Indian National Junior Science Olympiad (INJSO) – 2025

Indian Association of Physics Teachers (IAPT)

QUESTION PAPER WITH PROVISIONAL SOLUTIONS

Roll Number: ☐☐☐☐–☐☐☐☐–☐☐☐☐ **Date:** 1st February 2025

Duration: 3 Hours **Maximum Marks: 180**

Please Note:

1) Please write your roll number in the space provided above.
2) Use of non-programmable scientific calculators is allowed.
3) **The answer-sheet must be returned to the invigilator.** You can carry this question paper with you.
4) **Section I of this question paper has 15 questions (45 marks).**
   i. For each question in this section, **only one** of the four options is a correct answer.
   ii. For each question, a correct answer will earn 3 marks, a wrong answer will earn (–1) mark, and an un-attempted question will earn 0 marks.
   iii. If you mark more than one option, it would be treated as a wrong answer.
5) **Section II contains 9 questions worth 5 marks each. There is no negative marking (45 marks).**
   iv. For each of these questions one or more option(s) may be correct.
   v. You will get full credit for each question only if you mark all correct options and no wrong option. There are no partial marks for these 9 questions.
6) **Section III contains 8 questions (90 marks).**
   vi. For all the questions in this section, the process involved in arriving at the solution is as important as the final answer. Valid assumptions / approximations are perfectly acceptable. Please write your method clearly, explicitly stating all the reasonings/ assumptions / approximations.
   vii. In case you fall short of writing space for any question, you can ask for an extra sheet. You can ask for maximum of two extra sheets.

Happy Solving

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USEFUL CONSTANTS

Gravitational constant	$G \approx 6.674 \times 10^{-11}$ N m^2/kg^2
Gravitational acceleration	$g \approx 9.8$ m/s^2
Mass of electron	$m_e \approx 9.109 \times 10^{-31}$ kg
Charge of an electron	$e \approx 1.602 \times 10^{-19}$ C
Avogadro constant	$N_A \approx 6.022 \times 10^{23}$/mol
Specific heat capacity of water	$s = 4.2$ J / (g ^{0}C)
Density of water	$\rho_w = 10^3$ kg/m^3
Universal gas constant	$R \approx 8.314$ J / (mol K) and 0.0821 L.atm/mol.K
Atmospheric pressure	1 atm $\approx$ 101 325 Pa
Molar volume of gas at STP	$V_{STP} \approx 22.4$ L
STP	273 K and 1 atm
Molar volume of gas at 1 atm and 100 ◦C	$V_{100} \approx 30.6$ L
Permitivity of free space	$\epsilon_0 \approx 8.854 \times 10^{-12}$ C^2 N^{-1}m^{-2}
Radius of the Earth	$R_\oplus \approx 6400$ km
Radius of the Moon	$R_{moon} \approx 1700$ km

Element	Atomic Number	Atomic Mass		Element	Atomic Number	Atomic Mass
H	1	1.0		Cl	17	35.5
C	6	12.0		K	19	39.0
N	7	14.0		Ca	20	40.0
O	8	16.0		Fe	26	56.0
Na	11	23.0		Zn	30	65.4
Al	13	27.0		Ag	47	107.9
S	16	32.0		Au	79	197.0

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Section I

(Only one of the four options is correct)

1) An unusual and fatal neurological disease was observed in a sheep herd. Treatment with a broad-spectrum antibiotic proved ineffective. Upon autopsy, veterinarians discovered extensive damage and deformity in the brain tissue. Noting similarities to mad cow disease, they sought to confirm their hypothesis by processing the damaged tissue. The tissue was sectioned, blended in a mixer, and filtered through a 0.2 µm sieve. The resulting filtrate was then divided into three fractions for further testing under different treatments:

Fraction X: Exposed to 90°C for 20 minutes.
Fraction Y: Treated with high concentration of sodium hypochlorite for 60 minutes.
Fraction Z: Treated with highly active nuclease for 20 minutes at 25°C.

If these fractions are injected into healthy individual sheep, which of these fractions will cause same disease in sheep?

A) Only fraction X
B) Only fraction Y
C) Fractions Y and Z
D) Fractions X and Z

Solution (D): Since broad spectrum antibiotics did not cure the neurological disease, any microbial infections are ruled out. Had it been a virus, there wouldn't have survived any of these treatments to cause the disease. All these treatments either destroy or denature nucleic acids so they as well are ruled out. Proteins are known to have diverse range of stability to temperature (like Taq polymerases and other proteins from bacteria which survive is high temperatures). Treatment X is a normal condition of sterilization, which the proteins, called Prions, survive. However, quite longer exposure to high temperature do denature them as well. Since sodium hypochlorite used is very concentrated, these proteins get denatured and cannot cause infection. Since nucleases cannot degrade proteins Fraction Z will be still infectious.

2) A farmer in Udupi, a town in North costal Karnataka, decided to boost her income by planting popular fruit trees like Alphonso mangoes and Kashmiri apples in her very own optimised greenhouse facility. She purchased fresh fruits from organic farms of Goa and Kashmir, respectively. The seeds were removed and sowed in appropriate soil conditions and waited for them to germinate. Seeds of mango germinated easily whereas apple seeds remained intact and unsprouted. What is the likely reason for lack of germination from the apple seeds?

A) The warm temperature but not humidity was required to break dormancy of apple seeds.
B) Seeds needed cold period to break its dormancy.
C) Seeds came from a farm in a colder region rather than a warmer region.
D) Apple seeds have amygdalin, which upon metabolism releases cyanide, deters breaking of dormancy.

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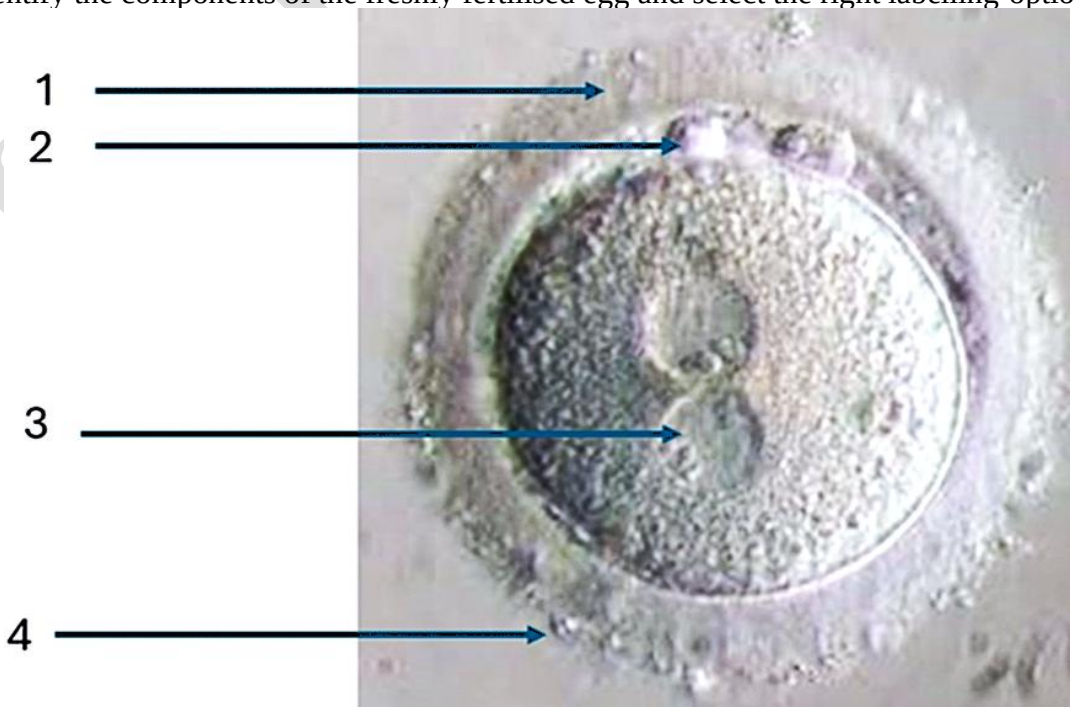
Solution (B): B is true as cold period breaks (cold stratification) the dormancy of apple seeds by sensing a warmer period will be following it. A is false as humidity and warm temperature helps in germination ONLY after the cold stratification phase. C is false as the dormancy of the apple is a genetic trait, unless a strain is developed. D is false as amygdalin is a deterrent to herbivores and have no role in regulating dormancy and germination.

3) Two hundred years ago, Assam (India) had a large population of migratory stork birds. During that time, infections caused by the West Nile Virus (WNV1 serotype) resulted in a mortality rate of only 10%. However, in the early 1900s, widespread superstitious beliefs and habitat destruction led to the mass killing of storks and the destruction of their nests, causing a drastic decline in their population. Thanks to decades of conservation efforts and increased awareness, the stork population has rebounded to a significant size. However, a recent outbreak of WNV1 has shown a 40% mortality rate among the birds. Which of the following option rightly explains the higher mortality rate?

A) Natural selection
B) Chance event
C) Genetic drift
D) Migratory effect

Solution (C): Genetic drift happens when a population's size is significantly reduced, resulting in a substantial loss of genetic diversity. Unlike natural selection, which promotes advantageous traits, genetic drift randomly decreases genetic variation, making populations more susceptible to diseases and environmental shifts. In this case, habitat destruction and overhunting, rather than a chance event or migratory effect, are responsible for the loss of genetic diversity.

4) Identify the components of the freshly fertilised egg and select the right labelling options.



PTJSO

A) 1) Zona pellucida; 2) Polar body; 3) Pronucleus; 4) Sperm
B) 1) Pronucleus; 2) Polar body; 3) Zona pellucida; 4) Sperm
C) 1) Zona pellucida; 2) Sperm; 3) Polar body; 4) Zona pellucida
D) 1) Sperm; 2) Pronucleus; 3) Polar body; 4) Zona pellucida

Solution (A): The freshly fertilised egg has the male and female pronuclei (3). The polar body (2) released just before fertilisation is located outside the oocyte, below the covering of the oocyte, zona pellucida (1). Sperm (4), which are unsuccessful in fertilising the oocyte, can be found sticking to the zona pellucida.

5) The following property of nucleic acid is most relevant for its ability to function as genetic material when compared to a protein.

A) Complementary base pairing.
B) Having a high density of negative charge enables them to form chromatins.
C) Having 4 bases instead of 20 amino acids.
D) Creates maximum structural diversity.

Solution (A): The base complementarity allows an effective and fail-safe method of oping/replicating the sequence information unlike amino acids (Option A). Option B is false this is a factor for compaction in a cell. Numbers of units to repeat is not at all criteria (Option C is false). Option D is false as nucleic acids have lesser structural diversity in comparison to proteins

6) In his examination, Aryan writes differences between voltaic cell and electrolytic cell. But he did not get full marks in this answer as he wrongly placed his statements in wrong column. Find ALL **INCORRECT** difference(s) from his answer given below:

Differences	**Voltaic cell**	**Electrolytic cell**
(i)	Anode is the positive electrode and cathode is the negative electrode.	Anode is the negative electrode and cathode is the positive electrode.
(ii)	The current flows in the cell from negative to positive electrode.	The current flows in the cell from positive to negative electrode.
(iii)	A spontaneous chemical reaction occurs in the cell to produce electricity.	A non-spontaneous chemical reaction takes place in the cell.
(iv)	The external battery drives the electrons that flow through cathode to anode.	The electrons flow from anode to cathode through the external circuit.
(v)	Oxidation takes place at positive electrode.	Oxidation takes place at negative electrode.

