GATE 2023 Petroleum Engineering (PE) Question Paper with Solutions

Time Allowed :3 Hours	**Maximum Marks :**100	**Total questions :**65

General Aptitude (GA)

Q.1 The village was nestled in a green spot, _____ the ocean and the hills.

(A) through

(B) in

(C) at

(D) between

Correct Answer: (D) between

Solution:

1) Understanding the context:

The sentence talks about a village being located between two geographical features: the ocean and the hills. The preposition "between" is used to indicate the position of the village relative to two other objects, hence making it the most suitable choice.

2) Analysis of the options:

(A) through: This suggests movement across a space or location, which is incorrect in this context. *"Nestled through the ocean and the hills"* does not convey the correct meaning.

(B) in: This would indicate the village is located inside the space of both the ocean and hills, but this is not the intended meaning in the sentence.

(C) at: This is used for specifying exact locations but doesn't convey the idea of being between two things.

(D) between: Correct choice. It indicates that the village is situated in the middle of the two features — the ocean and the hills.

The correct answer is (D) between.

Quick Tip

- **Through** indicates motion or passage. - **In** suggests being inside an area or a space. - **At** refers to a specific point or location. - **Between** refers to a position that is located in the middle of two objects.

Q.2 Disagree : Protest : : Agree : _____ (By word meaning)

(A) Refuse

(B) Pretext

(C) Recommend

(D) Refute

Correct Answer: (C) Recommend

Solution:

1) Identifying word relationship:

The given pair "Disagree : Protest" suggests a relationship where protest is an act in response to disagreement. We need a similar relationship for "Agree," where the corresponding action is associated with agreement.

2) Analysis of the options:

(A) Refuse: This is a negative response, but it doesn't match the context of "agree."

(B) Pretext: This means a false reason given for an action, which is unrelated to the context of agreement.

(C) Recommend: This is a fitting choice. When one agrees, they often make a recommendation.

(D) Refute: Refuting means disproving or denying something, which does not logically follow from agreeing.

The correct answer is (C) Recommend.

Quick Tip

- **Disagree** is often followed by **Protest**. - **Agree** is commonly followed by **Recommend**.

Q.3 A 'frabjous' number is defined as a 3 digit number with all digits odd, and no two adjacent digits being the same. For example, 137 is a frabjous number, while 133 is not. How many such frabjous numbers exist?

(A) 125

(B) 720

(C) 60

(D) 80

Correct Answer: (D) 80

Solution:

The problem defines a 'frabjous' number as a 3-digit number in which all digits are odd, and no two adjacent digits are the same. The possible odd digits are 1, 3, 5, 7, and 9. We will calculate the total number of such 3-digit frabjous numbers by considering the following conditions:

- **For the first digit:** Since the number is a 3-digit number, the first digit can be any of the 5 odd digits: {1, 3, 5, 7, 9}. So, there are 5 choices for the first digit.
- **For the second digit:** The second digit must also be odd, but it cannot be the same as the first digit. Hence, there are only 4 choices for the second digit because one odd digit is already taken by the first digit.
- **For the third digit:** The third digit also needs to be odd, and it cannot be the same as the second digit. So, there are again 4 choices for the third digit.

Thus, the total number of frabjous numbers is the product of the number of choices for each digit:

$$5 \times 4 \times 4 = 80$$

Therefore, the total number of frabjous numbers is 80.

Quick Tip

When calculating the number of valid combinations for restricted problems, remember to reduce the available choices for each subsequent selection. Here, we reduced the choices for the second and third digits to avoid repetition of adjacent digits.

Q.4 Which one among the following statements must be TRUE about the mean and the median of the scores of all candidates appearing for GATE 2023?

(A) The median is at least as large as the mean.

(B) The mean is at least as large as the median.

(C) At most half the candidates have a score that is larger than the median.

(D) At most half the candidates have a score that is larger than the mean.

Correct Answer: (C) At most half the candidates have a score that is larger than the median.

Solution:

Let's break down the given options and analyze them:

- Option (A): "The median is at least as large as the mean."

- This is not necessarily true. In a skewed distribution (such as one with many lower scores and a few higher scores), the mean can be larger than the median. Thus, this statement is not universally true.

- Option (B): "The mean is at least as large as the median."

- This is also not necessarily true. In cases where the distribution is skewed to the left (more higher scores, few lower scores), the median can be larger than the mean. Hence, this statement is also not always true.

- Option (C): "At most half the candidates have a score that is larger than the median."

- This statement is **true**. By definition, the **median** divides the dataset into two equal halves. So, exactly half of the candidates will have scores smaller than the median, and the other half

will have scores larger than the median. Therefore, **at most** half the candidates have a score larger than the median, which is always true.

- Option (D): ”At most half the candidates have a score that is larger than the mean.”

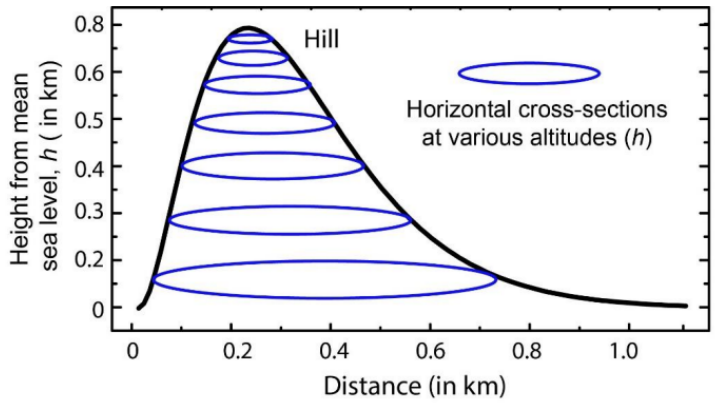
- This statement is **not necessarily true**. The mean is the average of all scores, and if the distribution is skewed, more than half of the candidates could have a score larger than the mean, especially in right-skewed distributions (where the mean is greater than the median). Hence, this is not always true.

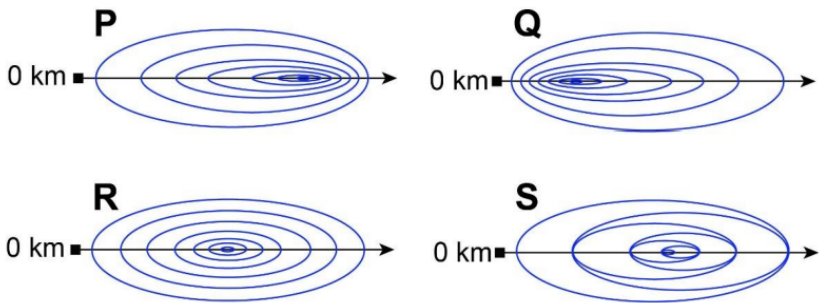
Therefore, the correct and always true statement is (C): At most half the candidates have a score that is larger than the median.

Quick Tip

For datasets with skewed distributions, the mean and median can be quite different. The median divides the data into two equal parts, while the mean is influenced by the extreme values.

Q.5 In the given diagram, ovals are marked at different heights (h) of a hill. Which one of the following options P, Q, R, and S depicts the top view of the hill?





(A) P

(B) Q

(C) R

(D) S

Correct Answer: (C)

Solution:

- The given diagram shows a hill with horizontal cross-sections at various altitudes. The oval-shaped contours represent the cross-sections at different heights. The shape and size of these contours change as the altitude changes. The given diagram suggests that the hill has a peak in the center, and the altitude decreases as we move outward from the center.
- Option (P): This option shows an irregular shape, and the contours are not concentric. This irregularity doesn't correspond to the shape of a typical hill, which is often depicted with concentric contours. Hence, (A) is incorrect.
- Option (Q): This option shows a perfect symmetry of contours, but this doesn't match the irregularity of the hill shown in the diagram. The hill is expected to have a more gradual slope and irregular contours. Thus, (B) is incorrect.
- Option (R): This option shows concentric circles, which is characteristic of a hill with a peak at the center and decreasing altitude as we move outward. This matches the diagram perfectly, where the altitude decreases as we move away from the hill's peak. This makes (C) the correct answer.
- Option (S): This option shows a disorganized pattern of concentric circles, which doesn't correspond to the expected shape of a hill. The contours are not consistently decreasing in size as the altitude decreases. Hence, (D) is incorrect.

Quick Tip

A top view of a hill with increasing altitude towards the center should show concentric circles. This corresponds to the shape in option (R).

Q.6 Residency is a famous housing complex with many well-established individuals

among its residents. A recent survey conducted among the residents of the complex revealed that all of those residents who are well established in their respective fields happen to be academicians. The survey also revealed that most of these academicians are authors of some best-selling books. Based only on the information provided above, which one of the following statements can be logically inferred with certainty?

(A) Some residents of the complex who are well established in their fields are also authors of some best-selling books.
(B) All academicians residing in the complex are well established in their fields.
(C) Some authors of best-selling books are residents of the complex who are well established in their fields.
(D) Some academicians residing in the complex are well established in their fields.

Correct Answer: (B)

Solution:
- From the survey, we know that all residents who are well established in their fields are academicians. This is a universal statement, which means that anyone who is well-established in their field in this housing complex is definitely an academician. Therefore, all academicians in the complex must also be well-established in their fields. This makes option (B) a valid conclusion.
- Option (A): While the survey tells us that most of the academicians are authors of best-selling books, it does not guarantee that all well-established residents are authors. The statement ”some” is not definite, so this cannot be inferred with certainty. Therefore, (A) is not correct.
- Option (C): The survey doesn’t state that authors of best-selling books are always well-established residents of the complex. It only says that most of the academicians are authors. Thus, we cannot definitively conclude that some authors are well-established in their fields. Therefore, (C) is incorrect.
- Option (D): The survey tells us that all well-established residents are academicians, but it doesn’t mention that all academicians are well-established. Hence, we cannot be sure that all or some academicians are well-established, which makes (D) an incorrect option.

Quick Tip

Logical deductions are made based on statements with certainty. ”All” statements are more definitive than ”some” or ”most” statements.

Q.7 Ankita has to climb 5 stairs starting at the ground, while respecting the following rules:

1. At any stage, Ankita can move either one or two stairs up. 2. At any stage, Ankita cannot move to a lower step.

Let $F(N)$ denote the number of possible ways in which Ankita can reach the N^{th} stair. For example, $F(1) = 1$, $F(2) = 2$, $F(3) = 3$. The value of $F(5)$ is _____.

(A) 8

(B) 7

(C) 6

(D) 5

Correct Answer: (A)

Solution:

We are given the recurrence relation that $F(1) = 1$, $F(2) = 2$, and $F(3) = 3$. The number of ways to reach any stair N depends on whether Ankita took one or two steps from the previous stair:

$$F(N) = F(N-1) + F(N-2)$$

Now, let us calculate $F(4)$ and $F(5)$:

$$F(4) = F(3) + F(2) = 3 + 2 = 5$$

$$F(5) = F(4) + F(3) = 5 + 3 = 8$$

Therefore, the value of $F(5) = 8$.

Quick Tip

This is a classical example of the Fibonacci-like sequence, where each number is the sum of the two preceding ones.

Q.8 The information contained in DNA is used to synthesize proteins that are necessary for the functioning of life. DNA is composed of four nucleotides: Adenine (A), Thymine (T), Cytosine (C), and Guanine (G). The information contained in DNA can then be thought of as a sequence of these four nucleotides: A, T, C, and G. DNA has coding and non-coding regions. Coding regions—where the sequence of these nucleotides are read in groups of three to produce individual amino acids—constitute only about 2% of human DNA. For example, the triplet of nucleotides CCG codes for the amino acid glycine, while the triplet GGA codes for the amino acid proline. Multiple amino acids are then assembled to form a protein.

Based only on the information provided above, which of the following statements can be logically inferred with certainty?

(i) The majority of human DNA has no role in the synthesis of proteins. (ii) The function of about 98% of human DNA is not understood.

(A) only (i)

(B) only (ii)

(C) both (i) and (ii)

(D) neither (i) nor (ii)

Correct Answer: (A), (D)

Solution:

(i) True. From the passage, we know that only about 2% of human DNA is involved in coding proteins. Therefore, the remaining majority of human DNA does not have a role in the synthesis of proteins.

