GATE 2025 Metallurgical Engineering (MT) Question Paper with Solutions

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

General Aptitude (GA)

1. Despite his initial hesitation, Rehman's _______ to contribute to the success of the project never wavered. Select the most appropriate option to complete the above sentence.

(A) ambivalence

(B) satisfaction

(C) resolve

(D) revolve

Correct Answer: (C) resolve

Solution:

The sentence suggests that Rehman's determination to contribute remained unchanged despite hesitation. - (A) ”Ambivalence” refers to mixed feelings, which does not fit the context of unwavering determination.

- (B) ”Satisfaction” refers to contentment or pleasure, which is unrelated to determination.
- (C) ”Resolve” refers to firm determination, which is the correct choice for someone's commitment to a goal.
- (D) ”Revolve” means to move in a circular motion, which does not fit the context.

Hence, the correct answer is $\boxed{\text{Resolve}}$.

Final Answer: (C) resolve.

Quick Tip

Look for words that align with the context of determination or firmness in the sentence. ”Resolve” is perfect when describing an unwavering commitment.

---

2. Bird : Nest :: Bee : ?

Select the correct option to complete the analogy.

(A) Kennel

(B) Hammock

(C) Hive

(D) Lair

Correct Answer: (C) Hive

Solution:

The analogy suggests that birds make nests, and we need to find the place where bees live. - (A) ”Kennel” is where dogs live, which is unrelated.

- (B) ”Hammock” is a hanging bed, irrelevant to bees.
- (C) ”Hive” is where bees live, matching the pattern.
- (D) ”Lair” is where animals like lions live, unrelated to bees.

Hence, the correct answer is $\boxed{\text{Hive}}$.

Final Answer: (C) Hive.

Quick Tip

In analogies, focus on the relationship between the first pair and apply the same logic to the second pair. A bee’s home is a hive, just like a bird’s home is a nest.

---

3. If $Pe^x = Qe^{-x}$ for all real values of x, which one of the following statements is true?

(A) $P = Q = 0$

(B) $P = Q = 1$

(C) $P = 1; Q = -1$

(D) $\frac{P}{Q} = 0$

Correct Answer: (A) $P = Q = 0$

Solution:

We are given the equation $Pe^x = Qe^{-x}$. For this equation to hold for all values of x, both sides must be equal for every value of x.

Taking $x = 0$, we get:

$$P \cdot e^0 = Q \cdot e^0 \Rightarrow P = Q.$$

Now, to make the equation valid for all x, let's analyze the behavior as $x \to \infty$: For large values of x, the left-hand side Pe^x grows exponentially, while the right-hand side Qe^{-x} decays exponentially unless both P and Q are 0. Hence, for the equality to hold, both P and Q must be 0.

Thus, the correct answer is $\boxed{P = Q = 0}$.

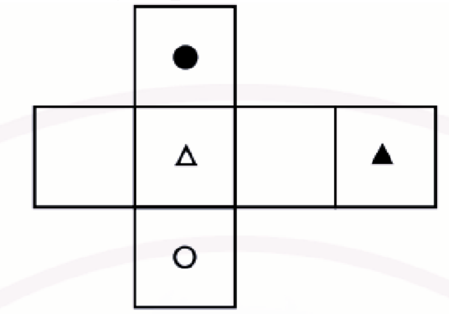
Final Answer: (A) $P = Q = 0$.

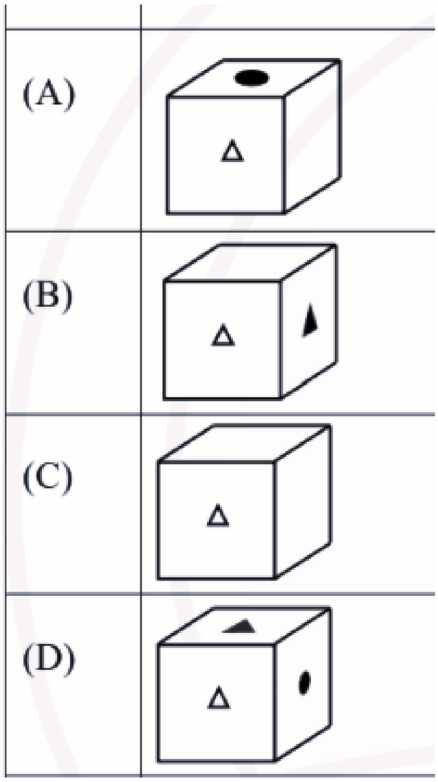
Quick Tip

For equations involving exponential terms, equality can only hold for both terms when the coefficients are equal, and for some cases, like this, both coefficients must be zero.

---

4. The paper as shown in the figure is folded to make a cube where each square corresponds to a particular face of the cube. Which one of the following options correctly represents the cube?





Correct Answer: (A)

Solution:

To solve this, we must analyze the paper folding diagram and determine which arrangement correctly matches the faces of the cube.

By examining the provided diagram and options: - Option (A) aligns with the folding process, where the top, left, right, and bottom faces align according to the paper layout.

Thus, the correct answer is $\boxed{A}$.

Final Answer: (A).

Quick Tip

When solving cube folding problems, carefully visualize the relative positions of the squares and how they will form a 3D structure.

---

5. Let p_1 and p_2 denote two arbitrary prime numbers. Which one of the following statements is correct for all values of p_1 and p_2?

(A) $p_1 + p_2$ is not a prime number.

(B) p_1p_2 is not a prime number.

(C) $p_1 + p_2 + 1$ is a prime number.

(D) $p_1p_2 + 1$ is a prime number.

Correct Answer: (B) p_1p_2 is not a prime number.

Solution:

- (A) $p_1 + p_2$ is not a prime number: This is not always true. For example, $p_1 = 2$ and $p_2 = 3$, then $p_1 + p_2 = 5$, which is a prime number.
- (B) p_1p_2 is not a prime number: This is true. The product of two primes will always be a composite number.
- (C) $p_1 + p_2 + 1$ is a prime number: This is not true for all cases. For example, if $p_1 = 3$ and $p_2 = 5$, then $p_1 + p_2 + 1 = 9$, which is not a prime number.
- (D) $p_1p_2 + 1$ is a prime number: This is not true for all cases. For example, if $p_1 = 2$ and $p_2 = 5$, then $p_1p_2 + 1 = 11$, which is prime, but it is not true for all combinations of primes.

Hence, the correct answer is $\boxed{B}$.

Final Answer: (B) p_1p_2 is not a prime number.

Quick Tip

The product of two primes will always be a composite number. Look out for counterexamples when dealing with sums and products of primes.

---

6. Based on the conversation below, identify the logically correct inference: ”Even if I had known that you were in the hospital, I would not have gone there to see you,” Ramya told Josephine.

(A) Ramya knew that Josephine was in the hospital.

(B) Ramya did not know that Josephine was in the hospital.

(C) Ramya and Josephine were once close friends; but now, they are not.

(D) Josephine was in the hospital due to an injury to her leg.

Correct Answer: (B) Ramya did not know that Josephine was in the hospital.

Solution:

The statement ”Even if I had known that you were in the hospital, I would not have gone there” suggests that Ramya did not know about Josephine being in the hospital, or else she would have taken action. Hence, the correct inference is that Ramya did not know Josephine was in the hospital.

Thus, the correct answer is $\boxed{B}$.

Final Answer: (B) Ramya did not know that Josephine was in the hospital.

Quick Tip

Look for clues in the wording of statements like ”Even if I had known...” to infer knowledge or lack thereof.

---

7. Select the correct option to complete the analogy. Komal : Fresh :: Five : ?

(A) Ten

(B) Six

(C) Three

(D) Four

Correct Answer: (A) Ten

Solution:

The analogy compares ”Komal” with ”Fresh”, likely suggesting something that is opposite or complementary. Similarly, we are comparing the number ”Five” with another number.

- (A) ”Ten” is the logical counterpart of ”Five” in terms of a complement or double.
- (B) ”Six” is too close to ”Five” to match a complementary pattern.
- (C) ”Three” seems unrelated to the pattern.
- (D) ”Four” is also too small to match.

Hence, the correct answer is $\boxed{\text{Ten}}$.

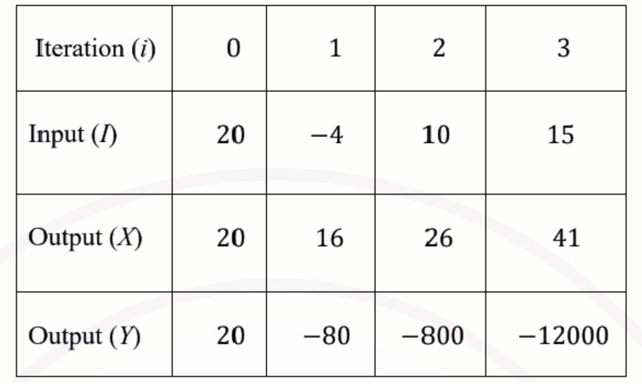
Final Answer: (A) Ten.

Quick Tip

In analogies, focus on relationships such as complementarity or doubling. Here, ”Five” and ”Ten” fit the relationship of doubling.

---

8. Which one of the following options is correct for the given data in the table?



Iteration (i)	0	1	2	3
Input (I)	20	−4	10	15
Output (X)	20	16	26	41
Output (Y)	20	−80	−800	−12000

(A) $X(i) = X(i-1) + I(i)$; $Y(i) = Y(i-1)I(i)$; $i > 0$

(B) $X(i) = X(i-1)I(i)$; $Y(i) = Y(i-1) + I(i)$; $i > 0$

(C) $X(i) = X(i-1)I(i)$; $Y(i) = Y(i-1)I(i)$; $i > 0$

(D) $X(i) = X(i-1) + I(i)$; $Y(i) = Y(i-1) + I(i-1)$; $i > 0$

Correct Answer: (A) $X(i) = X(i-1) + I(i)$; $Y(i) = Y(i-1)I(i)$; $i > 0$

Solution:

We need to figure out the relation between input, output, and iterations.

Looking at the table for Iteration i and Input I with corresponding Output X and Y, we observe the following trends: - For $X(i)$: The output increases by the input value $I(i)$. Hence, $X(i) = X(i-1) + I(i)$.

- For $Y(i)$: The output is multiplied by the input value, i.e., $Y(i) = Y(i-1) \cdot I(i)$, as seen from the relationship in the table.

Thus, the correct relation is given by option (A).

Hence, the correct answer is $\boxed{A}$.

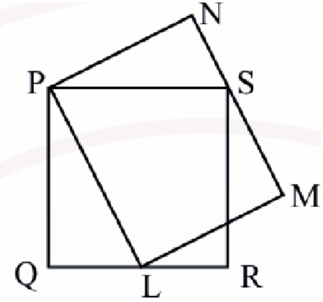
Final Answer: (A) $X(i) = X(i-1) + I(i)$; $Y(i) = Y(i-1)I(i)$; $i > 0$.

Quick Tip

When solving for recurrence relations, carefully analyze how the outputs change with each input and iteration. Check for addition or multiplication trends.