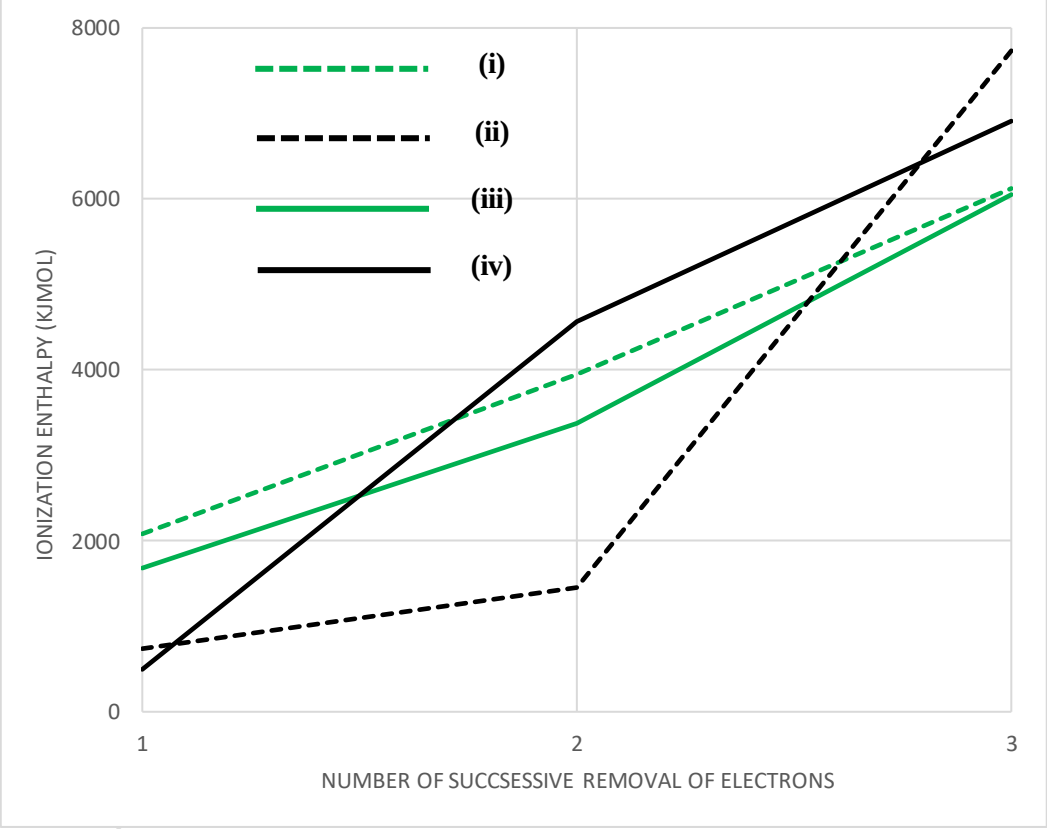
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(vi)	Reduction takes place at positive electrode.	Reduction takes place at negative electrode.
(vii)	Discharge of ions occur at both electrodes.	Discharge of ions occur only at cathode.

A) (vii)
B) (i), (iv), (v)
C) (iv), (vii)
D) (i), (iv), (v), (vii)

Solution: D

7) In the following graph, ionization enthalpies of successive elements in the periodic table are plotted against number of successive removal of electrons. Analyse the graph and predict the elements from the graph.



A) (i)– N, (ii) – O, (iii) – C, (iv) – B
B) (i)– N, (ii) – C, (iii) – Be, (iv) – B
C) (i)– Ne, (ii) – Mg, (iii) – F, (iv) – Na
D) (i)– P, (ii) – S, (iii) – Si, (iv) – Al

Solution: C

8) In the Haber process, 60 litres of hydrogen gas and 20 litres of nitrogen gas were taken for reaction which yielded only 25% of the expected product due to malfunctioning of the production unit. What is the mole fraction of ammonia in the mixture and what is the volume of ammonia extracted from the mixture at the same pressure?

A) 0.33, 40L
B) 0.14, 20L
C) 0.14, 10L
D) 0.33, 10L

Solution : C

$N_2 + 3H_2 \longrightarrow 2NH_3$

(20 L) (60 L) (40 L)

But, production yield is only 25%, thus NH_3 produced is only 10 L.

Thus, N_2 reacted = 5 L, H_2 reacted = 15 L.

Composition of the gaseous mixture at the end: NH_3 = 10 L; N_2 = (20 – 5) = 15 L; H_2 = (60 – 15) = 45 L Mole fraction of NH_3 = 1/7 =0.14

9) Given below are the boiling points of hydrocarbons containing 6 carbons. Choose the correct statement based on the data given.

neohexane	2,3-dimethlybutane	isohexane	*n*-hexane	cyclohexane
50^0 C	58^0 C	60^0 C	69^0 C	81^0 C

A) Cyclohexane has a higher boiling point than *n*-hexane because cyclohexane has a higher molecular weight than *n*-hexane.
B) *n*-hexane has a higher boiling point than isohexane, because *n*-hexane is a linear molecule and has lesser intermolecular Van der Waal's interaction than isohexane.
C) Replacing a carbon in any of the above given 6-carbon compounds with an oxygen, result in a molecule whose boiling point will be higher than the parent compound.
D) Fractional distillation is an efficient way to separate every hydrocarbon from each other from a mixture that contains equal amounts of all these compounds.

Solution (C)

10) During the Second World War, engineers developed rocket-powered aircrafts. The aircraft carried these two liquids: hydrazine (N_2H_4) and hydrogen peroxide, (H_2O_2). When these two liquids mix in the combustion chamber, they evaporate and then react rapidly to form nitrogen gas and steam. The equation for the reaction is

$$N_2H_4 + 2H_2O_2 \rightarrow N_2 + 4H_2O$$

Bond dissociation energy (BDE) is the amount of energy required to break a specific chemical bond in a molecule in its gaseous state.

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BOND	BOND DISSOCIATION ENERGY in kJ/mol
N≡N	945
N−N	159
N−H	391
O−O	143
O−H	463

Use the data given in the table above to calculate the total amount of energy released or absorbed by the chemical process.

A) Absorbs 788 kJ/mol
B) Releases 788 kJ/mol
C) Absorbs 2640 kJ/mol
D) Releases 2640 kJ/mol

Solution: (B)

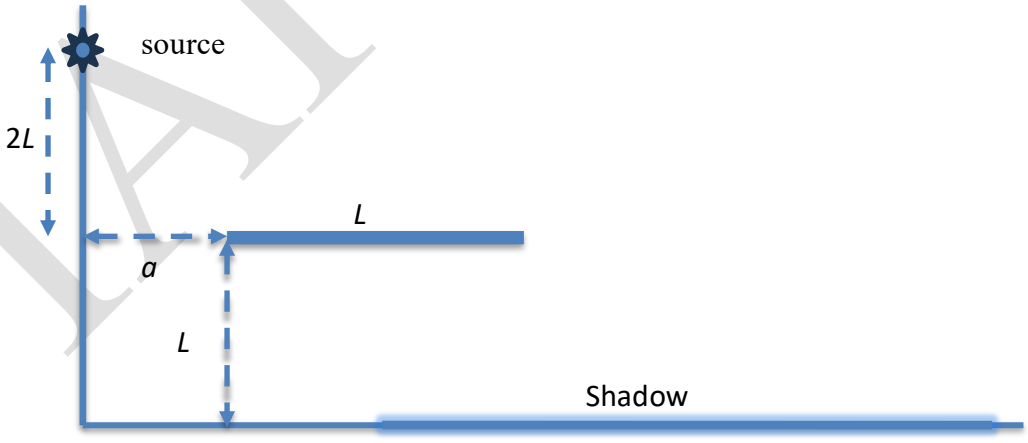
Energy released = E (N≡N) + 8 E(O-H) – E(N-N) - 4 E(N-H) – 2(O-O) – 4(O-H)

= E (N≡N) + 4 E(O-H) – E(N-N) - 4 E(N-H) – 2(O-O)

= 945 + 4(463) – (159) – 4(391) – 2(143) kJ/mol

= 786 -286 + 4x72 = 500 + 288 = 788 kJ/mol

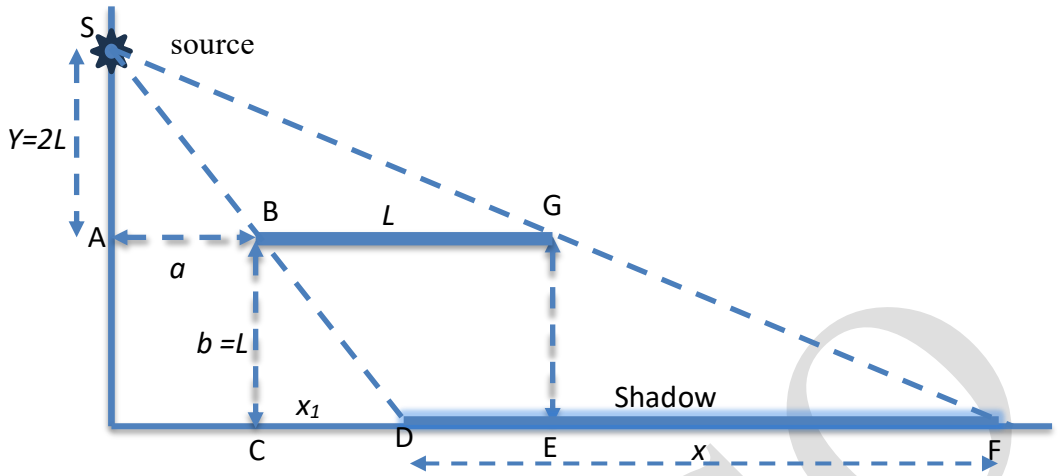
11) The shadow of a plank of length L is formed on the floor due to a point source, as shown in the figure. If the source comes down by 20% of the present vertical length ($2L$) from the plank, find the percentage change in the length of the shadow formed at the previous level.



A) 25%
B) 6.33%
C) 8.33%
D) 21%

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Solution (C): Refer to the diagram shown below.



Consider similar triangles SAB and BCD, we have $\frac{y}{a} = \frac{b}{x_1}$ or $x_1 = \frac{ab}{y}$ ---------(1)

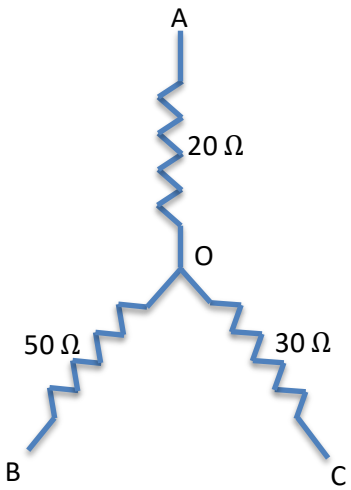
Consider similar triangles SAG and GEF, we have $\frac{y}{a+L} = \frac{b}{x-(L-x_1)}$. The length of shadow is given by $x = L - x_1 + \frac{b(a+L)}{y}$. Simplifying using equation (1) for x_1, we have, the shadow length, $x = L + \frac{bL}{y}$

If y decreases by 20% then the length of the shadow is $x^1 = L + \frac{bL}{0.8y} = L + 1.25\frac{bL}{y}$

The increase in the length of shadow is $\Delta x = x^1 - x = 1.25\frac{bL}{y} - \frac{bL}{y} = 0.25\frac{bL}{y}$.

The percentage of increase in the length of shadow is $\frac{\Delta x}{x} = \frac{25\frac{bL}{y}}{L+\frac{bL}{y}} = \frac{25b}{y+b} = \frac{25}{3} = 8.33\ \%$

12) A portion of an electrical network is shown in the adjacent figure. Electrostatic potential of terminals A and B are $V_A = 150$ V and $V_B = 40$ V respectively, the terminal C is open. Read the following statements:



Statement S1: If the terminal C is at potential $V_C = 30$ V, the current passing through 20 Ω resistor will be 3 A.
Statement S2: If terminal C is connected to the ground (i.e. $V_C = 0$ V), no current will flow through the 50 Ω resistor.
Statement S3: If terminal C is connected to terminal A, the electric power dissipated in the 30 Ω resistor will be about 15.1 W.
Now, choose the correct option.

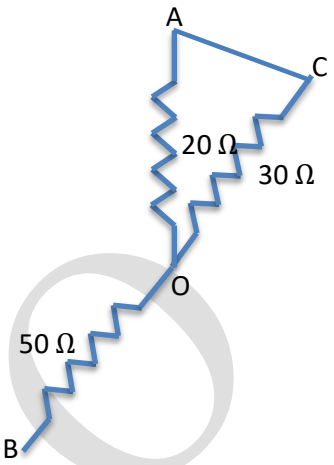
A) Statements S_1, S_2 and S_3 are incorrect.
B) Statements S_1 and S_3 are correct, and S_2 is incorrect.
C) Statements S_2 and S_3 are correct, and S_1 is incorrect.
D) All the statements S_1, S_2 and S_3 are correct.

