Grade 11 Physics Model Paper 1

ANSWER KEY

Full marks 75 · 3 hours

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

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Group A Multiple choice — 11 marks

Question 1 — 11 × 1 = 11

a. **(ii)** 4

b. **(iii)** 90°

c. **(ii)** The body moves with a uniform velocity.

d. **(iii)** Its velocity changes, and its acceleration points to the center of the circle.

e. **(ii)** 2.45 m/s²

f. **(iv)** Violet

g. **(iii)** Virtual, erect and magnified

h. **(iii)** 60 cm in front of the mirror, real and inverted, 3 times the object

i. **(ii)** 1.41

j. **(iv)** $4R$

k. **(ii)** Leptons

Group B Short answers, each on one content area — 40 marks

Question 2 — 5 marks

a. **Newton's second law:** the rate of change of momentum of a body is directly proportional to the net external force on it, and takes place in the direction of the force ($F = \frac{\Delta p}{\Delta t}$; for a fixed mass, $F = ma$). **[2]**

Impulse is the product of a force and the time for which it acts, $F\,\Delta t$; it equals the change in momentum it produces. Its unit is N s (the same as kg m/s).

Marking scheme

- Second law: rate of change of momentum proportional to (equal to) the net force, in the force's direction.
- Impulse = force × time (= change in momentum).

b. Take the direction the ball leaves the bat as positive. Then $u = -30$ m/s and $v = +20$ m/s, and **[2]**

$$\Delta p = m(v - u) = 0.160 \times (20 - (-30)) = 0.160 \times 50 = 8.0 \ \text{kg m/s}$$

$$F = \frac{\Delta p}{\Delta t} = \frac{8.0}{0.010} = 800 \ \text{N}$$

The average force is 800 N, in the direction the ball leaves the bat. (Using $20 - 30$ instead of $20 + 30$ forgets that velocity is a vector.)

Marking scheme

- Change in momentum 8.0 kg m/s, with the reversal of direction taken into account.

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- Average force 800 N, towards the direction the ball leaves the bat.

c. **No.** By Newton's third law the ball pushes the bat with a force equal and opposite to the bat's push on the ball, about 800 N, for the same 0.010 s. The bat hardly turns back because the batter's arms hold it and push it forwards, and with them it is far heavier than the ball; the forces between bat and ball are still equal. **[1]**

Marking scheme

- No: by Newton's third law the forces are equal and opposite (about 800 N each); the bat is held and heavier, so its motion changes little.

OR

a. **Hooke's law:** within the elastic limit, the extension of a body is directly proportional to the force (load) stretching it (equivalently, stress is proportional to strain). **[2]**

Young's modulus is the ratio of the normal (tensile) stress to the longitudinal strain it produces, within the elastic limit: $Y = \dfrac{F/A}{x/L}$.

Marking scheme

- Hooke's law: extension proportional to load (stress ∝ strain), within the elastic limit.
- Young's modulus = normal stress ÷ longitudinal strain, within the elastic limit.

b. **[2]**

$$F = mg = 20 \times 9.8 = 196\ \text{N}, \qquad A = 1.0\ \text{mm}^2 = 1.0 \times 10^{-6}\ \text{m}^2$$

$$\text{stress} = \frac{F}{A} = \frac{196}{1.0 \times 10^{-6}} = 1.96 \times 10^{8}\ \text{Pa}, \qquad \text{strain} = \frac{x}{L} = \frac{1.96 \times 10^{-3}}{2.0} = 9.8 \times 10^{-4}$$

$$Y = \frac{\text{stress}}{\text{strain}} = \frac{1.96 \times 10^{8}}{9.8 \times 10^{-4}} = 2.0 \times 10^{11}\ \text{Pa}$$

Stress about 2.0×10^{8} Pa, strain 9.8×10^{-4}, Young's modulus 2.0×10^{11} Pa.

