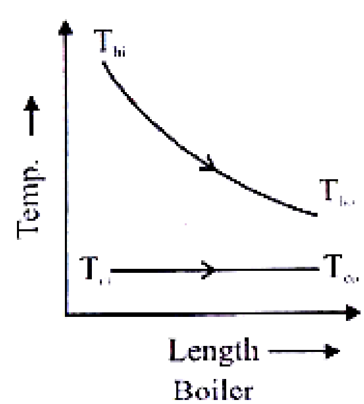
Previous 20-Years IES Answers

IES-1. Ans. (c)
IES-2. Ans. (b)
IES-3. Ans. (a)

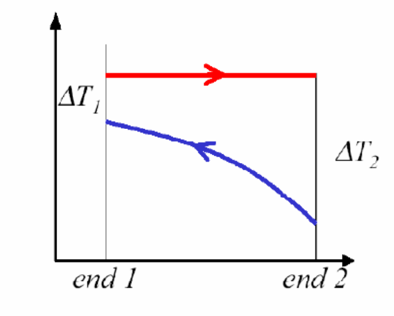


IES-4. Ans. (a)
IES-5. Ans. (d)

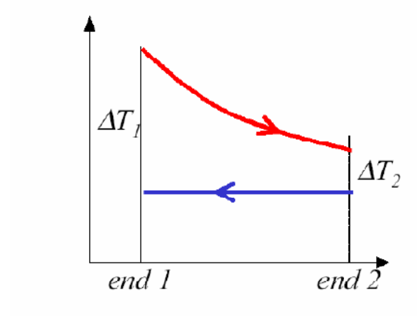




IES-6. Ans. (a) If liquid is evaporating or a vapour is condensing then whether heat exchanger is counter flow or otherwise is immaterial. Same matters for liquid/gas flows.



Condenser



Evaporator

IES-7. Ans. (b)

IES-8. Ans. (d)

IES-9. Ans. (b)

IES-10. Ans. (c)

IES-11. Ans. (d) Baffles help in improving heat transfer and also provide support for tubes.

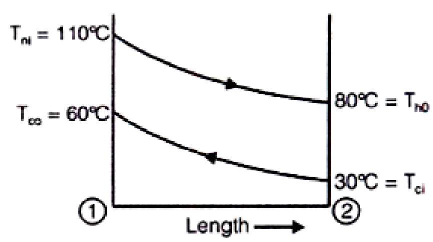
IES-12. Ans. (a) Capacity ratio of heat exchanger $= \dfrac{t_{h_1} - t_{h_2}}{t_{c_1} - t_{c_2}} = \dfrac{180° - 160°}{110° - 30°} = 0.25$

IES-13. Ans. (d)

IES-14. Ans. (c)

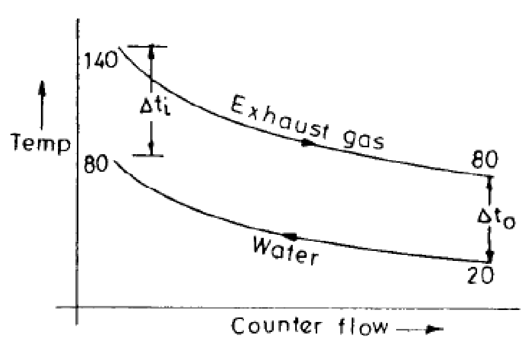
IES-15. Ans. (c) $\theta_1 = \theta_2 = 50°$

$$\theta_1 = \theta_2 = 50° \theta_1 = T_{hi} = T_\infty$$
$$= 110 - 60 = 50°\text{C}$$
$$\theta_2 = T_{ho} = T_{ci} = 80 - 30 = 50°\text{C}$$



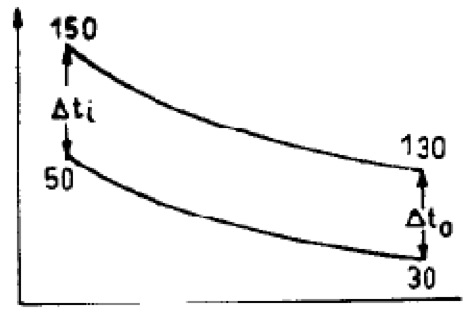
IES-16. Ans. (b) Both statements are correct but R is not exactly correct explanation for A.

IES-17. Ans. (b) $LMTD = \dfrac{\Delta t_o - \Delta t_i}{\log_e\left(\Delta t_o / \Delta t_i\right)}$ will be applicable when $\Delta t_i \neq \Delta t_o$ and if $\Delta t_i \neq \Delta t_o$ then $LMTD = \Delta t_i = \Delta t_o$



IES-18. Ans. (a)

IES-19. Ans. (d) Mean temperature difference = $\Delta t_i = \Delta t_o = 100°C$



IES-20. Ans. (d) Mean temperature difference

= Temperature of hot fluid at exit – Temperature of cold fluid at entry

= 60° – 40° = 20°C

IES-21. Ans. (d) Overall coefficient of heat transfer U W/m²K is expressed as $\frac{1}{U} = \frac{1}{h_i} + \frac{\Delta x}{k} + \frac{1}{h_o} = \frac{1}{25} + \frac{0.15}{0.15} + \frac{1}{25} = \frac{27}{25}$. So, $U = \frac{25}{27}$ which is closer to the heat transfer coefficient based on the bricks alone.

IES-22. Ans. (a)

IES-23. Ans. (d)

IES-24. Ans. (c) For parallel flow configuration, effectiveness $\in = \frac{1 - \exp(-2NTU)}{2}$

$\therefore$ Limiting value of $\in$ is therefore $\frac{1}{2}$ or 50%.

IES-25. Ans. (d)

IES-26. Ans. (c) $\in = \dfrac{1 - e^{-NTU\left(1 + \frac{C_{\min}}{C_{\max}}\right)}}{1 + \frac{C_{\min}}{C_{\max}}} = 1 - e^{-NTU}$

For Parallerl flow[As boiler and condenser $\frac{C_{\min}}{C_{\max}} \to 0$]

$= \dfrac{1 - e^{-NTU\left(1 + \frac{C_{\min}}{C_{\max}}\right)}}{1 + \frac{C_{\min}}{C_{\max}} e^{-NTU\left(1 + \frac{C_{\min}}{C_{\max}}\right)}} = 1 - e^{-NTU}$ for Counter flow

IES-27. Ans. (c)

IES-28. Ans. (b) Effectiveness, $\varepsilon = \frac{NTU}{1 + NTU} = 0.8$

IES-29. Ans. (a) In this case the effectiveness of the heat exchanger $(\varepsilon) = \frac{NTU}{1 + NTU}$

IES-30. Ans. (c)

IES-31. Ans. (a) Fin $- \sqrt{hp / kA} = m$

Heat exchanger $- NTU = UA / C_{\min}$

Transient conduction $- hl / k_{\text{solid}}$ (Biot No.)

