GATE 2026 Naval Architecture and Marine Engineering Question Paper with Solutions

ZOLLEGE

General Instructions

(i) This booklet contains 65 questions, each provided with a complete, step-by-step solution.

(ii) It comprises 34 single-correct multiple-choice questions, 15 multiple-correct questions and 16 numerical / integer-type questions.

(iii) These questions follow the GATE Naval Architecture and Marine Engineering examination pattern.

(iv) Questions carry 1 or 2 marks. MCQs have negative marking (1/3 or 2/3 of the marks); MSQ and numerical-answer (NAT) questions carry no negative marking.

(v) GATE is a 3-hour paper of 65 questions (100 marks).

(vi) A virtual scientific calculator is provided; physical calculators are not allowed.

(vii) Attempt each question on your own before reviewing the given solution.

(viii) For multiple-correct questions, all correct options must be selected to earn full marks.

(ix) For numerical questions, report the answer rounded exactly as asked.

1. Expedite, Hasten, Hurry, __________

Fill the blank by choosing a word with a meaning similar to that of the words given above.

(A) Accelerate

(B) Retard

(C) Provide

(D) Disable

Correct Answer: (A) Accelerate

SOLUTION:

Look at what expedite, hasten and hurry have in common before checking the options. All three verbs describe making a process quicker or getting something done sooner. The missing word must carry that same speed-up meaning.

1. **Accelerate**: to speed up a process or action, so it fits right alongside expedite, hasten and hurry.
2. **Retard**: to hold something back or make it slower. This pulls in the opposite direction.
3. **Provide**: to give or arrange something for someone. There is no link to pace at all.
4. **Disable**: to make something unable to function. This also has no connection to speed.

Since accelerate is the only word that means to hurry something along, the answer is option (A).

Quick Tip: Think about what expedite, hasten and hurry all have in common.

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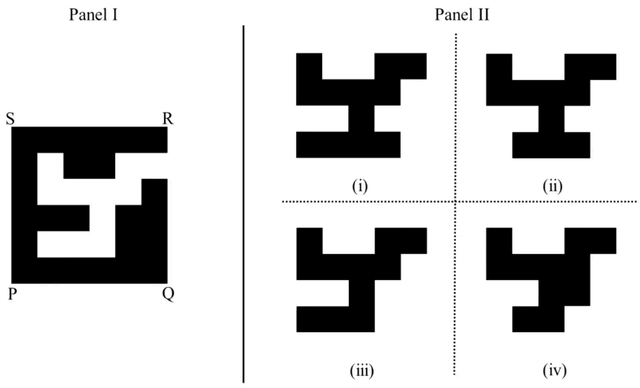
2. A black square PQRS has been cut into two parts. One part of it is shown in Panel I. Which one of the shapes in Panel II is the other part?



(A) (i)

(B) (ii)

(C) (iii)

(D) (iv)

Correct Answer: (C) (iii)

SOLUTION:

Step 1: Set up coordinates on the square.
Label the square PQRS with P at bottom left and R at top right, and divide each side into 6 equal parts using the step size of the notches in Panel I.
This gives a 6x6 grid of unit cells, 36 cells in all.

Step 2: Read off the shown piece.
Going row by row from the top edge (S to R) to the bottom edge (P to Q), mark which of the 36 cells in Panel I are black.
Counting gives 25 black cells, so the missing piece must fill the other 11 cells, always in the same fixed arrangement.

Step 3: Plot the missing 11 cells.

Row 2 has empty cells at columns 2, 5 and 6, row 3 has empty cells at columns 2, 3, 4 and 5, row 4 has an empty cell only at column 4, and row 5 has empty cells at columns 2, 3 and 4.
Together these 11 cells form one connected outline, 4 rows tall and 5 columns wide.

Step 4: Match this outline against Panel II.
Overlay the same 4x5 grid on each option and compare cell by cell with the outline from Step 3.
Options (i), (ii) and (iv) each differ from the outline in at least one cell, but option (iii) lines up with it in every cell.

Final Answer:
The shape in option (iii) is the exact complement of Panel I, so it is the other part of the square.

$$\boxed{\text{Answer} = \text{(iii)}}$$

Quick Tip: Overlay a grid on the square and work out exactly which cells the shown piece does not cover.

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3. A day can only be cloudy or sunny. The probability of a day being cloudy is 0.5, independent of the condition on other days. What is the probability that in any given four days, there will be three cloudy days and one sunny day?

(A) 1/4

(B) 3/4

(C) 2/3

(D) 3/8

Correct Answer: (A) 1/4

SOLUTION:

Step 1: Count the ways to choose which day is sunny.

Out of 4 days, exactly one day is sunny and the other three are cloudy.

There are $\binom{4}{1} = 4$ ways to pick which single day is the sunny one.

Step 2: Find the probability of one such arrangement.

Cloudy and sunny each have probability 0.5, and the days are independent.

Any one specific sequence of 3 cloudy days and 1 sunny day has probability $(0.5)^3 \times (0.5)^1 = (0.5)^4 = 1/16$.

Step 3: Add up all the arrangements.

Each of the 4 possible positions for the sunny day gives this same probability 1/16, and these outcomes do not overlap.

So the total probability is $4 \times 1/16 = 1/4$.

Final Answer:

Three cloudy days and one sunny day out of four occur with probability 1/4, so option (A) is correct.

$$\boxed{P = \frac{1}{4}}$$

Quick Tip: Use the binomial probability formula with $p = 0.5$ and $n = 4$.

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4. The values of Stock A and Stock B on a particular day are Rs. 50 and Rs. 80, respectively. An investor invests Rs. 100 in Stock A and Rs. 80 in Stock B. He sells all the stocks the next day when the value of Stock A is Rs. 55 and Stock B is Rs. 70. The profit made by the investor is Rs. ________

(A) 0

(B) 5

(C) 10

(D) 20

Correct Answer: (A) 0

SOLUTION:

Step 1: Work out the profit from Stock A alone.

Rs. 100 buys $100/50 = 2$ units of Stock A at Rs. 50 each.

Selling these 2 units at Rs. 55 each gives $2 \times 55 = 110$ rupees, so the gain on Stock A is $110 - 100 = 10$ rupees.

Step 2: Work out the profit or loss from Stock B alone.

Rs. 80 buys $80/80 = 1$ unit of Stock B at Rs. 80.

Selling this 1 unit at Rs. 70 gives 70 rupees, so Stock B shows a loss of $80 - 70 = 10$ rupees.

Step 3: Combine the two results.

Net profit = gain on Stock A minus loss on Stock B = $10 - 10 = 0$.

Final Answer:

The Rs. 10 gain on Stock A exactly cancels the Rs. 10 loss on Stock B, so the overall profit is 0.

$$\boxed{\text{Profit} = Rs.\ 0}$$

Quick Tip: Work out how many units of each stock the investment buys, then compare buying and selling value.

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5. 'When it is raining, peacocks dance.'
Based only on this sentence, which one of the following options is necessarily true?

(A) Peacocks dance only when it is raining.

(B) When peacocks dance, it is raining.

(C) When peacocks are not dancing, it is not raining.

(D) When it is not raining, peacocks do not dance.

Correct Answer: (C) When peacocks are not dancing, it is not raining.

SOLUTION:

Read the sentence as a rule: rain always brings out dancing peacocks, but the sentence never says dancing needs rain, and it never says no rain means no dancing. Test each option against a scenario where the rule still holds but peacocks dance for another reason, such as a nearby drum performance.

1. **Peacocks dance only when it is raining**: fails, because peacocks could also dance for the drum performance without any

rain, so this option does not have to be true.

2. **When peacocks dance, it is raining**: fails for the same reason, dancing does not force rain.
3. **When peacocks are not dancing, it is not raining**: this must hold, because if it were raining the rule guarantees dancing, so no dancing rules out rain every time.
4. **When it is not raining, peacocks do not dance**: fails, since the drum-performance scenario has no rain but still has dancing.

Only the statement in option (C) survives every scenario consistent with the sentence, so it is the one that is necessarily true.

Quick Tip: Find the contrapositive of the given conditional statement.

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6. Water : P :: Food : Q

Choose the P and Q combination from the options below to form a meaningful analogy.

(A) P = Thirst; Q = Hunger

(B) P = Drink; Q = Hunger

(C) P = Thirst; Q = Satiated

(D) P = Wet; Q = Critic

Correct Answer: (A) P = Thirst; Q = Hunger

SOLUTION:

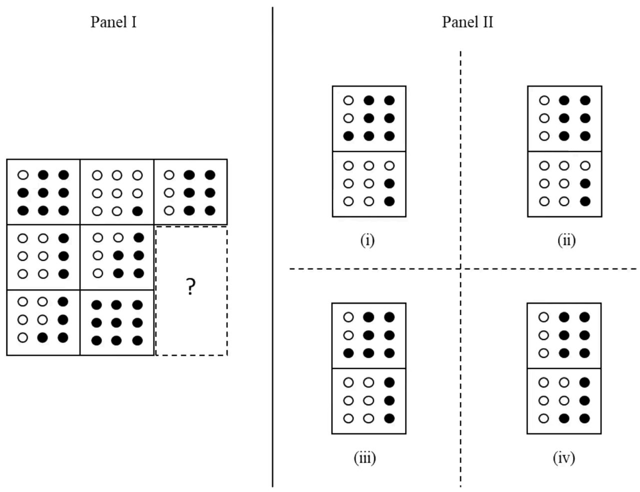
Treat the analogy as a template: item, then the need that item removes. Water removes thirst, so P should be the need that water removes, and by the same rule Q should be the need that food removes.

1. **P = Thirst; Q = Hunger**: drinking water takes away thirst and eating food takes away hunger, so the same template fits both sides perfectly.
2. **P = Drink; Q = Hunger**: Drink is close in meaning to water rather than the need it removes, so it does not match the template used for Q.
3. **P = Thirst; Q = Satiated**: Satiated is a feeling of being full after eating, not the need itself, so it is not parallel to Thirst.
4. **P = Wet; Q = Critic**: Wet simply describes water, and Critic is unrelated to food, so neither slot fits the needed pattern.

The pairing Thirst and Hunger is the only one that keeps the analogy consistent, confirming option (A).

Quick Tip: Think about what need each item satisfies.

7. Two tiles are missing in Panel I. Which one of the options in Panel II is the appropriate choice for the missing tiles?



(A) (i)

(B) (ii)

(C) (iii)

(D) (iv)

Correct Answer: (A) (i)

SOLUTION:

Step 1: Recognize the layout as a magic square in disguise.
Replace each 3x3 dot tile by the number of black dots it contains.
Reading off the 7 visible tiles of Panel I gives the grid: 8, 1, 6 on top; 3, 5 and a question mark in the middle; 4, 9 and a question mark at the bottom.

Step 2: Recall the property of this square.
This is the well known Lo Shu magic square, built from the digits 1 to 9 with every row, column and both diagonals summing to 15.
The completed square reads 8, 1, 6 on top, 3, 5, 7 in the middle, and 4, 9, 2 at the bottom.

Step 3: Read off the two missing values.
The middle-right tile must show 7 filled dots and the bottom-right tile must show 2 filled dots, since these are the only values that keep every row and column at 15.

Step 4: Check each option's dot counts.
Option (i) shows 7 filled dots on top and 2 filled dots below, matching the required pair exactly. Options (ii) and (iv) show only 6 dots in the upper tile, and option (iii) shows 3 dots in the lower tile instead of 2.

Final Answer:

The tile pair with counts 7 and 2 belongs to option (i), so that is the correct completion of Panel I.

$$\boxed{\text{Answer} = \text{(i)}}$$

Quick Tip: Count the filled dots in each tile and look for a magic square pattern.

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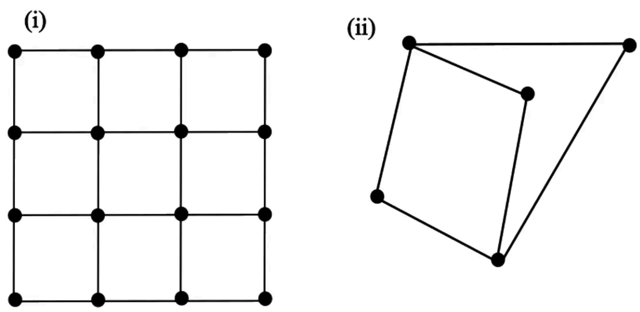
8. Figures (i) and (ii) represent intercity highway systems. The black dots represent cities and the line segments between them represent intercity highways.

A salesperson needs to make a trip. She needs to start from a city, visit each of the remaining cities exactly once, and finally return to the same city from which she started.

Which one of the following options is then true?



(A) Such a trip is possible for (i), but not for (ii).

(B) Such a trip is possible for (ii), but not for (i).

(C) Such a trip is possible for both (i) and (ii).

(D) Such a trip is possible neither for (i) nor for (ii).

Correct Answer: (A) Such a trip is possible for (i), but not for (ii).

SOLUTION:

This question tests whether a closed tour touching every city exactly once, a Hamiltonian circuit, can be drawn on each of the two road maps.

1. **Option A, trip possible for (i) but not (ii):** In the 4 by 4 grid, start at the top left city and go straight down the first column, cross to the second column, weave up and down through columns 2 to 4, and come back along the top row to the start. Because the grid has an even count of cities, $4 \times 4 = 16$, this weave closes into a single loop covering every city once. In the 5-city map, three cities sit on just two roads each, and both of those roads run to the same pair of hub cities. Making every one of those roads part of the loop would put three roads on one hub city, but a loop can carry only two roads per city, so the loop cannot be completed. This matches option A exactly.
2. **Option B, trip possible for (ii) but not (i):** Wrong, since the argument above shows (i) does allow a full round trip.
3. **Option C, trip possible for both:** Wrong, since (ii) fails the round trip test.
4. **Option D, trip possible for neither:** Wrong, since (i) does allow a full round trip.

So the correct choice is option A: the round trip works for (i) but breaks down for (ii).

Quick Tip: Treat each figure as a graph and check whether a Hamiltonian cycle, a closed tour hitting every city once, can be drawn on it.