Marking scheme

- Stress 1.96×10^{8} Pa and strain 9.8×10^{-4} (load in newtons, area in m², lengths in m).
- Young's modulus 2.0×10^{11} Pa.

c. With four times the area, the same load gives a quarter of the stress, so the wire stays well within its elastic limit (it stretches less and does not stay stretched, weaken or break), giving a margin of safety for jerks and heavier loads. **[1]**

Marking scheme

- Same load on a larger area: smaller stress, well within the elastic limit (safer, less extension).

Question 3 — 5 marks

a. Water has a very high specific heat capacity, so a kilogram of it stores a great deal of heat for each degree, and gives that heat out slowly as it cools: the bag stays warm for a long time. **[1]**

Marking scheme

- High specific heat capacity: stores much heat per degree and releases it over a long time.

b. **[3]**

$$Q = mc\,\Delta\theta = 1.2 \times 4200 \times (100 - 20) = 403\,200\ \text{J}$$

Power is energy per second, so

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$$t = \frac{Q}{P} = \frac{403\,200}{2000} = 201.6\ \text{s}$$

About 202 s, or 3.4 minutes.

Marking scheme

- $Q = mc\Delta\theta$ with $\Delta\theta = 80$ K.
- $Q = 4.03 \times 10^5$ J.
- $t = Q/P = 202$ s (about 3.4 min).

c. **Sooner.** The air pressure at Namche is lower, so water boils there at about 89 °C instead of 100 °C. **[1]**
The water needs to be heated through only about 69 K instead of 80 K, so less heat, and less time, is needed.

Marking scheme

- Sooner, because the lower pressure lowers the boiling point (about 89 °C), so less heat is needed.

Question 4 — 5 marks

a. **Temperature gradient** is the change of temperature per unit length along the direction of heat flow, $\frac{\theta_1 - \theta_2}{x}$ (unit K/m). **[3]**

Thermal conductivity k of a material is the rate of flow of heat through unit area of a slab of it, per unit temperature gradient across it, in the steady state: $k = \dfrac{Q/t}{A\,(\theta_1 - \theta_2)/x}$.

Its SI unit is **W/(m K)** (W m^{-1} K^{-1}).

Marking scheme

- Temperature gradient: change of temperature per unit length.
- Thermal conductivity: rate of heat flow per unit area per unit temperature gradient.
- Unit W/(m K).

b. **[2]**

$$\frac{Q}{t} = kA\,\frac{\theta_1 - \theta_2}{x} = 0.80 \times 1.5 \times \frac{15 - (-5)}{4.0 \times 10^{-3}} = 0.80 \times 1.5 \times 5000 = 6000\ \text{W}$$

About 6 kW flows out through one window (in practice less, since thin layers of air on each side of the glass add to the resistance to heat flow).

Yes. Still air is a very poor conductor of heat (its thermal conductivity is about 30 times smaller than glass's), so the air layer greatly lowers the rate of heat loss.

Marking scheme

- Rate of heat flow 6000 W (temperature difference 20 K, thickness in meters).
- Yes: still air is a bad conductor, so the double pane cuts the heat loss.

Question 5 — 5 marks

a. At constant volume, the pressure of a fixed mass of gas is directly proportional to its absolute temperature, $P \propto T$. (Equivalently, it rises by $\frac{1}{273}$ of its pressure at 0 °C for each degree of heating.) **[1]**

Marking scheme

- At constant volume, pressure of a fixed mass of gas ∝ absolute temperature.

b. The temperatures must be absolute: $T_1 = 17 + 273 = 290$ K and $T_2 = 46 + 273 = 319$ K. **[3]**

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \quad \Rightarrow \quad P_2 = P_1\,\frac{T_2}{T_1} = 2.0 \times 10^5 \times \frac{319}{290} = 2.2 \times 10^5\ \text{Pa}$$

The pressure rises to 2.2×10^5 Pa.

Marking scheme

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- Temperatures in kelvin: 290 K and 319 K.
- $P_1/T_1 = P_2/T_2$ (pressure law at constant volume).
- $P_2 = 2.2 \times 10^5$ Pa.

c. The mean kinetic energy of the molecules is proportional to the absolute temperature, so in the hotter tyre they move faster: they strike the walls more often and each strike gives a larger change of momentum, so the force per unit area on the walls, the pressure, is greater. **[1]**

Marking scheme

- Higher temperature, faster molecules: more frequent and harder collisions with the walls, so greater pressure.

