Grade 11 Physics Model Paper 2

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.

A practice paper by Science Playground, made to CDC's Specification Grid 2077, Grade 11 Physics (Phy. 101); not an official CDC or NEB paper.

Group A Multiple choice — 11 marks

Question 1 — 11 × 1 = 11

a. **(ii)** Work and torque

b. **(ii)** Inertia: their bodies tend to keep moving at the speed they had.

c. **(iii)** Zero

d. **(ii)** Steel has a larger Young's modulus, so it is more elastic in the physics sense.

e. **(iii)** 5 N

f. **(i)** Snell's law

g. **(ii)** Light from the bottom bends away from the normal as it leaves the water.

h. **(iii)** 30 cm from the lens, on the other side

i. **(iii)** 0.031

j. **(ii)** The electric potential is zero, but the electric field is not.

k. **(i)** Electrons

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

Question 2 — 5 marks

a. The **dimensions** of a physical quantity are the powers to which the fundamental quantities (mass M, length L, time T and so on) must be raised to represent it: velocity, for example, is $[M^0LT^{-1}]$. **[2]**

Principle of homogeneity: a physically correct equation has the same dimensions in every term on both sides; only quantities of the same dimensions can be added, subtracted or equated.

Marking scheme

- Dimensions: the powers of the fundamental quantities that represent the quantity.
- Homogeneity: every term of a correct equation has the same dimensions.

b. **[2]**

$$[v^2] = [u^2] = (LT^{-1})^2 = [L^2T^{-2}]$$

$$[2as] = [LT^{-2}] \times [L] = [L^2T^{-2}] \quad (\text{the number 2 has no dimensions})$$

Every term has the dimensions $[L^2T^{-2}]$, so **the equation is dimensionally correct**.

Marking scheme

- Dimensions of v^2 and u^2: $[L^2T^{-2}]$.
- Dimensions of $2as$: $[L^2T^{-2}]$, the same, so the equation is dimensionally correct.

c. **No.** Every term is in $[L]$, so it is dimensionally correct, but the right equation is $s = ut + \frac{1}{2}at^2$. **[1]** Dimensional analysis can't find a pure number such as $\frac{1}{2}$, so a dimensionally correct equation can still be wrong.

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Marking scheme

- No: dimensions can't check pure numbers (the ½ is missing), so a dimensionally correct equation may still be wrong.

OR

a. The **relative velocity** of a body A with respect to a body B is the velocity with which A appears to move to an observer on B: the rate of change of A's position as measured from B. **[2]**

$$\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$$

Marking scheme

- Relative velocity: the velocity of A as seen by an observer moving with B.
- $\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$.

b. The velocity of the rain relative to Kushal is $\vec{v}_{rain} - \vec{v}_{Kushal}$: 6.0 m/s down, plus 8.0 m/s towards the west. **[2]**

$$v = \sqrt{6.0^2 + 8.0^2} = 10\ \mathrm{m/s}, \qquad \tan\theta = \frac{8.0}{6.0} \Rightarrow \theta = 53^\circ$$

10 m/s, coming down at 53° to the vertical, slanting towards him from the east (the direction he is riding into).

Marking scheme

- Relative speed 10 m/s.
- At 53° to the vertical, coming from the front (east).

c. Tilted forwards, towards the east, at about 53° to the vertical: along the direction the rain comes from relative to him. **[1]**

Marking scheme

- Tilted forwards (into his direction of motion), at about 53° to the vertical.

Question 3 — 5 marks

a. The rails expand when they get hot. A gap lets each rail lengthen freely; without it, the rails would push hard against each other (thermal stress) and buckle the line. **[1]**

Marking scheme

- Room for the rails to expand when heated, so they do not buckle.

b. **[3]**

$$\Delta L = L_0\,\alpha\,\Delta\theta = 12 \times 1.2 \times 10^{-5} \times (45 - 10) = 12 \times 1.2 \times 10^{-5} \times 35 = 5.0 \times 10^{-3}\ \mathrm{m}$$

The gap must be at least about 5.0 mm. (Each rail grows 5.0 mm; half of it goes into the gap at each end, so the gap between two rails closes by 2.5 + 2.5 = 5.0 mm.)