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Solution (B): Statement S_1: If V_C is 30 V, then

$$\frac{150-V_0}{20}=\frac{V_0-40}{50}+\frac{V_0-30}{30}=\frac{3(V_0-40)+5(V_0-30)}{150}=\frac{8V_0-270}{150}$$

I.e. $\frac{150-V_0}{2}=\frac{8V_0-270}{15}$ or $15(150-V_0)=2(8V_0-270)$ or $15(150)+540=31V_0$



Thus, the voltage at O is $V_0=90$ V and Current in 20Ω is $I=\frac{150-90}{20}=3$ A

Statement S_2: If V_C is 0 V then $\frac{150-V_0}{20}=\frac{V_0-40}{50}+\frac{V_0}{30}=\frac{3(V_0-40)+5V_0}{150}=\frac{8V_0-120}{150}$

$\frac{150-V_0}{2}=\frac{8V_0-120}{15}$ or $15(150-V_0)=2(8V_0-120)$ or $15(150)+240=31V_0$

Thus, the voltage at O is $V_0=80.3$ V and Current in 50Ω is $I=\frac{80.3-40}{50}=0.8$ A

Statement S_3: When C is connected to A as shown in the figure, the equivalent resistance between terminals A-C and B is given by $R=\frac{20\times30}{20+30}+50=62\ \Omega$.

The current in the circuit is $I=\frac{150-40}{62}=\frac{55}{31}$ A

The current through 30 Ω is given by current divider relation, $I_{30}=I\times\frac{20}{20+30}=\frac{55}{31}\times\frac{20}{20+30}=\frac{22}{31}$A.

The electrical power dissipated in 30Ω resistor is $P=I^2R=\left(\frac{22}{31}\right)^2\times30=15.1$ W

13) A beaker partly filled with a liquid of density 1.2 g cm^{-3} is placed on a digital balance, and the reading is 440 g. A metal piece is tied at the end of a string, and the free end is held by hand. The metal piece is now completely immersed in the liquid without touching any side or bottom of the beaker. The reading in the digital balance has now become 500 g. The string is cutoff, and the metal-piece is dropped into the liquid without spilling water. It gets completely immersed in the liquid, rests at the bottom, and the reading becomes 680 g. The density of the metal is

A) 5200 kg m^{-3}
B) 4800 kg m^{-3}
C) 4000 kg m^{-3}
D) 6000 kg m^{-3}

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Solution (B):

Weight of the liquid = 440 g; Upthrust to the metal piece = 500 – 440 = 60 g

Weight of the displaced liquid = 60 g

Volume of the displaced liquid = (60/1.2) = 50 cm^3 = volume of the metal piece

Weight of the liquid + Weight of the metal = 680 g

So, Weight of the metal = 680 – 440 = 240 g and
Density of the metal = (240/50) = 4.8 g cm^{-3} = 4800 kg m^{-3}.

14) A small block B of mass 0.6 kg starts moving on a rough horizontal surface with an initial velocity of 6.0 m s^{-1}. The coefficient of friction between the block and surface, $\mu = 0.1$. frictional force on the block is expressed as

$$f = \mu \times \text{Normal force between the block and surface.}$$

After travelling through a distance of 10.2 m on the rough horizontal surface, block B collides with a plate P of mass 0.4 kg connected to the free end of an elastic massless spring of the force constant $k = 400$ N m^{-1}. The other end of the spring is attached to a rigid support S. After collision, block B and plate P stick together and move on a perfectly smooth surface ahead to compress the spring.

Assume that the spring obeys Hooke's law during compression. There is no frictional force on the block during the collision and thereafter. You may neglect the size of the block B and plate P for calculation.



Statement 1: The velocity of block B just before the collision is close to 4.0 m s^{-1}.
Statement 2: Maximum compression produced in the spring is 12 cm.
Statement 3: Work done by the friction on the block during the entire motion is close to -6.0 J.

Choose the correct option.

A) Statements 1, 2 and 3 are correct.
B) Statements 1 and 3 alone are correct.
C) Statements 1 and 2 alone are correct.
D) Statements 2 and 3 alone are correct.

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Solution (A): Before collision, frictional force on block, $f = \mu N = \mu mg$. The acceleration is $a = -\mu g = -0.1 \times 9.8 = -0.98\ \text{m s}^{-2}$. If velocity (v) of the block just before collision, $v^2 = 6^2 - 2 \times 0.98 \times 10.2 = 16.008$ and

$v = 4\ \text{m s}^{-1}$.

Applying conservation of linear momentum for block sticking to plate. The velocity of combined mass after collision is $0.6 \times 4 = (0.6 + 0.4)v^I$ and $v^I = 2.4\ \text{m s}^{-1}$.

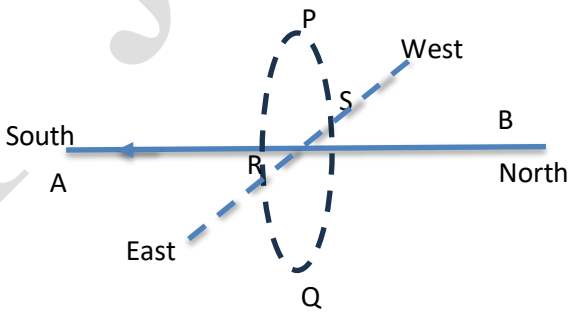
If $x_m$is the maximum compression in spring, applying conservation of mechanical energy is $\frac{1}{2}(0.6 + 0.4)(2.4)^2 = \frac{1}{2}(400)x_m^2$ and hence $x_m^2 = \frac{2.4^2}{400}$

That is $x_m = \frac{2.4}{20} = 0.12\ \text{m}\ or\ 12\ \text{cm}$.

Work done by friction during the motion is

$w = -\mu mgx = -0.1 \times 0.6 \times 9.8 \times 10.2 = -6.0\ \text{J}$

15) AB is a section of a long conductor carrying constant current (indicated by the arrow) placed along the north-south direction, as shown in the figure. P, Q, R and S are four points around the conductor near the centre and close to the conductor as shown in the figure. A small magnetic compass can be placed horizontally at point P and Q. At point R and S, the plane of compass is placed vertically (axis along East-West). The magnetic needle is free to rotate in the plane of the compass, and its mass is negligible. The direction of the north pole of the compass deflects in the direction of the resultant magnetic field at that point. Choose the correct statement.



A) At point Q, the North pole of the compass will deflect towards the East.
B) At point P, the North pole of the compass will deflect towards the East.
C) At point R, the North pole of the compass will deflect vertically down.
D) At point S, the North pole of the compass will not deflect.

Solution (A): Using Ampere's right-hand thumb rule is
At point Q, direction is East. At point P, direction is West. At point R, direction is vertically upward. At point S, direction is vertically downward.

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Section II

(One or more option(s) may be correct)

16) Scientists have discovered that the desert moss S*yntrichia caninervis*, found in Antarctica, can survive extreme Martian conditions. Known for its resilience to drought, further research shows it can withstand temperatures as low as -196°C, low oxygen (95% CO_2), and tolerate high levels of gamma radiation, making it a strong candidate for colonizing Mars. Researchers suggest it could play a crucial role in building biologically sustainable habitats for humans on other planets. Which of the following properties makes *S. caninervis* a potential candidate for colonizing Mars?

A) Cellular activities generate water as a net by-product.
B) High reproductive rate as an advantageous trait.
C) Sexual reproduction.
D) Low nutrient requirements.

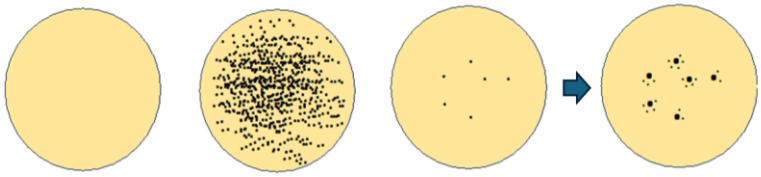
Solution: B and D

S*yntrichia caninervis* can be the 'pioneer species', which are characterized by their ability to tolerate harsh conditions, prepare the environment for sustenance of more complex species. Cellular metabolism in organisms, including mosses, generally involves water consumption (and recycling) rather than net production (thus, Option A is false). High reproductive rates allow it to rapidly colonise (thus, Option B is true). Sexual reproduction is inherently a rate-limiting process compared to asexual reproduction, so it may not be advantageous for a pioneering species (making Option C false). Interestingly, *S. caninervis* and other desert mosses have overcome this limitation by evolving asexual reproductive strategies. Being a photoautotroph, their low nutrient requirement is supported by the mineral activities of organic acids secreted by roots (thus, Option D is true).

17) Bacterial transformation is process where a bacterial cell takes up DNA from its environment. Gram-positive bacteria have this as an inherent property, but Gram-negative bacteria do require assistance. A student is tasked to perform bacterial transformation of an *Escherichia coli* strain with a suitable expression plasmid that allows the student to select the transformed cells having ampicillin resistance. The resistance to ampicillin was due to its degradation by the encoded protein that is secreted outside the cell. After transformation procedure, the bacterial cells were spread on plate containing ampicillin and incubated for 12 and 24 hr at 37°C. Parallelly, two more spread plates were done. One, to be sure of quality of antibiotic, bacterial cells alone were spread on plate with antibiotics. Second, to be assured that the bacterial strain is viable, they were spread on another plate without any antibiotics. These control plates were incubated as mentioned above.
The experimental observations are labelled as Plate 1, 2, 3a and 3b where the black dots on the plate indicate growth of bacterial colonies. The proposed hypothesis that can potentially explain the observations are stated as the options below. Mark the statements which is/are true.

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Components	Plate 1	Plate 2	Plate 3	
Bacterial cells spread	10^6	10^6	10^6	
Plate with ampicillin	100 mg/ml	0 mg/ml	100 mg/ml	
Plasmid DNA	0 ng	10 ng	10 ng	
Incubation time	12 hr	12 hr	**Plate 3a**: 12 hr	**Plate 3b**: 24 hr



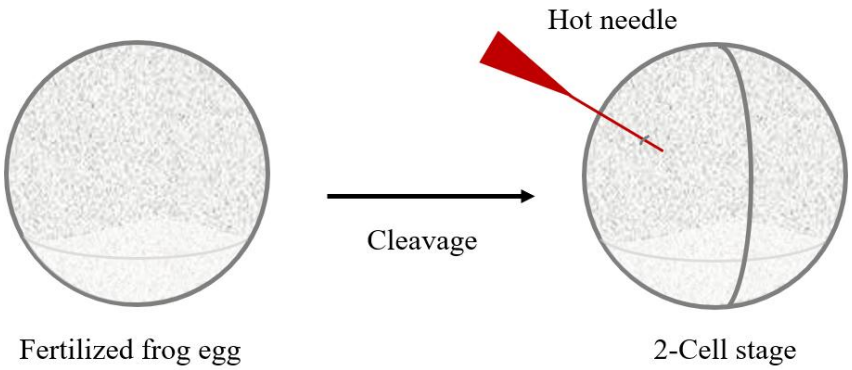
A) Instead of ampicillin, if a monobactam was used (both belong to same family of classification), a similar profile is expected to be observed.
B) The formation of big and small colonies as observed in Plate 3b results from fast growing and slow-growing transformants, usually observed after longer periods of incubation.
C) If Plate 1 was incubated further for 24 hrs, some small colonies would have appeared like in Plate 3b.
D) In Plate 3b, longer incubation led to ampicillin depletion around the transformant colonises and that allowed a few non-transformed cells to grow around as tiny colonies.

