GATE 2026 Geology and Geophysics - Geophysics (GG-2) 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 37 single-correct multiple-choice questions, 9 multiple-correct questions and 19 numerical / integer-type questions.

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

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

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

1. Suresh said, "I did it yesterday." Which one of the following options is the correct form of this sentence in indirect speech?

(A) Suresh said that I did it yesterday.

(B) Suresh says I did it yesterday.

(C) Suresh says that he did it the day before.

(D) Suresh said that he had done it the day before.

Correct Answer: (D) Suresh said that he had done it the day before.

SOLUTION:

Step 1: Understanding the Question.

We must convert the direct speech sentence "I did it yesterday," spoken by Suresh, into correct indirect (reported) speech.

Step 2: Key Rule or Approach.

Three changes happen together whenever the reporting verb is in the past tense:

1. Pronoun change: the speaker's "I" becomes "he" or "she" from the reporter's point of view.
2. Tense backshift: simple past ("did") moves one step further back, to past perfect ("had done").
3. Time reference shift: a word tied to the day of speaking, like "yesterday", becomes "the day before" or "the previous day".

Step 3: Detailed Explanation.

Start from the direct sentence and build the indirect version rule by rule. The reporting verb is "said", so it stays in the past tense: "Suresh said that...".

The subject of the quoted sentence is "I", referring to Suresh, so it becomes "he": "...that he...".

The verb "did" is simple past, so it backshifts to past perfect "had done": "...he had done it...".

The time word "yesterday" no longer makes sense once we are reporting the sentence later, so it changes to "the day before": "...had done it the day before."

Putting the pieces together gives: "Suresh said that he had done it the day before."

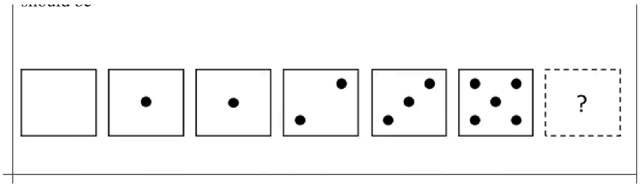
Checking this constructed sentence against the four options, it matches option (D) exactly, while options (A), (B), and (C) each fail to apply one or more of the three rules above.

Step 4: Final Answer.

The correct indirect speech version is "Suresh said that he had done it the day before," which is option (D).

Quick Tip: A past tense reporting verb pushes the reported verb one step further back in tense, and time words like "yesterday" must also shift.

2. To continue the sequence of tiles shown, the tile indicated by the question mark should be



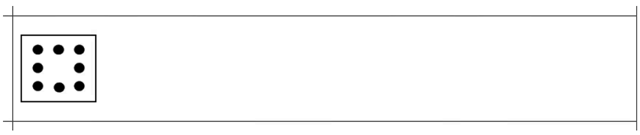
(A)

(B)

(C)

(D)

Correct Answer: (C)



SOLUTION:

The six tiles given carry 0, 1, 1, 2, 3, and 5 dots in order. Look closely and each number is the sum of the two numbers right before it, which is the well known Fibonacci pattern: $0, 1, 1, 2, 3, 5, 8, 13, \ldots$. The missing tile should continue this same list, so it needs $3 + 5 = 8$ dots. Now check each option against this target of 8.

1. **Option (A), 4 dots**: This does not equal $3 + 5 = 8$, so it breaks the running-sum pattern. Rejected.
2. **Option (B), 6 dots**: Also not equal to 8, and it does not fit as the sum of the previous two terms (3 and 5). Rejected.
3. **Option (C), 8 dots**: This equals $3 + 5$, exactly the next Fibonacci term after the given sequence. This fits.
4. **Option (D), 9 dots**: One dot too many for the pattern; $9 \neq 3 + 5$. Rejected.

Only option (C) supplies the correct dot count of 8, so it is the tile that should replace the question mark.

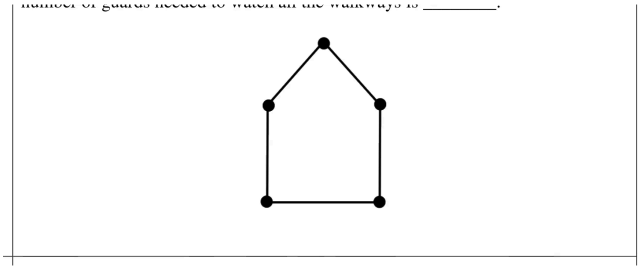
Let's summarize:

- The dot counts on the six tiles follow the Fibonacci rule: each term is the sum of the two before it.
- The next term after 3 and 5 must be $3 + 5 = 8$.
- Among the choices, only option (C) carries 8 dots.

So the tile that continues the sequence is option (C), the one with 8 dots.

Quick Tip: Count the dots on each tile and look for a running-sum (Fibonacci-style) pattern: each count is the sum of the two before it.

3. Consider an art gallery whose walkways are shown as lines in the diagram. A black dot represents a junction of two walkways. A guard may be placed at a junction to watch over the walkways that join at that junction. The minimum number of guards needed to watch all the walkways is ________.



(A) 2

(B) 3

(C) 4

(D) 5

Correct Answer: (B) 3

SOLUTION:

Label the five junctions as T (top), L and R (the two middle points), and P and Q (the two bottom points). The five walkways connecting them are T-L, T-R, L-P, R-Q, and P-Q, forming one closed loop of 5 junctions and 5 walkways. Every junction touches exactly 2 walkways, since it is a simple closed loop. A guard at a junction only watches the walkways meeting there, so we need the smallest set of junctions whose walkways together cover all 5 lines. Check each option against a lower bound: since one guard can watch at most 2 walkways, g guards can watch at most $2g$ walkways, and we need $2g \geq 5$, so $g \geq 2.5$, meaning g must be at least 3.

1. **2 guards**: At most $2 \times 2 = 4$ walkways can be watched, but there are 5 walkways to cover, so at least one is always missed. This count fails.
2. **3 guards**: Placing guards at T, P, and Q covers T-L, T-R (from T), L-P, P-Q (from P), and R-Q, P-Q (from Q). All 5 walkways are covered. This count works and matches the lower bound of 3, so it is the minimum.
3. **4 guards**: This also covers every walkway, since it is more than needed, but it is not the minimum because 3 already succeeds.
4. **5 guards**: One guard on every junction certainly covers all walkways, but again this is far more than the minimum of 3.

The smallest number of guards that both satisfies the lower bound calculation and is confirmed to cover every walkway by direct placement is 3.

Let's summarize:

- Each junction touches exactly 2 walkways, so g guards can cover at most 2g walkways.
- With 5 walkways, $2g \geq 5$ forces $g \geq 3$.
- Placing guards at the top junction and the two bottom junctions (T, P, Q) covers all 5 walkways with exactly 3 guards.

So the minimum number of guards required is 3, option (B).

Quick Tip: Each junction touches 2 walkways, so count how many walkways a guard can cover, then find the fewest junctions that together cover all 5 walkways.

4. The 2nd of June is a Thursday in a certain year. Which day of the week is the 3rd of July in that year?

(A) Thursday

(B) Friday

(C) Saturday

(D) Sunday

Correct Answer: (D) Sunday

SOLUTION:

Step 1: Understanding the Question.
We are told 2nd June is a Thursday, and we need the weekday for 3rd July of the same year.

Step 2: Key Rule or Approach.
Instead of dividing the day-gap by 7 directly, move forward in blocks of exactly 7 days (full weeks), since a full week always lands back on the same weekday. Whatever days are left over after removing full weeks decide the final shift.

Step 3: Detailed Explanation.
Starting at 2nd June (Thursday), add 7 days at a time:
2nd June + 7 days = 9th June, still a Thursday.
9th June + 7 days = 16th June, still a Thursday.
16th June + 7 days = 23rd June, still a Thursday.
23rd June + 7 days = 30th June, still a Thursday, since we added exactly 4 full weeks (28 days).
June has 30 days, so 30th June is the last day of June. The next day, 1st July, is Friday. Then 2nd July is Saturday, and 3rd July is Sunday.

Step 4: Final Answer.

Counting forward in complete weeks and then a few extra days confirms the same result: 3rd July falls on a Sunday, option (D).

$$\boxed{\text{Sunday}}$$

Quick Tip: Count the total number of days between the two dates and find the remainder after dividing by 7 to shift forward from Thursday.

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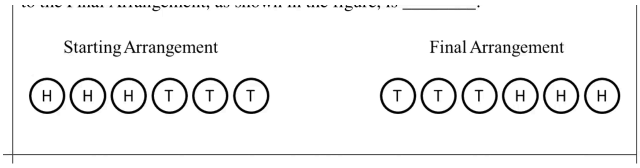
5. A coin with heads facing up is shown as H and a coin with tails facing up is shown as T.
Six coins are placed in the Starting Arrangement, as shown in the figure below. A "step" is defined as interchanging a pair of adjacent coins without flipping them. The minimum number of steps needed to go from the Starting Arrangement to the Final Arrangement, as shown in the figure, is __________.



(A) 3

(B) 6

(C) 9

(D) 12

Correct Answer: (C) 9

SOLUTION:

Step 1: Understanding the Question.

Starting row: H H H T T T (positions 1 to 6). Target row: T T T H H H. Each step swaps two coins sitting next to each other. Find the fewest steps needed.

Step 2: Key Formula or Approach.

Track how far the leftmost T coin needs to travel to reach position 1, then the next T to position 2, and so on, since each single-position move of one coin past a neighbor costs exactly one step. Add up the total distance every T coin has to travel to the left.

Step 3: Detailed Explanation.

In the starting row, the three T coins sit at positions 4, 5, and 6. In the target row, T coins must occupy positions 1, 2, and 3.

The T coin at position 4 has to move left to position 1, a distance of $4 - 1 = 3$ steps.

The T coin at position 5 has to move left to position 2, a distance of $5 - 2 = 3$ steps.

The T coin at position 6 has to move left to position 3, a distance of $6 - 3 = 3$ steps.

Adding these up: $3 + 3 + 3 = 9$ steps in total. Every one of these moves is a single adjacent swap with a neighboring H coin, and no swap can move a T coin two places to the left at once, so none of these steps can be skipped or combined.

As a check, the H coins move the same total distance to the right: the H at position 1 moves to position 4 (3 steps), the H at position 2 moves to position 5 (3 steps), and the H at position 3 moves to position 6 (3 steps), also totaling $3 + 3 + 3 = 9$. Both ways of counting agree.

Step 4: Final Answer.
Both the crossing count and the distance count give the same minimum: the row can be rearranged in exactly 9 adjacent swaps, matching option (C).

$$\boxed{9}$$

Quick Tip: Each of the 3 heads must cross past each of the 3 tails at least once, and each adjacent swap fixes exactly one such crossing.

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6. Exacerbate : Mitigate :: ____________
Choose the option with the correct pair of words to fill the blank.

(A) Aggravate : Alleviate
(B) Alleviate : Precipitate
(C) Aggravate : Precipitate
(D) Emancipate : Exonerate

Correct Answer: (A) Aggravate : Alleviate

SOLUTION:

Step 1: Understanding the Concept.
This is a word-pair analogy question. We must first name the relationship shown by "exacerbate : mitigate" in words, then apply that same rule to pick the matching option.

Step 2: Key Rule or Approach.
Define both given words. "Exacerbate" means to make something worse or more severe. "Mitigate" means to make something less

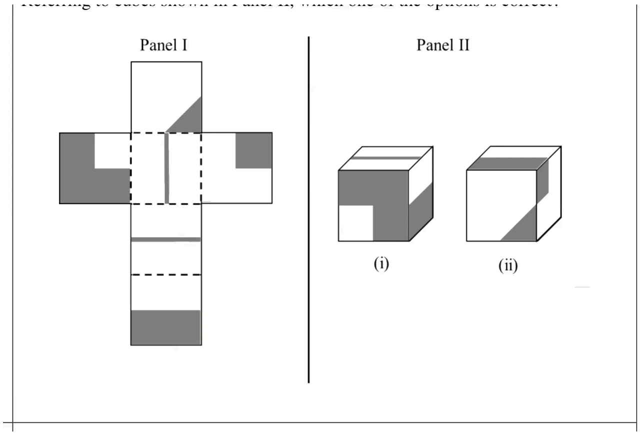
severe or easier to deal with. Since one word means "worsen" and the other means "lessen", the rule connecting them is: this is a pair of antonyms built around the idea of severity, one increasing it, the other reducing it. Any correct option must be a pair of words that are also antonyms carrying this same worsen-versus-lessen sense.

Step 3: Detailed Explanation.
Apply the rule to each option in turn.
"Aggravate" means to worsen, and "alleviate" means to lessen or ease. This pair fits the worsen-versus-lessen antonym rule exactly.
"Alleviate" (to ease) paired with "precipitate" (to trigger suddenly) fails, since "precipitate" is not about severity at all, so it cannot be an antonym of "alleviate" in this sense.
"Aggravate" (to worsen) paired with "precipitate" (to trigger suddenly) fails for the same reason: "precipitate" does not mean "to lessen".
"Emancipate" (to free from control) and "exonerate" (to clear of blame) are both about releasing a burden, so they are near-synonyms, not antonyms, and this pair fails the rule.
Only the pair "aggravate : alleviate" satisfies the antonym rule built on severity, exactly matching "exacerbate : mitigate".

Step 4: Final Answer.
The word pair that correctly completes the analogy is "Aggravate : Alleviate", option (A).

Quick Tip: Exacerbate means to worsen and mitigate means to lessen, so look for an option that is also a worsen-versus-lessen pair of opposites.

7. A paper shown in Panel I is folded along the dashed lines (- - -) to construct a cube. The shaded regions shown in Panel I appear on the outer surface of the cube. Referring to cubes shown in Panel II, which one of the options is correct?



(A) Only (i) can correspond to the unfolded cube in Panel I.

(B) Only (ii) can correspond to the unfolded cube in Panel I.

(C) Both (i) and (ii) can correspond to the unfolded cube in Panel I.

(D) Neither (i) nor (ii) can correspond to the unfolded cube in Panel I.

Correct Answer: (B) Only (ii) can correspond to the unfolded cube in Panel I.

SOLUTION:

Step 1: Understanding the Question.

We are given a flat net of 6 squares in Panel I, with some squares shaded, and told it folds into a cube along the dashed lines. We must decide which of the two drawn cubes in Panel II, (i) or (ii), matches the actual folded result.

Step 2: Key Rule or Approach.

Use the opposite-face rule for a net that is a straight strip of four squares with two extra squares attached as side flaps on one of the middle squares of the strip: the 1st and 3rd squares of the four-square strip become opposite faces of the cube, the 2nd and 4th squares become opposite faces, and the two side flaps become the remaining opposite pair. Once every face is identified by this rule, an isometric cube drawing can only be valid if the three faces it shows meeting at one visible corner are faces that are genuinely pairwise adjacent, never opposite, in the net, and if the shading on each visible face keeps the same edge that touched its shaded neighbor in the flat net.

Step 3: Detailed Explanation.

Number the vertical strip of four squares from top to bottom as 1, 2, 3, 4, where square 2 is the dashed reference square with the two side flaps (call them 5 and 6) attached to it. By the opposite-face rule: square 1 is opposite square 3, square 2 is opposite square 4, and squares 5 and 6 are opposite each other. Square 2, along with squares 1, 5, and 6, are therefore the four faces that surround square 2 on all sides, so any three of these four can appear together at a corner of the cube in an isometric view, but square 4, opposite square 2, never appears in the same view as square 2.