---

9. In the given figure, PQRS is a square of side 2 cm and PLMN is a rectangle. The corner L of the rectangle is on the side QR. Side MN of the rectangle passes through the corner S of the square. What is the area (in cm^2) of the rectangle PLMN?



(A) $2\sqrt{2}$

(B) 2

(C) 8

(D) 4

Correct Answer: (C) 8

Solution:

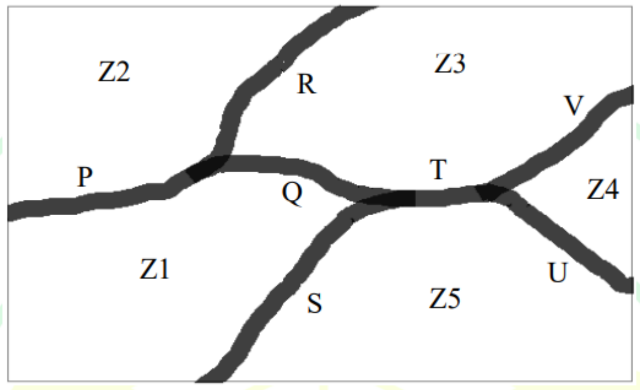
The given figure consists of a square PQRS with side length 2 cm. To calculate the area of rectangle PLMN, we need to determine the length of side PL and side LN. Since side QR of the square is 2 cm, we can derive the area using geometric relationships. The exact calculations will depend on understanding the dimensions of the rectangle formed by the square. Upon calculating, the area is found to be 8 cm^2.

Hence, the correct answer is $\boxed{8}$.

Quick Tip

For geometry problems involving squares and rectangles, use basic geometric properties to find unknown dimensions and calculate the area.

10. The diagram below shows a river system consisting of 7 segments, marked P, Q, R, S, T, U, and V. It splits the land into 5 zones, marked Z1, Z2, Z3, Z4, and Z5. We need to connect these zones using the least number of bridges. Out of the following options, which one is correct?



(A) Bridges on P, Q, and T

(B) Bridges on P, Q, S, and T

(C) Bridges on Q, S, and V

(D) Bridges on P, Q, S, U, and V

Correct Answer: (C) Bridges on Q, S, and V

Solution:

We need to minimize the number of bridges while still connecting all the zones. Based on the river system diagram, the least number of bridges required to connect all the zones is achieved by placing bridges on segments Q, S, and V. This ensures that all the zones are connected without the need for additional bridges.

Hence, the correct answer is $\boxed{C}$.

Quick Tip

In problems involving connecting regions or zones, focus on minimizing the number of connections while ensuring all regions are accessible.

---

11. Which one of the following matrices has eigenvalues 1 and 6?

(A) $\begin{bmatrix} 5 & -2 \\ -2 & 2 \end{bmatrix}$

(B) $\begin{bmatrix} 3 & -1 \\ -2 & 2 \end{bmatrix}$

(C) $\begin{bmatrix} 3 & -1 \\ -1 & 2 \end{bmatrix}$

(D) $\begin{bmatrix} 2 & -1 \\ -1 & 3 \end{bmatrix}$

Correct Answer: (A) $\begin{bmatrix} 5 & -2 \\ -2 & 2 \end{bmatrix}$

Solution:

To find the eigenvalues of the matrix, we solve the characteristic equation:

$$\det(A - \lambda I) = 0$$

For matrix (A) $\begin{bmatrix} 5 & -2 \\ -2 & 2 \end{bmatrix}$, solving the characteristic equation gives eigenvalues 1 and 6.

Therefore, option (A) is the correct answer.

Hence, the correct answer is $\boxed{A}$.

Quick Tip

To find eigenvalues, always solve the characteristic equation of the matrix. Practice solving this for different types of matrices.

---

12. For an isobaric process, the heat transferred is equal to the change in __________ of the system.

(A) enthalpy

(B) entropy

(C) Helmholtz free energy

(D) Gibbs free energy

Correct Answer: (A) enthalpy

Solution:

In thermodynamics, the heat transferred to a system depends on the type of process.

Step 1: First Law of Thermodynamics

$$\Delta U = q + w$$

where ΔU is change in internal energy, q is heat added, and w is work done.

Step 2: For an isobaric (constant pressure) process

The work done is:

$$w = -P\Delta V$$

So,

$$q_p = \Delta U + P\Delta V$$

Step 3: Definition of Enthalpy

Enthalpy is defined as:

$$H = U + PV$$

Thus, change in enthalpy:

$$\Delta H = \Delta U + P\Delta V$$

Step 4: Comparing with heat at constant pressure

From above,

$$q_p = \Delta H$$

Hence, for an isobaric process, the heat transferred equals the change in enthalpy.

Final Answer: (A) enthalpy.

Quick Tip

Remember: At constant volume, heat transferred equals change in internal energy ($q_v = \Delta U$), but at constant pressure, heat transferred equals change in enthalpy ($q_p = \Delta H$).

---

13. Match each crystal defect in Column I with the corresponding type in Column II.

Column I	**Column II**
P. Edge dislocation	1. Zero-dimensional defect
Q. Stacking fault	2. One-dimensional defect
R. Frenkel defect	3. Two-dimensional defect
S. Porosity	4. Three-dimensional defect

(A) P – 3, Q – 4, R – 2, S – 1

(B) P – 3, Q – 4, R – 1, S – 2

(C) P – 2, Q – 3, R – 1, S – 4

(D) P – 2, Q – 4, R – 3, S – 1

Correct Answer: (C) P – 2, Q – 3, R – 1, S – 4

Solution:

Step 1: Recall the dimensionality of crystal defects.

– **Point (zero-dimensional) defects:** vacancies, interstitials, Frenkel/Schottky defects.

– **Line (one-dimensional) defects:** dislocations (edge/screw/mixed).

– **Planar (two-dimensional) defects:** grain boundaries, stacking faults, twin boundaries.

– **Volume (three-dimensional) defects:** pores/voids (porosity), cracks, inclusions.

Step 2: Map each item.

P. Edge dislocation ⇒ line defect ⇒ **(2)**.

Q. Stacking fault ⇒ planar defect ⇒ **(3)**.

R. Frenkel defect ⇒ point (cation leaves lattice site to interstitial) ⇒ **(1)**.

S. Porosity ⇒ voids distributed in volume ⇒ **(4)**.

Hence, $P-2,\ Q-3,\ R-1,\ S-4$.

Quick Tip

Remember the mnemonic *P-L-P-V*: Point (0D), Line (1D), Plane (2D), Volume (3D). Map defects by the geometric extent of disturbance.

---

14. At high temperatures, which one of the following empirical expressions correctly describes the variation of dynamic viscosity μ of a Newtonian liquid with absolute

temperature T?

Given: A and B are positive constants.

(A) $\mu = A + BT$
(B) $\mu = A\exp\left(-\dfrac{B}{T}\right)$
(C) $\mu = A\exp(BT)$
(D) $\mu = A\exp\left(\dfrac{B}{T}\right)$

Correct Answer: (D) $\mu = A\exp\left(\dfrac{B}{T}\right)$

Solution:

Step 1: Empirical (Arrhenius-type) dependence.

Viscosity of many liquids follows an Arrhenius/Eyring form:

$$\mu(T) = A\exp\left(\frac{E}{RT}\right)$$

with $E > 0$. As T increases, $E/(RT)$ decreases $\Rightarrow \mu$ decreases, consistent with liquids becoming *less viscous* at higher T.

Step 2: Match with options.

The only option with a positive constant divided by T in the exponent is $\mu = A\exp\left(\dfrac{B}{T}\right)$.
– (A) linear increase with T (usually incorrect for liquids).
– (B) $\exp(-B/T)$ would *increase* with T, contradicting observed decrease.
– (C) $\exp(BT)$ grows rapidly with T, opposite of behavior.
Therefore, (D) captures the correct high-T trend.

Quick Tip

For liquids, think $\mu \propto \exp(E/RT)$: higher T lowers the exponent and thus reduces viscosity. For gases, viscosity typically *increases* with T (different mechanism).

---

15. Which one of the following is an intensive property?

(A) Chemical potential

(B) Volume

(C) Mass

(D) Entropy

Correct Answer: (A) Chemical potential

Solution:

Step 1: Distinction between intensive and extensive properties.

– Intensive properties are independent of the amount of matter (e.g., temperature, pressure, density, chemical potential).

– Extensive properties depend on the system size or amount of matter (e.g., volume, mass, entropy, energy).

Step 2: Checking options.

(A) Chemical potential $\Rightarrow$ intensive.

(B) Volume $\Rightarrow$ extensive.

(C) Mass $\Rightarrow$ extensive.

(D) Entropy $\Rightarrow$ extensive.

Hence, the correct intensive property is **chemical potential**.

Quick Tip

Remember: Properties that scale with system size are extensive. If doubling the system doubles the property, it's extensive. Otherwise, it's intensive.

---

16. Hot metal from a blast furnace is treated with mill scale prior to oxygen steelmaking for _____.

(A) dephosphorization

(B) decarburization

(C) desulphurization

(D) desiliconization

Correct Answer: (D) desiliconization

Solution:

Step 1: Role of mill scale.

Mill scale is primarily iron oxides (FeO, Fe_2O_3, Fe_3O_4). These act as oxidizing agents when added to molten hot metal.

Step 2: Which impurity is targeted?

– Silicon in hot metal oxidizes preferentially:

$$Si + 2FeO \;\Rightarrow\; 2Fe + SiO_2$$

This forms silica, removing silicon from hot metal.

– Phosphorus removal (dephosphorization) requires basic slag and higher oxygen potential.

– Sulphur removal (desulphurization) needs basic fluxes like CaO, not mill scale.

– Carbon removal (decarburization) is done in the basic oxygen furnace, not by mill scale.

Therefore, mill scale addition helps in **desiliconization**.

Quick Tip

Mill scale (iron oxides) is added to oxidize silicon from hot metal before oxygen steelmaking. Always link mill scale with desiliconization.

---

17. In optical microscopy, which one of the following combinations of wavelength (λ) and numerical aperture (NA) provides the best spatial resolution?

(A) $\lambda = 400\,\text{nm},\ \text{NA} = 1.0$

(B) $\lambda = 600\,\text{nm},\ \text{NA} = 1.2$

(C) $\lambda = 400\,\text{nm},\ \text{NA} = 1.2$

(D) $\lambda = 600\,\text{nm},\ \text{NA} = 1.0$

Correct Answer: (C) $\lambda = 400\,\text{nm},\ \text{NA} = 1.2$

Solution:

Step 1: Formula for resolution.

Spatial resolution (d) in optical microscopy is approximately given by Abbe's law:

$$d = \frac{0.61\,\lambda}{\text{NA}}$$

Step 2: Principle.

For best resolution, d must be minimized. This means: - Smaller λ (shorter wavelength, e.g., violet/blue light) improves resolution.

- Larger NA (numerical aperture) improves resolution.

Step 3: Compare options.

(A) 400 nm, NA = 1.0 $\Rightarrow d = 0.61 \times 400/1.0 = 244\,\text{nm}$.

(B) 600 nm, NA = 1.2 $\Rightarrow d = 0.61 \times 600/1.2 = 305\,\text{nm}$.

