CBSE Class 12 Physics

Sample Paper – 3

Duration: 180 Minutes **Maximum Marks: 70**

General Instructions

- This question paper contains **33 questions**. **All questions are compulsory**.
- The paper is divided into **five sections** – A, B, C, D and E.
- **Section A** (Q1–Q16) carries **1 mark** each: Q1–Q12 are multiple choice questions and Q13–Q16 are Assertion–Reason questions.
- **Section B** (Q17–Q21) carries **2 marks** each (Very Short Answer).
- **Section C** (Q22–Q28) carries **3 marks** each (Short Answer).
- **Section D** (Q29–Q30) carries **4 marks** each (case study based, with sub-parts).
- **Section E** (Q31–Q33) carries **5 marks** each (Long Answer).
- There is **no overall choice**, but an **internal choice** has been provided in some questions. Attempt only one of the alternatives in such questions.
- There is **no negative marking**. Use of a **calculator is not permitted**. You may use $c = 3 \times 10^8$ m/s, $h = 6.63 \times 10^{-34}$ J s, $e = 1.6 \times 10^{-19}$ C as required.

Section A (Q1–Q16) – 1 Mark Each

Q1. The electric potential at a point at distance r from a point charge is V. If the distance is halved to $r/2$, the potential at that point becomes:

(A) $2V$

(B) $\frac{V}{2}$

(C) $4V$

(D) $\frac{V}{4}$

Q2. Which of the following quantities of a conductor is *independent* of its length and area of cross-section?

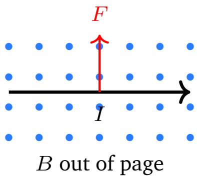
(A) Resistance

(B) Conductance

(C) Resistivity

(D) Drift velocity

Q3. A straight wire of length $L = 0.2$ m carries a current $I = 4$ A at right angles to a uniform magnetic field $B = 0.5$ T, as shown. The magnitude of the force on the wire is:



(A) 0.2 N

(B) 0.4 N

(C) 4 N

(D) 8 N

Q4. A conducting rod of length l moves with velocity v perpendicular to a uniform magnetic field B. The motional emf induced across its ends is:

(A) Bvl^2

(B) $\dfrac{Bv}{l}$

(C) $\dfrac{Bl}{v}$

(D) Blv

Q5. As the frequency of the applied AC source is increased, the capacitive reactance $X_C = \dfrac{1}{2\pi fC}$ of a capacitor:

(A) increases

(B) remains unchanged

(C) decreases

(D) first increases then decreases

Q6. Which type of electromagnetic wave is used in RADAR systems and in traffic speed guns?

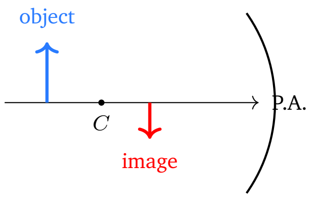
(A) Microwaves

(B) Gamma rays

(C) Ultraviolet rays

(D) X-rays

Q7. A concave mirror forms a real, inverted image of an object placed in front of it, as shown. The sign of the linear magnification m of this image is:



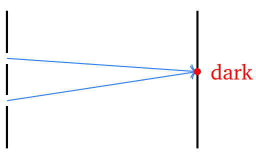
(A) positive and greater than one

(B) negative

(C) zero

(D) positive and less than one

Q8. In Young's double-slit experiment, a dark fringe is formed at a point on the screen when the path difference between the two interfering waves equals:



(A) $n\lambda$

(B) $2n\lambda$

(C) $(2n+1)\lambda$

(D) $\left(n+\frac{1}{2}\right)\lambda$

Q9. In a photoelectric experiment, a graph of the stopping potential V_0 against the frequency ν of the incident light is a straight line. Its slope is equal to:

(A) $\frac{e}{h}$

(B) h

(C) $\frac{h}{e}$

(D) he

Q10. The binding energy per nucleon of nuclei is maximum (about 8.8 MeV) for nuclei near which mass number A?

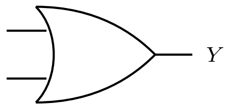
(A) 56

(B) 120

(C) 238

(D) 4

Q11. The logic gate whose symbol is shown below (curved back at the input side, no bubble at the output) is a:



(A) AND gate

(B) OR gate

(C) NAND gate

(D) NOR gate

Q12. Two capacitors of capacitance $3\,\mu$F and $6\,\mu$F are connected in *parallel*. The equivalent capacitance of the combination is:

(A) $2\,\mu$F

(B) $\frac{1}{9}\,\mu$F

(C) $18\,\mu$F

(D) $9\,\mu$F

Q13. Assertion (A): Kirchhoff's junction rule states that the algebraic sum of the currents meeting at a junction of a circuit is zero.
Reason (R): The junction rule is a consequence of the conservation of electric charge.

(A) Both A and R are true and R is the correct explanation of A.

(B) Both A and R are true but R is *not* the correct explanation of A.

(C) A is true but R is false.

(D) A is false but R is true.

Q14. Assertion (A): A transformer works with alternating current but not with direct current.
Reason (R): A transformer can step up or step down an alternating voltage.

(A) Both A and R are true and R is the correct explanation of A.

(B) Both A and R are true but R is *not* the correct explanation of A.

(C) A is true but R is false.

(D) A is false but R is true.

Q15. Assertion (A): When white light passes through a glass prism, red light deviates the least.
Reason (R): The refractive index of glass is greater for red light than for violet light.

(A) Both A and R are true and R is the correct explanation of A.

(B) Both A and R are true but R is *not* the correct explanation of A.

(C) A is true but R is false.

(D) A is false but R is true.

Q16. **Assertion (A):** A nucleus with a smaller binding energy per nucleon is more stable.

Reason (R): The binding energy per nucleon is a measure of the stability of a nucleus.

(A) Both A and R are true and R is the correct explanation of A.

(B) Both A and R are true but R is *not* the correct explanation of A.

(C) A is true but R is false.

(D) A is false but R is true.