Marking scheme

- $\Delta L = L_0 \alpha \Delta\theta$ with $\Delta\theta = 35$ K.
- Values substituted correctly.
- Gap about 5.0 mm.

c. It bends into an arc with the **brass on the inside** (the iron on the outside): brass also contracts more than iron when cooled, so it becomes the shorter strip, and the shorter strip must lie along the shorter, inner curve. **[1]**

Marking scheme

- Brass on the inside (concave side), because it contracts more on cooling and becomes the shorter strip.

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Question 4 — 5 marks

a. Two bodies are in **thermal equilibrium** when no net heat flows between them when they are in thermal contact: they are at the same temperature. **[3]**

Zeroth law: if two bodies are each in thermal equilibrium with a third, they are in thermal equilibrium with each other.

A thermometer is the third body. Left in contact with a body until they reach thermal equilibrium, it is at the body's temperature; by the zeroth law, two bodies that give the same reading are at the same temperature, without being put in contact with each other.

Marking scheme

- Thermal equilibrium: no net heat flow between bodies in contact (same temperature).
- Zeroth law stated.
- The thermometer reaches equilibrium with the body, so equal readings mean equal temperatures.

b. The thread goes the same fraction of the way between the fixed points on both scales: **[2]**

$$\frac{C-0}{100-0}=\frac{X-5}{95-5}\quad\Rightarrow\quad C=\frac{X-5}{90}\times 100$$

For $X=41$: $C=\frac{36}{90}\times 100=40$ °C.

It reads correctly when $C=X$: $\frac{X-5}{90}\times 100=X$, so $100X-500=90X$ and $X=50$ °C.

True temperature 40 °C; it reads correctly at 50 °C.

Marking scheme

- True temperature 40 °C.
- Reads correctly at 50 °C.

Question 5 — 5 marks

a. The energy radiated per second per unit area by a perfectly black body (its emissive power) is directly proportional to the fourth power of its absolute temperature: $E=\sigma T^4$. **[1]**

Marking scheme

- Emissive power of a black body $\propto T^4$ (absolute temperature).

b. In kelvin: $T=227+273=500$ K and $T_0=27+273=300$ K. The plate also absorbs radiation from the room, so **[3]**

$$P=\sigma A\,(T^4-T_0^4)=5.67\times 10^{-8}\times 0.020\times(6.25\times 10^{10}-0.81\times 10^{10})$$

$$P=5.67\times 10^{-8}\times 0.020\times 5.44\times 10^{10}=62\ \text{W}$$

About 62 W.

Marking scheme

- Temperatures in kelvin, 500 K and 300 K.
- Net loss $\sigma A(T^4-T_0^4)$.
- About 62 W.

c. **No.** Stefan's law uses the absolute temperature: 454 °C is 727 K, not twice 500 K. The energy radiated per second rises by $\left(\frac{727}{500}\right)^4\approx 4.5$ times, not 16. **[1]**

Marking scheme

- No: the temperature must be absolute (727 K against 500 K), so it rises only about 4.5 times.

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Question 6 — 5 marks

a. The **principal focus** is the point on the principal axis where rays parallel and close to the axis meet after reflection from the mirror. **[2]**

The **radius of curvature** is the radius of the sphere of which the mirror is a part: the distance from the pole to the center of curvature.

Marking scheme

- Principal focus: where paraxial rays parallel to the axis meet after reflection.
- Radius of curvature: radius of the sphere the mirror is part of (pole to center of curvature).

b. With the tooth closer than the focus, a concave mirror forms a virtual, erect and magnified image, so the dentist sees an enlarged, upright view of the tooth. A plane mirror only gives an image of the same size. **[1]**

Marking scheme

- Object within the focus: an erect, magnified (virtual) image.

c. With real distances positive: **[2]**

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{10} - \frac{1}{5.0} = -\frac{1}{10} \quad \Rightarrow \quad v = -10\ \text{cm}$$

The minus sign means a virtual image, 10 cm **behind** the mirror.

$$m = \frac{v}{u} = \frac{-10}{5.0} = -2$$

The image is **twice the size** of the tooth; the negative m in this convention means it is virtual and erect.

