Group A: Quick-reference Answer Key

Q	A	Marks	Q	A	Marks	Q	A	Marks	Q	A	Marks	Q	A	Marks
1	②	1	11	①	1	21	③	2	31	①	2	41	④	4
2	②	1	12	①	1	22	②	2	32	③	2	42	④	4
3	③	1	13	④	1	23	①	2	33	①	2	43	④	4
4	④	1	14	④	1	24	④	2	34	②	2	44	④	4
5	①	1	15	②	1	25	③	2	35	①	2	45	②	4
6	③	1	16	②	1	26	①	2	36	①	2	46	④	4
7	②	1	17	③	1	27	④	2	37	③	2	47	②	4
8	①	1	18	①	1	28	④	2	38	①	2	48	①	4
9	②	1	19	②	1	29	②	2	39	③	2	49	③	4
10	③	1	20	①	1	30	①	2	40	②	2	50	③	4

50 questions (20 × 1 mark, 20 × 2 marks, 10 × 4 marks), 100 marks total

Recommended Time: 2 hours 15 minutes.
Approximate Grade Boundaries (marks): A* > 80, A > 70, B > 60, C > 50, D > 40
Coverage is based on the OCR Specification.

Group A: Worked Solutions

A1. **Answer:** ②

The cone does not slow down during its fall, so must be accelerating downwards. The acceleration decreases from g (9.81 ms^{-2}) to zero (terminal velocity) so the magnitude of the resultant force is decreasing. (②)

A2. **Answer:** ②

During a phase change, the potential energy becomes less negative due to the intermolecular forces being overcome, while the kinetic energy (vibrational energy) stays the same. Since all heat energy supplied is used to break the bonds, there is no change in temperature. By definition, internal energy = kinetic energy + potential energy so this does change. (②)

A3. **Answer:** ③

Waves arrive constructively → 0, 2π, 4π, 6π etc phase difference.
The path difference is 20 - 16 = 4 m.
Any wavelength whose multiple includes 4 m will have a multiple of 2π phase difference. 1.0, 2.0 and 4.0 all divide into 4 m but 3.0 does not - its phase difference would be 480° (7π / 3 rad). (③)

A4. **Answer:** ④

$E = hf = QV \rightarrow V$ is proportional to $f \rightarrow V$ is inversely proportional to λ. (④)

A5. **Answer:** ①

Higher intensity → more photons → more electrons (since one-to-one interaction) → more charge flow → more current. (①)

Work function: (minimum) energy required to remove one electron from the **highest** energy level of a surface atom.

Stopping potential: p.d. that stops the photoelectric current when the material is connected to the positive terminal of a voltage source.

Energy of photons > energy of electrons (since some is 'consumed' by the work function) → frequency of photons > frequency of electrons (as waves) → λ of photons < λ of electrons (as waves).

A6. **Answer:** ③

$E_k = \frac{1}{2}mv^2$ and $p = mv$. Eliminating v, we get $E_k = \frac{1}{2}\frac{p^2}{m}$, then rearranging gives $m = \frac{1}{2}\frac{p^2}{E_k}$ = 3 kg. (③)

A7. **Answer:** ②

Rate of thermal conduction is proportional to ΔT for constant length and area.

Temperature drop for rod A : Temperature drop for rod B = 1 : 3 = 1 / 3. (②)

A8. **Answer:** ①

Total mass = 15 kg → resultant acceleration = 2 ms^{-2} (right).
Taking a free-body cut between *X* and *Y*, taking *W* and *X* as the system, the force F_{XY} is $F_{XY} = m_{XY} \times a_{XY}$ = (3 + 4) × 2 = 14 N. Positive sign indicates to the right, which is away from the object, meaning tension. (①)

(Note that this is faster than working out each bar force one after the other.)

A9. Answer: ②

When the truck accelerates, a force acts on the truck (say, to the right). This force does not act on the air in the back of the truck, which therefore remains at rest (Newton's third law; inertia). So the air moves to the left making the back of the truck more dense. The balloon (helium) now floats in a density (and hence pressure) differential and so sways to the right, 'floating' above the dense air. (②)

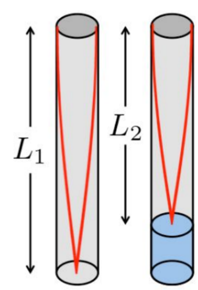
A10. Answer: ③

Chandrasekhar limit = 1.44 × Solar Mass.

Below this mass, the pressure at the core is sufficiently repelled by the electrons, but above, the electron degeneracy pressure is overcome, collapsing the star rapidly (hence unstable) and resulting in a supernova. (③)

A11. Answer: ①

Frequencies in ratio 3 : 4 → wavelengths in ratio 4 : 3 (since $v = f\lambda$).



