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GATE 2019
Mechanical Engineering

Questions and Solutions of afternoon session

Date of Exam : 2/2/2019

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GENERAL APTITUDE

Q.1 - Q.5 Carry One Mark each.

Q.1 Are there enough seats here? There are ________ people here than I expected.

(a) most
(b) more
(c) least
(d) many

Ans. (b)

Comparative degree adjective is required since comparison is indicated (use of 'than').

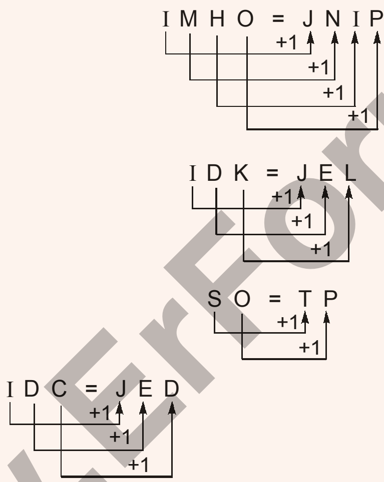
End of Solution

Q.2 If IMHO = JNIP; IDK = JEL; and SO = TP, then IDC = ________.

(a) JDE
(b) JED
(c) JDC
(d) JCD

Ans. (b)

So,



End of Solution

Q.3 Once the team of analysts identify the problem, we ________ in a better position to comment on the issue.

Which one of the following choices CANNOT fill the given blank?

(a) were to be
(b) are going to be
(c) will be
(d) might be

Ans. (a)

Since the 1st clause is in present tense, the second clause will not use past tense. are going to be, will be, might be fill the given blank appropriately.

End of Solution

Q.4 A final examination is the ________ of a series of evaluations that a student has to go through.

(a) insinuation (b) desperation

(c) culmination (d) consultation

Ans. (c)

Culmination refers to the end point or the final result of a process.

End of Solution

Q.5 The product of three integers X, Y and Z is 192. *Z* equal to 4 and P is equal to the average of X and Y. What is the minimum possible value of P?

(a) 8 (b) 7

(c) 9.5 (d) 6

Ans. (b)

Given, XYZ = 192, Z = 4

Now, XYZ = 192

$$XY = \frac{192}{4} = 48$$

XY = 48 → 1 × 48, 2 × 24, 3 × 16, 4 × 12, 6 × 8

Hence,

$$\text{minimum possible value of } P = \frac{X+Y}{2} = \frac{6+8}{2} = 7$$

End of Solution

Q.6 - Q.10 Carry Two Marks each.

Q.6 X is an online media provider. By offering unlimited and exclusive online content at attractive prices for a loyalty membership, X is almost forcing its customers towards its loyalty membership. If its loyalty membership continues to grow at its current rate, within the next eight years more households will be watching X than cable television. Which one of the following statements can be inferred from the above paragraph?

(a) Most households that subscribe to X's loyalty membership discontinue watching cable television

(b) Cable television operators don't subscribe to X's loyalty membership

(c) The X is cancelling accounts of non-members

(d) Non-members prefer to watch cable television

Ans. (a)

Most households that subscribe to X's loyalty membership discontinue watching cable television.

It is estimated that if X continues to offer loyalty membership, the number of subscribers of X will outgrow that of cable television. It is based on the assumption that most of the households subscribing to X don't watch cable television any longer.

End of Solution

Q.7 Fiscal deficit was 4% of the GDP in 2015, and that increased to 5% in 2016. If the GDP increased by 10% from 2015 to 2016, then percentage increase in the actual fiscal deficit is ______

(a) 25.00
(b) 35.70
(c) 10.00
(d) 37.50

Ans. (d)

Let GDP in 2015 = 100

GDP in 2016 = 100 + 10 = 110

Deficit in 2015 = 4

Deficit in 2016 = 5% of 110 = 5.5

Percentage increase in fiscal deficit $= \frac{5.5-4}{4} \times 100 = \frac{1.5}{4} \times 100 = 37.5\,\%$

End of Solution

Q.8 Mola is a digital platform for taxis in a city. It offers three type of rides-Pool, Mini and Prime. The table below presents the number of rides for the past four months. The platform earns one US dollar per ride. What is the percentage share of revenue contributed by prime to the total revenues of Mola, for the entire duration?

Type	Month			
	January	February	March	April
Pool	170	320	215	190
Mini	110	220	180	70
Prime	75	180	120	90

(a) 38.74
(b) 23.97
(c) 25.86
(d) 16.24

Ans. (b)

Revenue by pool = 170 + 320 + 215 + 190 = 895

Revenue by mini = 110 + 220 + 180 + 70 = 580

Revenue by prime = 75 + 180 + 120 + 90 = 465

Total revenue by Mola = 895 + 580 + 465 = 1940

Percentage of prime $= \frac{465}{1940} \times 100 = 23.97\%$

End of Solution

Q.9 While teaching a creative writing class in India. I was surprised at receiving stories from the students that were all set in distant places: in the American West with cowboys and in Manhattan penthouses with clinking ice cubes. This was, till an eminent Caribbean writer gave the once-colonized countries the confidence to see the shabby lives around them as worthy of being "told".

The writer of this passage is surprised by the creative writing assignments of his students, because ________ .

(a) None of the students had written about ice cubes and cowboys.
(b) None of the students had written stories set in India.
(c) Some of the students had written about ice cubes and cowboys.
(d) Some of the students had written stories set in foreign places.

Ans. (b)

None of the students had written stories set in India.

It is explicitly stated that the writer was surprised at receiving stories from the students that were all set in distant places.

End of Solution

Q.10 Two pipes P and Q can fill a tank in 6 hours and 9 hours respectively, while a third pipe R can empty the tank in 12 hours. Initially, P and R are open for 4 hours. Then P is closed and Q is opened. After 6 more hours R is closed. The total time taken to fill the tank (in hours) is _____

(a) 16.50
(b) 15.50
(c) 14.50
(d) 13.50

Ans. (c)

$$\text{In 1 hour } P \text{ can fill} = \frac{1}{6}$$

$$\text{In 1 hour } Q \text{ can fill} = \frac{1}{9}$$

$$\text{In 1 hour } R \text{ can empty} = \frac{1}{12}$$

$$\text{In 4 hour } (P + R) \text{ can fill} = 4\times\left(\frac{1}{6}-\frac{1}{12}\right) = \frac{1}{3}$$

$$\text{In 6 hour } (Q + R) \text{ can fill} = 6\left(\frac{1}{9}-\frac{1}{12}\right) = \frac{1}{6}$$

$$\text{In 10 hour tank can fill} = \frac{1}{3}+\frac{1}{6} = \frac{1}{2}$$

$$\text{Remaining part of tank} = 1-\frac{1}{2} = \frac{1}{2}$$

$$\frac{1}{2} \text{ tank } Q \text{ can fill} = \frac{1}{2}\times 9 = 4.5 \text{ hour}$$

$$\text{Total time} = 10 + 4.5 = 14.5 \text{ hours}$$

End of Solution

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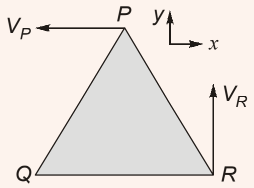
MECHANICAL ENGINEERING

Q.1 - Q.25 Carry One Mark each.

Q.1 A rigid triangular body, *PQR*. with sides of equal length of 1 unit moves on a flat plate. At the instant shown, edge *QR* is parallel to the x-axis and the body moves such that velocities of points *P* and *R* are V_P and V_R in the x and y directions, respectively. The magnitude of the angular velocity of the body is



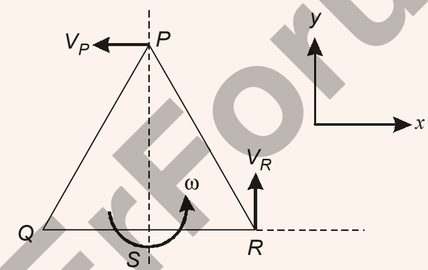
(a) $2V_P$

(b) $\frac{V_R}{\sqrt{3}}$

(c) $\frac{V_P}{\sqrt{3}}$

(d) $2\ V_R$

Ans. (d)



At the given instant, instantaneous centre (I_C) is at mid of *Q* and *R*, that is *S*.
Let's take ω to be angular velocity of body.

Then, $V_P = (PS)\cdot\omega$

$$\Rightarrow \quad \omega = \frac{V_P}{PS} = \frac{V_P}{\sqrt{3}/2} = \frac{2V_P}{\sqrt{3}} \qquad \{\because PQ = PR = QR = 1\}$$

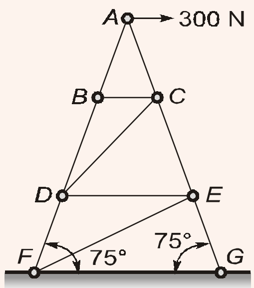
Also, $V_R = SR\cdot\omega$

$$\Rightarrow \quad \omega = \frac{V_R}{SR} = \frac{V_R}{1/2} = 2V_R$$

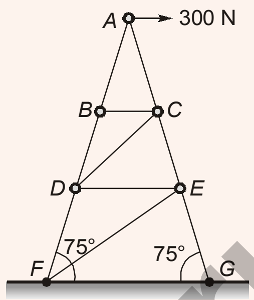
Observing options, $2V_R$ is correct i.e. option (d).

End of Solution

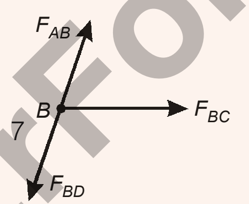
Q.2 The figure shows an idealized plane truss. If a horizontal force of 300 N is applied at point A, then the magnitude of the force produced in member CD is ________ N.