Heisler chart $- \frac{x}{2\sqrt{\alpha\tau}}$

IES-32. Ans. (c) $NTU = \frac{AU}{C_{\min}}$, $A = \text{Area} = 50\text{m}^2$

U = Overall heat transfer coefficient $= 100\ \text{W/m}^2\text{K}$

$C_{\min}$ = Heat capacity $= 1000\ \text{W/K}$

$$\therefore \quad NTU = \frac{50 \times 100}{1000} = 5$$

IES-33. Ans. (a) $NTU = \dfrac{UA}{C_{\min}} = \dfrac{200 \times 32.2}{1030 \times 5.25} = 1.2$

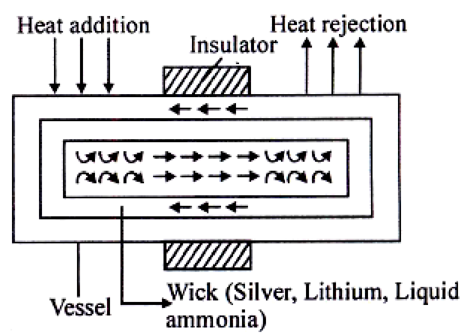
IES-34. Ans. (a) NTU (number of transfer units) used in analysis of heat exchanger is specified as $AU/C_{\min}$.

IES-35. Ans. (d)

IES-36. Ans. (a)

IES-37. Ans. (c) Heat pipe can be used in different ways. Insulated portion may be made of flexible tubing to permit accommodation of different physical constraints. It can also be applied to micro-electronic circuits to maintain constant temperature. It consists of a closed pipe lined with a wicking material and containing a condensable gas. The centre portion of pipe is insulated and its two non-insulated ends respectively serve as evaporators and condensers.

Heat pipe is device used to obtain very high rates of heat flow. In practice, the thermal conductance of heat pipe may be several hundred (500) times then that best available metal conductor, hence they act as super conductor.



IES-38. Ans. (a)

9. Radiation

OBJECTIVE QUESTIONS (GATE, IES, IAS)

Previous 20-Years GATE Questions

Absorptivity, Reflectivity and Transmissivity

GATE-1. In radiative heat transfer, a gray surface is one [GATE-1997]
(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.

The Stefan-Boltzmann Law

Common Data for Questions Q2 and Q3:

Radiative heat transfer is intended between the inner surfaces of two very large isothermal parallel metal plates. While the upper plate (designated as plate 1) is a black surface and is the warmer one being maintained at 727°C, the lower plate (plate 2) is a diffuse and gray surface with an emissivity of 0.7 and is kept at 227°C.

Assume that the surfaces are sufficiently large to form a two-surface enclosure and steady-state conditions to exist. Stefan-Boltzmann constant is given as 5.67×10^{-8} W/m^{2}K^4.

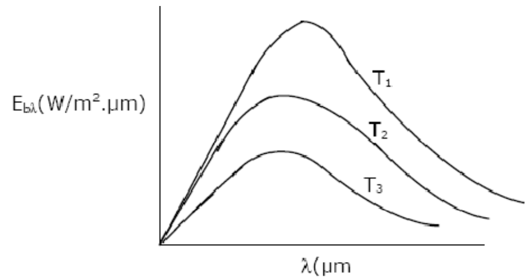
GATE-2. The irradiation (in kW/m^2) for the upper plate (plate 1) is: [GATE-2009]
(a) 2.5 (b) 3.6 (c) 17.0 (d) 19.5

GATE-3. If plate 1 is also a diffuse and gray surface with an emissivity value of 0.8, the net radiation heat exchange (in kW/m^2) between plate 1 and plate 2 is: [GATE-2009]
(a) 17.0 (b) 19.5 (c) 23.0 (d) 31.7

GATE-4. The following figure was generated from experimental data relating spectral black body emissive power to wavelength at three temperatures T_1, T_2 and T_3 ($T_1 > T_2 > T_3$). [GATE-2005]

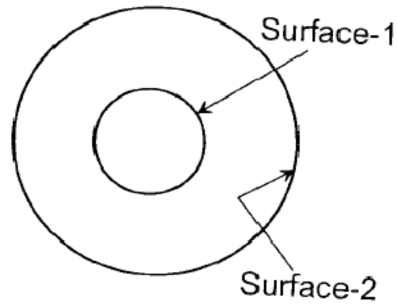
The conclusion is that the measurements are:

(a) Correct because the maxima in $E_{b\lambda}$ show the correct trend
(b) Correct because Planck's law is satisfied
(c) Wrong because the Stefan Boltzmann law is not satisfied
(d) Wrong because Wien's displacement law is not satisfied



Shape Factor Algebra and Salient Features of the Shape Factor

GATE-5. **A hollow encloser is formed between two infinitely long concentric cylinders of radii 1 m ans 2 m, respectively. Radiative heat exchange takes place between the inner surface of the larger cylinder (surface-2) and the outer surface of the smaller cylinder (surface-I). The radiating surfaces are diffuse and the medium in the enclosure is non-participating. The fraction of the thermal radiation leaving the larger surface and striking itself is:** **[GATE-2008]**



(a) 0.25 (b) 0.5 (c) 0.75 (d) 1

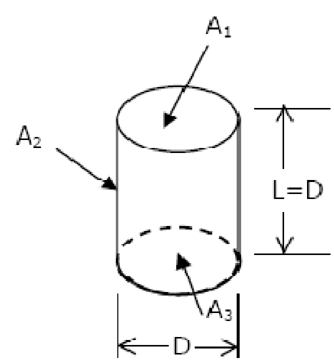
GATE-6. **The shape factors with themselves of two infinity long black body concentric cylinders with a diameter ratio of 3 are......... for the inner and..................... for the outer.** **[GATE-1994]**

(a) 0, 2/3 (b) 0, 1/3 (c) 1, 1/9 (d) 1, 1/3

GATE-7. **For the circular tube of equal length and diameter shown below, the view factor F_{13} is 0.17.**

The view factor F_{12} in this case will be:

(a) 0.17 (b) 0.21
(c) 0.79 (d) 0.83



[GATE-2001]

GATE-8. **What is the value of the view factor for two inclined flat plates having common edge of equal width, and with an angle of 20 degrees?** **[GATE-2002]**

(a) 0.83 (b) 1.17 (c) 0.66 (d) 1.34

GATE-9. A solid cylinder (surface 2) is located at the centre of a hollow sphere (surface 1). The diameter of the sphere is 1 m, while the cylinder has a diameter and length of 0.5 m each. The radiation configuration factor F_{11} is: [GATE-2005]

(a) 0.375 (b) 0.625 (c) 0.75 (d) 1

Heat Exchange between Non-black Bodies

GATE-10. The radiative heat transfer rate per unit area (W/m^2) between two plane parallel grey surfaces (emissivity = 0.9) maintained at 400 K and 300 K is: [GATE-1993]

(a) 992 (b) 812 (c) 464 (d) 567

(Stefan Boltzman constant. $\sigma = 5.67 \times 10^{-8}$ $W/m^2 K^4$)