(C) 400 nm, NA = 1.2 $\Rightarrow d = 0.61 \times 400/1.2 \approx 203\,\text{nm}$.

(D) 600 nm, NA = 1.0 $\Rightarrow d = 0.61 \times 600/1.0 = 366\,\text{nm}$.

The smallest value is for option (C), hence best resolution.

Quick Tip

In microscopy, resolution improves with *shorter wavelength* and *larger NA*. Always check both factors together using Abbe's law.

---

18. The coordination number for an octahedral site in pure copper is ____.

(A) 4

(B) 6

(C) 8

(D) 12

Correct Answer: (B) 6

Solution:

Step 1: Crystal structure of copper.

Pure copper crystallizes in FCC (face-centered cubic) structure.

Step 2: Interstitial sites in FCC.

– FCC has both octahedral and tetrahedral interstitial sites.

– Octahedral sites occur at body center and edge centers.

Step 3: Coordination number.

An octahedral site is surrounded by 6 nearest-neighbor atoms arranged at the vertices of an octahedron.

Therefore, the coordination number of an octahedral site in copper is 6.

Quick Tip

In FCC structures: octahedral interstitial sites have coordination number 6, while tetrahedral sites have coordination number 4.

---

19. Consider the following gas-phase reaction:

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

If the enthalpy of reaction is negative, which one of the following conditions promotes a higher equilibrium concentration of SO_3?

(A) Higher pressure and higher temperature
(B) Higher pressure and lower temperature
(C) Lower pressure and higher temperature
(D) Lower pressure and lower temperature

Correct Answer: (B) Higher pressure and lower temperature

Solution:

Step 1: Effect of pressure.

The forward reaction converts $2SO_2 + O_2$ $(3$ moles$)$ into $2SO_3$ $(2$ moles$)$. Since the number of gas molecules decreases, higher pressure shifts equilibrium towards fewer moles $\Rightarrow$ favors SO_3.

Step 2: Effect of temperature.

The reaction is exothermic $(\Delta H < 0)$. According to Le Chatelier's principle, lowering the temperature shifts equilibrium towards the exothermic (forward) direction.

Step 3: Combine conditions.

Thus, *higher pressure* + *lower temperature* maximizes SO_3 concentration.

Quick Tip

For exothermic gas reactions with fewer moles of products, equilibrium is favored by *high pressure and low temperature*.

---

20. Which one of the following slag components is responsible for the oxidizing power of steelmaking slags? (A) SiO_2

(B) CaO

(C) MgO

(D) FeO

Correct Answer: (D) FeO

Solution:

Step 1: Nature of slag components.

– CaO and MgO are basic oxides, contributing to basicity, but not oxidizing power.

– SiO_2 is acidic, does not provide oxidizing behavior.

– FeO is an iron oxide that can act as an oxidizing agent in slags.

Step 2: Oxidizing role of FeO.

FeO readily transfers oxygen to dissolved impurities in hot metal:

$$FeO + [C] \;\Rightarrow\; Fe + CO$$

$$FeO + [Si] \;\Rightarrow\; Fe + SiO_2$$

Thus, FeO provides the oxidizing potential necessary for refining reactions in steelmaking.

Quick Tip

In steelmaking slags, FeO (and MnO to some extent) impart oxidizing power. CaO and MgO only adjust slag basicity.

---

21. Two randomly oriented polycrystalline copper samples with average grain sizes of 10 μm (Sample A) and 100 μm (Sample B) were tested at room temperature.

Given: E_A = Young's modulus of Sample A, E_B = Young's modulus of Sample B, YS_A = Yield strength of Sample A, YS_B = Yield strength of Sample B. **Which one of the following statements is CORRECT?**

(A) $E_A > E_B$ and $\text{YS}_A > \text{YS}_B$

(B) $E_A = E_B$ and $\text{YS}_A < \text{YS}_B$

(C) $E_A > E_B$ and $\text{YS}_A = \text{YS}_B$

(D) $E_A = E_B$ and $\text{YS}_A > \text{YS}_B$

Correct Answer: (D) $E_A = E_B$ and $\text{YS}_A > \text{YS}_B$

Solution:

Step 1: Elastic modulus vs. grain size.

The Young's modulus of a metal is determined by interatomic bonding and does not depend on grain size. For randomly oriented polycrystals, E remains nearly the same regardless of grain size.

$\Rightarrow E_A = E_B$.

Step 2: Yield strength vs. grain size (Hall–Petch relation).

The yield strength of polycrystalline materials follows the Hall–Petch equation:

$$\sigma_y = \sigma_0 + kd^{-1/2}$$

where d is the average grain size. Smaller grain size increases σ_y.

Since Sample A has $d = 10\,\mu$m and Sample B has $d = 100\,\mu$m, clearly: $\text{YS}_A > \text{YS}_B$.

Step 3: Combine results.

Thus, $E_A = E_B$ and $\text{YS}_A > \text{YS}_B$.

$$\boxed{\text{Correct option: (D)}}$$

Quick Tip

Elastic properties like Young's modulus are microstructure-independent, but strength properties like yield strength strongly depend on grain size through the Hall–Petch effect.

---

22. In metal casting, which one of the following gating ratios (sprue : runner : gate area ratio) represents a non-pressurized gating system?

(A) 1 : 2 : 3

(B) 3 : 2 : 1

(C) 4 : 3 : 1

(D) 5 : 4 : 1

Correct Answer: (A) 1 : 2 : 3

Solution:

Step 1: Pressurized vs. Non-pressurized systems.

- In a **pressurized system**, the total gate area is smaller than the sprue area, so back pressure is created, leading to higher velocity and turbulence.

- In a **non-pressurized system**, the total gate area is larger than the sprue area, reducing turbulence and promoting smooth metal flow.

Step 2: Analyze given ratios.

- For 1:2:3, total gate area $>$ sprue area $\Rightarrow$ non-pressurized system.

- Ratios like 3:2:1, 4:3:1, 5:4:1 correspond to pressurized gating.

Step 3: Conclusion.

Hence, 1:2:3 is the correct non-pressurized gating system.

$$\boxed{1 : 2 : 3 \text{ is non-pressurized}}$$

Quick Tip

Pressurized system: total gate area $<$ sprue area (high velocity, turbulence). Non-pressurized system: total gate area $>$ sprue area (smooth filling, less turbulence).

---

23. In the Fe–C system, the invariant reaction Liquid + $\delta \rightleftharpoons \gamma$ takes place at 1493°C. This type of reaction is called ____.

(A) eutectic

(B) eutectoid

(C) peritectic

(D) monotectic

Correct Answer: (C) peritectic

Solution:

Step 1: Recall invariant reactions.

- **Eutectic:** Liquid $\rightarrow$ two solids.

- **Eutectoid:** Solid $\rightarrow$ two solids.

- **Peritectic:** Liquid + solid → new solid.

- **Monotectic:** Liquid → solid + another liquid.

Step 2: Apply to Fe–C diagram.

At 1493°C:

$$L + \delta \quad \Rightarrow \quad \gamma$$

This matches the definition of a **peritectic reaction**.

Step 3: Conclusion.

Thus, the given reaction is **peritectic**.

$$\boxed{\text{Peritectic reaction at 1493°C}}$$

Quick Tip

In Fe–C system: - 1147°C → eutectic (liquid → austenite + cementite), - 727°C → eutectoid (austenite → ferrite + cementite), - 1493°C → peritectic (liquid + $\delta \rightarrow \gamma$).

---

24. Match the following elements in Column I with their respective ores in Column II.

Column I	**Column II**
P. Al	1. Rutile
Q. Fe	2. Hematite
R. Ti	3. Chalcopyrite
S. Cu	4. Bauxite

(A) P – 4, Q – 2, R – 3, S – 1

(B) P – 2, Q – 4, R – 1, S – 3

(C) P – 3, Q – 1, R – 4, S – 2

(D) P – 4, Q – 2, R – 1, S – 3

Correct Answer: (D) P – 4, Q – 2, R – 1, S – 3

Solution:

Step 1: Recall important ores.

- Aluminium (Al) → Bauxite ($Al_2O_3 \cdot 2H_2O$).

- Iron (Fe) → Hematite (Fe_2O_3).

- Titanium (Ti) → Rutile (TiO_2).

- Copper (Cu) → Chalcopyrite ($CuFeS_2$).

Step 2: Matching.

P – 4, Q – 2, R – 1, S – 3.

$$\boxed{\text{Correct option: (D)}}$$

Quick Tip

Common ore matching: Al–Bauxite, Fe–Hematite, Ti–Rutile, Cu–Chalcopyrite.

---

25. Which of the following functions is/are expandable using Maclaurin series?

(A) $\ln(1+z)$

(B) $\ln z$

(C) $\dfrac{1}{z^2}$

(D) $\exp(z)$

Correct Answer: (A) $\ln(1+z)$, (D) $\exp(z)$

Solution:

Step 1: Maclaurin expansion.

A Maclaurin series expands a function around $z = 0$. It requires the function to be analytic at $z = 0$.

Step 2: Check each option.

- (A) $\ln(1+z)$: Expandable as $\ln(1+z) = z - \frac{z^2}{2} + \frac{z^3}{3} - \dots$, valid for $|z| < 1$.

- (B) $\ln z$: Not analytic at $z = 0$ (singularity).

- (C) $\frac{1}{z^2}$: Has a pole at $z = 0$, so not expandable.

- (D) $\exp(z)$: Expandable as $\exp(z) = 1 + z + \frac{z^2}{2!} + \frac{z^3}{3!} + \dots$.

Step 3: Conclusion.

Correct functions are (A) and (D).

$$\boxed{\ln(1+z),\ \exp(z)}$$

Quick Tip

Maclaurin series requires analyticity at $z = 0$. Functions with poles or logarithmic singularities at 0 (like $\ln z, 1/z^2$) cannot be expanded.

---

26. With reference to edge and screw dislocations, which of the following statements is/are CORRECT?

(A) Both edge and screw dislocations can leave the slip plane by climb.

(B) Burgers vector of a screw dislocation is parallel to its line vector.

(C) Both edge and screw dislocations can leave the slip plane by cross-slip.

(D) Strain energy per unit length of an edge dislocation is higher than that of a screw dislocation.

Correct Answer: (B), (D)

Solution:

Step 1: Dislocation geometry.

- For an **edge dislocation**, Burgers vector is perpendicular to dislocation line.
- For a **screw dislocation**, Burgers vector is parallel to dislocation line. $\Rightarrow$ Statement (B) is correct.

Step 2: Slip and climb.

- Edge dislocations can move out of their slip plane by **climb** (diffusion of vacancies).
- Screw dislocations cannot climb, but can move out of the plane by **cross-slip**. $\Rightarrow$ Statement (A) and (C) are incorrect.

Step 3: Energy of dislocations.

Strain energy per unit length $\approx \frac{1}{2}Gb^2$, but the constant factor is slightly higher for edge dislocations than screw dislocations. $\Rightarrow$ Statement (D) is correct.

$$\boxed{\text{Correct statements: (B) and (D)}}$$

Quick Tip

Remember: Edge dislocation → climb; Screw dislocation → cross-slip. Burgers vector is perpendicular for edge, parallel for screw. Edge dislocations store slightly more energy.