Ans. (0)

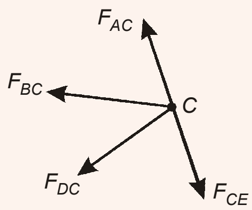


Considering joint B,



$\Rightarrow$ $F_{BC} = 0$ (for equilibrium)

Now considering joint C,



For equilibrium, $F_{DC} = 0$ (As $F_{BC} = 0$)

End of Solution

Q.3 The most common limit gage used for inspecting the hole diameter is

(a) Master gage (b) Plug gage
(c) Ring gage (d) Snap gage

Ans. (b)

End of Solution

Q.4 An analytic function $f(z)$ of complex variable $z = x + iy$ may be written as $f(z) = u(x, y) + iv(x, y)$. Then, $u\ (x, y)$ and $v(x, y)$ must satisfy,

(a) $\frac{\partial u}{\partial x} = \frac{-\partial v}{\partial y}$ and $\frac{\partial u}{\partial y} = \frac{\partial v}{\partial x}$

(b) $\frac{\partial u}{\partial x} = \frac{-\partial v}{\partial y}$ and $\frac{\partial u}{\partial y} = \frac{-\partial v}{\partial x}$

(c) $\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y}$ and $\frac{\partial u}{\partial y} = \frac{-\partial v}{\partial x}$

(d) $\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y}$ and $\frac{\partial u}{\partial y} = \frac{\partial v}{\partial x}$

Ans. (c)

C–R equation for the, $f(z) = u + iv$ to be analytic are $\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y}$ and $\frac{\partial u}{\partial y} = \frac{-\partial v}{\partial x}$

End of Solution

Q.5 Hardenability of steel is a measure of

(a) the depth to which required hardening is obtained when it is austenitized and then quenched.
(b) the ability to harden when it is cold worked
(c) the ability to retain its hardness when it is heated to elevated temperatures
(d) the maximum hardness that can be obtained when it is austenitized and then quenched

Ans. (a)

The depth and hardness achieved by quenching is called hardenability. Hardenability should not be confused with hardness. Hardenability can be defined as the depth to which a certain hardness level can be obtained by the quenching process.

End of Solution

Q.6 For a simple compressible system, v, s, p and T are specific volume, specific entropy, pressure and temperature, respectively. As per Maxwell's relations, $\left(\frac{\partial v}{\partial s}\right)_p$ is equal to

(a) $\left(\frac{\partial T}{\partial p}\right)_s$

(b) $\left(\frac{\partial p}{\partial v}\right)_T$

(c) $\left(\frac{\partial s}{\partial T}\right)_p$

(d) $-\left(\frac{\partial T}{\partial v}\right)_p$

Ans. (a)

As per Maxwell's relation,

$$\left(\frac{\partial v}{\partial s}\right)_p = \left(\frac{\partial T}{\partial p}\right)_s$$

End of Solution

Q.7 A spur gear has pitch circle diameter D and number of teeth T. The circular pitch of the gear is

(a) $\frac{D}{T}$ (b) $\frac{\pi D}{T}$

(c) $\frac{T}{D}$ (d) $\frac{2\pi D}{T}$

Ans. (b)

Pitch circle diameter = D

Number of teeth = T

Circular pitch, $P = \frac{\pi D}{T}$

End of Solution

Q.8 The fluidity of molten metal of cast alloys (without any addition of fluxes) increases with increase in

(a) freezing range (b) surface tension

(c) degree of superheat (d) viscosity

Ans. (c)

Fluidity:

- The ability of a metal of flow and fill a mold is known as fluidity.

Pouring temperature:

- The most important controlling factor of fluidity is the pouring temperature or the amount of superheat.
- Higher the pouring temperature, higher the fluidity.

End of Solution

Q.9 The cold forming process in which a hardened tool is pressed against a workpiece (when there is relative motion between the tool and the workpiece) to produce a roughened surface with a regular pattern is

(a) Roll forming (b) Chamfering

(c) Knurling (d) Strip rolling

Ans. (c)

End of Solution

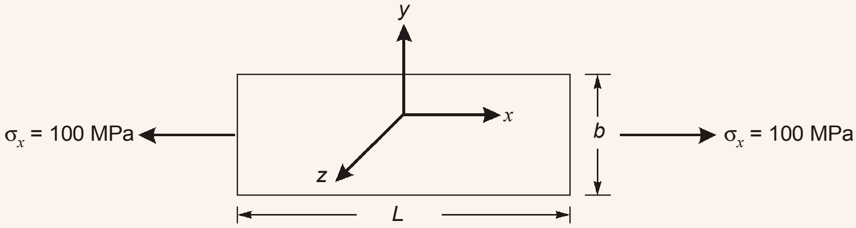
Q.10 Consider a linear elastic rectangular thin sheet of metal, subjected to uniform uniaxial tensile stress of 100 MPa along the length direction. Assume plane stress conditions in the plane normal to the thickness. The Young's modulus E = 200 MPa and Poisson's ratio ν = 0.3 are given. The principal strains in the plane of the sheet are

(a) (0.5, –0.5) (b) (0.5, –0.15)

(c) (0.35, –0.15) (d) (0.5, 0.0)

Ans. (b)

Given, $E = 200 \text{ MPa} = \nu = 0.3$



Assume plane stress condition, $\sigma_z = 0$

Given, $\sigma_y = 0$ and $\sigma_x \neq 0$ [Uniaxial state of stress condition]

As no shear stress acting on x and y face,

So, $\sigma_x = \sigma_1 = 100 \text{ MPa}$

$\sigma_y = \sigma_2 = 0$

$$\varepsilon_1 = \frac{\sigma_1}{E} - \nu\frac{\sigma_2}{E} = \frac{100}{200} - 0 = 0.5$$

$$\varepsilon_2 = \frac{\sigma_2}{E} - \nu\frac{\sigma_1}{E} = 0 - 0.3\left(\frac{100}{200}\right) = -0.15$$

Hence, option (b) is correct.

End of Solution

Q.11 Which one of the following modifications of the simple ideal Rankine cycle increases the thermal efficiency and reduces the moisture content of the steam at the turbine outlet?

(a) Decreasing the boiler pressure.

(b) Decreasing the condenser pressure.

(c) Increasing the boiler pressure.

(d) Increasing the turbine inlet temperature.

Ans. (d)

End of Solution

Q.12 Endurance limit of a beam subjected to pure bending decreases with

(a) decrease in the surface roughness and increase in the size of the beam

(b) decrease in the surface roughness and decrease in the size of the beam

(c) increase in the surface roughness and increase in the size of the beam

(d) increase in the surface roughness and decrease in the size of the beam

Ans. (c)

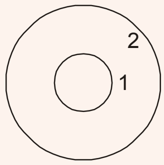
Endurance limit of beams subjected to pure bending decreases with increase in surface roughness, because it increases stress concentration factor which leads to decrease in endurance strength and by increasing size of beam the chances of number of voids and volumetric defects increases, which also lead to decrease in endurance limit.

End of Solution

Q.13 Sphere 1 with a diameter of 0.1 m is completely enclosed by another sphere 2 of diameter 0.4 m. The view factor F_{12} is

(a) 0.25
(b) 0.5
(c) 0.0625
(d) 1.0

Ans. (d)



$$F_{11} = 0$$

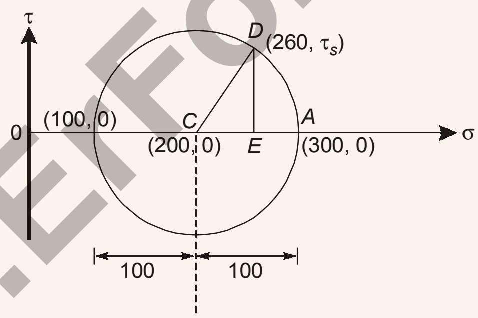
We know that, $F_{11} + F_{12} = 1$

$$F_{12} = 1$$

End of Solution

Q.14 The state of stress at a point in a component is represented by a Mohr's circle of radius 100 MPa centered at 200 MPa on the normal stress axis. On a plane passing through the same point, the normal stress is 260 MPa. The magnitude of the shear stress on the same plane at the same point is ______ MPa.

Ans. (80)



In ΔCDE, $(CD)^2 = (CE)^2 + (DE)^2$

$$(100)^2 = (60)^2 + (\tau_s)^2$$

$$\tau_s = 80 \text{ MPa}$$

End of Solution

Q.15 In an electrical discharge machining process, the breakdown voltage across inter electrode gap (IEG) is 200 V and the capacitance of the RC circuit is 50 μF. The energy (in J) released per spark across the IEG is ______ .

Ans. (1)

$$E = \frac{1}{2}CV_d^2 = \frac{1}{2} \times 50 \times 10^{-6} \times 200^2$$

$$= 1 \text{ J}$$

End of Solution

Q.16 The differential equation $\frac{dy}{dx} + 4y = 5$ is valid in the domain $0 \le x \le 1$ with $y(0) = 2.25$. The solution of differential equation is

(a) $y = e^{-4x} + 1.25$
(b) $y = e^{-4x} + 5$
(c) $y = e^{4x} + 5$
(d) $y = e^{4x} + 1.25$

Ans. (a)

$$P(x) = 4,\ Q(x) = 5$$

$$\text{I.F} = e^{\int P(x)dx} = e^{\int 4dx} = e^{4x}$$

$$ye^{4x} = \int 5e^{4x}dx + c$$

$$ye^{4x} = \frac{5}{4}e^{4x} + c$$

$$y = \frac{5}{4} + ce^{-4x}$$

Substitute given initial condition,

$$x = 0,\ y = 2.25$$

We get, $c = 1$

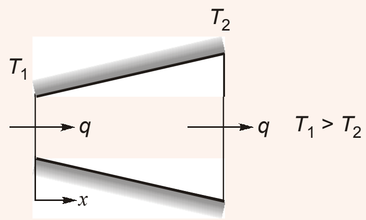
$$y = \frac{5}{4} + e^{-4x}$$

End of Solution

Q.17 One-dimensional steady state heat conduction takes place through a solid whose cross-sectional area varies linearly in the direction of heat transfer. Assume there is no heat generation in the solid and the thermal conductivity of the material is constant and independent of temperature. The temperature distribution in the solid is

(a) Quadratic
(b) Logarithmic
(c) Linear
(b) Exponential

Ans. (b)



$$A = f(x)$$

Let, $A = a + bx$

$$\dot{E}_{in} + \dot{E}_{out} + \not{\dot{E}}_g = \not{\dot{E}}_{st} \quad (\because \text{ steady state and no heat generation})$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$q \ne f(x)$ i.e. is constant

$$q = -kA_{cs}\frac{dT}{dx} = \text{constant}$$

$$A_{cs}\frac{dT}{dx} = \text{constant} \qquad (\because k \text{ will be constant for a material})$$

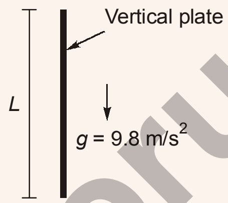
$$\int dT = \int \frac{C \cdot dx}{(a+bx)}$$

$$T = \frac{C}{b}\ln(a+bx) + C_1$$

Hence, temperature distribution in the solid is logarithmic.