GATE-11. A plate having 10 cm^2 area each side is hanging in the middle of a room of 100 m^2 total surface area. The plate temperature and emissivity are respectively 800 K and 0.6. The temperature and emissivity values for the surfaces of the room are 300 K and 0.3 respectively. Boltzmann's constant $\sigma = 5.67 \times 10^{-8}$ $W/m^2 K^4$. The total heat loss from the two surfaces of the plate is: [GATE-2003]

(a) 13.66 W (b) 27.32 W (c) 27.87 W (d) 13.66 MW

Previous 20-Years IES Questions

Introduction

IES-1. Fraction of radiative energy leaving one surface that strikes the other surface is called [IES-2003]

(a) Radiative flux
(b) Emissive power of the first surface
(c) View factor
(d) Re-radiation flux

IES-2. Assertion (A): Heat transfer at high temperature is dominated by radiation rather than convection. [IES-2002]
Reason (R): Radiation depends on fourth power of temperature while convection depends on unit power relationship.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the of A
(c) A is true but R is false
(d) A is false but R is true

IES-3. Assertion (A): In a furnace, radiation from the walls has the same wavelength as the incident radiation from the heat source. [IES-1998]
Reason (R): Surfaces at the same temperature radiate at the same wavelength.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-4. Consider following parameters: [IES-1995]
1. **Temperature of the surface**
2. **Emissivity of the surface**
3. **Temperature of the air in the room**
4. **Length and diameter of the pipe**

The parameter(s) responsible for loss of heat from a hot pipe surface in a room without fans would include

(a) 1 alone (b) 1 and 2 (c) 1, 2 and 3 (d) 1, 2, 3 and 4

IES-5. Which one of the following modes of heat transfer would take place predominantly, from boiler furnace to water wall? [IES-1993]

(a) Convection (b) Conduction
(c) Radiation (d) Conduction and convection

IES-6. A solar engine uses a parabolic collector supplying the working fluid at 500°C. A second engine employs a flat plate collector, supplying the working fluid at 80°C. The ambient temperature is 27°C. The ratio maximum work obtainable in the two cases is: [IES-1992]

(a) 1 (b) 2 (c) 4 (d) 16

Absorptivity, Reflectivity and Transmissivity

IES-7. Consider the following statements: [IES-1998]
1. **For metals, the value of absorptivity is high.**
2. **For non-conducting materials, reflectivity is low.**
3. **For polished surfaces, reflectivity is high.**
4. **For gases, reflectivity is very low.**

Of these statements:

(a) 2, 3 and 4 are correct (b) 3 and 4 are correct
(c) 1, 2 and 4 are correct (d) 1 and 2 are correct

IES-8. When α is absorbtivity, ρ is reflectivity and τ is transmisivity, then for diathermanous body, which of the following relation is valid? [IES-1992]

(a) $\alpha = 1, \rho = 0, \tau = 0$ (b) $\alpha = 0, \rho = 1, \tau = 0$
(c) $\alpha = 0, \rho = 0, \tau = 1$ (d) $\alpha + \rho = 1, \tau = 0$

IES-9. Match List-I with List-II and select the correct answer [IES-1996]

List-I	List-II
A. Window glass	**1.** Emissivity independent of wavelength
B. Gray surface	**2.** Emission and absorption limited to certain bands of wavelengths
C. Carbon dioxide	**3.** Rate at which radiation leaves a surface
D. Radiosity	**4.** Transparency to short wave radiation

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

IES-10. Assertion (A): Solar Radiation is mainly scattered or transmitted but not absorbed by the atmosphere. [IES-1992]
Reason (R): Absorptivity of atmosphere is low.
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

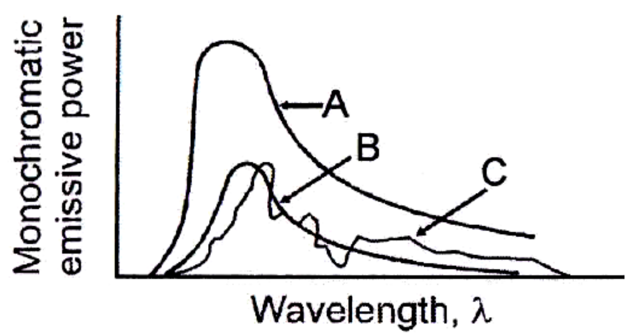
Black Body

IES-11. Match List-I (Type of radiation) with List-II (Characteristic) and select the correct answer: [IES-2002]

List-I	List-II
A. Black body	**1.** Emissivity does not depend on wavelength
B. Grey body	**2.** Mirror like reflection
C. Specular	**3.** Zero reflectivity
D. Diffuse	**4.** Intensity same in all directions

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

IES-12. Consider the diagram given above. Which one of the following is correct?



(a) Curve A is for gray body, Curve B is for black body, and Curve C is for selective emitter.
(b) Curve A is for selective emitter, Curve B is for black body, and Curve C is for grey body. **[IES-2007]**
(c) Curve A is for selective emitter, Curve B is for grey body, and Curve C is for black body.
(d) Curve A is for black body, Curve B is for grey body, and Curve C is for selective emitter.

IES-13. Assertion (A): The nose of aeroplane is painted black. [IES-1996]
Reason (R) Black body absorbs maximum heat which is generated by aerodynamic heating when the plane is flying.
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

The Stefan-Boltzmann Law

IES-14. Two spheres A and B of same material have radii 1 m and 4 m and temperature 4000 K and 2000 K respectively [IES-2004]
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

IES-15. 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 cooling rate is about. [IES-2003]
(a) 31.1 (b) 41.5 (c) 50.3 (d) 80.4

IES-16. If the temperature of a solid state changes from 27°C to 627°C, then emissive power changes which rate [IES-1999; 2006]
(a) 6 : 1 (b) 9 : 1 (c) 27 : 1 (d) 81: 1

IES-17. A spherical aluminium shell of inside diameter 2 m is evacuated and used as a radiation test chamber. If the inner surface is coated with carbon black and maintained at 600 K, the irradiation on a small test surface placed inside the chamber is: [IES-1999]
(Stefan-Boltzmann constant σ = 5.67 × 10^{-8} W/m^{2}K^4)
(a) 1000 W/m^2 (b) 3400 W/m^2 (c) 5680 W/m^2 (d) 7348 W/m^2

IES-18. A large spherical enclosure has a small opening. The rate of emission of radiative flux through this opening is 7.35 kW/m^2. The temperature at the inner surface of the sphere will be about (assume Stefan Boltzmann constants σ = 5.67 × 10^{-8} W/m^{2}K^4) [IES-1998]
(a) 600 K (b) 330 K (c) 373 K (d) 1000 K

Kirchoff's Law

IES-19. What is the ratio of thermal conductivity to electrical conductivity equal to? [IES-2006]
(a) Prandtl number (b) Schmidt number
(c) Lorenz number (d) Lewis number

IES-20. Match List-I with List-II and select the correct answer using the code given below the lists: [IES-2008]

List-I	List-II
A. Heat transfer through solid	**1.** Radiation heat transfer
B. Heat transfer from fluid	**2.** Fourier's law of heat conduction
C. Heat transfer in boiling liquid	**3.** Convection heat transfer
D. Heat transfer from one body to another body separated in space	**4.** Newton's law of cooling

