

GATE 2023 Chemical Engineering Question Paper

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| Time Allowed :3 Hours | Maximum Marks :100 | Total Questions :65 |
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General Instructions

Read the following instructions very carefully and strictly follow them:

1. Each GATE 2023 paper consists of a total of 100 marks. The examination is divided into two sections – General Aptitude (GA) and the Candidate's Selected Subjects. General Aptitude carries 15 marks, while the remaining 85 marks are dedicated to the candidate's chosen test paper syllabus.
2. GATE 2023 will be conducted in English as a Computer Based Test (CBT) at select centres in select cities. The duration of the examination is 3 hours.
3. MCQs carry 1 mark or 2 marks.
4. For a wrong answer in a 1-mark MCQ, 1/3 mark is deducted.
5. For a wrong answer in a 2-mark MCQ, 2/3 mark is deducted.
6. No negative marking for wrong answers in MSQ or NAT questions.

General Aptitude

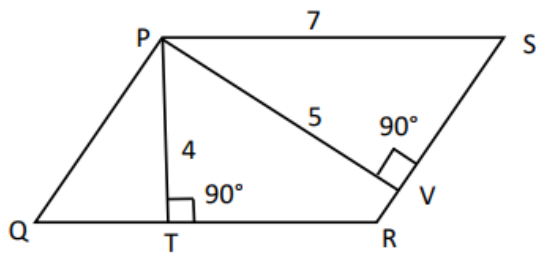
Q1. “You are delaying the completion of the task. Send _____ contributions at the earliest.”

- (A) you are
- (B) your
- (C) you're
- (D) yore

Q.2. References : _____ : Guidelines : Implement (By word meaning)

- (A) Sight
- (B) Site
- (C) Cite
- (D) Plagiarise

Q.3. In the given figure, PQRS is a parallelogram with $PS = 7$ cm, $PT = 4$ cm and $PV = 5$ cm. What is the length of RS in cm? (The diagram is representative.)

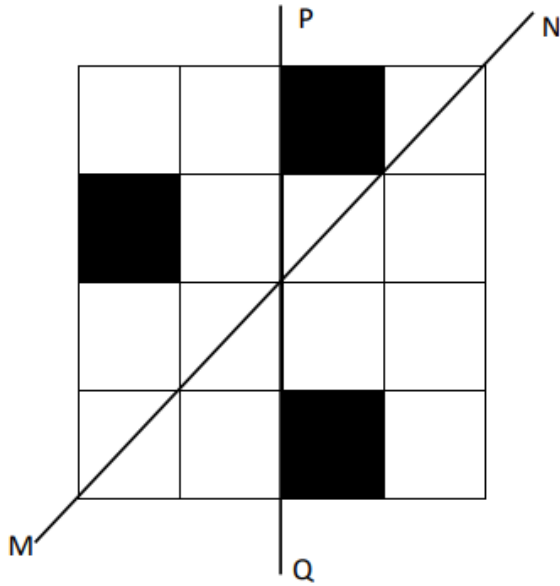


- (A) $\frac{20}{7}$
 (B) $\frac{28}{5}$
 (C) $\frac{9}{2}$
 (D) $\frac{35}{4}$

Q4. In 2022, June Huh was awarded the Fields medal, which is the highest prize in Mathematics. When he was younger, he was also a poet. He did not win any medals in the International Mathematics Olympiads. He dropped out of college. Based only on the above information, which one of the following statements can be logically inferred with certainty?

- (A) Every Fields medalist has won a medal in an International Mathematics Olympiad.
 (B) Everyone who has dropped out of college has won the Fields medal.
 (C) All Fields medalists are part-time poets.
 (D) Some Fields medalists have dropped out of college.

Q5. A line of symmetry is defined as a line that divides a figure into two parts in a way such that each part is a mirror image of the other part about that line. The given figure consists of 16 unit squares arranged as shown. In addition to the three black squares, what is the minimum number of squares that must be coloured black, such that both PQ (vertical) and MN (the bottom-left to top-right diagonal) form lines of symmetry? (The figure is representative)



- (A) 3
- (B) 4
- (C) 5
- (D) 6

Q6. Human beings are one among many creatures that inhabit an imagined world. In this imagined world, some creatures are cruel. If in this imagined world, it is given that the statement “Some human beings are not cruel creatures” is FALSE, then which of the following set of statement(s) can be logically inferred with certainty?

- (i) All human beings are cruel creatures.
- (ii) Some human beings are cruel creatures.
- (iii) Some creatures that are cruel are human beings.
- (iv) No human beings are cruel creatures.

- (A) only (i)
- (B) only (iii) and (iv)
- (C) only (i) and (ii)
- (D) (i), (ii) and (iii)

Q7. To construct a wall, sand and cement are mixed in the ratio of 3:1. The cost of sand and that of cement are in the ratio of 1:2.

If the total cost of sand and cement to construct the wall is 1000 rupees, then what is the cost (in rupees) of cement used?

- (A) 400
- (B) 600

- (C) 800
 - (D) 200
-

Q8. The World Bank has declared that it does not plan to offer new financing to Sri Lanka, which is battling its worst economic crisis in decades, until the country has an adequate macroeconomic policy framework in place. In a statement, the World Bank said Sri Lanka needed to adopt structural reforms that focus on economic stabilisation and tackle the root causes of its crisis. The latter has starved it of foreign exchange and led to shortages of food, fuel, and medicines. The bank is repurposing resources under existing loans to help alleviate shortages of essential items such as medicine, cooking gas, fertiliser, meals for children, and cash for vulnerable households. Based only on the above passage, which one of the following statements can be inferred with *certainty*?