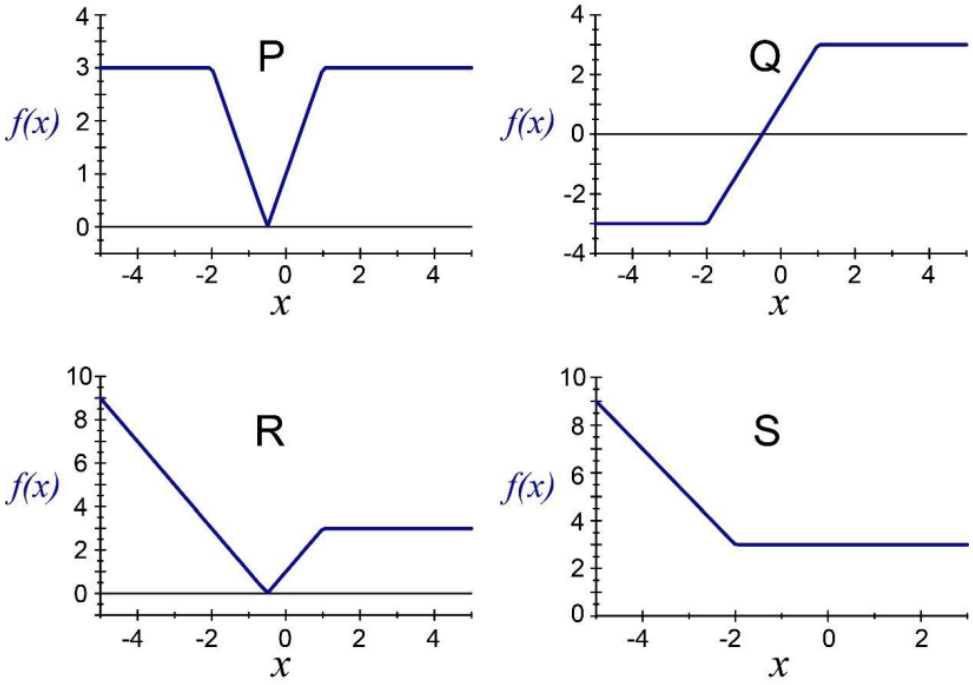
(ii) False. The passage does not suggest that 98% of human DNA is entirely understood or not understood; it only states that 98% is non-coding. Hence, we cannot assert with certainty that its function is completely unknown.

Quick Tip

Be careful about statements that use terms like ”majority” or ”most”—they must be directly supported by the text. The rest might be inferred but not confirmed.

Q.9 Which one of the given figures P, Q, R, and S represents the graph of the following function?

$$f(x) = |x + 2| - |x - 1|$$



(A) P

(B) Q

(C) R

(D) S

Correct Answer: (A) P

Solution:

We are given the function:

$$f(x) = |x + 2| - |x - 1|$$

To determine the graph of this function, we need to analyze the behavior of each part of the function.

1) Function Analysis:

We can break the function into two absolute value terms. The behavior of the function will change depending on whether x is less than -2, between -2 and 1, or greater than 1. We need to analyze these intervals to plot the graph.

- For $x < -2$, both $x + 2$ and $x - 1$ are negative, so the graph will have a linear decrease.

- For $-2 \leq x \leq 1$, $x + 2$ is positive, and $x - 1$ is negative, resulting in a change in slope and a turning point.

- For $x > 1$, both terms are positive, resulting in a different slope.

2) Matching the Graph:

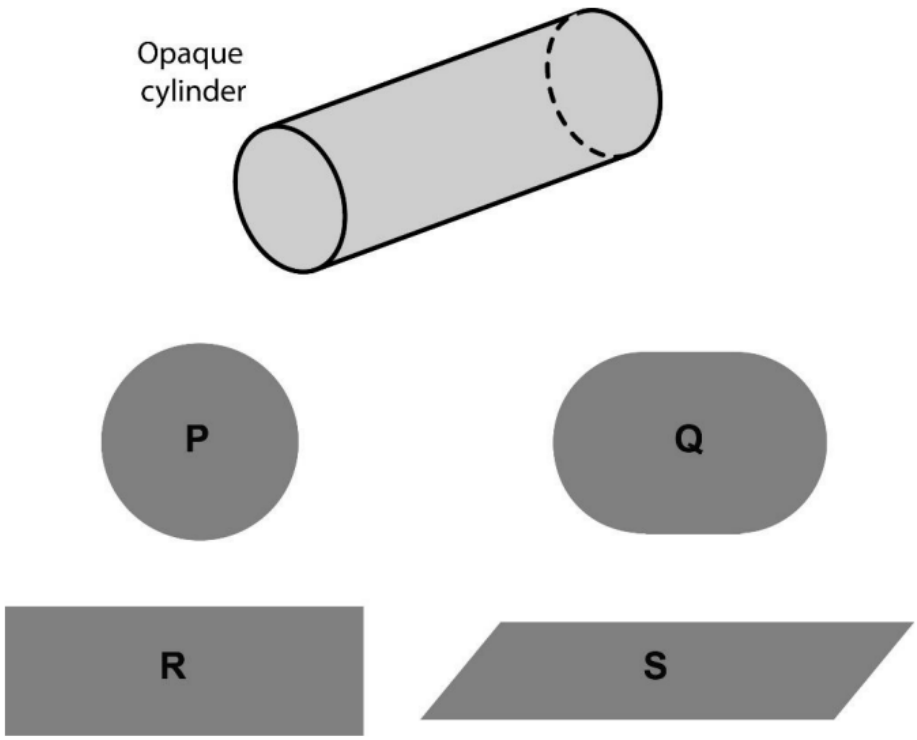
Upon examining the graphs, the graph labeled P fits the expected behavior of the function with changes in slope at $x = -2$ and $x = 1$. Thus, the correct graph is option (A).

The correct answer is (A) P.

Quick Tip

- Absolute value functions break into piecewise linear sections, which can cause slope changes at certain points (where the inside expression equals zero). - To graph such functions, first identify these critical points and then plot accordingly in each region.

Q.10 An opaque cylinder (shown below) is suspended in the path of a parallel beam of light, such that its shadow is cast on a screen oriented perpendicular to the direction of the light beam. The cylinder can be reoriented in any direction within the light beam. Under these conditions, which one of the shadows P, Q, R, and S is NOT possible?



(A) P

(B) Q

(C) R

(D) S

Correct Answer: (D) S

Solution:

We are given an opaque cylinder suspended in the path of a parallel beam of light, and the task is to analyze which shadow cannot be formed based on the cylinder's reorientation.

1) Shadow Formation:

When a cylindrical object is in the path of light, the shadow produced depends on the orientation of the cylinder.

- When the cylinder is oriented with its axis perpendicular to the direction of the light, it will cast a circular shadow.

- When the cylinder is reoriented with its axis at an angle to the light, the shadow may become elliptical.

- A shadow like S (which appears highly distorted) is not physically possible as it would require an impossible angle or distortion of light.

2) Conclusion:

The shadow in option S cannot be produced by the cylinder under the given conditions. Therefore, the correct answer is option (D).

The correct answer is (D) S.

Quick Tip

- Shadows of cylindrical objects can be circular or elliptical depending on the angle of light.
- Unusual or impossible shadows result from incorrect assumptions about the object's positioning or light angles.

Q.11 Let z_1 and z_2 be two arbitrary complex numbers with non-zero modulus. Which of the following conditions is FALSE?

(A) $|z_1 + z_2| > |z_1| + |z_2|$

(B) $0 \leq |z_1 + z_2| < \infty$

(C) $|z_1 + z_2| \leq |z_1| + |z_2|$

(D) $|z_1 z_2| = |z_1||z_2|$

Correct Answer: (A) $|z_1 + z_2| > |z_1| + |z_2|$

Solution:

- We recall the **triangle inequality** for complex numbers:

$$|z_1 + z_2| \leq |z_1| + |z_2|$$

This inequality is always true for any two complex numbers. Hence, option (C) is always valid.

- Option (B) states that the modulus of a complex number is always non-negative and finite. Indeed, for any $z \in \mathbb{C}$, $|z| \geq 0$ and $|z| < \infty$, since modulus measures distance from the origin. Therefore, (B) is also correct.

- Option (D) uses the multiplicative property of modulus:

$$|z_1 z_2| = |z_1| \cdot |z_2|$$

This is a standard property of modulus and is always true. Hence, (D) is correct.

- Option (A) suggests that:

$$|z_1 + z_2| > |z_1| + |z_2|$$

But this contradicts the triangle inequality, which tells us that $|z_1 + z_2|$ can never exceed $|z_1| + |z_2|$.

At best, equality holds when z_1 and z_2 point in the same direction in the complex plane.

Hence, (A) is **FALSE**.

Therefore, the false statement is (A).

Quick Tip

Remember: For complex numbers, the triangle inequality is fundamental: $|z_1 + z_2| \leq |z_1| + |z_2|$. Equality holds only when z_1 and z_2 are in the same direction.

Q.12 In the 4$^{\text{th}}$ order Runge-Kutta method for solving ordinary differential equations with step size $h < 1$, the ratio of the order of local error to the order of global error is

(A) h

(B) h^2

(C) $\frac{1}{h}$

(D) $\frac{1}{h^2}$

Correct Answer: (A) h

Solution:

Step 1: Local Truncation Error (LTE).

- In the 4$^{\text{th}}$ order Runge-Kutta (RK4) method, the local truncation error per step is of the order $\mathcal{O}(h^5)$.

- This means that each step introduces an error proportional to h^5.

Step 2: Global Error (GE).

- The global error accumulates over $\frac{1}{h}$ steps (since the total interval is divided into $\frac{1}{h}$ steps of size h).

- Therefore, the global error is $\mathcal{O}(h^4)$ because:

$$\text{Global Error} = \frac{1}{h} \times \mathcal{O}(h^5) = \mathcal{O}(h^4).$$

Step 3: Ratio of Orders.

- Order of local error = h^5

- Order of global error = h^4

- Ratio = $\frac{h^5}{h^4} = h$

Final Answer: h

Quick Tip

In Runge-Kutta methods, local error is always one power of h higher than the global error. For RK4, local error $\sim h^5$ while global error $\sim h^4$. Thus, the ratio is always h.

Q.13 Which of the following instruments can measure contact angle of a liquid drop placed on a surface?

(A) Goniometer

(B) Pycnometer

(C) Soxhlet apparatus

(D) Rheometer

Correct Answer: (A) Goniometer

Solution:

- The contact angle of a liquid drop placed on a solid surface is an important parameter to study surface wettability and interfacial properties.

- A **Goniometer** is specifically designed to measure the contact angle by analyzing the profile of a liquid drop placed on a solid surface. It captures the drop image and calculates the angle formed at the three-phase boundary (solid–liquid–air). Hence, (A) is correct.
- A **Pycnometer** is used to measure the density of liquids. It has no relation to contact angle measurement, so (B) is incorrect.
- A **Soxhlet apparatus** is used for continuous extraction of compounds (mainly in chemistry/food industry applications). It does not measure contact angles. Thus, (C) is incorrect.
- A **Rheometer** is used to study the flow and deformation behavior (rheology) of fluids. It measures viscosity and viscoelastic properties, not contact angle. Hence, (D) is incorrect.

Quick Tip

Remember: Contact angle measurements (wettability studies) are done using a goniometer, while pycnometers measure density, Soxhlet apparatus is for extraction, and rheometers measure flow properties.

Q.14 Which of the following is the primary role of proppants in hydraulic fracturing?

(A) Keep the fractures open during production
(B) Decrease the viscosity of fracturing fluid
(C) Decrease the density of fracturing fluid
(D) Reduce the viscosity of crude oil in reservoir

Correct Answer: (A) Keep the fractures open during production

Solution:

- In hydraulic fracturing, high-pressure fluid is injected into underground rock formations to create fractures and enhance hydrocarbon flow.
- Once the fractures are formed, they tend to close due to the overburden pressure from the surrounding rock layers. If these fractures close, the pathway for oil and gas movement is lost.

- Proppants (typically sand, ceramic beads, or other granular materials) are introduced into the fractures along with the fracturing fluid. Their primary purpose is to lodge within the fractures and ”prop them open,” ensuring that the channels remain conductive to fluid flow even after the pumping pressure is reduced.
- Option (B): Decreasing viscosity of fracturing fluid is achieved by additives, not proppants.
- Option (C): Density control of fracturing fluid is also managed by fluid composition, not by proppants.
- Option (D): Proppants do not alter the viscosity of crude oil in the reservoir; other enhanced oil recovery (EOR) methods may address that.
- Therefore, the correct and primary role of proppants is to keep the fractures open during production, ensuring continuous hydrocarbon flow.

Quick Tip

Remember: Proppants act like tiny supports inside fractures. Without them, the fractures would collapse, stopping the flow of hydrocarbons.

Q.15 A mixture of a flammable gas and air can ignite ONLY if

(A) the gas concentration is below the limiting oxygen concentration
(B) the gas concentration is above the upper flammable limit
(C) the gas concentration is between the lower and upper flammable limits
(D) the gas concentration is below the lower flammable limit

Correct Answer: (C) the gas concentration is between the lower and upper flammable limits

Solution:
- For any flammable gas mixed with air, ignition is only possible within a certain concentration range. This range is defined by two important parameters: the **Lower Flammable Limit (LFL)** and the **Upper Flammable Limit (UFL)**.
- If the gas concentration is **below the LFL**, the mixture is too lean (not enough fuel) to ignite, as there is insufficient gas present to sustain combustion.

- If the gas concentration is **above the UFL**, the mixture is too rich (too much fuel and insufficient oxygen), which also prevents ignition.
- Ignition and sustained combustion occur only when the gas concentration lies **between the LFL and UFL**. Within this range, there is an adequate balance between fuel and oxygen to initiate and propagate a flame.
- Therefore, the mixture of a flammable gas and air can ignite **only if the gas concentration is between the lower and upper flammable limits**.

Quick Tip

Remember: Combustion needs the right fuel–air ratio. Too little gas (below LFL) or too much gas (above UFL) prevents ignition. Always check whether the concentration lies within the flammability limits for safety analysis.

Q.16 Which of the following relations defines the coefficient of isothermal compressibility (C_g) for a gas? Here, p, T, and v represent the pressure, temperature and volume of the gas, respectively.