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

IES-21. Match List-I with List-ll and select the correct answer using the codes given below the lists: [IES-1999]

List-I	List-II
A. Stefan-Boltzmann law	**1.** $q = hA\,(T_1 - T_2)$
B. Newton's law of cooling	**2.** $E = \alpha E_b$
C. Fourier's law	**3.** $q = \dfrac{kL}{A}(T_1 - T_2)$
D. Kirchoff's law	**4.** $q = \sigma A\left(T_1^4 - T_2^4\right)$
	5. $q = kA\left(T_1 - T_2\right)$

Codes: A B C D A B C D

(a)	4	1	3	2	(b)	4	5	1	2
(c)	2	1	3	4	(d)	2	5	1	4

IES-22. Match List-I (Law) with List-II (Effect) and select the correct answer using the code given below the lists: [IES-2008]

	List-I		List-II
A.	Fourier's Law	**1.**	Mass transfer
B.	Stefan Boltzmann Law	**2.**	Conduction
C.	Newton's Law of Cooling	**3.**	Convection
D.	Ficks Law	**4.**	Radiation

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

Planck's Law

IES-23. What is the basic equation of thermal radiation from which all other equations of radiation can be derived? [IES-2007]

(a) Stefan-Boltzmann equation (b) Planck's equation
(c) Wien's equation (d) Rayleigh-Jeans formula

IES-24. The spectral emissive power E_λ for a diffusely emitting surface is: [IES-1998]

$E_\lambda = 0$ for $\lambda < 3$ μm
$E_\lambda = 150$ W/m²μm for $3 < \lambda < 12$ μm
$E_\lambda = 300$ W/m²μm for $12 < \lambda < 25$ μm
$E_\lambda = 0$ for $\lambda > 25$ μm

The total emissive power of the surface over the entire spectrum is:

(a) 1250 W/m^2 (b) 2500 W/m^2 (c) 4000 W/m^2 (d) 5250 W/m^2

IES-25. The wavelength of the radiation emitted by a body depends upon [IES-1992]

(a) The nature of its surface (b) The area of its surface
(c) The temperature of its surface (d) All the above factors.

Wien Displacement Law

IES-26. Match List-I with List-II and select the correct answer using the code given below the lists: [IES-2005]

	List-I		List-II
A.	Radiation heat transfer	**1.**	Fourier number
B.	Conduction heat transfer	**2.**	Wien displacement law
C.	Forced convection	**3.**	Fourier law
D.	Transient heat flow	**4.**	Stanton number

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

IES-27. Sun's surface at 5800 K emits radiation at a wave-length of 0.5 μm. A furnace at 300°C will emit through a small opening, radiation at a wavelength of nearly [IES-1997]

(a) 10 μ (b) 5 μ (c) 0.25 μ (d) 0.025 μ

Intensity of Radiation and Lambert's Cosine Law

IES-28. Which one of the following statements is correct? [IES-2007]
For a hemisphere, the solid angle is measured
(a) In radian and its maximum value is π
(b) In degree and its maximum value is 180°
(c) In steradian and its maximum value is 2 π
(d) In steradian and its maximum value is π

IES-29. Intensity of radiation at a surface in perpendicular direction is equal to: [IES-2005; 2007]
(a) Product of emissivity of surface and $1/\pi$
(b) Product of emissivity of surface and π
(c) Product of emissive power of surface and $1/\pi$
(d) Product of emissive power of surface and π

IES-30. The earth receives at its surface radiation from the sun at the rate of 1400 W/m². The distance of centre of sun from the surface of earth is 1.5×10^8 m and the radius of sun is 7.0×10^8 m. What is approximately the surface temperature of the sun treating the sun as a black body? [IES-2004]
(a) 3650 K (b) 4500 K (c) 5800 K (d) 6150 K

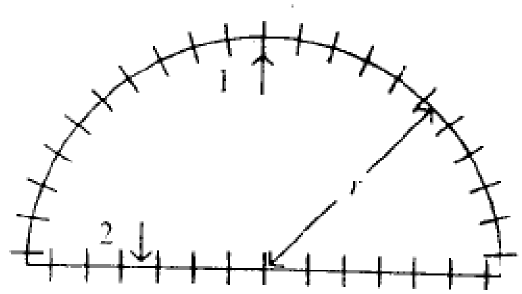
Shape Factor Algebra and Salient Features of the Shape Factor

IES-31. What is the value of the shape factor for two infinite parallel surface separated by a distance *d*? [IES-2006]
(a) 0 (b) ∞ (c) 1 (d) d

IES-32. Two radiating surfaces A_1 = 6 m² and A_2 = 4 m² have the shape factor F_{1-2} = 0.1; the shape factor F_{2-1} will be: [IES-2010]
(a) 0.18 (b) 0.15 (c) 0.12 (d) 0.10

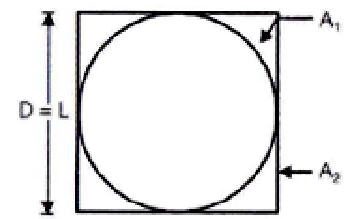
IES-33. What is the shape factor of a hemispherical body placed on a flat surface with respect to itself? [IES-2005]
(a) Zero (b) 0·25 (c) 0·5 (d) 1·0

IES-34. A hemispherical surface 1 lies over a horizontal plane surface 2 such that convex portion of the hemisphere is facing sky. What is the value of the geometrical shape factor F_{12}?
(a) ¼ (b) ½
(c) 3/4 (d) 1/8



[IES-2004]

IES-35. **What will be the view factor F_{21} for the geometry as shown in the figure above (sphere within a cube)?**



(a) $\frac{\pi}{2}$ (b) $\frac{\pi}{4}$

(c) $\frac{\pi}{3}$ (d) $\frac{\pi}{4}$

[IES-2009]

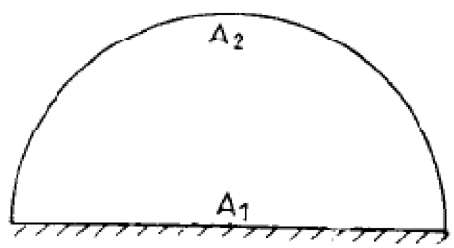
IES-36. **The shape factor of a hemispherical body placed on a flat surface with respect to itself is:** **[IES-2001]**

(a) Zero (b) 0.25 (c) 0.5 (d) 1.0

IES-37. **A small sphere of outer area 0.6 m² 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 cubical hall?** **[IES-2004]**

(a) 4 m (b) 5 m (c) 6 m (d) 10 m

IES-38. **A long semi-circular dud is shown in the given figure. What is the shape factor F_{22} for this case?**

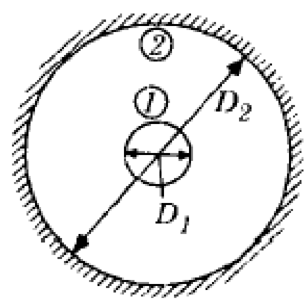


(a) 1.36 (b) 0.73

(c) 0.56 (d) 0.36

[IES-1994]