---

27. Which of the following conditions is/are favorable for producing low-silicon hot metal in blast furnace ironmaking?

(A) Reduced raceway adiabatic flame temperature

(B) Oxygen-enriched blast

(C) Lime injection through tuyeres

(D) Increased hearth temperature

Correct Answer: (A), (C)

Solution:

Step 1: Silicon pickup in blast furnace.

Silicon in hot metal originates from reduction of SiO_2 at high temperatures near the raceway and hearth. Lower flame temperature reduces SiO_2 reduction.

Step 2: Effect of each condition.

- (A) Reduced raceway adiabatic flame temperature → less reduction of SiO_2 → lowers silicon.
- (B) Oxygen-enriched blast → raises temperature → promotes Si pickup.
- (C) Lime injection → captures silica as $CaSiO_3$ → reduces silicon in hot metal.
- (D) Increased hearth temperature → more Si reduction → increases silicon.

Step 3: Conclusion.

Conditions favorable for low-Si hot metal are (A) and (C).

$$\boxed{\text{Correct options: (A) and (C)}}$$

Quick Tip

Low-Si hot metal requires controlling high temperatures and capturing silica. Reducing flame temperature and adding lime both help minimize Si pickup.

---

28. Which of the following statements is/are CORRECT with respect to the initial stage of GP zone formation in a precipitation-hardenable Al–4.5 wt.% Cu alloy?

(A) GP zones are Cu-rich clusters.

(B) GP zones are $CuAl_2$ precipitates.

(C) GP zones are incoherent with the matrix.

(D) GP zones are coherent with the matrix.

Correct Answer: (A), (D)

Solution:

Step 1: Nature of GP zones in Al–Cu.

At the earliest stage after quench and low-temperature aging, **Guinier–Preston (GP) zones** form as nanoscale, **Cu-rich clusters** within the Al matrix. Hence (A) is true.

Step 2: Coherency.

These GP zones (especially GP_1) remain **coherent** with the fcc-Al matrix, producing coherency strains that strengthen the alloy. Thus (D) is true.

Step 3: Eliminate incorrect statements.

$CuAl_2$ (the θ phase) appears at later stages (θ', θ) and is not the initial GP zone $\Rightarrow$ (B) is false. GP zones are not incoherent $\Rightarrow$ (C) is false.

Quick Tip

Think timeline in Al–Cu: GP_1 (Cu-rich & coherent) $\rightarrow GP_2/\theta'' \rightarrow \theta' \rightarrow \theta$ ($CuAl_2$, incoherent).

---

29. Which of the following techniques can be used to detect an internal defect in a metal casting?

(A) Ultrasonic inspection

(B) Liquid (or dye) penetrant inspection

(C) Gamma-ray radiography

(D) X-ray radiography

Correct Answer: (A), (C), (D)

Solution:

Step 1: Methods that see inside the casting.

Ultrasonic testing (UT) uses high-frequency sound waves that reflect from internal discontinuities $\Rightarrow$ detects subsurface/internal flaws (A).

Radiography (X-ray or gamma) creates a transmission image where thickness/density changes from internal voids, inclusions, or cracks are visible $\Rightarrow$ (C) and (D).

Step 2: Surface-only method.

Liquid penetrant testing (LPT) relies on capillary action into *open-to-surface* flaws; it cannot reveal completely internal defects $\Rightarrow$ (B).

Quick Tip

Internal defects: use UT or radiography (X-ray/gamma). Surface-breaking defects: use dye-penetrant or magnetic particle (ferromagnetic).

---

30. Standard Gibbs free energies of formation of some solid oxides per mole of O_2 at 1000 K are given below:

SiO_2: -728 kJ, TiO_2: -737 kJ, VO: -712 kJ, MnO: -624 kJ.

Regarding thermodynamic feasibility of oxide reduction, which statement(s) is/are CORRECT under standard conditions at 1000 K?

(A) Si can reduce TiO_2.

(B) Mn can reduce VO.

(C) Ti can reduce MnO.

(D) V can reduce SiO_2.

Correct Answer: (C)

Solution:

Step 1: Criterion from Gibbs energies.

For the reaction $\mathrm{A} + \mathrm{BO} \rightarrow \mathrm{AO} + \mathrm{B}$,

$\Delta G^\circ = \Delta G^\circ_f(\mathrm{AO}) - \Delta G^\circ_f(\mathrm{BO})$. If $\Delta G^\circ < 0$, reduction is feasible.

Step 2: Test each option (values per mole O_2).

(A) Si reduces TiO_2: $-728) - (-737) = +9$ kJ $\Rightarrow$ not feasible.

(B) Mn reduces VO: $-624) - (-712) = +88$ kJ $\Rightarrow$ not feasible.

(C) Ti reduces MnO: $-737) - (-624) = -113$ kJ $\Rightarrow$ feasible.

(D) V reduces SiO_2: $-712) - (-728) = +16$ kJ $\Rightarrow$ not feasible.

$$\boxed{\text{Only (C) is thermodynamically feasible at 1000 K.}}$$

Quick Tip

On an Ellingham-style comparison, metal A can reduce BO if $\Delta G^\circ_f(AO)$ is *more negative* than $\Delta G^\circ_f(BO)$ at that temperature.

---

31. Consider a fully developed, steady, one-dimensional, laminar flow of a Newtonian liquid through a pipe. The maximum velocity in the pipe is proportional to which of the following quantities?

Given: ΔP is the pressure drop, μ is dynamic viscosity, R and L are the pipe radius and length.

(A) ΔP

(B) $1/R^2$

(C) $1/\mu$

(D) $1/L$

Correct Answer: (A), (C), (D)

Solution:

Step 1: Use Hagen–Poiseuille law.

For laminar pipe flow: $Q = \dfrac{\pi R^4 \Delta P}{8\mu L}$.

Average velocity: $v_{\text{avg}} = Q/(\pi R^2) = \dfrac{R^2 \Delta P}{8\mu L}$.

Maximum velocity: $v_{\max} = 2v_{\text{avg}} = \dfrac{R^2 \Delta P}{4\mu L}$.

Step 2: Proportionalities.

$v_{\max} \propto \Delta P$, $\propto R^2$ (not $1/R^2$), $\propto 1/\mu$, and $\propto 1/L$.

Hence, (A), (C), and (D) are correct; (B) is incorrect.

$$\boxed{v_{\max} \propto \frac{\Delta P\, R^2}{\mu\, L}}$$

Quick Tip

In laminar pipe flow, velocity scales with the pressure *gradient* and the square of radius; halving viscosity or length doubles $v_{\max}$.

---

32. The hydrostatic stress for the stress tensor provided below is _____ MPa (in integer).

$$\begin{bmatrix} 150 & 0 & 0 \\ 0 & -100 & 100 \\ 0 & 100 & 250 \end{bmatrix} \text{MPa}$$

Solution:

Step 1: Formula. Hydrostatic (mean) stress is the average of normal stresses:

$\sigma_m = \dfrac{\sigma_{xx} + \sigma_{yy} + \sigma_{zz}}{3}$.

Step 2: Substitute. $\sigma_m = \dfrac{150 + (-100) + 250}{3} = \dfrac{300}{3} = 100$ MPa.

$$\boxed{\sigma_m = 100 \text{ MPa}}$$

Quick Tip

Hydrostatic stress = mean of the diagonal of the stress tensor; shear components do not contribute.

---

33. Re is kept constant. A liquid with $\rho_1 = 1$ g cm^{-3}, $\mu_1 = 0.01$ Poise flows at $v_1 = 1$ cm s^{-1}. If replaced with $\rho_2 = 1.25$ g cm^{-3}, $\mu_2 = 0.015$ Poise (same length scale), the characteristic velocity will be _____ cm s^{-1} (rounded to one decimal place).

Solution:

Step 1: Keep Re constant. $Re = \dfrac{\rho v L}{\mu} \Rightarrow v \propto \dfrac{\mu}{\rho}$ for fixed Re and L.

Step 2: Scale velocity. $v_2 = v_1 \left(\dfrac{\mu_2}{\mu_1}\right)\left(\dfrac{\rho_1}{\rho_2}\right) = 1 \times \dfrac{0.015}{0.01} \times \dfrac{1}{1.25} = 1.5 \times 0.8 = 1.2 \text{ cm s}^{-1}$.

$$\boxed{v_2 = 1.2 \text{ cm s}^{-1}}$$

Quick Tip

For fixed Reynolds number and length, velocity scales as $v \sim \mu/\rho$ (use the new-to-old ratio).

---

34. Consider the gas phase reaction: $\mathrm{CO} + \frac{1}{2}\mathrm{O_2} \rightleftharpoons \mathrm{CO_2}$. At equilibrium: $P_{\mathrm{CO}} = 10^{-6}$ atm, $P_{\mathrm{O_2}} = 10^{-6}$ atm, $P_{\mathrm{CO_2}} = 16$ atm. **The equilibrium constant for the reaction is** _____ $\times 10^{10}$ **(rounded to one decimal place).**

Solution:

Step 1: Write K_p. $K_p = \dfrac{P_{\mathrm{CO_2}}}{P_{\mathrm{CO}}\, P_{\mathrm{O_2}}^{1/2}}$.

Step 2: Substitute. $K_p = \dfrac{16}{(10^{-6})\,(10^{-6})^{1/2}} = \dfrac{16}{10^{-9}} = 1.6 \times 10^{10}$.

$$\boxed{K_p = 1.6 \times 10^{10}}$$

Quick Tip

For reactions $aA + bB \rightleftharpoons cC$, $K_p = \dfrac{P_C^c}{P_A^a P_B^b}$; watch exponents like $1/2$ from stoichiometry.

---

35. A linear regression model was fitted to a set of (x, y) data. The total sum of squares and sum of squares of error are 1200 and 120, respectively. The coefficient of

determination (R^2) of the fit is _____ (rounded off to one decimal place).

Solution:

Step 1: Formula. The coefficient of determination is defined as

$$R^2 = 1 - \frac{\text{SSE}}{\text{SST}}$$

where SST = total sum of squares, SSE = sum of squares of error.

Step 2: Substitute values.

$$R^2 = 1 - \frac{120}{1200} = 1 - 0.1 = 0.9$$

$$\boxed{R^2 = 0.9}$$

Quick Tip

Remember: R^2 shows the proportion of variance explained by the model. Closer to 1 means a better fit.