End of Solution

Q.18 A thin vertical flat plate of height L, and infinite width perpendicular to the plane of the figure, is losing heat to the surroundings by natural convection. The temperatures of the plate and the surroundings and the properties of the surrounding fluid are constant. The relationship between the average Nusselt and Rayleigh numbers is given as $Nu = K\,Ra^{1/4}$, where K is a constant. The length scales for Nusselt and Rayleigh numbers are the height of the plate. The height of the plate is increased to 16 L keeping all other factors constant.



If the average heat transfer coefficient for the first plate is h_1 and that for the second plate is h_2 , the value of the ratio h_1/h_2 is ________ .

Ans. (2)

$$Nu = K(\text{Ra})^{1/4}$$

$$Nu = \frac{hD}{K}$$

In this case of vertical plate $D = L$

$$Nu = \left(\frac{hL}{K}\right)$$

$$\frac{hL}{K} = K(\text{Ra})^{1/4} = K\left[\frac{g\beta L^3 \Delta T}{\nu^2} \times \text{Pr}\right]^{1/4}$$

So,

$$h \,\alpha\, \frac{1}{(L)^{1/4}}$$

$$\frac{h_1}{h_2} = \left(\frac{L_2}{L_1}\right)^{1/4}$$

$$\left(\frac{h_1}{h_2}\right) = (16)^{1/4} = 2$$

End of Solution

Q.19 In matrix equation $[A]\{X\} = \{R\}$

$$[A] = \begin{bmatrix} 4 & 8 & 4 \\ 8 & 16 & -4 \\ 4 & -4 & 15 \end{bmatrix}, \{X\} = \begin{Bmatrix} 2 \\ 1 \\ 4 \end{Bmatrix} \text{ and } \{R\} = \begin{Bmatrix} 32 \\ 16 \\ 64 \end{Bmatrix}$$

One of the eigen values of Matrix $[A]$ is

(a) 4
(b) 15
(c) 8
(d) 16

Ans. **(d)**

$$[A]\{x\} = \begin{bmatrix} 4 & 8 & 4 \\ 8 & 16 & -4 \\ 4 & -4 & 15 \end{bmatrix}\begin{bmatrix} 2 \\ 1 \\ 4 \end{bmatrix} = \begin{bmatrix} 32 \\ 16 \\ 64 \end{bmatrix} = 16\begin{bmatrix} 2 \\ 1 \\ 4 \end{bmatrix} = 16\{x\}$$

So, one of the eigen value is 16.

End of Solution

Q.20 A two-dimensional incompressible frictionless flow field is given by $\vec{u} = x\hat{i} - y\hat{j}$. If ρ is the density of the fluid, the expression for pressure gradient vector at any point in the flow field is given as

(a) $-\rho(x\hat{i} + y\hat{j})$
(b) $-\rho(x^2\hat{i} + y^2\hat{j})$
(c) $\rho(x\hat{i} - y\hat{j})$
(d) $\rho(x\hat{i} + y\hat{j})$

Ans. **(a)**

Euler's equation for vector form (incompressible and frictionless)

$$\vec{F}_p + \vec{F}_g = \vec{F}_i$$

$$\vec{F}_p + \vec{F}_g = m\vec{a}$$

$$\vec{g} = g_x\hat{i} + g_y\hat{j} + g_z\hat{k}$$

$$\vec{g} = 0\hat{i} + 0\hat{j} + (-g)\hat{k}$$

$$-\nabla p + \rho\vec{g} = \rho\frac{D\vec{V}}{Dt}$$

$$-\nabla p + \rho\vec{g} = \rho\left[u\frac{\partial\vec{V}}{\partial x}i + v\frac{\partial\vec{V}}{\partial y}\hat{j} + w\frac{\partial\vec{V}}{\partial z}\hat{k} + \frac{\partial\vec{V}}{\partial t}\right]$$

$$-\nabla p + \rho\vec{g} = \rho\left[x\hat{i} + (-y)(-\hat{j}) + 0 + 0\right]$$

$$-\nabla p + \rho\left[0\hat{i} + 0\hat{j}\right] = \rho\left[x\hat{i} + y\hat{j}\right]$$

$$\Delta p = -\rho\left[x\hat{i} + y\hat{j}\right]$$

End of Solution

Q.21 The transformation matrix for mirroring a point in x-y plane about the line $y = x$ is given by

(a) $\begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix}$

(b) $\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$

(c) $\begin{bmatrix} 0 & -1 \\ -1 & 0 \end{bmatrix}$

(d) $\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$

Ans. **(b)**

The transformation matrix for mirroring a point in x-y plane about the line $y = x$ is

$$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

Option (b) is correct.

End of Solution

Q.22 The directional derivative of the function $f(x, y) = x^2 + y^2$ along a line directed from (0, 0) to (1, 1), evaluated at point $x = 1$, $y = 1$ is

(a) $4\sqrt{2}$

(b) 2

(c) $2\sqrt{2}$

(d) $\sqrt{2}$

Ans. **(c)**

Directional derivative of $f(x, y)$ at $P(1, 1)$ along the direction of line joining (0, 0) to (1, 1) $= \nabla f \cdot \frac{\bar{a}}{|\bar{a}|}$

where, $\bar{a}$ = line joining (0, 0) and (1, 1)

$$\bar{a} = (1-0)\hat{i} + (1-0)\hat{j} = \hat{i} + \hat{j}$$

and

$$\nabla f = \hat{i}\frac{\partial f}{\partial x} + \hat{j}\frac{\partial f}{\partial y} + \hat{k}\frac{\partial f}{\partial z}$$

$$= 2x\hat{i} + 2y\hat{j}$$

$$(\nabla f)_{P(1,\,1)} = 2\hat{i} + 2\hat{j}$$

$\therefore$ Directional derivative of $f(x, y)$ at $P(1, 1)$ in the direction of $\vec{a}$

$$= \nabla f \cdot \frac{\bar{a}}{|\bar{a}|} = \left(2\hat{i} + 2\hat{j}\right) \cdot \frac{\left(\hat{i} + \hat{j}\right)}{\sqrt{2}}$$

$$= \frac{2+2}{\sqrt{2}} = 2\sqrt{2}$$

End of Solution

Q.23 If x is the mean of data 3, x, 2 and 4, then the mode is _______

Ans. (3)

$$\text{Mean, } x = \frac{3 + x + 2 + 4}{4}$$
$$4x = 9 + x$$
$$3x = 9$$
$$x = 3$$

So the given numbers are 3, 3, 2, 4

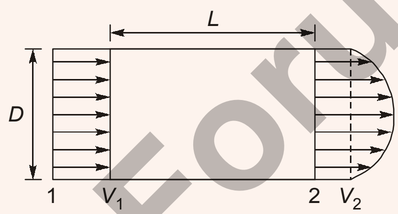
Mode = 3

Mode = Maximum times repeated value.

End of Solution

Q.24 Water enters a circular pipe of length L = 5.0 m and diameter D = 0.20 m with Reynolds number Re_D = 500. The velocity profile at the inlet of the pipe is uniform while it is parabolic at the exit. The Reynolds number at the exit of the pipe is ______.

Ans. (500)



$$Re = \frac{\rho VD}{\mu} \text{ for pipe flow}$$
$$V = \text{mean velocity}$$

Exit mean velocity V_2

$$\dot{m}_{in} = \dot{m}_{out}$$
$$\rho A_1 V_1 = \rho A_2 V_2$$

{∵ Water is incompressible fluid, so density will remain same}

Given, $A_1 = A_2$

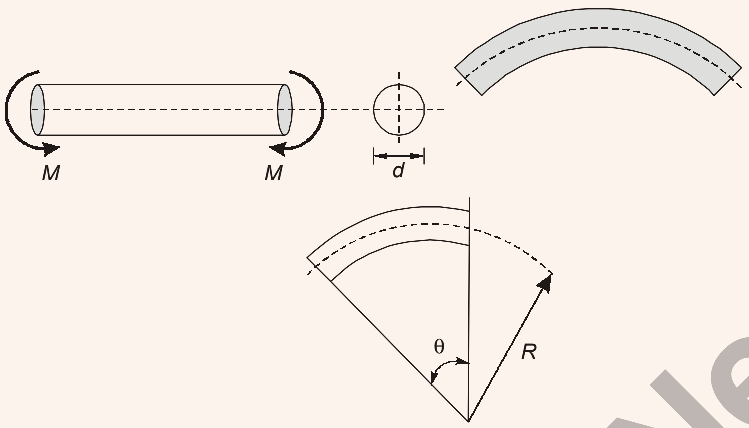
∴ $V_1 = V_2$

So, Reynolds number is constant i.e. 500 at exit.