Solution: A and D

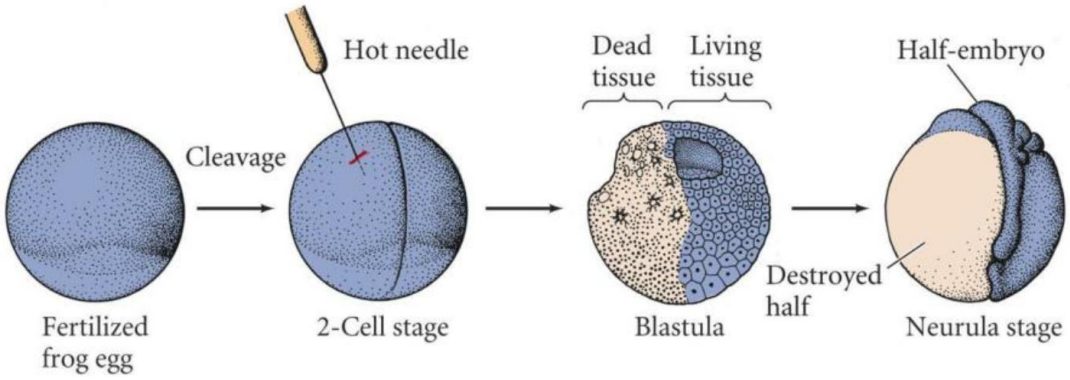
A is true as one of the fundamental principles of biological classification (taxonomy) is to group individuals based on identical and similar characteristics. The suggested experimental setup of Option B is false as only one strain of bacteria was used. Also, had it been so, smaller colonies would have come up randomly. Option C is false as there is no enzyme produced or present in Plate 1 to degrade the antibiotics. Option D is true as when Plate 3a were checked after 12 hr only those cells which got transformed secreted is enzyme to degrade ampicillin around it. When the same plate was incubated further for 12 hr (Plate 3b), as the transformant cells kept growing, in the surrounding region the ampicillin concentration significantly comes down due to its degradation and that allowed a few of the surviving non-transformed cells to start its growth. Since their growth initiated lately, their colony size is relatively small.
Note: Satellite colonies are a natural phenomenon in bacterial transformation experiments while using selection with penicillin and its derivatives. These smaller cells are not transformed; they do not start growing late but rather survive during antibiotic is getting degraded. They will never grow when transferred to a fresh plate with ampicillin.

18) Imagine a fascinating scenario where a fertilized frog egg begins its journey of development. This zygote has now undergone its very first division, resulting in two identical cells that together hold the potential to create a complete organism. This is a crucial phase in the early development of the frog embryo, where each of these two cells is identical in appearance. A scientist thought what would happen if one of the cells is pricked with a hot needle, without damaging the other cell?
Mark the statements which is/are true.

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A) The other cell develops into half embryo but then doesn't survive.
B) The other cell develops into complete embryo.
C) The other cell develops into a mature frog of half the natural size
D) The pricked cell does not contribute to the development of embryo.



Solution: A and D.

This is observations of Wilhelm Roux's experiment which led him to conclude that embryo development is mosaic in nature. Eventually, Driesch's Experiment proved him wrong. Option A is true as the remaining cell typically develops into half of the normal embryo but did not develop beyond as the pricking destroyed the cellular machinery from participating in any subsequent cell-cell-interactions, cell division or differentiation. Option B is false as the remaining cell cannot develop into a complete embryo by itself because it is missing essential contents from the destroyed cell. Option C is false as the normal developmental processes are shared between the two cells so a single cell cannot mature beyond embryo stage. Instead of pricking, if both cells are separated, both would have evolved into mature frogs owing to their totipotency. Option D is true as the cell that is destroyed by the hot needle does not contribute to the development of the embryo, as it is no longer viable.

19) In the final examination of Class X, a chemistry teacher asked her students to make different solutions of acid and alkali. The students prepared different mixtures according to the table given below. Each student ultimately mixed the solutions that they prepared into one flask.

Student	$HCl_{(aq)}$ solution (mL)			$H_2SO_{4(aq)}$ solution (mL)			$NaOH_{(aq)}$ solution (mL)			Pure water (mL)
	0.1 M	0.2 M	0.5 M	0.1 M	0.2 M	0.5 M	0.1 M	0.2 M	0.5 M	
U	-	20	-	25	-	-	-	-	20	35
V	50	-	-	-	-	10	-	25	-	15
W	25	-	-	-	25	-	-	-	25	25
X	-	20	-	-	20	-	20	-	-	40
Y	-	-	14	35	-	-	-	-	8	43
Z	-	-	20	-	15	-	-	30	-	35

After the mixing activity, which set of the students got a solution of approximately pH = 1 ?

A) U, W, X
B) V, X, Z
C) U, W, Y
D) V, Y, Z

Solutions (B & D):

Student	$HCl_{(aq)}$ solution (milli equivalent)	$H_2SO_{4(aq)}$ solution (milli equivalent)	$NaOH_{(aq)}$ solution (milli equivalent)	Acidic solution (milli equivalent)	pH
U	4	5	10	Basic	-
V	5	10	5	10	1
W	2.5	10	12.5	Neutral	-
X	4	8	2	10	1
Y	7	7	4	10	1
Z	10	6	6	10	1

Volume of the acid-alkali mixtures = 100 mL

20) Electron gain enthalpy is the energy change that occurs when an isolated gaseous atom gains an electron to form a negatively charged ion. It reflects the tendency of an atom to attract and bind an extra electron. Following experimental results are provided in the table as shown below:

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Process	Electron gain enthalpy ($kJmol^{-1}$)	Process	Electron gain enthalpy ($kJmol^{-1}$)
$O_{(g)} + e^- \rightarrow O^-_{(g)}$	-140	$S_{(g)} + e^- \rightarrow S^-_{(g)}$	-200
$O^-_{(g)} + e^- \rightarrow O^{2-}_{(g)}$	+780	$S^-_{(g)} + e^- \rightarrow S^{2-}_{(g)}$	+640

Choose the correct statement(s):

A) First electron gain process is more favourable for sulphur than that of oxygen because electron-electron repulsion is more in the valence shell of oxygen atom than that of sulphur atom.
B) Second electron gain process is more favourable for oxygen than that of sulphur because the size of O^{2-} anion is less than the size of S^{2-}.
C) $O_{(g)} + 2e^- \rightarrow O^{2-}_{(g)}$ process is more favourable than $S_{(g)} + 2e^- \rightarrow S^{2-}_{(g)}$ because the first ionisation energy of neon is higher than the first ionisation energy of argon
D) In general, the second electron gain enthalpy is positive because a negatively charged anion resists accepting an additional electron more than a neutral atom does.

Answer: (A) & (D)

21) A salt mixture is made with 0.03 mole each of iron (II) oxalate, iron (III) oxalate, iron (II) sulphite, iron (III) sulphite, iron (II) nitrate and iron (III) nitrate in acidic medium. The mixture is oxidised separately with potassium permanganate and potassium dichromate. Find the **CORRECT** statement(s) relating to above oxidation processes.

A) 33.53 g potassium dichromate is required for the oxidation process and two ions present in the salt mixture will not participate in the oxidation process.
B) 27.95 g potassium dichromate is required for the oxidation process and three ions present in the salt mixture will participate in the oxidation process.
C) 15.01 g potassium permanganate is required for the oxidation process and three ions present in the salt mixture will participate in the oxidation process.
D) 18.02 g potassium permanganate is required for the oxidation process and two ions present in the salt mixture will not participate in the oxidation process.

Solutions ((B) and (D)): In the above problem, only iron (II), oxalate and sulphite ions will participate in the reaction and oxidized by permanganate and dichromate ions separately in acidic medium, whereas iron (III) and nitrate ions will not participate in the reaction.

1) $5Fe^{2+} \rightarrow 5Fe^{3+} + 5e$
2) $2.5\ C_2O_4^{2-} \rightarrow 5CO_2 + 5e$
3) $2.5\ SO_3^{2-} + 2.5H_2O \rightarrow 2.5\ SO_4^{2-} + 5H^+ + 5e$
4) $MnO_4^- + 8H^+ + 5e \rightarrow Mn^{2+} + 4H_2O$
5) $Cr_2O_7^{2-} + 14H^+ + 6e \rightarrow 2Cr^{3+} + 7H_2O$

Total mole oxidised	Total mole permanganate required	Mass of permanganate required	Total mole of dichromate required	Mass of dichromate required

JEE JSO

Iron (II) --- 0.03+0.03+0.03=0.09	0.018		0.015	
Oxalate --- 0.03+0.09=0.12	0.048		0.04	
Sulphite --- 0.03+0.09=0.12	0.048		0.04	
	0.114	18.02 g	0.095	27.95 g

22) Four geometrical areas in the shapes of a parallelogram, a rhombus, a right-angled isosceles triangle and an equilateral triangle are taken. A point mass *m* is placed on the corners of every area. A unit mass must be placed at a point within the boundary of each of these areas so that it remains in equilibrium (masses interact gravitationally). Ignore the gravitational attraction due to the earth while working out this problem. Identify the correct options.

A) If the unit mass is kept at the centroid of each geometrical areas, it will be in equilibrium.

B) In the parallelogram and in the rhombus, the unit mass will be in equilibrium if placed at the intersection of their diagonals, and for equilibrium in the equilateral triangle, it should be kept on its in-centre.

C) In the rhombus and the parallelogram, the unit mass must be kept on the respective centroids, and in the equilateral triangle, the unit mass must be kept on its circumcentre.

D) There is no point inside the right-angled isosceles triangle for keeping this unit mass so that it remains in equilibrium.

Solution (B, C and D)

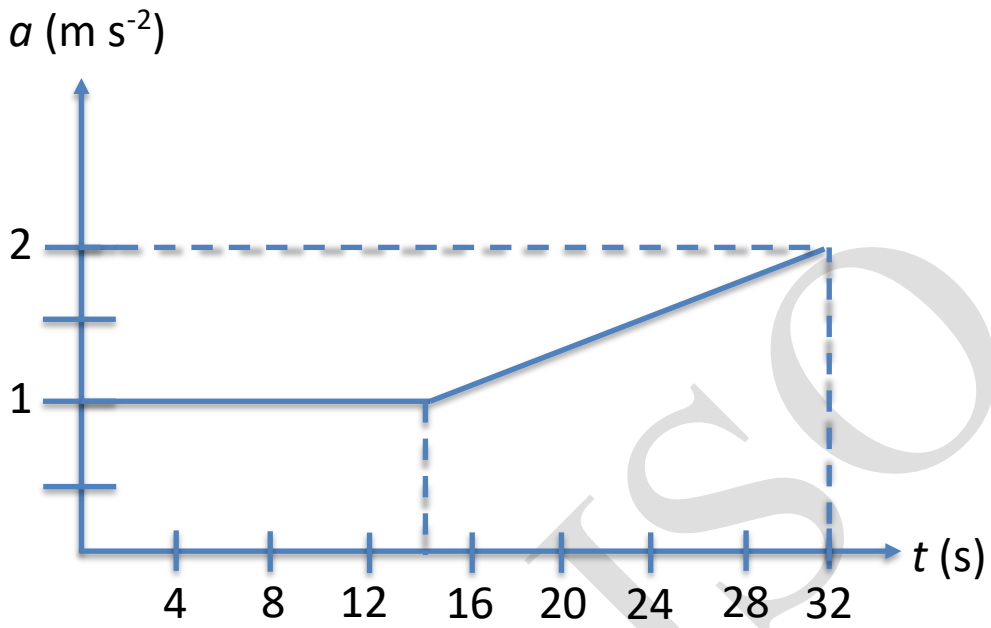
The centroid for the rhombus and the parallelogram is the point of intersection of their diagonals and the mid-point of the respective diagonal. So, a unit mass kept there should have equal and opposite forces of attraction from the two respective corners. And hence the unit mass will remain in equilibrium at that point.

In an equilateral triangle the centroid, the in centre and the circumcentre all are indicated by one unique point. However, this point may be referred to by different names. (So, the options B & C are correct)

In a right-angled isosceles triangle, a median drawn from the right-angle is a perpendicular to the hypotenuse. We can only look for a suitable point on this line for placing the unit mass. There is a point on this line where the two other lines drawn from the other two angles may meet to produce an angle of 120^0 between them. But the lengths of these two lines will not be the same as the line from the right angle drawn up to this point. Moreover, for this triangle the circumcentre lies on the hypotenuse giving no equilibrium for the unit mass placed there. The in-centre has got different distances from the different vertices. So, there is no point for arriving at equilibrium for this triangle. (so, option D is correct, and option A is wrong)

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23) In the graph shown below, the time-acceleration of a particle that has started from an initial velocity of 2 m s^{-1} is given. Identify the correct options given below.



A) The particle will have a displacement of 657 m at the end of 32 s.
B) The displacement of the particle cannot be determined using average acceleration as the particle is not moving with constant acceleration.
C) The particle will have a velocity 41 m s^{-1} after 32 s.
D) The velocity of the particle at the end of 32 s is 43 m s^{-1}.

Solution (B and D): Velocity at the end of 32 s is the sum of the two areas of *a-t* graph

option B is correct because for linear change of acceleration we can take the average acceleration to find velocity but not displacement. A is wrong since the displacement is calculated the using average acceleration.

$1 \times 32 + \frac{1}{2} \times 18 \times 1 = 41$ m s^{-1}. But the initial velocity was 2 m s^{-1}. So, the final velocity is 43 m s^{-1} Hence option D is correct.