Question 6 — 5 marks

a. The **critical angle** is the angle of incidence in the denser medium for which the angle of refraction in the rarer medium is 90°. **[2]**

Total internal reflection happens when (i) light travels from an optically denser medium towards a rarer one, and (ii) the angle of incidence is greater than the critical angle.

Marking scheme

- Critical angle: the angle of incidence in the denser medium that gives a refraction angle of 90°.
- Both conditions: denser to rarer, and angle of incidence greater than the critical angle.

b. Diamond's refractive index (2.42) is much higher than glass's, so its critical angle is small (about 24°). Most light inside it meets the faces at more than the critical angle and is totally reflected many times before it escapes through a few faces, so those faces flash brightly. **[1]**

Marking scheme

- High refractive index, small critical angle: light is totally reflected again and again inside and comes out in bright flashes.

c. **[2]**

$$\sin C = \frac{1}{\mu} = \frac{1}{1.5} = 0.667 \quad \Rightarrow \quad C = 41.8^\circ$$

The critical angle is about 42°.

Marking scheme

- $\sin C = 1/\mu$.
- $C \approx 41.8^\circ$.

OR

a. The **power** of a lens is the reciprocal of its focal length in meters, $P = \frac{1}{f}$; it measures how strongly the lens converges or diverges light. Its SI unit is the **diopter** (D), the power of a lens of focal length 1 m. **[2]**

Marking scheme

- Power = 1/f (f in meters), the converging or diverging ability.
- Unit: diopter (D), i.e. m^{-1}.

b. It is thinner in the middle than at its edges, so a parallel beam passing through it is bent away from the principal axis and spreads out, as if coming from its focus. **[1]**

Marking scheme

- A parallel beam spreads out (bent away from the axis) after passing through it.

c. With a concave lens's focal length negative: **[2]**

$$P = P_1 + P_2 = \frac{1}{0.25} + \frac{1}{-1.00} = 4.0 - 1.0 = +3.0\ \mathrm{D}$$

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$$F = \frac{1}{P} = \frac{1}{3.0} = 0.33\ \text{m} = 33\ \text{cm}$$

Power +3.0 D, focal length about 33 cm: the combination is converging.

Marking scheme

- $P = 4.0 - 1.0 = +3.0$ D.
- $F \approx 33$ cm, converging (positive power).

Question 7 — 5 marks

a. Rubbing brings the two surfaces into close contact, and electrons are transferred from the glass to the silk (glass holds its electrons less tightly). The glass is left with fewer electrons than protons, so it is **positive**; the silk gains the same number of electrons and becomes **negative** by the same amount, since charge is neither created nor destroyed. **[2]**

Marking scheme

- Electrons move from the glass to the silk, leaving the glass positive.
- The silk becomes negative, with an equal and opposite charge (charge is conserved).

b. Between A and B the forces from the two charges on the third charge point in opposite directions, so they can cancel there. Let the point be x meters from A. Equal sizes of force: **[3]**

$$\frac{k\,(4.0\ \mu\text{C})\,q}{x^2} = \frac{k\,(1.0\ \mu\text{C})\,q}{(0.30 - x)^2} \quad \Rightarrow \quad \frac{4}{x^2} = \frac{1}{(0.30 - x)^2}$$

Taking square roots, $\dfrac{2}{x} = \dfrac{1}{0.30 - x}$, so $0.60 - 2x = x$ and $x = 0.20$ m.

20 cm from A (10 cm from B). Outside AB the two forces point the same way and can't cancel.

No: q cancels from both sides. A positive charge there is pushed equally by both; a negative one is pulled equally by both. Either way the forces balance at the same point.

Marking scheme

- Equates the two Coulomb forces with distances x and $0.30 - x$ (the point between the charges).
- $x = 0.20$ m: 20 cm from the 4.0 µC charge.
- Independent of the third charge: q cancels, for either sign.