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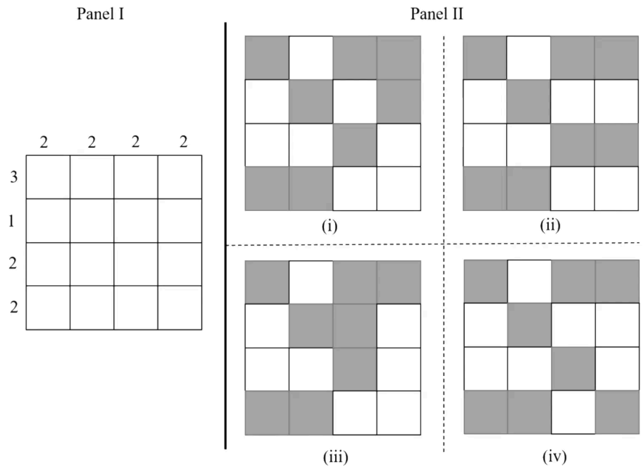
9. The figure in Panel I below is a grid of cells with four rows and four columns. The numbers on the top and on the left represent the number of cells that are to be shaded in that column and row, respectively. Which one of the options shown in Panel II below represents the grid shaded correctly?



(A) (i)

(B) (ii)

(C) (iii)

(D) (iv)

Correct Answer: (B) (ii)

SOLUTION:

A grid-shading puzzle like this is solved by treating the row numbers and column numbers as two separate checks that a correct panel must pass together.

1. **Option A, panel (i):** Counting shaded cells row by row gives 3, 2, 1, 2 from top to bottom. The needed pattern is 3, 1, 2, 2, so the middle two rows are swapped and this panel fails.
2. **Option B, panel (ii):** Counting row by row gives 3, 1, 2, 2, which is exactly the target row pattern. Counting column by

column, every column also comes to 2, matching the target of 2 in each column. Both checks pass, so this panel is correct.

3. **Option C, panel (iii):** The row counts again come out as 3, 2, 1, 2, the same mismatch as panel (i), so it fails.
4. **Option D, panel (iv):** The row counts come out as 3, 1, 1, 3, which does not match the needed 3, 1, 2, 2 pattern, so it fails too.

Since panel (ii) is the only one whose rows and columns both match Panel I's numbers, option B is correct.

Quick Tip: Count the shaded cells in each row and each column of every option and compare with Panel I's numbers.

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10. An unbiased six-faced dice whose faces are marked with numbers 1, 2, 3, 4, 5, and 6 is rolled twice in succession and the number on the top face is recorded each time. The probability that the sum of the two recorded numbers is a prime number is ________

(A) $\frac{3}{36}$

(B) $\frac{13}{36}$

(C) $\frac{15}{36}$

(D) $\frac{19}{36}$

Correct Answer: (C) $\frac{15}{36}$

SOLUTION:

Rolling two dice in a row creates $6 \times 6 = 36$ equally likely pairs, and this problem asks what fraction of those pairs add up to a prime number.

1. **List every sum from 2 to 12 and mark which ones are prime:** sums 4, 6, 8, 9, 10, and 12 are not prime, while sums 2, 3, 5, 7, and 11 are prime.
2. **Count how many pairs give each prime sum:** sum 2 comes from 1 pair, sum 3 from 2 pairs, sum 5 from 4 pairs, sum 7 from 6 pairs, and sum 11 from 2 pairs. Adding these gives $1 + 2 + 4 + 6 + 2 = 15$ pairs out of 36 total.
3. **Turn the count into a probability:** $P = \frac{15}{36}$, which stays in this form since it matches one of the listed options directly.

The other three options, $\frac{3}{36}$, $\frac{13}{36}$, and $\frac{19}{36}$, all come from missing or double counting some of the five prime sums, so option C, $\frac{15}{36}$, is the correct probability.

Quick Tip: List the sums from 2 to 12 that are prime, then count the dice pairs giving each of those sums.

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11. The determinant of the matrix $\begin{pmatrix} 1 & p & q+r \\ 1 & q & r+p \\ 1 & r & p+q \end{pmatrix}$ is ________.

(A) pqr

(B) $p+q+r$

(C) $pq+qr+rp$

(D) 0

Correct Answer: (D) 0

SOLUTION:

Step 1: Expand the determinant directly along the first column.

For a 3 by 3 matrix, expanding along column 1 gives $\Delta = 1 \cdot \begin{vmatrix} q & r+p \\ r & p+q \end{vmatrix} - 1 \cdot \begin{vmatrix} p & q+r \\ r & p+q \end{vmatrix} + 1 \cdot \begin{vmatrix} p & q+r \\ q & r+p \end{vmatrix}$.

Step 2: Work out each 2 by 2 minor.

First minor: $q(p+q) - r(r+p) = pq + q^2 - r^2 - rp$. Second minor: $p(p+q) - r(q+r) = p^2 + pq - rq - r^2$. Third minor: $p(r+p) - q(q+r) = pr + p^2 - q^2 - qr$.

Step 3: Combine the three minors with their signs.

$\Delta = (pq + q^2 - r^2 - rp) - (p^2 + pq - rq - r^2) + (pr + p^2 - q^2 - qr)$. Group the terms: the q^2 terms give $q^2 - q^2 = 0$, the p^2 terms give $-p^2 + p^2 = 0$, the r^2 terms give $-r^2 + r^2 = 0$. The remaining terms are $pq - rp + rq - pq + pr - qr$, and pairing pq with $-pq$, $-rp$ with pr, and rq with $-qr$ cancels everything.

Final Answer:

Every term cancels out, so the determinant reduces to zero regardless of the values chosen for p, q, and r.

$$\boxed{\Delta = 0}$$

Quick Tip: Check whether adding two of the columns produces a column that is a multiple of another column.

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12. The gradient of a scalar field is ________.

(A) a vector

(B) a scalar

(C) a second order tensor

(D) always zero

Correct Answer: (A) a vector

SOLUTION:

Step 1: Recall how the gradient is built.

Take a scalar field $\phi(x, y, z)$, a function that assigns one number to every point in space. Its gradient is formed by collecting the three partial derivatives $\frac{\partial \phi}{\partial x}$, $\frac{\partial \phi}{\partial y}$, and $\frac{\partial \phi}{\partial z}$, and attaching them to the unit directions $\hat{i}$, $\hat{j}$, $\hat{k}$.

Step 2: Check what kind of object this produces.

An object built from three components, each tied to a direction in space, is exactly the definition of a vector. So $\nabla\phi$ has both a size, given by $|\nabla\phi| = \sqrt{\left(\frac{\partial \phi}{\partial x}\right)^2 + \left(\frac{\partial \phi}{\partial y}\right)^2 + \left(\frac{\partial \phi}{\partial z}\right)^2}$, and a direction, the direction of steepest increase of ϕ.

Step 3: Rule out the other choices.

It cannot be a plain scalar, since a scalar has no direction attached to it. It is not a second order tensor either, since that order of object comes from differentiating a vector field, not a scalar field. It is also not always zero, since it vanishes only where the field has a flat spot, not at every point.

Final Answer:

The gradient of a scalar field is always a vector.

$$\boxed{\nabla\phi \text{ is a vector}}$$

Quick Tip: Write out the definition of gradient using partial derivatives and check what type of quantity it forms.

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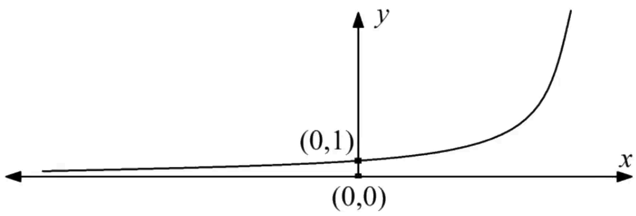
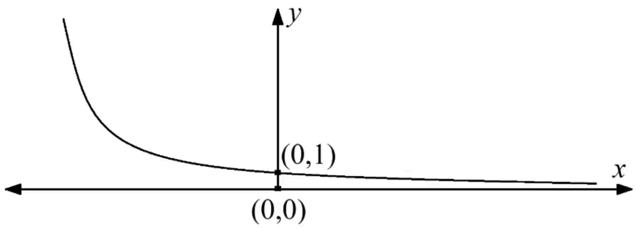
13. Which ONE of the following curves represents the equation $y = e^{-x}$?
Figures not to scale

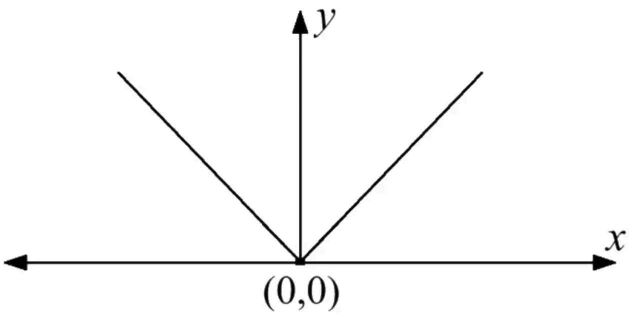
(A)



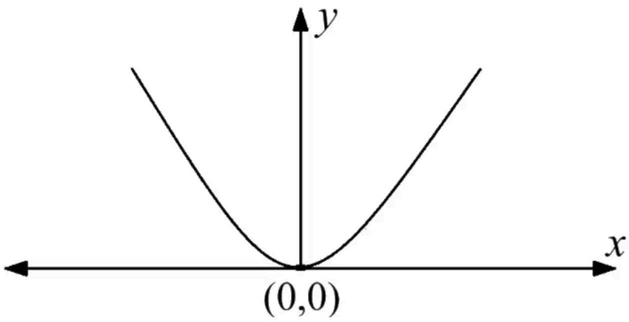
(B)



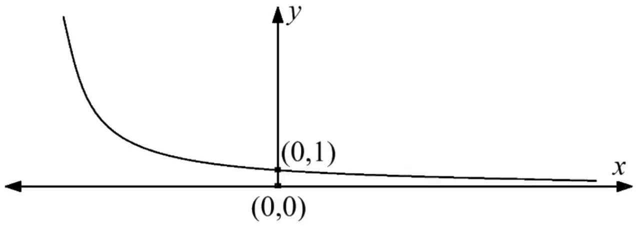
(C)



(D)



Correct Answer: (B)



SOLUTION:

Since $y = e^{-x}$ can be rewritten as $y = \left(\frac{1}{e}\right)^x$, this is an exponential decay curve, and matching it to a picture just means checking growth direction and shape.

1. **Option A:** This curve starts near zero on the left, sits at $(0, 1)$, and rises steeply on the right. That is growth as x increases, which fits $y = e^x$, not $y = e^{-x}$.
2. **Option B:** This curve is steep and high on the left, comes down through $(0, 1)$, and flattens toward the x-axis on the right. That is decay as x increases, matching $y = e^{-x}$ exactly.
3. **Option C:** This is a V-shaped curve with a sharp corner at the origin, which looks like $y = |x|$ style behaviour, not a smooth exponential.
4. **Option D:** This is a U-shaped curve touching zero at the origin, which looks like a curve such as $y = x^2$, not an exponential that never reaches zero.

Only option B has the decaying exponential shape that $y = e^{-x}$ actually has, so option B is correct.

Quick Tip: Check the sign of the derivative of e^{-x} and see whether the curve should rise or fall as x increases.

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14. The Fourier series expansion of the function $f(x) = |\cos(x)|$ in the interval $(-\pi, \pi)$ is $\alpha + \beta\left[\frac{1}{3}\cos(2x) - \frac{1}{15}\cos(4x) + \cdots\right]$.

The values of α and β respectively are ________.

(A) $2/\pi$ and $4/\pi$

(B) $4/\pi$ and $2/\pi$

(C) $\pi/2$ and $\pi/4$

(D) $\pi/4$ and $\pi/2$

Correct Answer: (A) $2/\pi$ and $4/\pi$

SOLUTION:

The Fourier expansion of $|\cos x|$ on $(-\pi, \pi)$ is a standard result that can be quoted and then matched term by term to the series given in the question.

1. **State the known expansion:** $|\cos x| = \frac{2}{\pi} + \frac{4}{\pi}\left[\frac{1}{1\cdot 3}\cos(2x) - \frac{1}{3\cdot 5}\cos(4x) + \frac{1}{5\cdot 7}\cos(6x) - \cdots\right]$, obtained from the general formula $|\cos x| = \frac{2}{\pi} + \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n+1}}{4n^2-1}\cos(2nx)$.
2. **Simplify the first two bracket terms:** $\frac{1}{1\cdot 3} = \frac{1}{3}$ and $\frac{1}{3\cdot 5} = \frac{1}{15}$, so the bracket reads $\frac{1}{3}\cos(2x) - \frac{1}{15}\cos(4x) + \cdots$, which is precisely the bracket printed in the question.
3. **Match the outside factors:** Comparing $\frac{2}{\pi} + \frac{4}{\pi}[\cdots]$ with $\alpha + \beta[\cdots]$ term by term gives $\alpha = \frac{2}{\pi}$ and $\beta = \frac{4}{\pi}$ directly, with no extra computation needed once the bracket is checked to line up.

So $\alpha = 2/\pi$ and $\beta = 4/\pi$, which is option A.

Quick Tip: Compute the constant term and the coefficient of cos(2x) in the Fourier series of |cos x| and compare with the given form.

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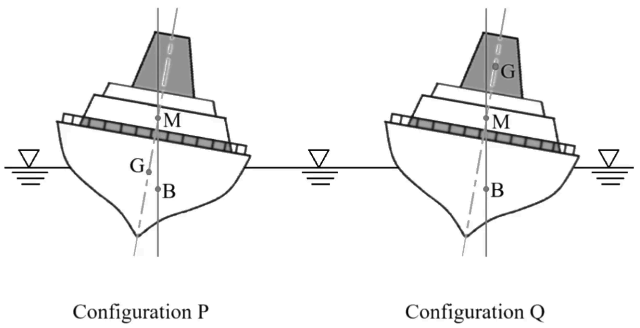
15. Consider two configurations P and Q of a stationary ship floating in calm water with transverse sections as shown in the figure, where M is the metacentre, G is the centre of gravity, and B is the centre of buoyancy.



Which ONE of the following statements is TRUE regarding the static stability of the ship?

(A) Configuration P is stable and configuration Q is unstable.

(B) Both configurations are stable.

(C) Configuration P is unstable and configuration Q is stable.

(D) Both configurations are unstable.

Correct Answer: (A) Configuration P is stable and configuration Q is unstable.

SOLUTION:

Step 1: Recall the stability condition.

A floating body is in stable equilibrium when its metacentre M lies above its centre of gravity G, so the metacentric height $GM = KM - KG$ is positive.

If G lies above M instead, GM turns negative and the body is unstable.

Step 2: Read the point order in configuration P.

In the sketch of configuration P, going up from the waterline, B is lowest, then G, then M sits highest.

So M is above G, which gives GM > 0, and configuration P is stable.

Step 3: Read the point order in configuration Q.

In configuration Q the order changes: B is lowest, then M, then G sits highest of all, above M.

So G is above M, which gives GM < 0, and configuration Q is unstable.