- (A) According to the World Bank, the root cause of Sri Lanka's economic crisis is that it does not have enough foreign exchange.
 - (B) The World Bank has stated that it will advise the Sri Lankan government about how to tackle the root causes of its economic crisis.
 - (C) According to the World Bank, Sri Lanka does not yet have an adequate macroeconomic policy framework.
 - (D) The World Bank has stated that it will provide Sri Lanka with additional funds for essentials such as food, fuel, and medicines.
-

Q9. The coefficient of x^4 in the polynomial $(x - 1)^3(x - 2)^3$ is equal to

- (A) 33
 - (B) -3
 - (C) 30
 - (D) 21
-

Q10. Which one of the following shapes can be used to tile (completely cover by repeating) a flat plane, extending to infinity in all directions, without leaving any empty spaces in between them? The copies of the shape used to tile are identical and are not allowed to overlap.

- (A) circle
 - (B) regular octagon
 - (C) regular pentagon
 - (D) rhombus
-

Q.11. Which one of the following is the CORRECT value of y , as defined by the expression given below?

$$y = \lim_{x \rightarrow 0} \frac{2x}{e^x - 1}$$

- (A) 1
 - (B) 2
 - (C) 0
 - (D) ∞
-

Q.12. The vector \vec{v} is defined as

$$\vec{v} = zx \hat{i} + 2xy \hat{j} + 3yz \hat{k}.$$

Which one of the following is the CORRECT value of divergence of \vec{v} , evaluated at the point $(x, y, z) = (3, 2, 1)$?

- (A) 0
 - (B) 3
 - (C) 14
 - (D) 13
-

Q.13. Given that $F = \frac{|z_1 + z_2|}{|z_1| + |z_2|}$, where $z_1 = 2 + 3i$ and $z_2 = -2 + 3i$ with $i = \sqrt{-1}$, which one of the following options is CORRECT?

- (A) $F < 0$
 - (B) $F < 1$
 - (C) $F > 1$
 - (D) $F = 1$
-

Q.14. For a two-dimensional plane, the unit vectors $(\hat{e}_r, \hat{e}_\theta)$ of the polar coordinate system and (\hat{i}, \hat{j}) of the cartesian coordinate system are related by

$$\hat{e}_r = \cos \theta \hat{i} + \sin \theta \hat{j}, \quad \hat{e}_\theta = -\sin \theta \hat{i} + \cos \theta \hat{j}.$$

Which one of the following is the CORRECT value of $\frac{\partial(\hat{e}_r + \hat{e}_\theta)}{\partial \theta}$?

- (A) 1
- (B) \hat{e}_θ
- (C) $\hat{e}_r + \hat{e}_\theta$
- (D) $-\hat{e}_r + \hat{e}_\theta$

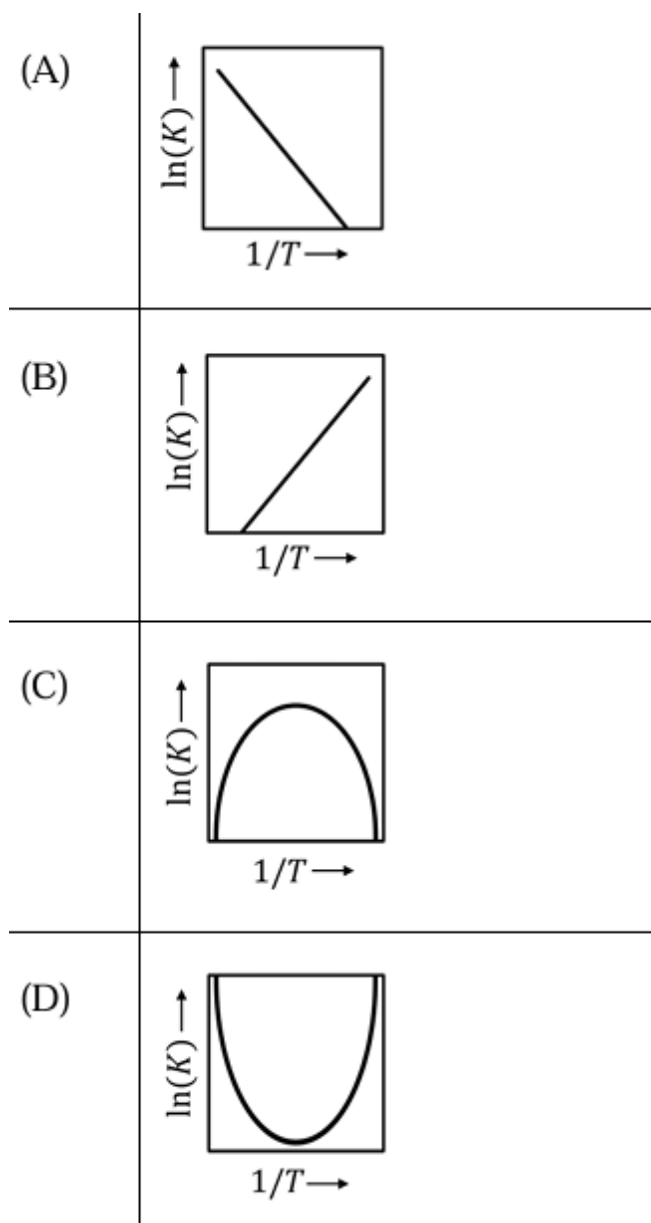
Q.15. Which one of the following statements related to octane number is NOT correct?