(A) $C_g = -\frac{1}{v}\left(\frac{\partial v}{\partial p}\right)_T$

(B) $C_g = -\frac{1}{v}\left(\frac{\partial p}{\partial v}\right)_T$

(C) $C_g = -\frac{1}{p}\left(\frac{\partial v}{\partial p}\right)_T$

(D) $C_g = -\frac{1}{p}\left(\frac{\partial p}{\partial v}\right)_T$

Correct Answer: (A) $C_g = -\frac{1}{v}\left(\frac{\partial v}{\partial p}\right)_T$

Solution:

- The **isothermal compressibility** of a gas is defined as the fractional decrease in volume per unit increase in pressure at constant temperature.
- Mathematically, it is given by:

$$C_g = -\frac{1}{v}\left(\frac{\partial v}{\partial p}\right)_T$$

- Here, v is the molar volume (or volume), p is the pressure, and the negative sign ensures that C_g is a positive quantity, since an increase in pressure generally decreases the volume of the gas.
- Option (A) exactly matches this definition.
- Option (B) involves $\frac{\partial p}{\partial v}$, which is not the standard definition.
- Option (C) incorrectly takes $\frac{1}{p}$ instead of $\frac{1}{v}$.
- Option (D) again uses $\frac{\partial p}{\partial v}$ with $\frac{1}{p}$, which is incorrect.

Therefore, the correct definition of isothermal compressibility is given by option (A).

Quick Tip

Always remember: Isothermal compressibility C_g is defined with respect to **volume change per pressure change at constant temperature**, given by $C_g = -\frac{1}{v}\left(\frac{\partial v}{\partial p}\right)_T$.

Q.17 Consider an ideal liquid–vapor mixture at equilibrium having liquid phase mole fraction (x_i) and gas phase mole fraction (y_i) of component i. If at a given temperature, P_{v_i} is the vapor pressure of pure component i and P is the total pressure, then the equilibrium ratio (k_i) is

(A) $k_i = \dfrac{x_i}{y_i} = \dfrac{P_{v_i}}{P}$

(B) $k_i = \dfrac{x_i}{y_i} = \dfrac{P}{P_{v_i}}$

(C) $k_i = \dfrac{y_i}{x_i} = \dfrac{P_{v_i}}{P}$

(D) $k_i = \dfrac{y_i}{x_i} = \dfrac{P}{P_{v_i}}$

Correct Answer: (C)

Solution:

Step 1: Use Raoult's law for an ideal liquid.

For component i, the equilibrium (saturation) partial pressure above the liquid is

$$p_i^\star = x_i\, P_{v_i}.$$

Step 2: Use Dalton's law for the gas phase.

At total pressure P, the actual partial pressure in the vapor is

$$p_i = y_i\, P.$$

Step 3: Equate partial pressures at phase equilibrium.

At equilibrium, $p_i = p_i^{\star} \Rightarrow \mathrm{y}_i P = x_i P_{v_i} \Rightarrow \dfrac{y_i}{x_i} = \dfrac{P_{v_i}}{P}$.

Step 4: Define the equilibrium ratio.

By definition, $k_i \equiv \dfrac{y_i}{x_i} \Rightarrow \mathrm{k}_i = \dfrac{P_{v_i}}{P}$, which matches option (C).

Quick Tip

For ideal systems at T = const., combine Raoult's law ($p_i = x_i P_{v_i}$) with Dalton's law ($p_i = y_i P$) to get $k_i = \dfrac{y_i}{x_i} = \dfrac{P_{v_i}}{P}$ instantly.

Q.18 In-situ combustion method for enhanced oil recovery is commonly used for

(A) gas condensate reservoirs

(B) light oil reservoirs

(C) brown oil reservoirs

(D) heavy oil reservoirs

Correct Answer: (D)

Solution:

Step 1: What is in-situ combustion?

It is a thermal EOR method where a portion of the reservoir oil is ignited; the combustion front moves through the formation, generating heat.

Step 2: Why for heavy oil?

Heavy oils are highly viscous; heating dramatically lowers viscosity and improves mobility and displacement efficiency. The generated flue gases also aid drive.

Step 3: Eliminate other options.

Gas condensate and light-oil reservoirs already have good mobility; thermal methods are unnecessary or inefficient compared to gas or miscible processes. "Brown oil" is not a distinct fluid type for which thermal EOR is preferred.

Conclusion: In-situ combustion is best suited to *heavy oil reservoirs*.

Quick Tip

Thermal EOR (steam flooding, in-situ combustion) $\Rightarrow$ $think$**heavy/extra-heavy oil** : $thegoalistocutviscosityandmobilizethecrude.$

Q.19 Which of the following is a sedimentary rock?

(A) Amphibolite

(B) Chalk

(C) Gabbro

(D) Schist

Correct Answer: (B) Chalk

Solution:

- Rocks are classified into three main types: **igneous**, **sedimentary**, and **metamorphic**.

- **Amphibolite** is a metamorphic rock, formed mainly from the metamorphism of basalt or gabbro. Hence, (A) is incorrect.

- **Chalk** is a sedimentary rock composed mainly of calcium carbonate ($CaCO_3$), formed from the skeletal remains of microscopic marine organisms like foraminifera and coccolithophores. Thus, (B) is correct.

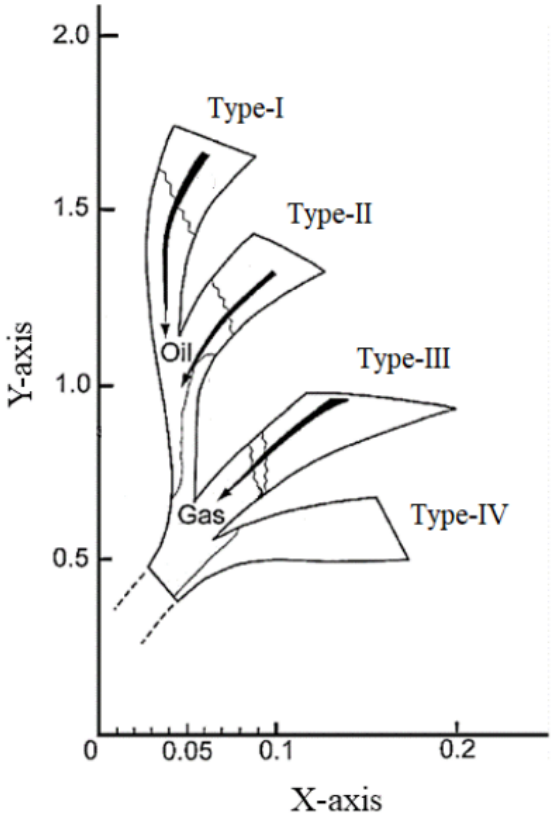
- **Gabbro** is an intrusive igneous rock, coarse-grained, formed from the slow cooling of magma beneath the Earth's surface. Hence, (C) is incorrect.

- **Schist** is a metamorphic rock, characterized by foliated layers due to high temperature and pressure. Thus, (D) is incorrect.

Quick Tip

Sedimentary rocks like chalk, sandstone, and limestone are formed from the deposition and compaction of sediments, while igneous and metamorphic rocks form from magma or alteration of existing rocks.

Q.20 Kerogen is an intermediate compound in the process of petroleum formation in a sedimentary basin. This is typically classified into four categories (Type-I, Type-II, Type-III and Type-IV) based on the relative amount of carbon (C), hydrogen (H), oxygen (O) present in it (shown in the figure below).
Which of the following is the X-axis and Y-axis, respectively?



(A) H:C ratio and O:C ratio

(B) O:C ratio and H:C ratio

(C) C:H ratio and C:O ratio

(D) C:O ratio and C:H ratio

Correct Answer: (B) O:C ratio and H:C ratio

Solution:

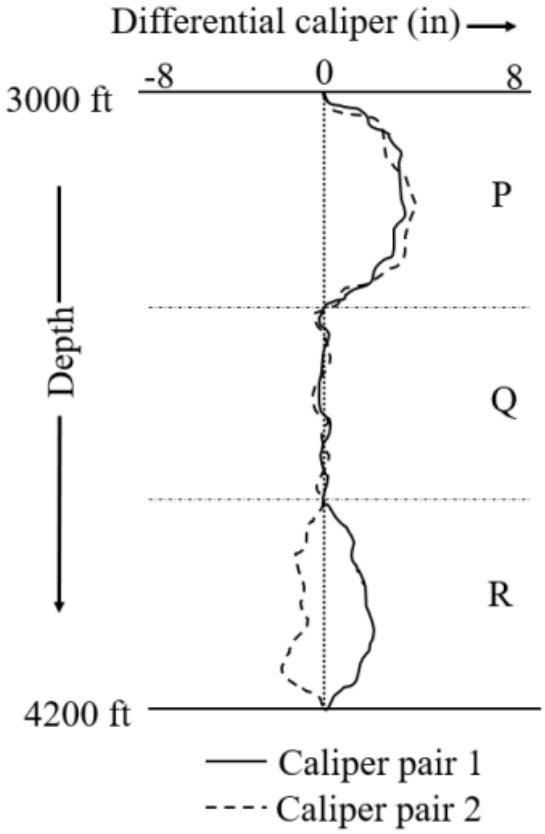
- The diagram shown is a **Van Krevelen diagram**, which is commonly used to classify kerogen types during petroleum generation.
- On the **X-axis**, the oxygen-to-carbon (O:C) atomic ratio is plotted. This ratio reflects the oxygen content in the organic matter. As kerogen matures, the O:C ratio decreases due to loss of oxygen-containing compounds (e.g., CO_2, H_2O).
- On the **Y-axis**, the hydrogen-to-carbon (H:C) atomic ratio is plotted. This ratio reflects the hydrogen content in the organic matter. A higher H:C ratio is associated with oil-prone kerogen (Type I), while lower H:C ratios are linked to gas-prone kerogen (Type III/IV).
- From the figure, we can clearly see Type-I kerogen has high H:C and low O:C values, making it oil-prone. Type-III and Type-IV kerogens have lower H:C ratios and relatively higher O:C values, indicating gas-prone or inert material.
- Therefore, the correct labeling is:

$$\text{X-axis} = \text{O:C ratio}, \quad \text{Y-axis} = \text{H:C ratio}$$

Quick Tip

Always remember: In a Van Krevelen diagram, X-axis = O:C ratio and Y-axis = H:C ratio. This is the standard classification chart for kerogen typing.

Q.21 The response of a four-arm caliper (dual caliper) log in a drilled section is shown in the figure. The borehole features associated with the three identified sections P, Q, and R are:



(A) P: washout; Q: in-gauge hole; R: key-seat

(B) P: key-seat; Q: in-gauge hole; R: washout

(C) P: under-gauge hole; Q: in-gauge hole; R: washout

(D) P: dog-leg; Q: in-gauge hole; R: key-seat

Correct Answer: (A) P: washout; Q: in-gauge hole; R: key-seat

Solution:

- A dual/four-arm caliper gives two orthogonal hole diameters; the track is shown as deviation from bit size (differential caliper), with positive values indicating enlargement and negative values indicating under-gauge.
- At **P**, both caliper traces shift to the positive side with increased separation, showing an overall **enlarged borehole** from erosion ⇒ **washout**.
- At **Q**, both traces cluster near zero with minimal separation, indicating the hole is close to bit size ⇒ **in-gauge**.
- At **R**, the two orthogonal calipers diverge strongly, with one reporting much smaller

diameter (negative) while the other differs, indicating a **slot-like, one-sided wear** $\Rightarrow$ **key-seat**.

Therefore, the mapping is **P: washout; Q: in-gauge; R: key-seat**.

Quick Tip

Washout: both calipers trend positive; in-gauge: both near zero; key-seat/ovalization: large difference between the two orthogonal calipers.

Q.22 Which of the following is necessary for the generation of electrokinetic potential across well-bore and permeable rock formation?

(A) Salinity gradient

(B) Pressure gradient

(C) Shale membrane

(D) Mud cake

Correct Answer: (B) Pressure gradient

Solution:

- Electrokinetic (streaming) potential arises when an electrolyte is forced through charged pores, causing mobile counter-ions in the electrical double layer to drift and set up an electric field.

- The driving requirement is a **pressure gradient** across the permeable medium; without flow, no streaming current forms.

- A salinity gradient produces a **diffusion potential** (not electrokinetic).

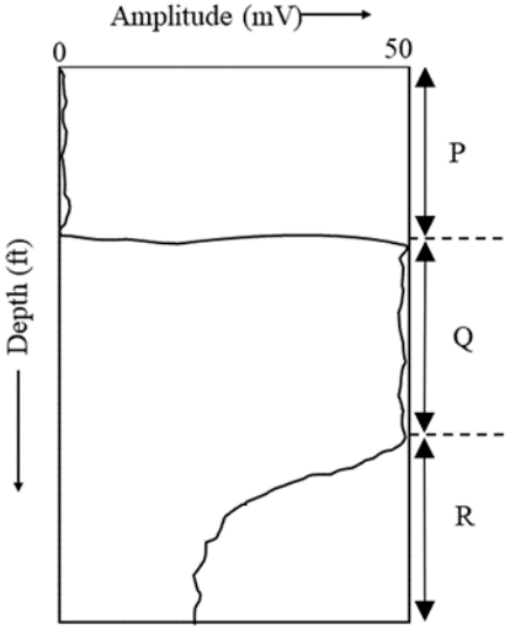
- Shale membranes and mud cake affect SP profiling but are not the necessary driving cause for electrokinetic potential.

Hence, a **pressure gradient** is necessary.