Final Answer:

Configuration P is stable and configuration Q is unstable.

$$\text{P: GM} > 0 \text{ (stable)}, \quad \text{Q: GM} < 0 \text{ (unstable)}$$

Quick Tip: Compare the vertical order of G and M in each sketch; stability needs M above G.

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16. If the indicated power of an IC engine at NO-LOAD condition is 0.5 kW, then the friction power is _______ kW.

(A) 1

(B) 2

(C) 0.5

(D) 0

Correct Answer: (C) 0.5

SOLUTION:

This question tests the basic power balance of an IC engine and what no load means for that balance.

1. **1 kW**: This would need the friction power to be double the indicated power, which cannot happen because friction power can never exceed the indicated power that produces it.
2. **2 kW**: This is four times too large, and there is no physical reason for friction power to exceed indicated power at no load.
3. **0.5 kW**: At no load the engine delivers no useful output, so brake power BP is zero. Since indicated power equals BP plus friction power, all 0.5 kW of indicated power is spent overcoming friction, giving FP = 0.5 kW. This matches the given data exactly.
4. **0 kW**: This would mean the engine has no internal friction at all, which is not realistic since fuel still burns to keep the engine running with no external load.

The correct choice is (C): the friction power is 0.5 kW, equal to the indicated power measured at no load.

Quick Tip: At no load the brake power is zero, so think about where the indicated power goes.

17. A ship floating in seawater has a TPC (Tonne Per Centimeter immersion) of 20.

If bilge keel of total mass 65.1 tonne and volume 44 m^3 is added to the ship, then the change in the mean draft is _______ cm.

Assume that after bilge keel fitment, the TPC remains constant, and the ship undergoes parallel sinkage. Density of seawater is 1025 kg/m^3.

(A) 0.5

(B) 1

(C) 0.55

(D) 1.1

Correct Answer: (B) 1

SOLUTION:

This question checks whether you remember that TPC alone is not enough when the added object also has its own submerged volume, since part of its weight is carried by that displacement.

1. **0.5 cm**: This comes from ignoring the keel's volume and using only a fraction of its weight, so it does not match either the given mass or volume.
2. **1 cm**: The keel's volume of 44 cubic metres displaces 44 times 1.025, which is 45.1 tonne of seawater on its own. That leaves 65.1 minus 45.1, or 20 tonne, to be carried by parallel sinkage. Dividing 20 tonne by the TPC of 20 gives exactly 1 cm, so this is correct.
3. **0.55 cm**: This would follow from taking half the correct sinkage or misreading the TPC value, and it does not follow from the

given numbers.

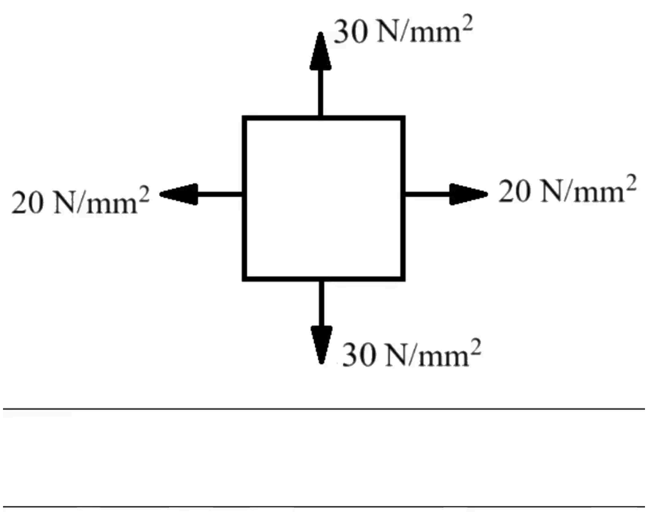
4. **1.1 cm**: This overshoots because it treats the full 65.1 tonne as needing parallel sinkage without subtracting the buoyancy the keel volume already gives.

The correct choice is (B): the mean draft changes by 1 cm once the keel's own displaced volume is accounted for.

Quick Tip: Subtract the buoyancy from the keel's own volume before dividing the rest by TPC.

• • •

18. The state of plane stress in an element is shown in the figure.



The maximum shear stress in the element is _______ N/mm^2.

(A) 0

(B) 5

(C) 10

(D) 25

Correct Answer: (B) 5

SOLUTION:

This question tests the direct formula for maximum in-plane shear stress from two known normal stresses acting with no shear on the given faces.

1. **0**: This would only hold if the two normal stresses were equal, but here they differ, 20 versus 30, so shear stress must exist on some other plane.
2. **5**: With sigma x equal to 20 and sigma y equal to 30, and zero shear on the given faces, these two values are already the principal stresses. Half their difference, 30 minus 20 over 2, gives 5, the maximum in-plane shear stress. This is correct.
3. **10**: This equals the full difference of the two stresses instead of half of it, a common slip when the factor of 2 is dropped.
4. **25**: This is close to an average of the two normal stresses, not their half-difference, so it does not represent a shear stress here.

The correct choice is (B): the maximum shear stress works out to 5 N/mm squared, using half the difference of the two principal stresses.

Quick Tip: Both given faces have zero shear, so sigma x and sigma y are already the principal stresses.

19. The virtual work principle states that _______.

(A) external virtual work is equal to internal virtual work

(B) there is equilibrium of external and internal forces

(C) virtual work is inversely proportional to virtual displacement

(D) the potential energy of the system is equal to its kinetic energy

Correct Answer: (A) external virtual work is equal to internal virtual work

SOLUTION:

Step 1: State what a virtual displacement is.
A virtual displacement is a small, imaginary displacement consistent with the supports, applied to a body already in equilibrium.

Step 2: Write the virtual work statement.
For the body to stay in equilibrium under this imaginary displacement, the work done by the external loads must equal the work done by the internal forces as the structure deforms: $W_{external} = W_{internal}$.

Step 3: Rule out the other statements.
Force equilibrium alone does not define virtual work, there is no inverse proportionality in its definition, and potential energy equalling kinetic energy belongs to dynamics, not this principle.

Final Answer:
The principle links external and internal virtual work directly.

$$W_{ext} = W_{int}$$

Quick Tip: Think about what equality virtual work sets up between outside loads and internal deformation.

• • •

20. The potential flow theory assumes that the flow is _______.

(A) irrotational, inviscid and incompressible

(B) rotational, viscous and incompressible

(C) rotational, viscous and compressible

(D) irrotational, inviscid and compressible

Correct Answer: (A) irrotational, inviscid and incompressible

SOLUTION:

Step 1: Recall why potential flow is used.
Potential flow theory is a simplified model used to study flow around ship hulls and other bodies without solving the full viscous flow equations.

Step 2: List the three assumptions it needs.
It assumes the fluid is inviscid, so no friction between fluid layers, incompressible, so density ρ stays constant, and irrotational, so the vorticity $\nabla \times \vec{v} = 0$ everywhere.

Step 3: Match with the given options.
Only the option listing irrotational, inviscid and incompressible together matches this standard set; the other options mix in rotation, viscosity, or compressibility.

Final Answer:

These three conditions together allow a single velocity potential to exist.

$$\nabla \times \vec{v} = 0, \quad \mu = 0, \quad \rho = \text{constant}$$

Quick Tip: Recall the three conditions needed for a velocity potential function to exist.

• • •

21. The RAO (Response Amplitude Operator) of a floating body with no forward speed is denoted by $H(\omega)$.

If it encounters a wave spectrum $S(\omega)$, then its response spectrum is _______.

(A) $H(\omega)S(\omega)$

(B) $|H(\omega)|^2 S(\omega)$

(C) $|H(\omega)|^3 S(\omega)$

(D) $|H(\omega)|S(\omega)$

Correct Answer: (B) $|H(\omega)|^2 S(\omega)$

SOLUTION:

This question tests the standard spectral relation used in seakeeping analysis to convert a wave spectrum into a ship response spectrum.

1. $H(\omega)S(\omega)$: The RAO can be a complex number carrying phase information, so multiplying it directly with an energy spectrum does not give a physically meaningful energy quantity, so this option is wrong.

2. $|H(\omega)|^2 S(\omega)$: A spectrum measures energy, which scales with amplitude squared, so passing a wave spectrum through a linear system scales it by the squared magnitude of that system's transfer function. This matches the standard seakeeping formula for response spectra, so it is correct.
3. $|H(\omega)|^3 S(\omega)$: There is no physical basis for a cubic scaling in a linear spectral response relation, so this option is wrong.
4. $|H(\omega)| S(\omega)$: This uses the magnitude to the first power, which would fit an amplitude spectrum, not an energy spectrum, so this option is wrong.

The correct choice is (B): the response spectrum equals the wave spectrum multiplied by the square of the RAO magnitude.

Quick Tip: Remember that spectra represent energy, so amplitude ratios must be squared.

• • •

22. The sway-yaw coupled maneuvering equation of motion for a ship is

$$\begin{bmatrix} M - Y_{\dot{v}} & -Y_{\dot{r}} \\ -N_{\dot{v}} & I_z - N_{\dot{r}} \end{bmatrix} \begin{bmatrix} \dot{v} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} Y_v & Y_r \\ N_v & N_r \end{bmatrix} \begin{bmatrix} v \\ r \end{bmatrix} + \begin{bmatrix} Y_\delta \\ N_\delta \end{bmatrix} \delta_R$$

For a control-fixed straight-line stability, the eigenvalues of the function should be _______.

(A) real and negative

(B) real and positive

(C) complex numbers with positive real part and negative imaginary part

(D) zero

Correct Answer: (A) real and negative

SOLUTION:

Course (straight-line) stability of a ship is a classic linear-systems question hiding inside a naval architecture problem: does the free response of the sway-yaw system decay back to zero disturbance, and does it do so without swinging past the target heading?

1. **real and negative**: correct. A negative real root gives pure exponential decay $e^{-|\lambda|t}$, so v and r die out monotonically and the ship settles back onto a straight course without hunting.
2. **real and positive**: wrong. A positive real root grows without bound as $e^{|\lambda|t}$, so any small disturbance (a gust, a wave) would keep pulling the bow further off course, which is the definition of a directionally unstable hull.
3. **complex with positive real part and negative imaginary part**: wrong. Complex roots always occur in conjugate pairs for a real system, so this description is not even self-consistent, and a positive real part still means the oscillation amplitude grows.
4. **zero**: wrong. A zero eigenvalue means the system stays wherever it is disturbed to (neutral, marginal stability), it never actively returns to the original straight course, so this is not stability.

Only option A, real and negative eigenvalues of the sway-yaw system, describes a hull that is inherently directionally stable when the rudder is fixed amidships, so A is the correct choice.

Quick Tip: Think about what root type of the linearised sway-yaw system gives a smooth, non-oscillatory return to the straight course.

• • •

23. Which of the following ordinary differential equations is/are linear?

(A) $(x+1)\dfrac{dy}{dx} - y = e^x(x+1)^2$

(B) $\dfrac{dy}{dx} - \dfrac{dx}{dy} = \dfrac{y}{x} - \dfrac{x}{y}$

(C) $\dfrac{d^2y}{dx^2} + n^2x = 0$, where n is a constant

(D) $xy\dfrac{dy}{dx} = 1 + x + y + xy$

Correct Answer: (A) $(x+1)\dfrac{dy}{dx} - y = e^x(x+1)^2$; (C) $\dfrac{d^2y}{dx^2} + n^2x = 0$, where n is a constant

SOLUTION:

Step 1: Recall the test for linearity.

An ODE is linear in y if it can be arranged as $a_n(x)y^{(n)} + \cdots + a_1(x)y' + a_0(x)y = f(x)$, meaning every term with y or a derivative of y is multiplied only by a function of x, never by y itself, and y never appears inside a reciprocal, square root or other nonlinear wrapper.

Step 2: Test option A.

$(x+1)y' - y = e^x(x+1)^2$ already has this shape: coefficient $(x+1)$ on y', coefficient -1 on y, both functions of x only. So A passes.

Step 3: Test option B.

$y' - \frac{dx}{dy} = \frac{y}{x} - \frac{x}{y}$ needs $\frac{dx}{dy} = 1/y'$, giving a $1/y'$ term, and it also has x/y on the right, so y appears in a denominator. Both features fail the test, so B is nonlinear.

Step 4: Test option C.

$y'' + n^2x = 0$ is just $y'' = -n^2x$: the only y-term is y'' with coefficient 1, and the rest is a pure function of x. This passes the test cleanly.

Step 5: Test option D.

$xy\,y' = 1 + x + y + xy$ has y' multiplied by xy, a term that includes y, so the coefficient of y' is not a function of x alone. This fails, so D is nonlinear.

Final Answer:

Options A and C meet the linear ODE definition and B and D do not.

$$\boxed{\text{A and C}}$$

Quick Tip: Check whether y and its derivative appear only to the first power, with coefficients that depend on x alone.

• • •

24. Which of the following structures is/are mainly used for harbor berthing?

(A) Dolphins

(B) Jetty

(C) Quay

(D) Jacket

Correct Answer: (A) Dolphins ; (B) Jetty ; (C) Quay

SOLUTION:

This question is really about sorting port and harbor infrastructure from offshore platform infrastructure. Only structures that a ship can lie alongside and moor to count as berthing structures.

1. **Dolphins**: correct. These are clusters of piles or small caissons set apart from the main wharf, used to take mooring lines or to cushion a ship's approach, so they directly support berthing.
2. **Jetty**: correct. A jetty extends from the shoreline into the water and gives ships a berthing face on one or both sides, so cargo or passengers can be handled.
3. **Quay**: correct. A quay runs along the natural shoreline and is the everyday berthing wall found in most ports, built to let a ship lie flush against it.
4. **Jacket**: wrong. A jacket is the braced steel lattice that sits on the seabed and carries an offshore oil or gas platform's deck; it has nothing to do with tying up ships and is not found in a harbor's berthing area.

So dolphins, jetty and quay are all correct, giving the answer A, B and C.

Quick Tip: Ask which of the four is actually a place a ship ties up, and which one is an offshore platform foundation.

• • •

25. Which ONE or MORE of the following welds can be performed through resistance welding method?

(A) Seam

(B) Spot

(C) Fillet

(D) Groove

Correct Answer: (A) Seam ; (B) Spot

SOLUTION:

Step 1: Recall how resistance welding works.

Two copper electrodes clamp the plates together and a large current is forced through the contact area. Heat from the plates' own electrical resistance melts a small fused zone, no filler rod and no arc is used.

Step 2: Match this to seam and spot welds.

Spot welding uses two point electrodes to fuse overlapping sheets at one spot, which is the direct textbook example of this process. Seam welding replaces the point electrodes with rolling wheel electrodes, so the same resistance heating happens continuously along a line, giving a leak tight seam. Both fit the resistance welding description.

Step 3: Rule out fillet and groove.

