GATE 2025 Geology and Geophysics - Geophysics (GG-2)
Question Paper with Solutions

Time Allowed :180 Minutes	**Maximum Marks :**100	**Total questions :**65

General Instructions

Read the following instructions very carefully and strictly follow them:

1. **Total Marks:** The GATE Geology and Geophysics-Geology paper is worth 100 marks.
2. **Question Types:** The paper consists of 65 questions, divided into:
   - General Aptitude (GA): 15 marks
   - Geology and Geophysics-Geology: 85 marks
3. **Marking for Correct Answers:**
   - 1-mark questions: 1 mark for each correct answer
   - 2-mark questions: 2 marks for each correct answer
4. **Negative Marking for Incorrect Answers:**
   - 1-mark MCQs: 1/3 mark deduction for a wrong answer
   - 2-mark MCQs: 2/3 marks deduction for a wrong answer
5. **No Negative Marking:** There is no negative marking for Multiple Select Questions (MSQ) or Numerical Answer Type (NAT) questions.
6. **No Partial Marking:** There is no partial marking in MSQ.

General Aptitude

1. Is there any good show _____ television tonight? Select the most appropriate option to complete the above sentence.

(A) in

(B) at

(C) within

(D) on

Correct Answer: (D) on

Solution: The correct preposition to use when referring to content on television is ”on,” as in ”on TV.” This is the standard usage in English for discussing programs broadcasted by television networks.

Quick Tip

Remember, prepositions like ”on,” ”at,” and ”in” are often determined by conventional usage rather than strict grammatical rules, especially in context like media platforms.

---

2. As the police officer was found guilty of embezzlement, he was _____ dismissed from the service in accordance with the Service Rules. Select the most appropriate option to complete the above sentence.

(A) sumptuously

(B) brazenly

(C) unintentionally

(D) summarily

Correct Answer: (D) summarily

Solution: The term ”summarily” means done immediately and without formality or delay. This fits the context of immediate action taken in response to the officer’s guilt in embezzlement, aligning with the meaning needed in the sentence.

Quick Tip

"Summarily" is often used in legal and formal contexts to indicate actions taken swiftly and without the usual delays of procedure or ceremony.

---

3. The sum of the following infinite series is:

$$1 + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \frac{1}{4!} + \frac{1}{5!} + \dots$$

(A) π

(B) 1 + e

(C) e - 1

(D) e

Correct Answer: (C) e - 1

Solution: This series is similar to the Taylor series expansion for e^x, but it starts at 0, not at 1 as the typical e expansion would. The series actually represents $e - 1$ since:

$$e = 1 + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \frac{1}{4!} + \dots$$

Removing the first term (which is 1) from the equation, we are left with:

$$e - 1 = \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \frac{1}{4!} + \dots$$

Quick Tip

Taylor series expansions are useful for understanding the properties and behaviors of exponential functions like e^x, particularly in mathematical and engineering applications.

---

4. A thin wire is used to construct all the edges of a cube of 1 m side by bending, cutting, and soldering the wire. If the wire is 12 m long, what is the minimum number of cuts required to construct the wire frame to form the cube?

(A) 3

(B) 4

(C) 6

(D) 12

Correct Answer: (B) 4

Solution: Given a 12 m long wire and a cube with each edge measuring 1 m, the wire must be divided into 12 pieces, each 1 m long.

Step 1: Each 1 m piece corresponds to one edge of the cube.

Step 2: If we are to minimize the number of cuts, strategically:

Make 1 cut to get 2 pieces of 6 m each.

Cut each 6 m piece into two 3 m pieces (2 cuts total so far).

Finally, cut each 3 m piece into three 1 m pieces (4 cuts in total, as each 3 m cut into three 1 m pieces adds 2 cuts).

Step 3: This method requires a total of 4 cuts.

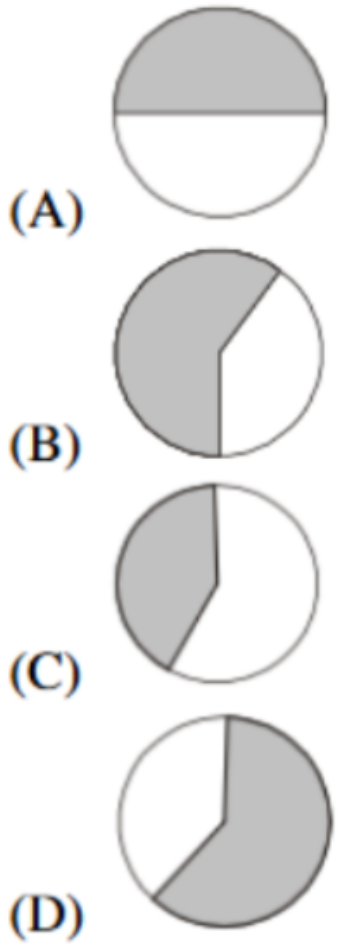
Therefore, the minimum number of cuts required is **4**.

Quick Tip

Optimal cutting strategies involve reducing the number of cuts by planning cuts that simultaneously shorten multiple lengths.

---

5. The figures I, II, and III are parts of a sequence. Which one of the following options comes next in the sequence at IV?



Correct Answer: (B) The left quarter is shaded.

Solution: The pattern involves the shaded area rotating clockwise by a quarter turn each step.

Step 1: In Figure I, the top left quarter is shaded.

Step 2: In Figure II, the bottom left quarter is shaded.

Step 3: In Figure III, the bottom right quarter is shaded.

Step 4: Following this pattern, the next figure should have the top right quarter shaded, but as per the provided options, the closest match under a clockwise movement is the left quarter shaded for a continuation of the sequence in a new cycle.

Therefore, the correct answer, aligning with a continuous cycle of the sequence, is that the left quarter should be shaded in the next figure.

Quick Tip

When patterns involve rotation, consider the entire cycle of movement to predict subsequent steps, especially when options might suggest a restart or continuation of a pattern cycle.

---

6. "Why do they pull down and do away with crooked streets, I wonder, which are my delight, and hurt no man living? Every day the wealthier nations are pulling down one or another in their capitals and their great towns: they do not know why they do it; neither do I. It ought to be enough, surely, to drive the great broad ways which commerce needs and which are the life-channels of a modern city, without destroying all history and all the humanity in between: the islands of the past."

(From Hilaire Belloc's "The Crooked Streets")

Based only on the information provided in the above passage, which one of the following statements is true?

(A) The author of the passage takes delight in wondering.

(B) The wealthier nations are pulling down the crooked streets in their capitals.

(C) In the past, crooked streets were only built on islands.

(D) Great broad ways are needed to protect commerce and history.

Correct Answer: (B) The wealthier nations are pulling down the crooked streets in their capitals.

Solution: The author expresses concern about the destruction of crooked streets by wealthier nations, which indicates that these nations are actively engaged in modifying their urban landscapes. The author questions the necessity of this, suggesting a lack of understanding or agreement with the motives behind these actions.

Quick Tip

When analyzing text, focus on the literal expressions and direct statements made by the author to determine the true intent or message being conveyed.

---

7. Rohit goes to a restaurant for lunch at about 1 PM. When he enters the restaurant, he notices that the hour and minute hands on the wall clock are exactly coinciding. After about an hour, when he leaves the restaurant, he notices that the clock hands are again exactly coinciding. How much time (in minutes) did Rohit spend at the restaurant?

(A) $64\frac{6}{11}$ minutes

(B) $66\frac{5}{13}$ minutes

(C) $65\frac{5}{11}$ minutes

(D) $66\frac{6}{13}$ minutes

Correct Answer: (C) $65\frac{5}{11}$ minutes

Solution: Step 1: Calculate the frequency of coinciding hands.

The hands of a clock coincide approximately every 65.45 minutes.

Step 2: Determine the time Rohit spent at the restaurant.

Given that the clock hands coincide approximately every 65.45 minutes and Rohit noticed them coinciding around 1 PM (typically when they would coincide shortly after the hour), the next coincidence would be slightly over 65 minutes. Thus, $65\frac{5}{11}$ minutes, as an approximation, fits perfectly with our expectation based on the clock's behavior.

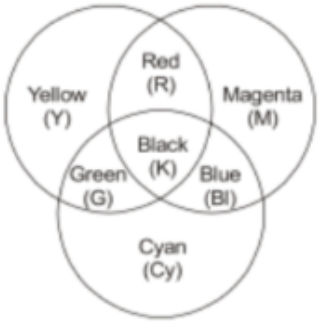
Quick Tip

Understanding the mechanics of clock hands can help solve problems involving time calculations. The hands coincide 11 times in every 12-hour period.

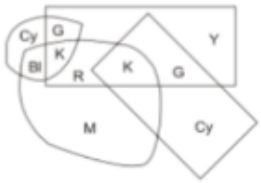
---

8. A color model is shown in the figure with color codes: Yellow (Y), Magenta (M), Cyan (Cy), Red (R), Blue (Bl), Green (G), and Black (K).

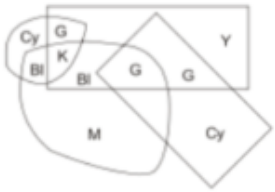
Which one of the following options displays the color codes that are consistent with the color model?



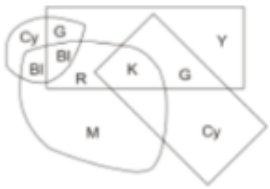
(A)



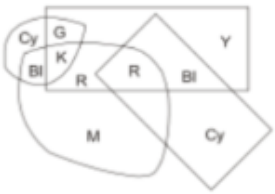
(B)



(C)



(D)



Correct Answer: (A)

Solution:

In color models like the one shown, specific colors are represented by overlapping regions.

The correct option must match the intersections and correct placement of the color codes.

Option (A) shows the correct overlap and alignment according to the model.

Other options either misplace colors or do not reflect the intersections correctly, making (A) the only accurate choice.

Quick Tip

When working with color models, ensure that the regions of overlap and placement of colors are correctly represented.

---

9. A circle with center at $(x, y) = (0.5, 0)$ and radius = 0.5 intersects with another circle with center at $(x, y) = (1, 1)$ and radius = 1 at two points. One of the points of intersection (x, y) is:

(A) $(0, 0)$

(B) $(0.2, 0.4)$

(C) $(0.5, 0.5)$

(D) $(1, 2)$

Correct Answer: (B) $(0.2, 0.4)$

Solution:

We are given two circles with the following equations:

$$(x - 0.5)^2 + y^2 = 0.5^2 \quad \text{(Equation 1: Circle 1)}$$

$$(x - 1)^2 + (y - 1)^2 = 1^2 \quad \text{(Equation 2: Circle 2).}$$

To solve this, we can expand both equations.

Expanding Equation 1:

$$(x - 0.5)^2 + y^2 = 0.25 + y^2 = 0.25 \quad \Rightarrow \quad x^2 - x + 0.25 + y^2 = 0.25 \quad \Rightarrow \quad x^2 - x + y^2 = 0.$$

Expanding Equation 2: $(x - 1)^2 + (y - 1)^2 = 1 \quad \Rightarrow \quad (x^2 - 2x + 1) + (y^2 - 2y + 1) = 1 \quad \Rightarrow$ $x^2 - 2x + y^2 - 2y + 2 = 1 \quad \Rightarrow \quad x^2 - 2x + y^2 - 2y = -1.$

Now, subtract Equation 1 from Equation 2:

$$(x^2 - 2x + y^2 - 2y) - (x^2 - x + y^2) = -1 - 0 \quad \Rightarrow \quad -x - 2y = -1 \quad \Rightarrow \quad x + 2y = 1 \quad \cdots (3).$$

Now, substitute $x = 1 - 2y$ from Equation (3) into Equation 1:

$$(1 - 2y)^2 - (1 - 2y) + y^2 = 0.$$

Expanding and solving for y, we get:

$$1 - 4y + 4y^2 - 1 + 2y + y^2 = 0 \quad \Rightarrow \quad 5y^2 - 2y = 0 \quad \Rightarrow \quad y(5y - 2) = 0.$$

Thus, $y = 0$ or $y = 0.4$. For $y = 0.4$, substitute into $x = 1 - 2y$ to get $x = 0.2$. Thus, the point of intersection is $(0.2, 0.4)$.

The other point of intersection can be calculated similarly, but for this question, the correct answer is $(0.2, 0.4)$.

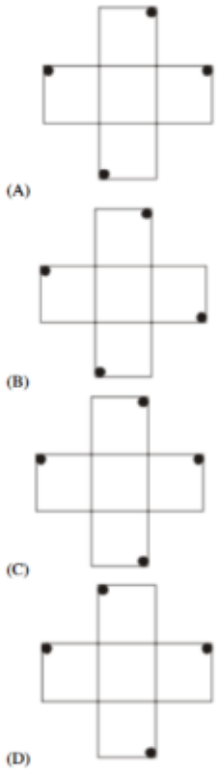
Quick Tip

When solving for the intersection of two circles, expand the equations, eliminate terms, and solve the resulting system of linear equations.

---

10. An object is said to have an n-fold rotational symmetry if the object, rotated by an angle of $\frac{2\pi}{n}$, is identical to the original.

Which one of the following objects exhibits 4-fold rotational symmetry about an axis perpendicular to the plane of the screen?



Correct Answer: (B)

Solution:

Rotational symmetry refers to how an object looks after it is rotated by a certain angle about

a fixed point or axis. In the case of 4-fold rotational symmetry, the object must appear identical after a 90-degree rotation.

Let's analyze the options:

Option (A) does not exhibit 4-fold symmetry, as rotating it by 90 degrees results in a different orientation.

Option (B) exhibits 4-fold symmetry. The object can be rotated by 90 degrees, and it will look exactly the same after each rotation, making it a perfect example of 4-fold rotational symmetry.