End of Solution

Q.25 A wire of circular cross-section of diameter 1.0 mm is bent into a circular arc of radius 1.0 m by application of pure bending moments at its ends. The Young's modulus of the material of the wire is 100 GPa. The maximum tensile stress developed in the wire is _______ MPa.

Ans. (50)



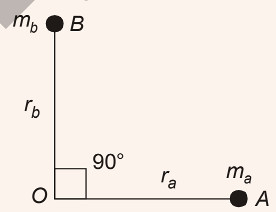
$$(\sigma_b)_{max} = \frac{EY_{max}}{R}$$

$$(\sigma_b)_{max} = \frac{E\frac{d}{2}}{R} = \frac{100 \times 10^3 \times 0.5}{1000} = 50 \text{ MPa}$$

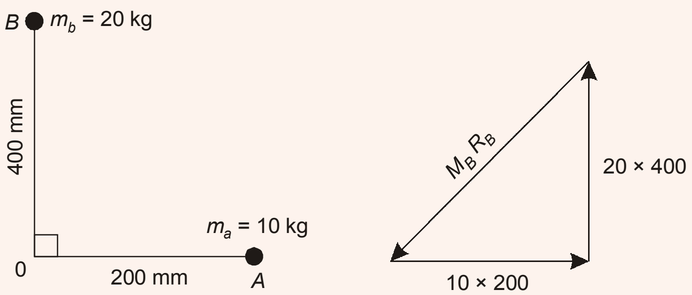
End of Solution

Q.26 - Q.55 Carry Two Marks each.

Q.26 Two masses A and B having mass m_a and m_b respectively, lying in the plane of the figure shown, are rigidly attached to a shaft which revolves about an axis through O perpendicular to the plane of the figure. The radii of rotation of the masses m_a and m_b are r_a and r_b, respectively. The angle between lines OA and OB is 90°. If m_a = 10 kg, m_b = 20 kg, r_a = 200 mm and r_b = 400 mm, then the balance mass to be placed at a radius of 200 mm is ________ kg (round off to two decimal places).



Ans. (41.23)



Force polygon

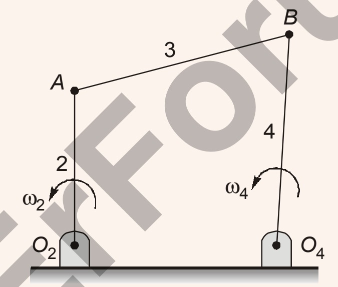
$$\text{Balance mass radius, } R_B = 200 \text{ mm}$$
$$M_B = ?$$
$$M_B R_B = \sqrt{(10\times 200)^2 + (20\times 400)^2}$$
$$M_B \times 200 = 8246.211$$
$$M_B = 41.23 \text{ kg}$$

End of Solution

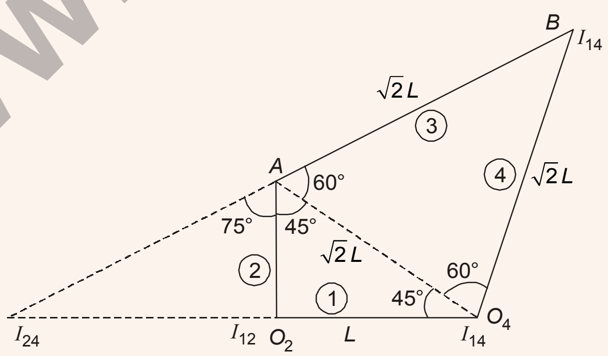
Q.27 A four bar mechanism is shown in the figure. The link numbers are mentioned near the links. Input link 2 is rotating anticlockwise with a constant angular speed ω_2. Length of different links are:

$$O_2O_4 = O_2A = L,$$
$$AB = O_4B = \sqrt{2}L$$

The magnitude of the angular speed of the output link 4 is ω_4 at the instant when link 2 makes an angle of 90° with O_2O_4 as shown. The ratio $\frac{\omega_4}{\omega_2}$ is ______ (round off to two decimal places).



Ans. (0.79)



According to Arnold's Kennedy theorem,

$$\Rightarrow \qquad \tan 75° = \frac{(I_{24}I_{12})}{(L)}$$

$$(I_{24}I_{12}) = (L \tan 75°) = 3.732\, L$$

$$(I_{24}I_{14}) = 4.732\,L$$

$$\omega_2 \times (I_{24}I_{12}) = \omega_4\,(I_{24}I_{14})$$

$$\frac{\omega_4}{\omega_2} = \frac{I_{24}I_{12}}{I_{24}I_{14}}$$

$$\frac{\omega_4}{\omega_2} = \left(\frac{3.732}{4.732}\right) = 0.7886$$

End of Solution

Q.28 A gas tungsten arc welding operation is performed using a current of 250 A and an arc voltage of 20 V at a welding speed of 5 mm/s. Assuming that the arc efficiency is 70%, the net heat input per unit length of the weld will be______kJ/mm (round off to one place).

Ans. **(0.7)**

Given data,

Welding current, I = 250 A

Voltage, V = 20 V

Welding speed, v = 5 mm per second

Arc heat transfer efficiency, η = 70%

Heat required per unit length,

$$H_s = \frac{VI}{v} \times \eta = \frac{250 \times 20}{5 \times 1000} \times 0.7 = \frac{700}{1000} = 0.7 \text{ kJ/mm}$$

End of Solution

Q.29 Given a vector $\bar{u} = \frac{1}{3}\left(-y^3\hat{i} + x^3\hat{j} + z^3\hat{k}\right)$ and $\hat{n}$ as the unit normal vector to the surface of the hemisphere $\left(x^2 + y^2 + z^2 = 1;\ z \geq 0\right)$, the value of integral $\int(\nabla \times \bar{u})\cdot\hat{n}\,dS$ evaluated on the curved surface of the hemisphere S is

(a) π

(b) $\frac{\pi}{2}$

(c) $\frac{-\pi}{2}$

(d) $\frac{\pi}{3}$

Ans. **(b)**

Given $\bar{u}$ is differentiable vector in the given open surface bounded by closed contour C i.e. C: $x^2 + y^2 = 1$, $z = 0$

By stoke's theorem

$$\iint_s \text{curl}\,\vec{F}\cdot\hat{n}\,ds = \oint_c \bar{F}\cdot\overline{dr}$$

$$\iint_s (\nabla \times \bar{u})\cdot\hat{n}\,ds = \oint_c \bar{u}\cdot\overline{dr}$$

$$= \frac{1}{3}\oint -y^3 dx + x^3 dy \qquad (\because z = 0)$$

C : $x = \cos\theta \Rightarrow dx = -\sin\theta d\theta;\ y = \sin\theta \Rightarrow dy = \cos\theta d\theta;\ \theta : 0 \text{ to } 2\pi$

$$= \frac{1}{3}\int_0^{2\pi} \sin^4\theta d\theta + \frac{1}{3}\int_0^{2\pi} \cos^4\theta d\theta$$

$$= \frac{4}{3}\int_0^{\pi/2} \sin^4\theta d\theta + \frac{4}{3}\int_0^{\pi/2} \cos^4\theta d\theta$$

$$= \frac{4}{3}\left(\frac{3}{4}\times\frac{1}{2}\times\frac{\pi}{2} + \frac{3}{4}\times\frac{1}{2}\times\frac{\pi}{2}\right) = \frac{\pi}{2}$$

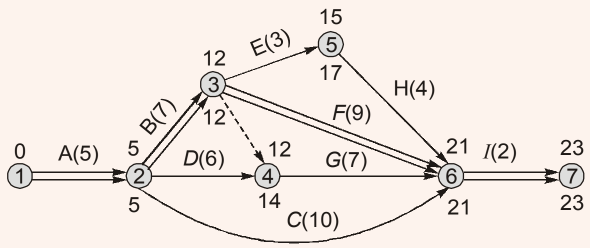
End of Solution

Q.30 The activities of a project, their duration and the precedence relationships are given in the table. For example, in a precedence relationship "X < Y, Z" means that X is predecessor of activities Y and Z. The time to complete the activities along the critical path is ________ weeks.

Activity	Duration (Weeks)	Precedence Relationship
A	5	$A < B,C,D$
B	7	$B < E,F,G$
C	10	$C < I$
D	6	$D < G$
E	3	$E < H$
F	9	$F < I$
G	7	$G < I$
H	4	$H < I$
I	2	....

(a) 25
(b) 21
(c) 17
(d) 23

Ans. (d)



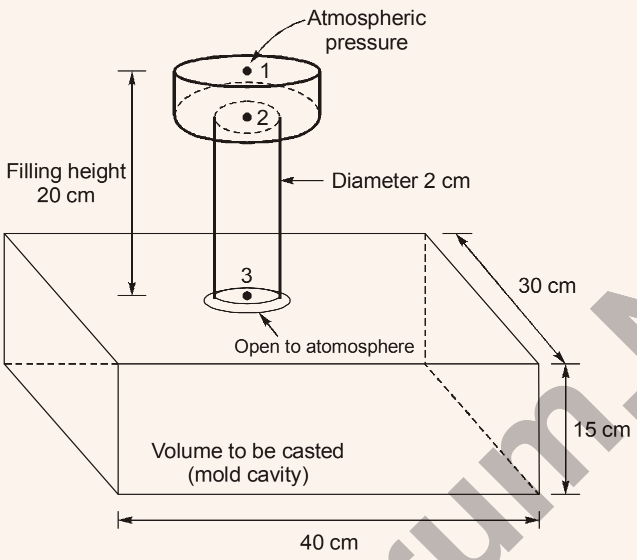
So critical path is A - B - F - I

Critical path duration = 23 weeks

Correct option is (d).