Fillet and groove describe the shape of the joint itself (a corner fillet, or a machined groove between butted edges), not the heating method. Filling that shape needs molten filler metal deposited by an arc or gas process, something resistance electrodes cannot supply.

Final Answer:

Seam and spot are resistance welding types; fillet and groove are joint shapes made by arc welding.

$$\boxed{\text{A and B}}$$

Quick Tip: Think about which weld types are defined by how the electrodes touch the plates rather than by joint geometry needing filler.

• • •

26. Which of the following factors affect(s) knocking in a Diesel engine?

(A) Injection timing

(B) Cetane number of the fuel

(C) Spark timing

(D) Compression ratio

Correct Answer: (A) Injection timing ; (B) Cetane number of the fuel ; (D) Compression ratio

SOLUTION:

Diesel knock is controlled by the ignition delay period, the gap between fuel injection and the start of combustion. Any factor that shortens or lengthens that gap changes how badly the engine knocks.

1. **Injection timing**: correct. If fuel is injected too early into cooler, lower pressure air, or too late, the delay period changes and more fuel can accumulate before ignition, increasing knock.
2. **Cetane number of the fuel**: correct. Cetane number is a direct measure of a fuel's self ignition quality, a low cetane fuel takes longer to ignite, builds up more unburned fuel, and knocks harder.
3. **Spark timing**: wrong. Diesel combustion is compression ignition with no spark plug at all, so there is no spark timing to adjust; this option belongs to petrol engines, not Diesel engines.
4. **Compression ratio**: correct. Raising the compression ratio raises the air temperature the fuel is injected into, shortening the delay period and reducing the chance of knock.

Since spark timing simply does not exist in a Diesel engine, the remaining three, injection timing, cetane number and compression ratio, are the correct answer: A, B and D.

Quick Tip: Remember a Diesel engine ignites fuel by compression heat alone, so ask which factors change that ignition delay.

• • •

27. During a captive maneuvering model test of a ship with a rudder, which ONE or MORE of the following coefficients can be calculated using an oblique towing test (straight line test with a drift angle)?

(A) Y_v and Y_{vvv}

(B) N_v and N_{vvv}

(C) $Y_{v\delta\delta}$ and $N_{v\delta\delta}$

(D) $N_{r\delta\delta}$ and $N_{vr\delta}$

Correct Answer: (A) Y_v and Y_{vvv} ; (B) N_v and N_{vvv} ; (C) $Y_{v\delta\delta}$ and $N_{v\delta\delta}$

SOLUTION:

Step 1: Fix what an oblique towing test physically does.
The model is towed on a straight track at a set drift angle so it has a sway velocity v but the carriage path is a straight line, which means the yaw rate $r = 0$ for the entire run. The rudder angle δ can be set and held fixed for each run.

Step 2: List what varies during the test.
Across a set of runs the test sweeps drift angle (hence v) and can also sweep the fixed rudder angle δ. It never sweeps r, since the carriage itself does not rotate during a run.

Step 3: Sort the four coefficient pairs by whether they contain r.

$Y_v, Y_{vvv}, N_v, N_{vvv}$ depend only on v, so they come straight out of the drift angle sweep. $Y_{v\delta\delta}, N_{v\delta\delta}$ depend on v and δ, both of which the test controls, so they can be fitted too. $N_{r\delta\delta}, N_{vr\delta}$ both contain r, a variable this test structurally cannot change, so they are unreachable here.

Final Answer:

Only the coefficients free of yaw rate, in options A, B and C, can be found from an oblique towing test.

$$\boxed{\text{A, B and C}}$$

Quick Tip: Ask which coefficients need the yaw rate to be nonzero, since an oblique towing test always keeps yaw rate at zero.

28. The weight of a ship is uniformly distributed along its length. Under which ONE or MORE of the following conditions will the ship be subjected to hogging moment?

Note: The weight is equal to buoyancy in all of the following conditions.

(A) When buoyancy per unit length is greater than weight per unit length amidships

(B) When weight per unit length is greater than buoyancy per unit length in the bow and stern region

(C) When the ship is on a single wave with its crest at midship and troughs at the bow and stern

(D) When the ship is on a single wave with its crests at the bow, stern and the trough at midship

Correct Answer: (A) When buoyancy per unit length is greater than weight per unit length amidships ; (B) When weight per unit length is greater than buoyancy per unit length in the bow and stern region ; (C) When the ship is on a single wave with its crest at midship and troughs at the bow and stern

SOLUTION:

Longitudinal bending of a ship's hull depends on how buoyancy support is spread along the length compared with the uniformly spread weight. Hogging always means relatively more upward support in the middle and relatively less at the ends.

1. **Buoyancy per unit length greater than weight per unit length amidships**: correct. Extra buoyant lift in the middle pushes the center of the hull up faster than the ends, arching it into a hog.
2. **Weight per unit length greater than buoyancy per unit length at the bow and stern**: correct. If the ends carry more weight than the local buoyancy can support, they sink relative to the middle, which is again the hogging shape, just described from the ends instead of the middle.
3. **Wave crest at midship, troughs at bow and stern**: correct. A crest amidships raises the local waterline and buoyancy there while the bow and stern sit lower in troughs with less buoyant support, giving the classic hogging wave profile.
4. **Wave crests at bow and stern, trough at midship**: wrong. Here the ends get the extra buoyant support from the crests while the middle sits in the trough with less support, which bends the hull the other way into a sagging shape, not hogging.

So the conditions that hog the ship are A, B and C; option D instead describes sagging.

Quick Tip: Picture whether the extra upward push sits in the middle or at the ends of the ship in each case.

• • •

29. Which of the following processes is/are used for heat addition in an air-standard dual cycle?

(A) Isochoric

(B) Isobaric

(C) Isentropic

(D) Isothermal

Correct Answer: (A) Isochoric ; (B) Isobaric

SOLUTION:

Step 1: Trace the dual cycle stages.
Start from state 1 with isentropic compression to state 2, no heat transfer here.
From state 2 to state 3 the gas is heated at constant volume, this is the isochoric leg.

Step 2: Check the second heat addition leg.
From state 3 to state 4 the gas keeps absorbing heat, but now at constant pressure, this is the isobaric leg.
After state 4 the gas expands isentropically to state 5 and then rejects heat at constant volume back to state 1, and neither of these two legs adds heat.

Step 3: Match against the options.
Isentropic and isothermal processes do not appear as heat addition steps anywhere in this cycle, so C and D drop out.

Final Answer:
Heat is added first at constant volume, then at constant pressure. Options A (isochoric) and B (isobaric) are the correct choices.

Quick Tip: Think about the two-stage heat addition in a dual cycle, one part at fixed volume and one at fixed pressure.

• • •

30. Which ONE or MORE of the following methods of shifting weights can be used to improve the transverse stability of a rectangular pontoon?
Note: CG denotes the vertical centre of gravity of the pontoon.

(A) From below the CG to above the CG

(B) From above the CG to below the CG

(C) From port to starboard at the same height from the keel

(D) From forward to aft at the same height from the keel

Correct Answer: (B) From above the CG to below the CG

SOLUTION:

Step 1: Write down the GM relation.
$GM = KB + BM - KG$, where KB and BM are fixed by the hull shape and the draft.
Only KG changes when weight is shifted inside the pontoon, so only vertical shifts matter for GM.

Step 2: Test each shift against this rule.

Moving weight from below the CG to above the CG raises KG, so GM falls, ruling out option A.

Moving weight from above the CG to below the CG lowers KG, so GM rises, which is exactly what improves stability.

The port to starboard and forward to aft shifts happen at a fixed height above the keel, so KG does not change at all in either case, ruling out C and D.

Final Answer:

Only a downward shift of weight, from above the CG to below the CG, raises GM.

The correct option is B.

Quick Tip: Ask which shift actually lowers the vertical centre of gravity, since GM depends only on KG among these choices.

• • •

31. Which ONE or MORE of the following can be caused by scavenging in a two-stroke Diesel engine?

(A) Dilution of incoming fuel-air mixture

(B) Loss of incoming air

(C) Pushing out exhaust gases by incoming air

(D) Autoignition

Correct Answer: (B) Loss of incoming air ; (C) Pushing out exhaust gases by incoming air

SOLUTION:

Step 1: Recall what scavenging physically does.
Fresh air enters near bottom dead centre and sweeps the burnt gas out through the exhaust port before the next compression stroke.
This sweeping action is exactly what option C describes, so it is correct.

Step 2: Check the known scavenging loss.
Because inlet and exhaust ports are open together for a short overlap period, part of the fresh air passes straight out with the exhaust gas instead of staying in the cylinder.
This wasted air is the loss described in option B, so B is correct too.

Step 3: Rule out the remaining options.
A Diesel engine injects fuel after the air charge is already trapped and compressed, so there is no fuel-air mixture present during scavenging to dilute, ruling out A.
Autoignition depends on compression ratio and injection timing, not on the scavenging air flow, ruling out D.

Final Answer:
Scavenging causes loss of some fresh air and is itself the act of pushing exhaust gas out.
Options B and C are the correct choices.

Quick Tip: Remember scavenging in a Diesel engine moves only air, not a fuel-air mixture, and some of that air always escapes with the exhaust.

• • •

32. A vessel of 5000 m^3 displacement floating in seawater has a rectangular tank of length 6 m and width 10 m. The tank is half-filled with seawater as shown in the figure.

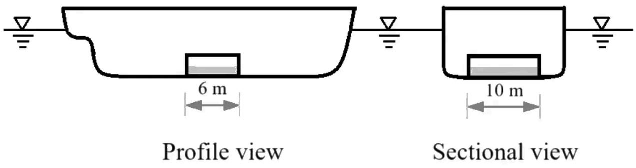


Figure not to scale

The virtual reduction in metacentric height due to free surface effect is ________ m (answer in one decimal place).

Correct Answer: 0.1

SOLUTION:

Free surface effect happens because a partly filled tank lets liquid slosh sideways whenever the ship heels, and that shifting liquid behaves like a virtual rise of the vessel's centre of gravity instead of adding real stability. The size of this virtual rise depends only on the tank's own free surface shape and the ship's total displacement volume, not on how deep the tank is or how full it is.

From the figure, the tank's free surface is a rectangle of fore-aft length 6 m and athwartship breadth 10 m. For a rectangular free surface, the relevant second moment of area about the centreline is $i = lb^3/12$, which uses the breadth raised to the third power because that is the direction the liquid actually swings across. Substituting the values gives $i = 6 \times 1000/12 = 500\ \text{m}^4$.

The general free surface correction is $FSC = (\rho_{liquid}/\rho_{sw}) \times i/V$. Since the tank holds seawater and the vessel also floats in seawater, the density ratio cancels to 1, leaving $FSC = i/V = 500/5000$. This works out to 0.1 m, so the metacentric height is effectively reduced by 0.1 m by this free surface.

Quick Tip: Use FSC = i/V with the tank's breadth cubed in the moment of inertia, since the tank liquid matches the seawater density.

• • •

33. A solid beam with a rectangular cross-section of breadth 0.5 m and depth 0.12 m, experiences a vertical shear force of 50 kN at a section. The maximum shear stress in that section is _______ MPa (answer in two decimal places).

Correct Answer: 1.25

SOLUTION:

Shear stress across a solid rectangular beam is not the same everywhere on the section. It is zero at the top and bottom edges and rises to a peak at the neutral axis, following a parabolic curve, so simply dividing the shear force by the area only gives an average value, not the true peak.

The cross-sectional area here is $A = b \times d = 0.5 \times 0.12 = 0.06$ square metres. With a shear force of $V = 50$ kN, the average shear stress works out to $\tau_{avg} = V/A = 50000/0.06 = 833333.33$ pascals.

For a rectangle, the peak shear stress at the neutral axis is exactly one and a half times this average value, a standard result that comes from the parabolic shear stress formula for a rectangular section. So $\tau_{max} = 1.5 \times 833333.33 = 1250000$ pascals.

Converting to megapascals by dividing by one million gives $\tau_{max} = 1.25$ MPa, which is the maximum shear stress carried at that section.

Quick Tip: Find the average shear stress V/A first, then multiply by 1.5 since a rectangular section has a parabolic shear distribution.

• • •

34. Consider two insulated tubes with air flowing steadily through them. The flow rate and temperature of the air are 0.1 kg/s, 20 °C in tube 1 and 0.2 kg/s, 25 °C in tube 2.
If the two streams are allowed to mix adiabatically, the steady-state temperature of the mixed stream is _______ °C (rounded off to one decimal place).
Assume a constant C_p for air.

Correct Answer: 23.3

SOLUTION:

When two streams of the same fluid mix adiabatically in a steady flow with no work done, energy conservation means the total enthalpy carried in by both streams must equal the enthalpy carried out by the combined stream. There is no heat loss to account for since both tubes are insulated.

For an ideal gas with constant C_p, the enthalpy flow of a stream is just $\dot{m}C_pT$. Writing the balance for the two inlet streams and the single outlet stream gives $\dot{m}_1C_pT_1 + \dot{m}_2C_pT_2 = (\dot{m}_1 + \dot{m}_2)C_pT_{mix}$, and since C_p appears in every term it drops out completely.

What remains is a mass flow weighted average of temperature. Plugging in $\dot{m}_1 = 0.1$ kg/s at 20 C and $\dot{m}_2 = 0.2$ kg/s at 25 C gives T_{mix} $= (0.1 \times 20 + 0.2 \times 25)/(0.1 + 0.2) = 7/0.3$.

Working that out gives $T_{mix} = 23.33$ C, which rounds to 23.3 C, the steady state temperature of the combined air stream.

Quick Tip: Use a steady-flow energy balance with constant Cp, it reduces to a mass-weighted average of the two inlet temperatures.

• • •

35. Consider a reversible heat engine with a thermal efficiency of 55%. The engine is reversed and operated as a heat pump between the same temperature reservoirs.
If the heat supplied from the low temperature reservoir is 45 kJ/cycle, then the absolute value of heat rejected is _______ kJ/cycle (answer in integer).

Correct Answer: 100

SOLUTION:

A reversible engine and a reversible heat pump running between the same two reservoirs share the exact same temperature ratio, because reversibility fixes $Q_L/Q_H = T_L/T_H$ regardless of which direction the cycle runs. This lets us reuse the efficiency information from the engine mode directly in the heat pump mode.

As an engine, $\eta = 1 - T_L/T_H = 0.55$, so $T_L/T_H = 0.45$. This is the same ratio that connects the heat pump's cold-side heat intake Q_L and hot-side heat rejection Q_H, since $Q_L/Q_H = T_L/T_H$.