- (A) Linear alkanes with higher carbon number have higher octane number.
- (B) Branching in linear alkanes increases their octane number.
- (C) Catalytic reforming of hydrocarbons increases their octane number.
- (D) Gasoline quality is measured in terms of octane number.

Q.16. Which one of the following options represents the major components of oleum?

- (A) Sulfuric acid and nitric acid
- (B) Concentrated sulfuric acid and petroleum jelly
- (C) Sulfuric acid and hydrochloric acid
- (D) Sulfuric acid and sulfur trioxide

Q.17. For a reversible endothermic chemical reaction with constant heat of reaction over the operating temperature range, K is the thermodynamic equilibrium constant. Which one of the following figures shows the CORRECT dependence of K on temperature T ?



Q.18. Nitrile rubber is manufactured via polymerization process. Which one of the following options is the **CORRECT** pair of monomers used in this process?

- (A) Acrylonitrile and styrene
- (B) Acrylonitrile and butadiene
- (C) Butadiene and styrene
- (D) Butadiene and isoprene

Q.19. John and Jane independently performed a thermodynamic experiment, in which X and Y represent the initial and final thermodynamic states of the system, respectively. John performed the experiment under reversible conditions, for which the change in entropy of the system was ΔS_{rev} . Jane performed the experi-

ment under irreversible conditions, for which the change in entropy of the system was ΔS_{irr} . Which one of the following relationships is CORRECT?

- (A) $\Delta S_{\text{rev}} = \Delta S_{\text{irr}}$
- (B) $\Delta S_{\text{rev}} > \Delta S_{\text{irr}}$
- (C) $\Delta S_{\text{rev}} < \Delta S_{\text{irr}}$
- (D) $\Delta S_{\text{rev}} = 2\Delta S_{\text{irr}}$

20. For a packed-bed comprising of uniform-sized spherical particles of diameter D_p , the pressure drop across the bed is given by the Kozeny–Carman (laminar Ergun) equation when the particle Reynolds number (Re_p) < 1 . Under this condition, minimum fluidization velocity is proportional to D_p^n . Which one of the following is the CORRECT value of exponent n ?

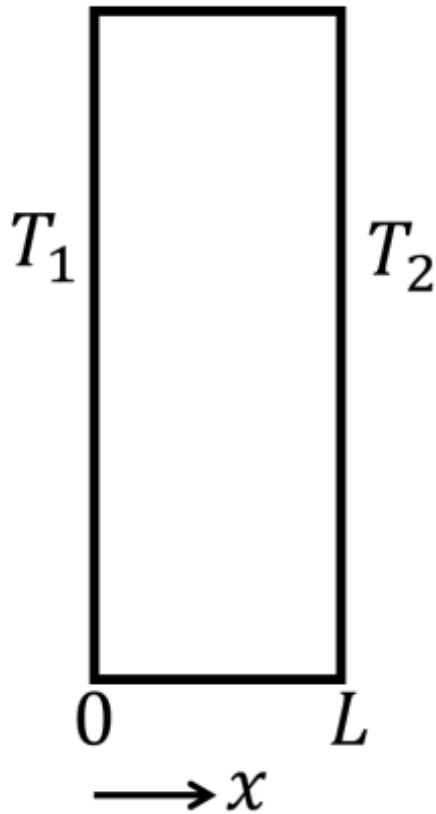
- (A) 2
- (B) -1
- (C) -2
- (D) 1

Q21. Match the quantities in Group 1 with their units in Group 2 listed in the table below.

| Group 1 | Group 2 |
|---|---|
| P) Thermal conductivity | I) $\text{W} \cdot \text{m}^{-2}\text{K}^{-1}$ |
| Q) Convective heat transfer coefficient | II) $\text{W} \cdot \text{m}^{-1}\text{K}^{-1}$ |
| R) Stefan-Boltzmann constant | III) $\text{W} \cdot \text{K}^{-1}$ |
| S) Heat capacity rate | IV) $\text{W} \cdot \text{m}^{-2}\text{K}^{-4}$ |

- (A) P-II, Q-I, R-IV, S-III
- (B) P-I, Q-II, R-III, S-IV
- (C) P-III, Q-IV, R-II, S-I
- (D) P-IV, Q-I, R-III, S-II

22. A slab of thickness L , as shown in the figure, has cross-sectional area A and constant thermal conductivity k . T_1 and T_2 are the temperatures at $x = 0$ and $x = L$, respectively. Which one of the following options is the CORRECT expression of the thermal resistance for steady-state one-dimensional heat conduction?



- (A) $\frac{L}{kA}$
- (B) $\frac{LA}{k}$
- (C) $\frac{kA(T_1 - T_2)}{L}$
- (D) $\frac{A}{Lk}$

Q23. Spray dryers have many advantages. Which one of the following is NOT an advantage of a typical spray dryer?