Section B (Q17–Q21) – 2 Marks Each

Q17. A capacitor of capacitance $5\,\mu$F is charged to a potential difference of 100 V. Calculate the energy stored in the capacitor. **[2]**

Q18. Two resistors of $6\,\Omega$ and $3\,\Omega$ are connected in parallel. Find the equivalent resistance of the combination. **[2]**

Q19. The current in the primary of a pair of coils changes at the rate of 20 A/s and induces an emf of 10 V in the secondary. Calculate the mutual inductance of the pair of coils. **[2]**

OR

A series RL circuit connected to an AC source has resistance $R = 30\,\Omega$ and inductive reactance $X_L = 40\,\Omega$. Find the power factor of the circuit.

Q20. An object is placed 20 cm in front of a concave mirror, and its real image is formed 30 cm in front of the mirror. Find the linear magnification produced by the mirror. **[2]**

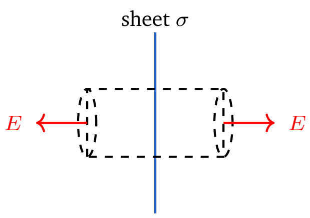
Q21. Light of frequency 1×10^{15} Hz falls on a metal of work function 2 eV. Using Einstein's photoelectric equation, find the stopping potential for the emitted photoelectrons. (Take $h = 6.63 \times 10^{-34}$ J s, 1 eV$= 1.6 \times 10^{-19}$ J.) **[2]**

OR

A radioactive sample contains 2×10^6 nuclei and has a decay constant $\lambda = 0.05\ \text{s}^{-1}$. Find the activity of the sample.

Section C (Q22–Q28) – 3 Marks Each

Q22. Using Gauss's law, derive an expression for the electric field due to an infinite plane sheet of charge with uniform surface charge density σ, using a cylindrical (pillbox) Gaussian surface.



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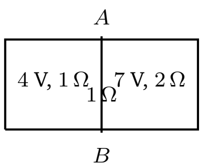
Q23. In the two-loop network shown, a cell of emf 4 V (internal resistance $1\,\Omega$) and a cell of emf 7 V (internal resistance $2\,\Omega$) drive current through a $1\,\Omega$ resistor connected between the junctions. Using Kirchhoff's rules, find the current in each of the three branches.



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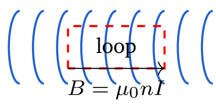
Q24. Using Ampere's circuital law, derive an expression for the magnetic field B inside a long straight solenoid having n turns per unit length and carrying current I.



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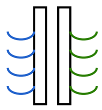
Q25. A transformer draws an input power of 1000 W from the mains. The power delivered to the load in the secondary circuit is measured to be 800 W. Find the efficiency of the transformer.



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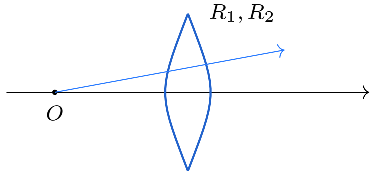
OR

Explain, with a rough sketch, how the inductive reactance X_L and the capacitive reactance X_C of a series AC circuit vary as the frequency f of the source is increased from a low value.

Q26. Derive the lens maker's formula $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ for a thin convex lens, with the help of a ray diagram.



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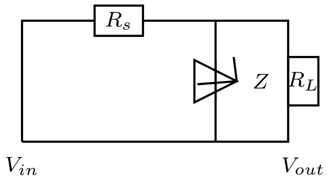
OR

A tank contains water of refractive index $\mu = \frac{4}{3}$. A coin lies at the bottom, at a real depth of 4 cm below the surface. Find the apparent depth of the coin as seen from directly above, and the apparent upward shift.

Q27. An electron is accelerated from rest through a potential difference of 100 V. Using the relation $\lambda = \frac{12.27}{\sqrt{V}}$ Å (with V in volts), calculate the de Broglie wavelength associated with the electron. **[3]**

Q28. With the help of a labelled circuit diagram, explain how a Zener diode is used as a voltage regulator.



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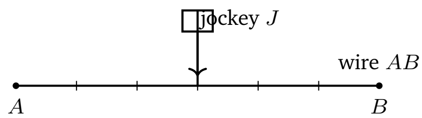
Section D (Q29–Q30) – 4 Marks Each (Case Study)

Q29. Case Study – The Potentiometer.

A potentiometer has a long uniform resistance wire AB along which a steady current flows from a driver cell. Because the potential drop is proportional to the length of wire, a potentiometer can compare emfs and measure the internal resistance of a cell without drawing current at balance.



Based on the above, answer the following:

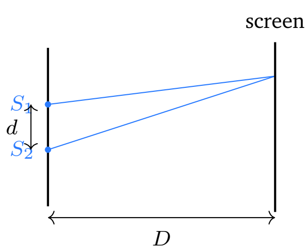
(i) State the principle on which a potentiometer works. (1)

(ii) Two cells are balanced at lengths 300 cm and 150 cm respectively. Find the ratio of their emfs $E_1 : E_2$. (1)

(iii) A cell balances at 250 cm on open circuit. When a resistance $R = 4\,\Omega$ is connected across the cell, the balance length falls to 200 cm. Find the internal resistance of the cell. (2)

Q30. Case Study – Young's Double-Slit Experiment.

Two narrow slits S_1 and S_2, separated by d, are illuminated by monochromatic light of wavelength λ. On a screen at distance D the superposition of the two coherent waves produces alternate bright and dark fringes of equal width β.



Take $d = 1$ mm, $D = 1$ m and $\lambda = 500$ nm, and answer the following:

(i) Write the expression for the fringe width β. (1)

(ii) Calculate the fringe width β for the given data. (1)

(iii) Find the distance of the 5^{th} bright fringe from the central maximum. (2)

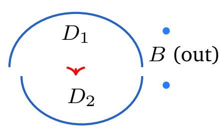
Section E (Q31–Q33) – 5 Marks Each

Q31. (a) Using Gauss's law, write the expressions for the electric field due to (i) an infinite plane sheet of charge of surface density σ, and (ii) a uniformly charged thin spherical shell of charge Q and radius R, at points outside and inside the shell.
(b) A charge $Q = 4\,\mu$C is distributed uniformly over a thin spherical shell. Find the electric field at a point 0.2 m from the centre, which lies outside the shell. (Take $\dfrac{1}{4\pi\varepsilon_0} = 9 \times 10^9$ N m^2/C^2.) **[5]**

OR

(a) Draw a Wheatstone bridge and derive its balance condition $\dfrac{P}{Q} = \dfrac{R}{S}$ using Kirchhoff's rules.
(b) In a balanced Wheatstone bridge, $P = 10\,\Omega$, $Q = 20\,\Omega$ and $R = 15\,\Omega$. Find the value of the unknown resistance S.