Now with the engine reversed into a heat pump, the heat absorbed from the low temperature reservoir is given as $Q_L = 45$ kJ/cycle. Rearranging the ratio gives $Q_H = Q_L \times (T_H/T_L) = 45/0.45$.

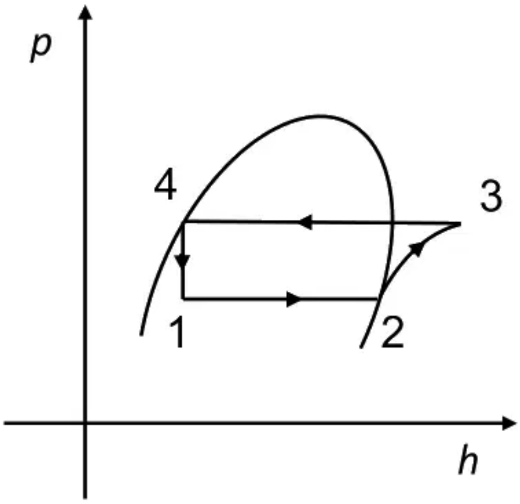
This works out to exactly 100 kJ/cycle, so the heat pump rejects 100 kJ/cycle to the high temperature reservoir, which is the required answer.

Quick Tip: First get T_L/T_H from the engine efficiency, then reuse the same ratio for the heat pump's Q_L/Q_H.

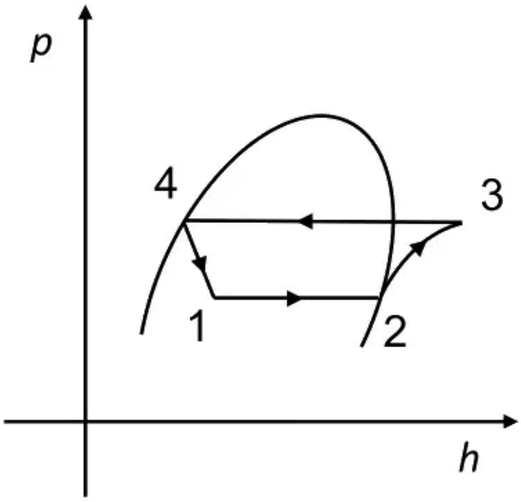
• • •

36. Identify the *p*-*h* diagram that denotes a vapor compression refrigeration cycle with flash intercooling from the following.
The pressure and specific enthalpy of the working fluid are represented by *p* and *h* respectively.

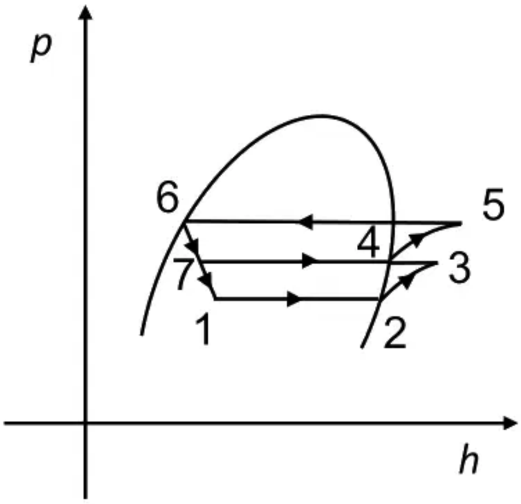
(A)



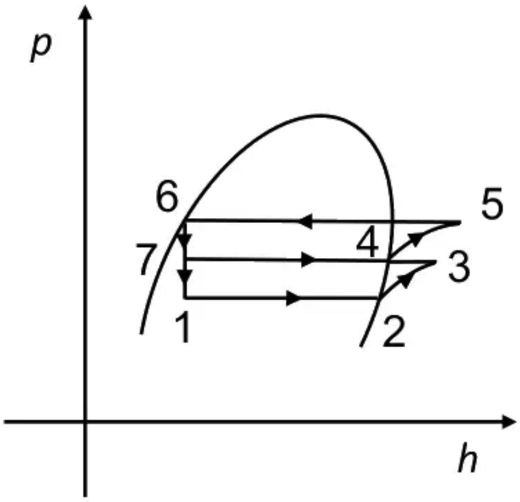
(B)



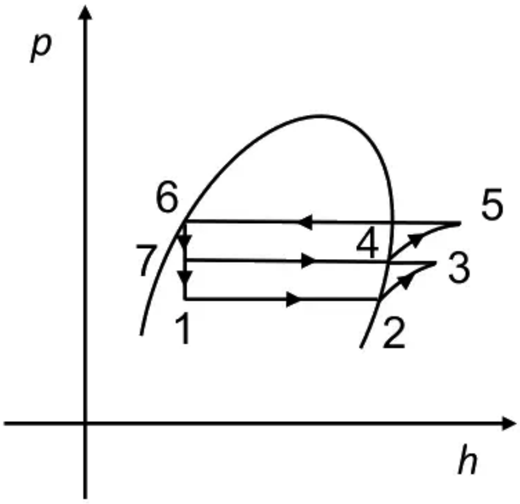
(C)



(D)



Correct Answer: (D)



SOLUTION:

Step 1: List what a flash intercooling cycle must contain.

A two stage vapor compression cycle with flash intercooling needs two compressors, a condenser, a flash chamber at an intermediate pressure, and two expansion valves. That gives seven distinct states: 1 (evaporator exit), 2 (after the low stage compressor), 3 (saturated vapor leaving the flash chamber), 4 (state after 2 and 3 mix), 5 (after the high stage compressor), 6 (condenser exit, saturated liquid), and 7 (after the first expansion valve, entering the flash chamber).

Step 2: Drop the four state options.

Options A and B each draw only states 1, 2, 3 and 4, a single compression stage with a single throttle valve. That is an ordinary vapor compression cycle, not one with flash intercooling, so both get ruled out no matter how small the drawing difference between them is.

Step 3: Compare the two seven state options.

Both C and D put 6 and 5 on the high pressure line, and 7, 4, 3 on the intermediate pressure line, with 1 and 2 on the low pressure line, so the skeleton is right in both. The liquid leaving the flash chamber still has to throttle a second time, from 7 down to 1, before it reaches the evaporator. Option C does not mark this second expansion as its own process, while option D draws both throttling legs, 6 to 7 and 7 to 1, as separate arrowed steps.

Final Answer:

Only option D shows the full sequence: two compressions, one condensation, flash chamber mixing, and two throttling steps, which is what defines a flash intercooling cycle.

$$\text{Correct option} = D$$

Quick Tip: Count how many states the working fluid passes through and check whether both throttling steps around the flash chamber are drawn.

• • •

37. Which ONE of the following options CORRECTLY matches the efficiencies in **Column 1** with the corresponding definitions in **Column 2**?

Column 1		Column 2	
I	Gear efficiency	P	Ratio of delivered power to shaft power
II	Shaft efficiency	Q	Ratio of shaft power to brake power
III	Hull efficiency	R	Ratio of thrust power to delivered power
IV	Propeller (behind-hull) efficiency	S	Ratio of effective power to thrust power

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

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

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

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

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

SOLUTION:

Step 1: Write the power chain in order.

Power leaves the engine as brake power P_B, passes through the gearbox to become shaft power P_S, travels along the shafting to become delivered power P_D at the propeller, gets turned by the propeller into thrust power P_T, and finally moves the hull as effective power P_E.

Step 2: Attach one efficiency to each link.

P_S/P_B is the gear efficiency, the only step between brake power and shaft power, so it is Q. P_D/P_S is the shaft efficiency, the step from shaft power to delivered power, so it is P. P_T/P_D is the propeller (behind-hull) efficiency, turning delivered power into thrust, so it is R. P_E/P_T is the hull efficiency, turning thrust power into effective power, so it is S.

Step 3: Match each roman numeral.

I (Gear) needs Q, II (Shaft) needs P, III (Hull) needs S, IV (Propeller, behind-hull) needs R.

Final Answer:

The set I-Q, II-P, III-S, IV-R is option A.

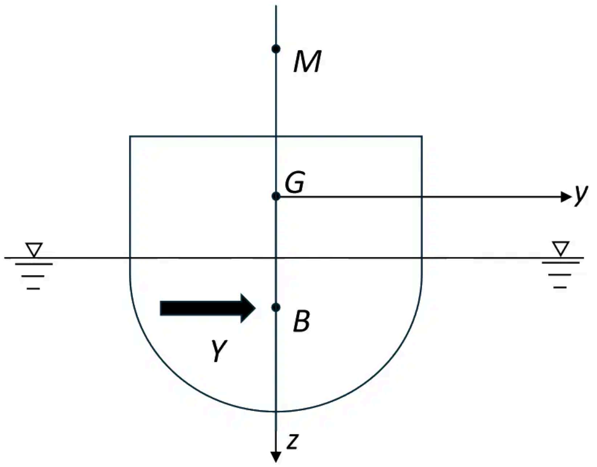
$$\text{Correct option} = A$$

Quick Tip: Trace the power chain from brake power at the engine down to effective power at the hull, one link at a time.

38. A ship is undergoing a steady starboard turn. Assume that the total hydrodynamic forces Y including the rudder forces act at the centre of buoyancy B.
If W is the weight of the ship, G is the centre of gravity and M is the transverse metacentre, then the magnitude of the heel angle ϕ is given by

______.

Assume that ϕ is small.



(A) $\left|\dfrac{Y \times BG}{W \times GM}\right|$

(B) $\left|\dfrac{W \times BG}{Y \times GM}\right|$

(C) $\left|\dfrac{W \times GM}{Y \times BG}\right|$

(D) $\left|\dfrac{Y \times GM}{W \times BG}\right|$

Correct Answer: (A) $\left|\dfrac{Y \times BG}{W \times GM}\right|$

SOLUTION:

Step 1: Set up the couple using the figure axes.

In the figure, y points athwartship and z points down, with M above G and G above B before the ship heels. The force Y acts at B along the y direction and stays constant through the steady turn.

Step 2: Write the restoring couple that appears once the ship heels.
Once the ship heels by a small angle ϕ, the line of action of the buoyancy force shifts sideways from G by the righting arm GZ, and for a small angle $GZ = GM \sin\phi \approx GM\,\phi$. The weight W acting through G and the shifted buoyancy force together form a restoring couple of size $W \times GM \times \phi$ that always pushes the ship back upright.

Step 3: Balance the disturbing couple from Y against this restoring couple.
The disturbing couple comes from Y acting at B while the mass of the ship effectively resists at G, a vertical distance BG away, giving a disturbing moment $Y \times BG$. In steady turning the ship heels to a fixed angle where these two couples cancel: $Y \times BG = W \times GM \times \phi$.

Final Answer:
Rearranging for the heel angle and reporting it as a magnitude gives the same expression.

$$\boxed{\phi = \left|\frac{Y \times BG}{W \times GM}\right|}$$

Quick Tip: Balance the heeling moment created by the offset horizontal force Y against the usual righting moment W times GM times the heel angle.

• • •

39. A ship undergoing harmonic oscillation has an uncoupled heave motion, $\eta_3(t)$, governed by the following equation

$$(M + A_{33})\,\ddot{\eta}_3(t) + B_{33}\,\dot{\eta}_3(t) + K_{33}\eta_3(t) = f_3(t)$$

If $F_3(\omega)$ is the Fourier transform of $f_3(t)$, then the response in the frequency domain can be written as _______.

(A) $\dfrac{F_3(\omega)}{-\omega^2(M + A_{33}) + i\omega B_{33} + K_{33}}$

(B) $\dfrac{iF_3(\omega)}{-\omega^2(M + A_{33}) + i\omega B_{33} + K_{33}}$

(C) $\dfrac{F_3(\omega)}{\omega^2(M + A_{33}) - i\omega B_{33} + K_{33}}$

(D) $\dfrac{F_3(\omega)}{\omega^2(M + A_{33}) + \omega B_{33} + K_{33}}$

Correct Answer: (A) $\dfrac{F_3(\omega)}{-\omega^2(M + A_{33}) + i\omega B_{33} + K_{33}}$

SOLUTION:

Step 1: Use the Fourier transform property for derivatives.
Taking the Fourier transform is linear, and it turns a time derivative into multiplication by $i\omega$ in the frequency domain. So if $H_3(\omega)$ is the transform of $\eta_3(t)$, then $\dot{\eta}_3(t)$ transforms to $i\omega H_3(\omega)$, and $\ddot{\eta}_3(t)$ transforms to $(i\omega)^2 H_3(\omega) = -\omega^2 H_3(\omega)$.

Step 2: Transform the whole equation term by term.
$(M + A_{33})\ddot{\eta}_3(t)$ becomes $-\omega^2(M + A_{33})H_3(\omega)$, $B_{33}\dot{\eta}_3(t)$ becomes $i\omega B_{33}H_3(\omega)$, and $K_{33}\eta_3(t)$ becomes $K_{33}H_3(\omega)$. The right side $f_3(t)$ becomes $F_3(\omega)$ directly, by definition.

Step 3: Combine and solve for $H_3(\omega)$.

Adding the transformed terms and setting them equal to $F_3(\omega)$ gives $H_3(\omega)\left[-\omega^2(M + A_{33}) + i\omega B_{33} + K_{33}\right] = F_3(\omega)$, the same bracket as a mass, damping and stiffness combination evaluated at frequency ω.

Final Answer:

Solve for the frequency response directly.

$$\boxed{H_3(\omega) = \frac{F_3(\omega)}{-\omega^2(M + A_{33}) + i\omega B_{33} + K_{33}}}$$

Quick Tip: Turn each time derivative into a factor of i times omega using the standard Fourier transform property.

• • •

40. Adverse pressure gradient implies that _______.

(A) pressure decreases in the direction of flow

(B) pressure increases in the direction of flow

(C) pressure is zero everywhere within the flow field

(D) pressure is uniform (non-zero) everywhere within the flow field

Correct Answer: (B) pressure increases in the direction of flow

SOLUTION:

Step 1: Write the boundary layer momentum balance near a wall.

Close to a solid wall the fluid velocity is nearly zero, so the momentum equation there reduces mainly to a balance between the pressure gradient and the wall shear stress, roughly $\mu\left(\frac{\partial^2 u}{\partial y^2}\right)_{wall} = \frac{dp}{dx}$.

Step 2: Read what a positive dp/dx does to the flow.

If dp/dx is positive, pressure is rising along the flow direction x. That pressure rise acts like a brake on the slow moving fluid inside the boundary layer, decelerating it further and, if strong enough, pushing it backward and causing separation.

Step 3: Name this condition.

A positive dp/dx, meaning pressure increasing along the flow direction, is defined as an adverse pressure gradient because it opposes the flow instead of assisting it.