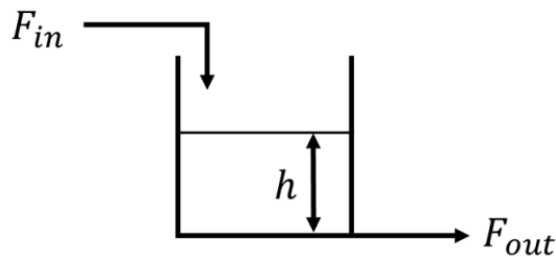
- (A) Has short drying time
- (B) Produces hollow spherical particles
- (C) Has high heat efficiency
- (D) Is suitable for heat sensitive materials

Q24. Which one of the following quantities of a flowing fluid is measured using a rotameter?

- (A) Static pressure
- (B) Dynamic pressure
- (C) Volumetric flow rate

(D) Viscosity

25. A liquid surge tank has F_{in} and F_{out} as the inlet and outlet flow rates respectively, as shown in the figure. F_{out} is proportional to the square root of the liquid level h . The cross-sectional area of the tank is 20 cm^2 . Density of the liquid is constant everywhere in the system. At steady state, $F_{in} = F_{out} = 10 \text{ cm}^3\text{s}^{-1}$ and $h = 16 \text{ cm}$. The variation of h with F_{in} is approximated as a first-order transfer function. Which one of the following is the CORRECT value of the time constant (in seconds) of this system?

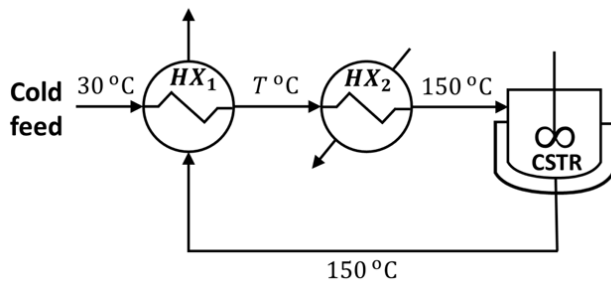


- (A) 20
- (B) 32
- (C) 64
- (D) 128

26. A packed distillation column, with vapor having an average molecular weight of $45 \text{ kg} \cdot \text{kmol}^{-1}$, density of $2 \text{ kg} \cdot \text{m}^{-3}$ and a molar flow rate of $0.1 \text{ kmol} \cdot \text{s}^{-1}$, has a flooding velocity of $0.15 \text{ m} \cdot \text{s}^{-1}$. The column is designed to operate at 60% of the flooding velocity. Which one of the following is the CORRECT value for the column diameter (in m)?

- (A) $\frac{5}{\sqrt{\pi}}$
- (B) $5\sqrt{\pi}$
- (C) 4π
- (D) $\frac{10}{\sqrt{\pi}}$

Q27. An isothermal jacketed continuous stirred tank reactor (CSTR) operating at 150°C is shown. The cold feed at 30°C is first preheated to T ($T < 150^\circ\text{C}$) in heat exchanger HX_1 (using process-to-process heat recovery) and then heated to 150°C in a utility heater HX_2 . Mass flow rate and heat capacity are the same for all process streams and the overall heat transfer coefficient is independent of temperature. Which action will increase the value of T ?



- (A) Increase both heat transfer area of HX_1 and heat duty of HX_2 .
 - (B) Decrease both heat transfer area of HX_1 and heat duty of HX_2 .
 - (C) Increase the heat transfer area of HX_1 and decrease the heat duty of HX_2 .
 - (D) Decrease the heat transfer area of HX_1 and increase the heat duty of HX_2 .
-

Q28. Consider a system where a Carnot engine is operating between a source and a sink. Which of the following statements about this system is/are NOT correct?

- (A) This engine is reversible.
 - (B) The engine efficiency is independent of the source and sink temperatures.
 - (C) This engine has the highest efficiency among all engines that operate between the same source and sink.
 - (D) The total entropy of this system increases at the completion of each cycle of the engine.
-

Q29. For a fully developed turbulent flow of an incompressible Newtonian fluid through a pipe of constant diameter, which of the following statements is/are CORRECT?

- (A) Reynolds stress, averaged over a sufficiently long time, is zero everywhere inside the pipe.
 - (B) Reynolds stress at the pipe wall is zero.
 - (C) Average velocity of the fluid is half of its center-line velocity.
 - (D) Average pressure gradient in the flow direction is constant.
-

30. Given that E (in $\text{W}\cdot\text{m}^{-2}$) is the total hemispherical emissive power of a surface maintained at a certain temperature, which of the following statements is/are CORRECT?

- (A) E does not depend on the direction of the emission.
 - (B) E depends on the viewfactor.
 - (C) E depends on the wavelength of the emission.
 - (D) E does not depend on the frequency of the emission.
-

31. The position $x(t)$ of a particle, at constant ω , is described by $\frac{d^2x}{dt^2} = -\omega^2x$ with initial conditions $x(0) = 1$ and $\left.\frac{dx}{dt}\right|_{t=0} = 0$. The position of the particle at $t = \frac{3\pi}{\omega}$ is _____ (in integer).

Q32. Burning of methane in a combustor yields carbon monoxide, carbon dioxide, and water vapor. Methane is fed to the combustor at $100 \text{ mol}\cdot\text{hr}^{-1}$, of which 50% reacts. The theoretical oxygen requirement (in $\text{mol}\cdot\text{hr}^{-1}$) is _____ (rounded off to one decimal place).