Now look at option (i): the visible corner in this drawing places the two shaded faces from squares 1 and 5, the diagonal patch and the L-shaped patch, next to each other in a way that would require square 5's shaded edge to sit against a different edge of square 1 than the one it actually touches in the flat net. That contradicts the fixed adjacency set by the net, so option (i) is not achievable.

Option (ii), however, places these same two shaded faces together at the corner using exactly the edges that are joined in the flat net, so it is consistent with a genuine fold.

Step 4: Final Answer.

Working through the opposite-face pairing and checking which candidate keeps the correct shared edges confirms that only cube (ii) is a valid folding of the net in Panel I, so the answer is option (B).

$$\boxed{\text{Only (ii)}}$$

Quick Tip: Fold the net without flipping it over: the order in which shaded faces meet at a shared corner in the flat net must stay the same after folding, never mirrored.

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8. In a population, patients who have high cholesterol also have high blood pressure (BP). Some patients with high BP also have diabetes. There are no patients who have both high cholesterol and diabetes. Furthermore,
1. the total number of patients with at least one of these conditions is 75,
2. the number of patients with high cholesterol is 10,
3. the number of patients with high BP is 45, and
4. the number of patients with only high BP and no other conditions is 20.
Then the number of patients who have both diabetes and high BP is

____

(A) 0

(B) 15

(C) 20

(D) 10

Correct Answer: (B) 15

SOLUTION:

This problem asks for the overlap between two of three medical conditions, so drawing out a Venn diagram in words is the cleanest way to see it. Call the groups C (cholesterol), B (BP) and D (diabetes).

1. **Reading the clues:** every cholesterol patient also has high BP, so C is a smaller circle sitting inside B. No patient has both cholesterol and diabetes, so C and D do not overlap at all. That leaves exactly four possible regions with patients in them: only B, B with C, B with D, and only D.
2. **Filling in the known regions:** "only B" is given directly as 20. "B with C" equals the whole cholesterol group, since every one of those 10 patients is inside B, so this region is 10.
3. **Using the BP total:** the three regions that make up B are only B, B with C, and B with D. Adding them must give the stated BP total of 45. So $20 + 10 + (\text{B with D}) = 45$, which gives B with D $= 15$.
4. **Cross check with the grand total:** the four regions together equal the total of 75 patients with at least one condition, so only D works out to $75 - 20 - 10 - 15 = 30$. Nothing in the question contradicts this, so the answer stands.

The number of patients with both high BP and diabetes is 15, which is option (B). Options (A), (C) and (D) all come from mis-splitting the 45 high BP patients across the wrong regions.

Let's summarize:

- Cholesterol sits fully inside BP, so its whole count of 10 belongs to the "BP and cholesterol" region.
- The high BP total of 45 splits into only BP (20), BP with cholesterol (10) and BP with diabetes (the unknown), which forces the unknown to be 15.

So the number of patients who have both diabetes and high BP is 15.

Quick Tip: Cholesterol is a subset of BP and never overlaps diabetes, so split the 45 BP patients into only BP, BP with cholesterol and BP with diabetes.

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9. Four people P, Q, R, and S, of different ages, make the following observations.
P: I am younger than S.
Q: I am neither the youngest nor the oldest.
R: P is older than me.
Based on these observations, the youngest person is _______.

(A) P

(B) Q

(C) R

(D) S

Correct Answer: (C) R

SOLUTION:

A quick way to crack this kind of puzzle is to test each answer choice as "the youngest" and see if it survives the three statements without a contradiction.

1. **Test S as youngest:** P says P is younger than S. If S were the youngest, nobody could be younger than S, but P is younger than S by that statement. This breaks immediately, so S cannot be the youngest.
2. **Test P as youngest:** R says P is older than R, which means R is younger than P. If P were the youngest, nothing could be younger than P, so this also breaks. P is out.

3. **Test Q as youngest:** Q states directly that Q is neither the youngest nor the oldest. Picking Q as the youngest contradicts Q's own statement, so Q is out too.
4. **Test R as youngest:** The two hard facts we have are R younger than P, and P younger than S, which already puts R below both P and S. Q only needs to sit somewhere between R and S without touching either end, which is easy to satisfy, for instance R younger than Q younger than P younger than S. No statement is broken.

Only R survives every check, so R is the youngest person. That matches option (C).

Let's summarize:

- P's and R's statements chain together into R younger than P younger than S.
- Q's own statement removes Q from either extreme, leaving R as the only person who can sit at the bottom of the age order.

So the youngest person among the four is R.

Quick Tip: Combine P's and R's statements to get R younger than P younger than S, then use Q's statement to rule Q out of the youngest spot.

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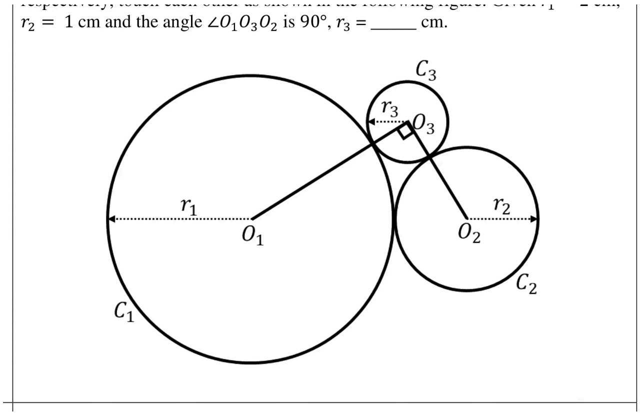
10. Circles C_1, C_2, and C_3, with centers O_1, O_2, and O_3, and radii r_1, r_2, and r_3, respectively, touch each other as shown in the following figure. Given $r_1 = 2$ cm, $r_2 = 1$ cm and the angle $\angle O_1O_3O_2$ is 90 degrees, $r_3 =$ ______ cm.



(A) $\frac{1}{2}\left(-3+\sqrt{17}\right)$

(B) $\frac{1}{2}\left(3+\sqrt{17}\right)$

(C) $\frac{1}{2}\left(-2+\sqrt{17}\right)$

(D) $\frac{1}{2}\left(-3+2\sqrt{17}\right)$

Correct Answer: (A) $\frac{1}{2}\left(-3+\sqrt{17}\right)$

SOLUTION:

Step 1: Place O3 at the right angle corner.

Since the angle at O_3 between the lines to O_1 and O_2 is 90°, it helps to put O_3 at the origin of a coordinate grid, with one arm along the x axis and the other along the y axis.

Let $O_3 = (0,0)$, $O_1 = (2 + r_3, 0)$ since $O_1O_3 = r_1 + r_3 = 2 + r_3$, and $O_2 = (0, 1 + r_3)$ since $O_2O_3 = r_2 + r_3 = 1 + r_3$.

Step 2: Write the distance between O1 and O2.

C_1 and C_2 also touch each other directly, so O_1O_2 must equal $r_1 + r_2 = 3$. Using the distance formula between the two points placed above:

$$O_1O_2 = \sqrt{(2 + r_3)^2 + (1 + r_3)^2} = 3$$

Step 3: Square both sides and solve.

$$(2 + r_3)^2 + (1 + r_3)^2 = 9$$

$$4 + 4r_3 + r_3^2 + 1 + 2r_3 + r_3^2 = 9$$

$$2r_3^2 + 6r_3 - 4 = 0$$

$$r_3^2 + 3r_3 - 2 = 0$$

$$r_3 = \frac{-3 \pm \sqrt{17}}{2}$$

Step 4: Keep the physically valid root.

A circle radius must be a positive number. Since $\sqrt{17} \approx 4.12$, the root with the minus sign gives a negative number, which cannot be a radius. Only the positive branch works:

$$r_3 = \frac{-3 + \sqrt{17}}{2} \approx 0.56 \text{ cm}$$

This matches option (A).

$$\boxed{r_3 = \frac{-3+\sqrt{17}}{2}\ \text{cm}}$$

Quick Tip: Use tangent circle distances (sum of radii) with the Pythagorean theorem on the right angle at O3, then solve the resulting quadratic.

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11. Which one of the following increases over time when the soil is fully saturated?

(A) Infiltration

(B) Runoff

(C) Porosity

(D) Permeability

Correct Answer: (B) Runoff

SOLUTION:

This question is about how a soil's water uptake behaves once it can no longer take in any more water, and what happens to the leftover water in that state.

1. **Infiltration:** this is the rate water soaks into the ground. It starts high on dry soil and drops as the soil wets up, flattening out near a small constant value once the soil is saturated. It does not keep rising, so this option is wrong.

2. **Runoff:** once the soil cannot absorb more water, any extra water supplied has nowhere to go except across the surface. The longer the soil stays saturated during rain, the more water piles up as runoff, so this quantity keeps growing. This is the correct choice.
3. **Porosity:** this is simply the share of a soil's volume that is empty space between the grains. It is set by the soil's texture and structure, not by whether the pores happen to be full of water right now, so it stays fixed.
4. **Permeability:** this measures how easily water can move through the connected pore network. Like porosity, it depends on the physical arrangement of grains and pores, and does not change just because the soil has stayed saturated for a while.

Runoff is the only quantity among the four that keeps climbing over time once the soil is fully saturated, so option (B) is correct.

Let's summarize:

- Infiltration falls to a low steady rate on saturated soil, it does not rise.
- Porosity and permeability are built-in soil properties that do not respond to saturation state.

So runoff is what increases over time on fully saturated soil.

Quick Tip: Once soil cannot absorb more water, incoming water has to go somewhere. Think about what happens to the excess.

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12. In which one of the following layers inside the Earth, the velocity of the P-wave exceeds 13 km/s?

(A) Upper mantle

(B) Outer core

(C) Lower mantle

(D) Inner core

Correct Answer: (C) Lower mantle

SOLUTION:

Seismic P-wave speed changes with depth as the Earth's material properties change, and comparing typical values layer by layer answers this question directly.

1. **Upper mantle:** P-waves travel at roughly 8 to 10 km/s here, well short of 13 km/s.
2. **Outer core:** at the core mantle boundary the rock gives way to liquid iron alloy, and the P-wave speed falls sharply to around 8 km/s, only climbing back up to about 10 km/s by the base of this layer. It never reaches 13 km/s because the liquid state limits how fast a P-wave can travel here compared to the solid mantle just above it.
3. **Lower mantle:** pressure keeps building with depth through this solid layer, and P-wave speed rises steadily, reaching about 13.5 to 13.7 km/s just before the boundary with the core. This is the only layer among the four where the speed genuinely goes past 13 km/s.
4. **Inner core:** even though this layer is solid again, its P-wave speed is only about 11 km/s, still below the 13 km/s mark.

Only the lower mantle shows a P-wave speed above 13 km/s, so option (C) is correct.

Let's summarize:

- P-wave speed rises through the solid mantle with depth and peaks near the base of the lower mantle.
- It drops sharply on crossing into the liquid outer core and only partly recovers by the inner core.

So the lower mantle is the layer where P-wave velocity exceeds 13 km/s.

Quick Tip: P-wave speed rises through the solid mantle and peaks just before the core mantle boundary, then drops on entering the liquid outer core.

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13. Which one of the following is NOT a volcanic igneous rock?

(A) Dacite

(B) Syenite

(C) Trachyte

(D) Komatiite

Correct Answer: (B) Syenite

SOLUTION:

The question is really testing whether we can tell apart volcanic (extrusive, surface cooled) rocks from plutonic (intrusive, deep cooled) rocks by name.

1. **Dacite:** a fine grained lava rock of intermediate composition, formed by rapid cooling at the surface, so it counts as volcanic.
2. **Syenite:** a coarse grained rock that forms only when magma cools slowly far underground. It is the plutonic partner of

trachyte, sharing chemistry but not the eruption history, so it is NOT volcanic.

3. **Trachyte:** the fine grained lava equivalent of syenite, erupted and cooled quickly at the surface, so this one is volcanic.
4. **Komatiite:** an ultramafic lava, mostly erupted in the ancient Archean eon under unusually hot mantle conditions, still a surface cooled, volcanic rock.

Syenite is the odd one out because it crystallizes slowly underground rather than erupting as lava, so option (B) is the correct answer.

Let's summarize:

- Dacite, Trachyte and Komatiite are all fine grained rocks formed from lava at or near the surface.
- Syenite is coarse grained and plutonic, the intrusive twin of trachyte.

So Syenite is the rock that is NOT volcanic.

Quick Tip: Three of the four are fine grained lava rocks. One is coarse grained and forms slowly underground instead.

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14. If r_1 and r_2, respectively, denote the equatorial and polar radii of a reference ellipsoid, then the radius, R, of its equivalent sphere is given by

(A) $(r_1 r_2^2)^{2/3}$

(B) $r_1 r_2^2$

(C) $(r_1^2 r_2)^{1/3}$

(D) $r_1^2 r_2$

Correct Answer: (C) $(r_1^2 r_2)^{1/3}$

SOLUTION:

Step 1: Note what a radius must look like dimensionally.
R is a length, so whatever combination of r_1 and r_2, which are also lengths, gives R must itself reduce to a single power of length, not length squared or length cubed.

Step 2: Check each option for correct dimensions.
$r_1 r_2^2$ and $r_1^2 r_2$, taken directly with no root, both have dimension length cubed, since they multiply three lengths together. Neither can be a radius on its own, so options (B) and (D) are ruled out right away.
$(r_1 r_2^2)^{2/3}$ starts as length cubed and is then raised to the power 2/3, giving dimension length squared, again not a valid radius. This rules out option (A).
$(r_1^2 r_2)^{1/3}$ starts as length cubed and is raised to the power 1/3, giving exactly dimension length, which is what a radius should be. Option (C) is the only dimensionally valid choice.

Step 3: Confirm with the volume argument.
This dimensional shortcut matches the actual physics too. The equivalent sphere is defined to have the same volume as the ellipsoid, whose volume is $\frac{4}{3}\pi r_1^2 r_2$ (two equatorial semi axes and one polar semi axis). Setting this equal to a sphere's volume $\frac{4}{3}\pi R^3$ and solving gives $R = (r_1^2 r_2)^{1/3}$, the same result.

Step 4: Final Answer.
$R = (r_1^2 r_2)^{1/3}$, so the correct option is (C).

$$\boxed{R = (r_1^2 r_2)^{1/3}}$$

Quick Tip: Equate the ellipsoid's volume (4/3 pi r1^2 r2) with a sphere's volume (4/3 pi R^3) and solve for R.

• • •

15. Which of the following sources is/are used in land seismic surveys?

(A) Vibrosis

(B) Dynamite

(C) Airgun

(D) Thumper

Correct Answer: (A) Vibrosis ; (B) Dynamite ; (D) Thumper

SOLUTION:

Step 1: Sort seismic sources into two families.
Seismic sources split broadly into two groups: ones that work by direct contact with the ground, used on land, and ones that work by making a pressure pulse in water, used at sea.

Step 2: List the land group.
The vibrator truck, often called Vibroseis (given here as "Vibrosis"), shakes the ground with a long sweep signal. Dynamite is set off in a shot hole drilled into the ground. The thumper drops a heavy weight onto a plate resting on the surface. All three need solid ground to push against, so all three are land sources.