Q32. (a) With the help of a labelled diagram, explain the principle and working of a cyclotron, and derive the expression for the cyclotron frequency.
(b) A cyclotron accelerates protons in a magnetic field of 0.5 T. Taking the proton charge $q = 1.6 \times 10^{-19}$ C and mass $m = 1.67 \times 10^{-27}$ kg, find the cyclotron frequency.



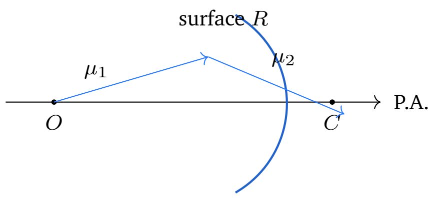
[5]

OR

(a) An AC source is connected to a series LCR circuit at resonance. Derive the value of the impedance and the current at resonance.

(b) At resonance a series LCR circuit has $R = 10\,\Omega$ and is connected to a source of rms voltage 20 V. Find the rms current in the circuit at resonance.

Q33. (a) Derive the relation $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$ for refraction of light at a single convex spherical surface separating two media of refractive indices μ_1 and μ_2.



(b) A point object is placed in air 60 cm from the pole of a convex spherical surface of radius 20 cm, separating air from glass of refractive index $\mu_2 = 1.5$ $(\mu_1 = 1)$. Find the position of the image. **[5]**

OR

(a) In Young's double-slit experiment, derive the expression for the fringe width β of the interference pattern, with a suitable diagram.

(b) In such an experiment, the slit separation is 0.2 mm, the screen is 1.5 m away, and the wavelength of light used is 600 nm. Find the fringe width.

Detailed Solutions

Q1.

Solution

Concept — Potential of a point charge: The electric potential at distance r from a point charge q is $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$, so $V \propto \frac{1}{r}$.

Step 1 — Write the original potential:

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}.$$

Step 2 — Halve the distance: Replace r by $\frac{r}{2}$:

$$V' = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r/2)}.$$
$$= \frac{1}{4\pi\varepsilon_0}\frac{2q}{r}.$$
$$= 2V.$$

Why other options are wrong: (B) $\frac{V}{2}$ and (D) $\frac{V}{4}$ assume potential falls when brought closer; (C) $4V$ uses a $1/r^2$ dependence, which is the field, not the potential.

Final Answer: New potential $= 2V \Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q1

Q2.

Solution

Concept — Resistivity: Resistivity ρ is a property of the material (and its temperature) alone. It does not depend on the shape or size of the conductor, whereas resistance $R = \rho\frac{\ell}{A}$ does.

Step 1 — Test each quantity: Resistance $R = \rho\frac{\ell}{A}$ depends on ℓ and A. Conductance $G = \frac{1}{R}$ also depends on ℓ and A.

Step 2 — Identify the invariant: Resistivity ρ is fixed for a given material at a given temperature, independent of ℓ and A.

Why other options are wrong: (A) resistance and (B) conductance both scale with dimensions; (D) drift velocity depends on the current and cross-section through $v_d = \dfrac{I}{nAe}$.

Final Answer: Resistivity is independent of dimensions $\Rightarrow$ $\boxed{\text{C}}$

Answer: (C) Go Back to Q2

Q3.

Solution

Concept — Force on a current-carrying conductor: For a straight wire perpendicular to a uniform field, $F = BIL$.

Step 1 — List the data:

$$B = 0.5\ \text{T}, \quad I = 4\ \text{A}, \quad L = 0.2\ \text{m}.$$

Step 2 — Substitute in $F = BIL$:

$$F = (0.5)(4)(0.2).$$

Step 3 — Multiply:

$$F = (0.5)(0.8) = 0.4\ \text{N}.$$

Why other options are wrong: (A) 0.2 N drops the factor of current; (C) 4 N and (D) 8 N omit the length or the field factor.

Final Answer: $F = 0.4\ \text{N} \Rightarrow \boxed{\text{B}}$

Answer: (B) Go Back to Q3

Q4.

Solution

Concept — Motional emf: A rod of length l moving with speed v perpendicular to a field B sweeps area at rate lv, so the induced emf is $\varepsilon = Blv$.

Step 1 — Rate of area sweep: In time dt the rod sweeps area $dA = l\,(v\,dt)$.

Step 2 — Rate of change of flux:

$$\frac{d\phi}{dt} = B\frac{dA}{dt} = B\,l\,v.$$

Step 3 — Induced emf:

$$\varepsilon = \frac{d\phi}{dt} = Blv.$$

Why other options are wrong: (A) Bvl^2 has an extra length factor; (B) and (C) place v or l in the denominator, giving wrong dimensions.

Final Answer: $\varepsilon = Blv \Rightarrow \boxed{\text{D}}$

Answer: (D) Go Back to Q4

Q5.

Solution

Concept — Capacitive reactance: $X_C = \frac{1}{2\pi fC}$, so $X_C \propto \frac{1}{f}$.

Step 1 — Read the dependence: Frequency f appears in the denominator of X_C.

Step 2 — Increase the frequency: As f rises, $\frac{1}{2\pi fC}$ falls, so X_C decreases (a capacitor offers less opposition at high frequency).

Why other options are wrong: (A) increases contradicts the inverse relation; (B) constant ignores the f dependence; (D) has no physical basis for a monotonic $1/f$ law.

Final Answer: X_C decreases as f increases $\Rightarrow \boxed{\text{C}}$

Answer: (C) Go Back to Q5

Q6.