IES-39. **Consider two infinitely long blackbody concentric cylinders with a diameter ratio D_2/D_1 = 3. The shape factor for the outer cylinder with itself will be:**



(a) 0 (b) 1/3

(c) 2/3 (d) 1

[IES-1997]

IES-40. **Match List-I with List-II and select the correct answer using the code given below the Lists:** **[IES-2007]**

	List-I		List-II
A.	Heat Exchangers	**1.**	View factor
B.	Turbulent flow	**2.**	Effectiveness
C.	Free convention	**3.**	Nusselt number
D.	Radiation heat transfer	**4.**	Eddy diffusivity

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

IES-41. Match List-I with List-II and select the correct answer using the code given below the lists: [IES-2006]

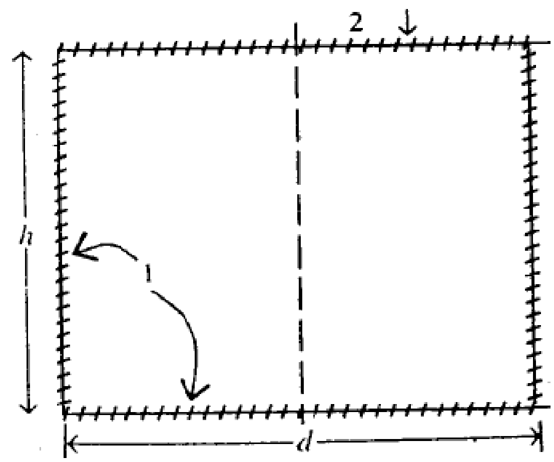
List-I	List-II
A. Radiation heat transfer	**1.** Biot's number
B. Conduction heat transfer	**2.** View factor
C. Forced convection	**3.** Fourier's law
D. Transient heat flow	**4.** Stanton number

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

IES-42. What is the value of the shape factor F_{12} in a cylindrical cavity of diameter d and height h between bottom face known as surface 1 and top flat surface know as surface 2?

(a) $\dfrac{2h}{2h+d}$ (b) $\dfrac{2d}{d+4h}$

(c) $\dfrac{4d}{4d+h}$ (d) $\dfrac{2d}{2d+h}$



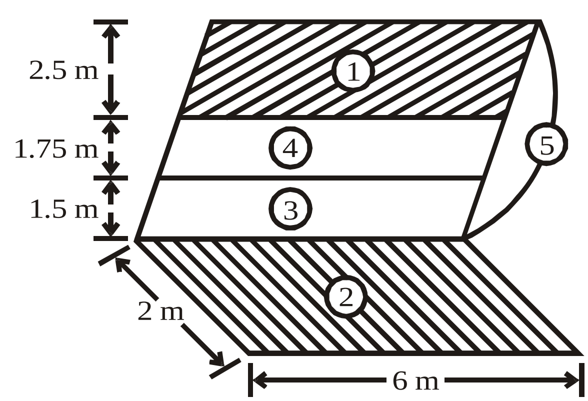
[IES-2004]

IES-43. An enclosure consists of the four surfaces 1, 2, 3 and 4. The view factors for radiation heat transfer (where the subscripts 1, 2, 3, 4 refer to the respective surfaces) are F_{11} = 0.1, F_{12} = 0.4 and F_{13} = 0.25. The surface areas A_1 and A_4 are 4 m² and 2 m² respectively. The view factor F_{41} is: [IES-2001]

(a) 0.75 (b) 0.50 (c) 0.25 (d) 0.10

IES-44. With reference to the above figure, the shape factor between 1 and 2 is:

(a) 0.272
(b) 0.34
(c) 0.66
(d) Data insufficient



[IES-2010]

Heat Exchange between Non-black Bodies

IES-45. Match List-I (Surface with orientations) with List-II (Equivalent emissivity) and select the correct answer: [IES-1995; 2004]

	List-I		List-II
A.	Infinite parallel planes	**1.**	ε_1
B.	Body 1 completely enclosed by body 2 but body 1 is very small	**2.**	$\dfrac{1}{\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_2}-1}$
C.	Radiation exchange Between two small grey bodies	**3.**	$\dfrac{1}{\dfrac{1}{\varepsilon_1}+\left(\dfrac{A_1}{A_2}\right)\left(\dfrac{1}{\varepsilon_2}-1\right)}$
D.	Two concentric cylinders with large lengths	**4.**	$\varepsilon_1\varepsilon_2$

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

IES-46. What is the equivalent emissivity for radiant heat exchange between a small body (emissivity = 0.4) in a very large enclosure (emissivity = 0·5)? [IES-2008]

(a) 0·5 (b) 0·4 (c) 0·2 (d) 0·1

IES-47. 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 $q_{1-2} = A_1\varepsilon_1\sigma\left(T_1^4 - T_2^4\right)$. What is 'the assumption for this equation?[IES-2008]

(a) $\varepsilon_2 = 1$ (b) $\varepsilon_2 = 0$

(c) A_1 is very small as compared to A_2

(d) Small body is at centre of enclosure

IES-48. Two large parallel grey plates with a small gap, exchange radiation at the rate of 1000 W/m² when their emissivities are 0.5 each. By coating one plate, its emissivity is reduced to 0.25. Temperature remains unchanged. The new rate of heat exchange shall become: [IES-2002]

(a) 500 W/m² (b) 600 W/m² (c) 700 W/m² (d) 800 W/m²

IES-49. 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? [IES-1993; 2007]

(a) $\varepsilon_1\varepsilon_2$ (b) $\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_2}$

(c) $\dfrac{1}{\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_2}}$ (d) $\dfrac{1}{\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_2}-1}$

IES-50. The radiative heat transfer rate per unit area (W/m^2) between two plane parallel grey surfaces whose emissivity is 0.9 and maintained at 400 K and 300 K is: [IES-2010]

(a) 992 (b) 812 (c) 567 (d) 464

Rate of Heat Transfer

$q = f_{12} \cdot \sigma \cdot (T_1^4 - T_2^4) = 0.8182 \times 5.67 \times 10^{-8} (400^4 - 300^4)\ W/m^2 = 812\ W/m^2$

IES-51. What is the net radiant interchange per square meter for two very large plates at temperatures 800 K and 500 K respectively? (The emissivity of the hot and cold plates are 0.8 and 0.6 respectively. Stefan Boltzmann constant is $5.67 \times 10^{-8}\ W/m^2 K^4$). [IES-1994]

(a) 1.026 kW/m^2 (b) 10.26 kW/m^2 (c) 102.6 kW/m^2 (d) 1026 kW/m^2

Electrical Network Analogy for Thermal Radiation Systems

IES-52. Using thermal-electrical analogy in heat transfer, match List-I (Electrical quantities) with List-II (Thermal quantities) and select the correct answer: [IES-2002]

	List-I		**List-II**
A.	Voltage	**1.**	Thermal resistance
B.	Current	**2.**	Thermal capacity
C.	Resistance	**3.**	Heat flow
D.	Capacitance	**4.**	Temperature

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

IES-53. For an opaque plane surface the irradiation, radiosity and emissive power are respectively 20, 12 and 10 W/m^2.What is the emissivity of the surface? [IES-2004]