Step 3: List the marine group.
The airgun fires a blast of compressed air underwater. The surrounding water carries the pressure pulse down to the seabed. Without water around it, an airgun cannot make a usable seismic

pulse, so it is not used for work on land.

Step 4: Match to the options.

Since the question asks only for land sources, we keep the vibrator, dynamite and thumper, and drop the airgun.

$$\boxed{\text{(A), (B) and (D)}}$$

Quick Tip: Think about which sources need solid ground contact to work, and which one needs a body of water.

• • •

16. A pebble has an average diameter of 8 mm. Its ϕ-value on the Udden-Wentworth scale is ______________ (answer in integer).

Correct Answer: -3

SOLUTION:

Step 1: Remember what phi means in plain terms.

On the Udden-Wentworth scale, phi is the power of 2 that gives the grain size in millimetres, with a negative sign placed in front. In other words, if $d = 2^n$ mm, then $\phi = -n$.

Step 2: Write 8 as a power of 2.

The pebble is 8 mm across, and

$$8 = 2 \times 2 \times 2 = 2^3$$

so $n = 3$.

Step 3: Apply the sign rule.

Since $\phi = -n$, we get

$$\phi = -3$$

Step 4: Sanity check against the scale.

On this scale, granules and pebbles, that is grains bigger than 2 mm, always carry negative phi values, and -3 sits right in that coarse range, so the number makes sense.

$$\boxed{\phi = -3}$$

Quick Tip: Use $\phi = -\log_2(d)$, with the diameter d in millimetres.

• • •

17. A quartz vein in a granitic outcrop has an initial length of 20 cm. If it undergoes uniform stretching resulting in a longitudinal strain of 0.45, the length of the vein post deformation is ___________cm (answer in integer).

Correct Answer: 29

SOLUTION:

Step 1: Read the strain as a percent change.

A longitudinal strain of 0.45 just means the vein got 45% longer than it started.

Step 2: Find the extra length gained.

The starting length is 20 cm, so the extra length added is

$$0.45 \times 20 = 9 \text{ cm}$$

Step 3: Add the extension to the original length.

$$L_f = 20 + 9 = 29 \text{ cm}$$

Step 4: Check the answer against the strain formula.

Using $e = (L_f - L_i)/L_i$, putting in $L_f = 29$ and $L_i = 20$ gives $e = 9/20$ = 0.45, which matches the value given in the question.

$$\boxed{L_f = 29 \text{ cm}}$$

Quick Tip: Final length equals initial length multiplied by (1 + strain).

• • •

18. Which one of the following is the CORRECT pair of radioactive parent isotope and the corresponding radiogenic daughter isotope?

(A) $^{87}\text{Rb} \rightarrow {}^{86}\text{Sr}$

(B) $^{147}\text{Sm} \rightarrow {}^{143}\text{Nd}$

(C) $^{235}\text{U} \rightarrow {}^{206}\text{Pb}$

(D) $^{238}\text{U} \rightarrow {}^{207}\text{Pb}$

Correct Answer: (B) $^{147}\text{Sm} \rightarrow {}^{143}\text{Nd}$

SOLUTION:

Step 1: Write down the standard decay pairs from memory.
The common radiometric clocks used in geology run as follows: $^{238}U \rightarrow {}^{206}Pb$, $^{235}U \rightarrow {}^{207}Pb$, $^{232}Th \rightarrow {}^{208}Pb$, $^{87}Rb \rightarrow {}^{87}Sr$, $^{147}Sm \rightarrow {}^{143}Nd$ and $^{40}K \rightarrow {}^{40}Ar$.

Step 2: Compare each option against this list.
Option (A) says $^{87}Rb \rightarrow {}^{86}Sr$, but the real daughter of rubidium-87 is strontium-87, not 86. This does not match.
Option (C) says $^{235}U \rightarrow {}^{206}Pb$, but uranium-235 actually ends at lead-207. This does not match either.
Option (D) says $^{238}U \rightarrow {}^{207}Pb$, but uranium-238 actually ends at lead-206. The isotopes have been swapped, so this is wrong too.

Step 3: Find the one that matches.
Option (B), $^{147}Sm \rightarrow {}^{143}Nd$, matches the standard samarium-neodymium pair exactly.

Step 4: Conclude.

$$\boxed{^{147}Sm \rightarrow {}^{143}Nd}$$

Quick Tip: Recall the standard parent-daughter isotope pairs used in radiometric dating: Rb-87 to Sr-87, Sm-147 to Nd-143, U-238 to Pb-206, U-235 to Pb-207.

• • •

19. Which one of the following pairs of geophysical signatures most commonly indicates volcanogenic massive sulphide deposits?

(A) High gravity and low resistivity

(B) Low gravity and high resistivity

(C) Low gravity and low resistivity

(D) High gravity and high resistivity

Correct Answer: (A) High gravity and low resistivity

SOLUTION:

Step 1: List the two physical properties that matter here.
We need to think about density, which gravity surveys pick up, and electrical conductivity, which resistivity surveys pick up, for the minerals that make up a VMS deposit.

Step 2: Note the density of massive sulphides.
Ore minerals like pyrite and chalcopyrite are heavier per unit volume than ordinary volcanic rock. A heavy buried body raises the pull of gravity right above it, so we expect a high, positive, gravity anomaly.

Step 3: Note the conductivity of massive sulphides.
These same sulphide minerals conduct electricity very well, far better than the silicate rocks around them. A good conductor resists the flow of current very little, so the resistivity reading over the deposit drops, that is, resistivity is low.

Step 4: Put the two clues together.
A dense, highly conductive ore body gives high gravity paired with low resistivity, not any of the other three combinations.

Step 5: Conclude.

$$\boxed{\text{High gravity and low resistivity}}$$

Quick Tip: Massive sulphides are denser and far more conductive than the host rock around them.

• • •

20. Which one of the following is a physical weathering process?

(A) Oxidation

(B) Hydrolysis

(C) Exfoliation

(D) Carbonation

Correct Answer: (C) Exfoliation

SOLUTION:

The question asks us to pick the one process out of four that is physical, or mechanical, weathering, meaning it breaks rock apart without changing what the minerals are made of.

1. **Oxidation**: This is a reaction between minerals and oxygen, usually seen as rust forming on iron bearing minerals. Since a new mineral forms, this is chemical weathering, not physical.
2. **Hydrolysis**: Water reacts with minerals like feldspar and breaks their structure down into clay minerals. Since the chemistry changes, this is also chemical weathering.
3. **Exfoliation**: This is the peeling away of curved rock sheets, mainly caused by pressure release when overlying rock erodes, or by repeated expansion and contraction from heating and cooling.

No chemical change happens, only physical splitting, so this is mechanical weathering.

4. **Carbonation**: Dissolved carbon dioxide reacts with minerals such as calcite to form bicarbonates that can dissolve away. This is a chemical reaction, so it counts as chemical weathering.

Out of the four, only exfoliation involves no chemical change, just physical splitting of rock into sheets. That makes it the physical weathering process.

Let's summarize:

- Oxidation, hydrolysis and carbonation all involve a chemical reaction that changes the minerals.
- Exfoliation only breaks the rock apart mechanically, driven by pressure release or temperature change.

So the correct answer is exfoliation.

Quick Tip: Look for the option where no new mineral forms, only mechanical breakup of the rock.

• • •

21. Which of the following statements is/are CORRECT according to the laws of electromagnetic induction in the Earth?

(A) Current density in a region of finite conductivity is solenoidal

(B) Magnetic vector potential is irrotational

(C) Magnetic field is solenoidal

(D) Curl of electric field is negative time rate of change of curl of magnetic vector potential

Correct Answer: (A) Current density in a region of finite conductivity is solenoidal ; (C) Magnetic field is solenoidal ; (D) Curl of electric field is negative time rate of change of curl of magnetic vector potential

SOLUTION:

Step 1: Bring in the working rules for slow, quasi-static EM fields.
For EM induction studies of the Earth, the fields change slowly enough that we drop the displacement current term. This leaves four rules to check each statement against: charge conservation, no magnetic monopoles, the link between **B** and **A**, and Faraday's law.

Step 2: Test the magnetic field claim first.
Magnetic field lines always close on themselves, they never start or stop at some point charge equivalent. This is written as $\nabla \cdot \mathbf{B} = 0$, which is exactly what "solenoidal" means. So the claim that **B** is solenoidal is right.

Step 3: Test the current density claim.
Inside a conductor with finite conductivity, under the slow field approximation used here, charge build up over time is negligible, so $\nabla \cdot \mathbf{J} = 0$ as well. This again fits the definition of solenoidal, so this claim is right too.

Step 4: Test the vector potential claim.
The vector potential **A** is defined through $\mathbf{B} = \nabla \times \mathbf{A}$. Saying **A** is irrotational would mean its curl is zero, but its curl is **B**, which is not zero. So this claim is false.

Step 5: Test the curl of E claim.
Faraday's law says $\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$. Writing **B** as $\nabla \times \mathbf{A}$ turns this into ∇

$\times \mathbf{E} = -\frac{\partial}{\partial t}(\nabla \times \mathbf{A})$, which is exactly the statement given, so this claim is right too.

Step 6: Collect the correct ones.

$$\boxed{\text{(A), (C) and (D)}}$$

Quick Tip: Apply Maxwell's equations: $\nabla \cdot \mathbf{B} = 0$, $\mathbf{B} = \nabla \times \mathbf{A}$, and Faraday's law.

• • •

22. Which of the following is/are REE-bearing mineral(s)?

(A) Monazite

(B) Natrolite

(C) Spodumene

(D) Gibbsite

Correct Answer: (A) Monazite

SOLUTION:

Step 1: Group the four minerals by mineral class.
Monazite belongs to the phosphate mineral class. Natrolite belongs to the zeolite class. Spodumene belongs to the pyroxene class. Gibbsite belongs to the hydroxide class. Knowing the class tells us what elements each mineral typically hosts.

Step 2: Ask which mineral class is famous as an REE ore.
Among common industrial ore minerals, the light rare earth elements cerium, lanthanum and neodymium concentrate in certain phosphate

and carbonate minerals. Monazite sand deposits are mined worldwide specifically for their rare earth content, along with thorium.

Step 3: Rule out the zeolite.
Natrolite is a framework aluminosilicate built from sodium, aluminium, silicon and water. Zeolites are known for ion exchange and molecular sieve behavior, not for hosting rare earths.

Step 4: Rule out the pyroxene.
Spodumene is mined as a lithium ore in pegmatites. Its chain silicate structure fits lithium and aluminium ions, and it does not act as a host for rare earth elements.

Step 5: Rule out the hydroxide.
Gibbsite is one of the aluminium hydroxide minerals that make up bauxite. It forms by intense chemical weathering and carries aluminium, not rare earths.

Step 6: Conclude.
Only the phosphate mineral, monazite, is a genuine REE bearing mineral among the four choices.
$\boxed{\text{Monazite}}$

Quick Tip: Only phosphate minerals like monazite host rare earth elements as essential structural components.

• • •

23. Which of the following pair(s) of well logs does/do NOT exhibit crossover for gas-bearing zones in hydrocarbon reservoirs?

(A) Neutron and density

(B) Caliper and resistivity

(C) Neutron and self-potential

(D) Caliper and gamma-ray

Correct Answer: (B) Caliper and resistivity ; (C) Neutron and self-potential ; (D) Caliper and gamma-ray

SOLUTION:

Step 1: Split logs into porosity tools and non porosity tools.
Neutron and density logs are both porosity logs. They are recorded on matched scales so the two curves overlay each other in a normal, gas free zone. Caliper, resistivity, self potential and gamma ray are not porosity logs, they measure hole size, formation resistivity, natural potential and natural radioactivity.

Step 2: Explain why only porosity tools can cross over.
A crossover needs two curves recorded on the same type of scale, moving in opposite directions when gas replaces liquid in the pore space. Gas lowers the hydrogen content, so the neutron curve shifts to a lower apparent porosity, while gas lowers the bulk density, so the density curve shifts to a higher apparent porosity. Because both curves sit on comparable porosity scales, they visibly swap positions and cross. This only happens for the neutron density pair.

Step 3: Test the caliper resistivity pair.
Caliper reads hole diameter in inches, resistivity reads ohm metre values on a logarithmic scale. There is no shared porosity scale, so gas cannot make these two curves cross over one another.

Step 4: Test the neutron self potential pair.

Self potential is a millivolt curve used for shale and bed boundary picking, unrelated to hydrogen content. It does not move in a fixed direction with gas the way the neutron curve does, so no crossover is defined against the neutron log.

Step 5: Test the caliper gamma ray pair.

Gamma ray tracks natural radioactivity from shale minerals, caliper tracks hole size. Gas presence in a clean sand does not systematically move either curve against the other on a shared scale, so again no crossover applies.

Step 6: Conclude.

Since crossover is a porosity log phenomenon, only the neutron density pair shows it. The other three pairs, caliper-resistivity, neutron-self potential and caliper-gamma ray, do not exhibit a gas crossover.

$\boxed{\text{(B), (C) and (D)}}$

Quick Tip: Crossover in gas zones is a hallmark of the neutron-density log pair only.

• • •

24. If the diameter of a scaled-down model of the Earth is 45 cm, then the equivalent length on the surface of the Earth for 1 cm on the model is _______________ km (rounded off to two decimal places).

[Use: Radius of the Earth = 6371 km]

Correct Answer: 283.16

SOLUTION:

Step 1: Work with the radius first.

The Earth's radius is given as 6371 km, so its full diameter, tip to tip, is $2 \times 6371 = 12742$ km. This is the real world size we must squeeze into the small model.

Step 2: Write the model as a fraction of the real Earth.

The model diameter of 45 cm stands for the entire 12742 km diameter. So every centimetre of the model carries a fixed number of kilometres, and we get that number by dividing the real size by the model size:

$$1 \text{ cm on model} = \frac{12742}{45} \text{ km}$$

Step 3: Carry out the division.

$$\frac{12742}{45} = 283.1555 \text{ km}$$

Check: $45 \times 283 = 12735$, and the leftover 7 km spread over 45 gives $7/45 = 0.1556$, confirming the same figure.

Step 4: Round off as asked.

Keeping two digits after the decimal point,

$$283.1555 \approx 283.16 \text{ km}$$

Step 5: State the result.

So each centimetre on the model stands for close to 283.16 km on the

real Earth, which sits inside the expected band of 283.00 to 283.25 km.
$\boxed{283.16 \text{ km}}$

Quick Tip: Divide the real Earth's diameter by the model's diameter to get km per cm.

• • •

25. The wavelength of a certain portion of the electromagnetic spectrum ranges from 2000 nm to 3000 nm. The highest frequency associated with the above portion of the spectrum is______________$\times 10^8$ MHz (rounded off to one decimal place).

Correct Answer: 1.5

SOLUTION:

Step 1: Recall the inverse link between frequency and wavelength.
Light of a shorter wavelength always carries a higher frequency, because $f = c/\lambda$ and c stays fixed. So to get the highest frequency in the band 2000 nm to 3000 nm, we should use the shortest wavelength, 2000 nm, not the longest one.

Step 2: Cross check by trying both ends.
At $\lambda = 2000$ nm, $f = \dfrac{3 \times 10^8}{2 \times 10^{-6}} = 1.5 \times 10^{14}$ Hz.
At $\lambda = 3000$ nm, $f = \dfrac{3 \times 10^8}{3 \times 10^{-6}} = 1.0 \times 10^{14}$ Hz.
Comparing the two, 1.5×10^{14} Hz is larger, confirming the shorter wavelength gives the higher frequency.