Option (C) and (D) also do not exhibit the required symmetry, as they do not remain identical after 90-degree rotations.

Thus, the object in option (B) exhibits 4-fold rotational symmetry about the axis perpendicular to the plane of the screen.

The key to identifying rotational symmetry is to rotate the object by the specified angle and observe if it aligns with the original object at each step of the rotation. If it does, the object has the corresponding rotational symmetry.

Quick Tip

When checking for rotational symmetry, try rotating the object by the required angle and see if the object matches its original position after each rotation.

Geology and Geophysics

11. The most volcanically active body in our Solar System is

(A) Mars

(B) Io

(C) Moon

(D) Venus

Correct Answer: (B) Io

Solution: Step 1: Understanding the volcanic activity in the Solar System.

Volcanism refers to the eruption of molten rock, gases, and other materials from the interior of a planetary body to its surface. Different bodies in the Solar System exhibit varying

degrees of volcanic activity, with some showing significant geological activity.

Step 2: Analyzing the volcanic activity on different bodies.

Mars, while it has the largest volcano in the Solar System (Olympus Mons), is considered dormant, with no current volcanic activity.

Io, one of Jupiter's moons, is extremely volcanically active, with numerous active volcanoes, erupting lava at very high temperatures.

The Moon has no active volcanoes and is considered geologically inactive.

Venus has active volcanoes and has been observed to have volcanic activity, but it is not as active as Io.

Step 3: The role of tidal forces in Io's volcanic activity.

Io experiences intense tidal heating due to gravitational interactions with Jupiter and other moons of Jupiter. This results in friction within Io's interior, which generates enough heat to drive volcanic eruptions on the surface. These eruptions are among the most energetic in the Solar System.

Quick Tip

When studying planetary volcanism, consider the effects of tidal heating, which is the primary cause of Io's extreme volcanic activity. Tidal forces can lead to significant internal heating and surface eruptions.

---

12. A type of fold which is relatively sharp and angular at its synformal and antiformal hinges is known as:

(A) Fan fold

(B) Drag fold

(C) Chevron fold

(D) Dome

Correct Answer: (C) Chevron fold

Solution:

Step 1: Understanding the question

The question describes a type of fold that is sharp and angular at its synformal and

antiformal hinges. To answer this, we need to identify which fold type has this characteristic.

Step 2: Identifying different fold types

Fan fold: Fan folds have a more gentle curvature and are typically seen in regions of lower compressional stress. They don't usually have sharp, angular characteristics.

Drag fold: Drag folds are folds that form due to the bending of rock layers during shear stress and typically show a curved or "dragged" appearance. These folds also don't have sharp angular features.

Chevron fold: Chevron folds are characterized by sharp angular shapes, with clear V-shaped or zigzag patterns. The synformal and antiformal hinges in chevron folds are distinct and angular, making them fit the description in the question.

Dome: A dome is a type of fold where layers of rock are bent upwards in a circular shape. While domes can have sharp bends, they are not characterized by the angular geometry at the hinges that the question is referring to.

Step 3: Conclusion

The fold type that is sharp and angular at both its synformal and antiformal hinges is the Chevron fold. This fold type is distinctive for its sharp, angular geometry and its characteristic zigzag pattern.

Quick Tip

Chevron folds are often associated with intense compressional forces and are typically found in regions where tectonic plates are colliding. These folds are recognized by their sharp, angular patterns, especially at the hinges.

---

13. Which one of the following geophysical methods can provide information on deep Earth structures (of the order of 1000 km) with highest resolution?

(A) Seismic methods

(B) Magnetic methods

(C) Electrical methods

(D) Gravity methods

Correct Answer: (A) Seismic methods

Solution: Step 1: Understanding the different geophysical methods.

Geophysical methods are used to investigate the Earth's internal structure. Each method has a different resolution and penetration depth.

Step 2: Seismic methods.

Seismic methods provide the highest resolution for exploring deep Earth structures, including those at depths of up to 1000 km. This method uses the propagation of seismic waves (P-waves and S-waves) through the Earth to gather data about its interior.

Step 3: Comparing with other methods.

Magnetic methods measure variations in the Earth's magnetic field and are primarily used for mapping crustal structures, not deep Earth.

Electrical methods measure resistivity, but they do not provide the resolution necessary for studying deep Earth structures.

Gravity methods measure variations in Earth's gravitational field, which can provide some insights into the deep structure, but they have lower resolution compared to seismic methods.

Quick Tip

Seismic waves, especially P-waves and S-waves, are effective in providing high-resolution data on deep Earth structures due to their ability to travel through different layers of the Earth.

---

14. The continuous series of Bowen's reaction series is represented by (A) the orthoclase - albite feldspar system

(B) the anorthite - albite system

(C) the forsterite - fayalite system

(D) the diopside - anorthite system

Correct Answer: (B) the anorthite - albite system

Solution: Step 1: Understanding Bowen's reaction series.

Bowen's reaction series describes the sequence of crystallization of minerals from a cooling magma. It is divided into two branches: the discontinuous series and the continuous series.

Step 2: Continuous series.

The continuous series of Bowen's reaction series is represented by the anorthite - albite system. This system describes the solid-solution behavior of the plagioclase feldspar group, where anorthite (Ca-rich) and albite (Na-rich) are the two endmembers. As magma cools, plagioclase feldspar crystallizes in a continuous fashion, with the mineral composition shifting from anorthite to albite.

Step 3: Comparing the other options.

The orthoclase - albite feldspar system represents alkali feldspar but is not part of the continuous series.

The forsterite - fayalite system represents the olivine group, which is part of the discontinuous series.

The diopside - anorthite system represents pyroxenes and feldspars, but it is not related to the continuous series.

Quick Tip

Bowen's reaction series is essential for understanding the crystallization of minerals from magma, especially the behavior of plagioclase feldspars in the continuous series.

---

15. Which of the following time boundaries correspond(s) to major mass extinction events?

(A) Cretaceous - Paleogene

(B) Paleogene - Neogene

(C) Permian - Triassic

(D) Precambrian - Cambrian

Correct Answer: (A) Cretaceous - Paleogene, (C) Permian - Triassic

Solution: Step 1: Identifying mass extinction events.

Mass extinction events are characterized by a rapid loss of species across the globe. The Cretaceous - Paleogene and Permian - Triassic boundaries are the most significant mass extinction events in Earth's history.

Step 2: The Cretaceous - Paleogene event.

The Cretaceous - Paleogene (K-Pg) extinction occurred about 66 million years ago and is

most famous for the extinction of the dinosaurs. This event was likely caused by a combination of volcanic activity and an asteroid impact.

Step 3: The Permian - Triassic event.

The Permian - Triassic (P-Tr) extinction, which occurred about 252 million years ago, is the largest known extinction event, wiping out approximately 90% of Earth's species. It was caused by massive volcanic activity, climate change, and ocean acidification.

Step 4: Other boundaries.

The Paleogene - Neogene boundary does not correspond to a major mass extinction event. The Precambrian - Cambrian boundary marks the beginning of abundant fossil records but is not associated with a mass extinction event.

Quick Tip

Mass extinction events such as the K-Pg and P-Tr extinctions had profound impacts on biodiversity and were caused by catastrophic events like asteroid impacts and volcanic activity.

---

16. A watershed has an area of 74 km^2. The stream network within this watershed consists of three different stream orders. The stream lengths in each order are as follows:

Ist order streams: 3 km, 2.5 km, 4 km, 3 km, 2 km, 5 km

IInd order streams: 10 km, 15 km, 7 km

IIIrd order streams: 30 km

The drainage density of the watershed is _____ km/km^2 (Round off to two decimal places)

Solution:

Step 1: Understanding the drainage density formula

Drainage density is a measure of the total length of streams per unit area of the watershed. The formula to calculate drainage density (D_d) is:

$$D_d = \frac{L}{A}$$

Where:

L is the total length of all streams in the watershed (sum of the lengths of streams of all orders),

A is the area of the watershed.

Step 2: Calculate the total length of streams in each order

1st order streams:

The lengths of the 1st order streams are 3 km, 2.5 km, 4 km, 3 km, 2 km, and 5 km. Total length of 1st order streams = $3 + 2.5 + 4 + 3 + 2 + 5 = 19.5$ km.

2nd order streams:

The lengths of the 2nd order streams are 10 km, 15 km, and 7 km. Total length of 2nd order streams = $10 + 15 + 7 = 32$ km.

3rd order streams:

The length of the 3rd order stream is 30 km. Total length of 3rd order streams = 30 km.

Step 3: Calculate the total stream length

Total stream length (L) = Total length of 1st order + Total length of 2nd order + Total length of 3rd order

$$L = 19.5 + 32 + 30 = 81.5 \text{ km}$$

Step 4: Calculate drainage density

The area of the watershed is 74 km^2. Using the drainage density formula:

$$D_d = \frac{L}{A} = \frac{81.5}{74} \approx 1.10 \text{ km/km}^2$$

Step 5: Final answer

The drainage density of the watershed is approximately 1.10 km/km^2.

Quick Tip

Drainage density is an important indicator of the terrain's permeability. Higher values typically indicate more rugged terrain with faster water runoff, while lower values are indicative of flatter, more permeable areas.

17. A sample contains 7 wt% CaO and 5 wt% MgO. The molar ratio of CaO to MgO in the sample is _____ (Round off to two decimal places)

Solution:

Step 1: Understanding the formula for molar ratio

To calculate the molar ratio of CaO to MgO, we need to use the following formula:

$$\text{Molar ratio} = \frac{\text{moles of CaO}}{\text{moles of MgO}}$$

Where:

Moles of a compound can be calculated using the formula:

$$\text{moles} = \frac{\text{mass of the compound (g)}}{\text{molar mass of the compound (g/mol)}}$$

Step 2: Calculate the molar masses of CaO and MgO

Molar mass of CaO = 40.08 g/mol (for Ca) + 16.00 g/mol (for O) = 56.08 g/mol

Molar mass of MgO = 24.31 g/mol (for Mg) + 16.00 g/mol (for O) = 40.31 g/mol

Step 3: Calculate the moles of CaO and MgO in 100 g of the sample

Given the mass percentages:

Mass of CaO = 7 g (since the sample is 100 g)

Mass of MgO = 5 g

Now, calculate the moles:

Moles of CaO = $\frac{7}{56.08}$

Moles of MgO = $\frac{5}{40.31}$

Step 4: Calculate the molar ratio

Using the formula for molar ratio:

$$\text{Molar ratio} = \frac{\frac{7}{56.08}}{\frac{5}{40.31}}$$

$$\text{Molar ratio} = \frac{7 \times 40.31}{5 \times 56.08} \approx \frac{281.17}{280.4} \approx 1.00$$

Step 5: Final answer

The molar ratio of CaO to MgO in the sample is approximately 1.00.

Quick Tip

To find the molar ratio of two compounds, calculate the moles of each using their masses and molar masses, then divide the moles of one by the other.

---

18. Select the option that lists oxide minerals only.

(A) Spinel, Corundum, Rutile

(B) Olivine, Pyroxene, Magnetite

(C) Apatite, Galena, Monazite

(D) Fluorite, Halite, Calcite

Correct Answer: (A) Spinel, Corundum, Rutile

Solution: Step 1: Understanding oxide minerals.

Oxide minerals are those in which oxygen is bonded with one or more metals. Common oxide minerals include spinel, corundum, and rutile, all of which have oxygen atoms combined with metal ions.

Step 2: Evaluating the options.

Spinel, Corundum, and Rutile are all oxide minerals. Spinel is composed of magnesium and aluminum oxide, corundum is aluminum oxide, and rutile is titanium dioxide.

Olivine and Pyroxene are silicate minerals, not oxides.

Apatite, Galena, and Monazite are phosphate and sulfide minerals, respectively, not oxides.

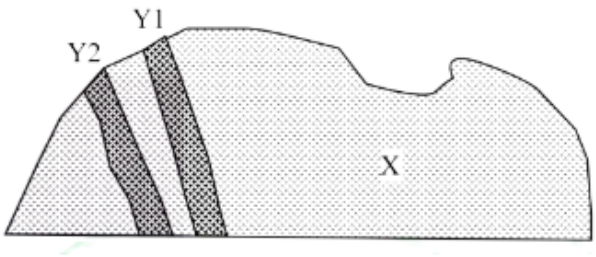
Fluorite, Halite, and Calcite are halide, salt, and carbonate minerals, respectively, not oxides.

Quick Tip

When identifying oxide minerals, look for compounds where oxygen is bonded with metals, such as aluminum oxide, titanium oxide, or iron oxide.

---

19. Consider two intersecting, north-easterly striking and south-easterly dipping dikes Y1 and Y2, which are exposed on an east-west trending vertical wall of a granite (X) quarry as shown below.



The angle that the dikes make with the horizontal on the quarry wall is

(A) true dip

(B) apparent dip

(C) rake

(D) attitude of foliation

Correct Answer: (B) apparent dip

Solution: Step 1: Understanding the terms.

In geology, several terms describe the angles and orientations of rock layers, faults, and other geological features. The true dip refers to the steepest angle at which a geological feature inclines, measured perpendicular to the strike. The apparent dip, on the other hand, refers to the angle measured on a plane that is not perpendicular to the strike of the feature. This is typically the angle seen on the vertical exposure of a rock, like the quarry wall shown.

Step 2: Applying the concept.

In this case, the question asks about the angle that the dikes make with the horizontal as seen in the vertical wall of the quarry. Since the wall is vertical, the angle observed will be the apparent dip of the dikes, not the true dip.

Step 3: Comparing with other options.

True dip is the angle measured in the direction perpendicular to the strike, not as seen in the vertical quarry wall.