$L_1 = 20$ cm → $L_2 = 15$ cm → depth of water = 5 cm. (①)

A12. Answer: ①

Turns ratio (step up) = 20 → current steps down by factor 20 → $I_2 = 0.2$ A.
Power dissipated in cables $= I^2 R = 0.2^2 \times 1500 = 60$ W. (①)

A13. **Answer:** ④

Balancing both nucleon and proton numbers,

$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{88}_{35}Br + ^{145}_{57}La + 3\ ^{1}_{0}n$

$^{145}_{57}La \rightarrow ^{145}_{56}Ba\ (+\ ^{0}_{0}e^{-} + ^{0}_{0}\bar{\nu}_{e})$

Neutrons in decay product = 145 - 56 = 89. (④)

A14. **Answer:** ④

Diffraction slit separation = 1 / (300 × 10^3) = 3.333 × 10^{-6} m^{-1}.
Using the formula $d \sin \theta = n\lambda$, with θ at the maximum possible diffraction angle of 90° (the edges of the screen), we get n = 5.29, which rounds down to 5. Since these spots appear on both sides of the screen, there are 10 diffraction spots plus the original zeroth-order spot at $\theta = 0°$ for a total of 11 spots. (④)

A15. **Answer:** ②

Technetium-99m is used as it decays by double gamma emission and internal conversion from the metastable state with a half-life of 6 hours. It is synthesised in the hospital labs using a molybdenum-technetium generator. (②)

A16. **Answer:** ②

Intensity reflection coefficient = $\left(\frac{Z_2 - Z_1}{Z_1 + Z_2}\right)^2$, where $Z = \rho c$ is the acoustic impedance
Values of Z are then Air = 429, Water = 1.5 × 10^6, Muscle = 1.341 × 10^6,
Fat = 1.709 × 10^6, Bone = 6.732 × 10^6.

The media with the closest-matching impedances will minimise the reflection losses. Calculate to confirm: Air into Bone = 0.9997, Water into Muscle = 0.00313, Fat into Water = 0.00424, Muscle into Fat = 0.01456. (②)

A17. **Answer:** ③

Spring stiffness (divided by g) $k = \frac{21}{3.5 - 0.5}$ = 7 g cm^{-1}

→ self-extension = $\frac{m}{7}$ = 0.5 cm → m = 3.5 g. (③)

A18. Answer: ①

Connected in series → currents must be the same in both.
Total voltages must add to 6 V.
Only points on the graph which match this are at (2 V, 0.5 A) and (4 V, 0.5 A)
→ current = 0.5 A. (①)

A19. Answer: ②

Capacitors C and $2C$ must store equal charge. Capacitors $6C$ and $3C$ must store equal charge. This is because otherwise, a current would flow between the two inner plates. Since $Q = VC$, the voltage is inversely proportional to C.

Top row: C in ratio 1 : 2 → V across capacitors in ratio 2 : 1 → $V_a = V/3$
Bottom row: C in ratio 6 : 3 = 2 : 1 → V across capacitors in ratio 1 : 2 → $V_b = 2V/3$
Potential difference $= V_b - V_a = V/3$ (②)

A20. Answer: ①

Work input = 42 × 5 = 210 J (**A**)
No friction → heat absorbed by liquid = work done by force
Heat absorbed: $Q = mc\,\Delta T \rightarrow \Delta T = \frac{Q}{mc} = \frac{210}{0.1 \times 4200} = 0.5$ K
→ **A** only. (①)

A21. Answer: ③

Find the equivalent resistance by simplifying the circuit first.

Combine top resistors in series: $16 + 47 = 63\ \Omega$.
Combine middle resistors: $\left(\frac{1}{54} + \frac{1}{123+21}\right)^{-1} = 39.2727\ \Omega$
Combine rightmost resistors in parallel: $\left(\frac{1}{39.2727} + \frac{1}{71}\right)^{-1} = 25.2861\ \Omega$
Again: $\left(\frac{1}{25.2861+63} + \frac{1}{106}\right)^{-1} = 48.1678\ \Omega$
Finally: $48.1678 + 17 = 65.1678 = 65.2\ \Omega$.

Total power $= \frac{V^2}{R} = \frac{5^2}{65.2} = 0.383$ W ≈ 380 mW (③)

A22. Answer: ②

Transverse wave → particles oscillate vertically (perpendicular to direction of wave propagation).

Distance in one cycle = up, down, down, up → 4 × amplitude
= 4 × 0.04 = 0.16 m.