Solution

Concept — Uses of EM waves: Microwaves (wavelength of the order of centimetres) are used in RADAR, satellite communication and speed guns because they travel in straight lines and reflect well off vehicles and aircraft.

Step 1 — Match the application: RADAR and traffic speed guns work by sending out a beam and detecting the reflected (Doppler-shifted) signal; this is done with microwaves.

Step 2 — Conclusion: The correct wave is the microwave.

Why other options are wrong: (B) gamma rays and (D) X-rays are highly penetrating ionising radiations, not used for ranging; (C) ultraviolet is used in sterilisation, not RADAR.

Final Answer: Microwaves $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q6

Q7.

Solution

Concept — Sign of magnification: The linear magnification of a mirror is $m = -\frac{v}{u}$. For a real image formed by a concave mirror, both u and v are negative (same side), and the image is inverted, giving $m < 0$.

Step 1 — Nature of the image: A real image formed by a concave mirror is inverted relative to the object.

Step 2 — Apply the sign rule: An inverted image corresponds to a negative magnification, $m = -\frac{v}{u} < 0$.

Why other options are wrong: (A) and (D) positive values would mean an erect (virtual) image; (C) zero magnification is not physical for a finite image.

Final Answer: The magnification is negative $\Rightarrow$ $\boxed{\text{B}}$

Answer: (B) Go Back to Q7

Q8.

Solution

Concept — Condition for a dark fringe: Destructive interference (a dark fringe) occurs where the path difference is an odd multiple of half the wavelength, i.e. $\Delta = (2n-1)\frac{\lambda}{2} = \left(n - \frac{1}{2}\right)\lambda$, which is equivalently written $\left(n + \frac{1}{2}\right)\lambda$ for $n = 0, 1, 2, \ldots$

Step 1 — Recall the interference rule: Bright fringe needs $\Delta = n\lambda$; dark fringe needs $\Delta =$ (half-integer)$\times\lambda$.

Step 2 — Write the dark-fringe condition:

$$\Delta = \left(n + \frac{1}{2}\right)\lambda.$$

Why other options are wrong: (A) $n\lambda$ and (B) $2n\lambda$ are bright-fringe conditions; (C) $(2n+1)\lambda$ is a whole (odd) multiple of λ, not of $\frac{\lambda}{2}$.

Final Answer: Dark fringe at $\Delta = \left(n + \frac{1}{2}\right)\lambda \Rightarrow \boxed{\text{D}}$

Answer: (D) Go Back to Q8

Q9.

Solution

Concept — Stopping potential graph: Einstein's equation gives $eV_0 = h\nu - W$, so $V_0 = \frac{h}{e}\nu - \frac{W}{e}$, a straight line in ν with slope $\frac{h}{e}$.

Step 1 — Rearrange Einstein's equation:

$$eV_0 = h\nu - W.$$

$$V_0 = \frac{h}{e}\,\nu - \frac{W}{e}.$$

Step 2 — Identify the slope: Comparing with $y = mx + c$, the slope is

$$\text{slope} = \frac{h}{e}.$$

Why other options are wrong: (A) $\frac{e}{h}$ is the reciprocal; (B) h and (D) he have the wrong dimensions for a potential-per-frequency slope.

Final Answer: Slope $= \frac{h}{e} \Rightarrow \boxed{\text{C}}$

Answer: (C) Go Back to Q9

Q10.

Solution

Concept — Binding energy curve: The binding energy per nucleon rises with mass number, peaks at about 8.8 MeV near $A \approx 56$ (iron region), and then decreases slowly for heavier nuclei.

Step 1 — Recall the shape of the curve: The maximum of the binding-energy-per-nucleon curve lies in the region of iron and nickel.

Step 2 — Read off the mass number: This peak corresponds to $A \approx 56$ (iron, ^{56}Fe).

Why other options are wrong: (B) 120 and (C) 238 lie on the descending part of the curve; (D) 4 (helium) is a local peak but well below the maximum.

Final Answer: Maximum near $A = 56 \Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q10

Q11.

Solution

Concept — OR gate symbol: An OR gate has a curved (concave) input side and a pointed output, with *no* inversion bubble. Its output is high when *any* input is high: $Y = A + B$.

Step 1 — Read the symbol: Two inputs feed a body that curves inward at the back and comes to a point at the output, and there is no bubble.

Step 2 — Identify the gate: This is the OR gate, $Y = A + B$.

Why other options are wrong: (A) AND has a flat back and rounded front; (C) NAND and (D) NOR both carry an output bubble (inversion), which is absent here.

Final Answer: OR gate $\Rightarrow$ $\boxed{\text{B}}$

Answer: (B) Go Back to Q11

Q12.

Solution

Concept — Capacitors in parallel: For capacitors in parallel the equivalent capacitance is the sum, $C_p = C_1 + C_2$.

Step 1 — Write the rule:

$$C_p = C_1 + C_2.$$

Step 2 — Substitute the values:

$$C_p = 3 + 6.$$

$$= 9\ \mu\text{F}.$$

Why other options are wrong: (A) $2\,\mu$F and (B) $\frac{1}{9}\,\mu$F use the series formula $\frac{C_1 C_2}{C_1 + C_2}$ or its reciprocal; (C) $18\,\mu$F multiplies the two values.

Final Answer: $C_p = 9\,\mu\text{F} \Rightarrow \boxed{\text{D}}$

Answer: (D) Go Back to Q12

Q13.

Solution

Concept — Assertion–Reason on Kirchhoff's junction rule: Judge each statement, then decide whether R explains A.

Step 1 — Assertion: The junction (node) rule says $\sum I = 0$ at a junction, i.e. the total current entering equals the total leaving. So A is **true**.

Step 2 — Reason: Charge cannot accumulate at a junction in steady state, so whatever charge enters per second must leave per second; this is conservation of charge. So R is **true**.

Step 3 — Does R explain A? The junction rule is a direct statement of charge conservation at the node, so R correctly explains A.

Why other options are wrong: (B) denies a real explanatory link; (C),(D) misjudge a truth value.

Final Answer: Both true, R explains A $\Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q13

Q14.

Solution

Concept — Assertion–Reason on the transformer: Judge each statement, then test the explanatory link.