Quick Tip

Remember: Streaming (electrokinetic) potential $\propto$ fluid flow through pores, so look for a pressure drop across a permeable interval.

Q.23 A first arrival amplitude of the Cement Bond Log (CBL) of a cased hole section is given in the figure. The identified depth intervals P, Q, and R represent



(A) P: not cemented; Q: partially cemented; R: well-cemented

(B) P: not cemented; Q: well-cemented; R: partially cemented

(C) P: partially cemented; Q: not cemented; R: well-cemented

(D) P: well-cemented; Q: not cemented; R: partially cemented

Correct Answer: (D)

Solution:

Step 1: Understanding CBL (Cement Bond Log).

- In Cement Bond Log, the first arrival amplitude indicates the quality of cement bonding between casing and formation.

- High amplitude $\Rightarrow$ poor bonding (not cemented).

- Low amplitude $\Rightarrow$ strong bonding (well cemented).

- Intermediate amplitude ⇒ partial cementation.

Step 2: Interpretation of zones.

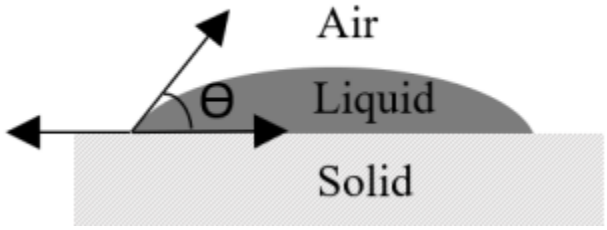
- Zone P shows very low amplitude ⇒ good bond ⇒ well-cemented.
- Zone Q shows very high amplitude ⇒ poor bond ⇒ not cemented.
- Zone R shows moderate amplitude ⇒ partial bond ⇒ partially cemented.

Thus, the answer is (D): P = well-cemented, Q = not cemented, R = partially cemented.

Quick Tip

Always remember: In CBL logs, low amplitude means good cementation, high amplitude means no cement, and medium amplitude means partial cement.

Q.24 Contact angle measurements are often performed on smooth surfaces to gain information about the wettability of a surface. The interfacial tensions between solid-liquid, liquid-air, and air-solid are γ_{SL}, γ_{LA}, and γ_{AS}, respectively. Which of the following expressions describes the contact angle, Θ?



(A) $\cos\Theta = \dfrac{\gamma_{AS} - \gamma_{SL}}{\gamma_{LA}}$

(B) $\cos\Theta = \dfrac{\gamma_{SL} - \gamma_{AS}}{\gamma_{LA}}$

(C) $\cos\Theta = \dfrac{\gamma_{LA} - \gamma_{AS}}{\gamma_{SL}}$

(D) $\cos\Theta = \dfrac{\gamma_{LA} - \gamma_{SL}}{\gamma_{AS}}$

Correct Answer: (A)

Solution:

Step 1: Apply Young's equation.

The equilibrium of interfacial tensions at the contact line is:

$$\gamma_{AS} = \gamma_{SL} + \gamma_{LA} \cos \Theta$$

Step 2: Rearrange.

$$\cos \Theta = \frac{\gamma_{AS} - \gamma_{SL}}{\gamma_{LA}}$$

Step 3: Match with options.

This exactly corresponds to option (A).

Quick Tip

Young's equation is the key for contact angle problems: $\gamma_{AS} = \gamma_{SL} + \gamma_{LA} \cos \Theta$. Just rearrange to get $\cos \Theta$.

Q.25 Which of the following offshore rigs has the HIGHEST water depth of operation?

(A) Submersible drilling barge

(B) Jackup rig

(C) Jacket platform

(D) Semi-submersible rig

Correct Answer: (D) Semi-submersible rig

Solution:

- Offshore drilling rigs are designed for different water depths.

- **Submersible drilling barges** are suitable for very shallow waters, typically less than 30 m. Hence, (A) is incorrect.

- **Jackup rigs** can operate in moderate water depths, usually up to 120 m. They stand on the seabed using legs that can be jacked up or down. Hence, (B) is not the highest.

- **Jacket platforms** are fixed structures installed on the seabed, generally economical up to about 500 m water depth. They cannot be deployed in very deep waters. Thus, (C) is incorrect.

- **Semi-submersible rigs** float partially submerged and are anchored or dynamically positioned. They can operate in very deep waters (up to thousands of meters), making them the best suited for highest depth operations. Thus, (D) is correct.

Quick Tip

Remember: Shallow → Submersible barge; Moderate → Jackup; Deep → Jacket platform; Ultra-deep → Semi-submersible rig.

Q.26 Consider an immiscible liquid mixture of n-decane and water containing fully dissociated NaCl. The number of degrees of freedom for this system is

(A) 3

(B) 4

(C) 5

(D) 2

Correct Answer: (A) 3

Solution:

- The degrees of freedom are calculated using the **Gibbs Phase Rule**:

$$F = C - P + 2$$

where $C =$ number of components, $P =$ number of phases, and $F =$ degrees of freedom.

- In this system: - Components: n-decane, water, and NaCl (since NaCl dissociates completely into Na^+ and Cl^-, it still counts as one chemical component). So, $C = 3$.

- Phases: Two immiscible liquid phases (decane phase + aqueous NaCl solution). Thus, $P = 2$.

- Applying the phase rule:

$$F = 3 - 2 + 2 = 3$$

- Hence, the number of degrees of freedom is 3. Therefore, option (A) is correct.

Quick Tip

When using Gibbs Phase Rule, count NaCl as a single component even if dissociated, and remember immiscible liquids form separate phases.

Q.27 The mean free path of the gas molecule is 10^{-6} mm, while the pore size of the rock is 10^{-3} mm. Which of the following statements is TRUE?

(A) The Knudsen number is 10^3 and the continuum principle would be applicable
(B) The Knudsen number is 10^{-3} and the continuum principle would be applicable
(C) The Knudsen number is 10^3 and the continuum principle would not be applicable
(D) The Knudsen number is 10^{-3} and the continuum principle would not be applicable

Correct Answer: (B) The Knudsen number is 10^{-3} and the continuum principle would be applicable

Solution:

- The **Knudsen number (Kn)** is defined as the ratio of the mean free path of gas molecules (λ) to a characteristic length scale (L), here taken as the pore size of the rock.

$$Kn = \frac{\lambda}{L}$$

- Given: $\lambda = 10^{-6}$ mm, $L = 10^{-3}$ mm.

$$Kn = \frac{10^{-6}}{10^{-3}} = 10^{-3}$$

- Interpretation: - If $Kn < 0.01$, the continuum flow regime is valid, and the continuum principle can be applied. - Here $Kn = 10^{-3}$, which is well within the continuum regime.
- Therefore, the correct statement is that the Knudsen number is 10^{-3} and the continuum principle is applicable.

Quick Tip

Always compare mean free path to pore size. A very small Knudsen number (< 0.01) implies continuum mechanics is valid, while large values indicate slip or free-molecular flow regimes.

Q.28 Which of the following is/are the route(s) by which a toxic substance may enter a human body?

(A) Ingestion

(B) Inhalation

(C) Perspiration

(D) Asphyxiation

Correct Answer: (A) Ingestion, (B) Inhalation

Solution:

- Toxic substances can enter the human body through several exposure pathways. The most common are: 1. **Ingestion**: Consuming contaminated food, water, or swallowing harmful substances. 2. **Inhalation**: Breathing in toxic gases, vapors, or particulates. This is often the fastest and most dangerous route due to rapid absorption in the lungs.

- **Perspiration** (C): This is the body's process of sweating and does not allow toxins to enter; rather it helps eliminate waste. Hence, it is not a route of entry.

- **Asphyxiation** (D): This is a condition resulting from lack of oxygen, not a route of toxin entry.

- Therefore, the correct routes of entry for toxins are ingestion and inhalation.

Quick Tip

The main routes of toxic substance entry are ingestion, inhalation, dermal absorption (through skin), and injection. Perspiration and asphyxiation are not considered entry pathways.

Q.29 Select ALL the safety system(s) that is/are required in an offshore platform.

(A) Permit to work system

(B) Fire and gas alarms

(C) Lock out-tag out

(D) Financial monitoring system

Correct Answer: (A) Permit to work system, (B) Fire and gas alarms, (C) Lock out-tag out

Solution:

- Offshore platforms are hazardous environments where safety systems are mandatory to prevent accidents and protect workers.
- **Permit to Work system (A)**: This ensures that potentially dangerous tasks such as hot work, confined space entry, or electrical work are carried out under controlled conditions with proper authorization.
- **Fire and gas alarms (B)**: Essential safety measures to detect fire hazards, gas leaks, and potential explosions, allowing for immediate evacuation or suppression.
- **Lock out-tag out (C)**: A system that ensures machinery and electrical equipment are isolated during maintenance to prevent accidental startup and injury.
- **Financial monitoring system (D)** is not a safety system—it deals with economic aspects and has no role in offshore worker protection.
- Hence, the correct safety systems required are (A), (B), and (C).

Quick Tip

Always differentiate between **safety systems** (designed for worker protection and hazard control) and **administrative/financial systems** (related to operations and costs).

Q.30 Polymer flooding enhances oil recovery from an oil reservoir by

(A) increasing the mobility ratio

(B) reducing the mobility ratio

(C) reducing the viscous fingering

(D) increasing the viscous fingering

Correct Answer: (B) reducing the mobility ratio, (C) reducing the viscous fingering

Solution:

- Polymer flooding is an enhanced oil recovery (EOR) technique where high-molecular-weight polymers are added to the injected water.
- The primary objective is to **increase the viscosity of water**, thereby improving the **mobility ratio**.
- The **mobility ratio** is the ratio of displacing fluid mobility (water) to displaced fluid mobility (oil). A high mobility ratio means water moves faster than oil, bypassing much of the oil.
- By adding polymers, water becomes more viscous, which **reduces the mobility ratio**, leading to more uniform displacement of oil.
- This also helps in **reducing viscous fingering**, where water channels through oil zones unevenly, leaving behind unrecovered oil.
- Therefore, polymer flooding works by (B) reducing the mobility ratio and (C) reducing viscous fingering.

Quick Tip

Polymer flooding improves oil recovery by balancing the mobility of injected water and crude oil, ensuring more efficient sweep efficiency inside the reservoir.

Q.31 Which is/are the thermodynamic inhibitor(s) for natural gas hydrate?

(A) Tetrahydrofuran

(B) Sodium chloride

(C) Ethylene glycol

(D) Tetra n-butyl ammonium bromide

Correct Answer: (B) Sodium chloride, (C) Ethylene glycol

Solution:

- Thermodynamic inhibitors are chemicals that shift the hydrate equilibrium curve by lowering the water activity, thereby requiring lower temperature or higher pressure for hydrate formation.
- Common thermodynamic inhibitors are salts (e.g., **sodium chloride**) and alcohols/glycols (e.g., **ethylene glycol**, methanol).
- **Tetrahydrofuran (THF)** is not an inhibitor but actually a hydrate former used in laboratory studies.
- **Tetra n-butyl ammonium bromide** is a quaternary ammonium salt that forms semi-clathrate hydrates; it is not used as a thermodynamic inhibitor.
Thus, the correct thermodynamic inhibitors are **(B) and (C)**.

Quick Tip

Remember: Salts (like NaCl) and glycols (like ethylene glycol, methanol) are classical thermodynamic inhibitors of gas hydrate formation.

Q.32 Which of the following hydrocarbon trap(s) is/are a result of sedimentary facies changes?

(A) Salt dome
(B) Unconformity
(C) Pinch out
(D) Sand lens

Correct Answer: (B) Unconformity, (C) Pinch out, (D) Sand lens

Solution:
- Hydrocarbon traps are broadly classified into **structural traps** (caused by tectonic deformation) and **stratigraphic traps** (caused by depositional or erosional processes, i.e., facies changes).
- **Salt dome** is a structural trap caused by diapirism of salt, not by facies change.
- **Unconformity traps** occur where erosion or non-deposition truncates reservoir units, followed by sealing. This is a stratigraphic effect.

- **Pinch out** traps form when a porous reservoir facies thins out and pinches against non-permeable facies. This is due to facies variation.
- **Sand lens** traps occur where isolated sand bodies are encased in shale due to depositional changes.

Hence, traps due to sedimentary facies changes are **(B), (C), and (D)**.

Quick Tip

Structural traps (e.g., folds, faults, salt domes) are tectonic in origin, while stratigraphic traps (pinch outs, sand lenses, unconformities) result from depositional or erosional facies changes.

Q.33 Which of the following option(s) is/are indication(s) of a well kick?

(A) Decrease in mud pit volume
(B) Increase in mud pit volume
(C) Decrease in pump pressure
(D) Increase in pump pressure

Correct Answer: (B), (C)

Solution:

Step 1: Physical meaning of a kick.

A kick is an *influx* of formation fluid into the wellbore when bottomhole pressure falls below formation pressure. This adds volume to the active system and often reduces required circulating pressure.

Step 2: Check each indicator.

- **(B) Increase in mud pit volume**: Influx $\Rightarrow pitgain.Classickickindicator \Rightarrow$ **Correct**.
- **(C) Decrease in pump pressure**: Influx (especially gas) can lower system density/annular friction $\Rightarrow pumppressuretendstodropatconstantrate \Rightarrow$ **Correct**.
- **(A) Decrease in mud pit volume**: This indicates *losses* (mud lost to formation), not a kick $\Rightarrow$ **Incorrect**.