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

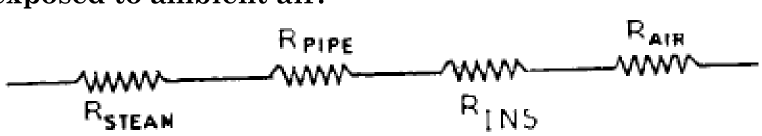
IES-54. Heat transfer by radiation between two grey bodies of emissivity ε is proportional to (notations have their usual meanings) [IES-2000]

(a) $\dfrac{(E_b - J)}{(1-\varepsilon)}$ (b) $\dfrac{(E_b - J)}{(1-\varepsilon)/\varepsilon}$ (c) $\dfrac{(E_b - J)}{(1-\varepsilon)^2}$ (d) $\dfrac{(E_b - J)}{(1-\varepsilon^2)}$

IES-55. Solar radiation of 1200 W/m^2 falls perpendicularly on a grey opaque surface of emissivity 0.5. If the surface temperature is 50°C and surface emissive power 600 W/m^2, the radiosity of that surface will be: [IES-2000]

(a) 600 W/m^2 (b) 1000 W/m^2 (c) 1200 W/m^2 (d) 1800 W/m^2

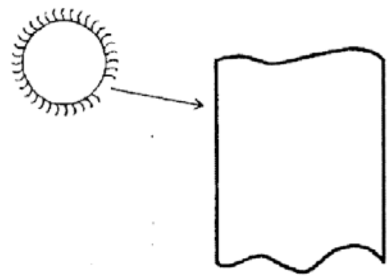
IES-56. A pipe carrying saturated steam is covered with a layer of insulation and exposed to ambient air. [IES-1996]

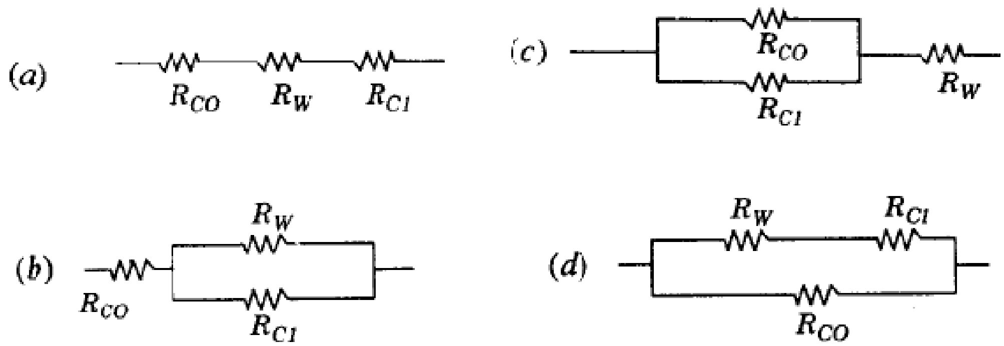


The thermal resistances are as shown in the figure.

Which one of the following statements is correct in this regard?
(a) R_{sream} and R_{pipe} are negligible as compared to R_{ins} and R_{air}
(b) R_{pipe} and R_{air} are negligible as compared to R_{ins} and R_{steam}
(c) R_{steam} and R_{air} are negligible as compared to R_{pipe} and R_{ins}
(d) No quantitative data is provided, therefore no comparison is possible.

IES-57. Solar energy is absorbed by the wall of a building as shown in the above figure. Assuming that the ambient temperature inside and outside are equal and considering steady-state, the equivalent circuit will be as shown in (Symbols: R_{co} = $R_{convection,outside}$ R_{CI} = $R_{convection,inside}$ and R_w = R_{Wall})





[IES-1998]

IES-58. Which of the following would lead to a reduction in thermal resistance?
1. **In conduction; reduction in the thickness of the material and an increase in the thermal conductivity. [IES-1994]**
2. **In convection, stirring of the fluid and cleaning the heating surface.**
3. **In radiation, increasing the temperature and reducing the emissivity.**

Codes: (a) 1, 2 and 3 (b) 1 and 2 (c) 1 and 3 (d) 2 and 3

Radiation Shields

IES-59. 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 would be the number of shields? [IES-1992; 2004]
(a) 1 (b) 2 (c) 3 (d) 4

IES-60. Two long parallel plates of same emissivity 0.5 are maintained at different temperatures and have radiation heat exchange between them. The radiation shield of emissivity 0.25 placed in the middle will reduce radiation heat exchange to: [IES-2002]
(a) ½ (b) ¼ (c) 3/10 (d) 3/5

Answers with Explanation (Objective)

Previous 20-Years GATE Answers

GATE-1. Ans. (b)
GATE-2. Ans. (a)
GATE-3. Ans. (d)
GATE-4. Ans. (d)
GATE-5. Ans. (b) It is shape factor = $1-\frac{A_1}{A_2}=1-\frac{\pi D_1 L}{\pi D_2 L}=1-\frac{1}{2}=0.5$
GATE-6. Ans. (a)
GATE-7. Ans. (d) Principal of conservation gives

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

$F_{1-1}=0,$ flat surface cannot see itself

$\therefore \quad 0+F_{1-2}+0.17=1 \qquad$ or $F_{1-2}=0.83$

GATE-8. Ans. (a) $F_{12}=F_{21}=1-\sin\left(\alpha/2\right)=1-\sin 10=0.83$

GATE-9. Ans. (c) $F_{2-2}=0;\ F_{2-1}=1$ and

$A_1F_{1-2}=A_2F_{2-1}$ or $F_{1-2}=\frac{A_2}{A_1}$

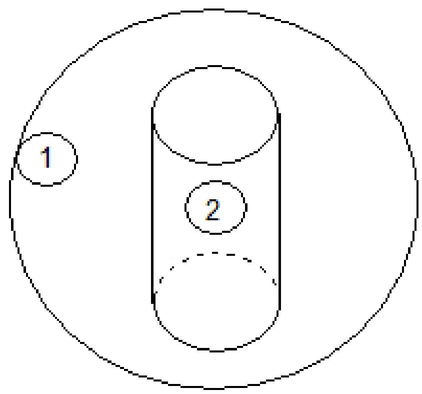
and $F_{1-1}+F_{1-2}=1$ gives

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

$=1-\frac{\left(\pi DL+2\times\pi D^2/4\right)}{4\pi r^2}$

[and given $D=L$]

$F_{1-1}=1-\frac{1.5\times0.5^2}{4\times0.5^2}=0.625$



GATE-10. Ans. (b) $f_{12}=\frac{1}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1}=\frac{1}{\frac{1}{0.9}+\frac{1}{0.9}-1}=0.818$

$Q=f_{12}\sigma\left(T_1^4-T_2^4\right)=0.818\times5.67\times10^{-8}\left(400^4-300^4\right)=812\,\text{W}$

GATE-11. Ans. (b) Given: $A_1=2\times10\,\text{cm}^2=2\times10^{-3}\,\text{m}^2$ and $A_2=100\,\text{m}^2$