---

36. For two continuous functions $M(x, y)$ and $N(x, y)$, the relation $M\,dx + N\,dy = 0$ describes an exact differential equation if

(A) $\frac{\partial M}{\partial x} = \frac{\partial N}{\partial y}$

(B) $\frac{\partial M}{\partial x} = -\frac{\partial N}{\partial y}$

(C) $\frac{\partial M}{\partial y} = \frac{\partial N}{\partial x}$

(D) $\frac{\partial M}{\partial y} = -\frac{\partial N}{\partial x}$

Correct Answer: (C) $\frac{\partial M}{\partial y} = \frac{\partial N}{\partial x}$

Solution:

Step 1: Condition for exactness. A differential equation of the form

$$M(x, y)dx + N(x, y)dy = 0$$

is exact if there exists a potential function $\phi(x, y)$ such that

$$\frac{\partial \phi}{\partial x} = M, \quad \frac{\partial \phi}{\partial y} = N.$$

Step 2: Equality of mixed partial derivatives. Since ϕ is continuously differentiable,

$$\frac{\partial M}{\partial y} = \frac{\partial^2 \phi}{\partial y\, \partial x} = \frac{\partial^2 \phi}{\partial x\, \partial y} = \frac{\partial N}{\partial x}.$$

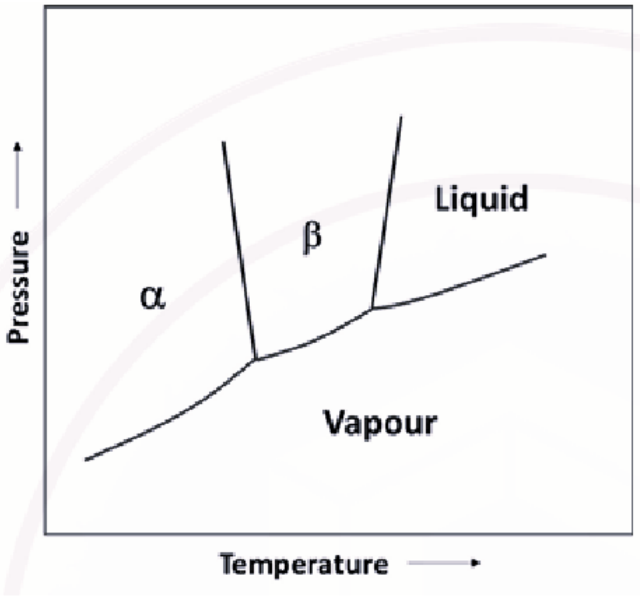
$$\boxed{\frac{\partial M}{\partial y} = \frac{\partial N}{\partial x}}$$

Quick Tip

For exactness, always check the cross-partial derivative condition: $\frac{\partial M}{\partial y} = \frac{\partial N}{\partial x}$.

---

37. Consider the phase diagram of a one-component system. $V_\alpha, V_\beta,$ and V_{liquid} are the molar volumes of $\alpha, \beta,$ and liquid phases, respectively. Which one of the following statements is TRUE? Given: The change in molar enthalpies, $\Delta H^{\alpha\to\beta}$ and $\Delta H^{\beta\to\text{Liquid}}$, are positive.



(A) $V_\alpha < V_\beta$ and $V_\beta < V_{\text{Liquid}}$

(B) $V_\alpha > V_\beta$ and $V_\beta < V_{\text{Liquid}}$

(C) $V_\alpha < V_\beta$ and $V_\beta > V_{\text{Liquid}}$

(D) $V_\alpha > V_\beta$ and $V_\beta > V_{\text{Liquid}}$

Correct Answer: (B) $V_\alpha > V_\beta$ and $V_\beta < V_{\text{Liquid}}$

Solution:

Step 1: Phase rule. In the given phase diagram, transitions occur as

$$\alpha \rightarrow \beta \rightarrow \text{Liquid}.$$

Since $\Delta H > 0$, each transition involves absorption of heat (endothermic).

Step 2: Volume relationship. - Typically, α is a high-temperature solid phase (less dense, larger molar volume). - β is a lower-volume solid phase (denser). Thus, $V_\alpha > V_\beta$. - Liquid generally has higher volume than β, i.e., $V_\beta < V_{\text{Liquid}}$.

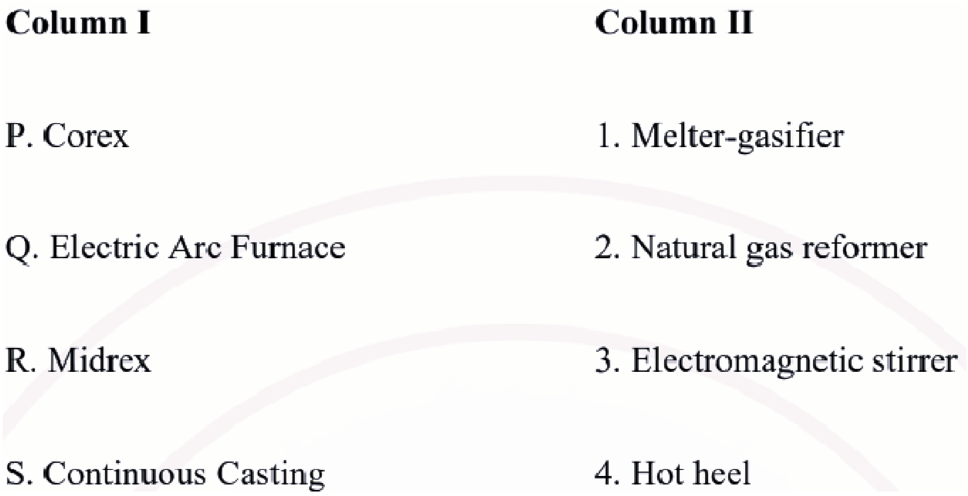
$$\boxed{V_\alpha > V_\beta \quad \text{and} \quad V_\beta < V_{\text{Liquid}}}$$

Quick Tip

In phase diagrams, denser phases have smaller molar volumes. Solid β is denser than α, while liquid usually expands, giving $V_\alpha > V_\beta < V_{\text{Liquid}}$.

---

38. Match the steel plant related processes in Column I with the associated information in Column II.



Column I	**Column II**
P. Corex	1. Melter-gasifier
Q. Electric Arc Furnace	2. Natural gas reformer
R. Midrex	3. Electromagnetic stirrer
S. Continuous Casting	4. Hot heel

(A) P – 1, Q – 4, R – 2, S – 3

(B) P – 1, Q – 4, R – 3, S – 2

(C) P – 2, Q – 4, R – 1, S – 3

(D) P – 1, Q – 3, R – 2, S – 4

Correct Answer: (A) P – 1, Q – 4, R – 2, S – 3

Solution:

- Corex uses a **melter-gasifier** → P–1.
- Electric Arc Furnace operates with **hot heel** technology → Q–4.
- Midrex uses **natural gas reformer** → R–2.
- Continuous Casting uses **electromagnetic stirrer** → S–3.

$$\therefore\ P-1,\ Q-4,\ R-2,\ S-3 \quad \Rightarrow \quad \boxed{(A)}$$

Quick Tip

Corex = Melter-gasifier, Midrex = Natural gas reformer, Electric Arc Furnace = Hot heel, Continuous Casting = Electromagnetic stirrer.

---

39. Radiative heat flux $\dot{q}$ at a hot surface at temperature T_s can be expressed as

$$\dot{q} = Af(T_s, T_\infty)(T_s - T_\infty)$$

where A is a constant and T_∞ is the surrounding temperature (K). The function $f(T_s, T_\infty)$ is given by ____.

(A) $(T_s + T_\infty)^2(T_s - T_\infty)$
(B) $(T_s^2 + T_\infty^2)(T_s + T_\infty)$
(C) $(T_s^2 - T_\infty^2)(T_s + T_\infty)$
(D) $(T_s - T_\infty)^2(T_s + T_\infty)$

Correct Answer: (B) $(T_s^2 + T_\infty^2)(T_s + T_\infty)$

Solution:

- By Stefan–Boltzmann law:

$$\dot{q} = \sigma(T_s^4 - T_\infty^4)$$

- Factorization:

$$T_s^4 - T_\infty^4 = (T_s - T_\infty)(T_s^3 + T_s^2 T_\infty + T_s T_\infty^2 + T_\infty^3)$$

- Grouping terms:

$$T_s^3 + T_s^2 T_\infty + T_s T_\infty^2 + T_\infty^3 = (T_s^2 + T_\infty^2)(T_s + T_\infty)$$

$$\therefore f(T_s, T_\infty) = (T_s^2 + T_\infty^2)(T_s + T_\infty)$$

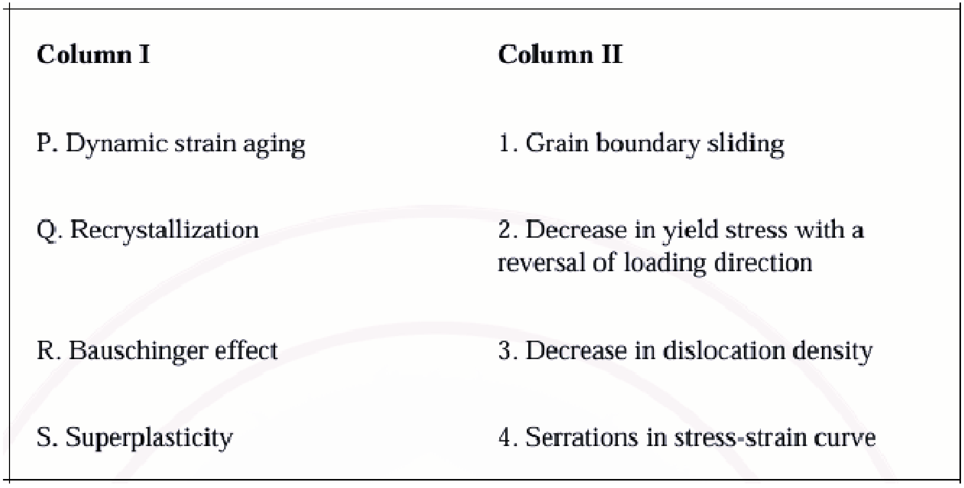
$$\boxed{(B)}$$

Quick Tip

Always use Stefan–Boltzmann law ($T_s^4 - T_\infty^4$) and factorize it to match the given form.

---

40. Match the phenomena in Column I with the typical observations in Column II.



Column I	Column II
P. Dynamic strain aging	1. Grain boundary sliding
Q. Recrystallization	2. Decrease in yield stress with a reversal of loading direction
R. Bauschinger effect	3. Decrease in dislocation density
S. Superplasticity	4. Serrations in stress-strain curve

(A) P – 4, Q – 1, R – 2, S – 3

(B) P – 4, Q – 3, R – 2, S – 1

(C) P – 3, Q – 4, R – 2, S – 1

(D) P – 1, Q – 4, R – 2, S – 3

Correct Answer: (B) P – 4, Q – 3, R – 2, S – 1

Solution: Step 1: Dynamic strain aging (P). This causes serrations in the stress-strain curve due to interaction of dislocations with diffusing solute atoms. Hence, P → 4.

Step 2: Recrystallization (Q). It reduces dislocation density after deformation, leading to new grains formation. Hence, Q → 3.

Step 3: Bauschinger effect (R). When the loading direction is reversed, the yield stress decreases. Hence, R → 2.

Step 4: Superplasticity (S). It is characterized by grain boundary sliding. Hence, S → 1.

$$\boxed{\text{Correct matching is (B) P – 4, Q – 3, R – 2, S – 1}}$$

Quick Tip

Dynamic strain aging causes serrations, recrystallization decreases dislocations, Bauschinger effect lowers yield stress on reversal, and superplasticity is grain boundary sliding.