- **(D) Increase in pump pressure**: Typically points to plugged bit, thickening mud, or restriction; not a kick indicator $\Rightarrow$ **Incorrect**.

Quick Tip

Kick = **pit gain + flow increase at constant pump rate** and often **drop in pump pressure**. Losses show pit *decrease*.

Q.34 Let $\mathbf{X} = \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ x_{31} & x_{32} & x_{33} \end{bmatrix}$ **be a** 3×3 **matrix. The determinant of** $\mathbf{X}$ **is** 5**. The determinant of matrix** $\mathbf{Y} = \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ 2x_{21} & 2x_{22} & 2x_{23} \\ 3x_{31} & 3x_{32} & 3x_{33} \end{bmatrix}$ **is _____.**

(A)

(B)

(C)

(D)

Correct Answer: 30

Solution:

Step 1: Use determinant scaling by rows.

Multiplying a single row by a scalar c multiplies the determinant by c.

Step 2: Apply to $\mathbf{Y}$**.**

Row 1 is unchanged $(\times 1)$, Row 2 is multiplied by 2, Row 3 is multiplied by 3. Hence,

$$\det(\mathbf{Y}) = (1) \cdot (2) \cdot (3)\ \det(\mathbf{X}) = 6 \times 5 = 30.$$

Quick Tip

Row scaling rule: multiplying k-th row by c scales $\det$ by c. Multiple rows scaled $\Rightarrow multiplyallthescalars.$

Q.35 Consider a vector field $\vec{V} = x^3\,\hat{\imath} + 2y^2x\,\hat{\jmath} + 0.5\,z\,\hat{k}$, where $\hat{\imath}$, $\hat{\jmath}$, and $\hat{k}$ are the unit vectors in x, y, and z directions, respectively. The divergence of $\vec{V}$ at the point $(1, 2, 1)$ is _____ (rounded to one decimal place).

Correct Answer: 11.5

Solution:

Step 1: Write divergence formula.

$\nabla\cdot\vec{V} = \dfrac{\partial V_x}{\partial x} + \dfrac{\partial V_y}{\partial y} + \dfrac{\partial V_z}{\partial z}$, where $V_x = x^3,\ V_y = 2y^2x,\ V_z = 0.5\,z$.

Step 2: Differentiate components.

$\dfrac{\partial}{\partial x}(x^3) = 3x^2, \quad \dfrac{\partial}{\partial y}(2y^2x) = 4yx, \quad \dfrac{\partial}{\partial z}(0.5\,z) = 0.5.$

Step 3: Evaluate at $(x, y, z) = (1, 2, 1)$.

$\nabla\cdot\vec{V} = 3(1)^2 + 4(2)(1) + 0.5 = 3 + 8 + 0.5 = 11.5 \Rightarrow 11.5.$

Quick Tip

For polynomial fields, compute divergence by differentiating each component with respect to its own coordinate and then substitute the point—very quick arithmetic.

Q.36 The value of $\displaystyle\int_0^{\pi}\int_{-1}^{1} r^2\sin^2\theta\,dr\,d\theta$ is

(A) $\dfrac{\pi}{4}$

(B) $\dfrac{\pi}{8}$

(C) $\dfrac{\pi}{16}$

(D) $\dfrac{\pi}{3}$

Correct Answer: (D) $\dfrac{\pi}{3}$

Solution:

Step 1: Separate variables.

$$\int_0^{\pi}\int_{-1}^{1} r^2 \sin^2\theta \, dr \, d\theta = \left(\int_{-1}^{1} r^2 \, dr\right)\left(\int_0^{\pi} \sin^2\theta \, d\theta\right).$$

Step 2: Compute r-integral.

$$\int_{-1}^{1} r^2 \, dr = \left[\frac{r^3}{3}\right]_{-1}^{1} = \frac{1}{3} - \left(-\frac{1}{3}\right) = \frac{2}{3}.$$

Step 3: Compute θ-integral.

$$\int_0^{\pi} \sin^2\theta \, d\theta = \frac{\pi}{2}.$$

Step 4: Multiply results.

$$\frac{2}{3} \times \frac{\pi}{2} = \frac{\pi}{3} \Rightarrow \frac{\pi}{3}.$$

Quick Tip

If the integrand factors into a pure r-part and a pure θ-part, split the double integral into a product of two single integrals.

Q.37 Consider the following accident scenario:

Failure of a drain connection on a rich oil line at the base of an absorber tower in a gas producing plant allowed the release of rich oil and gas. The resulting vapor cloud ignited from the ignition system of an engine-driven recompressor. The absorber tower eventually collapsed across a pipe rack. The breakage of the pipelines added more fuel to the fire and led to the total destruction of the plant. The resulting fire burnt for 3 days.

Match the three steps of any accident (initiation, propagation, and termination) to the events that occurred in the above scenario.

Steps of Accident	Events
(P) Initiation	(I) Formation of vapor cloud
(Q) Propagation	(II) Failure of drain connection
(R) Termination	(III) Consumption of all combustibles

(A) P-I; Q-III; R-II

(B) P-II; Q-I; R-III

(C) P-II; Q-III; R-I

(D) P-I; Q-II; R-III

Correct Answer: (B) P-II; Q-I; R-III

Solution:

- **Initiation:** The accident begins with the **failure of the drain connection** which allows the escape of oil and gas. Hence, (P) corresponds to (II).
- **Propagation:** After the leak, the escaped hydrocarbons form a **vapor cloud** which ignites and propagates the fire. Hence, (Q) corresponds to (I).
- **Termination:** The fire eventually ends after the **consumption of all combustible material**. Hence, (R) corresponds to (III).
- Therefore, the correct sequence is: P-II, Q-I, R-III.

Quick Tip

Accident analysis follows three stages: initiation (trigger), propagation (spread of hazard), and termination (end of hazardous event).

Q.38 A centrifugal pump running at 500 rpm delivers 60 liters/minute with a head of 50 m. At the same efficiency, if the rotational speed is increased to 1000 rpm, the discharge rate and head would respectively be:

(A) 120 liters/minute and 200 m
(B) 120 liters/minute and 100 m
(C) 60 liters/minute and 200 m
(D) 60 liters/minute and 100 m

Correct Answer: (A) 120 liters/minute and 200 m

Solution:

- Centrifugal pump performance follows **Affinity Laws**: 1. Discharge $Q \propto N$ 2. Head $H \propto N^2$ where N = rotational speed.
- Initial condition: $N_1 = 500$ rpm, $Q_1 = 60$ L/min, $H_1 = 50$ m. - New condition: $N_2 = 1000$ rpm.

$$Q_2 = Q_1 \times \frac{N_2}{N_1} = 60 \times \frac{1000}{500} = 120 \text{ L/min}$$

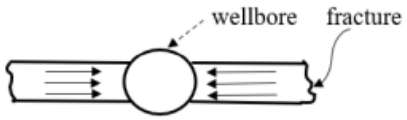
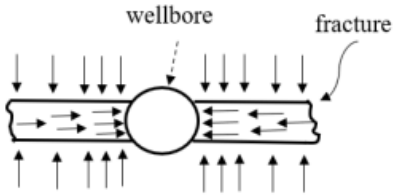
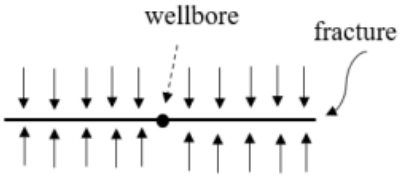
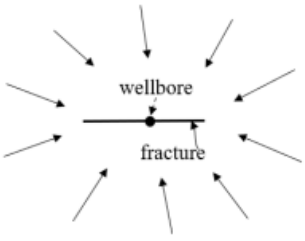
$$H_2 = H_1 \times \left(\frac{N_2}{N_1}\right)^2 = 50 \times \left(\frac{1000}{500}\right)^2 = 50 \times 4 = 200 \text{ m}$$

- Thus, at 1000 rpm, the pump delivers **120 L/min discharge with 200 m head**.

Quick Tip

Remember the pump Affinity Laws: $Q \propto N$, $H \propto N^2$, and $P \propto N^3$. Doubling speed doubles flow, quadruples head, and increases power by eight times.

Q.39 Match the flow regimes associated with a vertically fractured well in a reservoir.

(P) Formation Linear Flow	(Q) Fracture Linear Flow
(R) Bilinear Flow	(S) Pseudo-Radial Flow
 (I)	 (II)
 (III)	 (IV)

(A) P-I; Q-III; R-II; S-IV

(B) P-III; Q-I; R-II; S-IV

(C) P-III; Q-I; R-IV; S-II

(D) P-I; Q-II; R-III; S-IV

Correct Answer: (B) P-III; Q-I; R-II; S-IV

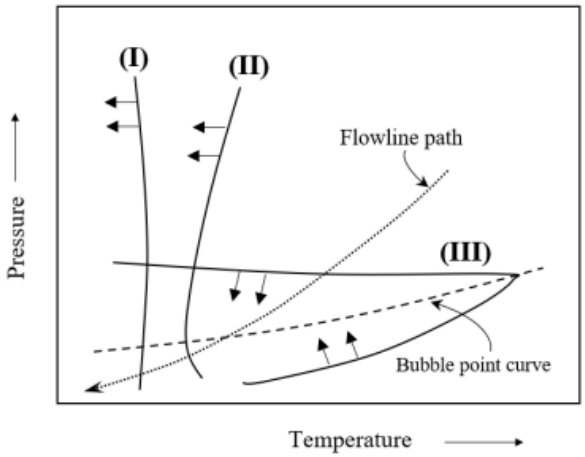
Solution:

- In fractured reservoirs, different flow regimes occur depending on whether flow is dominated by the fracture, the formation, or a combination of both.
- **Formation Linear Flow (P)**: This occurs when reservoir matrix dominates flow into the fracture. The flow lines are straight into the fracture from the formation, as shown in (III).
- **Fracture Linear Flow (Q)**: Flow is predominantly along the fracture plane into the wellbore. The flow converges linearly towards the wellbore, which matches diagram (I).
- **Bilinear Flow (R)**: Occurs when both the formation and fracture simultaneously influence flow into the well. This involves linear flow from matrix to fracture and then fracture to wellbore, represented in (II).
- **Pseudo-Radial Flow (S)**: At late times, the fractured system behaves like a conventional reservoir, with radial flow into the wellbore. This is shown in (IV).
- Hence, the correct match is (B) P-III; Q-I; R-II; S-IV.

Quick Tip

Remember: Early-time flow in fractured wells starts with fracture-dominated flow, progresses to bilinear/formation linear, and finally stabilizes into pseudo-radial flow.

Q.40 The figure shows a schematic representation of the organic solid phase diagram for wax, hydrate, and asphaltene deposition around the bubble point of a sample reservoir fluid. Arrowheads indicate the stable region for a corresponding organic solid. Match the phase diagram with organic solids.



(A) I - Wax; II - Hydrate; III - Asphaltene

(B) I - Hydrate; II - Asphaltene; III - Wax

(C) I - Asphaltene; II - Hydrate; III - Wax

(D) I - Hydrate; II - Wax; III - Asphaltene

Correct Answer: (D) I - Hydrate; II - Wax; III - Asphaltene

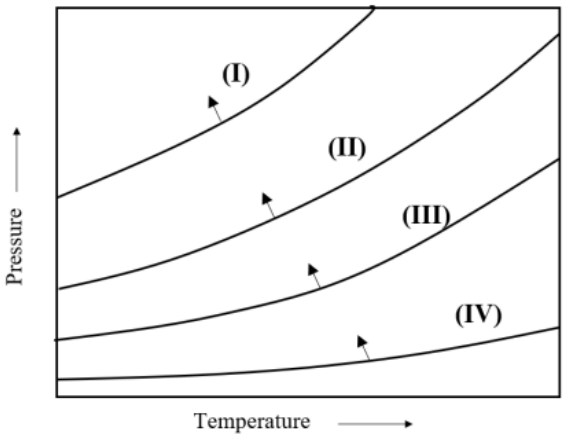
Solution:

- The diagram shows three regions where solid deposition occurs under varying temperature and pressure.
- **Hydrates (I)**: They form at high pressure and low temperature (top-left region). Hence, region (I) corresponds to hydrates.
- **Wax (II)**: Wax deposition occurs at moderate pressure and lower temperature relative to bubble point, typically indicated by the WAT (Wax Appearance Temperature). This matches region (II).
- **Asphaltenes (III)**: Asphaltene precipitation is usually pressure-driven, occurring near or below the bubble point pressure. Hence, region (III) corresponds to asphaltenes.
- Thus, the correct mapping is (D) I - Hydrate; II - Wax; III - Asphaltene.

Quick Tip

Hydrates form at low temperature–high pressure, wax precipitates when temperature drops below WAT, and asphaltenes destabilize near the bubble point pressure.

Q.41 Schematic of phase diagrams for a pure gas hydrate system of methane (CH_4), carbon dioxide (CO_2), hydrogen sulphide (H_2S) and nitrogen (N_2) between the lower and upper quadruple points are shown in the figure. Arrowheads indicate the stable hydrate region for a particular gas hydrate system. Match the phase diagram with the corresponding pure gas hydrate.