$T_1=800\,\text{K} \qquad T_2=300\,\text{K}$

$\varepsilon_1=0.6 \qquad \varepsilon_2=0.3$

Interchange factor $\left(f_{1-2}\right)=\frac{1}{\frac{1}{\varepsilon_1}+\frac{A_1}{A_2}\left(\frac{1}{\varepsilon_2}-1\right)}=\frac{1}{\frac{1}{0.6}+\frac{2\times10^{-3}}{100}\left(\frac{1}{0.3}-1\right)}=0.6$

$Q_{net}=f_{1-2}\sigma A_1\left(T_1^4-T_2^4\right)=0.6\times5.67\times10^{-8}\times2\times10^{-3}\left(800^4-300^4\right)\text{W}=27.32\,\text{W}$

Previous 20-Years IES Answers

IES-1. Ans. (c)
IES-2. Ans. (a)
IES-3. Ans. (d) Wall and furnace has different temperature.
IES-4. Ans. (d) All parameters are responsible for loss of heat from a hot pipe surface.
IES-5. Ans. (c) In boiler, the energy from flame is transmitted mainly by radiation to water wall and radiant super heater.
IES-6. Ans. (c) Maximum efficiency of solar engine $= \dfrac{T_1 - T_2}{T_1}$

$$= \frac{(500+273)-(27+273)}{50+273} = \frac{473}{773}\left(=\frac{W_1}{Q_1}\right) \text{ say,}$$

where, W is the work output for Q_1 heat input.

Maximum efficiency of second engine $= \dfrac{(273+80)-(273+27)}{273+80} = \dfrac{53}{353}\left(=\dfrac{W_2}{Q_2}\right)$ say,

where, W_2 is the work output of second engine for Q_2 heat output.
Assuming same heat input for the two engines, we have

$$\therefore \qquad \frac{W_1}{W_2} = \frac{473/7333}{53/353} = 4$$

IES-7. Ans. (c)
IES-8. Ans. (c)
IES-9. Ans. (c)
IES-10. Ans. (a)
IES-11. Ans. (d)
IES-12. Ans. (d)
IES-13. Ans. (b)
IES-14. Ans. (c) $E = \sigma A T^4$; $\quad \therefore \dfrac{E_A}{E_B} = \dfrac{4\pi r^2{}_A T_A{}^4}{4\pi r^2{}_B T_B{}^4} = \dfrac{1^2 \times 4000^4}{4^2 \times (2000)^4} = 1$
IES-15. Ans. (a)
IES-16. Ans. (d) Emissive power $(E) = \varepsilon\sigma T^4$ or $\dfrac{E_1}{E_2} = \left(\dfrac{T_1}{T_2}\right)^4 = \left(\dfrac{300}{900}\right)^4 = \dfrac{1}{81}$
IES-17. Ans. (d) Irradiation on a small test surface placed inside a hollow black spherical chamber $= \sigma T^4 = 5.67 \times 10^{-8} \times 600^4 = 7348$ W/m^2
IES-18. Ans. (a) Rate of emission of radiative flux $= \sigma T^4$

or $\quad 7.35\times10^3 = 5.67\times10^{-8}\times T^4 \quad$ or $\; T = 600\,\text{K}$

IES-19. Ans. (c)
IES-20. Ans. (b)

Heat transfer through solid	→	Fourier's law of heat conduction
Heat transfer from hot surface to surrounding fluid	→	Newton's law of cooling
Heat transfer in boiling liquid	→	Convection heat transfer
Heat transfer from one body to	→	Radiation heat

another transfer separated in space

IES-21. Ans. (a)

IES-22. Ans. (b)

IES-23. Ans. (b)

IES-24. Ans. (d) Total emissive power is defined as the total amount of radiation emitted by a body per unit time

i.e. $E = \int E_\lambda \lambda d\lambda = 0\times 3 + 150\times(12-3) + 300\times(25-12) + 0[\alpha]$

$$= 150\times 9 + 300\times 13 = 1350 + 3900 = 5250 \text{ W/m}^2$$

IES-25. Ans. (c)

IES-26. Ans. (c)

IES-27. Ans. (b) As per Wien's law, $\lambda_1 T_1 = \lambda_2 T_2$ *or* $5800\times 0.5 = \lambda_2 \times 573$

IES-28. Ans. (c)

IES-29. Ans. (c) We know that, $I = \dfrac{E}{\pi}$

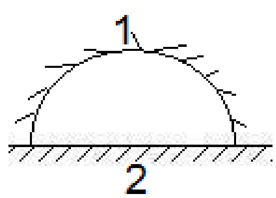
IES-30. Ans. (c)

IES-31. Ans. (c) All the emission from one plate will cross another plate. So Shape Factor in one.

IES-32. Ans. (b) $A_1F_{1-2} = A_2 F_{2-1}$

or $F_{2-1} = \dfrac{A_1}{A_2}.F_{1-2} = \dfrac{6}{4}\times 0.1 = 0.15$

IES-33. Ans. (c)



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

$A_1F_{-2} = AF_{2-1}$

or $F_{1-2} = \dfrac{A_2}{A_1}\times F_{2-1} = \dfrac{\pi r^2 \times 1}{2\pi r^2} = \dfrac{1}{2}$

$F_{1-1} + F_{1-2} = 1 \ \ or \ \ F_{1-1} = \dfrac{1}{2} = 0.5$

IES-34. Ans. (b) $F_{22} = 0; \quad \therefore F_{21} = 1$

$A_1F_{12} = A_2F_{21}$ or $F_{12} = \dfrac{A_2}{A_1} = \dfrac{\pi r^2}{2\pi r^2} = \dfrac{1}{2}$

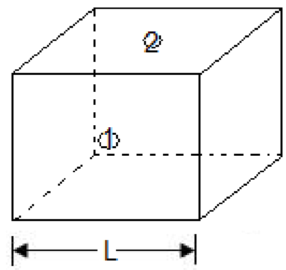
IES-35. Ans. (d) $F_{11} + F_{12} = 1; \quad \because \quad F_{11} = 0$

$0 + F_{12} = 1 \quad \Rightarrow F_{12} = 1$

$A_1F_{12} = A_2F_{21} \quad \Rightarrow F_{21} = \dfrac{A_1}{A_2} = \dfrac{4\pi\left(\dfrac{D}{2}\right)^2}{6D^2} = \dfrac{\pi}{6}$

IES-36. Ans. (c)

IES-37. Ans. (b)



Shape factor F_{12} means part of radiation body 1 radiating and body 2 absorbing

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

or $0 + F_{12} = 1$

then $A_1F_{12} = A_2F_{21}$ *or* A_2F_{21}

or $F_{21} = \dfrac{A_1}{A_2} \times F_{12} = \dfrac{0.6}{6L^2} \times 1 = 0.004$

or $L = \sqrt{\dfrac{0.6}{6 \times 0.004}} = 5\,\text{m}$

IES-38. Ans. (d) Shape factor $F_{22} = 1 - \dfrac{A_1}{A_2} = 1 - \dfrac{2rl}{\pi rl} = 0.36$