33. The viscosity of an incompressible Newtonian fluid is measured using a capillary tube of diameter 0.5 mm and length 1.5 m. The fluid flow is laminar, steady and fully developed. For a flow rate of $1 \text{ cm}^3\text{s}^{-1}$, the pressure drop across the length of the tube is 1 MPa. If the viscosity of the fluid is $k \times 10^{-3} \text{ Pa}\cdot\text{s}$, the value of k is _____ (rounded off to two decimal places).

Q.34. A liquid L containing a dissolved gas S is stripped in a countercurrent operation using a pure carrier gas V . The liquid phase inlet and outlet mole fractions of S are 0.1 and 0.01, respectively. The equilibrium distribution of S between V and L is governed by $y_e = x_e$, where y_e and x_e are the mole fractions of S in V and L , respectively. The molar feed rate of the carrier gas stream is twice that of the liquid stream. Under dilute solution conditions, the minimum number of ideal stages required is _____ (in integer).

35. In a binary gas-liquid system, $N_{A,EMD}$ is the molar flux of a gas A for equimolar counter diffusion with a liquid B . $N_{A,UMD}$ is the molar flux of A for steady one-component diffusion through stagnant B . Using the mole fraction of A in the bulk of the gas phase as 0.2 and that at the gas-liquid interface as 0.1 for both the modes of diffusion, the ratio of $N_{A,UMD}$ to $N_{A,EMD}$ is equal to _____ (rounded off to two decimal places).

Q.36. An exhibition was held in a hall on 15 August 2022 between 3 PM and 4 PM during which any person was allowed to enter only once. Visitors who entered before 3:40 PM exited the hall exactly after 20 minutes from their time of entry. Visitors who entered at or after 3:40 PM, exited exactly at 4 PM. The probability distribution of the arrival time of any visitor is uniform between 3 PM

and 4 PM. Two persons X and Y entered the exhibition hall independent of each other. Which one of the following values is the probability that their visits to the exhibition overlapped with each other?

- (A) $\frac{5}{9}$
 (B) $\frac{4}{9}$
 (C) $\frac{2}{9}$
 (D) $\frac{7}{9}$

Q.37. Simpson's one-third rule is used to estimate the definite integral $I = \int_{-1}^1 \sqrt{1-x^2} dx$ with an interval length of 0.5. Which one of the following is the CORRECT estimate of I obtained using this rule?

- (A) $\frac{1}{3} - \frac{1}{\sqrt{3}}$
 (B) $\frac{1}{3} + \frac{2}{\sqrt{3}}$
 (C) $\frac{1}{3} + \frac{1}{\sqrt{3}}$
 (D) $\frac{1}{3} - \frac{2}{\sqrt{3}}$

38. Match the products in Group 1 with the manufacturing processes in Group 2 listed in the table below.

| Group 1 | Group 2 |
|------------------|------------------------------|
| P) Acetaldehyde | I) Sulfate process |
| Q) Sulfuric acid | II) Electric furnace process |
| R) Pulp | III) Wacker process |
| S) Phosphorus | IV) Contact process |

- (A) P-III, Q-IV, R-I, S-II
 (B) P-III, Q-I, R-IV, S-II
 (C) P-IV, Q-I, R-II, S-III
 (D) P-I, Q-IV, R-II, S-III

Q.39. Match the reactions in Group 1 with the catalysts in Group 2 listed in the table below.

| Group 1 | Group 2 |
|--|-----------------------------|
| P) $C_6H_6 + Cl_2 \longrightarrow$ Chlorobenzene + HCl | I) Mixed oxide of Mo and Fe |
| Q) $H_2C = CH_2 + \frac{1}{2}O_2 \longrightarrow$ Ethylene oxide | II) V_2O_5 |
| R) $CH_3OH + \frac{1}{2}O_2 \longrightarrow$ Formaldehyde + H_2O | III) $FeCl_3$ |
| S) Naphthalene + $\frac{9}{2}O_2 \longrightarrow$ Phthalic Anhydride + $2H_2O + 2CO_2$ | IV) Ag_2O |

- (A) P-III, Q-IV, R-II, S-I
 (B) P-III, Q-IV, R-I, S-II
 (C) P-IV, Q-II, R-I, S-III
 (D) P-IV, Q-III, R-I, S-II

40. Water in a container at 290 K is exposed to air containing 3 % CO_2 by volume. Air behaves like an ideal gas and is maintained at 100 kPa pressure. The liquid phase comprising of dissolved CO_2 in water behaves like an ideal solution. Use Henry's constant of CO_2 dissolved in water at 290 K as 12 MPa. Under equilibrium conditions, which one of the following is the CORRECT value of the mole fraction of CO_2 dissolved in water?

- (A) 2.9×10^{-4}
 (B) 0.9×10^{-4}
 (C) 2.5×10^{-4}
 (D) 0.5×10^{-4}

41. The enthalpy (H , in $J \cdot mol^{-1}$) of a binary liquid system at constant temperature and pressure is given as

$$H = 40x_1 + 60x_2 + x_1x_2(4x_1 + 2x_2),$$

where x_1 and x_2 represent the mole fractions of species 1 and 2 in the liquid, respectively. Which one of the following is the CORRECT value of the partial molar enthalpy of species 1 at infinite dilution, \bar{H}_1^∞ (in $J \cdot mol^{-1}$)?