Final Answer:

So the defining condition is pressure rising in the direction of flow.

$$\frac{dp}{dx} > 0 \implies \text{adverse pressure gradient}$$

Quick Tip: Think about whether the pressure change is pushing the flow forward or holding it back near a wall.

• • •

41. The drag force on a non-lifting smooth body immersed in an incompressible, irrotational, uniform flow is _______.

(A) zero

(B) finite and greater than zero

(C) infinite

(D) finite and less than zero

Correct Answer: (A) zero

SOLUTION:

Step 1: State the assumptions in play.

The flow is incompressible and irrotational, so it can be described by a velocity potential, and the body is smooth and non-lifting, so no circulation is generated around it.

Step 2: Use symmetry of the potential flow solution.

For a closed smooth body in a uniform stream, the potential flow solution builds up a pressure field that is symmetric between the front and back of the body, since the flow that decelerates approaching the nose reaccelerates by the same amount leaving the tail. Integrating this symmetric pressure over the body surface gives equal and opposite contributions fore and aft, so the net force along the flow direction is zero.

Step 3: Check the other possible drag source.

Drag can also come from viscous skin friction, but the flow here is treated as inviscid (no viscosity term appears), so there is no shear stress on the surface either.

Final Answer:

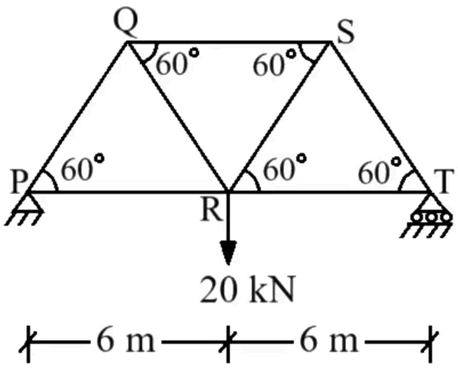
With both pressure drag and friction drag equal to zero, the total drag predicted by ideal flow theory is zero, which is d'Alembert's paradox.

$$\boxed{D = 0}$$

Quick Tip: Recall what ideal, inviscid potential flow theory predicts for the fore and aft pressure symmetry on a smooth body.

• • •

42. For the truss shown in the figure, the magnitude of force in the member PR is ________ kN.



(A) 10

(B) 0

(C) $\dfrac{10}{\sqrt{3}}$

(D) $\dfrac{20}{\sqrt{3}}$

Correct Answer: (C) $\dfrac{10}{\sqrt{3}}$

SOLUTION:

Step 1: Get the reactions from symmetry, same as before.

Because the geometry and the single 20 kN load at R both sit symmetric about the centreline through R, the pin at P and the roller at T each pick up 10 kN vertically, with no horizontal reaction at P.

Step 2: Apply Lami's theorem at joint P.

At joint P only three forces act: the vertical reaction $R_P = 10$ kN pointing up, the force in member PQ along the 60 degree incline, and the force in member PR along the horizontal. Treating these three concurrent forces with Lami's theorem, the angle between R_P and PR is 90 degrees, the angle between R_P and PQ is 150 degrees, and the angle between PQ and PR is 120 degrees.

Step 3: Write the Lami ratio and solve.

$\frac{R_P}{\sin(120°)} = \frac{F_{PR}}{\sin(150°)} = \frac{F_{PQ}}{\sin(90°)}$. Using $R_P = 10$ kN, $\sin(120°) = \sqrt{3}/2$ and $\sin(150°) = 1/2$:

$$F_{PR} = R_P \times \frac{\sin(150°)}{\sin(120°)} = 10 \times \frac{1/2}{\sqrt{3}/2} = \frac{10}{\sqrt{3}} \text{ kN.}$$

Final Answer:

This matches the joint resolution method exactly.

$$\boxed{|F_{PR}| = \frac{10}{\sqrt{3}} \approx 5.77 \text{ kN}}$$

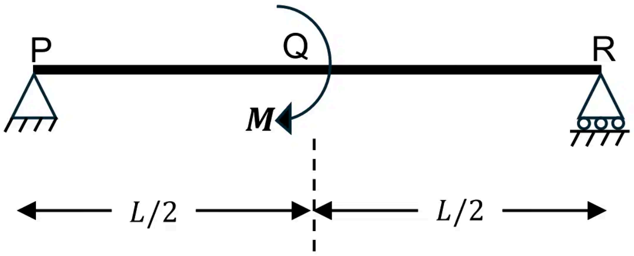
Quick Tip: Use symmetry to get the support reactions first, then resolve the two members meeting at joint P.

• • •

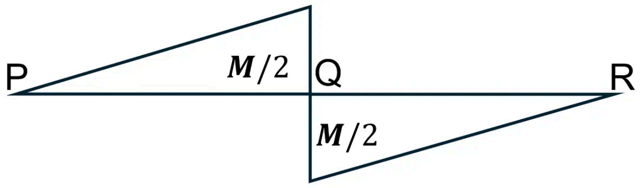
43. Choose the CORRECT bending moment diagram for the simply supported beam shown in the figure with a concentric moment M at mid span.

Consider hogging as positive and sagging as negative.

Figures not to scale



(A)



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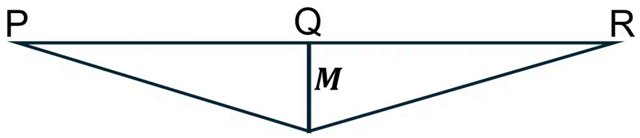
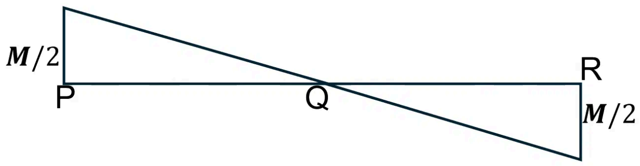
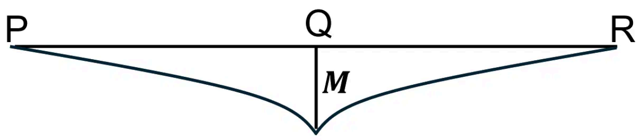


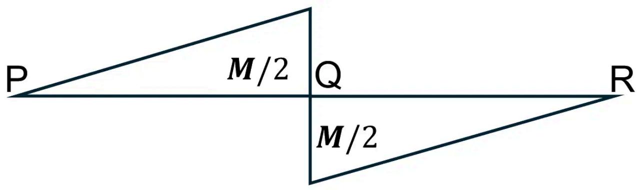
(C)



(D)



Correct Answer: (A)



SOLUTION:

Step 1: Note what a point moment does to a BM diagram.

The shear force diagram changes only at a point load, while the bending moment diagram jumps at a point where an external couple acts. That jump equals the couple itself, M.

Since beam PR carries no other load, the shear force stays constant along the whole span.

Step 2: Use symmetry and the end conditions.
Both P and R are simple supports, and a simple support carries zero moment. So the bending moment must be zero right at P and right at R.
Because Q sits exactly at the centre, the beam looks the same from either end. So the moment just left of Q and just right of Q must have equal size, splitting the jump M into two equal halves of $M/2$.

Step 3: Build the diagram from these facts.
Starting from zero at P, the moment must vary linearly up to magnitude $M/2$ just before Q. It then jumps across to the opposite sign, then varies linearly again back to zero at R.
Checking each choice: B and D show no discontinuity at Q at all, just one smooth value, which contradicts a concentrated moment's jump. C shows a moment of $M/2$ surviving at the supports, which a pin or roller cannot sustain.

Final Answer:
Only the diagram with zero end values and a symmetric $M/2$ jump at Q, option A, fits every condition.

$$\boxed{\text{Option A}}$$

Quick Tip: Remember a simple support carries zero moment, and a point couple creates a jump in the BM diagram equal to its own magnitude.

44. The stresses in a shaft are:
(i) Shear stress due to torsion
(ii) Normal stress due to bending moments
(iii) Axial stress

Which ONE of the following options lists the stresses that are considered while designing a circular propeller shaft?

(A) (i) and (ii) only

(B) (ii) and (iii) only

(C) (i) and (iii) only

(D) (i), (ii) and (iii)

Correct Answer: (D) (i), (ii) and (iii)

SOLUTION:

Step 1: List every load path into the shaft.
A propeller shaft sits between the engine and the propeller. The engine side feeds in torque, the propeller side feeds in thrust and a rotating weight. Check torsion, axial load, and bending separately.

Step 2: Check torsion.
Torque delivered by the engine to spin the propeller sets up a shear stress that varies with radius, largest at the outer surface of the circular shaft. So item (i) must be kept.

Step 3: Check bending.
The propeller overhangs the last bearing and has its own weight, and shaft misalignment adds further bending. This gives a bending moment along the shaft and a normal bending stress. So item (ii) must be kept.

Step 4: Check axial stress.
Thrust generated by the propeller to push the ship is carried by the shaft to the thrust bearing, loading the shaft axially in compression. So item (iii) must be kept too.

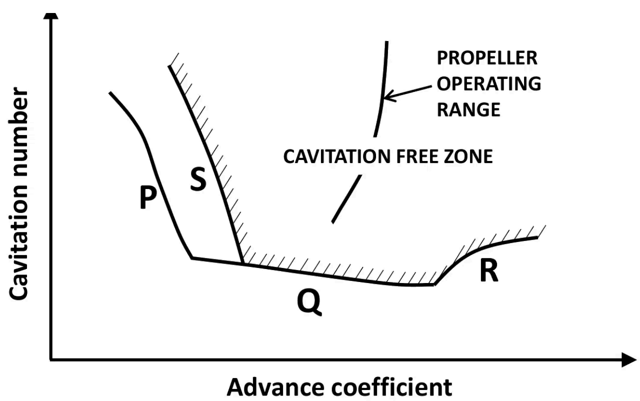
Final Answer:
All three stress types act together on a propeller shaft, so a safe design must combine them.

$$\boxed{\text{(i), (ii) and (iii)}}$$

Quick Tip: Think about every load a propeller shaft carries: torque from the engine, its own bending, and the propeller's thrust.

• • •

45. The figure depicts the cavitation pattern of a propeller.



Which ONE of the following options CORRECTLY gives the description for the labels P, Q, R, S, respectively in the figure?

(A) Face cavitation, Bubble cavitation, Back cavitation, Tip cavitation

(B) Back cavitation, Bubble cavitation, Face cavitation, Tip cavitation

(C) Bubble cavitation, Face cavitation, Tip cavitation, Back cavitation

(D) Tip cavitation, Face cavitation, Bubble cavitation, Back cavitation

Correct Answer: (B) Back cavitation, Bubble cavitation, Face cavitation, Tip cavitation

SOLUTION:

A propeller cavitation bucket diagram plots the cavitation number against the advance coefficient. It traces a separate limit curve for each way cavitation can start on the blade, so reading it means matching each curve's position to the loading condition that produces that cavitation type.

1. **P**: this curve sits furthest left, at the lowest advance coefficient, where the blade is most heavily loaded and the suction side sees the largest pressure drop. That is the classic condition for back cavitation.
2. **Q**: this curve is the wide, nearly flat base of the bucket at the smallest cavitation numbers, spanning the normal working range. That is where bubble cavitation on the mid chord region is the limiting factor.
3. **R**: this curve is on the right side of the bucket, appearing again as the advance coefficient grows large and the angle of attack turns slightly negative. That lets the pressure (face) side of the blade cavitate.
4. **S**: this curve runs just next to P, close to the back cavitation limit but separate from it. It represents the tip vortex forming as flow rolls off the blade tip.

Matching P, Q, R, S to back, bubble, face and tip cavitation in that order gives option B.

Quick Tip: Match each curve's position, low J, wide flat base, high J, or next to the back boundary, to where that cavitation type actually starts on the blade.

• • •

46. The dry bulb temperature (DBT) of atmospheric humid air is 30°C. The dew point temperature (DPT) is also 30°C and the humidity ratio is $0.025 \dfrac{\text{kg of water vapor}}{\text{kg of dry air}}$.

The relative humidity (RH) of the air is _______ %.

(A) 100

(B) 25

(C) 50

(D) 0

Correct Answer: (A) 100

SOLUTION:

This question checks the link between dew point temperature and relative humidity, not a calculation with the given humidity ratio.

1. **(A) 100**: correct. The dew point is the temperature at which air of a given moisture content becomes saturated. The air here is already at its dew point, since DPT equals DBT, so it is saturated right now, and saturated air has relative humidity of 100 percent.

2. **(B) 25**: wrong. This would apply only if the actual vapor pressure were a quarter of the saturation vapor pressure, which would show up as a dew point well below the dry bulb temperature, not equal to it.
3. **(C) 50**: wrong, for the same reason. A dew point below the dry bulb temperature gives a relative humidity below 100 percent, but here the two temperatures coincide.
4. **(D) 0**: wrong. Zero relative humidity means completely dry air with no water vapor at all, which could never have a dew point equal to the dry bulb temperature.

Since the dew point equals the dry bulb temperature, the air is saturated, and option A, 100 percent, is correct.

Quick Tip: Recall that air at its dew point temperature is, by definition, saturated air.

• • •

47. Which of the following statements is/are TRUE regarding matrices?

(A) Every square matrix can be expressed as the sum of a symmetric and a skew-symmetric matrix.

(B) The determinant of a square matrix is same as that of its transpose.

(C) The product of a square matrix and its inverse results in the identity matrix.

(D) Eigenvalues of a square matrix are always real and positive.

Correct Answer: (A) Every square matrix can be expressed as the sum of a symmetric and a skew-symmetric matrix. ; (B) The determinant of a square matrix is same as that of its transpose. ; (C) The product of a square matrix and its inverse results in the identity matrix.

SOLUTION:

Each option makes a general claim about square matrices, so the question asks which standard matrix facts hold for every square matrix, and which needs an extra condition not stated here.

1. **Every square matrix can be expressed as the sum of a symmetric and a skew-symmetric matrix**: true. Writing $A = \frac{1}{2}(A + A^T) + \frac{1}{2}(A - A^T)$ always splits any square A into a symmetric part and a skew-symmetric part, with no extra condition needed.
2. **The determinant of a square matrix is same as that of its transpose**: true. Transposing a matrix does not change the value from the cofactor expansion of its determinant, so $\det(A) = \det(A^T)$ always.
3. **The product of a square matrix and its inverse results in the identity matrix**: true. This is exactly how the inverse is defined; whenever A^{-1} exists, $AA^{-1} = I$ holds by construction.
4. **Eigenvalues of a square matrix are always real and positive**: false. This only holds for special matrices, such as symmetric positive definite ones. A general square matrix, for example a simple rotation matrix, can have complex or negative eigenvalues.

So the correct statements are the first three, giving option A, B, C.

Quick Tip: Test the eigenvalue claim with a simple 2x2 matrix before trusting it as a general rule.