Step 1 — Assertion: A transformer needs a *changing* flux to induce an emf. AC continually changes the flux, whereas steady DC produces constant flux and no induced emf. So A is **true**.

Step 2 — Reason: A transformer can indeed step up or step down an alternating voltage according to the turns ratio. So R is **true**.

Step 3 — Does R explain A? The turns-ratio property describes *how much* the voltage changes, but it does *not* explain *why* DC fails (that reason is the need for changing flux). So R does not explain A.

Why other options are wrong: (A) claims an explanation that is not the actual cause; (C),(D) misjudge a truth value.

Final Answer: Both true, R not the explanation $\Rightarrow \boxed{\text{B}}$

Answer: (B) Go Back to Q14

Q15.

Solution

Concept — Dispersion by a prism: Deviation increases with refractive index. Red light has the *longest* wavelength and hence the *smallest* refractive index in glass, so it deviates the least.

Step 1 — Assertion: Red light deviates the least on passing through a prism. This is **true**.

Step 2 — Reason: The claim that "the refractive index of glass is greater for red than for violet" is **false**; glass has a *smaller* refractive index for red than for violet.

Step 3 — Combine: A is true but R is false.

Why other options are wrong: (A),(B) require R true; (D) requires A false.

Final Answer: A true, R false $\Rightarrow$ $\boxed{C}$

Answer: (C) Go Back to Q15

Q16.

Solution

Concept — Binding energy and stability: A *larger* binding energy per nucleon means the nucleons are more tightly bound, so the nucleus is *more* stable.

Step 1 — Assertion: "A nucleus with a *smaller* binding energy per nucleon is more stable" reverses the correct relation, so A is **false**.

Step 2 — Reason: Binding energy per nucleon is indeed the standard measure of nuclear stability. So R is **true**.

Step 3 — Combine: A is false and R is true.

Why other options are wrong: (A),(B) require A true; (C) requires R false.

Final Answer: A false, R true $\Rightarrow$ $\boxed{D}$

Answer: (D) Go Back to Q16

Q17.

Solution

Concept — Energy stored in a capacitor: $U = \frac{1}{2}CV^2$.

Step 1 — List the data:

$$C = 5\,\mu\text{F} = 5 \times 10^{-6}\ \text{F}, \quad V = 100\ \text{V}.$$

Step 2 — Substitute:

$$U = \frac{1}{2}(5 \times 10^{-6})(100)^2.$$

Step 3 — Evaluate the square and multiply:

$$U = \frac{1}{2}(5 \times 10^{-6})(10^4).$$

$$= \frac{1}{2}(5 \times 10^{-2}).$$

$$= 2.5 \times 10^{-2}\ \text{J} = 0.025\ \text{J}.$$

Final Answer: Energy stored $U = 0.025$ J $= 2.5 \times 10^{-2}$ J. **Go Back to Q17**

Q18.

Solution

Concept — Resistors in parallel: $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$, or $R_p = \frac{R_1R_2}{R_1 + R_2}$.

Step 1 — Use the product-over-sum form:

$$R_p = \frac{R_1R_2}{R_1 + R_2} = \frac{(6)(3)}{6 + 3}.$$

Step 2 — Numerator and denominator:

$$R_p = \frac{18}{9}.$$

Step 3 — Divide:

$$R_p = 2\ \Omega.$$

Final Answer: Equivalent resistance $= 2\,\Omega$. **Go Back to Q18**

Q19.

Solution

Concept — Mutual inductance: The emf induced in the secondary is $\varepsilon = M\dfrac{dI}{dt}$.

Step 1 — Write the given quantities:

$$\frac{dI}{dt} = 20 \text{ A/s}, \quad \varepsilon = 10 \text{ V}.$$

Step 2 — Solve for M:

$$M = \frac{\varepsilon}{dI/dt} = \frac{10}{20}.$$
$$= 0.5 \text{ H}.$$

Final Answer: Mutual inductance $M = 0.5$ H.

OR — Power factor of a series RL circuit:

Step 1 — Impedance:

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{30^2 + 40^2}.$$
$$= \sqrt{900 + 1600} = \sqrt{2500} = 50 \ \Omega.$$

Step 2 — Power factor:

$$\cos\varphi = \frac{R}{Z} = \frac{30}{50} = 0.6.$$

Final Answer (OR): Power factor $\cos\varphi = 0.6$. Go Back to Q19

Q20.

Solution

Concept — Magnification of a mirror: $m = -\dfrac{v}{u}$, using the sign convention (distances measured from the pole, real distances on the object side are negative).

Step 1 — Assign signs: Object and real image are both in front of the mirror:

$$u = -20 \text{ cm}, \quad v = -30 \text{ cm}.$$

Step 2 — Substitute in $m = -\dfrac{v}{u}$:

$$m = -\frac{(-30)}{(-20)}.$$

Step 3 — Simplify:

$$m = -\frac{30}{20} = -1.5.$$

Final Answer: $m = -1.5$; the image is real, inverted and 1.5 times the object size.
Go Back to Q20

Q21.

Solution

Concept — Einstein's photoelectric equation: $eV_0 = h\nu - W$, so $V_0 = \dfrac{h\nu - W}{e}$.

Step 1 — Photon energy in joules:

$$h\nu = (6.63 \times 10^{-34})(1 \times 10^{15}).$$

$$= 6.63 \times 10^{-19} \text{ J}.$$

Step 2 — Convert to eV:

$$h\nu = \frac{6.63 \times 10^{-19}}{1.6 \times 10^{-19}} = 4.14 \text{ eV}.$$

Step 3 — Subtract the work function:

$$eV_0 = h\nu - W = 4.14 - 2.0 = 2.14 \text{ eV}.$$

Step 4 — Stopping potential: Since the energy is already in eV, $V_0 = 2.14$ V.

Final Answer: Stopping potential $V_0 \approx 2.14$ V.

OR — Activity of a radioactive sample:

Step 1 — Formula: Activity $A = \lambda N$.