- (A) 100
 (B) 42
 (C) 64
 (D) 40

Q.42. Which one of the following represents the CORRECT effects of concentration polarization in a reverse osmosis process?

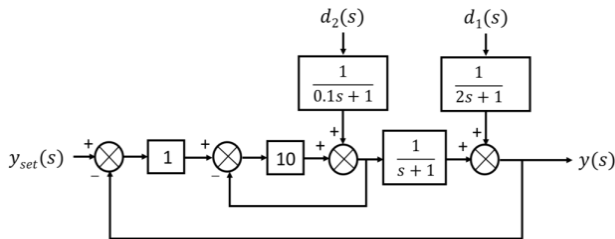
- (A) Reduced water flux and reduced solute rejection
 (B) Increased water flux and increased solute rejection

- (C) Reduced water flux and increased solute rejection
 (D) Increased water flux and reduced solute rejection

43. CO and H₂ participate in a catalytic reaction. The partial pressures (in atm) of the reacting species CO and H₂ in the feed stream are p_{CO} and p_{H_2} , respectively. While CO undergoes molecular adsorption, H₂ adsorbs via dissociative adsorption (as H atoms). The equilibrium constants (in atm⁻¹) corresponding to adsorption of CO and H₂ to the catalyst sites are K_{CO} and K_{H_2} , respectively. Total molar concentration of active sites per unit mass of the catalyst is C_t (in mol·(g cat)⁻¹). Both the adsorption steps are at equilibrium. Which one of the following expressions is the CORRECT ratio of the concentration of catalyst sites occupied by CO to that by hydrogen atoms?

- (A) $\frac{K_{CO} p_{CO}}{\sqrt{K_{H_2} p_{H_2}}}$
 (B) $\frac{K_{CO}}{\sqrt{K_{H_2}}}$
 (C) $\frac{p_{CO}}{\sqrt{p_{H_2}}}$
 (D) $\frac{K_{CO} p_{CO}}{K_{H_2} p_{H_2}}$

Q.44. A cascade control strategy is shown in the figure. The transfer function between the output (y) and the secondary disturbance (d_2) is defined as $G_{d2}(s) = \frac{y(s)}{d_2(s)}$. Which one of the following is the CORRECT expression for $G_{d2}(s)$?



- (A) $\frac{1}{(11s + 21)(0.1s + 1)}$
 (B) $\frac{1}{(s + 1)(0.1s + 1)}$
 (C) $\frac{s + 1}{(s + 2)(0.1s + 1)}$
 (D) $\frac{s + 1}{(s + 1)(0.1s + 1)}$

45. Level (h) in a steam boiler is controlled by manipulating the flow rate (F) of the make-up water using a proportional (P) controller. The transfer function is

$$\frac{h(s)}{F(s)} = \frac{0.25(1-s)}{s(2s+1)}.$$

The measurement and valve transfer functions are both 1. A process engineer wants the closed-loop response to give decaying oscillations under servo mode. Which one of the following is the CORRECT value of the controller gain?

- (A) 0.25
 - (B) 2
 - (C) 4
 - (D) 6
-

46. Which of the following statements is/are CORRECT?

- (A) Bond number includes surface tension.
 - (B) Jakob number includes latent heat.
 - (C) Prandtl number includes liquid-vapor density difference.
 - (D) Biot number includes gravity.
-

Q.47. If a matrix M is defined as $M = \begin{bmatrix} 10 & 6 \\ 6 & 10 \end{bmatrix}$, the sum of all the eigenvalues of M^3 is equal to _____ (in integer).

Q.48. The first derivative of the function

$$U(r) = 4 \left[\left(\frac{1}{r} \right)^{12} - \left(\frac{1}{r} \right)^6 \right]$$

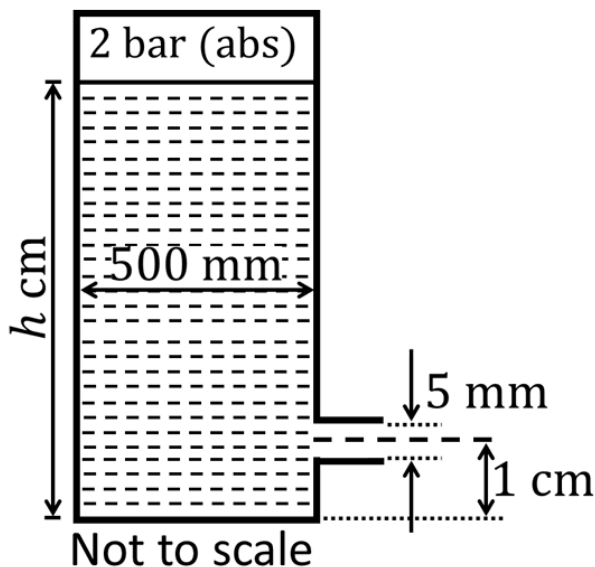
evaluated at $r = 1$ is _____ (in integer).

49. Wet air containing 10 mole percent water vapor is dried by continuously passing it through a column of CaCl_2 pellets. The pellets remove 50 percent of water from wet air entering the column. The mole percent of water vapor in the product stream exiting the column is _____ (rounded off to two decimal places).