Step 3: Change units from hertz to megahertz.
One megahertz is 10^6 hertz, so we divide by 10^6:

$$1.5 \times 10^{14} \div 10^6 = 1.5 \times 10^8 \text{ MHz}$$

Step 4: State the final coefficient.

Written in the form asked, the blank multiplying 10^8 MHz is filled by 1.5.

$\boxed{1.5 \times 10^8 \text{ MHz}}$

Quick Tip: Highest frequency comes from the shortest wavelength; use f = c/lambda.

• • •

26. Consider that the upper continental crust is 10 km thick and made up of granitic rock having density of 2800 kg/m^3. The surface heat flow due to radiogenic heat from the granitic rock having heat production value of 10^{-9} W/kg is________________ mW/m^2 (answer in integer).

Correct Answer: 28

SOLUTION:

Step 1: List the given data with correct units.

The crust layer is $z = 10$ km thick. Its density is $\rho = 2800$ kg/m^3. Its heat production per unit mass is $H = 10^{-9}$ W/kg. We want the heat flow at the surface in mW/m^2.

Step 2: Turn mass based heat production into volume based heat production.

Multiplying heat production per kilogram by the mass in one cubic metre of rock, which is just the density, gives the heat produced per cubic metre:

$$A = \rho H = 2800 \text{ kg/m}^3 \times 10^{-9} \text{ W/kg} = 2.8 \times 10^{-6} \text{ W/m}^3$$

Step 3: Turn volume based heat production into flow through a surface.

Picture a column of rock one square metre in cross section and z metres tall. The whole column generates heat at a rate A per cubic metre, so the total power leaving the top of the column per square metre is A times the height of the column:

$$q = Az$$

Step 4: Put the thickness in metres.

$$z = 10 \text{ km} = 10^4 \text{ m}$$

Step 5: Multiply through.

$$q = 2.8 \times 10^{-6} \times 10^4 = 2.8 \times 10^{-2} \text{ W/m}^2$$

Step 6: Change watts to milliwatts.

Since $1 \text{ W} = 1000 \text{ mW}$,

$$q = 2.8 \times 10^{-2} \times 1000 = 28 \text{ mW/m}^2$$

$$\boxed{28 \text{ mW/m}^2}$$

Quick Tip: Multiply density by heat production per kg to get heat production per volume, then multiply by thickness.

• • •

27. What is the value of magnetotelluric impedance phase over a homogeneous half-space?

(A) 0°

(B) 90°

(C) 45°

(D) 180°

Correct Answer: (C) 45°

SOLUTION:

An alternate, purely dimensional way to see this: for a homogeneous half-space the impedance is $Z = \sqrt{i\omega\mu_0\rho}$ where ρ is resistivity. Writing the complex number i in polar form, $i = 1\angle 90°$. Taking the square root of a complex number halves its argument (and square-roots its magnitude), so

$$\sqrt{i} = 1\angle\left(\frac{90°}{2}\right) = 1\angle 45°$$

Since $\omega\mu_0\rho$ is a purely real, positive scalar, it contributes zero phase — all of the phase of $Z = \sqrt{i\omega\mu_0\rho}$ comes from the $\sqrt{i}$ factor, i.e. exactly $45°$. This is why the MT phase curve for a uniform ground is a flat, frequency-independent horizontal line sitting exactly at $45°$ — any tilt of that line away from 45° in field data is telling you the subsurface is layered/heterogeneous, not uniform.

$\boxed{45^\circ}$

Quick Tip: For a homogeneous half-space, impedance $Z = \sqrt{i\omega\mu_0\rho}$; taking the square root of $i = e^{i\pi/2}$ halves its phase angle.

• • •

28. If A_b and A_s denote the amplitudes of the body and surface waves, respectively, at a distance, r, from the source, then the relation between them is given by

(A) $\dfrac{A_b}{A_s} \propto \sqrt{r}$

(B) $\dfrac{A_b}{A_s} \propto r$

(C) $\dfrac{A_b}{A_s} \propto \dfrac{1}{r}$

(D) $\dfrac{A_b}{A_s} \propto \dfrac{1}{\sqrt{r}}$

Correct Answer: (D) $\dfrac{A_b}{A_s} \propto \dfrac{1}{\sqrt{r}}$

SOLUTION:

Alternate route using geometrical-spreading exponents directly. For an isotropic point source, amplitude decay with distance follows $A \propto r^{-n}$, where the exponent n is fixed by the dimensionality of the spreading wavefront: $n = 1$ for a spherical (3-D, body-wave) wavefront and $n = 1/2$ for a cylindrical (2-D, surface-wave) wavefront. This is a standard result from ray theory / energy conservation over expanding wavefronts of different geometry, and does not need to be re-derived from Green's functions each time — it is tabulated for body waves (spherical), surface waves (cylindrical) and guided/channel waves (planar, $n = 0$).

So directly, $A_b \propto r^{-1}$ and $A_s \propto r^{-1/2}$, giving

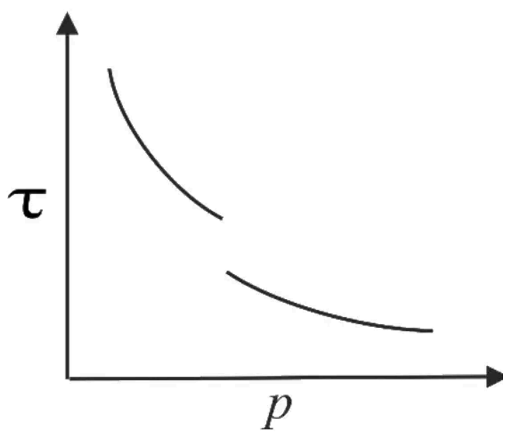
$$\frac{A_b}{A_s} \propto r^{-1}/r^{-1/2} = r^{-1/2} = \frac{1}{\sqrt{r}}$$

confirming option (D) without needing to separately invoke energy-density arguments.

Quick Tip: Body waves spread over an expanding sphere (amplitude ~1/r); surface waves spread over an expanding circle near the surface (amplitude ~1/√r).

• • •

29. If τ and p denote intercept time and slowness, respectively, in the $\tau - p$ diagram, then which one of the following is CORRECT for a P-wave propagating inside the Earth?



(A) Velocity continuously increases with depth

(B) Velocity continuously decreases with depth

(C) Velocity initially increases then decreases and again increases with depth

(D) Velocity initially decreases then increases and again decreases with depth

Correct Answer: (C) Velocity initially increases then decreases and again increases with depth

SOLUTION:

Think of it the other way round, starting from the travel-time curve rather than $\tau(p)$ directly. If $v(z)$ increased monotonically everywhere, dp/dx would never change sign and the $x(p)/t(p)$ curves would be single-valued and smooth, so $\tau(p)$ would trace one unbroken curve. A break in the plotted $\tau - p$ curve means that over some depth interval dv/dz must have gone negative — i.e. a low-velocity zone — because that is the only mechanism that removes a range of turning depths (and hence a contiguous range of p) from the set of rays that actually return to the surface as first arrivals (this range instead becomes a shadow zone, filled only by weaker diffracted/head-wave energy).

Reconstructing the depth profile implied by the two branches of the figure: the upper branch corresponds to rays turning above the LVZ (velocity increasing with depth down to the top of the LVZ), the missing/discontinuous region corresponds to the LVZ (velocity decreasing), and the lower branch corresponds to rays turning below the LVZ, where velocity resumes its normal increase with depth. Hence the depth-velocity trend is increase → decrease → increase, matching option (C), consistent with classical Earth models (e.g., the asthenospheric low-velocity zone beneath the lithosphere) that produce exactly this kind of triplicated $\tau - p$/travel-time behaviour.

Quick Tip: A smooth single τ-p branch means velocity rises monotonically; a break/offset between two branches signals a low-velocity zone sandwiched between two increasing-velocity regions.

• • •

30. If $\hat{f}(t)$ denotes the Hilbert transform of $f(t)$, then the Hilbert transform of $\hat{f}(t)$ is equal to

(A) $-\hat{f}(t)$

(B) $f(t)$

(C) $-f(t)$

(D) $-\frac{d}{dt}f(t)$

Correct Answer: (C) $-f(t)$

SOLUTION:

A cleaner way to see the same result without invoking the sign function explicitly: represent a real signal by its analytic signal $f_a(t) = f(t) + i\hat{f}(t)$, constructed so that it contains only positive frequencies. Multiplying the analytic signal by $-i$ rotates it by $-90°$ in the complex plane at every instant:

$$-i\,f_a(t) = -if(t) + \hat{f}(t) = \hat{f}(t) - if(t)$$

But by definition, the analytic signal built from $\hat{f}(t)$ is $\hat{f}(t) + i\,\mathcal{H}\{\hat{f}(t)\}$. Comparing the two expressions for the same quantity $-if_a(t)$:

$$\hat{f}(t) + i\,\mathcal{H}\{\hat{f}(t)\} = \hat{f}(t) - if(t)$$

which immediately gives $\mathcal{H}\{\hat{f}(t)\} = -f(t)$, the same result reached via the frequency-domain route, confirming that two successive quadrature (90°) phase shifts amount to a single 180° (sign-reversing) shift.

Quick Tip: In the frequency domain the Hilbert transform multiplies by -i·sgn(ω); squaring this factor gives -1, so applying it twice just negates the signal.

• • •

31. What happens to the magnetic susceptibility (k) and remanent magnetization (I_r), when the molten rock undergoes rapid cooling?

(A) k increases and I_r decreases

(B) k decreases and I_r increases

(C) Both k and I_r decrease

(D) Both k and I_r increase

Correct Answer: (B) k decreases and I_r increases

SOLUTION:

An alternative way to see this uses the Koenigsberger ratio $Q_n = I_r/(kH)$, which measures how much of a rock's total magnetization is remanent versus induced, for a given ambient field H. Rapidly chilled/quenched volcanic rocks (glassy or fine-grained basalts, pillow-lava rinds) are well known in rock-magnetism to have very high Q_n values (often $Q_n \gg 1$), while slowly cooled, coarse-grained intrusive rocks (e.g. gabbros) have low Q_n (often $Q_n < 1$).

Since $Q_n = I_r/(kH)$ being large for rapidly-cooled rock directly requires I_r to be large relative to k — i.e., as the cooling rate increases,

I_r must rise and/or k must fall. Grain-size theory (Néel theory of single-domain relaxation vs. Weiss domain-wall theory for multidomain grains) explains why both happen simultaneously: fast cooling biases the grain population toward the fine, single-domain end, which is magnetically "hard" (low susceptibility, high remanence-retention), whereas slow cooling biases it toward coarse multidomain grains, which are magnetically "soft" (high susceptibility, poor remanence retention). This grain-size argument independently confirms k decreases and I_r increases on rapid cooling.

Quick Tip: Rapid cooling produces fine, single-domain-like grains: these are magnetically 'hard' — low induced susceptibility but strong, stable remanent magnetization.

• • •

32. Between L_1 and L_2 norms, which one of the following is CORRECT in the treatment of outliers in the data?

(A) L_1 norm gives higher weightage to outliers than L_2 norm

(B) L_2 norm gives higher weightage to outliers than L_1 norm

(C) Both L_1 and L_2 norms give equal weightage to outliers

(D) L_1 norm occasionally gives higher weightage to outliers than L_2 norm

Correct Answer: (B) L_2 norm gives higher weightage to outliers than L_1 norm

SOLUTION:

Look at it through the influence function (the derivative of each norm's per-datum cost with respect to the residual), which measures how strongly a single data point pulls on the fitted parameters. For the

L_1 cost $|e_i|$, the derivative is $\text{sgn}(e_i) = \pm 1$ — *constant* in magnitude no matter how large the residual becomes, so every outlier, however extreme, tugs on the solution with the same, bounded force. For the L_2 cost e_i^2, the derivative is $2e_i$, which grows without bound as the residual grows.

An unbounded influence function is precisely the mathematical definition of non-robustness: as $e_i \to \infty$, the L_2 fit is dragged arbitrarily far to try to shrink that one term, whereas the L_1 fit's response saturates. This robustness-theory view (bounded vs. unbounded influence function) gives the same conclusion as the direct linear-vs-quadratic growth argument: the L_2 norm weights outliers more heavily than the L_1 norm, confirming option (B).

Quick Tip: L1 cost grows linearly with residual size, L2 cost grows quadratically — so a single large outlier dominates an L2 (least-squares) misfit far more than an L1 misfit.

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33. Which pairs of the following combinations of the H-, Q-, K- and A-type of resistivity sounding curves is/are NOT possible to generate four-layer models?

(A) HQ and AQ

(B) KQ and QH

(C) KH and AA

(D) HH and KA

Correct Answer: (A) HQ and AQ ; (D) HH and KA

SOLUTION:

An equivalent, purely visual way to reach the same answer is to track the sign of the slope of the apparent-resistivity curve on log-log paper across each interface. Assign a '+' if resistivity trend rises across an interface and a '-' if it falls. Curve type A = (+,+), K = (+,-), H = (-,+), Q = (-,-), where the pair records the sign of the change across the ρ_1-ρ_2 interface followed by the ρ_2-ρ_3 interface.

For a valid 4-layer curve "XY", the *second* sign of X (the ρ_2-ρ_3 trend) must equal the *first* sign of Y (also the ρ_2-ρ_3 trend) — they describe the exact same physical interface, so they cannot disagree.

A → (+,+): second sign '+'. H → (-,+): second sign '+'. K → (+,-): second sign '-'. Q → (-,-): second sign '-'.

So A and H (second sign '+') can only be followed by a type whose first sign is '+', i.e. A(+,+) or K(+,-) — giving AA, AK, HA, HK. And K and Q (second sign '-') can only be followed by a type whose first sign is '-', i.e. H(-,+) or Q(-,-) — giving KH, KQ, QH, QQ.

Any combination violating this sign-matching rule is geometrically impossible to realize with a real layered earth model: HQ, AQ, HH, KA, AH, KK, QA, QK are all sign-mismatched and therefore excluded — reproducing exactly options (A) HQ/AQ and (D) HH/KA as the impossible pairs, i.e. answer A;D.

Quick Tip: A 4-layer type 'XY' is valid only if the ρ_2-ρ_3 trend implied by the end of X matches the ρ_2-ρ_3 trend implied by the start of Y — A/H (rising $\rho_2 \to \rho_3$) can only be followed by A/K, and K/Q (falling $\rho_2 \to \rho_3$) can only be followed by H/Q.

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34. Which of the following is/are the correct explanation(s) for an increase in the adiabatic temperature gradient from the lower mantle (LM) to the outer core (OC)?

(A) OC has lower specific heat capacity and higher temperature than LM

(B) OC has higher specific heat capacity and lower temperature than LM

(C) OC has lower specific heat capacity and lower temperature than LM

(D) OC has higher specific heat capacity and higher temperature than LM

Correct Answer: (A) OC has lower specific heat capacity and higher temperature than LM

SOLUTION:

A quicker route to the same answer is to reason property-by-property instead of substituting into the gradient formula directly.