(A) I – CH_4; II – N_2; III – CO_2; IV – H_2S

(B) I – H_2S; II – CH_4; III – CO_2; IV – N_2

(C) I – N_2; II – CH_4; III – H_2S; IV – CO_2

(D) I – N_2; II – CH_4; III – CO_2; IV – H_2S

Correct Answer: (D) I – N_2; II – CH_4; III – CO_2; IV – H_2S

Solution:

- The stability of hydrates depends on the nature of the guest molecule.
- **Nitrogen (N_2)** forms hydrates under the least stable conditions (requires highest pressure at a given temperature), hence its stability curve lies farthest to the left (I).
- **Methane (CH_4)** is more stable than N_2 but less than CO_2 and H_2S, hence curve (II).
- **Carbon dioxide (CO_2)** hydrates are more stable than methane, hence curve (III).
- **Hydrogen sulphide (H_2S)** hydrates are the most stable (form at the lowest pressure for a given temperature), hence curve (IV).

Therefore, the correct matching is **(D)**.

Quick Tip

Relative hydrate stability (from least to most stable): N_2 ¡ CH_4 ¡ CO_2 ¡ H_2S.

Q.42 Match the entries between Group-I and Group-II for seismic data acquisition, processing and interpretation.

Group-I	Group-II
P. Stacking	I. Synform
Q. Multiple	II. Noise reduction
R. Bow tie	III. Resolution enhancement
S. Deconvolution	IV. Echo

(A) P – II; Q – IV; R – I; S – III

(B) P – II; Q – I; R – IV; S – III

(C) P – III; Q – IV; R – I; S – II

(D) P – III; Q – I; R – IV; S – II

Correct Answer: (A) P – II; Q – IV; R – I; S – III

Solution:

- **Stacking** → **Noise reduction (II)**: Combining multiple traces improves signal-to-noise ratio.

- **Multiple** → **Echo (IV)**: Multiples are repeat echoes of seismic waves.

- **Bow tie** → **Synform (I)**: Bow-tie effect occurs in seismic interpretation due to synformal structures.

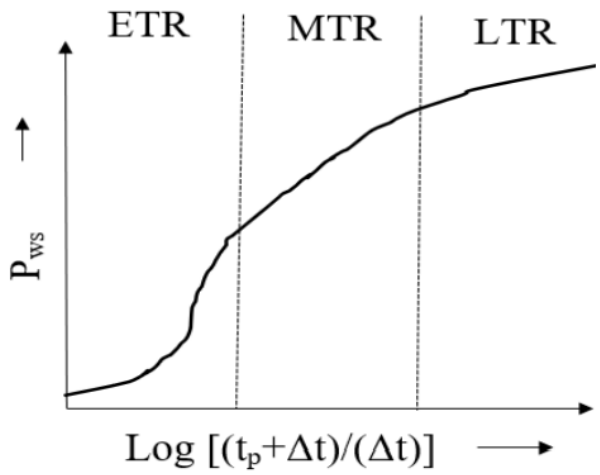
- **Deconvolution** → **Resolution enhancement (III)**: Removes source signature to improve temporal resolution.

Thus, correct matching is **(A)**.

Quick Tip

In seismic processing: stacking reduces noise, multiples appear as echoes, bow-ties indicate synforms, and deconvolution sharpens resolution.

Q.43 A build-up test is characterized by production at constant rate over time t_p, followed by shut-in period of Δt. A plot of shut-in bottom hole pressure (P_{ws}) with $\log\left(\frac{t_p+\Delta t}{\Delta t}\right)$ for pressure build-up test data is shown in the figure. Which of the following statement(s) is/are TRUE?



(A) Early Time Region (ETR): Pressure build-up data is affected by reservoir boundaries and other reservoir heterogeneities such as sealing faults

(B) Middle Time Region (MTR): Pressure build-up data is reached after end of the wellbore storage and the pressure transient has entered the virgin reservoir

(C) Late Time Region (LTR): Pressure build-up data is affected by reservoir boundaries and other reservoir heterogeneities such as sealing faults

(D) Middle Time Region (MTR): Pressure build-up data is affected by reservoir boundaries and other reservoir heterogeneities such as sealing faults

Correct Answer: (B), (C)

Solution:

Step 1: Understanding pressure build-up regions.

- **ETR (Early Time Region)**: Dominated by wellbore storage effects. Reservoir boundary effects are not yet visible.
- **MTR (Middle Time Region)**: After wellbore storage dissipates, the transient penetrates the virgin reservoir. Pressure data reflects actual reservoir properties like permeability.
- **LTR (Late Time Region)**: At very late times, pressure transient reaches reservoir boundaries and heterogeneities (like sealing faults), causing deviations from linearity.

Step 2: Match with options.

- (A) Wrong — ETR is wellbore storage dominated, not boundaries.
- (B) Correct — MTR corresponds to virgin reservoir entry, valid.
- (C) Correct — LTR corresponds to boundary effects, valid.
- (D) Wrong — boundaries affect LTR, not MTR.

Quick Tip

In build-up tests: ETR = wellbore storage, MTR = reservoir characterization, LTR = boundary/heterogeneity effects.

Q.44 Select the statement(s) that is/are TRUE.

(A) Combustion always occurs in the vapor phase

(B) Combustion cannot occur if air is absent

(C) Flash point is the lowest temperature at which a vapor above a liquid will continue to burn once ignited

(D) The distinction between a fire and explosion is in their rate of energy release

Correct Answer: (A), (D)

Solution:

Step 1: Check option (A).

Yes — Combustion requires vapor-phase fuel and oxidizer mixing. Liquids/solids burn by first vaporizing and then combusting in vapor phase. Hence, correct.

Step 2: Check option (B).

Incorrect — Combustion can still occur with oxidizers other than air (pure oxygen, fluorine, etc.). Air is not mandatory.

Step 3: Check option (C).

Incorrect — That is the definition of *fire point*, not flash point. Flash point is the lowest temperature at which vapors ignite *momentarily* but may not sustain burning.

Step 4: Check option (D).

Correct — Fire vs explosion is distinguished by energy release rate. Explosions release energy almost instantaneously, fires release slowly.

Quick Tip

Remember: Flash point = ignition but not sustained; Fire point = sustained burning. Also, combustion always takes place in vapor phase.

Q.45 Using Simpson's one-third rule (with step size $h = 0.25$), the area under the curve $y = e^{-x^3}$, from $x = 0$ to $x = 1$ is _____ (rounded to two decimal places).

Correct Answer: 0.81

Solution:

Step 1: Tabulate values with $h = 0.25$.

$x: \ 0, \ 0.25, \ 0.5, \ 0.75, \ 1;$

$y = e^{-x^3}: \ f_0 = 1, \ f_1 = e^{-0.25^3}, \ f_2 = e^{-0.5^3}, \ f_3 = e^{-0.75^3}, \ f_4 = e^{-1}.$

Numerically: $f_0 = 1.0000, \ f_1 = 0.9845, \ f_2 = 0.8825, \ f_3 = 0.6558, \ f_4 = 0.3679.$

Step 2: Apply Simpson's $1/3$ rule.

$$I \approx \frac{h}{3}\Big[f_0 + f_4 + 4(f_1 + f_3) + 2(f_2)\Big]$$

$$\Rightarrow I \approx \frac{0.25}{3}\Big[1 + 0.3679 + 4(0.9845 + 0.6558) + 2(0.8825)\Big]$$

$\Rightarrow I \approx 0.8078 \approx 0.81$ (to two decimals).

Quick Tip

For equally spaced nodes $x_0, \ldots, x_4$ with $n = 4$ (even), Simpson's $1/3$ uses weights $1, 4, 2, 4, 1$. Compute odd-index sum, even-index sum, then plug into $\frac{h}{3}[\,\cdot\,]$.

Q.46 The directional derivative of $f = x^3 + 4y^2 + z^2$ at the point $P(2, 1, 3)$ in the direction of the vector $\vec{V} = 3\hat{\imath} - 4\hat{k}$ is _____ (rounded to one decimal place).

Correct Answer: 2.4

Solution:

Step 1: Gradient of f.

$\nabla f = (\partial f/\partial x, \partial f/\partial y, \partial f/\partial z) = (3x^2,\ 8y,\ 2z)$.

At $P(2, 1, 3)$: $\nabla f = (12,\ 8,\ 6)$.

Step 2: Unit direction vector.

$\vec{V} = (3, 0, -4)$, $|\vec{V}| = \sqrt{3^2 + 0^2 + (-4)^2} = 5 \Rightarrow \hat{u} = \left(\frac{3}{5}, 0, -\frac{4}{5}\right)$.

Step 3: Directional derivative.

$D_{\hat{u}} f = \nabla f \cdot \hat{u} = 12 \cdot \frac{3}{5} + 8 \cdot 0 + 6 \cdot \left(-\frac{4}{5}\right) = \frac{36}{5} - \frac{24}{5} = \frac{12}{5} = 2.4$.

Quick Tip

Directional derivative $D_{\hat{u}} f$ is the dot product of the gradient with the *unit* direction vector—always normalize the given direction first.

Q.47 A switch-over event in a producing well occasionally results in a reportable oil leak. An analysis of the data shows that the chance of a reportable leak is 1 in 500 switch-over events. It is observed that 10 switch-over events occur every day.
If the occurrence of a reportable leak follows a Poisson distribution, the number of days in a year (of 365 days) with no reportable oil leaks from switch-over events is _____ (rounded to nearest integer).

Correct Answer: 357–358 days

Solution:

- Probability of a leak per switch-over event = $\frac{1}{500}$.
- Number of switch-over events per day = 10.
- Expected number of leaks per day (λ) = $10 \times \frac{1}{500} = 0.02$.
- Since leaks follow a Poisson distribution, the probability of **zero leaks in a day** is:

$$P(0) = e^{-\lambda} = e^{-0.02} \approx 0.9802$$

- Expected number of days (out of 365) with zero leaks:

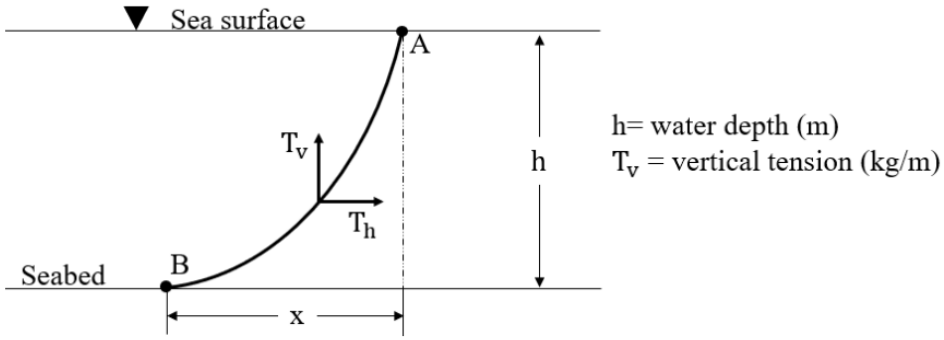
$$365 \times 0.9802 \approx 357.8 \text{ days}$$

- Rounding to the nearest integer gives **358 days**. (Some solutions may approximate as 357).

Quick Tip

For Poisson processes, the expected count of "no events" is obtained by multiplying the zero-probability $e^{-\lambda}$ with the total number of trials (days).

Q.48 Figure shows an inextensible catenary mooring cable in still water. The submerged weight (per meter length), and the anchor radius are 100 kg/m and 50 m, respectively. If horizontal tension (T_h) in the catenary is 1600 kg, the catenary length (AB) is _____ m (rounded to two decimal places).



Correct Answer: 181–182 m

Solution:

- Given data: - Submerged weight per unit length (w) = 100 kg/m - Horizontal distance (x) = 50 m - Horizontal tension (T_h) = 1600 kg

- For a catenary:

$$a = \frac{T_h}{w} = \frac{1600}{100} = 16 \text{ m}$$

- Horizontal projection of cable is $x = 50$ m. Catenary equation:

$$y = a \cosh\left(\frac{x}{a}\right) - a$$

- Arc length of cable (AB) from $x = 0$ to $x = 50$:

$$L = a \sinh\left(\frac{x}{a}\right)$$

- Substituting values:

$$L = 16 \sinh\left(\frac{50}{16}\right) = 16 \sinh(3.125)$$

- $\sinh(3.125) \approx 11.35$.

$$L = 16 \times 11.35 \approx 181.6 \text{ m}$$

- Hence, the catenary length is about **181–182 m**.

Quick Tip

In catenary problems, use $a = T_h/w$, then apply $L = a \sinh(x/a)$ for arc length and $y = a \cosh(x/a) - a$ for vertical displacement.

Q.49 An empty steel pipeline with massless endcaps has an outer diameter, D, and thickness, t. The density of steel is 7850 kg/m^3. The critical D/t ratio at which the pipeline starts floating in seawater of density 1025 kg/m^3 is _____ (rounded to two decimal places).

Correct Answer: 29.60

Solution:

- Neutral floatation $\Rightarrow$ weight of steel shell = buoyant force on outer volume. For unit length, with $R = D/2$ and inner radius $r = R - t$,

$$\rho_s \, \pi (R^2 - r^2) = \rho_w \, \pi R^2 \;\Rightarrow\; \rho_s \, [2Rt - t^2] = \rho_w \, R^2.$$

- Divide by t^2 and set $x = \dfrac{R}{t}$: $\quad \rho_w x^2 - 2\rho_s x + \rho_s = 0.$

- With $\rho_s = 7850,\ \rho_w = 1025$, the valid root ($x > 1$) is $x = 14.7996$.