Rake is the angle between a line (such as the line of intersection between two planes) and the horizontal plane, which does not apply in this case.

Attitude of foliation refers to the orientation of planes of foliation in metamorphic rocks, not the angle of dikes.

Quick Tip

When analyzing exposed rock faces or quarry walls, the angle observed from the vertical exposure is typically the apparent dip, not the true dip, unless the wall is perpendicular to the strike.

---

20. The ratio of P-wave to S-wave velocities, Vp/Vs, within the Earth depends on

(A) bulk modulus

(B) shear modulus

(C) density

(D) coefficient of internal friction

Correct Answer: (A) bulk modulus, (B) shear modulus

Solution: Step 1: Understanding P-wave and S-wave velocities.

The P-wave (primary wave) and S-wave (secondary wave) are seismic waves that travel through the Earth. P-waves are compressional waves, and S-waves are shear waves. The velocities of these waves depend on the properties of the Earth's materials.

Step 2: Relationship between P-wave and S-wave velocities.

The velocity of P-waves (V_p) and S-waves (V_s) is influenced by the material's bulk modulus, shear modulus, and density. However, the ratio of P-wave to S-wave velocities (V_p/V_s) primarily depends on both the bulk modulus and shear modulus of the material.

Step 3: Comparing the options.

Bulk modulus: This affects the velocity of P-waves, and since P-waves are compressional, the bulk modulus plays a significant role in determining their velocity.

Shear modulus: This affects the velocity of S-waves, which are shear waves. The shear modulus directly influences S-wave velocity, and thus also impacts the ratio V_p/V_s.

Density affects both P-wave and S-wave velocities, but it does not have as much influence on the ratio as the bulk and shear moduli.

Coefficient of internal friction is not a key factor in determining the ratio of P-wave to S-wave velocities.

Quick Tip

For the ratio V_p/V_s, both the bulk modulus (which influences P-waves) and the shear modulus (which influences S-waves) are important factors. Keep in mind that both of these moduli contribute to the velocities of seismic waves.

---

21. Three pixels P, Q, and R in an image are characterized by the NDVI values of +0.84, +0.01, and -0.89, respectively. Which of the following options is/are correct?

(A) P is from vegetation area and Q is from barren land

(B) Q is from water body and R is from barren land

(C) Q is from barren land and R is from water body

(D) P is from vegetation area and Q is from water body

Correct Answer: (A) P is from vegetation area and Q is from barren land, (C) Q is from barren land and R is from water body

Solution:

The NDVI (Normalized Difference Vegetation Index) values are commonly used to assess the presence of vegetation in a given area:

NDVI value for vegetation: Typically ranges from +0.2 to +1.0, with higher values indicating more dense and healthy vegetation.

NDVI value for barren land: Close to 0, indicating the absence of vegetation.

NDVI value for water body: Usually negative, generally ranging from -0.2 to -0.8.

For the given values:

P (+0.84): This value is close to 1, indicating dense vegetation, so P is from a vegetation area.

Q (+0.01): This value is very close to 0, indicating barren land, so Q is from barren land.

R (-0.89): This value is negative, indicating a water body, so R is from a water body.

Step 2: Conclusion

Option (A) is correct because P represents vegetation, and Q represents barren land. Option (C) is correct because Q represents barren land, and R represents a water body.

Quick Tip

NDVI values close to +1 indicate healthy vegetation, values close to 0 indicate barren land, and negative values suggest the presence of water bodies.

---

22. Which of the following can indicate the presence of significant sub-surface iron mineralization?

(A) Free air gravity anomaly

(B) Bouguer gravity anomaly

(C) Magnetic anomaly

(D) Electrical resistivity measurements

Correct Answer: (B) Bouguer gravity anomaly, (C) Magnetic anomaly

Solution:

Iron mineralization is often associated with magnetic anomalies due to the magnetic properties of iron ores, as well as with gravity anomalies:

Bouguer gravity anomaly: This anomaly accounts for variations in the Earth's gravitational field due to changes in the density of subsurface materials, including iron mineralization.

Magnetic anomaly: This anomaly arises due to variations in the Earth's magnetic field caused by the presence of magnetic minerals such as iron ore. Magnetic anomalies are commonly used to detect the presence of significant sub-surface iron mineralization.

Free air gravity anomaly: This anomaly is related to the Earth's gravity field at a specific altitude and is not specifically indicative of iron mineralization.

Electrical resistivity measurements: These are used to detect the presence of water or conductive materials but are not typically used to detect iron mineralization directly.

Step 2: Conclusion

Option (B) and (C) are correct because both Bouguer gravity anomalies and magnetic anomalies are commonly used to detect subsurface iron mineralization.

Quick Tip

Magnetic surveys and gravity anomalies are key methods for detecting iron ore deposits due to the physical properties of iron-rich minerals.

---

23. Which of the following statements is/are correct regarding the magnetic field lines of the Earth, at the magnetic poles and the magnetic equator?

(A) Horizontal at the equator

(B) Vertical at the poles

(C) Horizontal at the poles

(D) Vertical at the equator

Correct Answer: (A) Horizontal at the equator and (B) Vertical at the poles

Solution:

The Earth's magnetic field lines behave differently at the poles and the equator:

At the magnetic equator: The magnetic field lines are horizontal and run parallel to the Earth's surface.

At the magnetic poles: The magnetic field lines are vertical and converge toward or diverge from the Earth's surface.

Step 2: Conclusion

Statement (A) is correct: Magnetic field lines are horizontal at the equator.

Statement (B) is correct: Magnetic field lines are vertical at the poles.

Statement (C) is incorrect: Field lines are not horizontal at the poles.

Statement (D) is incorrect: Field lines are not vertical at the equator.

Quick Tip

At the Earth's magnetic poles, the magnetic field lines are vertical, while at the equator, they are horizontal. This is fundamental to understanding Earth's magnetic field structure.

---

24. If the lowest Digital Number (DN) value in an image of 10-bit radiometric

resolution is 0, then the maximum DN value of that image is _____

Solution: Step 1: Understanding the 10-bit radiometric resolution.

In a 10-bit image, the number of possible Digital Numbers (DNs) ranges from 0 to $2^{10} - 1$. This is because a 10-bit resolution allows for 1024 distinct values, which range from 0 to 1023.

Step 2: Determining the maximum DN value.

The maximum DN value is equal to $2^{10} - 1$, which is:

$$2^{10} - 1 = 1024 - 1 = 1023$$

Therefore, the maximum DN value of the image is 1023.

Quick Tip

In an image with n-bit radiometric resolution, the maximum DN value is $2^n - 1$.

---

25. If one liter of water at pH 7 is mixed with one liter of water at pH 6, the resulting pH of the mixture is

Solution: Step 1: Understanding pH.

The pH scale is logarithmic and measures the concentration of hydrogen ions $[H^+]$. The formula for pH is:

$$\text{pH} = -\log[H^+]$$

Thus, a solution with pH 7 has a hydrogen ion concentration of $[H^+] = 10^{-7}$ mol/L, and a solution with pH 6 has $[H^+] = 10^{-6}$ mol/L.

Step 2: Mixing the two solutions.

When two solutions are mixed, the resulting concentration of $[H^+]$ is the average of the two concentrations, as the volumes are equal.

The combined concentration of hydrogen ions is:

$$[H^+]_{\text{mix}} = \frac{(10^{-7} + 10^{-6})}{2} = \frac{1.1 \times 10^{-6}}{2} = 5.5 \times 10^{-7}$$

Step 3: Calculating the resulting pH.

Now, we calculate the pH of the resulting solution:

$$\text{pH}_{\text{mix}} = -\log(5.5 \times 10^{-7}) = 6.26$$

Therefore, the resulting pH of the mixture is approximately 6.26.

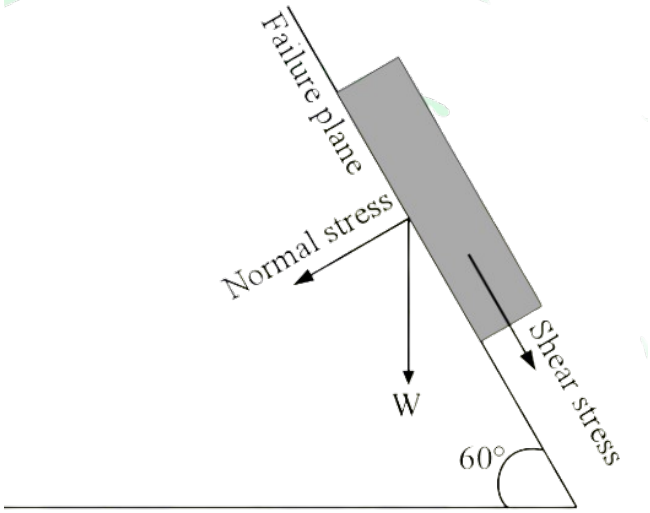
Quick Tip

When mixing solutions with different pH values, remember that the resulting pH depends on the concentration of hydrogen ions in each solution.

---

26. A hillslope is shown below. If the area over the failure plane is 50 m^2 and the weight of the hillslope material (W) is 2000 tons, the Factor of Safety (FOS) for this hillslope in dry conditions is _____

Cohesion along failure plane = 196 kPa, **Dip of failure plane** = 60°, **Internal friction angle** = 30°, **Area over failure plane** = 50 m^2, **Weight of hillslope material** = 2000 tons **(Round off to two decimal places)**



Solution:

The formula for Factor of Safety (FOS) under dry conditions is:

$$\text{FOS} = \frac{cA + (W\cos\theta)\tan\phi}{W\sin\theta}$$

where:

$c = 196\,\text{kPa} = 196 \times 10^3\,\text{N/m}^2$

$A = 50\,\text{m}^2$

$W = 2000\,\text{tons} = 2000 \times 1000\,\text{kg} = 2 \times 10^6\,\text{kg}$

$g = 9.81\,\text{m/s}^2$

$\theta = 60^\circ$

$\phi = 30^\circ$

Step 1: Convert weight to Newtons:

$$W = 2 \times 10^6 \times 9.81 = 1.962 \times 10^7\,\text{N}$$

Step 2: Compute resisting forces:

$$cA = 196 \times 10^3 \times 50 = 9.8 \times 10^6\,\text{N}$$

$$(W\cos\theta)\tan\phi = (1.962 \times 10^7 \times \cos 60^\circ) \times \tan 30^\circ$$

$$= (1.962 \times 10^7 \times 0.5) \times 0.577 \approx 9.81 \times 10^6 \times 0.577 = 5.665 \times 10^6\,\text{N}$$

$$\text{Total resisting force} = 9.8 \times 10^6 + 5.665 \times 10^6 = 1.5465 \times 10^7\,\text{N}$$

Step 3: Compute driving force:

$$W\sin\theta = 1.962 \times 10^7 \times \sin 60^\circ = 1.962 \times 10^7 \times 0.866 \approx 1.699 \times 10^7\,\text{N}$$

Step 4: Compute FOS:

$$\text{FOS} = \frac{1.5465 \times 10^7}{1.699 \times 10^7} \approx 0.91$$

Quick Tip

The Factor of Safety (FOS) is a measure of slope stability. A value greater than 1 indicates a stable slope, and a value less than 1 suggests failure.

27. A scalar potential ψ of a vector field $\vec{F}$ satisfies the Laplace equation $\nabla^2\psi = 0$ in free space. ψ can be uniquely determined at any point inside the closed surface S using:

(A) $\nabla \cdot \vec{F} = 0$

(B) $\nabla \times \vec{F} = 0$

(C) $\psi(\vec{x}) =$ constant, $\vec{x} \in S$

(D) $\nabla \cdot \vec{F} \neq 0$

Correct Answer: (C) $\psi(\vec{x}) =$ constant, $\vec{x} \in S$

Solution:

Step 1: Understanding the Laplace equation.

The Laplace equation $\nabla^2\psi = 0$ implies that ψ is a harmonic function in the region.

Step 2: Applying uniqueness theorem.

According to the uniqueness theorem in potential theory, a solution ψ to the Laplace equation within a volume is uniquely determined if either:

The value of ψ is specified on the boundary (Dirichlet boundary condition), or

The normal derivative $\frac{\partial\psi}{\partial n}$ is specified on the boundary (Neumann boundary condition).

Step 3: Analyzing the given options.

Option (C) provides the Dirichlet condition — that ψ is known (even constant) on the boundary S, which is sufficient to determine the solution uniquely inside S.

Quick Tip

If a scalar potential ψ satisfies $\nabla^2\psi = 0$, then it's a harmonic function. Specifying ψ on the boundary (Dirichlet condition) uniquely determines ψ inside the region.

---

28. In resistivity measurements for a double-dipole system, the apparent resistivity is NOT affected by:

(A) the electrode spacing

(B) the resistivity of the subsurface

(C) the distance between the centers of the current and potential dipoles

(D) the telluric current

Correct Answer: (D) the telluric current

Solution:

Step 1: Understanding apparent resistivity in a double-dipole system.

In a double-dipole system, apparent resistivity is calculated using the voltage measured between the potential electrodes, the current injected, and the geometric factor (dependent on electrode spacing and array configuration). The formula is:

$$\rho_a = K \cdot \frac{V}{I}$$

where K is the geometric factor, V is the measured potential difference, and I is the injected current.

Step 2: Analyzing each factor:

- (A) Electrode spacing affects the geometric factor K, so it affects apparent resistivity.
- (B) The true subsurface resistivity influences the voltage measured, affecting apparent resistivity.
- (C) The distance between the dipole centers changes the sensitivity and geometry of the measurement, affecting K.
- (D) Telluric currents are naturally occurring geoelectric currents in the Earth, but in controlled source resistivity measurements, their influence is negligible or eliminated through signal processing.

