Rwanda Physics Olympiad 2025-26

National Selection Test - First Round

Detailed Solutions

Constants and Data

The following constants are provided in the exam paper and used in these calculations:

- Gravitational acceleration $g = 9.81\,\mathrm{m/s^2}$
- Proton mass $m_p = 1.67 \times 10^{-27}\,\mathrm{kg}$
- Electron mass $m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$
- Elementary charge $e = 1.60 \times 10^{-19}\,\mathrm{C}$
- Coulomb constant $k = 8.99 \times 10^{9}\,\mathrm{N\,m^2/C^2}$

Section A: Multiple Choice Questions

A1. Potential Energy of a Helicopter

Question: A helicopter of mass $m = 2500\,\mathrm{kg}$ is parked on top of a building of height $h = 50\,\mathrm{m}$. What is the potential energy?
Solution: The gravitational potential energy (U) is given by:

$$U = mgh$$

Substituting the values:

$$U = 2500 \times 9.81 \times 50$$

$$U = 125000 \times 9.81$$

$$U = 1\,226\,250\,\mathrm{J} \approx 1.2 \times 10^{6}\,\mathrm{J}$$

Answer: E ($1.2 \times 10^{6}\,\mathrm{J}$)

A2. Average Speed on a Hill

Question: A car travels up a hill at $v_1 = 10\,\mathrm{m/s}$ and returns down at $v_2 = 20\,\mathrm{m/s}$. Distances are equal. What is the average speed?
Solution: Let the distance one way be d. Time up: $t_1 = d/v_1$. Time down: $t_2 = d/v_2$. Total average speed is total distance divided by total time:

$$v_{avg} = \frac{2d}{t_1 + t_2} = \frac{2d}{\frac{d}{v_1} + \frac{d}{v_2}} = \frac{2}{\frac{1}{v_1} + \frac{1}{v_2}} = \frac{2v_1 v_2}{v_1 + v_2}$$

$$v_{avg} = \frac{2(10)(20)}{10 + 20} = \frac{400}{30} = 13.33\,\mathrm{m/s}$$

Answer: C ($13.3\,\mathrm{m/s}$)

A3. Average Acceleration

Question: Initial velocity $v_i = +18\,\text{m/s}$. After $t = 2.4\,\text{s}$, velocity is $v_f = -30\,\text{m/s}$ (opposite direction).
Solution: Average acceleration is the change in velocity over time:

$$a = \frac{v_f - v_i}{t}$$

$$a = \frac{-30 - 18}{2.4} = \frac{-48}{2.4} = -20\,\text{m/s}^2$$

The magnitude is 20, direction is negative. **Answer:** B ($-20\,\text{m/s}^2$)

A4. Speed of Raindrops

Question: Raindrops fall $h = 1700\,\text{m}$. Find speed if no air resistance.
Solution: Using conservation of energy or kinematic equation $v^2 = u^2 + 2gh$ (with $u = 0$):

$$v = \sqrt{2gh}$$

$$v = \sqrt{2 \times 9.81 \times 1700} = \sqrt{33354} \approx 182.63\,\text{m/s}$$

Answer: D ($183\,\text{m/s}$)

A5. Tension in Elevator Cable

Question: Mass $m = 1600\,\text{kg}$. Originally moving downward at $v_0 = 12\,\text{m/s}$, comes to rest ($v = 0$) in distance $d = 42\,\text{m}$. Find tension.
Solution: First, find the acceleration required to stop the elevator. Let downward be negative. $v_0 = -12$, $v = 0$, $\Delta y = -42$.

$$v^2 = v_0^2 + 2a\Delta y \implies 0 = (-12)^2 + 2a(-42)$$

$$0 = 144 - 84a \implies a = \frac{144}{84} \approx 1.714\,\text{m/s}^2 \quad \text{(upwards)}$$

Now apply Newton's Second Law (Up is positive):

$$T - mg = ma$$

$$T = m(g + a) = 1600(9.81 + 1.714) = 1600(11.524)$$

$$T \approx 18\,438\,\text{N}$$

Answer: B ($1.84 \times 10^4\,\text{N}$)