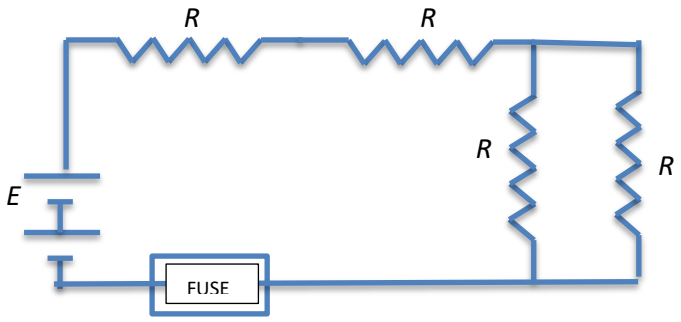
This can be done in an alternative way:

The velocity at the end of 14 s. 2 + 1. 14 = 16 m s^{-1}

For the next 18 s the average acceleration is 1.5 m s^{-2}. So, we may write,
16 + (1.5) 18 = 16 + 27 = 43 m s^{-1}.

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24) On an experiment board, four resistors, each of $R = 100\ \Omega$ rated 25 W, are connected to a DC supply of the emf equal to E volt and negligible internal resistance, as shown in the figure. A fuse wire of negligible resistance has been connected for protection. Choose the correct option/options.



A) The maximum possible value of E that can be applied, keeping the components safe is $E = 125$ V.
B) The maximum power that can be dissipated in all four resistors together is 62.5 W.
C) The current rating of fuse in the circuit is $I_{\max} = 1$ A.
D) The total power dissipated in all four resistors together when $E = 50$ V is 10 W.

Solution (A, B and D): Maximum permissible current in each resistor

$$I_{\max} = \sqrt{\frac{P}{R}} = \sqrt{\frac{25}{100}} = \frac{1}{2}\ \text{A}.$$

Equivalent resistance of combination $R_{\text{eq}} = 100 + 100 + \frac{100}{2} = 250\ \Omega$. The maximum value of $E = I_{\max}R_{\text{eq}} = \frac{1}{2} \times 250 = 125$ V. The maximum value of power is $P_{\max} = \left(\frac{1}{2}\right)^2 250 = 62.5$ W. Maximum current through fuse $I_{\max} = \frac{1}{2}$ A. When $E = 50$ V then

$$P = \frac{V^2}{R_{\text{eq}}} = \frac{50^2}{250} = 10\ \text{W}.$$

Section III

25) A decade ago, Suresh, Neema, Gulzar, David, Moriri, Indali, and Udit were schoolmates in Delhi, united by their shared passion for long-distance running. Moriri and Neema hailed from the highlands of Himachal Pradesh and Arunachal Pradesh, respectively, while Indali and Gulzar were born in coastal towns - Mangaluru and Vapi. Suresh, Udit, and David, on the other hand, were born in the plains: Chhattisgarh, Patna, and Anantapur, respectively.
Fast forward to present; now they are spread across various parts of India, each following different career paths. Suresh now supervises operations at the Mumbai dockyard, while Moriri works with an IT company in Bengaluru. Indali, a sports representative for Indian Railways, continues her passion for athletics. Gulzar leads a team in a textile industry, and Udit is part of an R&D team in a biotech company in Hyderabad. David serves in the Indian Army and is currently stationed in Ladakh, while Neema is a science communicator based in Bhopal.

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David planned for a hiking and trekking adventure to reunite with friends at Leh region after 6 months during summer. All happily agreed upon and Neema reached a month ahead via a roadway and took this opportunity to trek throughout Leh-Ladakh, interacting and spreading awareness among locals on issues of global warming. (**8 marks**)

Q1) During summer, rest others reached Leh by flight. Within a weeks' time some of them started to have mild to severe headache. Write the name(s) of people who had headache. **(2 Marks)**

Q2) Write the names of people who are relatively having higher RBCs in blood circulation than their other friends? (**2 Marks)**

Q3) If all of them start to trek within a weeks' time who all will be having higher lactic acid production in muscles? **(2 Marks)**

Q4**)** Doctor said that these headaches are outcome of _____. To have relief from this headache, locals suggested them to take ginger tea, which causes _____. Fill in the blanks with appropriate reasons. (**2 Marks)**

Solution

Q1) Ans: Suresh, Moriri, Indali, Gulzar, Udit. The actual cause of headaches at high altitude is altitude sickness/hypoxia (low oxygen levels in the blood) due to reduced atmospheric oxygen pressure at higher elevations. It leads to cerebral vasodilation (expansion of blood vessels in the brain) as the body tries to increase blood flow to deliver more oxygen to brain. This increased blood flow raises intracranial pressure, which contributes to the headache. Secondary outcomes are high blood pressure, dehydration and cold air just increases the pain. There is largely no association between the birthplace and adaption to hypoxia/high altitude conditions (except for some natives of Ladakh). So Moriri and Indali as well will have headache.

Q2) Ans: Indali, David and Neema. David and Neema have got acclimatised to Leh for a month and treks as well, whereas Indali is an active athlete. Again, Moriri must physiologically adapt to the new environment. Rest all aren't physically active now.

Q3) Ans: Suresh, Moriri, Indali, Gulzar and Udit. Since David and Neema are acclimatized and physically active at higher altitudes, anaerobic metabolism in their muscles will be much lower than in people coming from the plains. Although Moriri is an active athlete, she is from a plain region and is not yet acclimatized to high-altitude conditions. As a result, her muscles will rely more on anaerobic metabolism until she adapts to the lower oxygen levels.

Q4) Blank 1: hypoxia/low oxygen levels/altitude sickness; Blank 2: dilation of blood vessels. Note: 6-Gingerol in ginger temporarily dilates blood vessels to relieve headaches.

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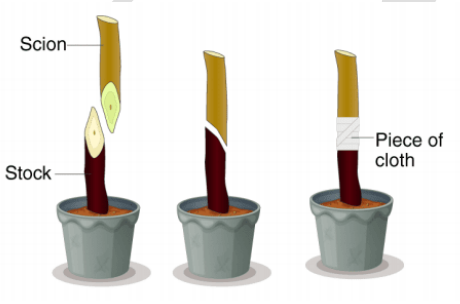
26) There are four sub-questions. There is no negative marking for any sub-questions.

(22 marks)

Q1) Transpiration takes place predominantly by stomata. They are specialised apparatus in epidermis with a pore space surrounded by two specialised cells called guard cells. These cells function as multisensory hydraulic valve. Environmental factors like light, temperature, relative humidity, and intracellular CO_2 are sensed by these guard cells and response leads to opening and closing of stomata. Mark the statement below as true and false with respect to stomatal movements. **(6 marks)**

A) Blue light activates proton pumps in guard cells. It will lead to ion uptake and water influx, which opens the stomata.
B) During stress conditions levels of abscisic acid increases. It will trigger opening of stomata to allow CO_2 intake to increase photosynthetic activity.
C) To open stomata, guard cells reduce turgidity and shrink itself reversibly.
D) Proton pump present in membrane of guard cells facilitates potassium ion uptake.
E) Potassium ions movement play key role and are actively transported into the guard cell during the opening and out during closing of stomata.
F) Low CO_2 concentration in leaves triggers stomatal opening meeting the requirement for photosynthesis

Q2) Graft is a widely used horticultural technique for plant propagation and development of new plant varieties using two segments (Scion and Stock) of plants from two different resources. **(2 marks)**



Arrange the statements given below that describes the sequential steps leading to a successful graft formation.

A) Formation of plasmodesmata at the cell-cell interface between scion and stock.
B) Regeneration of the cortex and epidermis at the interface between scion and stocks.
C) Coordinated development of vascular tissues at the interface between scion and stocks.
D) The cells at interface of scion and stock region go through a rapid phase of division forming callus.

Q3) Medicinal plants generally exhibit their therapeutic properties through the secondary metabolites. These are compounds that are produced by plants for various functions like defence against pathogens and pests, attractants for pollinators, signalling etc.

Below is a list of some examples that are attributed to the functional effects of secondary metabolites of various plants and their parts.

- Phenolics in the seeds consumed have antioxidant properties.

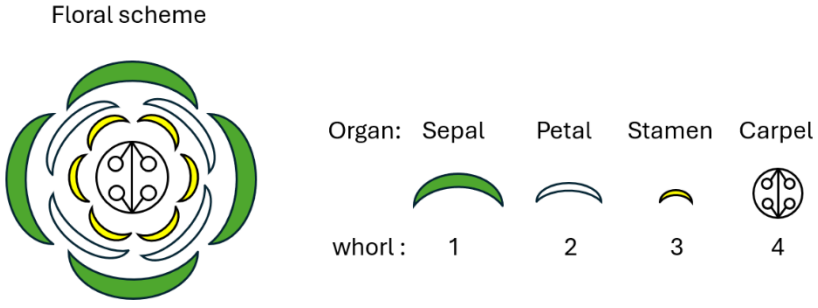
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- European travellers to Asia and Africa were advised to take bark infusion water as a precaution against malaria.
- Phytotoxic secretions from their roots are known to inhibit growth of other plants around it.
- Oil extract of leaves is used traditionally for wound healing.
- The astringent effect of the seeds relieves tooth ache.

Match the secondary metabolites of Column A with the use (in Column B) and the plant source (in Column C). **(5 marks)**

Column A	Column B	Column C
Secondary Metabolites	**Example**	**Plant Source**
1. Resveratrol	A. Anti-malarial	P. *Areca catechu*
2. Quinine	B. Analgesic	Q. *Mangifera indica*
3. Azadirachtin	C. Anti-inflammatory	R. *Arachis hypogaea*
4. Mangiferin	D. Insecticidal	S. *Azadirachta indica*
5. Catechins	E. Antioxidants	T. *Cinchona pubescens*

Q4) In *Arabidopsis thaliana*, a small weed, is an excellent model to study role of genes instructing the flowering pattern and location of organs. Flowers of *A. thaliana* are made up of four organs: sepal, petal, stamen and carpel which are arranged in circular layers called whorls.



Arabidopsis thaliana

Scientists discovered that the development of these flower parts is controlled by three groups of special genes called the A, B, and C genes which act alone or in combination to decide which part of the flower grows in each whorl. When they are mutated individually, in all the instances the number of whorls remained the same (4), but the floral parts within the whorls were replaced with floral parts from another whorl. It's never a mixture of random organs in any whorl.

- Mutation of gene A (Mutant A) resulted in flowers having only stamens and carpels.
- Mutation of gene B (Mutant B) resulted in flowers having only sepals and carpels.
- Mutation of gene C (Mutant C) resulted in flowers having only sepals and petals.

From the above information, deduce the outcome of the mutation(s) with respect to expression of organs in each whorl and fill in the complete words in each block. **(9 marks)**

Mutant type	Whorl number			
	1	2	3	4
Wild Type	Sepals	Petals	Stamen	Carpels
Mutant A				
Mutant B				
Mutant C				
Mutant AB				
Mutant AC				
Mutant BC				
Mutant ABC	Leaf-like	Leaf-like	Leaf-like	Leaf-like

Solution

Q1) (True: A, D, F False: B, C, E)

Q2) (D, A, C and then B): These are the sequential steps for a successful graft between the two different sources from callus formation, cellular connection, regeneration of vascular tissue to development of cortex and epidermal layer.

Partial marking only if sequence from start is correct, and not for correct middle or ending sequence.

Q3) 1 - E - R. 2 - A - T. 3 - D - S. 4 - C - Q. 5 - B - P.

Column A	**Column B**	**Column C**
Secondary Metabolites	**Use**	**Plant Source**
1. Resveratrol	E. Antioxidants	R. *Arachis hypogaea*
2. Quinine	A. Anti-malarial	T. *Cinchona pubescens*
3. Azadirachtin	D. Insecticide	S. *Azadirachta indica*
4. Mangiferin	C. Anti-inflammatory	Q. *Mangifera indica*
5. Catechins	B. Analgesic	P. *Areca catechu*

Mutant type	Whorl number			
	1	2	3	4
Wild Type	Sepals	Petals	Stamen	Carpels
Mutant A	Carpels	Stamens	Stamens	Carpels
Mutant B	Sepals	Sepals	Carpels	Carpels
Mutant C	Sepals	Petals	Petals	Sepals
Mutant AB	Carpels	Carpels	Carpels	Carpels
Mutant AC	Sepals	Sepals	Sepals	Sepals

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Mutant BC	Petals	Petals	Petals	Petals
Mutant ABC	Leaf-like	Leaf-like	Leaf-like	Leaf-like

Q4) The STEM clearly states that arrangement of whorls (1 to 4) in a flower - sepals, petals, stamens, and carpels - is always conserved in *Arabidopsis*. Mutations change the type of organ that forms in a whorl, not the spatial location of the whorls themselves.