Question 8 — 5 marks

a. The **capacitance** of a capacitor is the charge stored on either plate per unit potential difference between the plates, $C = \dfrac{Q}{V}$. Its SI unit is the **farad** (F), one coulomb per volt. **[2]**

Marking scheme

- Capacitance = charge stored per unit potential difference, $C = Q/V$.
- Unit farad (F) = C/V.

b. **[3]**

$$Q = CV = 150 \times 10^{-6} \times 300 = 0.045\ \text{C}$$

$$W = \tfrac{1}{2}CV^2 = \tfrac{1}{2} \times 150 \times 10^{-6} \times 300^2 = 6.75\ \text{J}$$

$$P = \frac{W}{t} = \frac{6.75}{1.5 \times 10^{-3}} = 4500\ \text{W} = 4.5\ \text{kW}$$

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A small battery cannot deliver thousands of watts. It charges the capacitor slowly over a few seconds, and the capacitor then gives out the stored energy in a very short time, at a very high power.

Marking scheme

- $Q = 0.045$ C and $W = 6.75$ J.
- Average power 4.5 kW.
- The capacitor stores energy slowly and releases it quickly, at a power the battery alone can't give.

Question 9 — 5 marks

a. One electron volt is the kinetic energy a particle with charge e gains when it moves through a potential difference of 1 V: $1\ \text{eV} = e \times 1\ \text{V} = 1.6 \times 10^{-19}$ J. It is charge times potential difference, which is work, so it measures energy. **[1]**

Marking scheme

- It is the energy (work = eV) gained by a charge e through 1 V, 1.6×10^{-19} J.

b. For a uniform field, $E = \dfrac{V}{d}$: **[2]**

$$E = \frac{500}{2.0 \times 10^{-2}} = 2.5 \times 10^{4}\ \text{V/m}$$

$$F = eE = 1.6 \times 10^{-19} \times 2.5 \times 10^{4} = 4.0 \times 10^{-15}\ \text{N}$$

towards the positive plate.

Marking scheme

- $E = V/d = 2.5 \times 10^{4}$ V/m (N/C).
- $F = eE = 4.0 \times 10^{-15}$ N.

c. The work done by the field is eV, and it all becomes kinetic energy: **[2]**

$$\tfrac{1}{2}mv^2 = eV = 1.6 \times 10^{-19} \times 500 = 8.0 \times 10^{-17}\ \text{J}\ (= 500\ \text{eV})$$

$$v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 8.0 \times 10^{-17}}{9.1 \times 10^{-31}}} = 1.3 \times 10^{7}\ \text{m/s}$$

About 1.3×10^{7} m/s. (The same answer comes from $v^2 = 2as$ with $a = F/m$.)

Marking scheme

- $\tfrac{1}{2}mv^2 = eV = 8.0 \times 10^{-17}$ J.
- $v \approx 1.3 \times 10^{7}$ m/s.

Group C Long answers, each on one content area — 24 marks

Question 10 — 8 marks

a. In an **elastic** collision the bodies bounce apart and the total kinetic energy after the collision equals that before; none is turned into other forms (collisions of gas molecules, and nearly so of steel or ivory balls). **[3]**

In an **inelastic** collision some kinetic energy is turned into other forms (heat, sound, the work of bending), so the total kinetic energy after is less. When the bodies stick together the collision is

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perfectly inelastic and the loss is the greatest possible.

Momentum is conserved in both kinds, as long as no external force acts; kinetic energy only in an elastic one.

Marking scheme

- Elastic: kinetic energy conserved.
- Inelastic: kinetic energy not conserved (changed to heat, sound, deformation); sticking together is perfectly inelastic.
- Momentum conserved in both (no external force).

b. Momentum is conserved (the friction from the floor is small during the short collision): **[2]**

$$m_1 u_1 + m_2 u_2 = (m_1 + m_2) v$$

$$200 \times 3.0 + 300 \times 0 = 500\, v \quad \Rightarrow \quad v = \frac{600}{500} = 1.2 \text{ m/s}$$

1.2 m/s, in the direction Sandhya was moving.