A6. Kinetic Energy of Proton

Question: Proton in circular orbit $r = 0.5\,\text{m}$, period $T = 2\,\text{s}$.
Solution: First, find the velocity:

$$v = \frac{2\pi r}{T} = \frac{2\pi(0.5)}{2} = \frac{\pi}{2} \approx 1.571\,\text{m/s}$$

Kinetic Energy (K):

$$K = \frac{1}{2}m_p v^2$$

$$K = 0.5 \times (1.67 \times 10^{-27}\,\text{kg}) \times (1.571)^2$$

$$K \approx 0.5 \times 1.67 \times 10^{-27} \times 2.467 \approx 2.06 \times 10^{-27}\,\text{J}$$

Answer: C ($2.1 \times 10^{-27}\,\text{J}$)

A7. Projectile Motion Time

Question: Stone thrown vertically returns in 4 s. If initial speed is doubled, what is the new time?
Solution: Time of flight for vertical projectile: $t = \frac{2v_0}{g}$. Since $t \propto v_0$, doubling the initial speed v_0 will double the time of flight. New time $= 2 \times 4 = 8$ s. **Answer:** B (8 s)

A8. Electrostatic Force

Question: Charges $2Q$ and Q separated by $L = 1$ m. Force $F = 2.2$ N. Find Q.
Solution: Coulomb's Law: $F = k\frac{|q_1 q_2|}{r^2} = k\frac{(2Q)(Q)}{L^2} = \frac{2kQ^2}{L^2}$.

$$2.2 = \frac{2(8.99 \times 10^9)Q^2}{1^2}$$

$$Q^2 = \frac{2.2}{2 \times 8.99 \times 10^9} \approx 1.223 \times 10^{-10}\,\mathrm{C}^2$$

$$Q = \sqrt{1.223 \times 10^{-10}} \approx 1.106 \times 10^{-5}\,\mathrm{C} = 11.0\,\mu\mathrm{C}$$

Answer: C (11.0 μC)

A9. Resistive Force Power Law

Question: Determine n where $F \propto v^n$ using the table data.
Solution: Let's test $n = 2$ (quadratic drag, common in air resistance):

- $v = 10, F = 37 \implies k = 37/100 = 0.37$
- $v = 15, F_{calc} = 0.37 \times 15^2 = 0.37 \times 225 = 83.25 \approx 83$
- $v = 27, F_{calc} = 0.37 \times 27^2 = 0.37 \times 729 = 269.73 \approx 270$
- $v = 35, F_{calc} = 0.37 \times 35^2 = 0.37 \times 1225 = 453.25 \approx 450$

The data fits $F \propto v^2$ very well. **Answer:** D (v^2)

A10. Normal Force

Question: Mass $m = 10$ kg, Pull force $F_p = 40$ N upwards. Find Normal force N.
Solution: Forces in vertical direction sum to zero (equilibrium):

$$N + F_p - mg = 0$$

$$N = mg - F_p$$

Using $g \approx 10\,\mathrm{m/s}^2$ (often used for integer answers like the options provided, though 9.81 is standard):

$$N = (10)(10) - 40 = 60 \text{ N}$$

Using $g = 9.81$: $N = 98.1 - 40 = 58.1$, which rounds to 60 among the options. **Answer:** D (60 N)

Section B: Written Questions

B1. Current and Electrons

Question: $I = 5\,\text{A}$, $t = 5\,\text{min}$. How many electrons traveled?
Solution: First, find the total charge Q:

$$Q = I \times t$$

Convert time to seconds: $t = 5 \times 60 = 300\,\text{s}$.

$$Q = 5 \times 300 = 1500\,\text{C}$$

The number of electrons n is total charge divided by elementary charge e:

$$n = \frac{Q}{e} = \frac{1500}{1.60 \times 10^{-19}}$$

$$n = 937.5 \times 10^{19} = 9.375 \times 10^{21}$$

Rounding gives 9.4×10^{21}. **Answer:** C (9.4×10^{21})