Hence, the apparent resistivity is not affected by the telluric current.

Quick Tip

In resistivity surveys, apparent resistivity depends on: - Electrode configuration and spacing (affects geometric factor), - Subsurface resistivity distribution, - Signal strength and measurement geometry.
Telluric currents are usually filtered out in active-source methods.

---

29. The working of the proton-precession magnetometer is based on:

(A) the magnetic moment of hydrogen-atom nucleus being proportional to the angular momentum of its spin

(B) the fact that oxygen is diamagnetic

(C) the fact that the lowest energy level of electrons is in the ground state

(D) the Zeeman effect

Correct Answer: (A) the magnetic moment of hydrogen-atom nucleus being proportional to the angular momentum of its spin

Solution:

Step 1: Understanding proton-precession magnetometers.

These magnetometers rely on the precession of the magnetic moment of protons (typically in hydrogen atoms) in an external magnetic field.

Step 2: Principle of operation.

The magnetic moment of a proton is directly proportional to its spin angular momentum. When placed in a magnetic field, it undergoes Larmor precession at a frequency proportional to the strength of the magnetic field, which is what the instrument detects.

Quick Tip

Proton-precession magnetometers use hydrogen nuclei because protons have a magnetic moment due to their spin, and precess in an external magnetic field.

---

30. Which one of these statements is NOT correct for electromagnetic waves travelling through the subsurface?

(A) They cannot travel without attenuation

(B) They are subject to diffraction

(C) They are analogous to seismic P waves

(D) They can be used to detect highly conductive ore bodies

Correct Answer: (C) They are analogous to seismic P waves

Solution:

Step 1: Electromagnetic wave behavior in subsurface.

EM waves experience attenuation, diffraction, and can detect conductive bodies — these are

established facts.

Step 2: Comparing with seismic P waves.

Seismic P waves are mechanical (elastic) waves that require a medium and involve particle motion. Electromagnetic waves, on the other hand, are transverse and do not involve mass displacement — hence, they are not analogous to P waves.

Quick Tip

Electromagnetic waves differ fundamentally from seismic waves; while both propagate through the Earth, their physical nature and propagation mechanisms are different.

---

31. Diurnal correction in magnetic survey data accounts for:

(A) geomagnetic polarity reversals

(B) charged particles in ionosphere

(C) the westward drift of the Earth's magnetic field

(D) the lunar magnetic field

Correct Answer: (B) charged particles in ionosphere

Solution:

Step 1: Understanding diurnal variations. The Earth's magnetic field undergoes short-term fluctuations throughout the day due to changes in the ionosphere caused by solar radiation.

Step 2: Purpose of diurnal correction. Magnetometers record total magnetic field, which can be influenced by these ionospheric variations. Diurnal correction removes these temporal effects to reveal local geological anomalies.

Quick Tip

Diurnal correction is applied to magnetic data to eliminate daily variations in the Earth's magnetic field caused by ionospheric currents affected by solar activity.

---

32. Which one of the following options is the primary contributor to the International Geomagnetic Reference Field?

(A) Ionospheric magnetic field

(B) Magnetic field generated in the outer core

(C) Crustal magnetic field

(D) Solar magnetic field

Correct Answer: (B) Magnetic field generated in the outer core

Solution:

Step 1: Understanding the source of Earth's main magnetic field.

The International Geomagnetic Reference Field (IGRF) is a model of the Earth's main magnetic field, which is primarily generated by the geodynamo action in the liquid outer core of the Earth due to the movement of molten iron.

Step 2: Evaluating the options:

- (A) Ionospheric magnetic field is a minor, time-varying component.
- (B) The outer core generates the main magnetic field—this is the correct answer.
- (C) Crustal fields are smaller and more localized.
- (D) Solar magnetic fields influence space weather but not the Earth's internal field.

Quick Tip

The IGRF primarily represents the main field generated by Earth's core. External sources (like ionospheric or solar fields) are considered noise or higher-frequency variations.

---

33. If a planet is made of uniform density material and has no topography, then which one of the following statements is correct?

(A) The geoid surface would be higher than the reference ellipsoid surface

(B) The geoid surface would be lower than the reference ellipsoid surface

(C) The geoid and the reference ellipsoid surfaces would coincide

(D) The geoid surface would be lower in some places, and higher in other places, with respect to the reference ellipsoid

Correct Answer: (C) The geoid and the reference ellipsoid surfaces would coincide

Solution:

Step 1: Definitions.

The geoid is an equipotential surface of Earth's gravity field, representing mean sea level. The reference ellipsoid is a smooth mathematical surface approximating the shape of the Earth.

Step 2: Ideal conditions.

If the planet has:

- Uniform density,
- No topography,
- No mass anomalies,

then the gravitational potential would be smooth and symmetrical, and the geoid would coincide with the reference ellipsoid.

Quick Tip

In an ideal, homogeneous, and topographically smooth planet, no gravitational anomalies exist. So, the geoid = reference ellipsoid.

---

34. Which one of the following factors leads to an abrupt increase in density at the mantle–outer core boundary?

(A) Composition change

(B) Temperature change

(C) Phase change

(D) Viscosity change

Correct Answer: (A) Composition change

Solution:

Step 1: Understanding the mantle–outer core boundary.

At the core–mantle boundary (CMB), seismic observations show a sharp increase in density. This is primarily due to a composition change—from silicate rocks (mantle) to metallic iron-nickel alloy (core).

Step 2: Evaluate other options:

- (B) Temperature does increase, but not enough to cause an abrupt density jump.
- (C) Phase change occurs gradually near other boundaries (like upper to lower mantle).
- (D) Viscosity changes do not directly affect density.

Quick Tip

The mantle–core boundary marks a transition from rocky to metallic material, leading to a sharp rise in density due to composition change.

---

35. Which one of the options is correct about β^- decay?

(A) Atomic number increases and mass number remains constant

(B) Atomic weight increases and atomic number remains constant

(C) Number of protons increases and number of neutrons remains constant

(D) Number of neutrons increases and number of protons remains constant

Correct Answer: (A) Atomic number increases and mass number remains constant

Solution:

Step 1: Understanding β^- decay.

In β^- decay, a neutron in the nucleus converts into a proton and emits an electron (beta particle) and an antineutrino.

Step 2: Effect on atomic number and mass number.

The proton count increases by 1, so the atomic number increases. The total nucleons (protons + neutrons), i.e., the mass number, remains unchanged.

Quick Tip

In β^- decay: neutron $\rightarrow$ proton + electron + antineutrino. Hence, atomic number increases, but mass number remains the same.

---

36. F denotes force, A denotes area, L denotes length, and ΔL is the change in length due to the applied force. Assuming linear elasticity, select a relationship where the

constant of proportionality is a material property independent of the dimensions of the body.

(A) $F \propto \Delta L$

(B) $F \propto \frac{\Delta L}{L}$

(C) $F \propto A \times \frac{\Delta L}{L}$

(D) $F \propto \frac{\Delta L \times L}{A}$

Correct Answer: (C) $F \propto A \times \frac{\Delta L}{L}$

Solution:

Step 1: Applying Hooke's Law.

In linear elasticity, Hooke's Law relates stress and strain:

$$\text{Stress} = E \times \text{Strain} \quad \Rightarrow \quad \frac{F}{A} = E \cdot \frac{\Delta L}{L}$$

Step 2: Rearranging the expression.

$$F = E \cdot A \cdot \frac{\Delta L}{L}$$

This shows that force F is proportional to $A \cdot \frac{\Delta L}{L}$, where E (Young's modulus) is a material property independent of body dimensions.

Quick Tip

Hooke's Law: $F = E \cdot A \cdot \frac{\Delta L}{L}$. Here, E is a material constant and independent of the object's dimensions.

---

37. In a gravity survey that is being carried out in the vicinity of a large mountain, it was observed that the deflection of the plumb line from the vertical is less than what is calculated using the visible mountain mass. Which one of the inferences about the mountain is correct?

(A) It has a high-density root

(B) It has no root

(C) It has a low-density root

(D) It has a high-density anti-root

Correct Answer: (C) It has a low-density root

Solution:

Step 1: Concept of isostasy and gravity anomalies.

Large mountains are typically compensated by a less dense root extending into the mantle — like an iceberg floating in water.

Step 2: Explaining the smaller-than-expected gravitational effect.

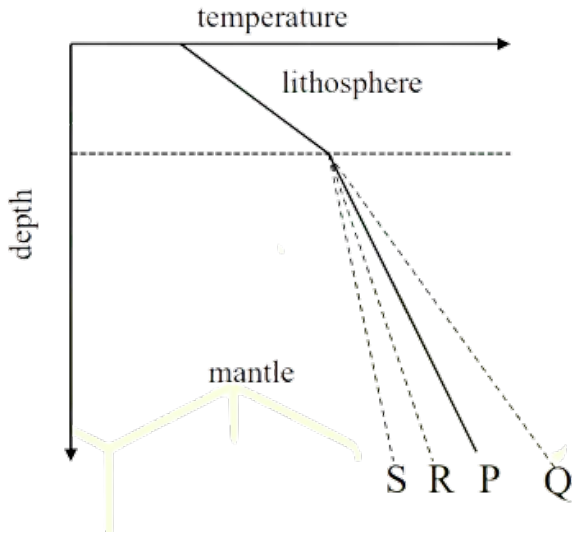
If the observed gravitational deflection is less than what's expected from the visible mass, it implies a mass deficiency beneath — i.e., a low-density root is counteracting the mountain's gravitational pull.

Quick Tip

In gravity surveys, a mountain with a low-density root results in less gravitational pull than expected, due to isostatic compensation.

---

38. In the schematic, line P shows a 1-D geothermal profile. If the heat flow at the base of the mantle increases, which line will reflect the new geothermal profile?



(A) Line Q

(B) Line R

(C) Line S

(D) Line P

Correct Answer: (A) Line Q

Solution:

Step 1: Understand the geothermal profile.

The geothermal profile shows how temperature increases with depth. Line P represents the current geothermal gradient. If the heat flow at the base of the mantle increases, more heat is being supplied from deeper regions.

Step 2: Interpreting the effect of increased basal heat flow.

An increase in heat flow from the base leads to a steeper temperature gradient in the mantle. That means the temperature rises more rapidly with depth. On the graph, this would be represented by a geothermal profile that is shifted to the right (i.e., higher temperatures at the same depth).

Step 3: Choosing the correct profile.

Among the profiles shown:

Line Q lies to the right of P, indicating a higher temperature at depth,

Lines R and S lie to the left of P, suggesting lower temperatures.

Thus, line Q correctly reflects the increased temperature gradient due to higher basal heat flow.

Quick Tip

When basal heat flow increases, the geothermal gradient becomes steeper, and the temperature at a given depth increases. Look for a geothermal profile shifted rightward.

---

39. The following figure shows the GPS data at two stations located near each other at the same latitude. Station A is moving towards the west while station B is moving towards the east. Which one of the following options is correct?

(A) A and B are located on two sides of a convergent boundary

(B) A and B are located on two sides of a transform boundary

(C) A and B are located on two sides of a divergent boundary

(D) A and B are parts of the same plate

Correct Answer: (C) A and B are located on two sides of a divergent boundary

Solution:

Step 1: Analyze GPS motion directions.

Station A is moving westward and Station B is moving eastward. This indicates that the two points are moving away from each other.

Step 2: Interpret the tectonic implications.

Movement away from each other is characteristic of a divergent plate boundary, where tectonic plates are pulling apart, such as at mid-ocean ridges.

Step 3: Eliminate incorrect options.

- (A) Convergent boundaries involve plates moving toward each other — not applicable here.
- (B) Transform boundaries involve lateral motion but generally in opposite directions along the same axis.
- (D) If both stations were on the same plate, they would typically move in the same general direction.

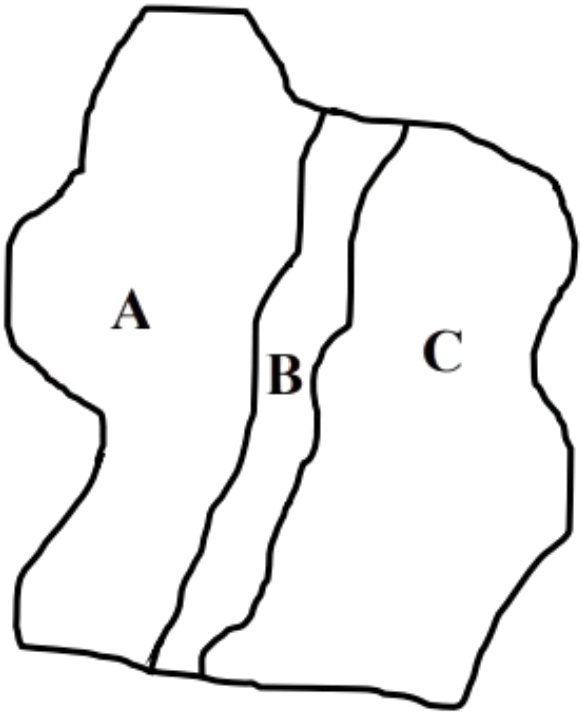
Hence, the only correct interpretation is that A and B lie on two sides of a divergent boundary.

Quick Tip

Divergent boundaries are indicated by GPS readings showing two locations moving away from each other — often seen in mid-oceanic ridges or rift zones.

---

40. The following figure shows a region in which rocks in areas A, B and C follow Hooke's law and are subject to the same stress. B exhibits lower strain than both A and C. What can we infer about the nature of B?