Step 2 — Substitute:

$$A = (0.05)(2 \times 10^6).$$

$$= 1 \times 10^5 \text{ disintegrations/s}.$$

Final Answer (OR): $A = 1 \times 10^5$ Bq. Go Back to Q21

Q22.

Solution

Concept — Gauss's law for a plane sheet: $\oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0}$. By symmetry the field of an infinite sheet is uniform and directed normally away from the sheet.

Step 1 — Choose a Gaussian surface: Take a small cylinder (pillbox) of cross-sectional area A piercing the sheet, with its flat faces parallel to the sheet on either side.

Step 2 — Flux through the pillbox: The curved side is parallel to $\vec{E}$ (no flux). Each flat face contributes EA:

$$\oint \vec{E} \cdot d\vec{A} = EA + EA = 2EA.$$

Step 3 — Charge enclosed: The pillbox encloses the charge on area A of the sheet:

$$q_{\text{enc}} = \sigma A.$$

Step 4 — Apply Gauss's law:

$$2EA = \frac{\sigma A}{\varepsilon_0}.$$

Step 5 — Solve for E:

$$E = \frac{\sigma}{2\varepsilon_0}.$$

Final Answer: $E = \frac{\sigma}{2\varepsilon_0}$, independent of distance from the sheet. Go Back to Q22

Q23.

Solution

Concept — Kirchhoff's rules: Junction rule ($\sum I = 0$) and loop rule ($\sum \varepsilon = \sum IR$). Let the junctions be A (top) and B (bottom), joined by three parallel branches.

Step 1 — Label the currents: Let I_1 flow from the 4 V cell into A, I_2 from the 7 V cell into A, and I_3 leave A through the $1\,\Omega$ resistor.

Step 2 — Junction rule at A:

$$I_1 + I_2 = I_3.$$

Step 3 — Let V be the potential of A above B. Applying the loop/branch relations $\left(I = \dfrac{\varepsilon - V}{r}\right)$:

$$I_1 = \frac{4-V}{1}, \quad I_2 = \frac{7-V}{2}, \quad I_3 = \frac{V}{1}.$$

Step 4 — Substitute into the junction equation:

$$(4-V) + \frac{7-V}{2} = V.$$

Step 5 — Multiply through by 2:

$$2(4-V) + (7-V) = 2V.$$

$$8 - 2V + 7 - V = 2V.$$

$$15 - 3V = 2V.$$

$$15 = 5V \;\Rightarrow\; V = 3\text{ V}.$$

Step 6 — Back-substitute:

$$I_1 = \frac{4-3}{1} = 1\text{ A}, \quad I_2 = \frac{7-3}{2} = 2\text{ A}, \quad I_3 = \frac{3}{1} = 3\text{ A}.$$

Final Answer: $I_1 = 1$ A, $I_2 = 2$ A, $I_3 = 3$ A (and $1 + 2 = 3$ satisfies the junction rule). **Go Back to Q23**

Q24.

Solution

Concept — Ampere's circuital law: $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enc}}$. Inside a long solenoid the field is uniform and axial; outside it is negligible.

Step 1 — Choose an Amperian loop: Take a rectangular loop of length L with one long side inside the solenoid (parallel to the axis) and the other outside.

Step 2 — Evaluate the line integral: Only the inner side contributes (B outside ≈ 0, and the short sides are perpendicular to $\vec{B}$):

$$\oint \vec{B} \cdot d\vec{l} = B\,L.$$

Step 3 — Current enclosed: If n is the number of turns per unit length, the loop of length L encloses nL turns, each carrying I:

$$I_{\text{enc}} = (nL)I.$$

Step 4 — Apply Ampere's law:

$$B\,L = \mu_0(nL)I.$$

Step 5 — Solve for B:

$$B = \mu_0 nI.$$

Final Answer: The field inside a long solenoid is $B = \mu_0 nI$, uniform and directed along the axis. **Go Back to Q24**

Q25.

Solution

Concept — Transformer efficiency: $\eta = \dfrac{P_{\text{out}}}{P_{\text{in}}} \times 100\%$.

Step 1 — Note the power values:

$$P_{\text{in}} = 1000\text{ W}, \quad P_{\text{out}} = 800\text{ W}.$$

Step 2 — Form the ratio:

$$\eta = \frac{800}{1000}.$$

Step 3 — Convert to a percentage:

$$\eta = 0.8 \times 100\% = 80\%.$$

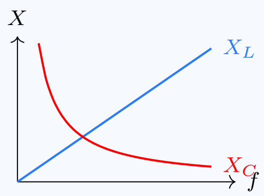
Final Answer: Efficiency $\eta = 80\%$.

OR — Variation of X_L and X_C with frequency:

Step 1 — Inductive reactance: $X_L = 2\pi fL$, so $X_L \propto f$ — it *increases* linearly from zero as the frequency rises (a straight line through the origin).

Step 2 — Capacitive reactance: $X_C = \dfrac{1}{2\pi fC}$, so $X_C \propto \dfrac{1}{f}$ — it is very large at low frequency and *decreases* (a rectangular hyperbola) as the frequency rises.

Step 3 — Crossing point: The two curves meet where $X_L = X_C$, which is the resonant frequency $f_0 = \dfrac{1}{2\pi\sqrt{LC}}$.



Final Answer (OR): X_L rises linearly with f while X_C falls as $1/f$; they are equal at resonance. **Go Back to Q25**

Q26.

Solution

Concept — Lens maker's formula: Treat the thin lens as two refracting surfaces in succession and apply the single-surface refraction relation $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$ to each.

Step 1 — First surface (R_1): Light goes from air (1) to glass (μ), forming an intermediate image at v_1:

$$\frac{\mu}{v_1} - \frac{1}{u} = \frac{\mu - 1}{R_1}.$$

Step 2 — Second surface (R_2): This image acts as the object for refraction from glass (μ) back to air (1):

$$\frac{1}{v} - \frac{\mu}{v_1} = \frac{1 - \mu}{R_2}.$$

Step 3 — Add the two equations: The $\frac{\mu}{v_1}$ terms cancel:

$$\frac{1}{v} - \frac{1}{u} = \frac{\mu - 1}{R_1} + \frac{1 - \mu}{R_2}.$$

$$\frac{1}{v} - \frac{1}{u} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right).$$

Step 4 — Define the focal length: For an object at infinity, $v = f$, and $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$:

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right).$$

Final Answer: $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$.