B2. Electrostatic vs Gravitational Force

Question: Find distance r where electrostatic force between two protons equals the gravitational force on a proton at Earth's surface (weight).
Solution: Electrostatic force: $F_E = k\frac{e^2}{r^2}$
Gravitational force (Weight): $F_G = m_p g$
Set $F_E = F_G$:

$$k\frac{e^2}{r^2} = m_p g$$

$$r^2 = \frac{ke^2}{m_p g}$$

$$r^2 = \frac{(8.99 \times 10^9)(1.60 \times 10^{-19})^2}{(1.67 \times 10^{-27})(9.81)}$$

$$r^2 = \frac{(8.99)(2.56) \times 10^{-29}}{16.38 \times 10^{-27}} \approx \frac{23.01}{16.38} \times 10^{-2} \approx 0.0140$$

$$r = \sqrt{0.0140} \approx 0.118\,\text{m}$$

Answer: B ($0.12\,\text{m}$)

B3. Charged Spheres Equilibrium

Question: Two spheres ($m = 5\,\text{g}, q = 2 \times 10^{-7}\,\text{C}$) hang from length $L = 0.5\,\text{m}$. Find angle θ.
Solution: Forces acting on one sphere: Tension T, Weight mg, Electric repulsion F_E. Horizontal: $T \sin\theta = F_E$
Vertical: $T \cos\theta = mg$
Divide equations: $\tan\theta = \frac{F_E}{mg}$. Using small angle approximation $\tan\theta \approx \sin\theta \approx \theta$ (in radians): Separation between charges $d \approx 2L\theta$.

$$F_E = \frac{kq^2}{d^2} \approx \frac{kq^2}{(2L\theta)^2}$$

$$\theta \approx \frac{kq^2}{mg(4L^2\theta^2)} \implies \theta^3 = \frac{kq^2}{4mgL^2}$$

Substitute values ($m = 0.005\,\mathrm{kg}$):

$$\theta^3 = \frac{(8.99 \times 10^9)(2 \times 10^{-7})^2}{4(0.005)(9.81)(0.5)^2}$$

$$\theta^3 = \frac{(8.99 \times 10^9)(4 \times 10^{-14})}{4(0.005)(9.81)(0.25)} = \frac{35.96 \times 10^{-5}}{0.04905} \approx 0.00733$$

$$\theta = \sqrt[3]{0.00733} \approx 0.194\,\mathrm{rad}$$

Convert to degrees: $0.194 \times \frac{180}{\pi} \approx 11.1°$. **Answer:** C (11.0°)

B4. Resistor Network

Question: Figure 2 (semi-parallel). Total resistance across AB equals R_1. Find R_3.
Solution: The circuit consists of R_1 and R_2 in parallel, connected in series with R_3.

$$R_{total} = R_{parallel} + R_3 = \left(\frac{R_1 R_2}{R_1 + R_2}\right) + R_3$$

We are given that $R_{total} = R_1$.

$$R_1 = \frac{R_1 R_2}{R_1 + R_2} + R_3$$

$$R_3 = R_1 - \frac{R_1 R_2}{R_1 + R_2}$$

$$R_3 = R_1 \left(1 - \frac{R_2}{R_1 + R_2}\right)$$

$$R_3 = R_1 \left(\frac{R_1 + R_2 - R_2}{R_1 + R_2}\right) = \frac{R_1^2}{R_1 + R_2}$$

Answer: E ($\frac{R_1^2}{R_1+R_2}$)

B5. Stopping Distance

Question: Reaction time $t_r = 0.5\,\mathrm{s}$, deceleration $a = 7.0\,\mathrm{m/s^2}$, total stop distance $d_{total} = 4.0\,\mathrm{m}$. Find max speed v.
Solution: Total distance = Reaction distance + Braking distance.

$$d_{total} = vt_r + \frac{v^2}{2a}$$

$$4.0 = 0.5v + \frac{v^2}{2(7.0)}$$

Multiply by 14 to clear denominator:

$$56 = 7v + v^2 \implies v^2 + 7v - 56 = 0$$

Using the quadratic formula:

$$v = \frac{-7 \pm \sqrt{49 - 4(1)(-56)}}{2} = \frac{-7 \pm \sqrt{49 + 224}}{2} = \frac{-7 \pm \sqrt{273}}{2}$$

$$v \approx \frac{-7 + 16.52}{2} = 4.76\,\mathrm{m/s}$$

Answer: A ($4.8\,\mathrm{m/s}$)