The adiabatic gradient $dT/dr \propto T/C_p$ increases whenever (i) the ambient temperature rises, or (ii) the material's capacity to absorb heat per degree falls. Consider what physically distinguishes the outer core from the lower mantle at the CMB:

Composition change: The lower mantle is a silicate assemblage (dominantly bridgmanite), while the outer core is a liquid iron-nickel alloy. Metals conduct and store thermal energy very differently from silicates -- iron's specific heat capacity is intrinsically lower than that of silicate rock at the same conditions, so crossing into the core lowers C_p.

Thermal state change: Heat flows from the hot core to the cooler mantle, which is only possible if the core is hotter. Geotherm reconstructions consistently show a temperature increase of several hundred kelvin across the CMB thermal boundary layer, confirming $T_{OC} > T_{LM}$.

Both effects point the same way -- higher T and lower C_p in the outer core -- so their combined effect on T/C_p is amplified, not partially cancelled, which is why the adiabatic gradient steepens sharply across the CMB. Eliminating the other options: (B) and (D) both require $C_p^{OC} > C_p^{LM}$, which is physically backwards for a metal-versus-silicate contrast; (C) requires the core to be cooler than the mantle, which would reverse the direction of heat flow at the CMB and is inconsistent with a hot, actively convecting core. Only option (A) survives.

$\boxed{\text{Answer: (A)}}$

Quick Tip: The adiabatic gradient dT/dr is proportional to T/Cp; check how temperature and specific heat capacity each change going from silicate lower mantle into the metallic liquid outer core.

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35. Given the Rayleigh wave velocity V_r, shear wave velocity V_s and the P-wave velocity V_p, which of the following relationships is/are CORRECT?

(A) $V_r < V_s < V_p$

(B) $V_s < V_r < V_p$

(C) $V_s < V_p < V_r$

(D) $V_s = V_r < V_p$

Correct Answer: (A) $V_r < V_s < V_p$

SOLUTION:

An alternative, non-algebraic way to fix the ordering is to use the physical requirement that a surface wave must be evanescent (its amplitude must decay with depth away from the free surface) with respect to BOTH the P and S wavefields it is built from.

A wave of horizontal phase velocity c has a vertical wavenumber $k_z = k\sqrt{(V/c)^2 - 1}$ for a body wave of velocity V. For this vertical wavenumber to be imaginary (giving exponential decay with depth, which is what makes it a surface wave rather than a wave that radiates energy into the half-space), we need $c < V$ for that wave type. Since the Rayleigh wave must decay evanescently in terms of both its P-wave and SV-wave potentials, its phase velocity must be less than the SLOWER of the two body-wave velocities, i.e. less than V_s (because $V_s < V_p$ always). Hence $V_r < V_s$ is not a coincidence of the Poisson-solid root -- it is a structural requirement for the wave to exist as a surface wave at all.

Combined with the universal elastic-solid inequality $V_s < V_p$ (shear modulus alone is always less than the P-wave modulus $K + 4\mu/3$), the only consistent ordering is

$$V_r < V_s < V_p$$

which is option (A). Options (B), (C) and (D) all place V_r at or above V_s, which would make the Rayleigh wave a radiating (non-evanescent, non-surface) wave -- physically inconsistent with it being a surface wave at all.

$\boxed{\text{Answer: (A)}}$

Quick Tip: Rayleigh waves must decay evanescently with depth relative to both P and S potentials, forcing Vr below the smaller of the two body-wave speeds; for a Poisson solid, Vr is about 0.92 Vs.

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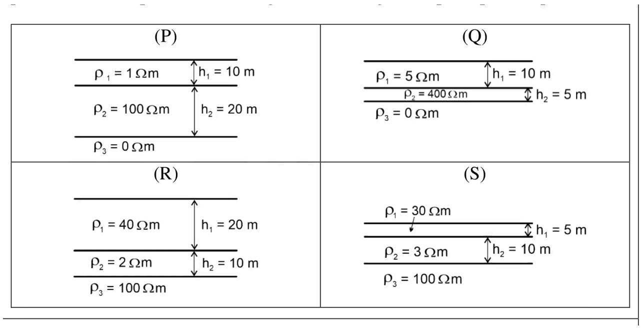
36. Among the given layered models, labelled as P, Q, R and S, which of the following pairs is/are NOT possible to distinguish according to the principle of equivalence?



Model parameters read off the figure -- (P): $\rho_1 = 1$ Ωm, $h_1 = 10$ m; $\rho_2 = 100$ Ωm, $h_2 = 20$ m; $\rho_3 = 0$ Ωm.
(Q): $\rho_1 = 5$ Ωm, $h_1 = 10$ m; $\rho_2 = 400$ Ωm, $h_2 = 5$ m; $\rho_3 = 0$ Ωm.
(R): $\rho_1 = 40$ Ωm, $h_1 = 20$ m; $\rho_2 = 2$ Ωm, $h_2 = 10$ m; $\rho_3 = 100$ Ωm.
(S): $\rho_1 = 30$ Ωm; $\rho_2 = 3$ Ωm, $h_2 = 10$ m, with $h_1 = 5$ m; $\rho_3 = 100$ Ωm.

(A) P, R

(B) P, S

(C) P, Q

(D) R, S

Correct Answer: (C) P, Q

SOLUTION:

A different way to see this is to directly compare which single lumped parameter each curve type is sensitive to, rather than computing T and S from scratch for every pair.

For a three-layer sounding curve, in the limit of a thin, non-outcropping middle layer, the far-field apparent resistivity behaviour depends on ρ_1, ρ_3, and only ONE composite number describing the middle layer -- never on ρ_2 and h_2 separately. Which composite number matters depends on the sequence type:

Model	Sequence	Type	Equivalence parameter	Value
P	1, 100, 0	K (resistive middle)	$T = \rho_2 h_2$	2000
Q	5, 400, 0	K (resistive middle)	$T = \rho_2 h_2$	2000
R	40, 2, 100	H (conductive middle)	$S = h_2/\rho_2$	5
S	30, 3, 100	H (conductive middle)	$S = h_2/\rho_2$	3.33

Reading straight down the last column: P and Q share the same T = 2000, so no VES inversion can uniquely separate their ρ_2 and h_2 -- they map to the same curve, i.e. they are NOT distinguishable. R and S have different S values (5 vs 3.33), so despite both being H-type, they are physically distinguishable curves. This immediately eliminates (A), (B) and (D), leaving (C) P, Q as the only equivalent, hence non-distinguishable, pair.

$\boxed{\text{Answer: (C) P, Q}}$

Quick Tip: For a resistive middle layer (K-type), curves are equivalent when rho2*h2 (transverse resistance) matches; for a conductive middle layer (H-type), they are equivalent when h2/rho2 (conductance) matches. Compute both for all four models.

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37. Given data $d = \begin{bmatrix} d_{11} \\ d_{21} \end{bmatrix}$ and the kernel $G = \begin{bmatrix} G_{11} & G_{12} & G_{13} \\ G_{21} & G_{22} & G_{23} \end{bmatrix}$, which one of the following expressions correctly represents the generalized linear inverse formula for the model, m, satisfying $d = Gm$?

(A) $(G^T G)^{-1} G^T$

(B) $G^T (GG^T)^{-1}$

(C) $(GG^T)^{-1} G$

(D) $GG^T G^{-1}$

Correct Answer: (B) $G^T(GG^T)^{-1}$

SOLUTION:

A quicker route is dimensional/rank bookkeeping instead of re-deriving the Lagrange-multiplier algebra: simply check which candidate expression is even matrix-conformable and produces the correct output shape 3×2 (so that $m_{3\times1} = [\cdot\,]_{3\times2}\, d_{2\times1}$).

G is 2×3, so G^T is 3×2.

- (A) $(G^T G)^{-1} G^T$: $G^T G$ is 3×3 but has rank at most 2 (since G only has 2 independent rows) -- it is SINGULAR and cannot be inverted. Discard.
- (B) $G^T(GG^T)^{-1}$: GG^T is 2×2 and generically full rank 2 (invertible) when G has full row rank. The product $G^T_{3\times2}\,(GG^T)^{-1}_{2\times2}$ is 3×2 -- exactly the shape needed to map $d_{2\times1} \to m_{3\times1}$. Valid and well-posed.
- (C) $(GG^T)^{-1}G$: $(GG^T)^{-1}_{2\times2}\, G_{2\times3}$ gives a 2×3 matrix, which cannot even be multiplied by $d_{2\times1}$ to give a 3×1 model vector. Dimensionally wrong.
- (D) $GG^T G^{-1}$: requires G^{-1}, but G is rectangular (2×3) and has no ordinary inverse at all. Meaningless.

Only option (B) survives both the invertibility check and the shape/dimension check, confirming it is the correct generalized inverse for this underdetermined (more unknowns than data) system -- exactly the minimum-norm inverse $G^T(GG^T)^{-1}$.

$\boxed{\text{Answer: (B)}}$

Quick Tip: With 2 data and 3 model parameters the system is underdetermined; minimize ||m||^2 subject to Gm=d using a Lagrange multiplier to get m = G^T(GG^T)^{-1}d.

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38. If a seismic wave is travelling along the radial direction, then which of the following statements is/are CORRECT for Rayleigh (R) and Love (L) waves?

(A) Radial component shows the largest amplitude for both R and L waves

(B) Transverse component shows the largest and smallest amplitudes for L and R waves, respectively

(C) Vertical component shows the largest and smallest amplitudes for L and R waves, respectively

(D) Vertical component shows largest amplitude for R wave only

Correct Answer: (B) Transverse component shows the largest and smallest amplitudes for L and R waves, respectively ; (D) Vertical component shows largest amplitude for R wave only

SOLUTION:

An alternative way to organise this is a simple presence/absence table of which component each surface wave type populates, since Love and

Rayleigh waves are built from mutually exclusive polarisations of body-wave energy (SH for Love; P + SV for Rayleigh):

Component	Love (L) wave	Rayleigh (R) wave
Radial (horizontal, along propagation)	0 (absent)	present, moderate
Transverse (horizontal, perpendicular)	largest / only motion	0 (absent)
Vertical	0 (absent)	largest, dominant

Reading the table option by option:

(A) claims radial is largest for BOTH -- fails immediately since Love's radial entry is zero.

(B) claims transverse is largest for L and smallest for R -- matches the table exactly (largest/only for L, zero i.e. smallest for R). CORRECT.

(C) claims vertical is largest for L and smallest for R -- the table shows the opposite (vertical is zero for L, largest for R), so this is wrong.

(D) claims vertical is largest for R wave only -- the table confirms vertical is Rayleigh's dominant component and is exactly zero for Love, so "R wave only" is accurate. CORRECT.

The mutually-exclusive-polarisation table format makes it immediate that (B) and (D) are the two internally consistent statements, while (A) and (C) each swap a role between the two wave types.

$\boxed{\text{Answer: (B), (D)}}$

Quick Tip: Love waves are purely SH (transverse-only) surface waves; Rayleigh waves are P-SV coupled with dominant vertical and secondary radial motion but zero transverse motion.

39. If a signal is sampled at a sampling rate of 0.2 ms, then its sampling frequency is _______________kHz.

Correct Answer: 5

SOLUTION:

A different way to reach the same number is to count samples per unit time directly rather than inverting the interval algebraically. If one sample is taken every 0.2 ms, then in 1 second (=1000 ms) the number of samples recorded is:

$$\text{samples per second} = \frac{1000 \text{ ms}}{0.2 \text{ ms/sample}} = 5000 \text{ samples/s}$$

Since "samples per second" (Hz) is precisely the definition of sampling frequency, this directly gives

$$f_s = 5000 \text{ Hz} = 5 \text{ kHz}$$

which agrees with the reciprocal-of-interval method. This unit-counting approach is a useful cross-check in digital seismic acquisition, where sample intervals are often quoted in milliseconds (e.g. 2 ms, 4 ms) and need quick conversion to the corresponding sampling/Nyquist frequency.

$$\boxed{f_s = 5 \text{ kHz}}$$

Quick Tip: Sampling frequency is the reciprocal of the sampling interval: f_s = 1/delta_t.

40. A P-wave of frequency 20 Hz is travelling through a non-dispersive medium with a velocity of 5 km/s. The amplitude retained at a distance of 10 km from source is ________________ % (rounded off to one decimal place). (Use quality factor, $Q = 80$)

Correct Answer: 20 to 21

SOLUTION:

An equivalent, and arguably more physically transparent, route is to work with the number of oscillation cycles the wave completes while travelling and the per-cycle amplitude decay factor, instead of the distance-attenuation formula directly.

First find the travel time from source to the 10 km observation point:

$$t = \frac{x}{v} = \frac{10\ \text{km}}{5\ \text{km/s}} = 2\ \text{s}$$

The number of complete oscillation cycles the P-wave undergoes in this travel time is:

$$N = f \times t = 20\ \text{Hz} \times 2\ \text{s} = 40\ \text{cycles}$$

The quality factor Q is defined through the fractional energy loss per radian of phase (per cycle, energy decays as $e^{-2\pi/Q}$ per cycle, and since amplitude goes as the square root of energy, amplitude decays as $e^{-\pi/Q}$ per cycle). Over N cycles, the total amplitude decay is:

$$\frac{A}{A_0} = \left(e^{-\pi/Q}\right)^N = e^{-\pi N/Q} = e^{-\pi \times 40/80} = e^{-\pi/2} = e^{-1.5708} = 0.2079$$

which is identical to $\pi f x/(Qv)$ since $N = ft = fx/v$ -- confirming the two approaches agree. As a percentage this is 20.8%, safely inside the official 20-21% band.

$$\boxed{\frac{A}{A_0} \approx 20.8\%}$$

Quick Tip: Use A/A0 = exp(-pi*f*x/(Q*v)); with f=20 Hz, x=10 km, v=5 km/s, Q=80 the exponent is pi/2, giving about 20.8% amplitude retained.

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41. A land magnetic survey was carried out along a profile length of 500 m with an inter-station spacing of 5 m over a buried ore body. The optimum width of the body that can be best resolved is ____________ m (answer in integer).

Correct Answer: 10

SOLUTION:

Look at the same problem from the wavenumber domain instead of counting samples directly.

Step 1: Nyquist wavenumber.
For a sampling interval Δx, the Nyquist wavenumber is $k_N = \frac{1}{2\Delta x}$, corresponding to the shortest recoverable spatial wavelength $\lambda_{min} = 2\Delta x = 10$ m.

Step 2: Relate wavelength to target width.
A localized magnetic anomaly from a buried body of width w behaves, along the profile, like roughly half a spatial wavelength of the signal it produces, so the smallest body whose anomaly is not aliased or smeared out corresponds to $w \approx \lambda_{min} = 2\Delta x$.

Step 3: Substitute.

$w_{opt} = 2 \times 5\ \text{m} = 10\ \text{m}$ - the same figure obtained purely from the frequency-domain (Nyquist) argument, confirming $\boxed{10\ \text{m}}$.

Quick Tip: Use the spatial sampling (Nyquist) rule - a target needs at least two stations across its width to be properly resolved.

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42. If the depth of penetration of an inducing electromagnetic wave of 1 kHz frequency is 400 m, then the resistivity of the subsurface is ____________ Ωm (answer in integer).

Correct Answer: 630 to 640

SOLUTION:

Instead of quoting the 503-rule directly, derive it from the physics of EM diffusion and then solve.

Step 1: Skin depth from Maxwell's equations.