50. Orsat analysis of a stack gas on a dry basis is: $N_2 = 65\%$, $CO_2 = 15\%$, $CO = 10\%$, $O_2 = 10\%$. The measured mole fraction of H_2O in the stack gas (wet basis) is 0.07. The mole fraction of N_2 on a wet basis is ----- (rounded off to two decimal places).

Q.51. A pump draws water (density = 1000 kg m^{-3}) at a steady rate of 10 kg s^{-1} . The pressures at the suction and discharge sides of the pump are -20 kPa (gauge) and 350 kPa (gauge), respectively. The pipe diameters at the suction and discharge side are 70 mm and 50 mm , respectively. The suction and discharge lines are at the same elevation, and the pump operates at an efficiency of 80% . Neglecting frictional losses in the system, the power (in kW) required to drive the pump is ----- (rounded off to two decimal places).

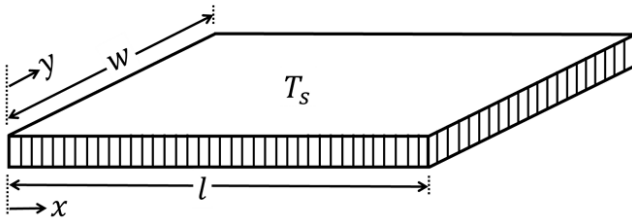
52. A cylindrical tank with a diameter of 500 mm contains water (density = $1 \text{ g} \cdot \text{cm}^{-3}$) up to a height h . A 5 mm diameter round nozzle, whose center is 1 cm above the base of the tank, has its exit open to the atmosphere. The pressure above the water level in the tank is maintained at 2 bar (abs). Neglect all frictional and entry/exit losses. Take $g = 10 \text{ m s}^{-2}$ and atmospheric pressure = 1 bar . The absolute value of initial $\frac{dh}{dt}$ (in mm s^{-1}) when $h = 51 \text{ cm}$ is ----- (rounded off to two decimal places).



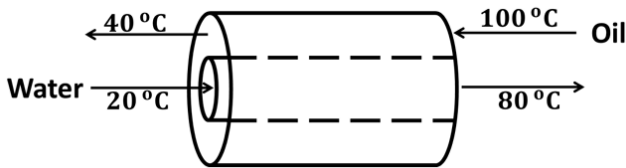
Q.53. A large tank is filled with water (density = 1 g cm^{-3}) up to a height of 5 m . A $100 \mu\text{m}$ diameter solid spherical particle (density = 0.8 g cm^{-3}) is released at the bottom of the tank. The particle attains its terminal velocity (v_t) after traveling to a certain height in the tank. Use acceleration due to gravity as 10 m s^{-2} and

water viscosity as 10^{-3} Pas. Neglect wall effects on the particle. If Stokes' law is applicable, the absolute value of v_t (in mm s^{-1}) is _____ (rounded off to two decimal places).

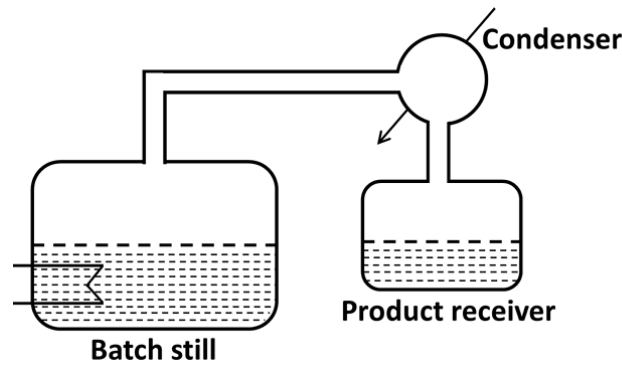
54. A fluid is flowing steadily under laminar conditions over a thin rectangular plate at temperature T_s as shown. The free-stream velocity and temperature are u_∞ and T_∞ , respectively. When the fluid flow is only in the x -direction, h_x is the local heat transfer coefficient. Similarly, when the fluid flow is only in the y -direction, h_y is the corresponding local heat transfer coefficient. Use the correlation $\text{Nu} = 0.332 \text{Re}^{1/2} \text{Pr}^{1/3}$ for the local heat transfer coefficient, where Nu, Re and Pr are the appropriate Nusselt, Reynolds and Prandtl numbers. The average heat transfer coefficients are defined as $\bar{h}_l = \frac{1}{l} \int_0^l h_x dx$ and $\bar{h}_w = \frac{1}{w} \int_0^w h_y dy$. If $w = 1$ m and $l = 4$ m, the value of the ratio \bar{h}_w/\bar{h}_l is _____ (in integer).



Q.55. A perfectly insulated, concentric tube countercurrent heat exchanger is used to cool lubricating oil using water as a coolant. Oil enters the outer annulus at a mass flow rate of 2 kg s^{-1} with a temperature of 100°C and leaves at 40°C . Water enters the inner tube at 1 kg s^{-1} with a temperature of 20°C and leaves at 80°C . Specific heats: $c_{p,\text{oil}} = 2089 \text{ J kg}^{-1}\text{K}^{-1}$, $c_{p,\text{water}} = 4178 \text{ J kg}^{-1}\text{K}^{-1}$. No phase change. Under steady state, the number of transfer units (NTU) is ____ (in integer).