End of Solution

Q.31 The figure shows a pouring arrangement for casting of a metal block. Frictional losses are negligible. The acceleration due to gravity is 9.81 m/s^2. The time (in s, round off to two decimal places) to fill up the mold cavity (of size 40 cm x 30 cm x 15 cm) is _______



Ans. (28.92)

Volume of mould cavity = $40 \times 30 \times 15$ cm^3

= 18000 cm^3

Apply Bernoulli's equation at point 1 and 3

$$\frac{P_{atm}}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_{atm}}{\rho g} + \frac{V_3^2}{2g} + 0$$

Assume $V_1 = 0$

$$V_3 = \sqrt{2gz_1}$$

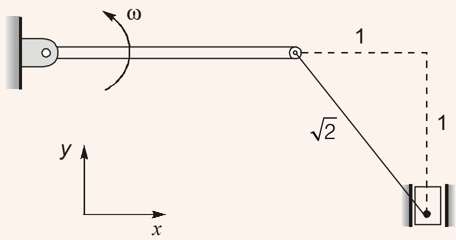
$$= \sqrt{2 \times 981 \times 20} = 198.09 \text{ cm/s}$$

$$\text{Mould filling time } (t_f) = \frac{\text{Volume}}{V_2 \times A_2}$$

$$= \frac{18000 \text{ cm}^3}{198.09 \text{ cm/s} \times \frac{\pi}{4}(2)^2 \text{cm}^2} = 28.92 \text{ second}$$

End of Solution

Q.32 The crank of a slider-crank mechanism rotates counterclockwise (CCW) with a constant angular velocity ω, as shown. Assume the length of the crank to be r.

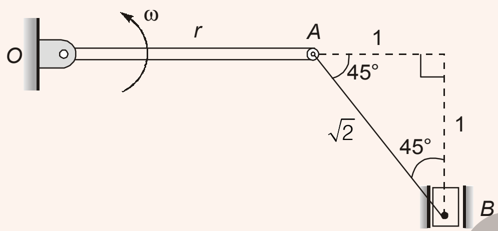


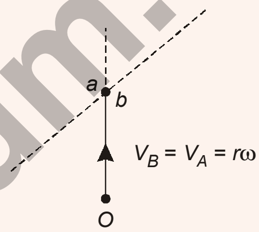
Using exact analysis, the acceleration of the slider in the y-direction, at the instant shown, where the crank is parallel to x-axis, is given by

(a) $\omega^2 r$ (b) $2\omega^2 r$

(c) $-2\omega^2 r$ (d) $-\omega^2 r$

Ans. (a)

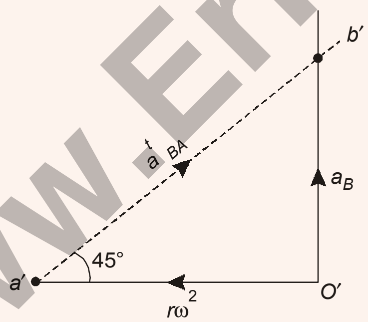




$$V_{BA} = 0$$

$$\Rightarrow \quad \omega_{BA} = 0$$

$$\text{Acceleration of } BA = 0$$



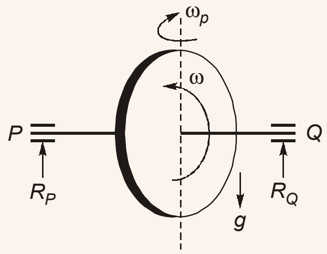
$(a^r_{BA} = 0, V_{BA} = 0)$

$$\tan 45° = \frac{a_B}{r\omega^2}$$

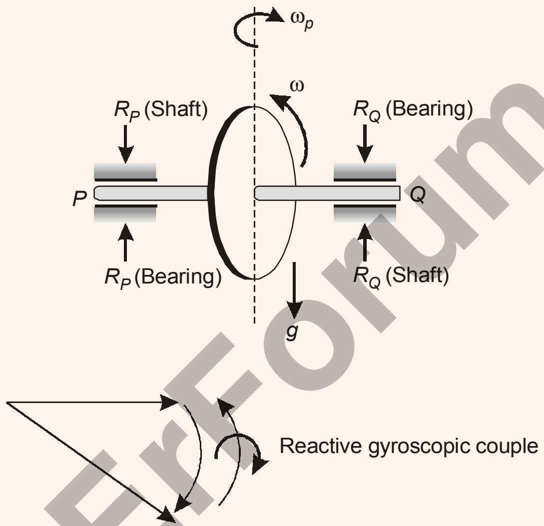
$$\Rightarrow \quad a_B = r\omega^2$$

End of Solution

Q.33 A uniform disc with radius r and a mass of m kg is mounted centrally on a horizontal axle of negligible mass and length of $1.5r$. The disc spins counter-clockwise about the axle with angular speed ω, when viewed from the right-hand side bearing, Q. The axle precesses about a vertical axis at $\omega_p = \omega/10$ in the clockwise direction when viewed from above. Let R_P and R_Q (positive upwards) be the resultant reaction forces due to the mass and the gyroscopic effect, at bearings P and Q, respectively. Assuming $\omega^2 r$ = 300 m/s^2 and g = 10 m/s^2, the ratio of the larger to the smaller bearing reaction force (considering appropriate signs) is ______ .



Ans. (–3)



Active gyroscopic couple = $I\omega\omega_p$

$$= \frac{mr^2}{2} \times \omega \times \frac{\omega}{10} = \left(\frac{m\omega^2 r^2}{20}\right)$$

Reaction force at bearing P due to gyroscopic couple is (R_{P_m})

$$R_{P_m} = \frac{m\omega^2 r^2}{20 \times 1.5r}$$

$$= \frac{m\omega^2 r^2}{20 \times 1.5r} = \frac{m\omega^2 r}{30} = 10m \text{ N (upward)}$$

Reaction force at bearing Q due to gyroscopic couple is R_{Q_m}

$$R_{Q_m} = \frac{m\omega^2 r^2}{20 \times 1.5r} = \frac{m\omega r}{30} = 10m \text{ N (downward)}$$

Reaction force at bearing P due to gravity $= \frac{mg}{2}$ (downward)

$$= 5m \text{ N}$$

Reaction force at bearing Q due to gravity $= \frac{mg}{2} = 5m$ N (upward)

Reaction at bearing P, $R_P = 10m$ N $- 5m$ N $= 5m$ N [Upward]

Reaction at bearing Q, $R_Q = -10m$ N $- 5m$ N $= -15m$ N [Upward]

$$\frac{R_Q}{R_P} = \frac{-15}{5} = -3$$

End of Solution

Q.34 Water flows through two different pipes A and B of the same circular cross-section but at different flow rates. The length of pipe A is 1.0 m and that of pipe B is 2.0 m. The flow in both the pipes is laminar and fully developed. If the frictional head loss across the length of the pipes is same, the ratio of volume flow rates Q_B/Q_A is _______ (round off to two decimal places).

Ans. (0.5)

Pipe - A $L_A = 1$ m

Pipe - B $L_B = 2$ m

$d_A = d_B$; $h_{fA} = h_{fB}$

$$\frac{32\mu V_A L_A}{w d_A^2} = \frac{32\mu V_B L_B}{w d_B^2}$$

$$\frac{V_B}{V_A} = \frac{d_B^2}{d_A^2} \times \frac{L_A}{L_B}$$

$$Q = AV$$

$$V = \frac{Q}{\frac{\pi}{4} d^2}$$

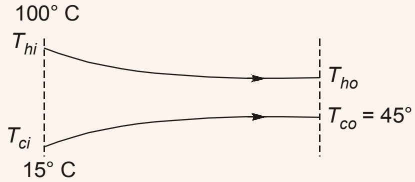
$$\frac{\dfrac{Q_B}{\frac{\pi}{4} d_B^2}}{\dfrac{Q_A}{\frac{\pi}{4} d_A^2}} = \frac{d_B^2}{d_A^2} \times \frac{L_A}{L_B}$$

$$\frac{Q_B}{Q_A} = \frac{d_B^4}{d_A^4} \times \frac{L_A}{L_B} = \frac{1}{2}$$ $\{\because$ Given $d_A = d_B\}$

End of Solution

Q.35 Hot and cold fluids enter a parallel flow double tube heat exchanger at 100 °C and 15 °C respectively. The heat capacity rates of hot and cold fluids are C_h = 2000 W/K and C_c = 1200 W/K respectively. If the outlet temperature of the cold fluid is 45 °C, the log mean temperature difference (LMTD) of the heat exchanger is ________K (round off to two decimal places).