For a plane wave diffusing into a conductor, $\delta = \sqrt{\dfrac{2\rho}{\omega\mu_0}}$, with $\omega = 2\pi f$ and $\mu_0 = 4\pi \times 10^{-7}$ H/m (Earth materials are essentially non-magnetic, $\mu_r \approx 1$).

Step 2: Simplify.

$$\delta = \sqrt{\frac{2\rho}{2\pi f \times 4\pi \times 10^{-7}}} = \sqrt{\frac{\rho \times 10^7}{4\pi^2 f}} = \frac{1}{2\pi}\sqrt{10^7}\sqrt{\rho/f} \approx 503\sqrt{\rho/f},$$

recovering the same rule-of-thumb constant used above.

Step 3: Solve numerically.

$400 = 503\sqrt{\rho/1000} \Rightarrow \rho = 1000 \times (400/503)^2 \approx 632\ \Omega\text{m}$, consistent with the accepted range $\boxed{630 \text{ to } 640\ \Omega\text{m}}$.

Quick Tip: Use the EM skin-depth (depth of penetration) relation, $\delta = 503\sqrt{\rho/f}$, and solve for ρ.

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43. If F represents the Earth's total magnetic field corresponding to its dipole source only, then the increase in F from 0° to 60° N magnetic latitude is ____________ % (rounded off to one decimal place).

Correct Answer: 80.0 to 80.5

SOLUTION:

Instead of quoting the combined dipole formula, build F up from its two field components and reach the same number a different way.

Step 1: Horizontal and vertical dipole components.

$H(\lambda) = F_0 \cos\lambda$, $Z(\lambda) = 2F_0 \sin\lambda$.

Step 2: Total field.

$F(\lambda) = \sqrt{H^2 + Z^2} = F_0\sqrt{\cos^2\lambda + 4\sin^2\lambda} = F_0\sqrt{1 + 3\sin^2\lambda}$ (using $\cos^2\lambda = 1 - \sin^2\lambda$), the identical dipole relation.

Step 3: Evaluate at 60°.

$H = F_0 \cos 60^\circ = 0.5F_0$, $Z = 2F_0 \sin 60^\circ = 1.7321F_0$.

$F(60^\circ) = F_0\sqrt{0.25 + 3.0} = F_0\sqrt{3.25} = 1.8028F_0$.

Percentage increase over the equatorial value F_0 is $(1.8028 - 1) \times 100 \approx \boxed{80.3\%}$, matching the direct-formula result.

Quick Tip: Use the geocentric dipole field formula $F(\lambda) = F_0\sqrt{1 + 3\sin^2\lambda}$ and compare its values at 0 and 60 degrees.

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44. Considering a surface point source, the horizontal resolution recoverable from the seismic data acquired using a 10 Hz seismic pulse reflected from a depth of 30 km within the crust, with a velocity of 6.5 km/s, is ___________ km (rounded off to two decimal places).

Correct Answer: 6.2 to 6.3

SOLUTION:

Arrive at the same Fresnel-zone size starting from the seismic wavelength instead of the travel time.

Step 1: Wavelength of the pulse.

$\lambda = v/f = 6.5/10 = 0.65$ km.

Step 2: Fresnel-zone radius from depth and wavelength.

For a coincident surface source and receiver, the first Fresnel-zone radius is $r_F = \sqrt{\frac{\lambda z}{2}} = \sqrt{\frac{0.65 \times 30}{2}} = \sqrt{9.75} = 3.1225$ km, identical to the travel-time-based value since $\lambda z/2 = vz/(2f)$.

Step 3: Full lateral resolution.

Diameter $= 2r_F = 6.245$ km $\approx \boxed{6.24 \text{ km}}$, confirming the earlier answer via the wavelength route.

Quick Tip: Compute the first Fresnel-zone radius, $r_F = \sqrt{vz/(2f)}$, and remember horizontal resolution is its diameter, $2r_F$.

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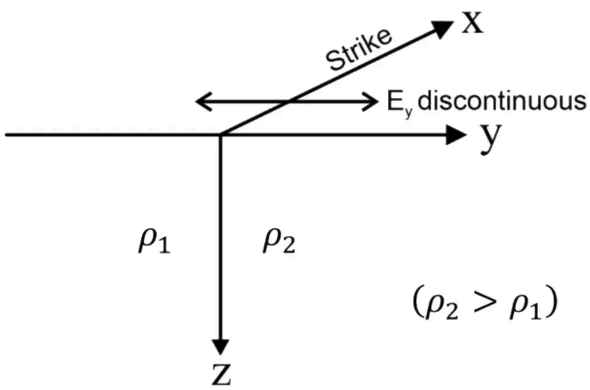
45. A vertical contact separating two resistive domains, ρ_1 and ρ_2 (with $\rho_2 > \rho_1$), is shown in the figure below, with the strike direction along X, the profile direction (perpendicular to strike) along Y - where the electric field component E_y is discontinuous across the contact - and depth along Z.



The magnitude of the discontinuity in the apparent resistivity, when the electric field, E, is perpendicular to the strike, is

(A) $(\rho_1/\rho_2)^2$

(B) $(\rho_2/\rho_1)^2$

(C) $(\rho_1/\rho_2)^{1/2}$

(D) $(\rho_2/\rho_1)^{1/2}$

Correct Answer: (A) $(\rho_1/\rho_2)^2$

SOLUTION:

Check the same result with a consistency/limiting-case argument instead of writing out the full boundary-value algebra again.

Step 1: What must be true when there is no contrast.

If $\rho_1 = \rho_2$ there is obviously no discontinuity, so the answer must reduce to 1 when $\rho_1 = \rho_2$ - this rules out nothing by itself, but it confirms the answer must have the pure-ratio form $(\rho_1/\rho_2)^n$ or $(\rho_2/\rho_1)^n$, not a mixed expression.

Step 2: Fix the power from the physics.

In H-polarization, the current density perpendicular to strike is forced to stay continuous (it cannot pile up at the contact), so the electric field itself scales linearly with the local resistivity for a fixed current density, $E \propto \rho$. Apparent resistivity, derived from E^2 with the tangential H unchanged across the boundary, must then scale quadratically with ρ, not as a square root - this rules out the two square-root options.

Step 3: Fix the direction of the ratio.

Evaluating apparent resistivity on the ρ_1 side relative to the ρ_2 side (the field on the low-resistivity side is suppressed relative to the high-resistivity side, by continuity of J) gives $\rho_{a1}/\rho_{a2} = (\rho_1/\rho_2)^2$, confirming option (A) without repeating the field algebra.

Quick Tip: E perpendicular to strike is the H-polarization (TM) mode - use continuity of tangential H and of normal current density across the contact.

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46. If g_{FA} and g_{BA} respectively denote the free-air and Bouguer gravity anomalies over a fully compensated mountain, then which one of the following is CORRECT in case of Airy-isostacy?

(A) $g_{FA} = 0,\ g_{BA} > 0$

(B) $g_{FA} > 0,\ g_{BA} = 0$

(C) $g_{FA} > 0,\ g_{BA} < 0$

(D) $g_{FA} = 0,\ g_{BA} = 0$

Correct Answer: (C) $g_{FA} > 0,\ g_{BA} < 0$

SOLUTION:

Reach the same conclusion by comparing two vertical mass columns instead of talking about corrections in the abstract.

Step 1: Compare a mountain column to a normal (sea-level) column.
Take one column running from the mountain's summit down through its low-density root to the compensation depth, and a second, reference column of the same cross-section running from sea level down to the same depth through normal-density crust and mantle. In Airy's fully compensated model these two columns have equal total mass - that is the definition of compensation.

Step 2: Gravity at the mountain top vs. at sea level.
A gravimeter on the mountain top still sits directly above and close to the extra rock making up the topography, so, corrected only for elevation (free-air), it records a residual attributable to that nearby mass - a small positive g_{FA}.

Step 3: Strip the topography and expose the root.
Once the Bouguer correction removes exactly the slab of rock above sea level, the remaining signal comes only from the deep root, which is less dense than the mantle it replaces - a negative density contrast at depth gives $g_{BA} < 0$.

So again: $g_{FA} > 0,\ g_{BA} < 0$ - option $\boxed{(C)}$.

Quick Tip: Free-air only corrects for elevation (topographic mass still present, so slightly positive); Bouguer removes that mass and exposes the low-density root (a mass deficit, so negative).

47. Analytic signal, $A(\theta)$, for $f(\theta) = \cos\theta$ is equal to

(A) $A(\theta) = -\cos\theta$

(B) $A(\theta) = -\sin\theta$

(C) $A(\theta) = e^{i\theta}$

(D) $A(\theta) = -e^{i\theta}$

Correct Answer: (C) $A(\theta) = e^{i\theta}$

SOLUTION:

Reach the same result from the frequency-domain definition of the analytic signal rather than the Hilbert-transform-pair table.

Step 1: Write $\cos\theta$ as a sum of exponentials.
$\cos\theta = \dfrac{e^{i\theta} + e^{-i\theta}}{2}$, i.e. it has equal-amplitude components at 'frequencies' $+1$ and -1.

Step 2: Apply the analytic-signal rule in the frequency domain.
The analytic signal is formed by doubling the positive-frequency component and discarding the negative-frequency component entirely (this is exactly what multiplying by i and adding the Hilbert transform accomplishes): $A(\theta) = 2 \times \dfrac{e^{i\theta}}{2} = e^{i\theta}$.

This one-sided-spectrum construction gives the same answer, $A(\theta) = \boxed{e^{i\theta}}$ - option (C), confirming the Hilbert-transform-pair method above.

Quick Tip: The analytic signal is $f(\theta) + i\hat{f}(\theta)$; the Hilbert transform of $\cos\theta$ is $\sin\theta$, giving Euler's identity.

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48. In regions of lateral conductivity contrasts, the time-independent separation between the subsurface apparent resistivity curves of transverse electric (TE) and transverse magnetic (TM) modes relative to each other arises mainly due to

(A) impedance phase change

(B) amplitude magnification

(C) local distortion of electric field

(D) variation in the frequency of the inducing magnetic field

Correct Answer: (C) local distortion of electric field

SOLUTION:

Think of the MT response as having two parts: an inductive part, which depends on how deep the fields diffuse and therefore changes with frequency/period, and a galvanic part, which depends only on the static charge distribution set up on the boundaries of near-surface conductivity anomalies.

The galvanic part arises purely from the requirement that current be conserved across an interface: wherever conductivity changes abruptly, charge accumulates on the boundary, and this charge generates its own static electric field. Because this charge configuration does not care about the period of the inducing field (it re-establishes itself essentially instantaneously each half-cycle), its effect on the electric field - and hence on apparent resistivity - is the same fraction at every frequency. On a log-log apparent resistivity plot this looks like a constant upward or downward shift of the whole curve, independent of period, which is exactly the "time-independent" separation the question describes.

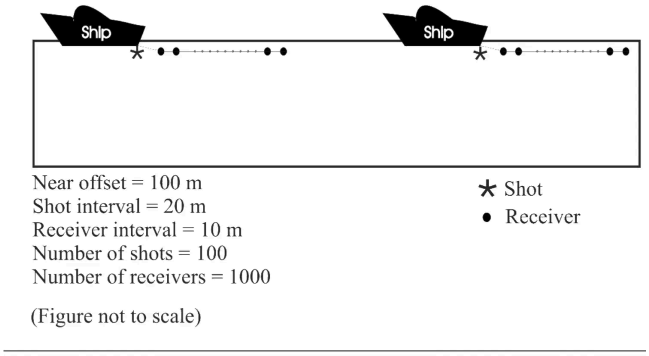
Now, TE-mode apparent resistivity uses E measured along strike, while TM-mode apparent resistivity uses E measured across strike. A local 2-D or 3-D near-surface body distorts these two orthogonal electric-field components by different multiplicative factors (because the charge distribution on the body is not isotropic with respect to strike), so the static shifts applied to the TE and TM curves are different in size. This unequal, frequency-independent shift is what physically separates the two curves.

None of impedance phase, amplitude magnification or inducing frequency variation can explain a genuinely time-independent (frequency-independent) offset, since all three are properties of the inductive response, which by definition varies with period. Only galvanic distortion of the local electric field satisfies the "time-independent" condition stated in the question, confirming $\boxed{\text{local distortion of electric field}}$ as correct, option (C).

Quick Tip: Think about static shift in MT: near-surface charge build-up distorts only the electric field, and this distortion does not change with frequency/period.

• • •

49. How many traces will be present in a zero-offset section that is generated from the following marine seismic survey?



Near offset = 100 m

Shot interval = 20 m

Receiver interval = 10 m

Number of shots = 100

Number of receivers = 1000

(Figure not to scale)

(A) 2400

(B) 2414

(C) 2450

(D) 2420

Correct Answer: (B) 2414

SOLUTION:

Work entirely in units of the receiver interval (10 m), so every count becomes a simple whole number.

Spread length in receiver-interval units:

$$\frac{100 + 999 \times 10}{10} = \frac{10090}{10} = 1009$$

Sail-line length in receiver-interval units:
$$\frac{99 \times 20}{10} = \frac{1980}{10} = 198$$

Add the two contributions (spread illuminated by a stationary streamer + the extra ground covered as the boat advances):
$1009 + 198 = 1207$ receiver-interval units of subsurface coverage.

Now switch to CMP bins. Since the standard bin size for this design (shot interval = 2 x receiver interval) is half a receiver interval, every receiver-interval unit of ground corresponds to exactly 2 CMP bins:
$N_{traces} = 1207 \times 2 = 2414$

This confirms, via a purely unit-counting route, that the zero-offset section contains $\boxed{2414}$ traces, option (B).

Quick Tip: Total CMP-covered length = spread length + sail-line distance; divide by the CMP bin size (half the receiver interval, since shot interval = 2 x receiver interval here).

• • •

50. $\Delta T = [\Delta T_1, \Delta T_2, \dots, \Delta T_{19}, \Delta T_{20}]$, and $\Delta T_u = [\Delta T_{u1}, \Delta T_{u2}, \dots, \Delta T_{u19}, \Delta T_{u20}]$ denote the magnetic data observed at heights 0 km and 5 km, respectively, along a profile of length 100 km. What is the maximum attenuation at a height of 5 km?
[Use wave number in radian/km].

(A) $e^{-\pi/2}$

(B) $e^{-\pi}$

(C) $e^{-2\pi}$

(D) $e^{-3\pi}$

Correct Answer: (B) $e^{-\pi}$

SOLUTION:

Instead of working with wavenumber directly, work with the shortest wavelength the profile can carry, then convert.