• • •

48. Consider a steady, two-dimensional, laminar, incompressible flow of water over a horizontal flat plate of length L with Reynolds number, $Re_L = 10^4$. The flat plate is aligned with the incoming free-stream flow. The x-axis is along the length of the plate while the y-axis is normal to the plate. The respective velocity components are u and v.

Which of the following statements is/are TRUE?

(A) For the flow within the boundary layer, $u \gg v$.

(B) For the flow within the boundary layer, $\frac{\partial u}{\partial y} \gg \frac{\partial u}{\partial x}$.

(C) The flow within the boundary layer is irrotational and inviscid.

(D) The thickness of the boundary layer is much less than the length of the flat plate.

Correct Answer: (A) For the flow within the boundary layer, $u \gg v$. ; (B) For the flow within the boundary layer, $\frac{\partial u}{\partial y} \gg \frac{\partial u}{\partial x}$. ; (D) The thickness of the boundary layer is much less than the length of the flat plate.

SOLUTION:

All four statements describe flow over a flat plate at Reynolds number 10^4, low enough to stay laminar over the full length. Each claim can be checked against the basic boundary layer picture, a thin viscous layer next to the wall with the free stream almost undisturbed just outside it.

1. **For the flow within the boundary layer, $u \gg v$**: true. Flow inside the layer runs mostly parallel to the plate, and the small velocity normal to the wall, v, stays far smaller than the streamwise velocity u.

2. **For the flow within the boundary layer, $\partial u/\partial y \gg \partial u/\partial x$**: true. u rises from zero at the wall to nearly the free stream value across a very thin layer in y, a much sharper change than the slow growth of the layer along x.
3. **The flow within the boundary layer is irrotational and inviscid**: false. The boundary layer is exactly where viscosity acts and where the velocity gradient produces vorticity, so calling it inviscid and irrotational contradicts its own definition.
4. **The thickness of the boundary layer is much less than the length of the flat plate**: true. Using $\delta/L \approx 5/\sqrt{Re_L}$ with $Re_L = 10^4$ gives $\delta/L \approx 0.05$, so the layer is only about 5 percent as thick as the plate is long.

So the true statements are the first, second and fourth, giving option A, B, D.

Quick Tip: Use the thin-layer scaling of boundary layer theory to check each velocity-gradient and thickness claim.

• • •

49. Pick the CORRECT statement(s) corresponding to the following equation

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = -\frac{1}{\rho} \nabla p + \mathbf{g} + \vartheta \nabla^2 \mathbf{u}$$

where $\mathbf{u}$ is the velocity vector, p is the pressure, ρ is the density, $\mathbf{g}$ is the gravitational acceleration vector, t is time, and ϑ is the kinematic viscosity.

(A) It represents the conservation of linear momentum.

(B) It is a nonlinear partial differential equation.

(C) It is valid for both Newtonian and non-Newtonian fluids.

(D) It is valid for incompressible flow.

Correct Answer: (A) It represents the conservation of linear momentum. ; (B) It is a nonlinear partial differential equation. ; (D) It is valid for incompressible flow.

SOLUTION:

The given equation is the Navier-Stokes momentum equation. Each statement can be checked by recalling what assumptions go into deriving this particular form, and what mathematical character its terms have.

1. **It represents the conservation of linear momentum**: true. The left side is the acceleration of a fluid particle following the flow, and the right side is the sum of the forces per unit mass acting on it, which is Newton's second law for a fluid.
2. **It is a nonlinear partial differential equation**: true. The convective term $\mathbf{u} \cdot \nabla\mathbf{u}$ has the unknown $\mathbf{u}$ multiplying its own derivative, which makes the whole equation nonlinear in the velocity field.
3. **It is valid for both Newtonian and non-Newtonian fluids**: false. The last term uses a single constant kinematic viscosity ϑ, which only describes a Newtonian fluid. A non-Newtonian fluid needs a different, shear-rate dependent stress model.
4. **It is valid for incompressible flow**: true. The viscous term written as $\vartheta\nabla^2\mathbf{u}$ is the simplified incompressible form of the

viscous stress divergence, so this is the standard incompressible Navier-Stokes equation.

So the correct statements are the first, second and fourth, giving option A, B, D.

Quick Tip: Check what the convective term does to linearity, and what the single-viscosity term assumes about the fluid.

• • •

50. Consider the flow of water over a smooth curved wall surface. It is given that the flow separates at some location R on the surface, known as the separation point.

Pick the CORRECT option(s).

(A) At R, the wall shear stress is zero.

(B) At R, $\frac{\partial u}{\partial y} = 0$, where y is normal to the surface and u is the velocity of the flow tangential to the surface.

(C) At R, viscosity of the fluid becomes zero.

(D) Immediately downstream of R, the direction of flow is reversed locally.

Correct Answer: (A) At R, the wall shear stress is zero. ; (B) At R, $\frac{\partial u}{\partial y} = 0$, where y is normal to the surface and u is the velocity of the flow tangential to the surface. ; (D) Immediately downstream of R, the direction of flow is reversed locally.

SOLUTION:

Step 1: Recall what defines a separation point.
In boundary layer flow over a curved wall, the fluid near the surface loses kinetic energy to friction and to the adverse pressure gradient once the wall curves away from the flow.
Separation is the point R where the velocity profile close to the wall stops moving forward.

Step 2: Write the wall condition in math form.
The tangential velocity is u and y is measured normal to the wall, so the wall shear stress is $\tau_w = \mu \left(\frac{\partial u}{\partial y}\right)_{y=0}$.
At R the fluid right at the wall is on the verge of reversing, so $\partial u/\partial y = 0$ there, and since μ is not zero, $\tau_w = 0$ too. This makes both A and B correct restatements of the same fact.

Step 3: Check the remaining options.
Viscosity μ is a property of the fluid and does not drop to zero at separation, so option C is wrong.
Just past R, the adverse pressure gradient overpowers the forward momentum near the wall, so the flow there turns backward, giving a local reverse flow and confirming option D.

Final Answer:
Options A, B and D describe the separation point correctly.

$$\boxed{\text{A, B, D}}$$

Quick Tip: Think about what happens to the velocity gradient at the wall right at the point where the boundary layer lifts off.

51. Which of the following Reynolds numbers do(es) NOT represent creeping flow?

(A) 0.01

(B) 0.001

(C) 5×10^5

(D) 2300

Correct Answer: (C) 5×10^5 ; (D) 2300

SOLUTION:

Creeping flow is the name given to very slow, highly viscous flow where the Reynolds number stays well under 1, so inertia forces barely matter compared with viscous forces.

1. **0.01**: This is much smaller than 1, so it sits comfortably in the creeping flow range.
2. **0.001**: Also much smaller than 1, again a creeping flow value.
3. 5×10^5: This is an extremely large Reynolds number, typical of fully turbulent flow, far outside the creeping flow range.
4. **2300**: This is the usual number quoted for transition from laminar to turbulent pipe flow, which is nowhere near the creeping flow limit.

So options C and D are the Reynolds numbers that do not represent creeping flow.

Quick Tip: Creeping flow needs the Reynolds number to be much smaller than 1.

• • •

52. Consider two engines operating on Otto and Diesel air-standard cycles with the same compression ratio.

Which of the following is/are TRUE about the thermal efficiency (η) and the peak pressure (p_{peak})?

(A) $\eta_{Otto} < \eta_{Diesel}$

(B) $\eta_{Otto} > \eta_{Diesel}$

(C) $(p_{peak})_{Otto} > (p_{peak})_{Diesel}$

(D) $(p_{peak})_{Otto} = (p_{peak})_{Diesel}$

Correct Answer: (B) $\eta_{Otto} > \eta_{Diesel}$; (C) $(p_{peak})_{Otto} > (p_{peak})_{Diesel}$

SOLUTION:

Both engines start from the same state and compress the charge through the same compression ratio, so the difference between them comes only from how heat is added after compression.

1. $\eta_{Otto} < \eta_{Diesel}$: Wrong. At equal compression ratio the Diesel cycle always carries a correction factor below 1 in its efficiency formula, which pulls its efficiency under the Otto value.
2. $\eta_{Otto} > \eta_{Diesel}$: Correct. Constant volume heat addition in the Otto cycle uses the compression ratio more effectively than the constant pressure addition in the Diesel cycle, so Otto wins on efficiency here.
3. $(p_{peak})_{Otto} > (p_{peak})_{Diesel}$: Correct. Since heat is added at constant volume in the Otto cycle, pressure rises steeply right after compression, producing a higher peak than the Diesel cycle where pressure stays flat during heat addition.
4. $(p_{peak})_{Otto} = (p_{peak})_{Diesel}$: Wrong, the peak pressures are not equal for the reason given above.

So the correct choices are B and C.

Quick Tip: Compare how pressure and efficiency behave for constant volume heat addition versus constant pressure heat addition at the same compression ratio.

• • •

53. For a dynamic system with single degree of freedom, choose the CORRECT statement(s).

(A) Damped natural frequency is greater than the undamped natural frequency.

(B) Dynamic response is always greater than static response at all excitation frequencies.

(C) Damping ratio can be estimated using logarithmic decrement method.

(D) A non-zero phase lag is always observed between the excitation and response for a damped system.

Correct Answer: (C) Damping ratio can be estimated using logarithmic decrement method. ; (D) A non-zero phase lag is always observed between the excitation and response for a damped system.

SOLUTION:

Step 1: Check the frequency statement.
For a damped single degree of freedom system, $\omega_d = \omega_n\sqrt{1-\zeta^2}$, and since ζ lies between 0 and 1 for an underdamped system, ω_d is always less than ω_n.
So the claim that damped frequency is greater than undamped frequency is false.

Step 2: Check the response magnitude statement.

The magnification factor $M = \dfrac{1}{\sqrt{(1-r^2)^2 + (2\zeta r)^2}}$, where $r = \omega/\omega_n$, falls below 1 for large r.

This means the dynamic response becomes smaller than the static response at high excitation frequencies, so this statement is also false.

Step 3: Check the damping ratio and phase statements.

The logarithmic decrement $\delta = \ln(x_1/x_2)$ between two successive free vibration peaks connects directly to ζ through $\zeta = \delta/\sqrt{4\pi^2 + \delta^2}$, so estimating damping ratio this way is valid.

The phase angle $\phi = \tan^{-1}\left(\dfrac{2\zeta r}{1-r^2}\right)$ is nonzero whenever $\zeta > 0$ and the system is excited, confirming a lag always exists for a damped system.

Final Answer:

Only the damping ratio and phase lag statements hold true.

$$\boxed{\text{C, D}}$$

Quick Tip: Recall how damping changes the natural frequency and how the magnification factor behaves at high frequency ratios.

• • •

54. A differentiable function $f(x)$ is such that $f(-0.1) = 2$, $f(0) = 1$, and $f(0.1) = 2$.

Then, $\dfrac{d^2 f}{dx^2}$ at $x = 0$ is ________ (answer in integer).

Correct Answer: 200

SOLUTION:

Step 1: Write Taylor expansions around $x = 0$.

For small h, $f(h) = f(0) + hf'(0) + \frac{h^2}{2}f''(0) + O(h^3)$ and $f(-h) = f(0) - hf'(0) + \frac{h^2}{2}f''(0) + O(h^3)$.

Step 2: Add the two expansions.

Adding cancels the odd $f'(0)$ term: $f(h) + f(-h) = 2f(0) + h^2 f''(0) + O(h^4)$.

Rearranging gives $f''(0) \approx \frac{f(h) + f(-h) - 2f(0)}{h^2}$, the same second derivative estimate reached from a different route.

Step 3: Plug in the numbers.

With $h = 0.1$: $f''(0) \approx \frac{2 + 2 - 2(1)}{(0.1)^2} = \frac{2}{0.01} = 200$.

Final Answer:

The Taylor series route confirms the same value for the second derivative.

$$\boxed{200}$$

Quick Tip: Use the standard three point central difference formula for the second derivative.

• • •

55. Consider the function $f(x, y) = x^3 + y^2$.

If $\vec{F} = \nabla f$, then $\displaystyle\int \vec{F} \cdot d\vec{r}$ evaluated from $(0, 0)$ to $(1, 2)$ is ________ (answer in integer).

Correct Answer: 5

SOLUTION:

Step 1: Find the gradient explicitly.
$\nabla f = \left(\dfrac{\partial f}{\partial x}, \dfrac{\partial f}{\partial y}\right) = (3x^2, 2y)$, so $\vec{F} = 3x^2\,\hat{\imath} + 2y\,\hat{\jmath}$.

Step 2: Pick a straight line path and parametrize it.
Let $x = t$, $y = 2t$ for t from 0 to 1, so $dx = dt$ and $dy = 2\,dt$.
Then $\vec{F} \cdot d\vec{r} = 3t^2\,dt + 2(2t)(2\,dt) = 3t^2\,dt + 8t\,dt$.

Step 3: Integrate over t.
$\int_0^1 (3t^2 + 8t)\,dt = \left[t^3 + 4t^2\right]_0^1 = 1 + 4 = 5.$
This matches the potential difference method exactly, since the field does not care which path is used.

Final Answer:
The value of the line integral is 5.

$$\boxed{5}$$

Quick Tip: A gradient field is path independent, so the integral is just the potential difference between the endpoints.

• • •

56. Consider a case where two identical six-faced fair dice are rolled simultaneously.

The probability of getting even numbers in both AND a sum equal to 5 and above is _______ (rounded off to two decimal places).

Correct Answer: 0.22

SOLUTION:

Step 1: Separate the two conditions.

Let event E be "both dice show even numbers" and event S be "the sum is 5 or more." We need $P(E \cap S)$.

Step 2: Find $P(E)$ and then restrict by S.

$P(E) = \frac{3}{6} \times \frac{3}{6} = \frac{9}{36}$, since each die has 3 even faces out of 6.

Within these 9 even-even pairs, only the pair (2,2) gives a sum below 5, since $2 + 2 = 4$. Every other even-even pair sums to 6 or more.

Step 3: Remove the failing pair and convert to probability.

So $9 - 1 = 8$ of the 9 even-even pairs also satisfy the sum condition, giving 8 favorable outcomes out of the full 36 outcomes.

$P(E \cap S) = \frac{8}{36} = 0.2222...$, which rounds to 0.22.

Final Answer:

The required probability rounds to 0.22.

$$\boxed{0.22}$$

Quick Tip: First list the outcomes where both dice are even, then keep only those with sum 5 or more.

57. Water of density 1000 kg/m^3 flows at a steady rate in a converging duct of circular cross-section. Let the areas of sections 1 and 2 be 100 cm^2 and 50 cm^2 respectively. The pressure and average velocity at section 1 are 110 kPa and 1 m/s.