Time period = 1 / 10 Hz = 0.1 s → wave cycles = 20 / 0.1 = 200
Total distance = 0.16 × 200 = 32 m. (②)

A23. Answer: ①

Let v be the speed of each side of the sun relative to the Earth as it rotates.
Doppler shift in wavelength for each side = $\pm \frac{\lambda v}{c}$
Total difference in wavelengths = $\frac{2\lambda v}{c}$ = 7.8 × 10^{-12} m → v = 1986.4 ms^{-1}
→ $\omega_{sun} = \frac{v}{r}$ = 2.854 × 10^{-6} rad s^{-1} → $T_{sun} = \frac{2\pi}{\omega_{sun}}$ = 2.202 × 10^{6} s.
Since T_{Earth} = 24 hrs × 60 × 60 = 86400 s, the ratio of the angular speeds is
$\frac{\omega_{Earth}}{\omega_{Sun}} = \frac{T_{Sun}}{T_{Earth}}$ = 25.5. (①)

A24. Answer: ④

Diffraction occurs noticeably when the gap between two sources is close to the wavelength. $\lambda = c / f$ = (3 × 10^{8}) / (600 × 10^{6}) = 0.5 m. Distance between maxima along line at receiver = $\lambda d / a$ (from $\lambda = ax / d$) = 0.5 * 1000 / 1 = 500 m.

Since λ = 0.5 ~ 1, diffraction effects could be significant. Since 500 m $>>$ λ, the distances between maxima are not close. (④)

(1st option is false: frequency has no effect on diffraction)
(2nd option is false: wavelength is close to gap size)
(3rd option is false: distance between maxima is large)

A25. Answer: ③

1st option is false: 'efficiency' is with reference to the amount of energy from the fuel source which is converted into useful electrical energy – this does not refer to the amount of electrical energy which is generated or consumed.

2nd option is false: again 'efficiency' is with reference to how much of the consumed energy is converted into useful other forms – this is not relevant to the difference between generation and consumption.

4th option seems unlikely as all electronics are tested and electricity consumption is managed by a select few companies.
By process of elimination, 3rd option is correct. (③)

A26. Answer: ①

Using SUVAT for linear acceleration kinematics:
$s = vt - \frac{1}{2}at^2 \rightarrow 2.5t^2 - 30t + 50 = 0 \rightarrow t = 2$ or 10 s.

Check initial speed using $v = u + at$:
If $t = 2$ s then $u = 20\ ms^{-1}$. If $t = 10$ s then $u = -20\ ms^{-1}$.
The longer time corresponds to the case where the car is initially reversing, going backwards and then eventually coming forwards to cross the bridge. This is not a reasonable way to cross the bridge so we take $t = 2$ s. (①)

A27. Answer: ④

Consider equilibrium state **1**. Balancing forces,
Tension in BC = $1g$; Tension in AB = $4g$; Tension in spring = $2g$.
Extension of spring = Tension / Stiffness = $2g / 200 = g / 100$ = 10 / 100 = 0.1 = x.

Next, suppose that state **2** was at equilibrium. Balancing forces similarly,
Tension in AB = $3g$; Tension in spring = g.
Extension of spring = $g / 200$ = 10 / 200 = 0.05 (m).

Therefore the system starts with a displacement of (0.1 - 0.05) = 0.05 m from its equilibrium position, which will be equal to its amplitude of oscillation. Therefore $y = 0.05$ and so $x + y = 0.15$. (④)

A28. Answer: ④

The temperature distribution will be non uniform (evaporation of tungsten and hence change in internal energy varies). At the position where temperature is maximum, the filament will break.

Towards the end of the life, the filament will become thinner. Considering the resistivity equation $\rho = \frac{RA}{L}$, A decreases as the filament breaks up so R must increase (with an additional increase due to the increase of ρ with T).

Black body radiation curve will become sharper and shift down wavelengths (higher frequencies) as temperature increases.

Consumed power will be less ($P = V^2 / R$), so it will emit less light. (④)

A29. Answer: ②

Let c = specific heat capacity, L = specific latent heat of liquid.
Let M_{cup} and C_{cup} be the mass and specific heat capacity of the container.

The first 5 g evaporates completely:
→ energy needed to heat and boil 5 g liquid = energy released
→ $(5 \times c \times (80 - 30)) + (5 \times L) = M_{cup} \times C_{cup} \times (110 - 80)$
→ $250c + 5L = 30\ M_{cup}C_{cup}$ (Eqn. 1)

The next 80 g cools the cup to 50 °C:
→ energy needed to warm 80 g liquid = energy released
→ $80 \times c \times (50 - 30) = M_{cup} \times C_{cup} \times (80 - 50)$
→ $1600c = 30\ M_{cup}C_{cup}$ (Eqn. 2)

Divide (Eqn. 1) by (Eqn. 2):
→ $(250c + 5L) / 1600c = 1$
→ $250 / 1600 + (L / c) / 320 = 1$
→ $L / c = 320 \times (1 - 250 / 1600) = 270$ (Units: K) (②)

A30. Answer: ①

Time between pulses = time period = 0.4 s.
Angular frequency = $2\pi / T = 2\pi / 0.4 = 15.7$ rad s^{-1} ~ 16 rad s^{-1}. (①)

When in the light, V across resistor = 4 V so V across LDR = 0.5 V.
When in the dark, V across resistor = 2 V so V across LDR = 2.5 V.