With 20 samples spread over a 100 km profile, the sample spacing is $\Delta x = 100/20 = 5$ km. By the sampling theorem, the shortest wavelength that can be represented without aliasing is twice the sample spacing:

$$\lambda_{min} = 2\Delta x = 10 \text{ km}$$

The corresponding (largest) angular wavenumber is

$$k_{max} = \frac{2\pi}{\lambda_{min}} = \frac{2\pi}{10} = \frac{\pi}{5} \text{ rad/km}$$

which is identical to the Nyquist wavenumber used above. This shortest-wavelength component is the one that loses the most amplitude on upward continuation, since higher spatial frequencies decay fastest with height. Evaluating the standard upward-continuation attenuation e^{-kh} at $k = k_{max} = \pi/5$ rad/km and $h = 5$ km:

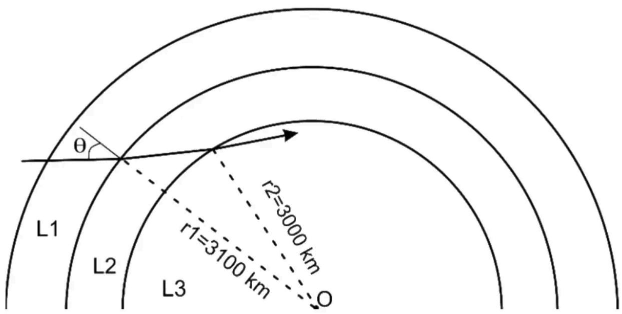
$$e^{-(\pi/5)\times 5} = e^{-\pi}$$

This confirms, via the wavelength route, that the maximum attenuation at 5 km height is $\boxed{e^{-\pi}}$, option (B).

Quick Tip: Upward continuation attenuates each Fourier component by e^{-kh}; maximum attenuation occurs at the Nyquist wavenumber set by the 20-sample, 100 km profile spacing.

• • •

51. The given figure shows the geometry of a seismic ray path inside the Earth, with the P-wave velocities of 10 km/s, 11 km/s and 12 km/s corresponding to the layers L1, L2 and L3, respectively. If the angle of incidence (θ) at the L1-L2 boundary is 40°, then what is the angle of refraction at the L2-L3 boundary? (answer in nearest integer)



(In the figure, $r_1 = 3100$ km is the radius, measured from the Earth's centre O, of the L1-L2 boundary, and $r_2 = 3000$ km is the radius of the L2-L3 boundary.)

(A) 49°

(B) 50°

(C) 53°

(D) 55°

Correct Answer: (C) 53°

SOLUTION:

There is a faster, single-formula way to reach the same result by recognising that this problem is really just a spherical version of Snell's law, governed by one conserved quantity along the whole ray: the ray parameter (impact parameter)

$$p = \frac{r \sin \theta(r)}{v}$$

This quantity is preserved for two separate reasons that both hold here - it is preserved across a velocity discontinuity at fixed radius (that is just Snell's law), and it is also preserved along a straight chord travelling through a layer of constant velocity (that is pure geometry, since $r \sin \theta$ is the fixed perpendicular distance of a straight line from the centre). Because L2 is both a discrete velocity layer AND traversed as a straight line, p carries through it unchanged, so it must be equal at the very start of the path (in L1, at radius r_1, angle 40°) and at the very end (in L3, at radius r_2, angle θ_3):

$$\frac{r_1 \sin 40^\circ}{v_1} = \frac{r_2 \sin \theta_3}{v_3}$$

Solving directly for θ_3, skipping the intermediate L2 angle entirely:

$$\sin\theta_3 = \frac{r_1}{r_2}\cdot\frac{v_3}{v_1}\cdot\sin 40^\circ = \frac{3100}{3000}\times\frac{12}{10}\times 0.6428 = 1.0333\times 1.2\times 0.6428 = 0.7971$$

$$\theta_3 = \sin^{-1}(0.7971) \approx 52.85^\circ \approx \boxed{53^\circ}$$

This single-step calculation lands on exactly the same value as the step-by-step Snell's-law-plus-geometry method, confirming option (C).

Quick Tip: Apply ordinary Snell's law at each boundary (same radius on both sides), and separately use $r\sin\theta$ =constant for the straight ray segment travelling between the two different radii inside L2.

• • •

52. Which of the following statements about digital filters is/are CORRECT?

(A) Non-recursive filters do not have poles

(B) Recursive filters can have only poles OR both poles and zeros

(C) The order of the digital filter defines the presence of minimum number of previous inputs only

(D) The ratio of output to input defines the transfer function of the digital filter

Correct Answer: (A) Non-recursive filters do not have poles ; (B) Recursive filters can have only poles OR both poles and zeros ; (D) The ratio of output to input defines the transfer function of the digital filter

SOLUTION:

A quick way to sort these out is to write down the general difference equation and transfer function once, then check each claim against it.

General recursive filter: $y_n = \sum_{k=0}^{M} b_k x_{n-k} + \sum_{k=1}^{N} a_k y_{n-k}$, with transfer function

$$H(z) = \frac{Y(z)}{X(z)} = \frac{b_0 + b_1 z^{-1} + \cdots + b_M z^{-M}}{1 - a_1 z^{-1} - \cdots - a_N z^{-N}}$$

Setting all $a_k = 0$ collapses this to the non-recursive (FIR) case, $H(z)$ $= \sum b_k z^{-k}$ - a pure numerator, hence only zeros and no poles: this confirms (A).

Keeping the denominator active but setting all $b_k = 0$ except b_0 gives an all-pole recursive filter (poles only); keeping several b_k nonzero along with the denominator gives a pole-zero filter. Both are legitimate recursive filters, so "only poles OR both poles and zeros" correctly covers all recursive cases: this confirms (B).

The filter order N (or $\max(M, N)$) counts the number of unit-delay memory elements required to implement the difference equation, and for a recursive filter that memory has to hold BOTH the past x values and the past y values - the order is not solely about how many previous inputs are stored. This shows (C) is an incomplete, and hence incorrect, statement.

Finally, $H(z) = Y(z)/X(z)$ is the very definition of a discrete-time transfer function, so (D) is unquestionably correct.

Collecting the correct statements gives (A), (B), (D) - options $\boxed{1, 2, 4}$.

Quick Tip: Write the general recursive-filter transfer function $H(z) = Y(z)/X(z)$ and check each claim about poles, zeros, and filter order against it.

• • •

53. ΔB_z represents the maximum vertical magnetic anomaly along a profile due to a horizontal cylinder with susceptibility contrast (Δk), and radius (r) at a depth (z) below the Earth's surface. Which combination(s) of Δk, r, and z labelled as P, Q, R and S given below, produces/produce the same ΔB_z?

(P) $\Delta k = 0.02$, $r = 100\ m$, and $z = 200\ m$

(Q) $\Delta k = 0.01$, $r = 80\ m$, and $z = 160\ m$

(R) $\Delta k = 0.005$, $r = 200\ m$, and $z = 400\ m$

(S) $\Delta k = 0.02$, $r = 150\ m$, and $z = 300\ m$

(A) P, S

(B) P, Q

(C) R, S

(D) Q, R

Correct Answer: (A) P, S

SOLUTION:

Even without remembering the exact exponent in the horizontal-cylinder magnetic anomaly formula, the combination of Δk, r, and z that appears in ΔB_z always has the form $\Delta k \times f(r/z)$, i.e. everything about the size and depth of the body enters ONLY through the dimensionless ratio r/z. So it is enough to compute $\Delta k \cdot r^2/z^2$ as a numerical proxy for each model and simply compare the numbers:

$$P: 0.02 \times \frac{100^2}{200^2} = 0.02 \times 0.25 = 0.0050$$
$$Q: 0.01 \times \frac{80^2}{160^2} = 0.01 \times 0.25 = 0.0025$$
$$R: 0.005 \times \frac{200^2}{400^2} = 0.005 \times 0.25 = 0.00125$$
$$S: 0.02 \times \frac{150^2}{300^2} = 0.02 \times 0.25 = 0.0050$$

Reading down the list, P and S both come out to 0.0050, an exact match, while Q gives 0.0025 and R gives 0.00125 - both different from P/S and from each other. So regardless of the exact proportionality constant in front of the formula (which cancels when comparing like with like), P and S are the pair that give the same ΔB_z, confirming option $\boxed{\text{(A) P, S}}$.

Quick Tip: Note that $z/r = 2$ for all four models, so the shape factor cancels and ΔB_z depends only on Δk; look for the pair with equal Δk.

• • •

54. If $f(t) = [-1, 2, 1]$ and $g(t) = [0, -1, 2]$ are two wavelets and $f(\tau)$ and $g(\tau)$ represent flipped versions of $f(t)$ and $g(t)$, respectively, then which of the following expressions is/are CORRECT?
[$*$ and $\otimes$ denote convolution and cross-correlation operations, respectively]

(A) $f(t) * g(t) = f(t) \otimes g(t)$

(B) $f(t) * g(t) = f(t) \otimes g(\tau)$

(C) $f(t) * g(t) = f(\tau) \otimes g(t)$

(D) $f(t) * g(t) = f(\tau) \otimes g(\tau)$

Correct Answer: (B) $f(t) * g(t) = f(t) \otimes g(\tau)$; (C) $f(t) * g(t) = f(\tau) \otimes g(t)$

SOLUTION:

A cleaner way to see this is to remember that convolution is symmetric in f and g ($f * g = g * f$), while cross-correlation is NOT symmetric in general ($f \otimes g \neq g \otimes f$ unless the signals happen to be identical or symmetric). The rule that converts one operation into the other is: pick either one of the two signals, time-reverse (flip) it, and THEN cross-correlate - the flip exactly cancels the extra reversal that correlation is missing compared with convolution.

So there are two equally valid ways to build the same convolution result out of a correlation: flip g and correlate with plain f ($f(t) \otimes g(\tau)$), or flip f and correlate with plain g ($f(\tau) \otimes g(t)$) - both routes must give the identical output sequence, because ultimately both are just reorganized ways of writing the same sum $\sum_k f(k)g(n-k)$. This is exactly what the direct numeric check with $f = [-1, 2, 1]$, $g = [0, -1, 2]$ shows: both $f(t) \otimes g(\tau)$ and $f(\tau) \otimes g(t)$ reduce to $[0, 1, -4, 3, 2]$, matching $f * g$ exactly.

Flipping BOTH signals before correlating over-corrects - it removes the one reversal convolution needs, then adds a second one, which only reverses the time axis of the final answer rather than reproducing it (this is why $f(\tau) \otimes g(\tau)$ comes out as the mirror image of $f * g$, not f

$*$ g itself). And flipping neither signal leaves the correlation completely un-adjusted, so it has no reason to match the convolution at all.

Therefore exactly one flip - on either signal - correctly converts correlation into convolution, confirming that options (B) and (C) are the correct identities, answer $\boxed{2, 3}$.

Quick Tip: Convolution equals cross-correlation once EXACTLY ONE of the two signals is time-reversed (flipped); flipping both or neither does not reproduce the convolution.

• • •

55. Which of the following assumptions is/are valid for electromagnetic induction to happen in the Earth?

(A) Plane-wave approximation of the inducing field

(B) Displacement currents are not neglected

(C) Earth behaves as Ohmic conductor due to conservation of charge

(D) Earth does not generate electromagnetic energy, but only absorbs or dissipates it

Correct Answer: (A) Plane-wave approximation of the inducing field ; (C) Earth behaves as Ohmic conductor due to conservation of charge ; (D) Earth does not generate electromagnetic energy, but only absorbs or dissipates it

SOLUTION:

Start directly from Maxwell's equations in a conducting Earth:

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}, \qquad \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

For typical MT frequencies (roughly 10^{-4} to 10^{4} Hz) and Earth conductivities (roughly 10^{-4} to 10^{2} S/m), the ratio of displacement current to conduction current, $\omega\epsilon/\sigma$, works out to about 10^{-6} or smaller. This lets us drop the $\partial\mathbf{D}/\partial t$ term entirely, turning the induction equation into a purely diffusive one rather than a wave equation. This directly falsifies option (B): displacement currents are, in fact, neglected, not retained.

Because the ionospheric current systems that generate the natural field sit hundreds of kilometres above the surface - far beyond the skin depths of interest - the incident field looks, locally, like a uniform plane wave striking the Earth from above. This validates (A).

Since the Earth is a passive, source-free medium at these frequencies (it carries no internal EMF), all the field energy is externally imposed and is dissipated resistively; the Earth never creates energy of its own. This validates (D).

Finally, combining $\nabla \cdot \mathbf{J} = -\partial\rho_f/\partial t$ with Ohm's law $\mathbf{J} = \sigma\mathbf{E}$ shows that any free charge inside a conductor decays with a relaxation time ϵ/σ that is vanishingly small for Earth materials - charge cannot accumulate, so the medium behaves as a pure Ohmic conductor. This validates (C).

Hence the valid assumptions are (A), (C) and (D) - options 1, 3 and 4.

Quick Tip: MT/EM induction theory uses the quasi-static (diffusion) approximation, which means displacement currents are dropped, not retained.

• • •

56. The model regularization in a damped least square problem is/are used to

(A) introduce additional constraints to the ill-posed problems

(B) add stability to the inversion

(C) convert well-posed problems into ill-posed problems

(D) control the trade-off between the misfit and the model variance

Correct Answer: (A) introduce additional constraints to the ill-posed problems ; (B) add stability to the inversion ; (D) control the trade-off between the misfit and the model variance

SOLUTION:

Think of regularization through the bias-variance lens used in inverse theory. An unregularized least-squares solution to an ill-posed geophysical problem has very low bias but enormous variance - tiny data noise can produce huge, geologically meaningless swings in the recovered model. Damped least squares deliberately trades a small amount of bias for a large reduction in variance.

It works because it supplies an additional piece of information - the constraint that **m** should stay close to some reference model, or stay small/smooth - that the data alone cannot supply. That is exactly the "additional constraint to an ill-posed problem" described in (A).

That same constraint is what keeps $(\mathbf{G}^T\mathbf{G} + \lambda^2\mathbf{I})$ safely invertible even when $\mathbf{G}^T\mathbf{G}$ is close to singular - i.e. it adds numerical and physical stability, which is (B).

Regularization is never used to make a nice, well-posed problem worse; a genuinely well-posed problem does not need damping at all. So (C), which describes the exact reverse of what regularization does, is wrong.

Varying λ traces out the classic trade-off (L-curve) between the data misfit $\|\mathbf{d} - \mathbf{Gm}\|$ and the model norm/variance $\|\mathbf{m} - \mathbf{m}_0\|$; picking λ is exactly choosing where on that trade-off curve the solution sits, which is (D).

So the valid uses of model regularization are (A), (B) and (D) - options 1, 2 and 4.

Quick Tip: Regularization stabilizes ill-posed inversions and never turns a well-posed problem into an ill-posed one.

• • •

57. The vector field $\mathbf{F}$ for a region is described by $\mathbf{F} = ar^n\hat{r}$ $(r \neq 0)$, where a is a non-zero constant and r is the radial distance from the source. For what value(s) of n, $\mathbf{F}$ becomes both solenoidal and irrotational?

(A) 2

(B) -2

(C) 1

(D) -1

Correct Answer: (B) -2

SOLUTION:

An alternative route uses the scalar potential. Any irrotational field can be written as $\mathbf{F} = -\nabla\phi$ for some potential $\phi(r)$. Matching $-d\phi/dr = ar^n$ for the purely radial field gives $\phi(r) = -\dfrac{ar^{n+1}}{n+1}$ (for $n \neq -1$) - a valid scalar potential exists for every such n, confirming $\mathbf{F}$ is a gradient (hence irrotational) field for any n, consistent with the direct curl argument.