Ans. (330.71)



$$C_h = 2000 \text{ W/K}$$
$$C_c = 1200 \text{ W/K}$$

By energy equation,

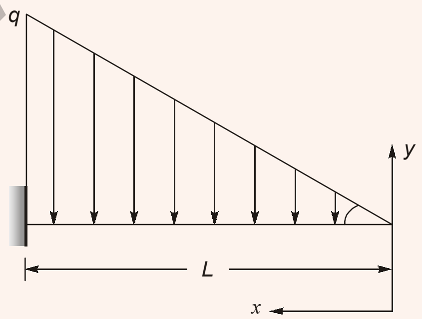
$$C_h(\Delta T_h) = C_c(\Delta T_c)$$
$$2000\,(100 - T_{ho}) = 1200\,(30)$$
$$T_{ho} = 82° \text{ C}$$

$$\text{LMTD} = \frac{(100-15)-(82-45)}{\ln\left(\frac{100-15}{82-45}\right)} = 57.71° \text{ C}$$

$$= (57.71 + 273)\text{K} = 330.71 \text{ K}$$

End of Solution

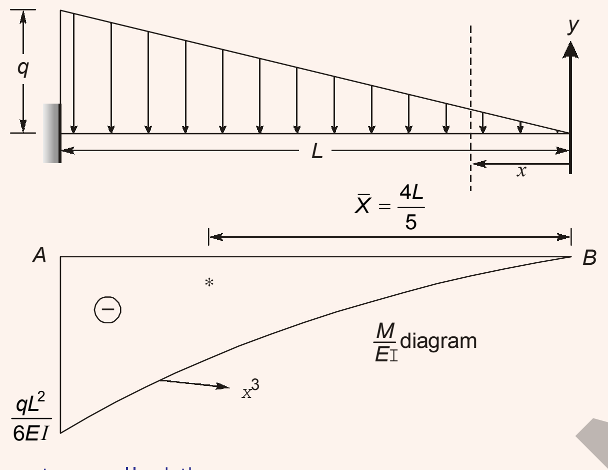
Q.36 A prismatic, straight, elastic, cantilever beam is subjected to a linearly distributed transverse load as shown below. If the beam length is L, Young's modulus E and area moment of inertia I, the magnitude of the maximum deflection is



(a) $\dfrac{qL^4}{10EI}$ (b) $\dfrac{qL^4}{60EI}$

(c) $\dfrac{qL^4}{15EI}$ (d) $\dfrac{qL^4}{30EI}$

Ans. (d)



By using moment area IInd theorem

$$Y_B - Y_A = A\bar{X} \text{ of } \frac{M}{EI} \text{diagram between } B \text{ and } A$$

$$Y_{max} - 0 = \left(\frac{1}{4}\right)\left(\frac{qL^2}{6EI}\right)(L)\left(\frac{4L}{5}\right)$$

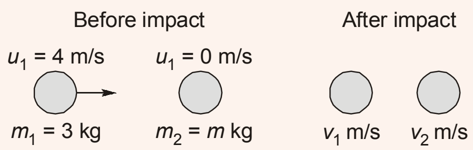
$$y_{max} = \frac{qL^4}{30EI}\ (\downarrow)$$

End of Solution

Q.37 A ball of mass 3 kg moving with a velocity of 4 m/s undergoes a perfectly-elastic direct-central impact with a stationary ball of mass m. After the impact is over, the kinetic energy of the 3 kg ball is 6 J. The possible value(s) of m is/are

(a) 1 kg only
(b) 1 kg, 9 kg
(c) 1 kg, 6 kg
(d) 6 kg only

Ans. (b)



Momentum is conserved

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

$$3 \times 4 + 0 = 3v_1 + mv_2 \quad \text{...(i)}$$

Coefficient of restitution ($e = 1$)

$$e = \frac{v_2 - v_1}{u_1 - u_2} = 1$$

$$\frac{v_2 - v_1}{4} = 1$$

$$v_2 - v_1 = 4 \text{ m/s} \quad \text{...(ii)}$$

KE of m_1 after impact is 6 J

$$\frac{1}{2}m_1v_1^2 = 6 \text{ J}$$

$$v_1 = \sqrt{\frac{6\times 2}{3}} = \pm 2 \text{ m/s}$$

From equation (ii),

For $v_1 = +2$ m/s

$v_2 = 6$ m/s

For $v_1 = -2$ m/s

$v_2 = 2$ m/s

From equation (i),

For $v_2 = 6$ m/s

$m = 1$ kg

For $v_2 = 2$ m/s

$m = 9$ kg

End of Solution

Q.38 In an orthogonal machining with a single point cutting tool of rake angle 10°, the uncut chip thickness and the chip thickness are 0.125 mm and 0.22 mm respectively. Using Merchant's first solution for the condition of minimum cutting force, the coefficient of friction at the chip-tool interface is ________ (round off to two decimal places).

Ans. (0.74)

$$\alpha = 10°$$

$$t = 0.125 \text{ mm}$$

$$t_c = 0.22 \text{ mm}$$

$$r = \frac{t}{t_c} = \frac{0.125}{0.22} = 0.5682$$

$$\tan\phi = \frac{r\cos\alpha}{1-r\sin\alpha} = \frac{0.5682\cos 10°}{1-0.5682\sin 10°}$$

or $\phi = 31.83°$

Using Merchant's thoery,

$$\phi = 45° + \frac{\alpha}{2} - \frac{\beta}{2}$$

or, $$31.83° = 45° + \frac{10°}{2} - \frac{\beta}{2}$$

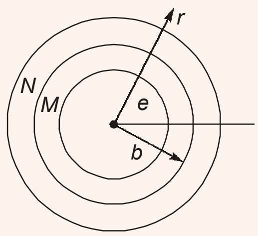
or, $$\beta = 36.34°$$

$$\mu = \tan\beta = \tan 36.34°$$

$$= 0.7356 \approx 0.74$$

End of Solution

Q.39 Consider two concentric circular cylinders of different materials M and N in contact with each other at $r = b$, as shown below. The interface at $r = b$ is frictionless. The composite cylinder system is subjected to internal pressure P. Let $\left(u_r^M, u_\theta^M\right)$ and $\left(\sigma_{rr}^M, \sigma_{\theta\theta}^M\right)$ denote the radial and tangential displacement and stress components, respectively, in material M. Similarly, $\left(u_r^N, u_\theta^N\right)$ and $\left(\sigma_{rr}^N, \sigma_{\theta\theta}^N\right)$ denote the radial and tangential displacement and stress components, respectively, in material N. The boundary conditions that need to be satisfied at the frictionless interface between the two cylinders are:



(a) $u_\theta^M = u_\theta^N$ and $\sigma_{\theta\theta}^M = \sigma_{\theta\theta}^N$ only

(b) $u_r^M = u_r^N$ and $\sigma_{rr}^M = \sigma_{rr}^N$ only

(c) $\sigma_{rr}^M = \sigma_{rr}^N$ and $\sigma_{\theta\theta}^M = \sigma_{\theta\theta}^N$ only

(d) $u_r^M = u_r^N$ and $\sigma_{rr}^M = \sigma_{rr}^N$ and $u_\theta^M = u_\theta^N$ and $\sigma_{\theta\theta}^M = \sigma_{\theta\theta}^N$

Ans. **(d)**

We have to consider only pressure effect i.e. shrinking effect should be neglected because interface is frictionless. Here, tangential, radial displacement and stresses will remain same at the interface.

End of Solution

Q.40 An air standard Otto cycle has thermal efficiency of 0.5 and the mean effective pressure of the cycle is 1000 kPa. For air assume specific heat ratio $\gamma = 1.4$ and specific gas constant $R = 0.287$ kJ/kg.K. If the pressure and temperature at the beginning of the compression stroke are 100 kPa and 300 K respectively, then the specific net work output of the cycle is______kJ/kg (round off to two decimal places).

Ans. **(708.60)**

As per given data,

$$\eta_{otto} = 0.5$$

$$v_1 = \frac{RT_1}{P_1} = \frac{0.287 \times 300}{100} = 0.861 \text{ m}^3\text{/kg}$$

$$\eta_{otto} = 1 - \frac{1}{(r)^{\gamma-1}}$$

$$0.5 = 1 - \frac{1}{(r)^{\gamma-1}}$$

$$(r)^{0.4} = 2$$
$$r = 5.65$$
$$\frac{v_1}{v_2} = 5.65$$
$$v_2 = \frac{0.861}{5.65}$$
$$v_2 = 0.1524 \text{ m}^3/\text{kg}$$
$$\text{Specific work output} = P_{mep} \times v_S$$
$$= 1000 \text{ kPa} \times (v_1 - v_2)$$
$$= 1000 \times (0.861 - 0.1524)$$
$$= 708.6 \text{ kJ/kg}$$

End of Solution

Q.41 The probability that a part manufactured by a company will be defective is 0.05. If 15 such parts are selected randomly and inspected, then the probability that at least two part will be defective is ________. (round off to two decimal places)

Ans. (0.17)

$n = 15,\ p = 0.05,\ q = 0.95$

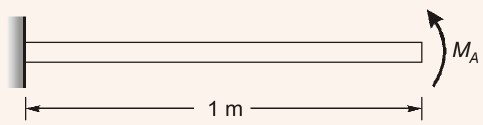
$$x \sim B(n, p) \approx x \sim P(\lambda)$$
$$\lambda = np = 15(0.05) = 0.75$$

P (Atleast two defective)

$$P(x \geq 2) = 1 - P(x \leq 1)$$
$$= 1 - (P(0) + P(1)) = 1 - e^{-0.75}(1 + (0.75))$$
$$= 1 - 1.75\,(e^{-0.75}) = 0.1733 \approx 0.17$$

End of Solution

Q.42 A horizontal cantilever beam of circular cross-section length = 1 m and flexural rigidity EI = 200 Nm^2 is subjected to an applied moment M_A = 1.0 Nm at the free end as shown in the figure. The magnitude of vertical deflection of the free end is _______ mm. (round off to one decimal place)

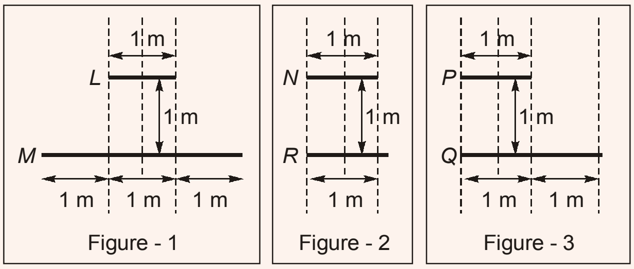


Ans. (2.50)

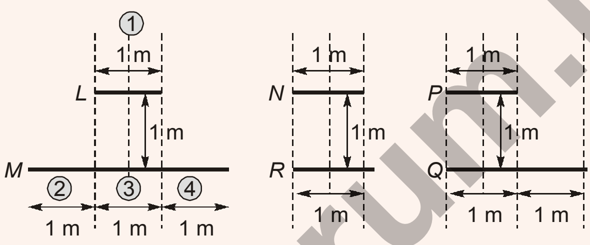
$$y_{max} = \frac{ML^2}{2EI} = \frac{1 \times 10^3 \times 10^6}{2 \times 200 \times 10^6} = 2.5 \text{ mm}$$

End of Solution

Q.43 Three sets of parallel plates LM, NR and PQ are given in figure 1, 2 and 3. The view factor F_{IJ} is defined as the fraction of radiation leaving plate I that is intercepted by plate J. Assume that the values of F_{LM} and F_{NR} are 0.8 and 0.4, respectively. The value of F_{PQ} (round off to one decimal place) is _______ .