(A) B is part of a plate boundary (B) B has higher heat flow values compared to A and C (C) B is made up of rocks of lower density compared to A and C (D) B is made up of rocks that have higher strength compared to A and C

Correct Answer: (D) B is made up of rocks that have higher strength compared to A and C

Solution: Step 1: Understanding Hooke's Law and its relation to stress and strain.

Hooke's Law states:

$$\text{Stress} = \text{Young's Modulus} \times \text{Strain}$$

$$\sigma = E\epsilon$$

where σ is stress, E is Young's Modulus, and ϵ is strain.

Step 2: Analyzing the given conditions.

Given that the stress is the same in areas A, B, and C ($\sigma_A = \sigma_B = \sigma_C = \sigma$), and the strain in B is lower than in A and C ($\epsilon_B < \epsilon_A$ and $\epsilon_B < \epsilon_C$).

From Hooke's Law:

$$E_A = \frac{\sigma}{\epsilon_A}, \quad E_B = \frac{\sigma}{\epsilon_B}, \quad E_C = \frac{\sigma}{\epsilon_C}$$

Since ϵ_B is the smallest, E_B must be the largest ($E_B > E_A$ and $E_B > E_C$).

Step 3: Relating Young's Modulus to the strength of rocks. Young's Modulus is a measure of a material's stiffness or resistance to elastic deformation under stress. A higher

Young's Modulus indicates a stiffer and generally stronger material that will exhibit less strain under the same stress.

Step 4: Evaluating the options.

(A) Plate boundaries can have various stress and strain regimes, so this doesn't directly imply lower strain.

(B) Higher heat flow usually weakens rocks, leading to higher strain under the same stress.

(C) Density is not directly related to the stress-strain relationship described by Hooke's Law.

(D) Higher strength in rocks implies a higher resistance to deformation, hence lower strain under the same stress. This aligns with B having a higher Young's Modulus.

Quick Tip

Remember Hooke's Law: For a given stress, a material with a higher Young's Modulus will exhibit lower strain, indicating higher stiffness and generally higher strength.

---

41. What is/are the primary effect(s) of applying upward continuation to magnetic field data?

(A) Decrease in the relative influence of shallow magnetic sources

(B) Increase in the relative influence of deeper magnetic sources

(C) Improvement in the detection of near-surface magnetic sources

(D) Movement of shallow magnetic sources closer to the observation plane

Correct Answer: (A) Decrease in the relative influence of shallow magnetic sources , (B) Increase in the relative influence of deeper magnetic sources

Solution:

Step 1: Understanding upward continuation.

Upward continuation is a mathematical transformation applied to potential field data (e.g., magnetic or gravity data) to simulate measurements at a higher elevation than the actual observation level.

Step 2: Effects on magnetic sources. It reduces the influence of shallow magnetic sources because their field strength decays rapidly with height.

In contrast, it relatively enhances the contribution from deeper sources, as their field strength

decays more slowly.

Step 3: Eliminating incorrect options.

(C) is incorrect because upward continuation suppresses, rather than enhances, near-surface anomalies.

(D) is incorrect; it's a misinterpretation — sources do not move, only their apparent influence changes.

Quick Tip

Upward continuation smoothens magnetic data by attenuating shallow source effects and highlighting deeper structures — useful in regional studies.

---

42. Half-life of ^{14}C is 5730 years. Suppose we start with 1 billion ^{14}C atoms, and after a certain interval of time only 125 million ^{14}C atoms remain, the number of half-lives that has elapsed is _____ (Answer in integer).

Correct Answer: 3

Solution:

Step 1: Understanding the half-life decay formula.

The decay of a substance follows the exponential decay formula:

$$N(t) = N_0 \left(\frac{1}{2}\right)^{t/T}$$

where:

$N(t)$ is the remaining number of atoms after time t,

N_0 is the initial number of atoms,

T is the half-life of the substance.

Step 2: Given values and calculation.

Initial number of atoms, $N_0 = 10^9$,

Remaining number of atoms, $N(t) = 125 \times 10^6$,

Half-life of ^{14}C, $T = 5730$ years.

We need to find the number of half-lives n, such that:

$$\frac{N(t)}{N_0} = \left(\frac{1}{2}\right)^n$$

Substitute the values:

$$\frac{125 \times 10^6}{10^9} = \left(\frac{1}{2}\right)^n \quad \Rightarrow \quad 0.125 = \left(\frac{1}{2}\right)^n$$

Step 3: Solving for n. Taking the logarithm on both sides:

$$\log(0.125) = n \log\left(\frac{1}{2}\right)$$

$$n = \frac{\log(0.125)}{\log(0.5)} = 3$$

Thus, the number of half-lives that have elapsed is 3.

Quick Tip

For half-life problems, use the decay formula and logarithms to calculate the number of half-lives.

---

43. When an external magnetic field of strength 1.5×10^{-3} A/m is applied to a rock sample, the measured intensity of magnetization is 0.5×10^{-3} A/m. The magnetic susceptibility of this rock is _____ (Round off to two decimal places).

Correct Answer: 0.33

Solution:

Step 1: Magnetic susceptibility formula. Magnetic susceptibility (χ) is defined as the ratio of the magnetization M to the applied magnetic field H:

$$\chi = \frac{M}{H}$$

where:

M is the intensity of magnetization,

H is the applied magnetic field strength.

Step 2: Given values and calculation.

Magnetization, $M = 0.5 \times 10^{-3}$ A/m,

Magnetic field strength, $H = 1.5 \times 10^{-3}$ A/m.

Substitute the values:

$$\chi = \frac{0.5 \times 10^{-3}}{1.5 \times 10^{-3}} = 0.33$$

Thus, the magnetic susceptibility of the rock is 0.33.

Quick Tip

To find magnetic susceptibility, divide the magnetization by the magnetic field strength.

---

44. If seismic signals of periods greater than 10 s are of interest, the minimum sampling frequency should be _____ Hz. (Round off to one decimal place).

Correct Answer: 0.2

Solution:

Step 1: Sampling theorem.

According to the Nyquist-Shannon sampling theorem, the minimum sampling frequency f_s should be at least twice the highest frequency component of the signal.

Step 2: Relation between frequency and period.

The frequency f is the reciprocal of the period T:

$$f = \frac{1}{T}$$

Given the period is greater than 10 s, the frequency corresponding to the maximum period (10 s) is:

$$f = \frac{1}{10} = 0.1\,\text{Hz}$$

Step 3: Minimum sampling frequency.

To satisfy the Nyquist criterion, the minimum sampling frequency should be:

$$f_s = 2 \times 0.1 = 0.2\,\text{Hz}$$

Thus, the minimum sampling frequency should be 0.2 Hz.

Quick Tip

To avoid aliasing in signal processing, always sample at least twice the highest frequency in the signal.

---

45. The components u, v, w of the displacement field along x, y, z directions, respectively, are given by:

$$u = -\sin(\omega t - kz)$$

$$v = \sin(\omega t - kz)$$

$$w = 0$$

where t, k, and ω are time, wavenumber, and angular frequency, respectively. Assuming k is real, which one of the following describes the wave?

(A) An S-wave propagating in the z direction

(B) A P-wave propagating in the z direction

(C) A Rayleigh wave with elliptical motion in the xy plane

(D) An S-wave travelling in the x direction

Correct Answer: (A) An S-wave propagating in the z direction

Solution:

Step 1: Analyzing the displacement field.

The displacement field components are given as:

$u = -\sin(\omega t - kz)$,

$v = \sin(\omega t - kz)$,

$w = 0$.

The displacement components u and v represent motion in the x- and y-directions, respectively, with a sinusoidal dependence on time and position.

Step 2: Type of wave.

The wave is characterized by transverse motion in the x and y directions, while there is no motion in the z-direction. This suggests a shear wave (S-wave), as shear waves involve motion perpendicular to the direction of propagation.

The wave propagates in the z-direction, as indicated by the dependence on z in the sine function for both u and v.

Step 3: Conclusion.

Therefore, this is an S-wave (shear wave) propagating in the z-direction.

Quick Tip

In shear waves (S-waves), the displacement is perpendicular to the direction of propagation.

46. Select the correct statement regarding surface waves and upper mantle structure.

(A) Surface waves cannot be used to infer the upper mantle structure as the amplitudes decay with increasing distance from the surface

(B) Surface waves can be used to infer the upper mantle structure as surface wave phase velocity varies with frequency

(C) Surface waves can be used to infer the upper mantle structure as the shear-wave velocity of the medium changes with frequency

(D) Surface waves cannot be used to infer the upper mantle structure as surface waves travel only along the surface and are not sensitive to the Earth's internal structure

Correct Answer: (B) Surface waves can be used to infer the upper mantle structure as surface wave phase velocity varies with frequency

Solution:

Step 1: Understanding surface waves.

Surface waves are seismic waves that travel along the Earth's surface. Their characteristics, such as velocity and amplitude, are influenced by the properties of the Earth's surface and near-surface layers. These waves typically have slower velocities compared to body waves (P-waves and S-waves).

Step 2: Effect of surface wave phase velocity.

Surface wave phase velocity is frequency-dependent and varies with the elastic properties of the Earth's layers, particularly in the upper mantle. By studying the dispersion (variation with frequency) of surface waves, we can infer information about the structure and properties of the upper mantle.

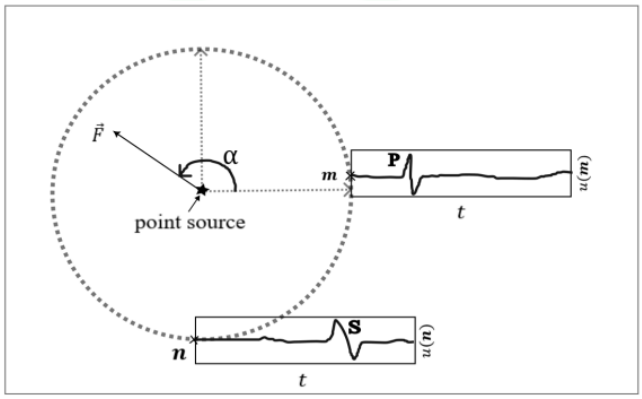
Step 3: Conclusion.

Thus, surface waves can indeed be used to infer the upper mantle structure, as the phase velocity of surface waves varies with frequency.

Quick Tip

Surface waves are valuable for investigating the Earth's upper mantle due to their sensitivity to the material properties of near-surface layers.

47. A geophysicist is analyzing the elastic-wave radiation to infer the body force equivalent of a seismic source. She has plotted the horizontal component of the displacement field, denoted as $u(m,t)$, for time t and location m. The measured field at two locations m and n is plotted in the figure. Note that S and P waves have negligible amplitudes at locations m and n, respectively. Assuming a homogeneous medium, select the most probable direction (specified by the angle α) along which the force $\vec{F}$ is applied.



(A) $\alpha = 0^\circ$

(B) $\alpha = 90^\circ$

(C) $\alpha = 135^\circ$

(D) $\alpha = 315^\circ$

Correct Answer: (A) $\alpha = 0^\circ$

Solution: We need to find the direction of force $\vec{F}$ based on seismic wave observations:

- P-waves are strong along $\vec{F}$, weak perpendicular
- S-waves are strong perpendicular to $\vec{F}$, weak along it

Given:

- At point m: S-waves are negligible $\Rightarrow m$ is along $\vec{F}$
- At point n: P-waves are negligible $\Rightarrow n$ is perpendicular to $\vec{F}$

This means:

- $\vec{F}$ must point directly toward m
- n must be at 90° to $\vec{F}$

From the options:

- $\alpha = 0^\circ$ matches this (force along x-axis)
- Other angles don't align properly

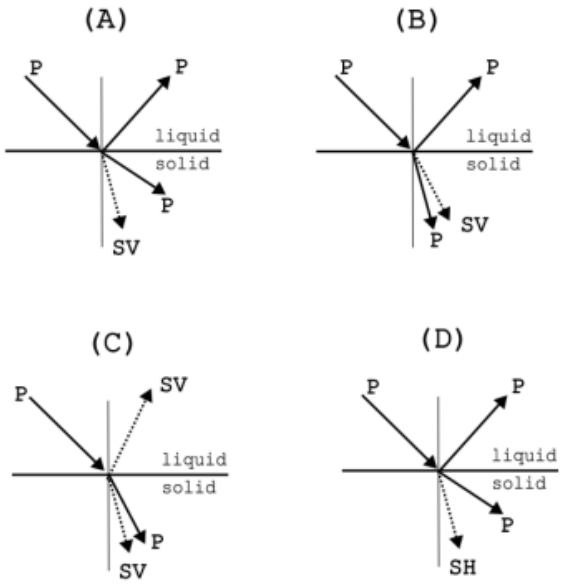
$\boxed{A}$

Quick Tip

The first motion polarity of P and S waves in a radiation pattern is crucial for determining the source mechanism. Remember the approximate angular dependence for a single force.

---

48. For a horizontal liquid-solid interface as shown, which one of the following ray diagrams with an incident P wave is correct? SH and SV denote shear-horizontal and shear-vertical waves, respectively.



(A) A

(B) B

(C) C

(D) D

Correct Answer: (A) A

Solution: Step 1: Understanding the behavior of seismic waves at a liquid-solid interface.

When a P-wave (compressional wave) encounters an interface between two media with different acoustic impedances, it can be reflected and refracted (transmitted) as both P-waves and S-waves (shear waves). However, the behavior is different when one of the media is a liquid.

Step 2: Analyzing wave propagation in a liquid.

Liquids can support compressional waves (P-waves) because they can be compressed. However, ideal liquids cannot support shear stresses, which means shear waves (S-waves, both SV and SH) cannot propagate through them.

Step 3: Considering an incident P-wave from the liquid side.

In this case, the incident P-wave is traveling from the liquid towards the liquid-solid interface.