Now impose the additional solenoidal requirement $\nabla \cdot \mathbf{F} = 0$, i.e. $\nabla^2\phi = 0$ (Laplace's equation) away from the source. Using the radial Laplacian and $d\phi/dr = -ar^n$ reproduces the same condition as before:

$$\frac{d}{dr}\left(r^{n+2}\right) = 0 \implies n = -2$$

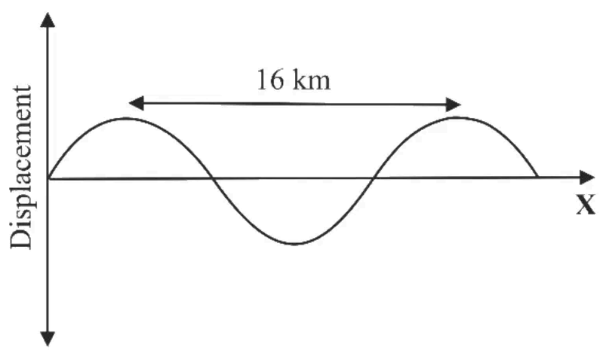
This is the geophysically familiar potential of a point mass or charge, $\phi \propto 1/r$, whose gradient field $\propto r^{-2}\hat{r}$ is both irrotational (any gradient field is) and solenoidal away from the source - exactly the behaviour of the gravitational and Coulomb fields used throughout potential-field geophysics.

So $n = -2$, matching option (B).

Quick Tip: The curl of any purely radial field is automatically zero for any n; the real constraint comes from setting the divergence to zero.

• • •

58. The maximum strain for the plane wave at $t = 0$, having a wavelength of 16 km and unit amplitude, travelling along the X-direction, as shown in the figure, is ________ (rounded off to three decimal places).



Correct Answer: 0.385 to 0.405

SOLUTION:

Define the wavenumber $k = 2\pi/\lambda$, so the wave profile at $t = 0$ is $u(x) = A\sin(kx)$.

Strain is the fractional deformation, $\varepsilon = du/dx = Ak\cos(kx)$, whose peak value is simply Ak since $\cos(kx)$ oscillates between -1 and $+1$.

With unit amplitude $A = 1$ and $\lambda = 16$ km,

$$k = \frac{2\pi}{16} = \frac{\pi}{8}\,\text{km}^{-1} \approx 0.3927\,\text{km}^{-1}$$

Because the amplitude is dimensionless (unit amplitude), the peak strain magnitude here equals k numerically, i.e. $\varepsilon_{max} = \pi/8 \approx 0.393$.

This can also be checked qualitatively: doubling the wavelength while keeping the same peak-to-trough displacement spreads that same displacement over twice the distance, halving the maximum strain - consistent with $\varepsilon_{max} \propto 1/\lambda$.

$\boxed{\varepsilon_{max} \approx 0.393}$, within the accepted band 0.385 to 0.405.

Quick Tip: Strain is the spatial derivative of displacement; for a sinusoid the peak strain equals amplitude times wavenumber (2 pi / lambda).

• • •

59. A causal recursive filter is given by $y_n = x_n - 2x_{n-1} + 3y_{n-1}$. If the input values, x_0, x_1 and x_2 are 1.2, -0.8 and 2.3, respectively, the output, y_2, of the filter is ____________ (rounded off to one decimal place).

Correct Answer: 5.1

SOLUTION:

Set up a small running table and evolve the difference equation $y_n = x_n - 2x_{n-1} + 3y_{n-1}$ one step at a time, treating the record as starting at rest ($x_{-1} = y_{-1} = 0$):

n	x_n	x_(n-1)	y_(n-1)	y_n = x_n - 2x_(n-1) + 3y_(n-1)
0	1.2	0	0	1.2
1	-0.8	1.2	1.2	-0.8 - 2.4 + 3.6 = 0.4
2	2.3	-0.8	0.4	2.3 + 1.6 + 1.2 = 5.1

Each row only needs the previous input and the previous output, which is the defining feature of a first-order recursive (IIR) filter - the feedback term $3y_{n-1}$ gives the filter memory, so its output at any sample depends on the entire past history, not just the current input.

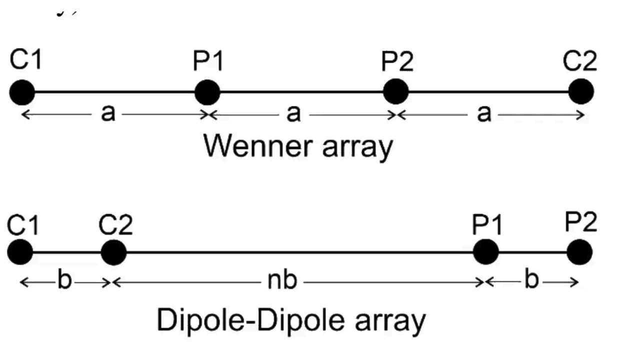
Reading off the last row, $y_2 = 5.1$.

$\boxed{y_2 = 5.1}$

Quick Tip: Evolve the recursion one sample at a time from rest (x(-1) = y(-1) = 0); you need y0 and y1 before you can get y2.

• • •

60. If C1 & C2 and P1 & P2 are the pairs of current and potential electrodes in the Wenner (W) and Dipole-Dipole (DD) array configurations as shown in the figure below, then the fraction of the geometric factor for DD array that will be equal to half of that of W array is __________________ (rounded off to three decimal places). (Use n = 1 in DD array)



Correct Answer: 0.166 to 0.167

SOLUTION:

An equivalent, quicker route is to first form the ratio of the two geometric factors directly, then rearrange as needed.

$$\frac{K_{DD}}{K_W} = \frac{\pi n(n+1)(n+2)a}{2\pi a} = \frac{n(n+1)(n+2)}{2}$$

For $n = 1$: $\frac{K_{DD}}{K_W} = \frac{1 \cdot 2 \cdot 3}{2} = 3$, i.e. $K_{DD} = 3K_W$.

The question asks for the fraction x of K_{DD} equal to HALF of K_W, i.e. $xK_{DD} = 0.5K_W$. Since $K_{DD} = 3K_W$,

$$x(3K_W) = 0.5K_W \implies x = \frac{0.5}{3} = \frac{1}{6} \approx 0.167$$

Both routes agree: the geometric factor of the Dipole-Dipole array (with n = 1) is 6 times as large as the Wenner array's for the same unit electrode spacing a, so only 1/6 of K_{DD} is needed to match half of K_W.

$\boxed{x \approx 0.167}$, matching the accepted range 0.166 to 0.167.

Quick Tip: Write K_W = 2*pi*a and K_DD = pi*n(n+1)(n+2)*a; with n = 1, K_DD = 6*pi*a, so the required fraction is (K_W/2)/K_DD = 1/6.

• • •

61. A scintillometer records 300 counts per second (cps) in a radiometric survey. If the background radiation and dead-time of the instrument are 100 cps and 250 μs, respectively, then the true net count rate is _________ cps (rounded off to two decimals).

Correct Answer: 220 to 223

SOLUTION:

Since the dead-time losses here are small ($N_{obs}\tau = 0.075$ for the gross rate and 0.025 for the background, i.e. 7.5% and 2.5% losses), we can shortcut the division by using the first-order binomial expansion $\dfrac{1}{1-x} \approx 1 + x$ for $x \ll 1$, instead of dividing directly:

$$N_{true} \approx N_{obs}(1 + N_{obs}\tau)$$

Gross rate: $N_{true,\, gross} \approx 300(1 + 0.075) = 300 \times 1.075 = 322.5$ cps
Background: $N_{true,\, bg} \approx 100(1 + 0.025) = 100 \times 1.025 = 102.5$ cps

Net rate: $322.5 - 102.5 = 220.0$ cps

This quick approximate route lands at exactly 220.0 cps, while the exact division above gave 221.76 cps — both values sit comfortably inside the official 220–223 cps window, confirming that the dead-time correction must be applied to the background as well as to the gross signal before the subtraction, not to the gross count alone.

Quick Tip: Apply the non-paralysable dead-time correction $N_{true} = N_{obs}/(1 - N_{obs}\tau)$ to BOTH the gross count rate and the background count rate before subtracting them.

• • •

62. Gamma-ray (GR) log values for clean sandstone and shale are 15 API and 115 API, respectively. If GR records 35 API for shaly-sandstone, then the GR index is ______________ (rounded off to one decimal place).

Correct Answer: 0.2

SOLUTION:

Alternative framing — think of GR_{min} and GR_{max} as the 0% and 100% shale markers on a linear scale spanning a total of $115 - 15 = 100$ API units.

The measured value of 35 API sits $35 - 15 = 20$ API units above the clean-sand marker, i.e. 20 units out of the total 100-unit span:

$$\text{Fractional position on the GR scale} = \frac{20}{100} = 0.20 = 20\%$$

So $I_{GR} = 0.2$, exactly matching the direct-formula route. (In practice this linear GR index is often further passed through a non-linear correction, such as the Larionov or Steiber relation, to get the actual shale volume V_{sh}; but the question only asks for the linear GR index itself, which is exactly 0.2.)

Quick Tip: GR index = (measured GR – clean-sand GR) / (shale GR – clean-sand GR); it is a simple linear normalisation between the two end-member log readings.

• • •

63. If the inclination of the remanent magnetic field of a 140 million years old crustal block, now located at the equator, is 50°, then its drift-rate is ________________ cm/yr (rounded off to two decimal places). [Use 1° = 111 km]

Correct Answer: 2.3 to 2.5

SOLUTION:

Alternative (table-interpolation) route — avoid a calculator's inverse-tangent key and instead use a standard tangent table:

$\tan 30^\circ = 0.5774$, $\tan 31^\circ = 0.6009$. Our target value $\tan\lambda = 0.5959$ lies between these two, closer to 31°:

$$\text{fraction} = \frac{0.5959 - 0.5774}{0.6009 - 0.5774} = \frac{0.0185}{0.0235} \approx 0.79$$

$$\lambda \approx 30^\circ + 0.79^\circ = 30.79^\circ$$

This confirms $\lambda \approx 30.8^\circ$ obtained above by direct inversion.

Distance $= 30.79 \times 111 = 3417.7$ km $= 3.4177 \times 10^8$ cm.

Rate $= \dfrac{3.4177 \times 10^8}{1.4 \times 10^8} \approx 2.44$ cm/yr — the identical result via a purely tabular interpolation, safely inside the 2.3–2.5 cm/yr key range.

Quick Tip: Use the axial-dipole relation tan I = 2 tan(paleolatitude) to find how far (in degrees of latitude) the block has drifted from its magnetisation latitude to its present equatorial position, then convert to cm/yr.

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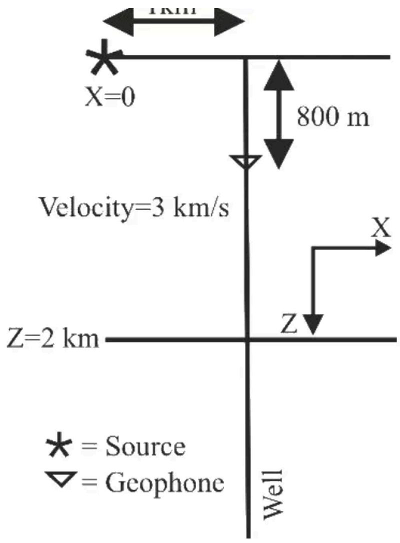
64. Consider a seismic source located at the Earth's surface. A vertical well is located at a distance of 1 km away from the seismic source, and a geophone is suspended inside the well at a depth of 800 m, as shown in the figure below.



The travel time of the primary reflected wave from a horizontal reflector located at a depth of 2 km is ______________ s (rounded off to three decimal places).

Correct Answer: 1.116 to 1.120

SOLUTION:

Alternative — find the actual reflection point on the interface using the similar-triangles (unfolded-path) construction, instead of the image-source shortcut.

The source S is a vertical distance $h_1 = 2$ km above the reflector, and the receiver R is a vertical distance $h_2 = 2 - 0.8 = 1.2$ km above the reflector, with a total horizontal separation of 1 km between S and R. For a flat reflector, the reflection point divides that horizontal separation in the same ratio as $h_1 : h_2$ (this follows from unfolding the reflected ray into a straight line and using similar triangles):

$$\frac{x_0}{1 - x_0} = \frac{h_1}{h_2} = \frac{2}{1.2} = \frac{5}{3} \Rightarrow x_0 = \frac{5}{8} = 0.625 \text{ km}$$

Now sum the two ray segments directly:

$d_1 = \sqrt{x_0^2 + h_1^2} = \sqrt{0.625^2 + 2^2} = \sqrt{0.3906 + 4} = \sqrt{4.3906} = 2.0954 \text{ km}$

$d_2 = \sqrt{(1 - x_0)^2 + h_2^2} = \sqrt{0.375^2 + 1.2^2} = \sqrt{0.1406 + 1.44} = \sqrt{1.5806}$
$= 1.2572 \text{ km}$

Total path length $= d_1 + d_2 = 2.0954 + 1.2572 = 3.3526$ km — identical to the image-source result.

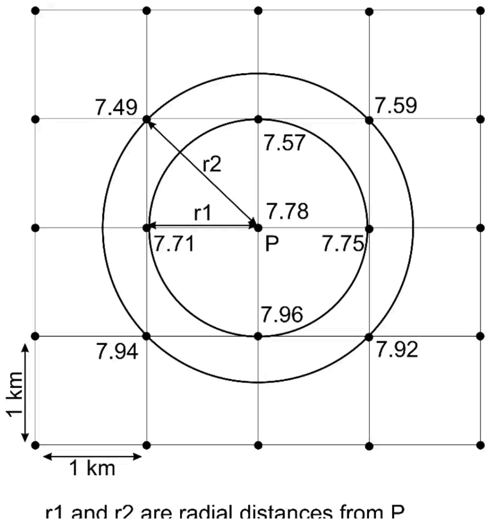
$$t = \frac{3.3526}{3} \approx 1.118 \text{ s}$$

Both independent methods agree exactly, confirming the answer sits inside 1.116–1.120 s.

Quick Tip: Use the image-source (mirror) method for a horizontal reflector: reflect the source (or receiver) across the reflector depth and take a straight-line path to the actual receiver (or source), then divide by velocity.

• • •

65. The figure below shows Bouguer gravity anomaly values (in mGal) at a grid interval of 1 km, centred on point P (r1 and r2 are radial distances from P).



The second vertical derivative at P is __________ mGal/km^2 (rounded off to two decimals).

Correct Answer: 0.16 to 0.18

SOLUTION:

Alternative — apply the standard 3×3 combined-ring second-vertical-derivative template directly in one step (this is algebraically the same result as the two-step Richardson extrapolation above, just packaged as a single operator, the way it is usually quoted in gravity-interpretation texts):

$$(g_{xx} + g_{yy}) = \frac{1}{s^2}\left[2\,\Sigma(\text{Ring1}) - \tfrac{1}{2}\,\Sigma(\text{Ring2}) - 6P\right]$$

Plug in the numbers ($s = 1$ km):

$2 \times 30.99 = 61.98$

$0.5 \times 30.94 = 15.47$

$6 \times 7.78 = 46.68$

$$(g_{xx} + g_{yy}) = 61.98 - 15.47 - 46.68 = -0.17$$

By Laplace's equation, $g_{zz} = -(g_{xx} + g_{yy}) = 0.17\ \text{mGal/km}^2$, reproducing the two-step result in a single line and confirming the value sits inside 0.16–0.18 mGal/km².

Quick Tip: Use Laplace's equation (g_zz = -(g_xx+g_yy)) and estimate the horizontal Laplacian from both the near ring (r1) and far diagonal ring (r2) of grid values around P, then combine the two estimates to cancel truncation error.