Ans. **(0.6)**



As
$$F_{NR} = 0.4$$
$$F_{LM} = F_{12} + F_{13} + F_{14}$$
$$F_{13} = F_{NR} = 0.4$$
$$F_{12} = F_{14}$$
$$F_{LM} = 0.8 = 0.4 + 2F_{12}$$
$$0.2 = F_{12}$$
$$F_{PQ} = F_{12} + F_{13}$$
$$= 0.2 + 0.4$$
$$= 0.6$$

End of Solution

Q.44 Annual demand of valves per year in a company is 10,000 units; the current order quantity is 400 valves per order. The holding cost is ₹ 24 per valve per year & the ordering cost is ₹ 400 per order. If the current order quantity is changed to Economic Order Quantity, then saving in the total cost of inventory per year will be ₹________. (Round off to two decimal places)

Ans. **(943.59)**

As per given data

Annual demand, D = 10000 units

Q = 400/order

Holding cost (C_h) = ₹24 unit/year

Ordering cost (C_o) = ₹400/order

$$(TIC)_I = \frac{D}{Q} \times C_o + \frac{Q}{2} \times C_h$$

$$= \frac{10000}{400} \times 400 + \frac{400}{2} \times 24$$

= ₹14800/year

If order quantity changed to EOQ,

$$TIC^* = \sqrt{2DC_oC_h}$$

$$= \sqrt{2 \times 10000 \times 400 \times 24}$$

= ₹13856.406/year

Hence total cost saving per year

= $(TIC)_I - TIC^*$

= 14800 – 13856.406

= ₹943.594/year

End of Solution

Q.45 A through hole is drilled in an aluminum alloy plate of 15 mm thickness with a drill bit of diameter 10 mm, at a feed of 0.25 mm/rev and a spindle speed of 1200 rpm. If the specific energy required for cutting this material is 0.7 N-m/mm^3, the power required is ______W (round off to two decimal places).

Ans. (274.89)

Power required = Specific energy consumption × MRR

Specific energy consumption = 0.7 Nm/mm^3 = 0.7 J/mm^3

$$MRR = \frac{\pi d^2}{4} \times fN$$

$$= \frac{\pi \times 10^2}{4} \times 0.25 \times 1200 \text{ mm}^3/\text{min}$$

= 23561.94 mm^3/min = 392.7 mm^3/s

∴ Power, P = 0.7 J/mm^3 × 392.7 mm^3/s

= 274.89 J/s = 274.89 W

End of Solution

Q.46 The aerodynamic drag on a sports car depends on its shape. The car has a drag coefficient of 0.1 with the windows and the roof closed. With the windows and the roof open, the drag coefficient becomes 0.8. The car travels at 44 km/h with the windows and roof closed for the same amount of power needed to overcome the aerodynamic drag, the speed of the car with the windows and roof open (round off to two decimal places), is________ km/h. (density of air and the frontal area may be assumed to be constant).

Ans. (22)

Case-1:

$$C_{D1} = 0.1$$
$$U_{\infty 1} = 44 \text{ km/h}$$

Case-2:

$$C_{D2} = 0.8$$
$$U_{\infty 2} = ?$$

As we know, Power, $P = C_D \times \frac{1}{2}\rho U_\infty^3 \times A$

For same power, density and frontal area,

$$(\text{power})_1 = (\text{power})_2$$

$$C_{D1}\frac{1}{2}\rho_1 A_1 U_{\infty 1}^3 = C_{D2}\frac{1}{2}\rho_2 A_2 U_{\infty 2}^3 \quad (\rho_1 = \rho_2)$$

$$U_\infty^3 \propto \frac{1}{C_D}$$

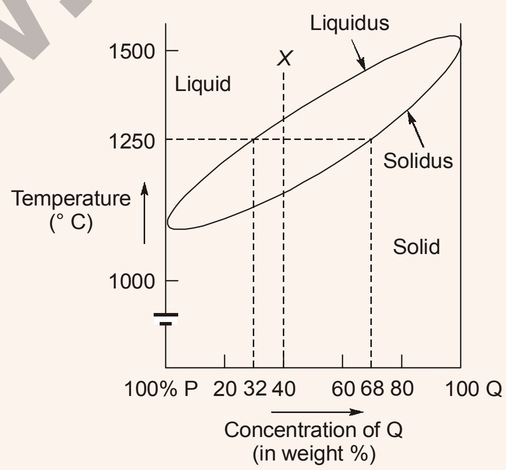
$$\Rightarrow \quad \left(\frac{U_{\infty 2}}{U_{\infty 1}}\right)^3 = \frac{C_{D1}}{C_{D2}}$$

$$\left(\frac{U_{\infty 2}}{44}\right)^3 = \frac{0.1}{0.8}$$

$$U_{\infty 2} = \frac{44}{2} = 22 \text{ km/h}$$

End of Solution

Q.47 The binary phase diagram of metals *P* and *Q* is shown in the figure. An alloy X containing 60% P and 40% Q (by weight) is cooled from liquid to solid state. The fractions of solid and liquid (in weight percent) at 1250° C, respectively, will be



(a) 68.0% and 32.0%
(b) 32.0% and 68.0%
(c) 22.2% and 77.8%
(d) 77.8% and 22.2%

Ans. (c)

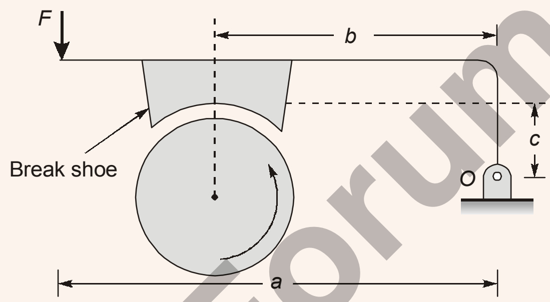
According to lever rule:

$$\text{Amount of solid phase} = \frac{(40-32)}{(68-32)} \times 100 = 22.2\%$$

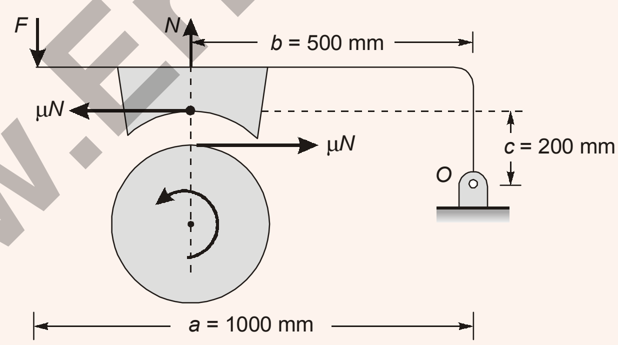
$$\text{Amount of liquid phase} = \frac{(68-40)}{(68-32)} \times 100 = 77.8\%$$

End of Solution

Q.48 A short shoe external drum brake is shown in the figure. The diameter of the brake drum is 500 mm. The dimensions a = 1000 mm, b = 500 mm and c = 200 mm. The coefficient of friction between the drum and the shoe is 0.35. The force applied on the lever F = 100 N as shown in the figure. The drum is rotating anti-clockwise. The braking torque on the drum is______Nm (round off to two decimal places).



Ans. (20.35)



Free body diagram

By considering the moment about point 'O'

$$F \times a = N \times b - \mu N \times c$$

$$100 \times 1000 = N \times 500 - 0.35N \times 200$$

$$N = 232.558 \text{ Newton}$$

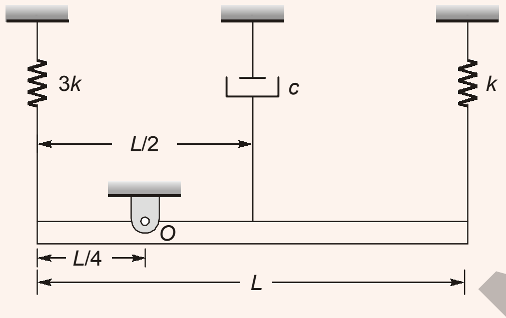
$$\text{Braking torque} = \mu N \times \frac{D}{2} = 0.35 \times 232.558 \times \frac{500}{2} \times 10^{-3}$$

$$\text{Braking torque} = 20.35 \text{ Nm}$$

End of Solution

Q.49 A slender uniform rigid bar of mass 'm' is hinged at 'O' and supported by two springs with stiffness $3k$ and k and a damper with damping coefficient c as shown in figure.