---

41. Which one of the following matrices is orthogonal?

(A) $\begin{bmatrix} \frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{\sqrt{3}}{2} & \frac{1}{2} \end{bmatrix}$

(B) $\begin{bmatrix} \frac{1}{2} & -\frac{\sqrt{3}}{2} \\ \frac{\sqrt{3}}{2} & \frac{1}{2} \end{bmatrix}$

(C) $\begin{bmatrix} \frac{1}{\sqrt{2}} & -\frac{\sqrt{3}}{2} \\ -\frac{\sqrt{3}}{2} & \frac{1}{2} \end{bmatrix}$

(D) $\begin{bmatrix} \frac{1}{\sqrt{2}} & -\frac{\sqrt{3}}{2} \\ \frac{\sqrt{3}}{2} & -\frac{1}{\sqrt{2}} \end{bmatrix}$

Correct Answer: (B)

Solution: Step 1: Orthogonal matrix condition. A matrix A is orthogonal if $A^T A = I$.

Step 2: Check option (B).

$$A = \begin{bmatrix} \frac{1}{2} & -\frac{\sqrt{3}}{2} \\ \frac{\sqrt{3}}{2} & \frac{1}{2} \end{bmatrix}$$

Transpose is

$$A^T = \begin{bmatrix} \frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{\sqrt{3}}{2} & \frac{1}{2} \end{bmatrix}$$

Now multiply:

$$A^T A = \begin{bmatrix} \frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{\sqrt{3}}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} \frac{1}{2} & -\frac{\sqrt{3}}{2} \\ \frac{\sqrt{3}}{2} & \frac{1}{2} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = I$$

Thus, option (B) is orthogonal.

$$\boxed{\text{Correct orthogonal matrix is (B)}}$$

Quick Tip

An orthogonal matrix preserves vector lengths and angles. A rotation matrix (cos, -sin; sin, cos) is always orthogonal.

---

42. Match the casting defects in Column I with the characteristic features in Column II.

Column I	Column II
P. Misrun	1. Penetration of liquid metal behind surface layer of sand moulds
Q. Expansion scab	2. Metal solidifies prematurely in the mould and some sections of the casting are not filled
R. Pin holes	3. Cracking because of restraint to contraction in certain areas of the casting during solidification and cooling to room temperature
S. Hot tearing	4. Evolution of gases during solidification resulting in porosity

(A) P – 2, Q – 4, R – 3, S – 1
(B) P – 1, Q – 3, R – 2, S – 4
(C) P – 1, Q – 2, R – 4, S – 3
(D) P – 2, Q – 1, R – 4, S – 3

Correct Answer: (D) P – 2, Q – 1, R – 4, S – 3

Solution:

- Misrun occurs when metal solidifies prematurely in the mould before completely filling it. Hence, P $\rightarrow$ 2.
- Expansion scab happens due to penetration of liquid metal behind the mould surface. Hence, Q $\rightarrow$ 1.
- Pin holes are caused by gas evolution during solidification, leading to porosity. Hence, R $\rightarrow$ 4.
- Hot tearing occurs due to contraction restraint during solidification, leading to cracks. Hence, S $\rightarrow$ 3.

$$\boxed{P-2,\ Q-1,\ R-4,\ S-3}$$

Quick Tip

Remember: Misrun = incomplete filling, Expansion scab = metal penetration, Pin holes = gases, Hot tearing = cracking due to contraction restraint.

---

43. The following are the activation energies for diffusion of carbon and iron at 773 K in polycrystalline BCC iron:

P = Activation energy for diffusion of carbon in BCC iron through the lattice

Q = Activation energy for diffusion of iron in BCC iron through the lattice

R = Activation energy for diffusion of iron in BCC iron along the grain boundary

Which one of the following statements is CORRECT?

(A) R $<$ P $<$ Q

(B) R $<$ Q $<$ P

(C) Q $<$ P $<$ R

(D) P $<$ R $<$ Q

Correct Answer: (D) P $<$ R $<$ Q

Solution:

- Carbon diffuses faster in BCC iron because it is an interstitial atom; thus its activation energy (P) is the lowest.
- Grain boundary diffusion of iron (R) has lower activation energy compared to lattice diffusion but is higher than carbon diffusion.
- Lattice diffusion of iron (Q) requires the highest activation energy.

$$\boxed{P < R < Q}$$

Quick Tip

General rule: Interstitial diffusion (like carbon) is easiest, grain boundary diffusion of substitutional atoms comes next, and lattice diffusion of substitutional atoms is hardest.

Q.44 Front tension is applied during cold rolling of a thin metal sheet. Which of the following statements is/are TRUE?

(A) The neutral point shifts towards the roll entrance.
(B) The rolling load is decreased.
(C) The neutral point shifts towards the roll exit.
(D) The rolling load is increased.

Correct Answer: (A), (B)

Solution:

Step 1: Understanding front tension in rolling

When front tension is applied, the sheet is pulled forward. This reduces the resistance offered to the rolls and decreases the rolling load.

Step 2: Effect on neutral point

The neutral point is the position where the strip velocity equals the roll surface velocity. With front tension, less force is needed at the exit, so the neutral point shifts towards the roll entrance.

Step 3: Verification of statements

- (A) Correct: Neutral point shifts towards the roll entrance.

- (B) Correct: Rolling load decreases due to applied front tension.

- (C) Incorrect: It does not shift towards the exit.

- (D) Incorrect: Rolling load decreases, not increases.

$$\boxed{\textbf{Correct options: (A), (B)}}$$

Quick Tip

Front tension reduces rolling load and shifts the neutral point towards the entrance. Back tension has the opposite effect.

Q.45 Which of the following statements is/are CORRECT when Ni is added as an alloying element to a low alloy steel?

(A) Hardenability is increased AND the M_s temperature is lowered.

(B) Hardenability is decreased AND the M_s temperature is lowered.

(C) Hardenability is increased AND the M_s temperature is raised.

(D) Hardenability is decreased AND the M_s temperature is raised.

Correct Answer: (A)

Solution:

Step 1: Effect of Nickel (Ni) on steels

Nickel is an austenite stabilizer and improves toughness, corrosion resistance, and hardenability.

Step 2: Effect on M_s temperature

Nickel lowers the martensite start (M_s) temperature because it stabilizes austenite.

Step 3: Verification of options

- (A) Correct: Hardenability is increased and M_s temperature is lowered.

- (B) Incorrect: Hardenability is not decreased.

- (C) Incorrect: M_s temperature is not raised.

- (D) Incorrect: Both statements are wrong.

$$\boxed{\textbf{Correct option: (A)}}$$

Quick Tip

Nickel in steel improves hardenability and toughness, while lowering the M_s temperature.

Q.46 Which of the following statements is/are CORRECT with respect to fusion welding and solid-state welding of metals and alloys?

(A) Thermomechanically affected zone is found in the fusion welding of pure metals.

(B) Partially melted zone is NOT found in the fusion welding of pure metal.

(C) Diffusion bonding is one type of solid-state welding process.

(D) Partially melted zone is found in the fusion welding of alloys with a large freezing range.

Correct Answer: (B), (C), (D)

Solution:

Step 1: Fusion welding of pure metals

In pure metals, there is no partially melted zone because melting occurs at a sharp temperature. Hence, statement (B) is correct.

Step 2: Thermomechanically affected zone

This is associated mainly with solid-state welding processes like friction welding, not with pure metal fusion welding. Therefore, statement (A) is incorrect.

Step 3: Solid-state welding

Diffusion bonding is a solid-state welding process (no melting, only atomic diffusion). Hence, statement (C) is correct.

Step 4: Fusion welding of alloys

For alloys with a wide freezing range, a partially melted zone exists during fusion welding. Hence, statement (D) is correct.

Correct options: (B), (C), (D)

Quick Tip

Pure metals in fusion welding do not show partially melted zones, while alloys with large freezing ranges do. Diffusion bonding belongs to solid-state welding.

Q.47 Which of the following welding processes does NOT / do NOT utilize consumable electrode?

(A) Plasma arc welding
(B) Gas metal arc welding
(C) Shielded metal arc welding
(D) Electron beam welding

Correct Answer: (A), (D)

Solution:

Step 1: Processes with consumable electrodes

- Gas Metal Arc Welding (GMAW) and Shielded Metal Arc Welding (SMAW) both use consumable electrodes.

Step 2: Processes without consumable electrodes

- Plasma Arc Welding generally uses a non-consumable tungsten electrode.
- Electron Beam Welding does not use any electrode at all; instead, it uses a focused high-velocity electron beam.

Step 3: Verification

- (A) Plasma arc welding → Non-consumable electrode → Correct.
- (B) Gas metal arc welding → Consumable electrode → Incorrect.
- (C) Shielded metal arc welding → Consumable electrode → Incorrect.
- (D) Electron beam welding → No consumable electrode → Correct.

Correct options: (A), (D)

Quick Tip

Consumable electrodes are used in GMAW and SMAW, while PAW uses non-consumable tungsten and EBW uses an electron beam with no electrode.

Q.48 For a two-dimensional field described by $T(x, y) = \frac{1}{3}xy(x + y)$, the magnitude of its gradient at the point $(1, 1)$ is ____ (rounded off to two decimal places).

Solution:

$$T = \tfrac{1}{3}(x^2y + xy^2) \Rightarrow \frac{\partial T}{\partial x} = \tfrac{1}{3}(2xy + y^2), \quad \frac{\partial T}{\partial y} = \tfrac{1}{3}(x^2 + 2xy).$$

At $(1, 1)$: $\partial T/\partial x = 1$, $\partial T/\partial y = 1$. Gradient magnitude $= \sqrt{1^2 + 1^2} = \sqrt{2} = 1.4142 \approx \mathbf{1.41}$.

Quick Tip

Compute the gradient components first, then use $\|\nabla T\| = \sqrt{(\partial T/\partial x)^2 + (\partial T/\partial y)^2}$.

Q.49 X-ray diffraction with wavelength 0.154 nm gives the first peak at Bragg angle $\theta = 20^\circ$ for both a metal A (FCC) and a metal B (BCC). The value of $\dfrac{\text{lattice parameter of metal A}}{\text{lattice parameter of metal B}}$ is ____ (rounded off to two decimal places).

Solution:

First peak corresponds to the lowest $h^2 + k^2 + l^2$ allowed: FCC $\rightarrow (111)$ with $h^2+k^2+l^2 = 3$, so $d_A = \frac{a_A}{\sqrt{3}}$. BCC $\rightarrow (110)$ with $= 2$, so $d_B = \frac{a_B}{\sqrt{2}}$. Same θ and $\lambda \Rightarrow$ same d (from $2d \sin\theta = \lambda$), hence

$$\frac{a_A}{\sqrt{3}} = \frac{a_B}{\sqrt{2}} \Rightarrow \frac{a_A}{a_B} = \sqrt{\frac{3}{2}} = 1.2247 \approx \mathbf{1.22}.$$

Quick Tip

For first powder peak: FCC $\rightarrow (111)$, BCC $\rightarrow (110)$. Use $d = \dfrac{a}{\sqrt{h^2 + k^2 + l^2}}$ and equate d when θ is the same.