Step 4: Analyzing the possible reflected and refracted waves.

When the P-wave hits the interface:

- A P-wave can be reflected back into the liquid. This is possible as liquids support P-waves.
- A P-wave can be refracted (transmitted) into the solid. Solids support P-waves.
- An S-wave can be refracted (transmitted) into the solid. When a P-wave strikes a solid-liquid interface (or vice versa) at an oblique angle, it generally generates both refracted P and S waves (specifically SV waves in the plane of incidence). SH waves would require a component of motion perpendicular to the plane of incidence in the incident wave, which is not the case for a simple P-wave incident in the plane of the diagram.
- An S-wave cannot be reflected back into the liquid because liquids do not support shear waves.

Step 5: Evaluating the given ray diagrams.

(A) Figure A shows a reflected P-wave in the liquid and both a refracted P-wave and a refracted SV-wave in the solid. This is consistent with the principles discussed above.

(B) Figure B shows a reflected P-wave, a refracted P-wave, and a refracted SV-wave. However, the refracted SV-wave is shown originating from the point of refraction of the

P-wave, which is conceptually correct, but the representation might be slightly misleading in some contexts. Nevertheless, the wave types are correct.

(C) Figure C shows a reflected P-wave and a refracted SV-wave, but no refracted P-wave. This is incorrect as a P-wave incident on a solid generally produces a refracted P-wave.

(D) Figure D shows a reflected P-wave, a refracted P-wave, and a refracted SH-wave. A P-wave incident on a horizontal interface in the plane of the diagram will not generate an SH-wave, which has particle motion perpendicular to this plane.

Step 6: Comparing options A and B.

Both options A and B show the correct wave types: reflected P, refracted P, and refracted SV. The difference lies in the visual representation of the refracted waves. In the absence of further specific conventions in the question, both diagrams essentially depict the correct physical phenomena. However, typically, reflection and refraction are shown originating from the point of incidence. Option A clearly shows this. Option B might be interpreted as the SV wave being generated due to the change in direction of the refracted P-wave within the solid, which is not the direct consequence at the interface. Therefore, option A is a more direct and standard representation.

Quick Tip

Remember that liquids support P-waves but not S-waves. When a P-wave encounters a liquid-solid interface, it can generate reflected P, refracted P, and refracted SV waves in the solid. SH waves are not generated by a P-wave incident on a horizontal interface in the plane of incidence.

---

49. Consider a steady-state heat conduction equation for the Earth's crust where A is the heat source and k is the thermal conductivity. Given the boundary conditions:

- $T = 0$ at the surface and
- Q is the heat flux at the surface,

Which one of the following options would be the temperature T at depth z?

(A) $\frac{-(Az+2Q)z}{2k}$

(B) $\frac{-(Az+2Q)z}{k}$

(C) $\frac{-(Az+Q)z}{2k}$

(D) $\frac{-(A+2Q)z^2}{2k}$

Correct Answer: (A) $\frac{-(Az+2Q)z}{2k}$

Solution:

Step 1: Heat conduction equation.

The steady-state heat conduction equation in one dimension is given by:

$$\frac{d^2T}{dz^2} = -\frac{A}{k}$$

where A is the heat source and k is the thermal conductivity.

Step 2: General solution.

Integrating once with respect to z, we get:

$$\frac{dT}{dz} = -\frac{Az}{k} + C_1$$

where C_1 is a constant of integration.

Step 3: Applying boundary conditions.

Using the boundary condition $T = 0$ at the surface $z = 0$, and knowing that heat flux Q is the gradient of temperature at the surface, we can express the solution for T at depth z:

$$T = \frac{-(Az + 2Q)z}{2k}$$

where Q is the heat flux at the surface.

Step 4: Conclusion.

Thus, the temperature T at depth z is:

$$T = \frac{-(Az + 2Q)z}{2k}$$

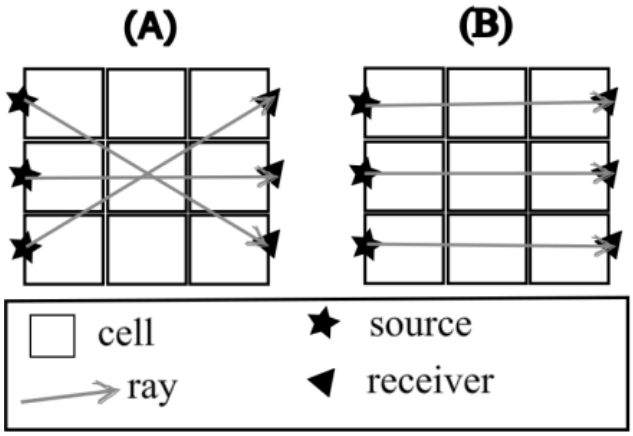
Quick Tip

In heat conduction problems with given boundary conditions, ensure you account for both the heat source and flux when determining the temperature profile.

---

50. Consider a ray tomography experiment, where the goal is to estimate the wave velocity of 9 square cells plotted in each of the cases A and B. The ray paths for

source-receiver pairs for both these cases are shown in the figure. Select the correct statement.



(A) Both A and B are well-determined problems

(B) Case A has a unique solution, and B is underdetermined

(C) Both A and B are mixed determined problems

(D) Case A is mixed determined, and B is underdetermined

Correct Answer: (D) Case A is mixed determined, and B is underdetermined

Solution: Step 1: Understanding the concept of well-determined, underdetermined, and overdetermined problems in ray tomography.

In ray tomography, we aim to determine the velocity distribution within a medium by measuring the travel times of waves along various ray paths passing through it. If we have N unknown parameters (velocities in N cells), we need a certain number of independent measurements (travel times along different rays) to solve for these parameters.

- **Well-determined:** The number of independent measurements is equal to the number of unknowns. This often leads to a unique solution, provided the ray paths provide sufficient coverage of the medium.
- **Underdetermined:** The number of independent measurements is less than the number of unknowns. This means there are infinitely many solutions that can satisfy the measurements.
- **Overdetermined:** The number of independent measurements is greater than the number of unknowns. This generally does not have a unique exact solution, but a best-fit solution can be obtained using methods like least squares.

- **Mixed determined:** Some parameters can be uniquely determined or well-constrained, while others remain poorly constrained or underdetermined due to the geometry of the ray paths.

Step 2: Analyzing Case A.

In Case A, there are 9 unknown velocity values (one for each cell). There are 8 ray paths (measurements). While the number of measurements is close to the number of unknowns, the specific configuration of the rays might lead to some cells or combinations of cells being better resolved than others. The central cell, for example, is sampled by multiple rays. However, without a formal analysis of the linear independence of the equations, it's plausible that the system is not fully well-determined and some degree of ambiguity or non-uniqueness exists for certain velocity parameters. Thus, Case A is likely a mixed determined problem.

Step 3: Analyzing Case B.

In Case B, there are 9 unknown velocity values. There are 6 ray paths (measurements) (3 horizontal and 3 vertical). The number of measurements is significantly less than the number of unknowns. This clearly indicates an underdetermined problem. There will be infinitely many velocity distributions that can satisfy the measured travel times along these 6 ray paths. The lack of diagonal rays severely limits the constraints on the individual cells and their combinations.

Step 4: Concluding based on the analysis.

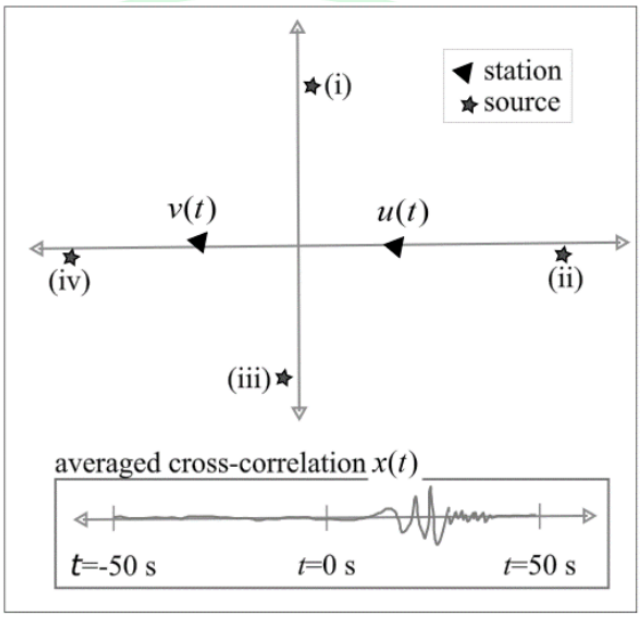
Based on the analysis, Case A likely results in a mixed determined problem where some velocity parameters might be reasonably constrained while others are not. Case B, with fewer measurements than unknowns and limited ray coverage, is clearly an underdetermined problem. Therefore, the correct statement is that Case A is mixed determined, and B is underdetermined.

Quick Tip

The determinacy of a tomography problem depends on the balance between the number of unknowns (e.g., cell velocities) and the number of independent measurements (e.g., travel times along ray paths), as well as the geometry and coverage of these paths. Insufficient or poorly distributed ray paths can lead to underdetermined or mixed determined systems.

---

51. Consider extracting the subsurface medium response by cross-correlating seismic ambient noise $u(t)$ and $v(t)$ measured at two stations. The cross-correlation $x(t) = \sum_\tau u(\tau)v(\tau + t)$ averaged over a period of one year is plotted in the figure, with most of the energy in the positive time lags. In this figure, four probable seismic sources are marked (i), (ii), (iii) and (iv). Assuming a homogeneous medium, select the source that is most probably excited.



(A) (i)

(B) (ii)

(C) (iii)

(D) (iv)

Correct Answer: (B) (ii)

Solution: The key point of this question lies in interpreting the cross-correlation expression:

$$x(t) = \sum_{\tau} u(\tau)v(\tau + t)$$

This equation measures how similar the signal $u(t)$ is to a time-shifted version of $v(t)$. If the result $x(t)$ shows high energy at positive time lags, it means that $u(t)$ leads $v(t)$ — in other words, the signal was observed at the first station (where $u(t)$ is recorded) before it was seen at the second station (where $v(t)$ is recorded).

Interpretation:

The ambient seismic energy (originating from a source) must have traveled from the location of the u-station to the location of the v-station.

Hence, the wavefront first reached station u, and only afterward reached station v.

Assuming a homogeneous medium:

The velocity of wave propagation is uniform in all directions.

The direction of energy propagation can thus be inferred directly from the sign of the time lag.

Given: Positive time lag $\Rightarrow$ signal at station u arrives earlier

Therefore, the source must lie closer to station u and in the direction toward station v

From the figure:

Among the four sources labeled (i) to (iv), source (ii) lies on the side from which energy would travel from u to v — consistent with the positive time lags observed in the cross-correlation.

Thus, **source (ii)** is the most likely origin of the seismic ambient noise observed.

Quick Tip

The interpretation of time lags in ambient noise cross-correlation depends on the definition used. Positive lag t in $\langle u(\tau)v(\tau + t)\rangle$ suggests u leads v. The dominant source location should be consistent with this observed delay, considering the station geometry and potential propagation effects.

---

52. Given the following electric field in Cartesian coordinates:

$$\mathbf{E} = x^2y\hat{i} + y^2z\hat{j} + z^2x\hat{k},$$

which of the following statements is/are correct?

(A) The electric field is not conservative

(B) The electric field is static

(C) Both divergence and curl of the electric field are zero

(D) Electric field is neither conservative nor static

Correct Answer: (A) The electric field is not conservative, (B) The electric field is static

Solution:

Step 1: Check if the electric field is conservative.

For a field to be conservative, its curl must be zero:

$$\nabla \times \mathbf{E} = \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z} \right) \times \left(x^2 y, y^2 z, z^2 x \right)$$

By calculating the curl, we find that:

$$\nabla \times \mathbf{E} = (2xy - 2xz)\hat{i} + (2yz - 2xy)\hat{j} + (2zx - 2yz)\hat{k}.$$

Since the curl is non-zero, the field is not conservative.

Step 2: Check if the electric field is static.

A static electric field should not depend on time. Since the given electric field has no time dependence, it is static.

Step 3: Conclusion. Thus, the correct answer is (A) and (B).

Quick Tip

To check if a vector field is conservative, calculate the curl. If the curl is zero, the field is conservative.

---

53. What factor(s) determine(s) the magnitude of peak ground acceleration measured at a particular station due to an earthquake?

(A) Distance from the earthquake

(B) Rupture directivity

(C) Origin time of the earthquake

(D) Type of soil

Correct Answer: (A) Distance from the earthquake, (B) Rupture directivity, (D) Type of soil

Solution:

Step 1: Understand the factors affecting peak ground acceleration.

Peak ground acceleration (PGA) depends on several factors:

The distance from the earthquake epicenter (closer to the epicenter generally leads to higher PGA),

The rupture directivity (the direction of the rupture affects the intensity of shaking),

The type of soil (soft soils amplify seismic waves more than hard rocks).

The origin time (C) does not significantly affect the PGA.

Step 2: Conclusion.

Thus, the correct answer includes (A), (B), and (D).

Quick Tip

Peak ground acceleration is affected by the distance to the earthquake, the directivity of the rupture, and local soil conditions.

---

54. Consider a geophysical inverse problem of the form $\mathrm{d} = \mathrm{Gm}$, where G is the forward operator, m is the model vector and d is the observed data vector. The Earth model parameters can be estimated using $\mathrm{m_{est}} = \mathrm{Hd}$, where H is the pseudoinverse of G. Given $\mathrm{G} = \mathrm{U}\Sigma\mathrm{V}^T$ as the singular value decomposition of G, and assuming G is full rank, which of the following options is/are correct?