Whorl	Floral Organ	Genes involved
1	Sepals	A
2	Petals	A + B
3	Stamens	B + C
4	Carpels	C

Individual mutational outcome reflects the default states as well as the interactional outcome of other genes. It leads to deciphering that gene A operates in in whorls 1 and 2; gene B operates in whorls 2 and 3; gene C operates in whorls 3 and 4.

27) pH TITRATION: Amit and Sumit have taken a joint school project under the guidance of their subject teacher to perform a weak acid (P) - strong base (Q) titration by using a pH meter and its theoretical verification at room temperature (30°C). Amit prepared an aqueous solution of **Q** in a 500 mL volumetric flask. 33 ml of this solution was utilised for complete neutralisation of 25 mL of a standard 1% (w/v) dibasic acid (molecular weight = 126). In another 500 mL volumetric flask, Sumit made an aqueous solution of 3.06% (w/v) monobasic acid **P** ($K_a = 4 \times 10^{-6}$). 25 mL of 0.12 M standard KOH solution was required to neutralise 20 mL of solution of **P**.

Now, Sumit started titration of acid (**P**) with base (**Q**) with a pH meter. 10 mL of aqueous acidic (**P**) solution is taken in a beaker and gradually small quantities of aqueous solution of base (**Q**) is added from the burette up to 19 mL mark. He noted the readings obtained from pH meter.

Their guide-teacher discussed the following concepts and equations for calculations of pH theoretically

$$\mathrm{HA\ (aq) + H_2O\ (l) \rightleftharpoons\ H_3O^+\ (aq) + A^-\ (aq)} \quad (1)$$

$$K = \frac{[H_3O^+][A^-]}{[HA][H_2O]} \quad (2)$$

$$K_a = \frac{[H_3O^+][A^-]}{[HA]} \quad (3)$$

$$\mathrm{pH} = \mathrm{p}K_a + \log \frac{[C_{\mathrm{salt}}]}{[C_{\mathrm{acid}}]} \quad (4)$$

$$\mathrm{pH} = 7 + \frac{1}{2}\mathrm{p}K_a + \frac{1}{2}\log C_{\mathrm{salt}} \quad (5)$$

The ionization equilibrium of the acid **P** is represented by equation (1). Applying the laws of chemical equilibrium we get equation (2). Since, concentration of water is very large and remains almost constant in solution; it can be combined with *K* to give another constant

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K_a, the ionization constant of acid, represented by equation (3). Before neutralisation or equivalence point and after addition of **Q**, equation (4) is valid. And at equivalence point equation (5) should be used.

Using these equations, Amit calculated pH of the solution mixture theoretically after each addition of **Q** in small quantities with above concepts and equations. Now, their guide-teacher compared both reading obtained from pH meter and theoretical calculation.

(21 marks)

Q 1: The molecular weight of monobasic acid P is **(2 marks)**

Q2: **(6 marks)**

Q 2.1: What is the molarity of solution Q?

Q. 2.2. Complete the following table in the answer sheet:

Neutralisation of 10 mL of aqueous solution of P with aqueous solution of Q

Sl. No.	**Volume of aqueous solution of Q added, mL**	**Calculated pH**
1	0.0	
2	1.0	
3	12.0	
4	12.5	
5	13.0	
6	19.0	

Q 3: **(5 marks)**

Q.3.1. Draw a graph of volume (mL) of Q added vs calculated pH, by connecting the points as a smooth curve. *(use the supplied graph sheet*)

Q. 3.2. Label the discrete parts that you notice on the curve. *(on the graph)*

Q. 3.3. Show the pH at equivalence on the graph.

Q 4: Provide a one/two sentence explanation for the transition that is noticed in terms of the concentration of the species in the solution, provide chemical equations to support your arguments. **(4 marks)**

Q.4.1. below pH ≈ 4.5 and

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Q.4.2. between pH ≈ 6.5 and pH ≈ 11.5.

Q 5: Considering the nature of the acid and base being used with respect to their ionisation power, justify the pH obtained at the equivalence point. Provide necessary chemical equations to support. **(2 marks)**

Q 6: Which indicator(s) would be preferred for the above titration? Choose from the given table and provide a 1-sentence explanation for your choice. **(2 marks)**

Indicator	**Colours**		**Colour transition pH range**
	Acid	**Base**	
Methyl violet	Yellow	Blue	0.0-1.6
Methyl orange	Red	Yellow	3.2-4.4
Methyl red	Yellow	Red	4.8-6.0
Bromothymol blue	Yellow	Blue	6.0-7.6
Phenol red	Yellow	Pink	6.8-8.0
Thymol blue	Yellow	Blue	8.0-9.6
Phenolphthalein	Colourless	Pink	8.2-10.0
Thymolphthalein	Colourless	Blue	9.3-10.5
Alizarin yellow	Yellow	Orange/Red	10.2-12.0

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SOLUTION Key for pH Titration

[Q1] **[2]**

25 mL of 0.12 M standard KOH solution is required to neutralise 20 mL aqueous solution made from above monobasic acid P. Thus, concentration of aqueous solution of monobasic acid P = [(25 x 0.12) / 20] M = 0.15 M.

Original solution of monobasic acid P = 3.06% (w/v).

Thus, 100 mL solution contains 3.06 g of monobasic acid P and 1000 mL solution contains 30.6 g of monobasic acid P. But, molarity of the solution is 0.15 M (which is calculated from the data obtained from titration with standard KOH solution).

Therefore, 1000 mL 0.15 M solution of monobasic acid P contains 30.6 g.

And, 1000 mL 1 M solution monobasic acid P contains 30.6/ 0.15 g = 204 g.

Therefore, molecular weight of monobasic acid P = 204

[Q2.1] Determination of concentration of aqueous solution of Q: **[2]**

Molecular weight of dibasic acid = 126

Equivalent weight of dibasic acid = 63

Concentration = 1% (w/v)

100mL contains 1g; then 25 mL contains 0.25 g.

Thus, g-equivalent of dibasic acid present in 25 mL solution = 0.25/63 = 0.00397

Then, in the aqueous solution g-equivalent of Q = 0.00397

Molarity of the aqueous solution of Q = (0.00397 x 1000)/33 = 0.12 M

[Q2.2] Neutralisation of 10 mL of aqueous solution of P with aqueous solution of Q: 6M

Here, 10 mL 0.15 M aqueous solution of monobasic weak acid A is titrated with 0.12 M aqueous solution of Q.

Determination of expression of pH for monobasic weak acid P: [2]

Using following equation for ionisation of monobasic weak acid P in aqueous solution:

$$HA\,(aq) + H_2O\,(l) \rightleftharpoons H_3O^+\,(aq) + A^-\,(aq)$$

We get ionisation constant, K_a for monobasic weak acid P in aqueous solution:

$$K_a = \{[H_3O^+]\,[A^-]\}/\,\{[HA]\}$$

Now, in aqueous solution, $[H_3O^+] = [A^-]$, thus, $K_a = [H_3O^+]^2/\,[HA]$, taking logarithm on both the side, and rearranging, we get,

$$pH = 1/2\ pK_a - 1/2 \log C_{acid}$$

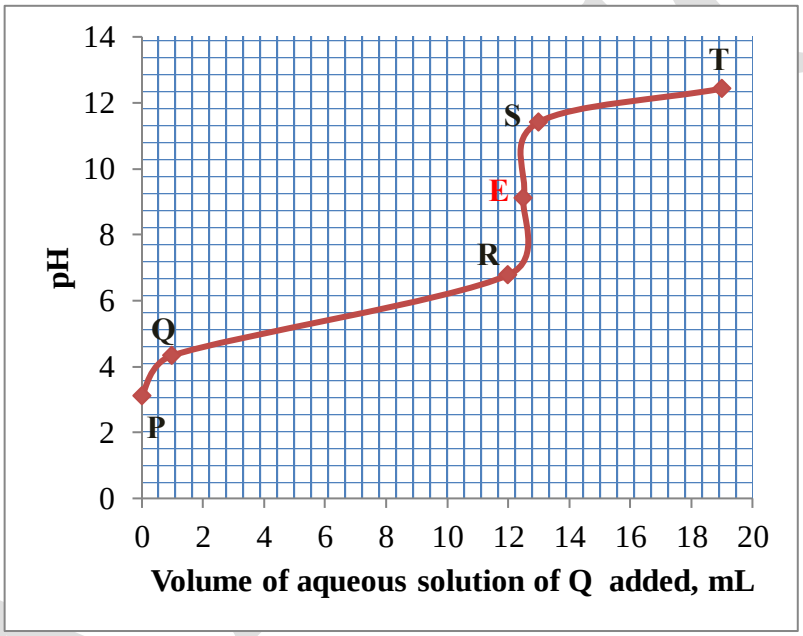
Table **[4]**

Sl. No.	Volume of aqueous solution of Q added, mL	Calculated pH
1 (1 mark)	0.0	$pH = 1/2\ pK_a - 1/2 \log C_{acid} = (½) \times 5.398 - (½) \times \log (0.15) = 2.699 + 0.412 = 3.111$
2 (0.5 marks)	1.0	$pH = pK_a + \log [C_{salt} / C_{acid}] = 5.398 + \log [0.12/(1.5 – 0.12)] = 5.398 – 1.061 = 4.337$
3 (0.5 marks)	12.0	$pH = pK_a + \log [C_{salt} / C_{acid}] = 5.398 + \log [1.44/(1.5 – 1.44)] = 5.398 + 1.380 = 6.778$

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4 (1 mark)	12.5	pH= 7 + 1/2 pK_a + 1/2 log C_{salt} = 7 + (½) x 5.398 + (½) x log [(0.15 x 10)/ 22.5] = 7 + 2.699 – 0.588 = 9.111
5 (0.5 marks)	13.0	$[OH^-]$ = (0.5 x 0.12)/ 23 = 0.0026 M; pOH= - log (0.0026) = 2.585; pH = 11.415
6 (0.5 marks)	19.0	$[OH^-]$ = (6.5 x 0.12)/ 29 = 0.0269 M; pOH= - log (0.0269) = 1.57; pH = 12.43

[Q3] Draw the above graph which was plotted by Sumit. **[5]**



[Q3.1] drawing the graph, labelling the axis and correct curve [3]

[Q3.2] labelling the discreet parts on the graph [1]

[Q3.3] marking the equivalence point [1]

[Q4] **[4]**

[Q4.1] Weak acids are not fully dissociated in solution so to begin with, we have a lower $[H^+]$, a higher starting pH and the presence of both weak acid molecule (HA) and its anion (A^-) in an equilibrium system. This state is indicated by the point P.

$$HA_{(aq)} \rightleftharpoons A^-_{(aq)} + H^+_{(aq)}$$

Just after addition of OH^- ions, a sudden jump is observed along PQ (first part of the curve). This is due to rapid conversion of the medium from a weak acidic solution to a buffer solution. **[2]**

[Q4.2] As both the acid (HA) and the conjugate base (A^-) are present, the solution acts as a buffer initially when the OH^- ions are added. These OH^- ions react with the H^+ ions causing the equilibrium position to shift to the right, generating more H^+. As a result, the H^+ ion concentration and hence the pH changes very slowly at the start of the titration which is observed along QR (second part of the curve). [2]

[Q5]A steep rise in the curve is observed after point R and pH jumps abruptly in the region RS. Mid-point between Q and R is the neutralisation or equivalence point (E). This neutralisation point is reached after the addition of 12.5 mL of 0.12 M aqueous solution of B. The pH at neutralisation point is observed as 9.1. This value remains identical for both pH metric study and calculation based on equation given; $pH = 7 + 1/2\ pK_a + 1/2 \log C_{salt}$. [2]

[Q6]

The pK_{In} values for the indicators thymol blue, phenolphthalein and thymolphthalein are very close to equivalence pH 9.1 for the above reaction. Any of the three indicators will be preferable for the above titration. **[1]**