IES-39. Ans. (c) $F_{11} + F_{12} = 1$ as $F_{11} = 0$ or $F_{12} = 1$

$$A_1F_{12} = A_2F_{21} \quad \text{or } F_{21} = \frac{A_1F_{12}}{A_2} = \frac{1}{3} \qquad \text{or } F_{22} = \frac{2}{3}$$

IES-40. Ans. (b)
IES-41. Ans. (d)
IES-42. Ans. (b) $F_{2-2} = 0, \ \therefore F_{2-1} = 1$

$$A_1F_{1-2} = A_2F_{2-1} \quad or \ F_{12} = \frac{A_2}{A_1} = \frac{\pi d^2/4}{\dfrac{\pi d^2}{4} + \pi Dh} = \frac{d}{d+4h}$$

IES-43. Ans. (b) $F_{14} = 1 - 0.1 - 0.4 - 0.25 = 0.25$

$$A_1F_{14} = A_4F_{41} \quad or\ F_{41} = \frac{A_1F_{14}}{A_4} = \frac{4}{2} \times 0.25 = 0.5$$

IES-44. Ans. (d)
IES-45. Ans. (c)
IES-46. Ans. (b)
IES-47. Ans. (c) When body 1 is completely enclosed by body 2, body 1 is large.

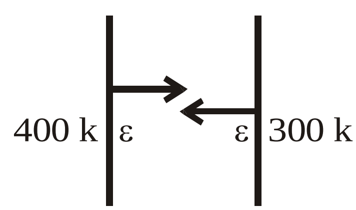
$$\therefore \quad \in \text{ is given by} \frac{1}{1/\in_1 + \dfrac{A_1}{A_2}\left(\dfrac{1}{\in_2} - 1\right)}.$$

$$\in = \in_1$$

$$\therefore \quad q_{1-2} = A_1 \in_1 \sigma = \left(T_1^4 - T_2^4\right)$$

IES-48. Ans. (b)
IES-49. Ans. (d)
IES-50. Ans. (b) Interchange factor (f_{12})

$$= \frac{1}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1} = \frac{1}{\dfrac{2}{0.9} - 1} = 0.8182$$



IES-51. Ans. (b) Heat transfer $Q = \sigma F_e F_A \left(T_1^4 - T_2^4\right) W/m^2$; $\sigma = 5.67 \times 10^{-8}$ W/m² K⁴

F_e = effective emissivity coefficient = $\dfrac{1}{\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_2}-1}=\dfrac{1}{\dfrac{1}{0.8}+\dfrac{1}{0.6}-1}=\dfrac{12}{23}$

Shape factor $F_A = 1$

$$Q = 5.67\times10^{-8}\times1\times\frac{12}{23}\left(800^4-500^4\right)=1026\ \text{W/m}^2=10.26\ \text{kW/m}^2$$

IES-52. Ans. (d)

IES-53. Ans. (c) $J=\varepsilon E_b+\left(1-\varepsilon\right)G$

$12=\varepsilon\times10+\left(1-\varepsilon\right)\times20$ or $\varepsilon=0.8$

IES-54. Ans. (b)

IES-55. Ans. (c)

IES-56. Ans. (a) The resistance due to steam film and pipe material are negligible in comparison to resistance of insulation material and resistance due to air film.

IES-57. Ans. (a) All resistances are in series.

IES-58. Ans. (b) 1. In conduction, heat resistance = $\Delta x/kA$

Thus reduction in thickness and increase in area result in reduction of thermal resistance.

2. Stirring of fluid and cleaning the heating surface increases value of h, and thus reduces thermal resistance.
3. In radiation, heat flow increases with increase in temperature and reduces with reduction in emissivity. Thus thermal resistance does not decrease. Thus 1 and 2 are correct.

IES-59. Ans. (c) $\dfrac{Q_{withinshield}}{Q_{without\,shield}}=\dfrac{1}{n+1}$ or $0.25=\dfrac{1}{n+1}$ or $n=3$

IES-60. Ans. (c)

10. Mass Transfer

OBJECTIVE QUESTIONS (GATE, IES, IAS)

Previous 20-Years IES Questions

Modes of Mass Transfer

IES-1. Consider the following statements: [IES-2010]

1. **Mass transfer refers to mass in transit due to a species concentration gradient in a mixture.**
2. **Must have a mixture of two or more species for mass transfer to occur.**
3. **The species concentration gradient is the driving potential for mass transfer.**
4. **Mass transfer by diffusion is analogous to heat transfer by conduction.**

Which of the above statements are correct ?

(a) 1, 2 and 3 only (b) 1, 2 and 4 only
(c) 2, 3 and 4 only (d) 1, 2, 3 and 4

IES-2. If heat and mass transfer take place simultaneously, the ratio of heat transfer coefficient to the mass transfer coefficient is a function of the ratio of: [IES-2000]

(a) Schmidt and Reynolds numbers (b) Schmidt and Prandtl numbers
(c) Nusselt and Lewis numbers (d) Reynolds and Lewis numbers

IES-3. In case of liquids, what is the binary diffusion coefficient proportional to? [IES-2006]

(a) Pressure only (b) Temperature only
(c) Volume only (d) All the above

IES-4. In a mass transfer process of diffusion of hot smoke in cold air in a power plant, the temperature profile and the concentration profile will become identical when: [IES-2005]

(a) Prandtl No. = 1
(b) Nusselt No. = 1
(c) Lewis No. = 1
(d) Schmilt No. = 1

IES-5. Given that: [IES-1997]

N_u = Nusselt number **R_e = Reynolds number**
P_r = Prandtl number **S_h = Sherwood number**
S_c = Schmidt number **G_r = Grashoff number**

The functional relationship for free convective mass transfer is given as:

$(a) N_u = f(G_r, P_r)$ $(b) S_h = f(S_c, G_r)$ $(c) N_u = f(R_r, P_r)$ $(d)\ S_h = f(R_e, S_c)$

IES-6. Schmidt number is ratio of which of the following? [IES-2008]

(a) Product of mass transfer coefficient and diameter to diffusivity of fluid
(b) Kinematic viscosity to thermal diffusivity of fluid
(c) Kinematic viscosity to diffusion coefficient of fluid
(d) Thermal diffusivity to diffusion coefficient of fluid

Answers with Explanation (Objective)

Previous 20-Years IES Answers

IES-1. Ans. (d)

IES-2. Ans. (b) $Nu_x = (conct.)_1 \times (\mathrm{Re})^{0.8} \times (\mathrm{Pr})^{1/3}$

$$Sh_x = (conct.)_2 \times (\mathrm{Re})^{0.8} \times (Se)^{1/3}$$

$$\therefore \frac{h_x}{h_{xm}} = (conct.)_3 \left(\frac{\mathrm{Pr}}{Se}\right)^{1/3}$$

IES-3. Ans. (b)

IES-4. Ans. (c)

IES-5. Ans. (b)

IES-6. Ans. (c) Schmidt number

$$Sc = \frac{\mu}{\rho \mathrm{D}} = \frac{\upsilon}{D} = \frac{\text{Momentum diffusivity}}{\text{Mass diffusivity}}$$