OR — Apparent depth:

Step 1 — Formula: apparent depth $= \dfrac{\text{real depth}}{\mu}$.

Step 2 — Substitute:

$$d' = \frac{4}{4/3} = 4 \times \frac{3}{4} = 3 \text{ cm}.$$

Step 3 — Apparent shift:

$$\Delta = 4 - 3 = 1 \text{ cm}.$$

Final Answer (OR): Apparent depth $= 3$ cm; the coin appears raised by 1 cm. Go Back to Q26

Q27.

Solution

Concept — de Broglie wavelength of an accelerated electron: $\lambda = \dfrac{h}{\sqrt{2meV}}$, which for an electron reduces to the handy form $\lambda = \dfrac{12.27}{\sqrt{V}}$ Å with V in volts.

Step 1 — Insert the accelerating voltage:

$$\lambda = \frac{12.27}{\sqrt{100}} \text{ Å}.$$

Step 2 — Evaluate the square root:

$$\sqrt{100} = 10.$$

Step 3 — Divide:

$$\lambda = \frac{12.27}{10} = 1.227 \text{ Å}.$$

Step 4 — Express in metres:

$$\lambda = 1.227 \times 10^{-10} \text{ m}.$$

Final Answer: $\lambda \approx 1.23$ Å $= 1.23 \times 10^{-10}$ m. Go Back to Q27

Q28.

Solution

Concept — Zener diode as a regulator: A Zener diode operated in reverse breakdown maintains a nearly constant voltage across itself; connected in parallel with the load, it holds the output steady against changes in input voltage or load current.

Step 1 — Circuit: The unregulated input V_{in} is applied through a series resistor R_s; the Zener diode is connected in reverse bias in parallel with the load R_L (as drawn). The output is taken across the Zener.

Step 2 — Working: In reverse breakdown the Zener holds a fixed voltage V_Z. Any excess input voltage is dropped across R_s.

Step 3 — If V_{in} rises: The extra voltage appears across R_s; the Zener draws more current so that $V_{\text{out}} = V_Z$ stays constant.

Step 4 — If the load current changes: The Zener adjusts its own current to keep the total current through R_s (and hence the drop across it) such that the output remains V_Z.

Final Answer: The Zener clamps the output at V_Z, giving a regulated $V_{\text{out}} = V_Z$ despite fluctuations in V_{in} or R_L. **Go Back to Q28**

Q29.

Solution

Concept — Potentiometer: The potential drop along a uniform current-carrying wire is proportional to its length, so the balancing length measures the emf/potential difference tapped off.

(i) Principle: A potentiometer works on the principle that when a steady current flows through a wire of uniform cross-section, the potential difference across any portion is directly proportional to its length: $V \propto \ell$.

(ii) Ratio of emfs: At balance, $E \propto \ell$, so

$$\frac{E_1}{E_2} = \frac{\ell_1}{\ell_2} = \frac{300}{150} = 2.$$

Hence $E_1 : E_2 = 2 : 1$.

(iii) Internal resistance: The internal resistance from balancing lengths is

$$r = R\left(\frac{\ell_1 - \ell_2}{\ell_2}\right).$$

$$r = 4\left(\frac{250-200}{200}\right).$$
$$= 4 \times \frac{50}{200}.$$
$$= 4 \times 0.25 = 1\ \Omega.$$

Final Answer: (i) $V \propto \ell$; (ii) $E_1 : E_2 = 2 : 1$; (iii) $r = 1\,\Omega$. **Go Back to Q29**

Q30.

Solution

Concept — YDSE fringe geometry: Fringe width $\beta = \frac{\lambda D}{d}$; the n-th bright fringe lies at $y_n = n\beta$ from the central maximum.

(i) Expression:

$$\beta = \frac{\lambda D}{d}.$$

(ii) Fringe width for the given data: With $\lambda = 500$ nm$= 5 \times 10^{-7}$ m, $D = 1$ m, $d = 1$ mm$= 1 \times 10^{-3}$ m,

$$\beta = \frac{(5 \times 10^{-7})(1)}{1 \times 10^{-3}}.$$
$$= 5 \times 10^{-4}\ \text{m} = 0.5\ \text{mm}.$$

(iii) Position of the 5^{th} bright fringe:

$$y_5 = 5\beta = 5 \times 0.5\ \text{mm}.$$

$$= 2.5\ \text{mm} = 2.5 \times 10^{-3}\ \text{m}.$$

Final Answer: $\beta = 0.5$ mm; the 5^{th} bright fringe is 2.5 mm from the centre. **Go Back to Q30**

Q31.

Solution

Concept — Gauss's law applications: Choose a Gaussian surface matching the symmetry of the charge distribution.

(a)(i) Infinite plane sheet: Using a pillbox with two faces of area A,

$$2EA = \frac{\sigma A}{\varepsilon_0} \ \Rightarrow\ E = \frac{\sigma}{2\varepsilon_0}.$$

The field is uniform and normal to the sheet.

(a)(ii) Thin spherical shell of charge Q, radius R: Outside ($r > R$), a concentric Gaussian sphere encloses all of Q:

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}.$$

Inside ($r < R$), no charge is enclosed:

$$E = 0.$$

(b) Numerical (field just outside, $r = 0.2$ m):

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2} = \frac{(9\times10^9)(4\times10^{-6})}{(0.2)^2}.$$

Step — Numerator:

$$(9\times10^9)(4\times10^{-6}) = 3.6\times10^4.$$

Step — Denominator:

$$(0.2)^2 = 0.04.$$

Step — Divide:

$$E = \frac{3.6\times10^4}{0.04} = 9\times10^5 \text{ N/C}.$$

Final Answer: $E_{\text{sheet}} = \dfrac{\sigma}{2\varepsilon_0}$; shell: outside $\dfrac{kQ}{r^2}$, inside 0; numerically $E = 9\times10^5$ N/C.