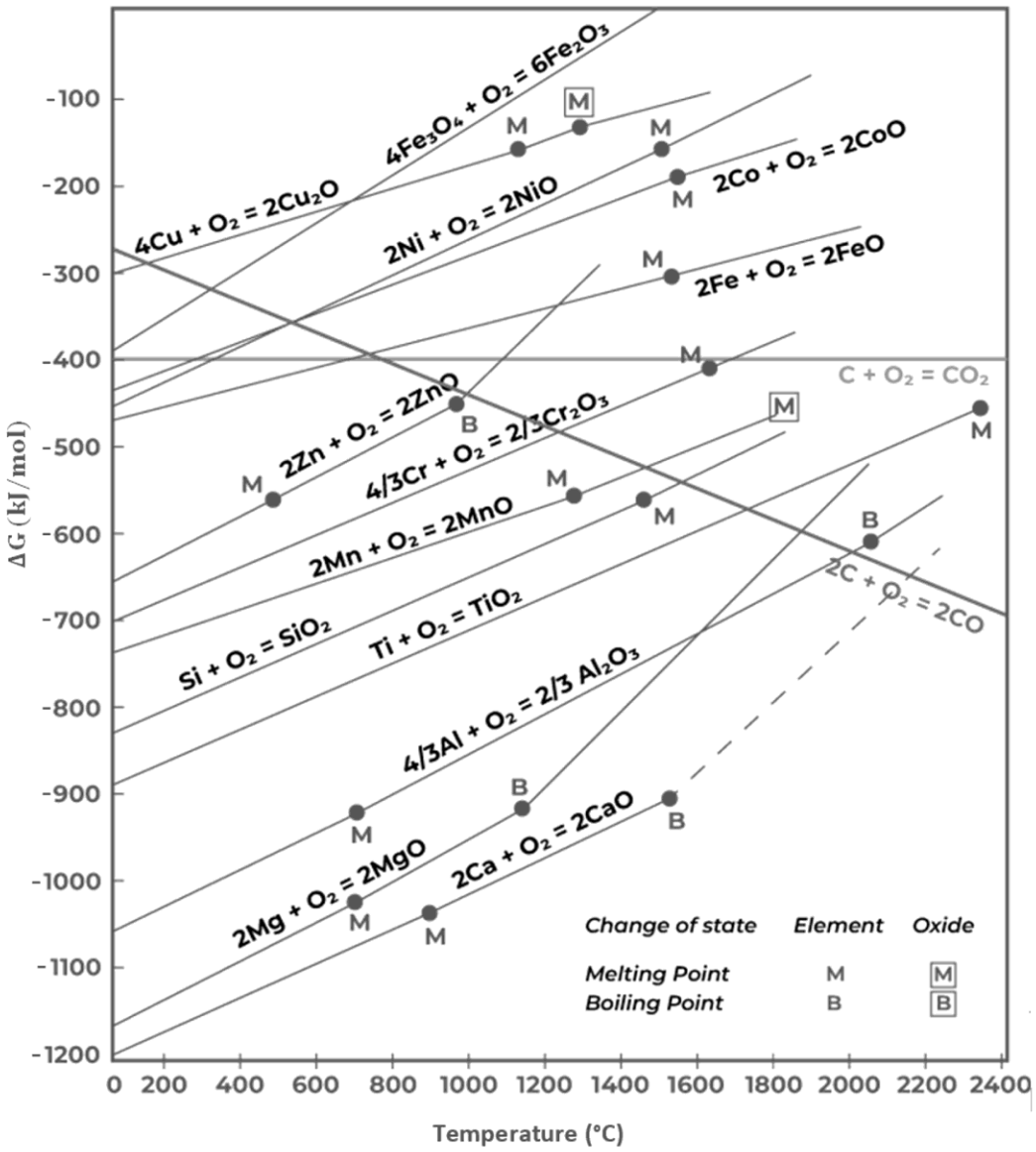
The most effective indicator, which I will choose, is phenolphthalein for the titration of weak monobasic acid A and base B, because sharp colour change from colourless to pink coupled with very near values of pK_{In} and equivalence pH makes phenolphthalein is the most effective indicator. **[1]**

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28) **METALLURGY :** Metals are extracted from their ores by various processes. Commonly, the metals in different chemical forms are converted into their oxides, and then these metal oxides are usually reduced to pure metal by using Carbon as reducing agent. Carbon combines with the oxygen of the metal oxide.

$$M_xO_y + yC \rightarrow xM + yCO$$

Ellingham diagrams are graphical representations used in metallurgy to predict the temperature dependence of the stability of oxides and other compounds. These diagrams plot the Gibbs free energy change (ΔG) of a reaction, typically involving the formation of a metal oxide after consuming one mole of oxygen, against temperature. Named after Harold Ellingham, who introduced them in 1944, they are valuable tools for understanding the thermodynamics of metal extraction and oxidation processes.



In an Ellingham diagram, the y-axis represents the Gibbs free energy change (ΔG) for the formation of oxide shown as metal + oxygen gas, and the x-axis represents temperature, usually in degrees Celsius or Kelvin. The change in Gibbs energy, ΔG for any process at any specified temperature, is described by the equation:

$$\Delta G = \Delta H - T\Delta S$$

where, ΔH is the enthalpy change and ΔS is the entropy change for the process. Enthalpy is a measure of the total heat content of a system. Entropy is a measure of the randomness or disorder of a system. Entropy increases from solids to liquids to gases due to the increasing freedom of movement and arrangement of molecules.

Ellingham diagrams are useful in determining which reducing agent can be employed to reduce a particular metal oxide. A reducing agent will only reduce an oxide if it results in a decrease in Gibbs free energy. On the diagram, this can be visualized by comparing the position of the lines for the metal oxide and the reducing agent's reaction with oxygen. The reducing agent must have a more negative ΔG at the specific temperature for the

reduction to be spontaneous. Therefore, the magnitude of the difference in the ΔG values for the formation of oxides helps in selecting the reducing agent. The greater the difference, the more spontaneous the reaction.

For example, carbon is often used as a reducing agent in metallurgy. The line for the formation of carbon monoxide from carbon intersects with the lines for various metal oxides at different temperatures. This intersection point indicates the temperature above which carbon can reduce that specific metal oxide to its metal form. The Ellingham diagram thus helps metallurgists determine the optimal temperatures and conditions for smelting and refining metals, such as in the extraction of iron in a blast furnace. **(9 marks)**

Based on the information given about Ellingham diagrams, answer the following:

Q1: Explain based on the nature of the reactants and products, why most of the lines in the Ellingham diagram slope upwards **(2 marks)**

Q2: Carbon forms two different oxides. Lines corresponding to formation of one of the oxides slopes downward with increase in temperature and the other one stays horizontal. Give a one/two sentence explanation for this phenomenon. **(2 marks)**

Q3: Bharathi was working in the research section of a metallurgical industry. She received an oxide ore each of Zinc and chromium to determine the conditions to extract the metals from their respective ores. She referred the Ellingham diagram. What would be the minimum temperature at which carbon can be used as a reducing agent to reduce the zinc ore? Write a balanced chemical equation denoting the process. **(2 marks)**

Q4. What are the possible metals that can reduce Cr_2O_3? Arrange them in the increasing order of their reducing ability at 800 °C. Which among them would be the most economical reducing agent that can be used. **(3 marks)**

Solution key for Metallurgy

[Q1] The formation of metal oxides consumes oxygen gas. As a result, entropy decreases and ΔS becomes negative. As temperature increases, the term $T\Delta S$ in the straight-line equation becomes positive. Therefore, the line slopes upwards. OR As temperature increases, the formation of oxides becomes less favourable, leading to an upward slope. Also, entropy for the formation of oxides increases and therefore negative ΔG decreases. [2]

[Q2] Carbon Monoxide Formation ($C + O_2 \rightarrow 2CO$): In the formation of CO, consumption of one mole of oxygen gas results in the formation of two moles of CO gas. Therefore, entropy increases and ΔS becomes positive. The line slopes downwards. It also implies that CO becomes more stable at higher temperatures due to higher $-\Delta G$ value. The reaction has a significant entropy change due to the production of gaseous CO. As temperature increases, the term $-T\Delta S$ in the Gibbs free energy equation becomes more negative (since ΔS is positive), making the overall ΔG more negative. The line slopes downwards. [1]

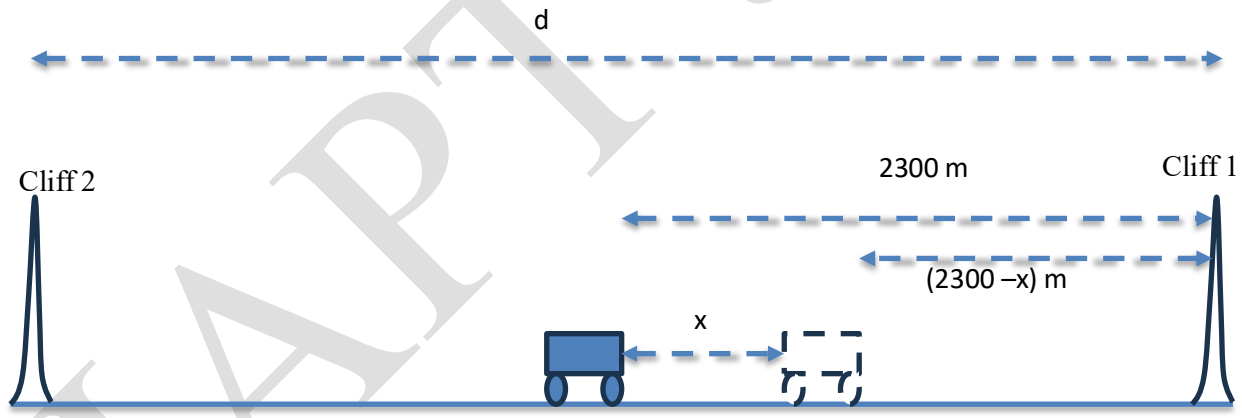
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Carbon Dioxide Formation ($C + O_2 \rightarrow CO_2$): In the formation of CO_2, consumption of one mole of oxygen gas results in the formation of one mole of CO_2 gas. Therefore, there is no change in entropy. The line is horizontal. This reaction has a lower increase in entropy compared to the formation of CO because both reactants (C and O_2) and the product (CO_2) are in simpler forms, with no significant increase in disorder. ΔG does not vary significantly with temperature. The line for ΔG remains nearly parallel to the temperature axis. [1]

[Q3] Conditions to reduce ZnO using carbon from Ellingham's diagram is 1100°C and limited supply of C [1]
The balanced chemical equation is $ZnO(s) + C(s) \rightarrow Zn(g) + CO(g)$ at 1100°C [1]

[Q4] The possible metals that can reduce Cr2O3 are Mn, Ti, Al, Mg, Ca [1]
Mn< Ti < Al < Mg< Ca in the increasing order of their reducing ability. [1.5]
Al is the most economical reducing agent. [0.5]

29) An engine is running at a speed of 72 km hr^{-1} towards cliff 1 along a railway track laid between two cliffs 1 & 2 separated by d km. The engine makes a whistle when it is 2.3 km away from the cliff in front of it. The driver of the engine receives the first echo from cliff 1 after 13 s. If the engine driver receives the 2nd echo 4 s after the first one, find the distance between the two cliffs and the velocity of sound. When will the engine driver receive a third echo, and what direction would that come from? **(5 marks)**



Solution: (a) Speed 72 kmph is 20 m s^{-1}.

In case of first echo, the time taken can be expressed as $t = \frac{2300+2300-x}{v}$

That is $13v = 4600 - x$. Here x is distance travelled by engine in 13 s. Thus, velocity of sound is $v = \frac{4600-(20\times13)}{13} = 333.85 \text{ m s}^{-1}$ (1.5 marks)

(b) In case of second echo which comes from cliff 2, the time taken can be expressed as $t = \frac{(d-2300)+(d-2300)+x}{v}$. That is $17v = 2d - 4600 + x$.