Current in light: $V = IR \rightarrow I = V / R = 4 / 1200 = 0.00333$ A
→ Resistance of LDR in light $= V / I = 0.5 / 0.00333 = 150\ \Omega$.
Current in dark: $I = 2 / 1200 = 0.001667$ A
→ Resistance of LDR in dark = 2.5 / 0.001667 = 1500 Ω.
→ Ratio of resistances is 1/10, not 10.

A31. Answer: ①

Since voltage is constant and $V = IR$, it follows that $I \propto \frac{1}{R}$.

Therefore, when T is low, R is high, I is low; when T is high, R is low, I is high. So the temperature scale will follow the direction of the current scale (either **A** or **B**).

At low temperatures, a fixed variation ΔT gives a very large ΔR. By considering uncertainties, it follows that $\frac{\Delta I}{I} \approx -\frac{\Delta R}{R}$. The RHS is very large, and so ΔI is also large (since the value of I is not *too* small).

Therefore, an increase in temperature from 0 °C to 20 °C requires a disproportionately large increase in current, meaning that the spacing between temperature marks must be larger at lower temperatures, matching ammeter **A.** (①)

A32. Answer: ③

Time period of light in air: λ / c = 600 nm / c = T = 2 × 10^{-15} s
Time to travel 300 nm in vacuum = 300 nm / c = T / 2
Time to travel 300 nm in material = 300 nm / (c / 2) = T

Therefore, after passing through the material, the light passing through one slit will be half a cycle out of phase with the other. Before, a maximum forms if path difference is $n\lambda$ or $2n\pi$ phase difference, but now since the initial phase difference is π, only π, 3π, 5π etc more phase difference is required. So the maxima form at different path differences and hence at different positions (shifted in y-direction). (③)

A33. Answer: ①

Let x = depth of well.
Time taken to fall = Total time - Reaction time - Echo Travel Time - Starting Error
T = 4.405 - (0.250 ± 0.050) - ($\frac{x}{343}$) - (0.000 ± 0.100); $T = \left(4.155 - \frac{x}{343}\right) \pm 0.150.$
From SUVAT, $x = \frac{1}{2} \times 9.81 \times T^2$.
Mean value of x satisfies the equation $x = 0.5 \times 9.81 \times \left(4.155 - \frac{x}{343}\right)^2$
Expand to a quadratic and solving gives x = 75.9 m.
Rearranging and solving gives T = 3.934 s.
Percentage uncertainty in $T = \frac{0.150}{3.934}$ = 0.03813 = 3.813%.
Percentage uncertainty in x = 2 × (percentage uncertainty in T) = 7.626%.
Absolute uncertainty in x = 5.788 m.
Therefore the depth is 75.9 ± 5.8 m. (①)

A34. Answer: ②

When the test tube begins to sink, the buoyant force must equal the combined weight of the test tube and the air bubble below it. Using units of cm and g,
$\rho_w(V_{tube} + V_{air})g = (m_{tube} + m_{air})g \Rightarrow 1 \times (\frac{5}{2.5} + V_{air}) = (5 + m_{air})$.
Since we are given that m_{air} is negligible, remove it from the equation to get V_{air} = 3 cm^3 → Δv = 0.3 cm^3.
From Boyle's law (ideal gas undergoing isothermal process), since v decreased by 10%, p must have increased by 10%, so we have p = 1 × 10^4 Pa. (②)

A35. Answer: ①

When the square is fully within the field ($L < x < 3L$), the induced current $I(x) = 0$ as there is no change in flux (so no e.m.f.). When moving in and out of the field, we can derive a formula for I as a function of speed v:

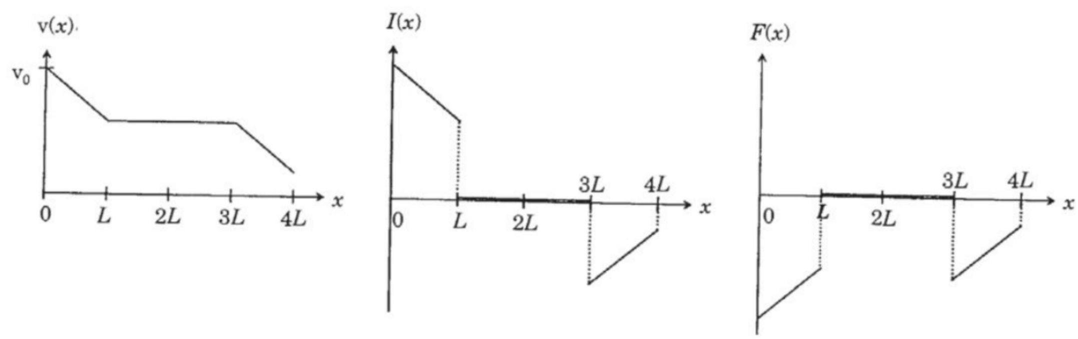
$$\varepsilon = V = IR \rightarrow I = \frac{\varepsilon}{R} = -\frac{1}{R}\frac{\Delta BA}{\Delta t} = -\frac{BL}{R}\frac{\Delta x}{\Delta t} = -\frac{BLv}{R}.$$

For $0 < x < L$, the magnetic flux is changing from zero to a positive value so there is a positive rate of change. So by Lenz's law, a force will be exerted against the motion (negative), decreasing v and hence decreasing I (by the derived formula). All graphs match.