B6. Dipole Field Force

Question: Test charge q on perpendicular bisector of dipole $-Q, +Q$ separated by $2a$. Distance r.
Solution: Let the $-Q$ be at $(-a, 0)$ and $+Q$ be at $(a, 0)$. Point is at $(0, r)$. Distance from each charge to q is $d = \sqrt{r^2 + a^2}$. Magnitude of force from each charge is $F = kQq/d^2$. Force from $+Q$ is repulsive (up and left). Force from $-Q$ is attractive (down and left). Vertical components cancel. Horizontal components add up (pointing left). Horizontal component of one force is $F_x = F \sin\phi$, where ϕ is the angle at the top vertex. $\sin\phi = \frac{a}{d} = \frac{a}{\sqrt{r^2+a^2}}$. Total Force $F_{net} = 2F\sin\phi = 2\left(\frac{kQq}{r^2+a^2}\right)\left(\frac{a}{\sqrt{r^2+a^2}}\right)$.

$$F_{net} = \frac{2kQqa}{(r^2 + a^2)^{3/2}}$$

Answer: C ($\frac{2kQqa}{(r^2+a^2)^{3/2}}$)

B7. Circuit Calculation

Question: Circuit with battery. Branch 1 has R_1, R_2 in series. Branch 2 has R_3. Voltage across R_2 is 12.0 V. $R_1 = 1, R_2 = 2, R_3 = 6$. Find Current in R_3.
Solution: Since R_1 and R_2 are in series in the top branch, they share the same current I_{top}.

$$V_{R2} = I_{top}R_2 \implies 12.0 = I_{top}(2.0) \implies I_{top} = 6.0\,\text{A}$$

The total voltage across the top branch (and thus the battery voltage, as they are in parallel with R_3) is:

$$V_{battery} = I_{top}(R_1 + R_2) = 6.0(1.0 + 2.0) = 18.0\,\text{V}$$

Since R_3 is in parallel, the voltage across it is also 18.0 V. Current in R_3:

$$I_{R3} = \frac{V}{R_3} = \frac{18.0}{6.0} = 3.0\,\text{A}$$

Answer: B (3.0 A)

B8. Zero Electric Field Position

Question: Charge $+q$ at $x = 0$, $+3q$ at $x = L$. Find position x where field is zero.
Solution: For field to be zero between two positive charges, the fields must oppose and cancel.

$$E_1 = E_2 \implies \frac{kq}{x^2} = \frac{k(3q)}{(L - x)^2}$$

Cancel k and q:

$$\frac{1}{x^2} = \frac{3}{(L - x)^2}$$

Take the square root of both sides:

$$\frac{1}{x} = \frac{\sqrt{3}}{L - x}$$

$$L - x = x\sqrt{3}$$

$$L = x + x\sqrt{3} = x(1 + \sqrt{3})$$

$$x = \frac{L}{1 + \sqrt{3}}$$

Answer: E ($\frac{L}{1+\sqrt{3}}$)

B9. Escape Speed

Question: Formula for escape speed from spherical planet mass M, radius R.
Solution: Conservation of Energy: Kinetic Energy + Potential Energy at surface = Kinetic Energy + Potential Energy at infinity. At infinity, min energy implies $v = 0$ and $U = 0$.

$$\frac{1}{2}mv_e^2 - \frac{GMm}{R} = 0$$

$$\frac{1}{2}v_e^2 = \frac{GM}{R}$$

$$v_e = \sqrt{\frac{2GM}{R}}$$

Answer: B ($v_e = \sqrt{\frac{2GM}{R}}$)

B10. Elastic Collision

Question: Ball A (m) with speed $u = 2\,\text{m/s}$ hits Ball B ($2m$) at rest. Elastic collision. Find final velocity of A.
Solution: Using the 1D elastic collision formula for the velocity of the first mass (v_1') given $v_2 = 0$:

$$v_1' = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)u$$

Here $m_1 = m$ and $m_2 = 2m$.

$$v_A' = \left(\frac{m - 2m}{m + 2m}\right)u = \left(\frac{-m}{3m}\right)u = -\frac{1}{3}u$$

Substitute $u = 2\,\text{m/s}$:

$$v_A' = -\frac{2}{3}\ \text{m/s}$$

Answer: B ($-\frac{2}{3}$ m/s)