56. Partially saturated air at 1 bar and 50°C is contacted with water in an adiabatic saturator. The air is cooled and humidified to saturation, and exits at 25°C with an absolute humidity of $0.02 \text{ kg water per kg dry air}$. Use latent heat of vaporization of water as 2450 kJ kg^{-1} , and average specific heats $c_{p,a} = 1.01 \text{ kJ kg}^{-1}\text{K}^{-1}$ (dry air) and $c_{p,w} = 4.18 \text{ kJ kg}^{-1}\text{K}^{-1}$ (liquid water). If the absolute humidity of air entering the adiabatic saturator is $\mathcal{H} \times 10^{-3} \text{ kg water per kg dry air}$, the value of \mathcal{H} is _____



(rounded off to two decimal places).

Q.57. Distillation of a non-reactive binary mixture with components A and B is carried out in a batch still as shown. The initial charge in the still is 1 kmol. The initial and final amounts of A in the still are 0.1 kmol and 0.01 kmol, respectively. The relative volatility is constant at $\alpha = 4.5$. The mole fraction of B remaining in the vessel is _____ (rounded off to three decimal places).

58. Fresh catalyst is loaded into a reactor for the reaction $A \rightarrow \text{products}$. The catalyst deactivates with time. The instantaneous activity $a(t)$ is defined as the ratio of the rate $-r'_A(t)$ (with deactivated catalyst) to the rate with fresh catalyst. Experimental correlation:

$$-r'_A(t) = -0.5t + 10 \quad (\text{mol (g cat)}^{-1} \text{ hr}^{-1}),$$

with t in hours. The activity of the catalyst at $t = 10$ hr is _____ (rounded off to one decimal place).

59. A unimolecular, irreversible liquid-phase reaction $A \rightarrow P$ is carried out in an ideal batch reactor at temperature T . The rate of reaction $(-r_A)$ (in $\text{mol m}^{-3} \text{s}^{-1}$) measured at different conversions X_A is given:

| X_A | 0 | 0.1 | 0.2 | 0.4 | 0.6 | 0.8 |
|--------|------|------|------|------|------|------|
| $-r_A$ | 0.45 | 0.35 | 0.31 | 0.18 | 0.11 | 0.05 |

The reaction is also carried out in an ideal CSTR at the same T with a feed concentration $C_{A0} = 1 \text{ mol m}^{-3}$ under steady state. For a conversion of 0.8, the space time (in s) of the CSTR is _____ (in integer).

Q.60. An irreversible liquid-phase second-order reaction $A \xrightarrow{k} B$ with rate constant $k = 0.2 \text{ L mol}^{-1} \text{ min}^{-1}$ is carried out isothermally in a non-ideal reactor. A tracer test gives the residence time distribution $E(t)$ shown: three rectangles (i), (ii), (iii) of equal areas; rectangles (i) and (ii) span $t = 5\text{--}10 \text{ min}$ (stacked), and (iii) spans $t = 10\text{--}15 \text{ min}$. Pure A of concentration $C_{A0} = 1.5 \text{ mol L}^{-1}$ is fed. Using the segregated model, determine the percentage conversion of A at the exit (rounded to the nearest integer).

61. The outlet concentration C_A of a plug flow reactor (PFR) is controlled by manipulating the inlet concentration C_{A0} . The transfer function is

$$\frac{C_A(s)}{C_{A0}(s)} = \exp \left[- \left(\frac{V}{F} \right) (k + s) \right],$$

with $V = 1 \text{ m}^3$, $F = 0.1 \text{ m}^3 \text{ min}^{-1}$, $k = 0.5 \text{ min}^{-1}$. Measurement and valve transfer functions are 1. Find the *ultimate gain* (proportional controller gain for sustained oscillations).

62. A measuring instrument has transfer function

$$G_m(s) = \frac{1.05}{2s + 1} e^{-s}.$$

At $t = 0$, a step of +1 unit is applied. Find the time taken for the output to increase by 1 unit.

63. A design engineer needs to purchase a membrane module (M) for a plant. Two options are available: M1 and M2. The overall plant life is 7 years. Interest rate is 8% per annum, compounded annually. The table gives purchase cost (lakhs of rupees) and expected life (years):

| | M1 | M2 |
|-----------------------|----|----|
| Purchase cost (lakhs) | 10 | 5 |
| Expected life (years) | 5 | 3 |

Find the difference in the net present value (NPV) of these two options over the 7-year horizon (lakhs of rupees).

64. A distillation column has a purchase cost of Rs. 10 lakhs with an installation factor 5.8. The installed capital is annualized over 6 years at 5% per annum, compounded annually. Find the annual cost (in lakhs of rupees) of the installed capital.

Q.65. Pumps A and B are being considered for purchase in a chemical plant. Cost details are: Pump A — installed cost 16000, uniform end-of-year maintenance 2400, salvage value 1000, service life 1 year; Pump B — installed cost 32000, uniform end-of-year maintenance 1600, salvage value S (unknown), service life 2 years. The interest rate is 10% per annum, compounded annually. For both pumps to have the same capitalized cost, find the salvage value S of pump B (in Rs., rounded to the nearest integer).

| Item | Pump A | Pump B |
|---------------------------------------|--------|--------|
| Installed cost (Rs.) | 16000 | 32000 |
| Uniform end of year maintenance (Rs.) | 2400 | 1600 |
| Salvage value (Rs.) | 1000 | ? |
| Service life (year(s)) | 1 | 2 |