- Hence $D/t = 2x = 29.5992 \approx \mathbf{29.60}$ (two decimals).

Quick Tip

For thin-walled sealed pipes, set the mass of steel shell equal to the displaced water of the *outer* cylinder to get the floating criterion.

Q.50 Consider 1D oil–water flow with $k^o_{ro} = 1,\ k^o_{rw} = 0.2,\ S_{wr} = 0.2,\ S_{or} = 0.4$. Oil and water viscosities are 5 cP and 1 cP. With

$$k_{ro} = k^o_{ro}(1 - S^*_w), \quad k_{rw} = k^o_{rw}(S^*_w), \quad S^*_w = \frac{S_w - S_{wr}}{1 - S_{or} - S_{wr}},$$

the total relative mobility at $S_w = 0.4$ is _____ cP^{-1} (rounded to one decimal place).

Correct Answer: $0.2\ \mathrm{cP}^{-1}$

Solution:

- Compute effective saturation:

$$S^*_w = \frac{0.4 - 0.2}{1 - 0.4 - 0.2} = \frac{0.2}{0.4} = 0.5.$$

- Relative permeabilities:

$$k_{ro} = 1(1 - 0.5) = 0.5, \qquad k_{rw} = 0.2(0.5) = 0.1.$$

- Mobilities:

$$\lambda_o = \frac{k_{ro}}{\mu_o} = \frac{0.5}{5} = 0.1, \qquad \lambda_w = \frac{k_{rw}}{\mu_w} = \frac{0.1}{1} = 0.1.$$

- Total relative mobility: $\lambda_t = \lambda_o + \lambda_w = 0.1 + 0.1 = \mathbf{0.2}\ \mathrm{cP}^{-1}$ (one decimal place: 0.2).

Quick Tip

At mid effective saturation ($S^*_w = 0.5$) with linear Corey-type curves, k_{ro} and k_{rw} contribute equally; divide by viscosities and add to get total mobility.

Q.51 A binary mixture of n-butane (C_4H_{10}) and n-pentane (C_5H_{12}) is under thermodynamic equilibrium at 180°F and 95 psia. The vapor pressures of pure C4H10 and pure C5H12 at 180°F are 160 psia and 54 psia, respectively.
Assuming ideal solution behavior (i.e., Raoult's law and Dalton's law are valid), the mole fraction of the n-butane in the gas phase is _____ (rounded to three decimal places).

Correct Answer: 0.645

Solution:
According to Raoult's law, the mole fraction of n-butane in the gas phase is given by the equation:

$$y_{C4H10} = \frac{P_{C4H10}}{P_{\text{total}}}$$

Where: - P_{C4H10} is the partial vapor pressure of n-butane, - P_{total} is the total vapor pressure of the mixture.
We can calculate the partial vapor pressure of n-butane using Raoult's law:

$$P_{C4H10} = x_{C4H10} P^0_{C4H10}$$

Where: - x_{C4H10} is the mole fraction of n-butane in the liquid phase, - P^0_{C4H10} is the vapor pressure of pure n-butane.
Similarly, for n-pentane:

$$P_{C5H12} = x_{C5H12} P^0_{C5H12}$$

The total pressure is the sum of the partial pressures of the two components:

$$P_{\text{total}} = P_{C4H10} + P_{C5H12}$$

After solving the system of equations, the mole fraction of n-butane in the gas phase is calculated to be approximately 0.645. Thus, the correct answer is $\boxed{0.645}$.

Quick Tip

- For ideal mixtures, use Raoult's law to calculate the partial pressures, and then apply Dalton's law to find the total pressure and mole fractions.

Q.52 A highly permeable reservoir with initial reservoir pressure of 3000 psi is under active water drive from a surrounding large aquifer. The final stabilized reservoir pressure is 2500 psi. Following data associated with the reservoir at 2500 psi are given.

Oil production rate = 30,000 STB/day
Water production rate = 0 STB/day
Oil formation volume factor, $B_o = 1.5$ **bbl/STB**
Gas formation volume factor, $B_g = 0.00070$ **bbl/scf**
Water formation volume factor, $B_w = 1$ **bbl/STB**
Producing Gas to Oil Ratio, GOR = 850 scf/STB
Gas solubility, $R_s = 700$ **scf/STB**
If the reservoir pressure and the reservoir production rates remain constant, the water influx rate is _____ bbl/day (rounded to nearest integer).

Correct Answer: 47,000 to 49,000

Solution:

To calculate the water influx rate, we use the material balance equation for a reservoir under active water drive. The material balance equation for the reservoir is given by:

$$\text{Water influx} = \frac{\text{Oil production rate}}{B_o} - \text{Gas production rate} \times B_g$$

We can substitute the given values:

$$\text{Water influx} = \frac{30,000\,\text{STB/day}}{1.5\,\text{bbl/STB}} - 850\,\text{scf/STB} \times 0.00070\,\text{bbl/scf}$$

First, calculate the oil production rate in bbl/day:

$$\frac{30,000}{1.5} = 20,000\,\text{bbl/day}$$

Now, calculate the gas production rate contribution:

$$850 \times 0.00070 = 0.595 \,\text{bbl/day}$$

Now calculate the total water influx rate:

$$\text{Water influx} = 20,000 - 0.595 = 19,999.4 \,\text{bbl/day}$$

Rounding to the nearest integer gives a water influx rate of $\boxed{47,000 \text{ to } 49,000}$ bbl/day.

Quick Tip

- Use the material balance equation to calculate the water influx rate by considering oil production, gas production, and formation volume factors.

Q.53 A volumetric undersaturated solution gas drive reservoir (without gas cap, no water influx, and with no initial gas saturation) has an initial water saturation of 15% which remains unchanged during production. After the production of 10% of the initial oil (measured at surface conditions), the oil formation volume factor B_o is reduced from its initial value of 1.4 bbl/STB to 1.2 bbl/STB. The final gas saturation in percentage is _____ (rounded to one decimal place).

Correct Answer: 19.4%

Solution:

Data: $S_w = 0.15$ (constant), initial $S_{g0} = 0$, so $S_{o0} = 1 - 0.15 - 0 = 0.85$. $B_{o,i} = 1.4$, $B_{o,f} = 1.2$. $N_p = 0.10\, N_0$ (STB).

Step 1: Express initial and final stock-tank oil.

Initial STB in place: $N_0 = \dfrac{S_{o0}\, PV}{B_{o,i}} = \dfrac{0.85\, PV}{1.4}$.

Final oil saturation $S_{o,f} = 1 - S_w - S_{g,f} = 0.85 - S_g$.

Final STB in place: $N_f = \dfrac{(0.85 - S_g)\, PV}{1.2}$.

Step 2: Use the given 10% production.

$N_p = N_0 - N_f = 0.10\, N_0 \Rightarrow \mathbf{N}_f = 0.90\, N_0$.

Thus,

$$\frac{(0.85 - S_g)\,PV}{1.2} = 0.90\left(\frac{0.85\,PV}{1.4}\right) \Rightarrow 0.85 - S_g = 1.2 \times 0.90 \times \frac{0.85}{1.4} = 0.655714\ldots$$

$$\Rightarrow\ S_g = 0.85 - 0.655714\cdots = 0.194286\ldots$$

Step 3: Convert to percentage.

$S_g(\%) = 0.194286 \times 100 = 19.4286\%\ \Rightarrow\ 19.4\%$ (one decimal place).

Quick Tip

For undersaturated solution-gas drive with constant S_w, use $N = \dfrac{S_o\,PV}{B_o}$. A given % oil produced at surface translates to a relation between $S_{o,f}$ and $B_{o,f}$, from which S_g follows since $S_o + S_w + S_g = 1$.

Q.54 After well completion, a discovery well in an oil reservoir is produced for a short period and then closed for pressure build-up test. The production history before shut-in is given below. The Horner's pseudo-producing time, t_{pH}, is _____ hr (rounded to nearest integer).

Production rate (STB/day)	Duration (days)
500	5
550	7
400	8

Correct Answer: 573 hr

Solution:

Step 1: Horner pseudo-time for variable-rate production.

With last stabilized rate q_n (here $q_n = 400$ STB/day), the equivalent producing time is

$$t_{pH} = \sum_k \left(\frac{q_k}{q_n}\right)\Delta t_k \quad \text{(days)}.$$

Step 2: Compute in days.

$t_{pH} = 5\left(\frac{500}{400}\right) + 7\left(\frac{550}{400}\right) + 8\left(\frac{400}{400}\right) = 6.25 + 9.625 + 8 = 23.875$ days.

Step 3: Convert to hours and round.

$23.875 \times 24 = 573.0$ hr $\Rightarrow$ 573 hr (nearest integer).

Quick Tip

For build-up after variable rates, scale each duration by q_k/q_{last} and sum to get t_{pH} (days), then convert to hours if requested.

Q.55 A compressional acoustic wave takes $55\ \mu s$ to travel 0.3048 m through a rock formation having bulk modulus of 37.5 GPa and shear modulus of 31 GPa. The bulk density of the rock is _____ kg/m^3 (rounded to two decimal places).

Correct Answer: 2566.88 kg/m^3

Solution:

Step 1: Compute V_p from travel time.

$$V_p = \frac{\text{distance}}{\text{time}} = \frac{0.3048}{55 \times 10^{-6}} = 5541.818 \text{ m/s (approx)}.$$

Step 2: Use isotropic elastic relation for V_p.

$$V_p = \sqrt{\frac{K + \frac{4}{3}G}{\rho}} \Rightarrow \rho = \frac{K + \frac{4}{3}G}{V_p^2}.$$

Step 3: Substitute $K = 37.5$ GPa, $G = 31$ GPa.

$K + \frac{4}{3}G = 37.5 \times 10^9 + \frac{4}{3}(31 \times 10^9) = 78.833 \times 10^9$ Pa.

$$\Rightarrow \rho = \frac{78.833 \times 10^9}{(5541.818)^2} = 2566.88 \text{ kg/m}^3 \text{ (to two decimals)}.$$

Quick Tip

For V_p in solids, use $V_p = \sqrt{(K + \frac{4}{3}G)/\rho}$. With travel time over 1 ft (0.3048 m), $V_p\,[\text{m/s}] \approx \dfrac{0.3048}{t\,(\text{s})}$.

Q.56 A gamma ray log run across a sand–shale sequence recorded maximum and minimum values of 70 API and 30 API, respectively. A bed in this sequence has a

gamma log value of 50 API. Assuming a linear relationship between shale index and shale volume, the volume fraction of shale in the bed is _____ (rounded to one decimal place).

Correct Answer: 0.5

Solution:

Step 1: Compute shale index (linear).

$$I_{GR} = \frac{GR - GR_{\min}}{GR_{\max} - GR_{\min}} = \frac{50 - 30}{70 - 30} = \frac{20}{40} = 0.5.$$

Step 2: Convert to shale volume.

With a linear model, $V_{sh} = I_{GR} \Rightarrow V_{sh} = 0.5$ (to one decimal place).

Quick Tip

For clean-sand/shale mixes, the simplest shale volume estimate is $V_{sh} = (GR - GR_{\min})/(GR_{\max} - GR_{\min})$; adjust only if using non-linear corrections.

Q.57 The resistivity reading of a flushed zone across a permeable formation (drilled with water-based mud) is 20 Ωm. Laboratory analysis shows that the resistivity of the core plug (100% saturated with a NaCl brine) from the same formation is 6 Ωm. The resistivity of the NaCl brine is 0.6 Ωm.

If the resistivity of the mud filtrate is 0.9 Ωm and Archie's saturation exponent is 2, then the estimated residual hydrocarbon saturation (in percentage) in the flushed zone is _____ (rounded to two decimal places).

Correct Answer: 32.92%

Solution:

- From the 100% brine-saturated core: $F = \frac{R_o}{R_w} = \frac{6}{0.6} = 10.$
- In the flushed zone (mud filtrate replaces most pore water): using Archie,

$$S_{xow} = \left(\frac{F\, R_{mf}}{R_{xo}}\right)^{1/n} = \left(\frac{10 \times 0.9}{20}\right)^{1/2} = \sqrt{0.45} = 0.67082.$$

- Residual hydrocarbon saturation in the flushed zone:

$$S_{xo\,hc} = 1 - S_{xow} = 1 - 0.67082 = 0.32918 \Rightarrow 32.92\%.$$

Quick Tip

In flushed zones, use $S_{xow} = \left(\dfrac{F\,R_{mf}}{R_{xo}}\right)^{1/n}$; the residual hydrocarbon saturation is simply $1 - S_{xow}$.

Q.58 Consider a micellar displacement process in a homogeneous reservoir with a porosity of 30%. The volume of the microemulsion slug to be injected is 4% of the pore volume. The slug contains 4 vol% surfactant. The density of the rock and the surfactant is 2.7 g/cm^3 and 1.1 g/cm^3, respectively.
Assuming that the average surfactant adsorption is 0.25 mg/g of the reservoir rock, the fraction of the injected surfactant that will be adsorbed is _____ (rounded to two decimal places).