(A) $\mathbf{H} = \mathbf{U}^T\Sigma^{-1}\mathbf{V}$

(B) $\mathbf{H} = \mathbf{V}\Sigma^{-1}\mathbf{U}^T$

(C) $\mathbf{H} = \mathbf{U}^T\Sigma^{-1}\mathbf{V}^T$

(D) $\mathbf{H} = \mathbf{U}\mathbf{U}^T\mathbf{V}\Sigma^{-1}\mathbf{U}^T$

Correct Answer: (B) $\mathbf{H} = \mathbf{V}\Sigma^{-1}\mathbf{U}^T$, (D) $\mathbf{H} = \mathbf{U}\mathbf{U}^T\mathbf{V}\Sigma^{-1}\mathbf{U}^T$

Solution:

Step 1: Using the pseudoinverse formula.

For a full rank matrix $\mathbf{G}$, its Moore-Penrose pseudoinverse $\mathbf{H}$ is given by:

$$\mathbf{H} = \mathbf{V}\Sigma^{-1}\mathbf{U}^T.$$

Step 2: Conclusion.

Thus, the correct formula for $\mathbf{H}$ is option (B) and (D).

Quick Tip

The Moore-Penrose pseudoinverse of a matrix $\mathbf{G}$ is given by $\mathbf{H} = \mathbf{V}\Sigma^{-1}\mathbf{U}^T$ for the singular value decomposition $\mathbf{G} = \mathbf{U}\Sigma\mathbf{V}^T$.

---

55. Consider ray tracing in an isotropic elastic Earth, with travel time function $T(x, y, z)$ in Cartesian coordinates. Select the correct option(s).

(A) The slowness vector is tangential to the wave fronts

(B) The slowness vector is parallel to the gradient of $T(x, y, z)$

(C) $T(x, y, z)$ is constant on a particular wave front

(D) $T(x, y, z)$ is constant along the rays

Correct Answer: (B) The slowness vector is parallel to the gradient of $T(x, y, z)$, (C) $T(x, y, z)$ is constant on a particular wave front

Solution:

Step 1: Understand slowness vector.

The slowness vector is defined as $\nabla T(x, y, z)$, i.e., the gradient of the travel time.

Step 2: Analyze wavefront properties.

Wavefronts represent surfaces of constant travel time, i.e., $T(x, y, z) =$ constant. Rays are perpendicular to wavefronts, so the slowness vector (being the gradient) is normal to the wavefront.

Step 3: Evaluate options.

(A) Incorrect: Slowness is normal, not tangential.

(B) Correct: Slowness vector $= \nabla T$.

(C) Correct: $T(x, y, z)$ is constant on a wavefront.

(D) Incorrect: T increases along a ray path.

Quick Tip

In ray theory, the slowness vector points in the direction of increasing travel time and is always normal to wavefronts.

56. Which of the following statements is/are correct regarding the properties of the oceanic lithosphere?

(A) Older lithosphere cools at a slower rate compared to younger lithosphere

(B) Heat flow increases with lithospheric age

(C) Heat flow in the lithosphere increases with distance from the spreading ridge

(D) Thickness of the lithosphere increases with age

Correct Answer: (A) Older lithosphere cools at a slower rate compared to younger lithosphere, (D) Thickness of the lithosphere increases with age

Solution:

Step 1: Understand cooling behavior with age.

Younger lithosphere cools rapidly. As it ages, the lithosphere becomes thermally insulated and the rate of cooling decreases, making (A) correct.

Step 2: Heat flow trends.

Heat flow is highest at the ridge (young lithosphere) and decreases with age and distance from the ridge, making (B) and (C) incorrect.

Step 3: Lithosphere thickness.

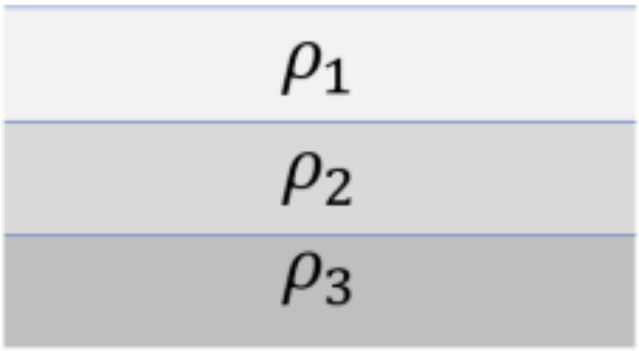
With cooling over time, the lithosphere becomes denser and thicker. Hence, (D) is correct.

Quick Tip

Oceanic lithosphere thickens and cools with age, and the rate of heat flow decreases as you move away from the ridge. Older lithosphere cools more slowly than younger lithosphere.

---

57. For a half space composed of 3 layers with resistivities ρ_1, ρ_2 and ρ_3, as shown in the figure, which of the following statements is/are correct about the variation of apparent resistivity with electrode spacing?



(A) If $\rho_1 < \rho_2 < \rho_3$, the curve of apparent resistivity increases monotonically

(B) If $\rho_1 < \rho_2 < \rho_3$, the curve of apparent resistivity decreases monotonically

(C) If $\rho_1 > \rho_2 < \rho_3$, the curve of apparent resistivity first decreases and then increases

(D) If $\rho_1 > \rho_2 > \rho_3$, the curve of apparent resistivity increases monotonically

Correct Answer: (A) If $\rho_1 < \rho_2 < \rho_3$, the curve of apparent resistivity increases monotonically; (C) If $\rho_1 > \rho_2 < \rho_3$, the curve of apparent resistivity first decreases and then increases

Solution: Step 1: Understanding the concept of apparent resistivity in layered media.

The apparent resistivity ρ_a is a measure that reflects the overall resistivity of the subsurface as a function of the depth of investigation, which is controlled by the electrode spacing. As the electrode spacing increases, the current penetrates deeper into the ground, and the measured apparent resistivity becomes more sensitive to the resistivity of the deeper layers.

Step 2: Analyzing the case $\rho_1 < \rho_2 < \rho_3$.

When the electrode spacing is small, the current flow is primarily confined to the top layer with resistivity ρ_1, so $\rho_a \approx \rho_1$. As the electrode spacing increases, the current penetrates into the second layer with resistivity $\rho_2 > \rho_1$, and then into the third layer with resistivity $\rho_3 > \rho_2$. Consequently, the apparent resistivity will gradually increase from a value close to ρ_1 towards values influenced by ρ_2 and then ρ_3. This results in a monotonically increasing curve of apparent resistivity with electrode spacing. Statement (A) is correct.

Step 3: Analyzing the case $\rho_1 > \rho_2 < \rho_3$.

For small electrode spacing, $\rho_a \approx \rho_1$. As the spacing increases, the current penetrates into the second layer with a lower resistivity $\rho_2 < \rho_1$, causing the apparent resistivity to decrease. With further increase in electrode spacing, the current reaches the third layer with resistivity

$\rho_3 > \rho_2$. If ρ_3 is sufficiently larger than ρ_2, the apparent resistivity will start to increase again, resulting in a curve that first decreases and then increases, showing a minimum. Statement (C) is correct.

Step 4: Analyzing the case $\rho_1 > \rho_2 > \rho_3$.

For small electrode spacing, $\rho_a \approx \rho_1$. As the spacing increases, the current penetrates into the second layer with a lower resistivity $\rho_2 < \rho_1$, causing ρ_a to decrease. Further increase in spacing leads to greater influence from the third layer with an even lower resistivity $\rho_3 < \rho_2$, causing ρ_a to decrease further. Thus, the curve of apparent resistivity will show a monotonic decrease. Statement (D) is incorrect.

Step 5: Analyzing the case $\rho_1 < \rho_2 > \rho_3$.

(This case was not explicitly asked, but for completeness) For small spacing, $\rho_a \approx \rho_1$. As spacing increases, influence of $\rho_2 > \rho_1$ increases ρ_a. Further increase leads to influence of $\rho_3 < \rho_2$. The curve would increase and then potentially decrease.

Therefore, the correct statements are (A) and (C).

Quick Tip

The apparent resistivity curve reflects the vertical resistivity profile. Transitions in resistivity with depth will cause changes in the slope of the apparent resistivity curve. A low resistivity layer sandwiched between higher resistivity layers will typically cause a decrease followed by an increase in apparent resistivity with increasing electrode spacing.

---

58. A loop of radius R carries a current I and produces a magnetic field B. Which of the following statements is/are correct about B?

(A) The magnitude of B is directly proportional to I

(B) The magnitude of B is inversely proportional to the square of radius R

(C) The direction of B is perpendicular to the plane of the loop

(D) The direction of B is parallel to the plane of the loop

Correct Answer: (A) The magnitude of B is directly proportional to I, (C) The direction of B is perpendicular to the plane of the loop

Solution:

Step 1: Use Biot–Savart law. The magnetic field at the center of a current-carrying loop is given by:

$$B = \frac{\mu_0 I}{2R}$$

So, $B \propto I$ and $B \propto \frac{1}{R}$, not $\frac{1}{R^2}$.

Step 2: Analyze direction.

The direction of the magnetic field is along the axis of the loop, which is perpendicular to its plane (right-hand rule).

Step 3: Evaluate options.

(A) Correct: $B \propto I$

(B) Incorrect: Field is inversely proportional to R, not R^2

(C) Correct: Field is perpendicular to the loop plane

(D) Incorrect: Field is not in the plane

Quick Tip

The magnetic field at the center of a current loop is proportional to the current and inversely proportional to the loop radius, and it points perpendicular to the loop.

---

59. In seismology, Born approximation of the scattered (perturbed) wavefield is given by

$$\delta u(\mathbf{r}, \mathbf{s}; t) \approx \int_V \delta r(\mathbf{x}) \left(u_0(\mathbf{x}, \mathbf{s}; t) {}_t u_0(\mathbf{r}, \mathbf{x}; t) \right) \, d\mathbf{x}.$$

Here,

- ${}_t$ denotes temporal convolution,
- $\delta r(\mathbf{x})$ is the strength of the scatterer at $\mathbf{x}$ in volume V,
- $\delta u(\mathbf{r}, \mathbf{s}; t)$ is the scattered wavefield measured at the receiver $\mathbf{r}$ from the source $\mathbf{s}$,
- $u_0(\mathbf{x}, \mathbf{s}; t)$ is the downgoing wavefield (to the scatterer at $\mathbf{x}$ from the source $\mathbf{s}$) in the unperturbed medium,
- $u_0(\mathbf{r}, \mathbf{x}; t)$ is the upgoing wavefield (to the receiver $\mathbf{r}$ from the scatterer at $\mathbf{x}$) in the unperturbed medium.

Select the correct statement(s).

(A) The Born approximation can be used to model multiply scattered waves

(B) The Born approximation can model only first-order scattering

(C) The scattered wavefield varies linearly with strength of the scatterers

(D) The Born approximation can be used to model head waves from a horizontal reflector

Correct Answer: (B), (C)

Solution:

Step 1: Understanding the Born approximation.

The Born approximation is a first-order perturbation method used to model wave scattering in weakly inhomogeneous media. It assumes that the scatterers are weak and that only single scattering (first-order scattering) is significant.

Step 2: Interpreting the equation.

The scattered wavefield is expressed as:

$$\delta u(\mathbf{r}, \mathbf{s}; t) \approx \int_V \delta r(\mathbf{x}) \left(u_0(\mathbf{x}, \mathbf{s}; t) {}_t u_0(\mathbf{r}, \mathbf{x}; t) \right) \, d\mathbf{x}$$

This shows that the scattered field is proportional to $\delta r(\mathbf{x})$, which implies a linear relationship between the scattered wavefield and the strength of the scatterer.

Step 3: Analyzing the options.

- (A) Incorrect. The Born approximation does not account for multiple scattering; it only includes the first-order effect.
- (B) Correct. It models only the first-order (single) scattering.
- (C) Correct. The wavefield is linearly dependent on the strength $\delta r(\mathbf{x})$.
- (D) Incorrect. Modeling head waves requires a more complex treatment than what the Born approximation provides.

Quick Tip

The Born approximation is valid for weak scattering and is linear in the perturbation. For multiple scattering or strong contrast media, more advanced methods such as the Rytov approximation or full-waveform modeling are necessary.

60. A primary electromagnetic field (H_P) is being generated from current I_P flowing in a coil A with negligible capacitance, such that $H_P = KI_P \sin \omega t$, where ω is the angular frequency, K is a constant and t is time. A secondary electromagnetic field is being produced by induction in a conducting coil B. The phase difference between the primary and the secondary electromagnetic fields depends on which of the following factors?

(A) Inductance of coil B

(B) Resistance of coil B

(C) Frequency of the primary electromagnetic field

(D) Total current (I_P) flowing through the coil A

Correct Answer: (A) Inductance of coil B, (B) Resistance of coil B, (C) Frequency of the primary electromagnetic field

Solution:

Step 1: Understand induced current and phase shift.

The secondary electromagnetic field is produced by the induced current in coil B due to the changing primary field. The response of coil B (i.e., the induced current and hence the secondary field) depends on its impedance.

Step 2: Impedance and phase shift.

The impedance of coil B is determined by its resistance R and inductance L. The phase angle ϕ between voltage (or induced emf) and current is given by:

$$\tan \phi = \frac{\omega L}{R}$$

So, the phase shift depends on ω (frequency), L, and R. Therefore, options (A), (B), and (C) are correct.