For $L < x < 3L$, the magnetic flux density is constant so the flux linkage is constant, and so no change and hence no emf and no force (constant velocity). All graphs match this.

For $3L < x < 4L$, the magnetic flux changes from a positive value to zero so there is a negative rate of change. A force will be exerted to the left (negative) so velocity will decrease again. This time however, the rate of change of area (and hence flux linkage) means the current is induced in the opposite direction with decreasing magnitude. $I(x)$ and $F(x)$ are both different here.

The correct graphs are: (①)



A36. Answer: ①

1: The p-n junction acts as an LED with a forward bias current flowing only when the direction of flow is p → n. From the geometry of the solenoid this requires an anti-clockwise current (looking inwards from **b** towards **c**). From the right-hand screw rule, this implies the solenoid induced magnetic field is from **c** towards **b** (to the left). This implies that the solenoidal field is 'North' at **b** and 'South' at **c**, which is setup to repel the permanent magnetic field. Since the magnet enters at **c** to cause light emission, the pole closest to **c** must be the South pole, i.e. X = North pole.

2: Repeating the above analysis for a magnet with its North pole entering at **b**, we find that the current direction is the same, so the LED is still in forward-bias mode, causing photons to be emitted.

3: There are energy losses due to the light and resistive heating in the p-n junction and solenoid, so the mechanical energies will not be the same.

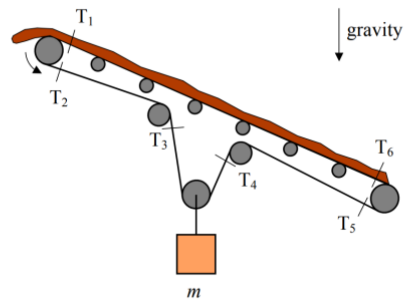
→ **1** and **2** only. (①)

A37. Answer: ③

Initial activity = 2.4×10^5 Bq. Half-lives passed = 11.5 hrs / (8 × 24) = 0.06.
Activity after 11.5 hrs = $2.4 \times 10^5 \times (½)^{0.06} = 2.302 \times 10^5$ Bq.
Considering concentration ratios, $115 / (2.302 \times 10^5) = 2.5 / V$
→ V = 5004 ml = 5.0 litres. (③)

A38. Answer: ①

Due to the weight of the belt and the aggregate, the tension varies throughout. Consider six points of interest along the belt, at which the tensions are $T_1 \ldots T_6$:



Consider the moments acting on the top roller. Let r be the roller radius.
$T_1 r - T_2 r = M \rightarrow T_1 > T_2$.

In the straight section of the belt, the tension T_1 must support T_6 and the aggregate + belt weight:

$T_1 \sin\theta = \rho V g + M_s g + T_6 \sin\theta$ (M_s: straight belt mass, V: aggregate volume)

Considering the other two hanging sections similarly, $T_2 > T_3$, $T_4 > T_5$, $T_3 > T_4$ and $T_5 < T_6$ (due to the frictional torque).

Therefore the total ordering is
$T_1 > T_2 > T_3 > T_4 > T_6 > T_5 \rightarrow$ Maximum is at **A** (roughly), Minimum is at **C**. (①)

A39. Answer: ③

Process $E \rightarrow F$ is isochoric (constant volume), so no work W is done.

Process $F \rightarrow H$ has steeper gradient than the isothermal $F \rightarrow G$, so it moves from a higher isotherm to a lower isotherm, so the temperature decreases.

Process $H \rightarrow E$ is isobaric (constant pressure) and volume V decreases so temperature also decreases (Charles' law), so RMS speed decreases. (③)

Process $G \rightarrow E$ is also isobaric. $\Delta U = Q - W$. Since V changes, $W \neq 0$, so $\Delta U \neq Q$.

A40. Answer: ②

Overall reaction:

$2\ H_2$ (gas) $\rightarrow 4\ {}^1_1H$ (plasma) $\rightarrow {}^4_2He$ (plasma) + $2\ e^+ + 2\ \nu_e + 2\ \gamma$

$= H_2$ (gas) $\rightarrow 2\ {}^1_1H$ (plasma) $\rightarrow 0.5\ {}^4_2He$ (plasma) + $e^+ + \nu_e + \gamma$

Neglecting the mass of the neutrino (it is tiny) and the gamma ray (it is zero),
Mass defect = 0.013812 amu per molecule of H_2 = 0.013812 g per mole of H_2