Marking scheme

- Conservation of momentum written for the two cars.
- $v = 1.2$ m/s.

c. **[3]**

$$\text{KE before} = \tfrac{1}{2} \times 200 \times 3.0^2 = 900 \text{ J}, \qquad \text{KE after} = \tfrac{1}{2} \times 500 \times 1.2^2 = 360 \text{ J}$$

540 J is lost, which is $\frac{540}{900} = 0.60$ of the original.

In general, $v = \frac{m_1 u_1}{m_1 + m_2}$, so the kinetic energy after is $\frac{1}{2}(m_1 + m_2)v^2 = \frac{1}{2} m_1 u_1^2 \times \frac{m_1}{m_1 + m_2}$. The fraction kept is $\frac{m_1}{m_1 + m_2}$, so the fraction lost is $1 - \frac{m_1}{m_1 + m_2} = \frac{m_2}{m_1 + m_2} = \frac{300}{500} = 0.60$. ✓

The lost energy goes into heat and sound and into the work of squashing the rubber bumpers and the riders' bodies; none of it is destroyed.

Marking scheme

- Kinetic energy lost 540 J, 60% of the original.
- Shows the fraction lost is $m_2/(m_1 + m_2)$.
- The energy goes to heat, sound and deformation (energy is conserved).

Question 11 — 8 marks

a. To seem at rest over one place, the satellite must keep pace with the turning Earth. It must therefore go round the same way the Earth turns, **west to east**, with the same period, 24 hours. **[2]**

Its orbit must be centered on the Earth's center, since gravity points there, and only an orbit **in the plane of the equator** stays over the same latitude; an orbit tilted to the equator would carry it north and south of it each day.

Marking scheme

- West to east with a 24-hour period, to keep pace with the Earth's rotation.
- In the equator's plane: any orbit is centered on the Earth's center, and only an equatorial one stays over the same point.

b. Gravity provides the centripetal force: **[3]**

$$\frac{GMm}{r^2} = \frac{m\, 4\pi^2 r}{T^2} \quad \Rightarrow \quad r^3 = \frac{GMT^2}{4\pi^2}$$

With $T = 24 \times 3600 = 86\,400$ s:

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$$r^3 = \frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times (86\,400)^2}{4\pi^2} = 7.57 \times 10^{22}\ \text{m}^3 \quad \Rightarrow \quad r = 4.23 \times 10^7\ \text{m}$$

$$h = r - R = 4.23 \times 10^7 - 0.64 \times 10^7 = 3.59 \times 10^7\ \text{m}$$

Radius about 42,300 km; height about 35,900 km.

Marking scheme

- $GMm/r^2 = m\,4\pi^2 r/T^2$, giving $r^3 = GMT^2/4\pi^2$.
- $r = 4.23 \times 10^7$ m (with $T = 86\,400$ s).
- $h = 3.59 \times 10^7$ m (about 36,000 km).

c. **[3]**

$$g' = \frac{GM}{r^2} = \frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24}}{(4.23 \times 10^7)^2} = 0.22\ \text{N/kg}$$

The claim is wrong. Gravity there is weaker, about $\frac{1}{44}$ of its value at the ground, but not zero. That pull is exactly what keeps the satellite on its circle: it supplies the centripetal force mv^2/r ($v = 2\pi r/T \approx 3.1$ km/s gives $v^2/r = 0.22$ m/s², the same). With no gravity, the satellite would fly off in a straight line. It stays up because it moves sideways fast enough that, as it falls, the Earth curves away beneath it.

Marking scheme

- $g' \approx 0.22$ N/kg (not zero).
- Gravity provides the centripetal force ($g' = v^2/r$), so the claim is wrong.
- Without gravity it would move off in a straight line; it is falling round the Earth all the time.