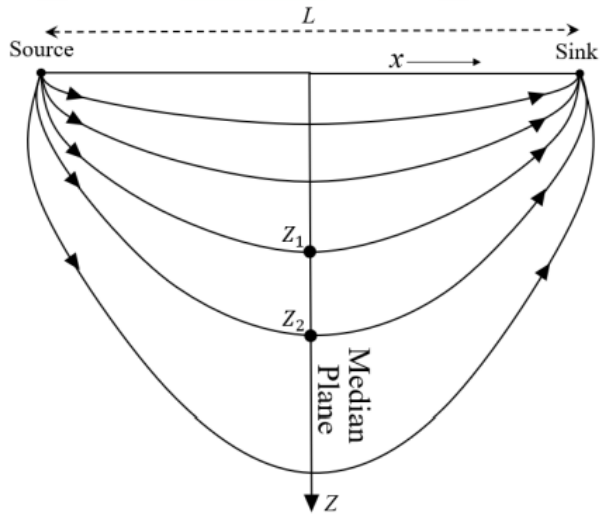
Step 3: Role of total current I_P.

While the amplitude of the primary field depends on I_P, the phase of the secondary field is governed by the properties of coil B and the frequency. Hence, option (D) is incorrect.

Quick Tip

The phase difference in electromagnetic induction setups typically depends on the inductance and resistance of the receiving coil and the frequency of the inducing signal.

61. Consider a medium of uniform resistivity with a pair of source and sink electrodes separated by a distance L, as shown in the figure. The fraction of the input current (I) that flows horizontally (I_x) across the median plane between depths $z_1 = \frac{L}{2}$ and $z_2 = \frac{L\sqrt{3}}{2}$, is given by $\frac{I_x}{I} = \frac{L}{\pi}\int_{z_1}^{z_2} \frac{dz}{(L^2/4+z^2)}$. The value of $\frac{I_x}{I}$ is equal to _____



Correct Answer: 0.17

Solution: Step 1: Substitute the limits of integration.

$$\frac{I_x}{I} = \frac{L}{\pi}\int_{L/2}^{L\sqrt{3}/2} \frac{dz}{(L^2/4+z^2)}$$

Step 2: Evaluate the integral.

Using the integral formula $\int \frac{dx}{a^2+x^2} = \frac{1}{a}\arctan(\frac{x}{a}) + C$ with $a = L/2$:

$$\int \frac{dz}{(L^2/4+z^2)} = \frac{1}{L/2}\arctan\left(\frac{z}{L/2}\right) = \frac{2}{L}\arctan\left(\frac{2z}{L}\right)$$

Step 3: Apply the limits of integration.

$$\frac{I_x}{I} = \frac{L}{\pi}\left[\frac{2}{L}\arctan\left(\frac{2z}{L}\right)\right]_{L/2}^{L\sqrt{3}/2} = \frac{2}{\pi}\left[\arctan\left(\frac{2(L\sqrt{3}/2)}{L}\right) - \arctan\left(\frac{2(L/2)}{L}\right)\right]$$

$$\frac{I_x}{I} = \frac{2}{\pi}\left[\arctan(\sqrt{3}) - \arctan(1)\right]$$

Step 4: Evaluate the arctangent values.

$$\arctan(\sqrt{3}) = \frac{\pi}{3}, \quad \arctan(1) = \frac{\pi}{4}$$

Step 5: Calculate the final value.

$$\frac{I_x}{I} = \frac{2}{\pi}\left[\frac{\pi}{3} - \frac{\pi}{4}\right] = \frac{2}{\pi}\left[\frac{4\pi - 3\pi}{12}\right] = \frac{2}{\pi}\left[\frac{\pi}{12}\right] = \frac{1}{6}$$

Step 6: Convert to decimal and round off to two decimal places.

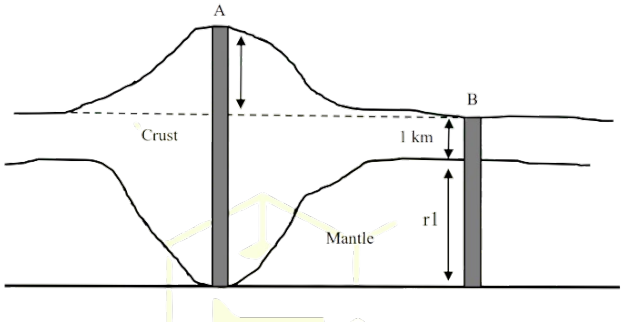
$$\frac{1}{6} \approx 0.1666... \approx 0.17$$

Quick Tip

Remember the integral of $\frac{1}{a^2+x^2}$ and the values of $\arctan$ for standard angles. Pay close attention to the limits of integration.

---

62. Suppose a mountain at location A is in isostatic equilibrium with a column at location B, which is at sea-level, as shown in the figure. The height of the mountain is 4 km and the thickness of the crust at B is 1 km. Given that the densities of crust and mantle are 2700 kg/m^3 and 3300 kg/m^3, respectively, the thickness of the mountain root (r1) is _____ km. (Answer in integer)



Correct Answer: 18

Solution: Step 1: Understand the principle of isostatic equilibrium.

Isostatic equilibrium implies that the pressure at a certain depth (compensation depth) due to the weight of the overlying material is the same for adjacent columns.

Step 2: Consider the excess mass due to the mountain.

The mountain at location A has an excess height of 4 km above the normal crustal thickness at sea level (location B). This excess mass per unit area is given by the height of the mountain multiplied by the density of the crust:

$$\text{Excess mass} = h_{mountain} \times \rho_c = 4 \text{ km} \times 2700 \text{ kg/m}^3$$

Step 3: Consider the buoyant force provided by the mountain root.

The mountain root (r1) is composed of crustal material that displaces mantle material. The buoyant force per unit area provided by the root is due to the density difference between the

mantle and the crust multiplied by the thickness of the root:

$$\text{Buoyant force (due to root)} = r1 \times (\rho_m - \rho_c) = r1 \times (3300 - 2700) \text{ kg/m}^3$$

Step 4: Equate the excess mass and the buoyant force for isostatic equilibrium.

For the mountain to be in isostatic equilibrium, the excess mass must be balanced by the buoyant force provided by the root:

$$h_{mountain} \times \rho_c = r1 \times (\rho_m - \rho_c)$$

$$4 \times 2700 = r1 \times (3300 - 2700)$$

$$10800 = r1 \times 600$$

Step 5: Solve for the thickness of the mountain root (r1).

$$r1 = \frac{10800}{600} = 18 \text{ km}$$

The thickness of the mountain root (r1) is 18 km.

Quick Tip

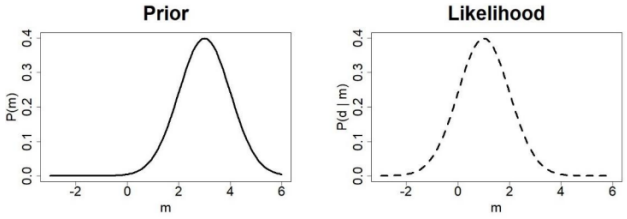
The concept of isostasy often involves balancing the weight of elevated topography with the buoyant force provided by a deeper crustal root. The density difference between the crust and the mantle is the key factor in determining the thickness of the root.

---

63. While doing Bayesian inference, consider estimating the posterior distribution of the model parameter (m), given data (d). Assume that Prior and Likelihood are proportional to Gaussian functions given by

$$\text{Prior} \propto \exp(-0.5(m-1)^2)$$

$$\text{Likelihood} \propto \exp(-0.5(m-3)^2)$$



The mean of the posterior distribution is _____ (Answer in integer)

Correct Answer: 2

Solution: Step 1: Apply Bayes' theorem.

The posterior distribution $P(m|d)$ is proportional to the product of the prior $P(m)$ and the likelihood $P(d|m)$:

$$P(m|d) \propto P(m) \times P(d|m) \propto \exp(-0.5(m-1)^2) \times \exp(-0.5(m-3)^2)$$

$$P(m|d) \propto \exp(-0.5[(m-1)^2 + (m-3)^2])$$

Step 2: Expand the exponent.

$$(m-1)^2 + (m-3)^2 = m^2 - 2m + 1 + m^2 - 6m + 9 = 2m^2 - 8m + 10$$

$$P(m|d) \propto \exp(-0.5[2m^2 - 8m + 10]) = \exp(-(m^2 - 4m + 5))$$

Step 3: Complete the square in the exponent.

$$m^2 - 4m + 5 = (m^2 - 4m + 4) + 1 = (m-2)^2 + 1$$

$$P(m|d) \propto \exp(-[(m-2)^2 + 1]) \propto \exp(-(m-2)^2)$$

Step 4: Identify the mean of the posterior distribution.

The posterior distribution is proportional to a Gaussian with mean $\mu_{post} = 2$.

Alternatively, using the formula for the mean of the posterior for Gaussian prior and likelihood:

Prior mean $\mu_p = 1$, prior variance $\sigma_p^2 = 1$. Likelihood mean $\mu_l = 3$, likelihood variance $\sigma_l^2 = 1$. Posterior mean $\mu_{post} = \frac{\frac{1}{\sigma_p^2}\mu_p + \frac{1}{\sigma_l^2}\mu_l}{\frac{1}{\sigma_p^2} + \frac{1}{\sigma_l^2}} = \frac{\frac{1}{1}\times 1 + \frac{1}{1}\times 3}{\frac{1}{1}+\frac{1}{1}} = \frac{1+3}{2} = \frac{4}{2} = 2$

The mean of the posterior distribution is 2.

Quick Tip

When the prior and likelihood are Gaussian, the posterior is also Gaussian. Its mean lies between the prior and likelihood means, weighted by their precisions (inverse variances).

---

64. Consider a two-dimensional reflection experiment, where a horizontal boundary between two layers is at a depth of 500 m below the free surface. A source and

geophone are placed on the free surface with an offset of 2000 m. The P-wave velocity of the top layer is 3000 m/s. The travel time of a recorded free-surface reflection multiple, which got reflected twice at the free surface, is _____ s.

Solution:

Step 1: Understanding the situation.

In this two-dimensional reflection experiment, the source and geophone are placed on the free surface, with the boundary at a depth of 500 m. The recorded wave is a multiple reflection, where the wave is reflected twice at the free surface.

Step 2: Analyzing the travel time.

The total travel time for a wave that is reflected twice at the free surface consists of:

The time for the wave to travel from the source to the boundary at depth $h = 500\,\text{m}$,

The time for the wave to travel back to the free surface after reflection,

The time for the wave to travel from the free surface to the receiver, which has an offset of $2000\,\text{m}$.

The total travel time for the free-surface reflection multiple is the sum of the round-trip travel times, taking into account the path the wave travels and the P-wave velocity of the top layer.

Step 3: Calculating the one-way travel time to the boundary.

The travel time to the boundary is calculated as:

$$t_1 = \frac{h}{v_p} = \frac{500}{3000} = 0.1667\,\text{seconds}.$$

where $v_p = 3000\,\text{m/s}$ is the P-wave velocity.

Step 4: Calculating the travel time for the offset.

The travel time for the wave to travel from the source to the receiver with an offset of 2000 m is calculated using the straight-line distance between the source and the receiver. The distance traveled is the hypotenuse of a right triangle with legs $2000\,\text{m}$ (offset) and $500\,\text{m}$ (depth).

The distance traveled is:

$$d = \sqrt{2000^2 + 500^2} = \sqrt{4000000 + 250000} = \sqrt{4250000} \approx 2061.55\,\text{m}.$$

The travel time for this distance is:

$$t_2 = \frac{d}{v_p} = \frac{2061.55}{3000} \approx 0.6872\,\text{seconds}.$$

Step 5: Calculating the total travel time.

The total travel time for the recorded free-surface reflection multiple is the sum of the following: 1. The travel time to the boundary: $t_1 = 0.1667\,\text{s}$, 2. The travel time for the offset: $t_2 = 0.6872\,\text{s}$, 3. The wave is reflected twice, so the total time is the sum of the round-trip travel times for both reflections:

$$\text{Total travel time} = 2 \times (t_1 + t_2) = 2 \times (0.1667 + 0.6872) = 2 \times 0.8539 \approx 1.7078\,\text{seconds}.$$

Thus, the travel time of the recorded free-surface reflection multiple is approximately:

$$\boxed{1.71\ \text{seconds}}.$$

Quick Tip

When calculating the travel time for a free-surface reflection multiple, ensure that you account for both the downward and upward travel paths, as well as the offset between the source and the receiver.

---

65. Consider the acceleration due to gravity g' at an altitude h of 50 km above the Earth's surface. If R is the radius of the Earth, and the acceleration due to gravity measured at the surface is g, the ratio of $\frac{g'}{g}$ is _____. (Assume $h \ll R$, $R = 6370$ km, and round off to two decimal places.)

Solution:

Step 1: Using the formula for gravitational acceleration at altitude.

The acceleration due to gravity at a height h above the Earth's surface is given by:

$$g' = g\left(\frac{R}{R+h}\right)^2$$

where:

g is the acceleration due to gravity at the surface,

R is the radius of the Earth, and

h is the height above the Earth's surface.

Step 2: Calculating the ratio $\frac{g'}{g}$.

The ratio $\frac{g'}{g}$ is:

$$\frac{g'}{g} = \left(\frac{R}{R+h}\right)^2$$

Substituting the given values:

$R = 6370\,\text{km}$,

$h = 50\,\text{km}$,

we get:

$$\frac{g'}{g} = \left(\frac{6370}{6370 + 50}\right)^2 = \left(\frac{6370}{6420}\right)^2$$

Step 3: Simplifying the expression.

First, calculate the ratio inside the parentheses:

$$\frac{6370}{6420} \approx 0.991 \quad \Rightarrow \quad (0.991)^2 \approx 0.982$$

Thus, the ratio of g' to g is approximately:

$$\frac{g'}{g} \approx 0.98$$

Quick Tip

The acceleration due to gravity decreases with altitude. For small heights compared to Earth's radius, the decrease is approximately proportional to the square of the ratio of the radii.