But the value of $x = 17 \times 20 = 340$

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Thus $17 \times 333.85 = 2d - 4600 + 340$. The distance between the two cliffs is

$d = \frac{9935.45}{2} = 4967.73$ m or 4.967 km. (2 marks)

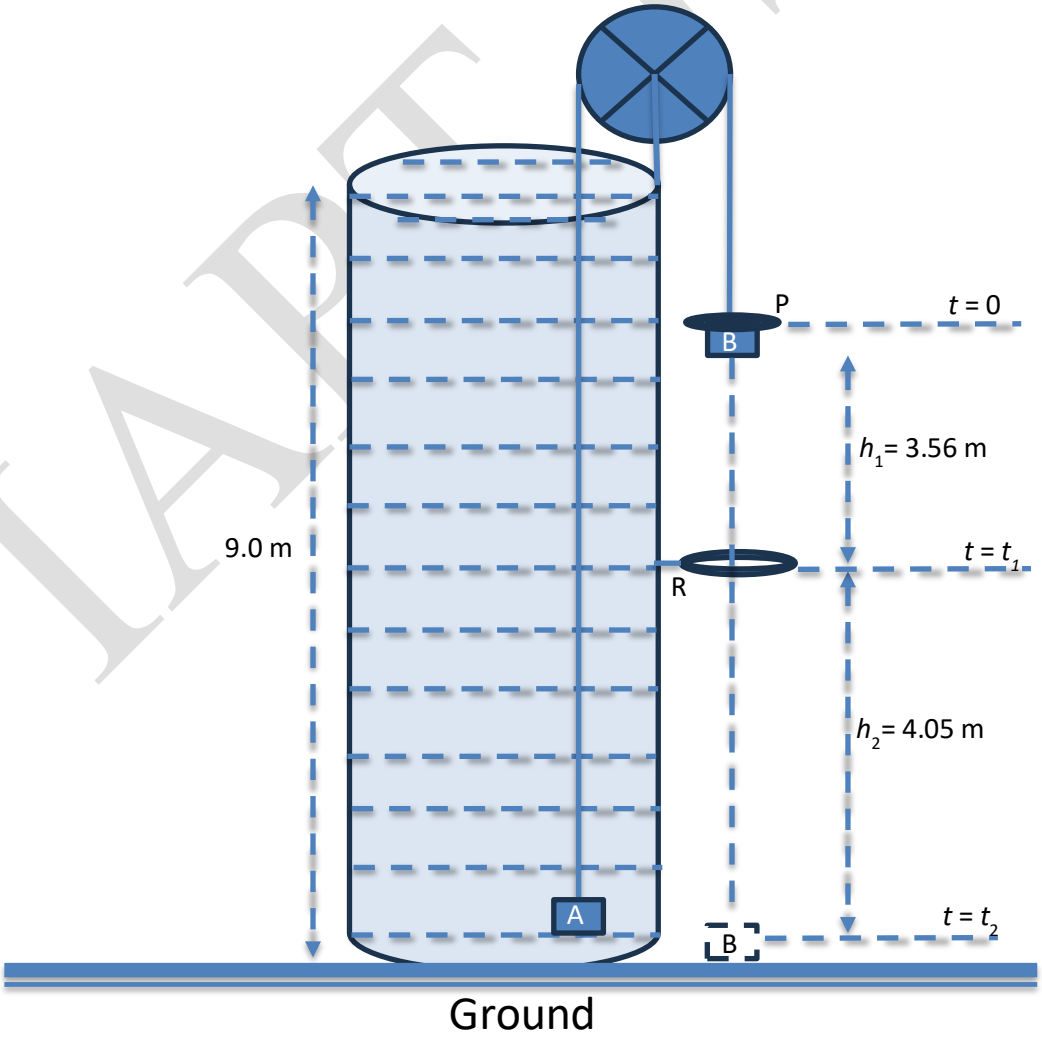
(c) The third echo will be from the second reflection from cliff 1 (sound coming from cliff 2 and reflecting at cliff 1). For the third echo is

$$vt = (2300 - x) + (2300 - x) - 20t = 4600 - 2(20 \times 170) - 20t$$

Thus $vt + 20t = 3920$.

The time taken for the third echo is $t = \frac{3920}{333.8+20} = 11.08$ s (1.5 marks)

30) A tank placed on the ground is filled with water up to a height of 9.00 m. A frictionless light pulley is attached to the top edge of the tank. Two identical cubical blocks, A and B, each of edge length 10 cm and relative density 5, are connected to two free ends of a light inextensible string which passes over this pulley. Thus, block A is hanging inside the water and block B is in the air. A rider P of mass 1kg is placed on block B. The arrangement is shown in the figure given below.



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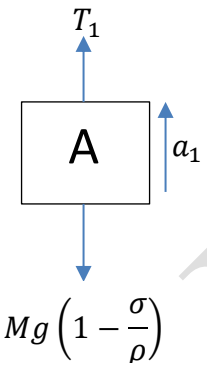
When the system is released at instant $t = 0$, block B with the rider descends through a distance h_1 for time t_1. At this instant, the rider is caught by the ring R that allows block B only to pass through it. At latter instant of time t_2, the block strikes the ground.
Assume that air resistance is negligible, and the effects of surface tension and viscosity of water are ignored. Density of water is 1000 kg m^{-3}. Answer the following questions.
(12 marks)

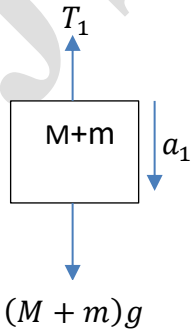
Q1) What are the masses of block A and B? **(1 mark)**
Q2) Calculate the acceleration of block A and tension in the string during time $t = 0$ to t_1 **(3 marks)**
Q3) Calculate the acceleration of block B and tension in the string during time $t = t_1$ to t_2. **(3 marks)**
Q4) Find out the values of t_1 and t_2. **(3 marks)**
Q5) Calculate the velocities of block A at instants of time t_1 and t_2. **(2 marks)**

Solution:

Q1. The volume and mass of each block is (1 mark)

$V = (10^{-1})^3 = 10^{-3}\text{m}^3$ and m = density × volume $= 10^{-3}(5 \times 10^3) = 5$ kg





Q2. Acceleration and tension during $t = 0$ to t_1: (3 marks)

For block A: $T_1 - Mg\left(1-\frac{\sigma}{\rho}\right) = Ma_1; T_1 - 5g\left(1-\frac{1}{5}\right) = 5a_1; T_1 - 4g = 5a_1$ (1)

For block B: $(M+m)g - T_1 = (M+m)a_1$ and $6g - T_1 = 6a_1$ (2)

Adding (1) and (2): $6g - 4g = (6+5)a_1$ and $a_1 = \frac{2g}{11} = \frac{2\times 9.8}{11} = 1.78$ m s^{-2}

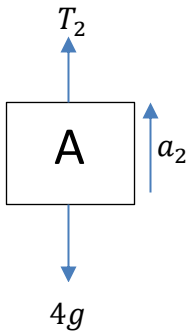
Tension $T_1 = 4g + 5a_1 = 4g + \frac{2g}{11} = \frac{46g}{11} = 48.1$ N

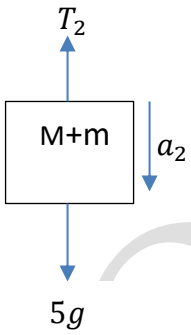
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Q3. Acceleration and tension during $t = t_1$ to t_2: (3 marks)

For block A: $T_2 - 4g = 5a_2$ (3)

For block B: $5g - T_2 = 5a_2$ (4)





Adding (3) and (4) $5g - 4g = (5 + 5)a_2$ and $a_2 = \frac{g}{10} = 0.98\ \text{m s}^{-2}$

Tension $T_2 = 4g + 5a_2 = 4g + \frac{5g}{10} = \frac{45g}{10} = 44.1\ \text{N}$

Q4. Time taken to reach the ring, $t_1 = \sqrt{\frac{2h_1}{a_1}} = \sqrt{\frac{2\times3.56}{1.78}} = 2\ \text{s}$. (3 marks)

At time t_1, the velocity is $v_1 = a_1 t_1 = 1.78 \times 2 = 3.56\ \text{m s}^{-1}$

Time taken t by the block B to travel from ring to table can be obtained using equation

$h_2 = v_1 t + \frac{1}{2} a_2 t^2$

$$4.05 = 3.5t + \frac{1}{2}0.98t^2$$

$$7t^2 + 50.86t - 57.8 = 0$$

Solving we get $t = 1$ or -8.26. Thus, the time taken is 1 s and the value of $t_2 = 3$ s.

Q5. The velocity of block A and B at time t_2 is given by $v_2 = v_1 + a_2 t = 3.56 + 0.98 \times 1 = 4.54\ \text{m s}^{-1}$.

The velocity of block A is 4.48 m s^{-1} in the upward direction. (2 mark)

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31) A moving coil galvanometer of the resistance $R_G = 50\ \Omega$ has equally spaced 30 division graduated on its circular scale. The deflection produced in galvanometer is directly proportional to the current passing through it.
When this galvanometer is connected in a single loop closed circuit in series with a battery (emf = 2.0 V, internal resistance is negligible) and a resistor $R = 9950\ \Omega$, the current produces a deflection of 10 division on the galvanometer scale. **(5 marks)**

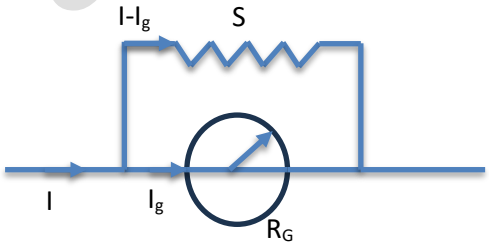


Q1) Calculate full scale deflection current I_g for this galvanometer. **(1 mark)**
Q2) Calculate the approximate value of resistance S that must be connected in parallel with this galvanometer to measure the current range 0 to 3 A.**(1.5 marks)**
Q3) If the shunt resistance in Q1 is a metal wire of length 15.7 cm of material having resistivity $2 \times 10^{-8}\ \Omega$ m, calculate the diameter of the wire. **(1.5 marks)**
Q4) Estimate the resistance of the ammeter so designed. **(1 mark)**

Solution:

Q1) The maximum current $I_g = \frac{E}{R+R_G}\frac{N}{n} = \frac{2.0}{9950+50} \times \frac{30}{10} = 600\ \mu A.$

Q2) To convert the galvanometer into $(0 - I)$ ammeter. In parallel combination, the voltage is same.



That is $(I - I_g)S = I_g R_G$

The shunt required is $S = \frac{I_g}{I-I_g} R_g = \frac{6\times10^{-4}}{3-6\times10^{-4}}\ 50 \cong 0.01\ \Omega$

Q3) In case of metal wire, $S = \frac{\rho l}{\pi r^2}$ or $r^2 = \frac{\rho l}{\pi S} = \frac{(2\times10^{-8})(15.7\times10^{-2})}{3.14\times10^{-2}} = 10^{-7}.$

The radius of the wire is $r = 0.316 \times 10^{-3}$ m.

The diameter of the wire is $d = 2r = 0.632 \times 10^{-3} m = 0632$ mm.

Q4) The resistance of ammeter is $R_A = \frac{R_G R_S}{R_G+R_S} = \frac{50\times0.01}{50+0.01} \cong 0.01\ \Omega.$

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32) Consider the following grid. The first column consists of optical objects (like mirrors, glass lenses, etc., kept in the air) and phenomena (formation of rainbow, mirage). The first row gives a list of optical properties and types of images. The incident beam is monochromatic. It can be diverging or parallel. Ignore partial reflection from the first surface of glass lenses or prism. Diminished image includes point image. All you should do is to place tick mark/s (√) in all the applicable cell/s. For Every wrong tick, 0.25 mark will be deducted. (**8 marks**)

	Prominent reflection	Refraction	Partial Internal reflection	Total internal reflection	Real image	Virtual image	Image size greater than object size	Image size smaller that object size	Image of same size
Metallic Convex mirror									
Metallic Concave mirror									
Equilateral glass prism									
Thin biconvex lens									
Thin biconcave lens									
Prism binoculars									
Metallic plane mirror									
Rainbow									

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Solution:

	Prominent reflection	Refraction	Internal reflection	Total internal reflection	Real image	Virtual image	Magnified image	Diminished image	Image of same size
Metallic Convex mirror	√					√		√	
Metallic Concave mirror	√				√	√	√	√	√
Equilateral glass prism		√		√		√			√
Thin biconvex lens		√			√	√	√	√	√
Thin biconcave lens		√				√		√	
Prism binoculars		√		√	√	√		√	
Metallic plane mirror	√					√			√
Rainbow		√	√						

There are totally 32 tick marks. The maximum marks are 8.

0.25 mark will be deducted for every addition tick mark other than these 32.

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