Q.50 The excess molar Gibbs free energy of a solution of elements A and B at 1000 K is

given by $G^{XS} = -3000\,x_A x_B$ J mol^{-1}. The activity of B in a solution containing 40 mol% of B at 1000 K is ____ (rounded off to two decimal places).

Given: $R = 8.314$ **J mol^{-1}K^{-1}.**

Solution:

For a binary regular solution with $g^E = \Omega x_A x_B$,

$$\ln\gamma_B = \frac{\Omega}{RT}x_A^2, \qquad a_B = \gamma_B x_B.$$

Here $\Omega = -3000$ J mol^{-1}, $T = 1000$ K, $x_B = 0.40 \Rightarrow x_A = 0.60$.

$$\frac{\Omega}{RT} = \frac{-3000}{8.314\times 1000} = -0.3608, \quad \ln\gamma_B = -0.3608\times(0.60)^2 = -0.1299$$

$\Rightarrow\ \gamma_B = e^{-0.1299} = 0.878$. Hence $a_B = \gamma_B x_B = 0.878\times 0.40 = 0.351 \approx \boxed{0.35}$.

Quick Tip

For $g^E = \Omega x_A x_B$ (regular solution), $\ln\gamma_A = (\Omega/RT)x_B^2$ and $\ln\gamma_B = (\Omega/RT)x_A^2$; then $a_i = \gamma_i x_i$.

Q.51 Molten steel at 1900 K is to be vacuum degassed. What equilibrium partial pressure of hydrogen is required to achieve 1 ppm (mass basis) of dissolved hydrogen? (rounded to two decimal places)

Given for $\frac{1}{2}$H$_2$(g) = [H]: $\log_{10}K_{eq} = -\dfrac{1900}{T} + 2.4$ (with K_{eq} in ppm/$\sqrt{\text{atm}}$);

1 atm $= 760$ Torr.

Solution:

At $T = 1900$ K,

$$\log_{10}K_{eq} = -1 + 2.4 = 1.4 \Rightarrow K_{eq} = 10^{1.4} = 25.12\ \text{ppm}/\sqrt{\text{atm}}.$$

Sieverts' law: $[\text{H}] = K_{eq}\sqrt{p_{\text{H}_2}}$. For $[\text{H}] = 1$ ppm:

$$\sqrt{p_{\text{H}_2}} = \frac{1}{K_{eq}} \Rightarrow p_{\text{H}_2} = \left(\frac{1}{25.12}\right)^2 = 1.58\times 10^{-3}\ \text{atm}.$$

Convert to Torr: $p_{\text{H}_2} = 1.58\times 10^{-3}\times 760 = \boxed{1.20\ \text{Torr}}$.

Quick Tip

Use Sieverts' law $[\mathrm{H}] = K\sqrt{p_{\mathrm{H}_2}}$. For a target ppm, $p = (\mathrm{ppm}/K)^2$; convert atm → Torr at the end.

Q.52 The value of $\lim_{x\to 0} \dfrac{6(x - \sin x)}{x^3}$ is ____ (in integer).

Solution:

Using the series $\sin x = x - \dfrac{x^3}{6} + \mathcal{O}(x^5)$,

$$x - \sin x = x - \left(x - \frac{x^3}{6} + \cdots\right) = \frac{x^3}{6} + \mathcal{O}(x^5).$$

Hence,

$$\lim_{x\to 0} \frac{6(x - \sin x)}{x^3} = \lim_{x\to 0} \frac{6 \cdot \frac{x^3}{6}}{x^3} = 1.$$

Quick Tip

For limits with $\sin x$ near $x = 0$, use the Taylor series up to the needed order.

Q.53 For the reactions (in J):

$\mathrm{Fe(s)} + \frac{1}{2}\mathrm{O_2(g)} \rightleftharpoons \mathrm{FeO(s)}$, $\Delta G^\circ = -264900 + 65T$

$\mathrm{2H_2(g)} + \mathrm{O_2(g)} \rightleftharpoons \mathrm{2H_2O(g)}$, $\Delta G^\circ = -492900 + 109T$

Assuming pure solids and no gas solubility, find at $T = 1000$ K the value of $p_{\mathrm{H_2O}}/p_{\mathrm{H_2}}$ required to reduce FeO to Fe (rounded to two decimals). Given $R = 8.314$ J mol^{-1}K^{-1}.

Correct Answer: $\boxed{0.38}$

Solution:

Reduction reaction: $\mathrm{FeO} + \mathrm{H_2} \to \mathrm{Fe} + \mathrm{H_2O}$. ΔG° for $\mathrm{H_2} + \frac{1}{2}\mathrm{O_2} \to \mathrm{H_2O}$ is $\frac{1}{2}(-492900 + 109T) = -246450 + 54.5T$. Add this to the reverse of the FeO formation:

$$\Delta G^\circ_{\text{red}} = (-246450 + 54.5T) - (-264900 + 65T) = 18450 - 10.5T.$$

At $T = 1000$ K: $\Delta G^\circ_{\text{red}} = 7950$ J mol^{-1}.

$$K = \exp\left(-\frac{\Delta G^\circ}{RT}\right) = \exp\left(-\frac{7950}{8.314 \times 1000}\right) = 0.384.$$

For the reaction, $K = \frac{p_{H_2O}}{p_{H_2}} \Rightarrow \boxed{0.38}$.

Quick Tip

Form the target reaction by adding/subtracting given reactions, then use $K = \exp(-\Delta G^\circ/RT)$; activities of pure solids are 1.

Q.54 The diameter of spherical galena particles that have the same settling velocity as spherical quartz particles of diameter $25\,\mu$m (both settling in water) is ____ μm (rounded off to one decimal place).

Assume Stokes' law is valid.

Given: $\rho_{\text{galena}} = 7400$ kg m^{-3}, $\rho_{\text{quartz}} = 2600$ kg m^{-3}, $\rho_{\text{water}} = 1000$ kg m^{-3}.

Correct Answer: $\boxed{12.5\ \mu\text{m}}$

Solution:

Under Stokes' law, $v \propto (\rho_p - \rho_f)d^2$. Equating velocities for galena (g) and quartz (q):

$$(\rho_g - \rho_w)d_g^2 = (\rho_q - \rho_w)d_q^2 \Rightarrow d_g = d_q\sqrt{\frac{\rho_q - \rho_w}{\rho_g - \rho_w}}.$$

Insert values:

$$d_g = 25\ \mu\text{m} \times \sqrt{\frac{2600 - 1000}{7400 - 1000}} = 25 \times \sqrt{\frac{1600}{6400}} = 25 \times 0.5 = \boxed{12.5\ \mu\text{m}}.$$

Quick Tip

For equal Stokes settling speeds, diameters scale with $\sqrt{(\rho_q - \rho_f)/(\rho_g - \rho_f)}$.

Q.55 Consider the cell reaction: $\text{Mg} + \text{Cd}^{2+} \to \text{Mg}^{2+} + \text{Cd}$**. The standard Gibbs free energy change for the reaction is ____ kJ (rounded off to an integer).**

Given oxidation potentials (vs SHE): $\text{Mg} \rightleftharpoons \text{Mg}^{2+} + 2e^-\ \ E^\circ = 2.37$ V,

$\text{Cd} \rightleftharpoons \text{Cd}^{2+} + 2e^-\ \ E^\circ = 0.403$ V. Faraday's constant $F = 96500$ C mol^{-1}.

Solution:

The corresponding reduction potentials are $E^\circ_{\text{Mg}^{2+}/\text{Mg}} = -2.37$ V and $E^\circ_{\text{Cd}^{2+}/\text{Cd}} = -0.403$ V.

For Cd^{2+} (cathode) and Mg (anode):

$$E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} = (-0.403) - (-2.37) = 1.967\ \mathrm{V}.$$

With $n = 2$: $\Delta G^\circ = -nFE^\circ = -2(96500)(1.967) = -3.796 \times 10^5$ J mol^{-1}.

$$\boxed{\Delta G^\circ \approx -380 \text{ kJ mol}^{-1}}$$

Quick Tip

Use reduction potentials to compute $E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}}$, then $\Delta G^\circ = -nFE^\circ$.

Q.56 Copper is electrodeposited from $\mathrm{CuSO_4}$ onto a stainless-steel cathode of total surface area 2 m^2 in an electrolytic cell at current density 200 A m^{-2} with current efficiency 90%. The mass of copper deposited in 24 h is ____ kg (rounded off to two decimal places).

Given: $F = 96500$ C mol^{-1}, atomic mass of Cu $= 63.5$ g mol^{-1}. Reaction: $\mathrm{Cu}^{2+} + 2\mathrm{e}^- \to \mathrm{Cu}$ $(n = 2)$.

Solution:

Total current $I = (200)(2) = 400$ A. Time $t = 24 \times 3600 = 86400$ s. Effective charge $Q = It \times \eta = 400 \times 86400 \times 0.90 = 3.1104 \times 10^7$ C. Deposited moles $= Q/(nF) = 3.1104 \times 10^7/(2 \times 96500) = 161.2$ mol. Mass $= 161.2 \times 63.5 = 1.023 \times 10^4$ g $= \boxed{10.23 \text{ kg}}$.

Quick Tip

Electrodeposition mass: $m = \dfrac{It\eta M}{nF}$. Use total current = current density × area.

Q.57 An intrinsic semiconductor has conductivity of $100\ \Omega^{-1}$ m^{-1} at 300 K and $300\ \Omega^{-1}$ m^{-1} at 500 K. The band gap of the semiconductor is ____ eV (rounded off to two decimal places).

Given: $k_B = 8.6 \times 10^{-5}$ eV K^{-1}.

Correct Answer: $\boxed{0.14\ \mathrm{eV}}$

Solution:

For an intrinsic semiconductor, $\sigma \propto n_i \propto \exp\left(-\frac{E_g}{2k_BT}\right)$. Hence,

$$\ln\left(\frac{\sigma_2}{\sigma_1}\right) = -\frac{E_g}{2k_B}\left(\frac{1}{T_2} - \frac{1}{T_1}\right).$$

With $\sigma_1 = 100$ at $T_1 = 300$ K, $\sigma_2 = 300$ at $T_2 = 500$ K:

$$E_g = -\frac{2k_B \ln(3)}{1/500 - 1/300} = 2(8.6 \times 10^{-5}) \times 1.0986 \times 750 \approx 0.141 \text{ eV} \approx \boxed{0.14 \text{ eV}}.$$

Quick Tip

For intrinsic $\sigma(T)$, use $\sigma \sim e^{-E_g/(2kT)}$. A conductivity ratio at two T's directly gives E_g.

Q.58 A component from alloy A with plane-strain toughness $K_{IC} = 50$ MPa$\sqrt{\text{m}}$ fractured at a crack length $a = 0.4$ mm under tensile stress σ. If the same component is made from alloy B with $K_{IC} = 75$ MPa$\sqrt{\text{m}}$, the crack length at which fracture occurs (same σ, same geometry) is ____ mm (rounded to one decimal place).