$\Delta m = 1.3812 \times 10^{-5}$ kg

$E = mc^2 = 1.2431 \times 10^{12}$ J = 1.24 TJ (②)

A41. Answer: ④

Let A be the cross-sectional area of one wire. Combining in parallel,

$$R = \left(\frac{1}{R_{Cu}} + \frac{6}{R_{Al}}\right)^{-1} = \left(\frac{A}{2\rho L} + \frac{6A}{3\rho L}\right)^{-1} = \frac{2\rho L}{5A}.$$

Considering the mass of the cable,

$$M = (3d)(AL) + 6d(AL) = 9dAL \Rightarrow A = \frac{M}{9dL}$$

Eliminating A, we get $R = \frac{2\rho L \times 9dL}{5M} = \frac{18\rho dL^2}{5M}$. (④)

A42. Answer: ④

Colours with wavelength closest to diffraction spacing are diffracted through a larger angle. Diffraction spacing = 1 / (300 * 1000) = 3.3×10^{-6} m = 3300 nm.
So longer wavelengths of light (red) are closest to this (800 nm).
So red is diffracted more while violet is diffracted less.
On the graph, red has higher intensity than violet. (④)

A43. Answer: ④

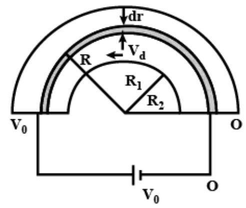


Figure 1

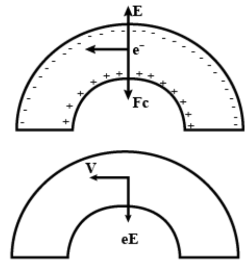


Figure 2

Consider the current in an infinitesimally thin semicircle, which is $dI = \frac{V_0 t\ dr}{\rho\pi r}$.
The electrons have an acceleration which points towards the centre of the circle, which must be provided by a force. The only source of a force is a radial electric field, so we have $eE = m_e v^2 / r$.

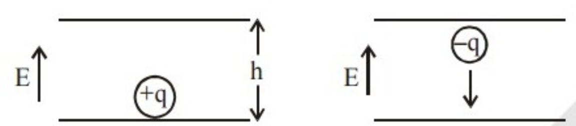
Since $I = AneV_d$, we have $dI = \frac{V_0 t\ dr}{\rho\pi r} = (t\ dr)\ nev \ \Rightarrow\ v = \sqrt{\frac{V_0}{\rho\pi ner}}$.

Substituting into the force balance, $E = \frac{m_e V_0}{e^2 r^2 \rho\pi n}$ (outwards) so

$\Delta V = -\frac{m_e V_0}{e^2 \rho\pi n}\int_{R_1}^{R_2}\frac{dr}{r^2} = \frac{m_e V_0}{e^2\rho\pi n}\left(\frac{1}{R_2} - \frac{1}{R_1}\right) < 0$ so the voltage is highest on the inside. (④)

A44. Answer: ④

What happens to the balls next? After hitting the top plate, the balls will get negatively charged and will now get attracted to the bottom plate which is positively charged. The motion of the balls will be periodic but **not** SHM since the force in the electric fields is constant (independent of position). (④)



Variation of I_{avg}? If Q is charge on balls, then $Q \propto V_0$ (since the balls act as spherical shell capacitors and $Q = VC$). Let t be the time to rise to the top. From SUVAT and **E**-field equations,

$$h = \frac{1}{2}at^2 = \frac{1}{2}\left(\frac{F}{m}\right)t^2 = \frac{1}{2}\left(\frac{QV_0}{mh}\right)t^2 \ \Rightarrow\ t = \sqrt{\frac{2mh^2}{QV_0}}$$

Since $I_{avg} = \frac{Q}{t}$, we have $I_{avg} \propto V_0 C \times \sqrt{QV_0} \propto V_0 \times \sqrt{V_0^2} \propto V_0^2$. (④)

A45. Answer: ②

The voltage across a component in the lower branch has a time constant of $RC = 50000 \times 20 \times 10^{-6} = 1$ s.
The voltage across a component in the upper branch has a time constant of $RC = 25000 \times 40 \times 10^{-6} = 1$ s.
Therefore, the functions representing the voltage at each end of the voltmeter contain $e^{-t/1}$ terms. The difference between these two will also contain $e^{-t/1}$, so must fit the form $V(t) = A - Be^{-t/1}$ where A and B are unknown constants, so the time constant is 1 s. (②)

A46. Answer: ④

Let the volumetric flow rate be $Q = Av = 3$ m^3 s^{-1}. Using conservation of mass, $\rho Q = \rho A_X v_X = \rho A_Y v_Y$, so $v_Y = 12$ ms^{-1}.