If the centres of the two sections are at the same elevation, then the pressure at section 2 is _______ kPa (answer in one decimal place).

Correct Answer: 108.5

SOLUTION:

Step 1: Get V_2 from the continuity equation.
The volume flow rate stays constant along the duct, so $Q = A_1V_1 = A_2V_2$.
Using $A_1 = 0.01\ \text{m}^2$, $A_2 = 0.005\ \text{m}^2$, $V_1 = 1\ \text{m/s}$, we get $Q = 0.01\ \text{m}^3/\text{s}$, so $V_2 = Q/A_2 = 0.01/0.005 = 2\ \text{m/s}$.

Step 2: Write Bernoulli's equation in head form.
$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$, and since $z_1 = z_2$, the elevation heads cancel out.

Step 3: Solve for the pressure difference directly.
$P_1 - P_2 = \frac{1}{2}\rho(V_2^2 - V_1^2) = \frac{1}{2}(1000)(4 - 1) = 1500\ \text{Pa}$.
So $P_2 = P_1 - 1500 = 110000 - 1500 = 108500\ \text{Pa}$, the pressure drops because the duct narrows and speeds up the flow.

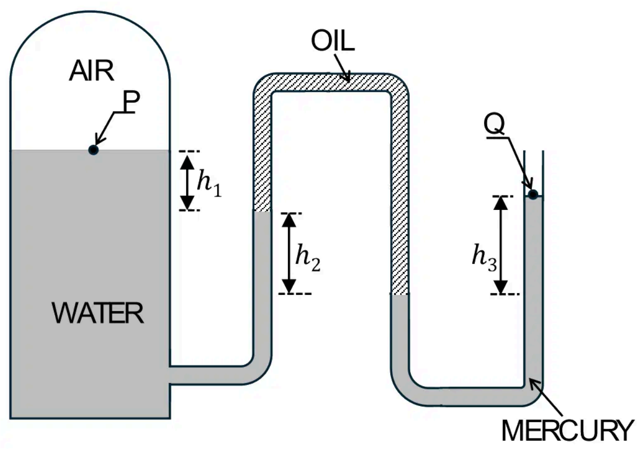
Final Answer:
The pressure at section 2 comes out to 108.5 kPa.

$$\boxed{108.5}$$

Quick Tip: Use continuity to get the velocity at section 2, then apply Bernoulli's equation between the two sections.

• • •

58. A static system consisting of air, water, oil and mercury is shown in the figure. If Q is open to the atmosphere, the gauge pressure at P is ________ kPa (rounded off to one decimal place).
Consider $g = 10$ m/s^2, $h_1 = 0.5$ m, $h_2 = 0.7$ m, $h_3 = 0.8$ m, density of water $= 1000$ kg/m^3, $SG_{oil} = 0.9$ and $SG_{mercury} = 13.6$ (where SG is specific gravity).



Correct Answer: 97.5

SOLUTION:

Step 1: Change every fluid column into an equivalent water head.
Using specific gravity, a mercury column of height h_3 carries the same pressure as $SG_{mercury}h_3$ metres of water, and an oil column of height h_2 carries the same pressure as $SG_{oil}h_2$ metres of water.

Step 2: Add up the heads from P to the open end Q.

Going from P down through water by h_1, then up through the oil loop by h_2, then up through mercury by h_3, brings us to atmospheric pressure at Q. In head terms: $P_{atm} = P_P + \rho_w g h_1 - \rho_w g(SG_{oil} h_2) - \rho_w g(SG_{mercury} h_3)$.

Step 3: Solve for the head at P and convert.

Rearranging, $P_P = \rho_w g(SG_{mercury} h_3 - SG_{oil} h_2 - h_1)$. Numerically $SG_{mercury} h_3 = 13.6 \times 0.8 = 10.88$ m, $SG_{oil} h_2 = 0.9 \times 0.7 = 0.63$ m, so the net water head is $10.88 - 0.63 - 0.5 = 9.75$ m.

Final Answer:

$P_P = 1000 \times 10 \times 9.75 = 97500$ Pa = 97.5 kPa, matching the 95 to 98 kPa key window.

$$\boxed{P_P = 97.5 \text{ kPa}}$$

Quick Tip: Start from the point open to atmosphere and add or subtract each fluid column's head on the way to P.

• • •

59. A ship of 4000 m^3 displacement has a block coefficient of 0.8. If the beam is 0.1 times the length and twice the draught, then the length of the ship is _______ m (answer in integer).

Correct Answer: 100

SOLUTION:

Step 1: Set up a single unknown scale factor.

Let the length be L. Then the beam is $B = 0.1L$ and, since the beam is twice the draught, the draught is $T = 0.05L$. All three dimensions are now written as multiples of L.

Step 2: Express the underwater volume and match it to the given displacement.

The block coefficient links the actual underwater volume to the box volume $L \times B \times T$, so $\nabla = C_b LBT$. Multiplying the three length terms gives $L \times 0.1L \times 0.05L = 0.005L^3$, so $\nabla = 0.8 \times 0.005L^3 = 0.004L^3$.

Step 3: Solve the cubic.

Setting this equal to the given displacement, $0.004L^3 = 4000$, so $L^3 = 10^6$ and taking the cube root gives $L = 100$ m. Checking: $B = 10$ m, $T = 5$ m, and $0.8 \times 100 \times 10 \times 5 = 4000\ \text{m}^3$, which confirms the result.

Final Answer:

The ship length works out to 100 m.

$$\boxed{L = 100\ \text{m}}$$

Quick Tip: Write beam and draught as fractions of length, then use the block coefficient volume formula.

• • •

60. A ship consumes 250 tonne of fuel when moving from sea to a river. On arrival, draught and trim (measured at rest) are the same as the corresponding values at sea.

The displacement of the ship in seawater is ________ tonne (answer in integer).

The density of seawater and river water are 1025 kg/m^3 and 1000 kg/m^3 respectively.

Correct Answer: 10250

SOLUTION:

Step 1: Fix the unknown as the shared underwater volume.

Call the submerged volume V. Because the draught and trim at the river are identical to those at sea, this same V applies in both places.

Step 2: Express both displacements through V and take the difference.

Displacement equals density times volume, so at sea $W_{sea} = 1.025V$ tonne (density in tonne/m^3) and in the river $W_{river} = 1.000V$ tonne. Fuel burned reduces the ship's weight, and this loss must equal the reduction predicted purely from the volume being fixed: $W_{sea} - W_{river} = (1.025 - 1.000)V = 0.025V$.

Step 3: Use the fuel burned to find V, then the seawater displacement.

Setting $0.025V = 250$ tonne gives $V = 10000\ \text{m}^3$. The displacement in seawater is then $W_{sea} = 1.025 \times 10000 = 10250$ tonne.

Final Answer:

The ship displaces 10250 tonne of seawater.

$$\boxed{W_{sea} = 10250\ \text{tonne}}$$

Quick Tip: Same draught in both waters means the underwater volume is unchanged, only the density differs.

61. The critical buckling load of a 6 m long, 10 cm diameter axially loaded solid steel column with hinged support at both ends is _______ kN (rounded off to nearest integer).
Assume Young's modulus of steel as 2×10^5 N/mm^2.

Correct Answer: 269

SOLUTION:

Step 1: Convert all data to consistent SI units first.
Diameter $d = 100$ mm $= 0.1$ m, length $L = 6$ m, and $E = 2 \times 10^5$ N/mm^2, which in pascals is $E = 2 \times 10^5 \times 10^6 = 2 \times 10^{11}$ Pa.

Step 2: Get the section's moment of inertia in mm to cross-check.
With $d = 100$ mm, $I = \pi d^4/64 = \pi(100)^4/64 = 4.909 \times 10^6$ mm^4, which converts to 4.909×10^{-6} m^4, the same value found from the metre-based calculation.

Step 3: Both ends pinned means no reduction factor is needed.
For a pin-pin column the effective length factor is 1, so $P_{cr} = \pi^2 EI/L^2$ $= \pi^2 \times 2 \times 10^{11} \times 4.909 \times 10^{-6}/36$. The numerator is 9.688×10^6, and dividing by 36 gives 269151 N.

Final Answer:
$P_{cr} = 269.2$ kN, rounding to 269 kN, which sits in the 268 to 270 kN range.

$$\boxed{P_{cr} \approx 269 \text{ kN}}$$

Quick Tip: Use Euler's formula with effective length equal to actual length since both ends are hinged.

• • •

62. A box shaped pontoon of length 100 m, breadth 12 m and draft 10 m is floating in water of density 1 tonne/m^3. The roll radius of gyration is 1% of the ship's length and the roll added mass moment of inertia is 20% of the roll mass moment of inertia. The vertical centre of buoyancy is located at half of the draft, and the vertical centre of gravity is at 6 m from the keel. The roll natural frequency of the pontoon is ________ rad/s (rounded off to two decimal places).
Assume g = 10 m/s^2.

Correct Answer: 1.29

SOLUTION:

Step 1: Build KM from the box-shape geometry.
The waterplane inertia for a box hull is $I_{wp} = LB^3/12 = 100 \times 1728/12 = 14400\ \mathrm{m}^4$, and the displaced volume is $\nabla = LBT = 100 \times 12 \times 10 = 12000\ \mathrm{m}^3$, so the metacentric radius is $BM = I_{wp}/\nabla = 1.2$ m. Adding $KB = T/2 = 5$ m gives $KM = 6.2$ m.

Step 2: Get GM and note the mass cancels in the frequency formula.
$GM = KM - KG = 6.2 - 6 = 0.2$ m. The undamped roll frequency is $\omega_n = \sqrt{g\,GM/k_{eff}^2}$, where k_{eff}^2 is the effective (mass plus added) squared radius of gyration; since the added inertia is 20% extra, $k_{eff}^2 = 1.2k^2$ with the mass itself dropping out of both sides.

Step 3: Insert the radius of gyration and compute.
$k = 0.01L = 1$ m, so $k_{eff}^2 = 1.2 \times 1^2 = 1.2\ \mathrm{m}^2$. Then $\omega_n = \sqrt{10 \times 0.2/1.2} = \sqrt{5/3} = 1.291$ rad/s.

Final Answer:

Rounded to two decimals, $\omega_n = 1.29$ rad/s, within the 1.27 to 1.31 rad/s key range.

$$\boxed{\omega_n \approx 1.29 \text{ rad/s}}$$

Quick Tip: Find GM from the box hull's BM and KB first, then use the roll frequency formula with added inertia.

• • •

63. A ship is moving at 10 m/s in head sea condition. A person on board counts the time period between two successive wave crests as π seconds. The frequency of the incoming wave is ________ rad/s (answer in integer). Assume g = 10 m/s^2.

Correct Answer: 1

SOLUTION:

Step 1: Turn the counted period into an encounter frequency.

The crests the observer counts arrive every $T_e = \pi$ s, so $\omega_e = 2\pi/T_e = 2$ rad/s.

Step 2: Bring in the head sea encounter formula as a quadratic in ω.

For head seas, the ship meets waves faster than they actually travel: $\omega_e = \omega + \omega^2 V/g$. Treating this as an equation in the unknown ω, with $V/g = 10/10 = 1$, it becomes $\omega^2 + \omega - \omega_e = 0$, i.e. $\omega^2 + \omega - 2 = 0$.

Step 3: Solve with the quadratic formula and pick the sensible root.

$\omega = \dfrac{-1 \pm \sqrt{1+8}}{2} = \dfrac{-1 \pm 3}{2}$, so $\omega = 1$ or $\omega = -2$. A negative frequency has no physical meaning here, so $\omega = 1$ rad/s.

Final Answer:

The incoming wave frequency is 1 rad/s.

$$\boxed{\omega = 1 \text{ rad/s}}$$

Quick Tip: Convert the counted crest period to encounter frequency, then use the head sea encounter relation.

• • •

64. A steel girder of length 10 m has one end rigidly attached to a ship's bulkhead and the other end free. It is subjected to a torsional moment of 30 kNm about its longitudinal axis at the free end. The shear modulus of steel is 80 GPa and the polar moment of inertia of the section is 6×10^{-4} m^4.

The total twist at the free end is _______ $\times 10^{-4}$ rad (rounded off to one decimal place).

Correct Answer: 62.5

SOLUTION:

Step 1: Compute the torsional stiffness GJ first.

$GJ = 80 \times 10^9 \times 6 \times 10^{-4} = 4.8 \times 10^7$ N.m². This single number tells us how much torque is needed per unit twist per unit length.

Step 2: Divide the torque-length product by this stiffness.

A cantilevered girder with torque applied only at the free end carries a constant internal torque of $T = 30000$ Nm along its whole $L = 10$ m span, so the total twist is $\theta = TL/(GJ) = (30000 \times 10)/(4.8 \times 10^7)$.

Step 3: Carry out the division.

$\theta = 300000/(4.8 \times 10^7) = 0.00625$ rad. Writing this in the requested form, $0.00625 = 62.5 \times 10^{-4}$ rad.

Final Answer:
The free end twists by 62.5×10^{-4} rad, right in the middle of the 62.4 to 62.6 key band.

$$\boxed{\theta \approx 62.5 \times 10^{-4} \text{ rad}}$$

Quick Tip: Use the torsion equation theta equals T L over G J with the full length carrying the applied torque.

• • •

65. A propeller of 4 m pitch is rotating at 120 rpm. It has a behind-hull propeller efficiency of 60% and a real slip of 25%.
If the power delivered to the propeller is 2800 kW, then the thrust produced by it is _______ kN (answer in integer).

Correct Answer: 280

SOLUTION:

Step 1: Work out how fast the propeller would advance with no slip.
At $n = 120$ rpm $= 2$ rev/s and pitch $P = 4$ m, one revolution would ideally push the propeller forward by the pitch, so the theoretical (pitch) speed is $V_p = nP = 8$ m/s.

Step 2: Apply the real slip to get the actual advance speed.
Real slip $S_R = 25\%$ means the propeller actually advances less than the pitch speed by that fraction: $V_a = V_p(1 - S_R) = 8 \times 0.75 = 6$ m/s.

Step 3: Back out thrust from the efficiency definition.

Since $\eta_B = TV_a/P_D$, thrust is $T = \eta_B P_D/V_a$. With $\eta_B = 0.6$, $P_D = 2800$ kW and $V_a = 6$ m/s: $T = (0.6 \times 2800)/6 = 1680/6 = 280$ kN.

Final Answer:

The propeller produces 280 kN of thrust.

$$\boxed{T = 280 \text{ kN}}$$

Quick Tip: Get the advance speed from pitch speed and slip, then use behind-hull efficiency to find thrust.