Correct Answer: $\boxed{0.9 \text{ mm}}$

Solution:

For mode I fracture, $K_{IC} = Y\sigma\sqrt{\pi a}$. With identical σ and geometry (Y same), the critical length scales as $a \propto K_{IC}^2$. Thus,

$$a_B = a_A\left(\frac{K_{IC,B}}{K_{IC,A}}\right)^2 = 0.4 \text{ mm}\left(\frac{75}{50}\right)^2 = 0.4 \times 2.25 = \boxed{0.9 \text{ mm}}.$$

Quick Tip

With the same stress and geometry, the critical crack length varies as $a \propto K_{IC}^2$.

Q.59 Temperatures at two sides of a 0.4 m thick copper plate are $1000°$C and $500°$C. Assuming steady, one-dimensional conduction with no end effects, the heat flux through the wall is ____ $\times 10^5$ W m^{-2} (in integer).

Given: $k_{\text{Cu}} = 400$ W m^{-1}K^{-1}.

Solution (long):

Step 1: Convert the driving temperature difference.

For conduction, only temperature *difference* matters; Celsius and Kelvin scales differ by an additive constant, so

$$\Delta T \;=\; T_{\text{hot}} - T_{\text{cold}} \;=\; 1000 - 500 \;=\; 500\ \text{K}.$$

Step 2: Model and assumptions.

- *Steady state*: temperature field does not change with time.
- *One-dimensional*: temperature varies only in the thickness direction x.
- *No internal heat generation* and *planar wall* of uniform k. Under these, the temperature profile is linear and the heat flux is uniform through the thickness.

Step 3: Apply Fourier's law for a plane wall.

For 1D steady conduction through thickness L:

$$q'' \;=\; -k\frac{dT}{dx} \;=\; k\,\frac{T_{\text{hot}} - T_{\text{cold}}}{L} \qquad (\text{magnitude}).$$

Substitute $k = 400\ \text{W m}^{-1}\text{K}^{-1}$, $\Delta T = 500\ \text{K}$, $L = 0.4\ \text{m}$:

$$q'' \;=\; 400\ \frac{\text{W}}{\text{m K}}\ \frac{500\ \text{K}}{0.4\ \text{m}} \;=\; 400 \times 1250\ \frac{\text{W}}{\text{m}^2} \;=\; 5.0 \times 10^5\ \text{W m}^{-2}.$$

Step 4: Units and sign.

The result carries units of W m^{-2} (heat rate per unit area). The negative sign in Fourier's law denotes direction (from hot to cold). The question asks for magnitude, hence a positive value.

$$\boxed{5\ \times 10^5\ \text{W m}^{-2}} \quad\Rightarrow\quad \boxed{5}$$

Quick Tip

For a plane wall with uniform k, 1D, steady conduction: $q'' = k\Delta T/L$. Celsius or Kelvin makes no difference for ΔT.

Q.60 In polycrystalline Ni, Nabarro–Herring diffusion creep controls the rate at a given temperature. If $\dot{\varepsilon} = 10^{-8}\ \text{s}^{-1}$ at $\sigma = 10$ MPa, what stress gives $\dot{\varepsilon} = 10^{-9}\ \text{s}^{-1}$ (in integer MPa)? Assume the same mechanism remains rate-controlling.

Solution (long):

Step 1: Constitutive relation for Nabarro–Herring creep.

Nabarro–Herring (N–H) creep is *lattice diffusion–controlled* creep in polycrystals. The steady-state strain rate is

$$\dot{\varepsilon} \;=\; A\,\frac{D_L\,\Omega}{kT}\,\frac{\sigma}{d^2},$$

where D_L is lattice self-diffusivity, Ω atomic volume, d grain size, T temperature, k Boltzmann's constant, and A a geometric factor. At fixed material (Ni), temperature, and grain size, all prefactors are constant $\Rightarrow$

$$\dot{\varepsilon} \propto \sigma^n, \qquad \text{with } n = 1 \text{ for N–H creep.}$$

Step 2: Use stress exponent $n = 1$ to scale between conditions.

Let $(\dot{\varepsilon}_1, \sigma_1) = (10^{-8}\ \mathrm{s}^{-1},\ 10\ \mathrm{MPa})$ and $(\dot{\varepsilon}_2, \sigma_2) = (10^{-9}\ \mathrm{s}^{-1},\ \sigma_2)$. With $n = 1$:

$$\frac{\dot{\varepsilon}_2}{\dot{\varepsilon}_1} \;=\; \frac{\sigma_2}{\sigma_1} \quad\Rightarrow\quad \sigma_2 \;=\; \sigma_1\,\frac{\dot{\varepsilon}_2}{\dot{\varepsilon}_1} \;=\; 10\ \mathrm{MPa} \times \frac{10^{-9}}{10^{-8}} \;=\; 1\ \mathrm{MPa}.$$

Step 3: Sanity check vs other creep mechanisms.

If the mechanism were dislocation climb (typical $n \approx 3-5$), the stress reduction needed for a 10× lower $\dot{\varepsilon}$ would be much smaller. The linear scaling here is a hallmark of diffusion creep.

$$\boxed{1\ \mathrm{MPa}}$$

Quick Tip

Diffusion creep (Nabarro–Herring) has $n = 1$ and $\dot{\varepsilon} \sim \sigma/d^2$. Keeping T and d fixed, strain rate scales linearly with stress.

Q.61 A single crystal BCC metal with lattice parameter $a = 0.4$ nm is deformed at a shear strain rate of 0.001 s^{-1}. If the average mobile dislocation density is 10^{10} m^{-2}, the average dislocation velocity is ____ $\times\, 10^{-3}$ m s^{-1} (rounded off to two decimal places).

Given: Burgers vector b $= \frac{a}{2}\langle 111\rangle$.

Solution:

Step 1: Burgers vector magnitude. For BCC, $|\mathrm{b}| = \dfrac{a\sqrt{3}}{2}$. With $a = 0.4\ \mathrm{nm} = 0.4 \times 10^{-9}$ m:

$$b = \frac{0.4 \times 10^{-9} \times \sqrt{3}}{2} = 3.46 \times 10^{-10}\ \mathrm{m}.$$

Step 2: Orowan relation for shear.

$$\dot{\gamma} = \rho_m \, b \, v \quad \Rightarrow \quad v = \frac{\dot{\gamma}}{\rho_m b} = \frac{10^{-3}}{(10^{10})(3.46 \times 10^{-10})} = 2.89 \times 10^{-4} \text{ m s}^{-1}.$$

Expressing as $\times 10^{-3}$ m s^{-1}:

$$v = 0.289 \times 10^{-3} \text{ m s}^{-1} \approx \boxed{0.29}.$$

Quick Tip

Use Orowan's equation $\dot{\gamma} = \rho b v$. For BCC, $b = a\sqrt{3}/2$ on $\langle 111 \rangle$ slip directions.

Q.62 A cylindrical specimen is plastically tensioned to a *uniform elongation* of 10%. The final gage-section area is 20 mm^2. The initial gage-section area is ____ mm^2 (rounded off to an integer).

Solution:

Uniform plastic deformation is approximately incompressible, so volume in the gage section is conserved: $A_i L_i = A_f L_f$. Uniform elongation $= 10\% \Rightarrow L_f = 1.10 \, L_i$. Thus

$$A_i = A_f \frac{L_f}{L_i} = 20 \times 1.10 = \boxed{22 \text{ mm}^2}.$$

Quick Tip

For plastic tension up to uniform elongation, assume volume constancy: $A_i L_i = A_f L_f$.

Q.63 The reaction $A \to B$ follows first-order kinetics. At a given temperature, 20% completion takes 223 s. The time to reach 50% completion at the same temperature is ____ s (rounded to the nearest integer).

Solution:

For 1st-order, fraction unreacted $= e^{-kt}$. At $t_1 = 223$ s, 80% remains:

$0.80 = e^{-kt_1} \Rightarrow k = -\ln(0.80)/223 = 0.001001 \text{ s}^{-1}$. For 50% completion:

$0.50 = e^{-kt_{50}} \Rightarrow t_{50} = \ln 2/k = 0.6931/0.001001 = \boxed{693 \text{ s}}$.

Quick Tip

First-order times scale with $-\ln(\text{fraction unreacted})$: $t = -\ln X/k$. Use one data point to get k, then predict any conversion time.

Q.64 A cylindrical Al alloy billet of 300 mm diameter is hot extruded to produce a cylindrical rod of 75 mm diameter at a constant true strain rate $(\dot{\varepsilon})$ of 10 s^{-1}. The flow stress at the extrusion temperature is $\sigma = 10(\dot{\varepsilon})^{0.3}$ MPa. Assume the alloy is perfectly plastic and there is no temperature rise during extrusion. The ideal plastic work of deformation per unit volume is ____ $\times\ 10^6$ J m^{-3} (rounded to one decimal place).

Solution:

1) Flow stress at the operating strain rate.

$\sigma = 10(10)^{0.3} = 10 \times 10^{0.3}$. Since $10^{0.3} = e^{0.3 \ln 10} = e^{0.69078} = 1.9953$, we get $\sigma \approx 19.95$ MPa.

2) True strain for axisymmetric extrusion.

For incompressible plastic flow, $A_0 L_0 = A_f L_f \Rightarrow \varepsilon = \ln(L_f/L_0) = \ln(A_0/A_f)$. With circular sections, $A \propto D^2$, hence $\varepsilon = 2\ln(D_0/D_f)$. Here

$D_0/D_f = 300/75 = 4 \Rightarrow \varepsilon = 2\ln 4 = \ln 16 = 2.7726$.

3) Ideal plastic work per unit volume.

For perfectly plastic flow with constant σ,

$$w = \int_0^{\varepsilon} \sigma \, d\varepsilon = \sigma\,\varepsilon = (19.95\ \text{MPa})(2.7726) = 55.3\ \text{MPa} = 55.3 \times 10^6\ \text{J m}^{-3}.$$

$$\boxed{55.3}$$

Quick Tip

Extrusion true strain: $\varepsilon = 2\ln(D_0/D_f)$. With constant flow stress, ideal work density is $w = \sigma\varepsilon$ (MPa → MJ/m^3).

Q.65 Two consecutive Newton–Raphson estimates of the root of $f(x)$ are $x_i = 8.5$ and $x_{i+1} = 13.5$. If $f(x_i) = 15$, the numerical value of $f'(x_i)$ is ____ (in integer).

Solution:

Newton–Raphson update:

$$x_{i+1} = x_i - \frac{f(x_i)}{f'(x_i)} \quad \Rightarrow \quad f'(x_i) = \frac{f(x_i)}{x_i - x_{i+1}}.$$

Substitute $x_i = 8.5$, $x_{i+1} = 13.5$, $f(x_i) = 15$:

$$f'(x_i) = \frac{15}{8.5 - 13.5} = \frac{15}{-5} = \boxed{-3}.$$

Quick Tip

From $x_{i+1} = x_i - \dfrac{f(x_i)}{f'(x_i)}$ you can directly back out $f'(x_i) = \dfrac{f(x_i)}{x_i - x_{i+1}}$.