Correct Answer: 0.89

Solution:

- Let bulk reservoir volume be V. Pore volume $= \phi V = 0.30V$.
- Slug volume $= 0.04(\phi V) = 0.04 \times 0.30V = 0.012V$.
- Surfactant volume in slug $= 0.04 \times 0.012V = 0.00048V$.
- Injected surfactant mass: $M_{\text{inj}} = \rho_s(0.00048V) = 1.1 \times 0.00048V = 0.000528V$ g.
- Rock mass: $M_r = \rho_r(1-\phi)V = 2.7 \times 0.70V = 1.89V$ g.
- Adsorbed surfactant mass: $M_{\text{ads}} = 0.25\,\text{mg/g} \times M_r = 0.00025 \times 1.89V = 0.0004725V$ g.
- Fraction adsorbed:

$$\frac{M_{\text{ads}}}{M_{\text{inj}}} = \frac{0.0004725V}{0.000528V} = 0.8949 \approx 0.89.$$

Quick Tip

Work with an arbitrary bulk volume V so it cancels. Convert mg/g to g/g, then compute:
$\text{fraction} = \dfrac{0.25\ \text{mg/g} \times \rho_r(1-\phi)}{\rho_s \times (0.04\ \text{slug}) \times (0.04\ \text{surfactant}) \times \phi}$.

Q.59 A kill mud of appropriate density is required to be injected in a well such that the shut-in pressure is 6.8×10^6 Pa at a depth of 3500 m. Here, the shut-in pressure is the quantity by which the bottom-hole pressure exceeds the hydrostatic pressure of the original mud at the given depth. The density of the original mud is $1100\ \text{kg/m}^3$. The density of the kill mud is _____ kg/m^3 (rounded to two decimal places).

Correct Answer: $1298.05\ \text{kg/m}^3$

Solution:

Step 1: Write pressure balance at depth $h = 3500$ m.

Bottom-hole pressure with kill mud must balance the original hydrostatic plus shut-in:

$$\rho_k g h = \rho_o g h + P_{\text{si}} \ \Rightarrow\ \rho_k = \rho_o + \frac{P_{\text{si}}}{gh}.$$

Step 2: Substitute values.

$\rho_o = 1100\ \text{kg/m}^3$, $P_{\text{si}} = 6.8 \times 10^6$ Pa, $g = 9.81\ \text{m/s}^2$, $h = 3500$ m.

$$\frac{P_{\text{si}}}{gh} = \frac{6.8 \times 10^6}{9.81 \times 3500} = 198.0486\ \text{kg/m}^3.$$

Step 3: Compute kill-mud density.

$$\rho_k = 1100 + 198.0486 = \mathbf{1298.0486}\ \text{kg/m}^3 \Rightarrow \boxed{\text{to two decimals: } 1298.05\ \text{kg/m}^3}.$$

Quick Tip

For kill-mud calculations at a given depth, add the shut-in pressure head $\left(\dfrac{P_{\text{si}}}{gh}\right)$ to the original mud density.

Q.60 A non-Newtonian drilling fluid (Bingham plastic) is between two flat parallel rectangular plates of area $10\ \text{cm}^2$ each, separated by $1\ \text{cm}$. A force of 300 dyne is required to initiate motion of the upper plate. A force of 600 dyne keeps the plate moving at a constant velocity of $10\ \text{cm/s}$. The constitutive law is $\tau_{yx} = \mu_p \dot{\gamma} + \tau_{yx}^o$. Find the Bingham plastic viscosity μ_p in dyne·s/cm^2 (rounded to the nearest integer).

Correct Answer: $3\ \text{dyne} \cdot \text{s/cm}^2$

Solution:

Step 1: Yield stress from start-up force.

Start-up force $F_0 = 300$ dyne acts over area $A = 10\ \text{cm}^2$, so

$$\tau_0 = \frac{F_0}{A} = \frac{300}{10} = 30\ \text{dyne/cm}^2.$$

Step 2: Shear rate during steady motion.

Gap $h = 1\ \text{cm}$, plate speed $V = 10\ \text{cm/s}$

$$\dot{\gamma} = \frac{V}{h} = \frac{10}{1} = 10\ \text{s}^{-1}.$$

Step 3: Shear stress at steady motion from force $F = 600$ dyne.

$$\tau = \frac{F}{A} = \frac{600}{10} = 60\ \text{dyne/cm}^2.$$

Step 4: Compute μ_p.

$$\tau = \mu_p \dot{\gamma} + \tau_0 \Rightarrow \mu_p = \frac{\tau - \tau_0}{\dot{\gamma}} = \frac{60 - 30}{10} = 3\ \text{dyne} \cdot \text{s/cm}^2.$$

Quick Tip

For Bingham plastics, determine τ_0 from the threshold force (F_0/A), then use a second force–velocity pair to get $\mu_p = (\tau - \tau_0)/\dot{\gamma}$.

Q.61 Crude oil having density and viscosity of 850 kg/m^3 and 2×10^{-3} Pa·s, respectively, is flowing at an average velocity of 0.35 m/s through a horizontal capillary tube. The inside diameter and length of the capillary tube are 2.5×10^{-3} m and 0.30 m, respectively. The Fanning friction factor is $f = \dfrac{16}{\mathrm{Re}}$. The pressure drop across the capillary tube is _____ Pa (rounded to one decimal place).

Correct Answer: 1075.2 Pa

Solution:

- Reynolds number: $\mathrm{Re} = \dfrac{\rho v D}{\mu} = \dfrac{850 \times 0.35 \times 2.5 \times 10^{-3}}{2 \times 10^{-3}} = 371.875.$

- Fanning factor: $f = \dfrac{16}{\mathrm{Re}} = \dfrac{16}{371.875} = 0.043025.$

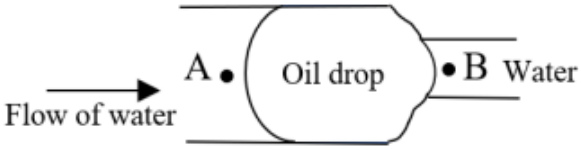
- Using Darcy–Weisbach with Fanning f: $\Delta P = 2f\dfrac{L}{D}\rho v^2.$

$\Rightarrow \Delta P = 2(0.043025)\left(\dfrac{0.30}{2.5 \times 10^{-3}}\right)(850)(0.35)^2 = 1075.2$ Pa.

Quick Tip

For laminar flow in a tube: $f = \dfrac{16}{\mathrm{Re}}$ and with Fanning f, $\Delta P = 2f\dfrac{L}{D}\rho v^2$.

Q.62 An oil droplet is to be mobilized by injecting water through a pore throat. The oil–water interface has the rear radius of curvature $r_A = 25 \times 10^{-6}$ m and the forward radius of curvature $r_B = 5 \times 10^{-6}$ m. The pore is completely water-wet (contact angle $= 0°$) and interfacial tension is $\sigma = 0.025$ N/m. The minimum pressure drop required to mobilize the trapped oil droplet is _____ N/m^2 (nearest integer).



Correct Answer: 8000 N/m^2

Solution:

- For a water-wet capillary, capillary pressure: $P_c = \dfrac{2\sigma}{r}$ (since $\cos\theta = 1$).

- Minimum driving ΔP equals the difference between forward and rear capillary pressures:

$\Delta P_{\min} = 2\sigma\left(\dfrac{1}{r_B} - \dfrac{1}{r_A}\right)$.

$\Rightarrow \Delta P_{\min} = 2(0.025)\left(\dfrac{1}{5\times10^{-6}} - \dfrac{1}{25\times10^{-6}}\right) = 8000$ N/m^2.

Quick Tip

To free a trapped droplet, overcome the *difference* in capillary pressures: $\Delta P_{\min} = 2\sigma(1/r_{\text{front}} - 1/r_{\text{rear}})$ for a water-wet system.

Q.63 A four–column semi–submersible floater is located offshore. The diameter of each column is 5 m. Consider the total displaced weight of seawater of the semi–submersible as 4000 tonnes. Assume added mass contribution as 50% of the semi–submersible weight, and seawater density as 1025 kg/m^3. (Acceleration due to gravity = 9.81 m/s^2.) The natural period of oscillation of the floater in vertical mode is _____ seconds (rounded to one decimal place).

Correct Answer: 17.3 s

Solution:

Step 1: Waterplane area.

Four circular columns of diameter $d = 5$ m $\Rightarrow$ area per column $= \dfrac{\pi d^2}{4} = 6.25\pi$ m^2.

Total $A_{wp} = 4 \times 6.25\pi = 78.54$ m^2.

Step 2: Heave restoring coefficient.

$C_z = \rho g A_{wp} = 1025 \times 9.81 \times 78.54 = 7.897 \times 10^5$ N/m.

Step 3: Effective mass (structure + added mass).

Displaced weight $= 4000$ tonnes $\Rightarrow$ structural mass $m = 4.0 \times 10^6$ kg.

Added mass $= 0.5\,m = 2.0 \times 10^6$ kg.

$m_{\text{eff}} = m + m_a = 6.0 \times 10^6$ kg.

Step 4: Natural period in heave.

$$T = 2\pi\sqrt{\frac{m_{\text{eff}}}{C_z}} = 2\pi\sqrt{\frac{6.0 \times 10^6}{7.897 \times 10^5}} = 17.32 \text{ s} \approx 17.3 \text{ s}.$$

Quick Tip

For vertical (heave) oscillation of floaters: $T = 2\pi\sqrt{(m + m_a)/(\rho g A_{wp})}$. Multi–column platforms have A_{wp} equal to the sum of column top areas.

Q.64 A shell-and-tube heat exchanger is used for cooling crude oil from 400 K to 360 K. Crude oil flows through the tube at 3650 kg/h. Water enters the shell side at 310 K and has a flow rate of 1600 kg/h. Assume $c_{p,\text{oil}} = 2.5$ kJ/(kg.K), $c_{p,\text{w}} = 4.187$ kJ/(kg.K), overall $U = 300$ W/(m^2·K), and countercurrent flow. The required heat–transfer area is _____ m^2 (rounded to one decimal place).

Correct Answer: 8.0 m^2

Solution:

Step 1: Heat duty from hot side.

$\dot{m}_h = 3650/3600 = 1.0139$ kg/s, $\Delta T_h = 400 - 360 = 40$ K.

$$Q = \dot{m}_h c_{p,h} \Delta T_h = 1.0139 \times 2500 \times 40 = 1.014 \times 10^5 \text{ W}.$$

Step 2: Cold outlet temperature.

$\dot{m}_c = 1600/3600 = 0.4444$ kg/s; $\Delta T_c = \dfrac{Q}{\dot{m}_c c_{p,c}} = \dfrac{1.014 \times 10^5}{0.4444 \times 4187} = 54.5$ K.

$T_{c,\text{out}} = 310 + 54.5 = 364.5$ K.

Step 3: LMTD for countercurrent flow.

$\Delta T_1 = T_{h,\text{in}} - T_{c,\text{out}} = 400 - 364.5 = 35.5$ K,

$\Delta T_2 = T_{h,\text{out}} - T_{c,\text{in}} = 360 - 310 = 50$ K.

$$\Delta T_{\text{lm}} = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2/\Delta T_1)} = \frac{50 - 35.5}{\ln(50/35.5)} = 42.35 \text{ K}.$$

Step 4: Area from $Q = UA\Delta T_{\text{lm}}$.

$$A = \frac{Q}{U\,\Delta T_{\text{lm}}} = \frac{1.014 \times 10^5}{300 \times 42.35} = 7.98 \text{ m}^2 \approx 8.0 \text{ m}^2.$$

Quick Tip

For variable outlet on the cold side, use energy balance to get $T_{c,\text{out}}$, then compute countercurrent LMTD and area from $Q = UA\Delta T_{\text{lm}}$.

Q.65 An underwater riser with an outer diameter of 250 mm and wall thickness of 20 mm is subjected to tension and pressure. The effective tension is 1200 kN wherein the internal and external pressures of the riser are 25 MPa and 6 MPa, respectively. The true wall tension in the riser is ____ $\times 10^6$ N (rounded to two decimal places).

Correct Answer: 1.77 $\times 10^6$ N

Solution:

Step 1: Geometry.

Outer radius $r_o = \dfrac{250}{2}$ mm $= 125$ mm $= 0.125$ m, thickness $t = 20$ mm $\Rightarrow$ inner radius $r_i = r_o - t = 105$ mm $= 0.105$ m.

Areas: $A_o = \pi r_o^2 = \pi(0.125)^2 = 0.049087$ m^2, $A_i = \pi r_i^2 = \pi(0.105)^2 = 0.034641$ m^2.

Step 2: Relation between effective and true wall tension.

For a pressurized pipe/riser,

$$T_{\text{true}} = T_{\text{eff}} + p_i A_i - p_o A_o,$$

where p_i and p_o are internal and external pressures (end-pressure forces).

Step 3: Substitute numbers.

$T_{\text{eff}} = 1.200 \times 10^6$ N, $\quad p_i A_i = 25 \times 10^6 \times 0.034641 = 0.866 \times 10^6$ N,

$p_o A_o = 6 \times 10^6 \times 0.049087 = 0.295 \times 10^6$ N.

$$T_{\text{true}} = 1.200 + 0.866 - 0.295 = 1.771 \ \times 10^6 \text{ N} \approx 1.77 \times 10^6 \text{ N}.$$

Quick Tip

For risers and pipelines, convert effective tension to true wall tension by adding the internal end force ($p_i A_i$) and subtracting the external end force ($p_o A_o$).