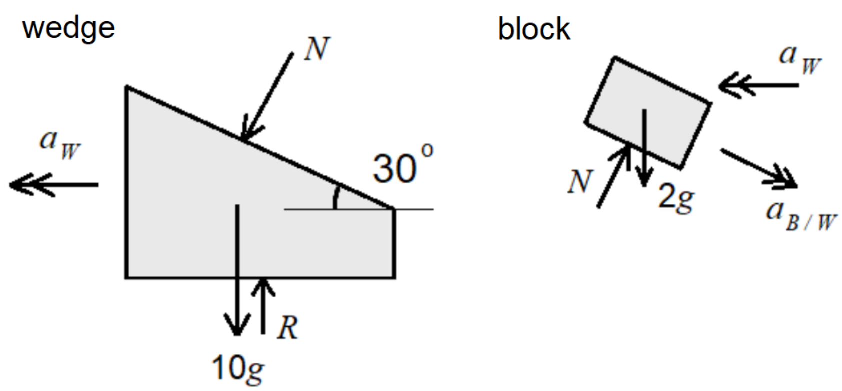
Using conservation of momentum (steady-flow momentum equation):
$F = \rho A_Y v_Y^2 - \rho A_X v_X^2 = 16.8$ kN. Fluid is accelerating → force acts to the right.
(Alternatively: force = mass flow rate × change in velocity)

Power = Rate of loss of mechanical energy
$= Q\,\Delta p = A_X v_X \times \frac{1}{2}\rho(v_Y^2 - v_X^2) = 142.8$ kW. (④)

A47. Answer: ②

Draw a free-body diagram of both the wedge and the block. Take the reference frame as the inertial (rest) frame i.e. with respect to the table.

$\boldsymbol{a_W}$: acceleration of wedge, parallel to table, $\boldsymbol{a_{B/W}}$: acceleration of block **relative** to wedge, parallel to wedge surface (since sliding velocity has no component normal to wedge), $\boldsymbol{a_B} = \boldsymbol{a_{B/W}} + \boldsymbol{a_W}$, acceleration of block (absolute, as vectors), N: normal contact force between block and wedge, equal and opposite on each body (Newton's 3rd law), R: reaction force between table and wedge, vertical.



Resolve forces on both bodies in two directions:

Block, ⊥ to incline: $2g\cos 30° - N = 2a_W \sin 30°$ $\rightarrow a_W + N = \sqrt{3}\,g$. (1)

Block, || to incline: $2g\sin 30° = a_{B/W} - a_W\cos 30°$ $\rightarrow a_B - (1 + \frac{\sqrt{3}}{2})\,a_W = g$. (2)

Wedge, ↕: $R - 10g - N\cos 30° = 0$ $\rightarrow R - \frac{\sqrt{3}}{2}N = 10g$. (3)

Wedge, ↔: $N\sin 30° = 10a_W$ $\rightarrow N = 20a_W$. (4)

Sub (4) into (1) to get $21a_W = \sqrt{3}\,g \rightarrow a_W = \frac{\sqrt{3}g}{21}$ (left) (**A** is correct).

Solve (2): $a_B = g + (1 + \frac{\sqrt{3}}{2})(\frac{\sqrt{3}g}{21}) = \frac{45 + 2\sqrt{3}}{42}\,g$ (right, down) (**B** is incorrect)

Sub into original form of (2): $a_{B/W} = g + \frac{\sqrt{3}}{2}(\frac{\sqrt{3}g}{21}) = \frac{15}{14}\,g$ (right, down)

(**C** is correct)

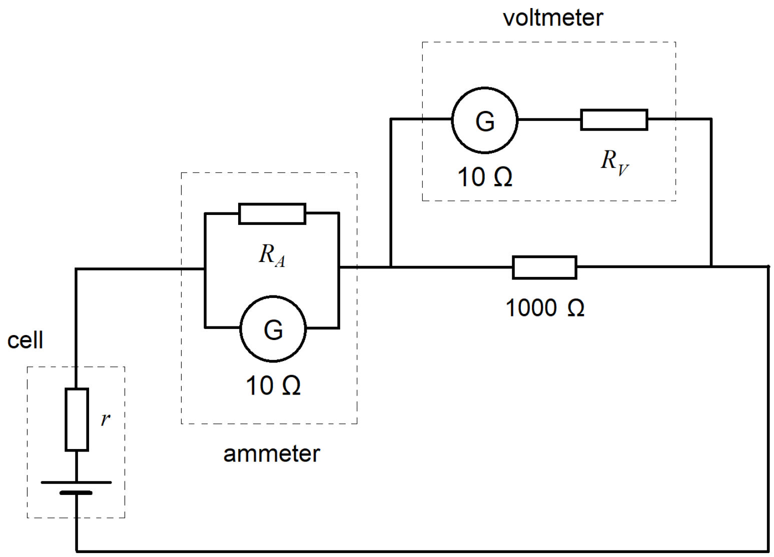
→ **A** and **C** are correct. (②)

A48. Answer: ①

Consider the density of the gas in the bubble. $\rho_{gas} = m / V \rightarrow \rho_{gas} \propto 1 / V$ (since mass of gas, m, remains constant). Since temperature is constant (isothermal process), as pressure is also inversely proportional to volume (Boyle's law) so $p_{bubble} \propto \rho_{gas} \propto 1 / V$. Since $V \propto r^3$ (radius of bubble), we now have $p_{bubble} \propto 1 / r^3$.