OR — Wheatstone bridge:

(a) With four arms P, Q, R, S and a galvanometer in the bridge arm, apply Kirchhoff's loop rule to the two loops. At balance no current flows through the galvanometer, so the same current I_1 flows through P and Q, and I_2 through R and S. Equal potentials at the galvanometer ends give $I_1P = I_2R$ and $I_1Q = I_2S$. Dividing,

$$\frac{P}{Q} = \frac{R}{S}.$$

(b) With $P = 10\,\Omega$, $Q = 20\,\Omega$, $R = 15\,\Omega$:

$$\frac{10}{20} = \frac{15}{S}.$$

$$S = 15\times\frac{20}{10} = 15\times2 = 30\ \Omega.$$

Final Answer (OR): $\dfrac{P}{Q} = \dfrac{R}{S}$; $S = 30\,\Omega$. **Go Back to Q31**

Q32.

Solution

Concept — Cyclotron: A charged particle is repeatedly accelerated across the gap between two D-shaped electrodes ("dees") while a perpendicular magnetic field bends it into semicircles of increasing radius.

(a) Principle and working: A high-frequency alternating voltage is applied across the two dees, kept in a uniform magnetic field B (perpendicular to their plane). Inside a dee the magnetic force provides the centripetal force,

$$qvB = \frac{mv^2}{r} \;\Rightarrow\; r = \frac{mv}{qB}.$$

The time to complete one semicircle is $t = \dfrac{\pi m}{qB}$, which is *independent of speed and radius*. Each time the particle crosses the gap the field polarity has reversed, so it is accelerated again. The period of revolution is

$$T = \frac{2\pi m}{qB}, \qquad f = \frac{1}{T} = \frac{qB}{2\pi m}.$$

This f is the cyclotron frequency.

(b) Numerical:

$$f = \frac{qB}{2\pi m} = \frac{(1.6 \times 10^{-19})(0.5)}{2\pi(1.67 \times 10^{-27})}.$$

Step — Numerator:

$$(1.6 \times 10^{-19})(0.5) = 0.8 \times 10^{-19} = 8 \times 10^{-20}.$$

Step — Denominator:

$$2\pi(1.67 \times 10^{-27}) = 1.05 \times 10^{-26}.$$

Step — Divide:

$$f = \frac{8 \times 10^{-20}}{1.05 \times 10^{-26}} \approx 7.6 \times 10^{6}\ \text{Hz}.$$

Final Answer: $f = \dfrac{qB}{2\pi m} \approx 7.6$ MHz.

OR — Series LCR at resonance:

(a) At resonance $X_L = X_C$, so the net reactance vanishes:

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + 0} = R.$$

The impedance is purely resistive and minimum, so the current is maximum:

$$I = \frac{V}{Z} = \frac{V}{R}.$$

(b) With $R = 10\,\Omega$, $V = 20$ V:

$$I = \frac{20}{10} = 2\text{ A}.$$

Final Answer (OR): At resonance $Z = R$; here $I = 2$ A. **Go Back to Q32**

Q33.

Solution

Concept — Refraction at a single spherical surface: Apply Snell's law in the small-angle (paraxial) approximation, using the exterior-angle theorem for the ray geometry.

(a) Derivation: Let a ray from object O in medium μ_1 meet a convex surface of radius R (centre C) and refract into medium μ_2, forming image I. For paraxial rays the angles are small, so $\sin\theta \approx \theta$ and Snell's law $\mu_1 \sin i = \mu_2 \sin r$ becomes

$$\mu_1 i = \mu_2 r.$$

Using the exterior-angle theorem at the two triangles, with α, β, γ the angles the rays make with the axis,

$$i = \alpha + \gamma, \qquad r = \gamma - \beta.$$

Substituting,

$$\mu_1(\alpha + \gamma) = \mu_2(\gamma - \beta).$$

For small angles, $\alpha \approx \frac{h}{-u}$, $\beta \approx \frac{h}{v}$, $\gamma \approx \frac{h}{R}$ (with h the height of incidence). Substituting and cancelling h:

$$\mu_1\left(\frac{1}{-u} + \frac{1}{R}\right) = \mu_2\left(\frac{1}{R} - \frac{1}{v}\right).$$

Rearranging with the sign convention gives

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}.$$

(b) Numerical: $\mu_1 = 1$, $\mu_2 = 1.5$, $R = +20$ cm, object distance $u = -60$ cm:

$$\frac{1.5}{v} - \frac{1}{-60} = \frac{1.5-1}{20}.$$

$$\frac{1.5}{v} + \frac{1}{60} = \frac{0.5}{20} = 0.025.$$

$$\frac{1.5}{v} = 0.025 - \frac{1}{60} = 0.025 - 0.01667 = 0.00833.$$

$$v = \frac{1.5}{0.00833} = 180 \text{ cm}.$$

Final Answer: $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$; the image forms 180 cm inside the glass (real).

OR — YDSE fringe width:

(a) For slits separated by d and a screen at distance D, the path difference at height y is $\Delta = \frac{yd}{D}$. Bright fringes require $\Delta = n\lambda$, so $y_n = \frac{n\lambda D}{d}$. The fringe width is

$$\beta = y_{n+1} - y_n = \frac{\lambda D}{d}.$$

(b) With $d = 0.2$ mm$= 2 \times 10^{-4}$ m, $D = 1.5$ m, $\lambda = 600$ nm$= 6 \times 10^{-7}$ m:

$$\beta = \frac{(6 \times 10^{-7})(1.5)}{2 \times 10^{-4}}.$$

$$= \frac{9 \times 10^{-7}}{2 \times 10^{-4}} = 4.5 \times 10^{-3} \text{ m} = 4.5 \text{ mm}.$$

Final Answer (OR): $\beta = \frac{\lambda D}{d} = 4.5$ mm. **Go Back to Q33**

Answer Key – Section A (Q1–Q16)

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	A	2	C	3	B	4	D	5	C
6	A	7	B	8	D	9	C	10	A
11	B	12	D	13	A	14	B	15	C
16	D								

Sections B–E are descriptive; refer to the Detailed Solutions above for full model answers and step marking.