For the system to be critically damped, the ratio of $\dfrac{c}{\sqrt{km}}$ should be ____



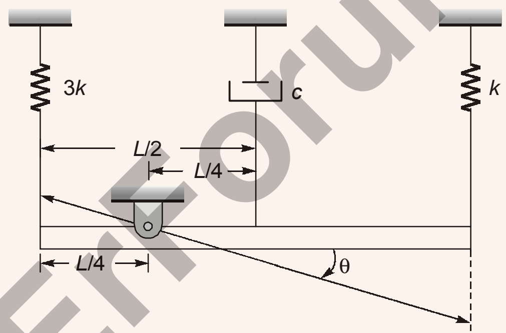
(a) $4\sqrt{7}$

(b) 2

(c) 4

(d) $2\sqrt{7}$

Ans. (a)



$$I = \frac{ml^2}{12} + m\left(\frac{l}{4}\right)^2 = \frac{ml^2}{12} + \frac{ml^2}{16} = \frac{7ml^2}{48}$$

Total torque about hinge 'O

$$I\ddot{\theta} + c\left(\frac{l}{4}\right)^2\dot{\theta} + \left[k\frac{9l^2}{16} + 3k\frac{l^2}{16}\right]\theta = 0$$

$$\frac{7ml^2}{48}\ddot{\theta} + \frac{cl^2}{16}\dot{\theta} + \frac{12kl^2}{16}\theta = 0$$

$$\frac{7ml^2}{3}\ddot{\theta} + (cl^2)\dot{\theta} + (12kl^2)\theta = 0$$

$$\ddot{\theta} + \left(\frac{3c}{7m}\right)\dot{\theta} + \left(\frac{36k}{7m}\right)\theta = 0 \qquad \left[\omega_n = \sqrt{\frac{36k}{7m}} = 6\sqrt{\frac{k}{7m}}\right]$$

$$2\xi\omega_n = \frac{3c}{7m}$$

For critical damping $\xi = 1$

$\Rightarrow \quad 2\omega_n = \dfrac{3c}{7m}$

$\Rightarrow \quad 2 \times 6\sqrt{\dfrac{k}{7m}} = \dfrac{3c}{7m}$

$\Rightarrow \quad 12 = \dfrac{3c}{\sqrt{km}\sqrt{7}}$

$\Rightarrow \quad \dfrac{c}{\sqrt{km}} = 4\sqrt{7}$

End of Solution

Q.50 A differential equation is given as

$$x^2\frac{d^2y}{dx^2} - 2x\frac{dy}{dx} + 2y = 4$$

The solution of differential equation in terms of arbitrary constant C_1 and C_2 is

(a) $y = \dfrac{C_1}{x^2} + C_2x + 2$

(b) $y = C_1x^2 + C_2x + 4$

(c) $y = C_1x^2 + C_2x + 2$

(d) $y = \dfrac{C_1}{x^2} + C_2x + 4$

Ans. **(c)**

Given D.E. is Euler-Cauchy differential equation,

Let $\quad x = e^z$

$\Rightarrow \quad z = \ln x$

Let, $\quad \dfrac{d}{dx} = D$ and $\dfrac{d}{dz} = \theta$

Then $\quad x\dfrac{d}{dx} = \dfrac{d}{dz}$

and $\quad x^2\dfrac{d^2}{dx^2} = \dfrac{d^2}{dz^2} - \dfrac{d}{dz}$

i.e. $\quad xD = \theta,\ x^2D^2 = \theta(\theta - 1)$

Sub in D.E.

We get $\quad (\theta(\theta-1) - 2\theta + 2)y = 4$

$(\theta - 1)(\theta - 2)y = 4$

It is LDE with constant coefficients

$\therefore \quad y = y_{CF} + y_{PI}$

$y_{CF} = (m-1)(m-2) = 0$

$\Rightarrow \quad m = 1, 2$

$\therefore \quad y_{CF} = C_1e^z + C_2e^{2z} = C_1x + C_2x^2$

$$y_{P.I.} = \frac{\phi(z)}{f(\theta)} = \frac{4 \times e^{0z}}{(\theta - 1)(\theta - 2)} = \frac{4}{2} = 2$$

Hence, $y = C_1 x + C_2 x^2 + 2$

So accordingly option (c) is correct.

End of Solution

Q.51 The thickness of a sheet is reduced by rolling (without any change in width) using 600 mm diameter rolls. Neglect elastic deflection of the rolls and assume that the coefficient of friction at the roll-workpiece interface is 0.05. The sheet enters the rotating rolls unaided. If the initial sheet thickness is 2 mm, the minimum possible final thickness that can be produced by this process in a single pass is______mm (round off to two decimal places).

Ans. (1.25)

$$D = 600 \text{ mm}$$
$$\mu = 0.05$$
$$h_0 = 2 \text{ mm}$$
$$h_{f\,min} = ?$$
$$h_0 - h_{f\,min} = \mu^2 R$$
$$2 - h_{f\,min} = 0.05^2 \times 300$$
$$h_{f\,min} = 1.25 \text{ mm}$$

End of Solution

Q.52 The derivative of $f(x) = \cos x$ can be estimated using the approximation $f'(x) = \frac{f(x+h) - f(x-h)}{2h}$.

The percentage error is calculated as $\left(\frac{\text{Exact value} - \text{Approx value}}{\text{Exact value}} \times 100\right)$. The percentage error in the derivative of $f(x)$ at $x = \frac{\pi}{6}$ radian choosing $h = 0.1$ radian is

(a) > 1% and < 5%
(b) < 0.1%
(c) > 0.1% and < 1%
(d) > 5%

Ans. (c)

Exact value

$$f'(x) = -\sin x$$

$$f'\left(\frac{\pi}{6}\right) = -\frac{1}{2}$$

Approximate value

$$f'(x) = \frac{\cos(x + 0.1) - \cos(x - 0.1)}{2(0.1)} = \frac{-\sin x \cdot \sin(0.1)}{2(0.1)}$$

$$f'\left(\frac{\pi}{6}\right) = -0.49916$$

Error = Exact value – Approximate value

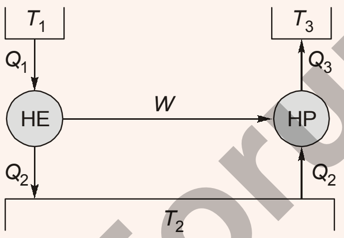
= –0.5 + 0.49916 = –0.00084

$\therefore$ $$\%\text{Error} = \frac{-0.00084}{0.5} \times 100 = 0.168\%$$

$\therefore$ The value is > 0.1% and <1%

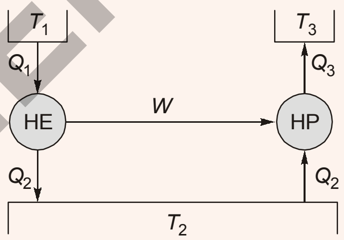
End of Solution

Q.53 The figure shows a heat engine (HE) working between two reservoirs. The amount of heat (Q_2) rejected by the heat engine is drawn by a heat pump (HP). The heat pump receives the entire work output (W) of the heat engine. If temperature, $T_1 > T_3 > T_2$, then the relation between the efficiency (η) of the heat engine and the coefficient of performance (COP) of the heat pump is



(a) COP = η^{-1}
(b) COP = 1 + η
(c) COP = $\eta^{-1} - 1$
(d) COP = η

Ans. (a)



$$\eta = \frac{W}{Q_1} = \frac{W}{Q_2 + W}$$

$$\text{COP} = \frac{Q_3}{W}$$

$$\text{COP} = \frac{Q_2 + W}{W}$$

$$\text{COP} = \frac{1}{\eta}$$

$\Rightarrow$ $$\text{COP} = \eta^{-1}$$

End of Solution

Q.54 An idealized centrifugal pump (blade outer radius of 50 mm) consumes 2 kW power while running at 3000 rpm. The entry of the liquid into the pump is axial and exit from the pump is radial with respect to impeller. If the losses are neglected, then the mass flow rate of the liquid through the pump is ________ kg/s (round off to two decimal places).

Ans. (8.11)

$$\text{Power} = 2 \text{ kW}$$
$$N = 3000 \text{ rpm}$$
$$R = 0.05 \text{ m} \times 2 = 0.1 \text{ m}$$
$$u = \frac{\pi DN}{60} = \frac{\pi \times 0.1 \times 3000}{60} = 15.708 \text{ m/s}$$

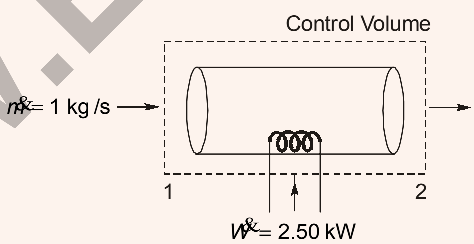
For centrifugal pump,

$$\text{Power} = \rho Q(u^2)$$
$$2 \times 10^3 = \dot{m}(15.708)^2$$
$$\dot{m} = 8.1056 \text{ kg/s}$$

End of Solution

Q.55 Water flowing at the rate of 1 kg/s through a system is heated using an electric heater such that the specific enthalpy of the water increases by 2.50 kJ/kg and the specific entropy increases by 0.007 kJ/kgK. The power input to the electric heater is 2.50 kW. There is no other work or heat interaction between the system and the surroundings. Assuming an ambient temperature of 300 K, the irreversibility rate of the system is ________ kW. (round off to two decimal places).

Ans. (2.10)



$$h_2 - h_1 = 2.50 \text{ KJ/kg}$$
$$s_2 - s_1 = 0.007 \text{ KJ/kgK}$$
$$\dot{I} = T_0\dot{S}_{gen} = 300 \times \dot{S}_{gen}$$
$$\dot{S}_{gen} = \dot{S}_{exit} - \dot{S}_{inlet} = (\dot{m}s_2) - (\dot{m}s_1 + 0)$$

(Entropy associated with work is zero)

$$= \dot{m}(s_2 - s_1) = 1 \times 0.007 = 0.007$$

$\therefore$ $$\dot{I} = 300 \times 0.007 = 2.10 \text{ kW}$$

Alternate Solution:

$$\Delta\dot{s}_{\text{universe}} = \Delta\dot{s}_{sys} + \Delta\dot{s}_{surr}$$

$$= \Delta\dot{s}_{sys}$$

$$= \dot{m}(s_2 - s_1) = 1(0.007)$$

$$\Delta\dot{s}_{\text{universe}} = 0.007 \text{ kW/K}$$

Irreversibility rate, $\dot{I} = T_0 \Delta\dot{s}_{\text{universe}}$

$$= 300 \times 0.007$$

$$= 2.1 \text{ kW}$$

End of Solution

■■■■