At any depth, pressure exerted by bubble = hydrostatic pressure + atm pressure.
At the bottom: $k / R^3 = h\rho g + P$
At a depth x: $k / r^3 = x\rho g + P$
Dividing the first equation by the second, $(k / R^3) / (k / r^3) = [h\rho g + P] / [x\rho g + P]$
$\rightarrow r^3 / R^3 = [h\rho g + P] / [x\rho g + P]$
$\rightarrow r^3 = R^3 [h\rho g + P] / [x\rho g + P]$
$\rightarrow r = R\,((h\rho g + P) / (x\rho g + P))^{1/3}$. (①)

A49. Answer: ③



At full-scale deflection, for the voltmeter, we have

100 mV = 2 μA × (10 Ω + R_V) $\rightarrow$ R_V = 49990 Ω

while for the ammeter, we have (for a total of 1 mA into the ammeter, only 2 μA must pass through the galvanometer, so use the current divider formula):

$$\frac{2\ \mu A}{1\ mA} = \frac{R_A}{R_A + 10\ \Omega} \rightarrow R_A = 0.02004008\ldots\ \Omega$$

Suppose that the cell has a voltage V_0, which may be different from its emf due to an internal resistance r.

Equivalent resistance of voltmeter || 1 kΩ: $\left(\frac{1}{1000} + \frac{1}{10 + R_V}\right)^{-1}$ = 980.392 Ω

Equivalent resistance of ammeter: $\left(\frac{1}{10} + \frac{1}{R_A}\right)^{-1}$ = 0.02 Ω

If I is the circuit current, then in test 1 kΩ resistor, current is $\frac{50000}{50000 + 1000} I = \frac{50}{51} I$.

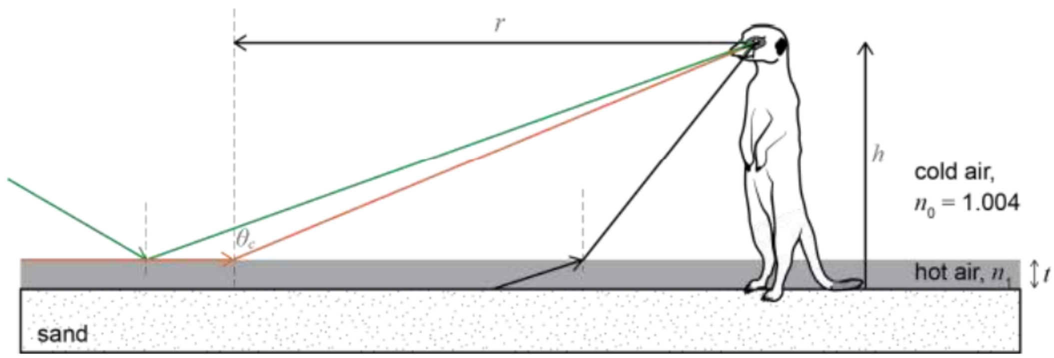
Measured voltage = $\frac{V_0}{980.412} \times \frac{50}{51} \times 1000$, Measured current = $\frac{V_0}{980.412}$.

Measured resistance = ratio = $\frac{50}{51} \times 1000 = 980.392\ \Omega$ = 980 Ω.

Note that this calculation only depended on the true resistance (fixed), and the properties of the voltmeter/ammeter construction, not the cell. (③)

A50. Answer: ③

Rays striking the hot-cool air interface at $> r$ (green) will undergo reflection, causing the mirage as the meerkat sees blue sky here. Rays striking closer than $< r$ (black) will reflect from the sand, which just looks like sand to the meerkat.



Therefore, the radius of the mirage is where total internal reflection (where 'internal' really refers to from the atmosphere) is no longer possible i.e. at the critical angle (orange). We have $sin\,\theta_c = \frac{n}{n_c}$ and by trigonometry and Pythagoras in the triangle, $sin\,\theta_c = \frac{r}{\sqrt{r^2+(h-t)^2}} \approx \frac{r}{\sqrt{r^2+h^2}}$ (since $h >> t$, we can say h - $t \approx h$).

Therefore $\frac{n}{n_c} = \frac{r}{\sqrt{r^2+h^2}}$, so re-arranging for r, we get

$(r^2+h^2)n^2 = r^2 n_c^2 \;\Rightarrow\; r^2(n_c^2 - n^2) = h^2 n^2$ (square both sides, cross-multiply)

$\Rightarrow\; r^2 = \frac{h^2 n^2}{n_c^2 - n^2} \;\Rightarrow\; r = \frac{hn}{\sqrt{n_c^2 - n^2}}$. (③)