OR

a. With no air resistance, the only force on the ball in flight is its weight, which acts vertically downwards. There is no horizontal force, so there is no horizontal acceleration and the horizontal velocity $u\cos\theta$ stays the same. The vertical velocity changes at the steady rate g: it falls from $u\sin\theta$ to zero at the top, then grows downwards. **[2]**

Marking scheme

- No horizontal force (weight is vertical), so horizontal velocity constant.
- Vertical acceleration g downward changes the vertical velocity.

b. $u\sin 30^\circ = 19.6 \times 0.5 = 9.8$ m/s and $u\cos 30^\circ = 19.6 \times 0.866 = 17.0$ m/s. **[3]**

$$T = \frac{2u\sin\theta}{g} = \frac{2 \times 9.8}{9.8} = 2.0\ \text{s}$$

$$H = \frac{u^2\sin^2\theta}{2g} = \frac{9.8^2}{2 \times 9.8} = 4.9\ \text{m}$$

$$R = \frac{u^2\sin 2\theta}{g} = \frac{19.6^2 \times \sin 60^\circ}{9.8} = 39.2 \times 0.866 = 33.9\ \text{m}$$

2.0 s, 4.9 m and about 34 m.

Marking scheme

- Time of flight 2.0 s.
- Greatest height 4.9 m.

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- Range about 33.9 m.

c. $R = \frac{u^2 \sin 2\theta}{g}$ is greatest when $\sin 2\theta = 1$, at $\theta = 45^\circ$: $R_{max} = \frac{19.6^2}{9.8} = 39.2$ m, more than 33.9 m. **The first statement is true.** **[3]**

At 60°, $\sin 120^\circ = \sin 60^\circ = 0.866$, so $R = 33.9$ m, the same as at 30°: angles that add up to 90° give the same range. **The second is true too.**

At 60°, $T = \frac{2 \times 19.6 \times \sin 60^\circ}{9.8} = 3.46$ s against 2.0 s: **the 60° kick stays up longer** (it goes higher, 14.7 m), while the 30° kick travels faster sideways.

Marking scheme

- 45° gives the maximum range, 39.2 m.
- 60° gives the same range as 30°, 33.9 m ($\sin 120^\circ = \sin 60^\circ$).
- The 60° kick is in the air longer (3.46 s against 2.0 s).

Question 12 — 8 marks

a. The **mass defect** is the amount by which the mass of a nucleus is less than the total mass of its separate protons and neutrons. **[3]**

The **binding energy** is the energy needed to pull a nucleus apart into its separate nucleons (equally, the energy given out when they come together to form it). It is the energy equivalent of the mass defect, $E = \Delta m\, c^2$.

A big nucleus has a big total binding energy just because it has many nucleons. The **binding energy per nucleon** is the energy needed, on average, to remove one nucleon, so it tells how tightly each nucleon is held: the higher it is, the more stable the nucleus.

Marking scheme

- Mass defect: mass of the separate nucleons minus the mass of the nucleus.
- Binding energy: energy to separate the nucleus into its nucleons, $\Delta m\, c^2$.
- Per nucleon shows how tightly each nucleon is bound (total grows with the number of nucleons).

b. **[3]**

$$\text{Mass of the nucleons} = 6 \times 1.00728 + 6 \times 1.00867 = 6.04368 + 6.05202 = 12.09570 \text{ u}$$

$$\Delta m = 12.09570 - 11.99671 = 0.09899 \text{ u}$$

$$E_b = 0.09899 \times 931.5 = 92.2 \text{ MeV}, \qquad \frac{E_b}{A} = \frac{92.2}{12} = 7.68 \text{ MeV per nucleon}$$

Marking scheme

- Mass defect 0.09899 u.
- Binding energy 92.2 MeV.
- 7.68 MeV per nucleon.

c. The binding energy per nucleon is highest, about 8.8 MeV, for nuclei near iron-56, and lower for both very heavy and very light nuclei. When uranium splits into two middle-sized nuclei, and when light nuclei join into a heavier one, the products sit nearer that peak: their nucleons are more tightly bound. The total binding energy rises, so the total mass falls, and the mass lost appears as energy, $E = \Delta m\, c^2$. **[2]**

Marking scheme

- Binding energy per nucleon peaks near iron-56 and is lower for heavy and light nuclei.
- Both fission and fusion move towards the peak: more tightly bound products, mass lost, energy released.

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