Marking scheme

- $v = -10$ cm: virtual, 10 cm behind the mirror.
- Magnification 2 (erect, twice the size).

OR

a. The **angle of deviation** is the angle between the direction of the ray entering the prism (produced forward) and the ray leaving it. **[2]**

The **angle of minimum deviation** is the smallest value the deviation takes as the angle of incidence is changed.

Marking scheme

- Deviation: angle between the incident ray produced and the emergent ray.
- Minimum deviation: its least value as the angle of incidence changes.

b. At minimum deviation the ray passes through the prism symmetrically: the angle of incidence equals the angle of emergence, and inside an equilateral (or isosceles) prism the ray runs parallel to the base. **[1]**

Marking scheme

- Symmetrically: angle of incidence = angle of emergence (ray parallel to the base).

c. For a thin prism, $\delta = (\mu - 1)A$: **[2]**

$$\delta_y = (1.50 - 1) \times 5.0^\circ = 2.5^\circ, \qquad \delta_r = (1.48 - 1) \times 5.0^\circ = 2.4^\circ$$

Yellow light is deviated 2.5°, red light 2.4°.

Marking scheme

- $\delta = (\mu - 1)A$: yellow 2.5°.
- Red 2.4°.

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Question 7 — 5 marks

a. Field lines start on positive charges and end on negative charges; they are closer together where the field is stronger; they meet a conductor's surface at right angles. **[2]**

They never cross: the tangent to a line at any point gives the direction of the field there. If two lines crossed, the field at that point would have two directions at once, which is impossible.

Marking scheme

- Two properties (from positive to negative; denser where the field is stronger; normal to a conductor's surface).
- They never cross, since the field at a point has only one direction.

b. Take a spherical Gaussian surface of radius r round the sphere, with the same center. By symmetry the field is radial and has the same size E everywhere on it, so the flux is $E \times 4\pi r^2$. Gauss's law says this equals $\frac{Q}{\varepsilon_0}$: **[3]**

$$E \cdot 4\pi r^2 = \frac{Q}{\varepsilon_0} \quad \Rightarrow \quad E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

the field of a point charge Q at the center.

At 30 cm: $E = \dfrac{9.0 \times 10^9 \times 2.0 \times 10^{-6}}{0.30^2} = 2.0 \times 10^5$ N/C, directed away from the sphere.

Inside a hollow charged conductor, a Gaussian surface encloses no charge, so **the field is zero**.

Marking scheme

- Gauss's law on a concentric sphere: $E \cdot 4\pi r^2 = Q/\varepsilon_0$, the field of a point charge at the center.
- $E = 2.0 \times 10^5$ N/C at 30 cm.
- Zero inside (no charge enclosed).

Question 8 — 5 marks

a. The **e.m.f.** of a cell is the energy it converts from chemical to electrical form per unit charge passing through it: the work done per coulomb in driving charge round the whole circuit (equal to the p.d. across its terminals when no current flows). **[2]**

The **internal resistance** is the resistance of the materials inside the cell to the current flowing through it.

Marking scheme

- E.m.f.: energy converted into electrical energy per unit charge through the cell.
- Internal resistance: the resistance inside the cell itself.

b. **[3]**

$$I = \frac{E}{R + r} = \frac{1.5}{2.5 + 0.50} = 0.50 \text{ A}$$

$$V = IR = 0.50 \times 2.5 = 1.25 \text{ V}, \qquad \text{lost volts} = Ir = 0.50 \times 0.50 = 0.25 \text{ V}$$

As a cell ages, its **internal resistance rises.** The current $\frac{E}{R+r}$ falls, more of the e.m.f. is lost inside the cell, and the terminal p.d. across the bulb drops, so the bulb gets less power and glows dimmer.

Marking scheme

- Current 0.50 A.
- Terminal p.d. 1.25 V and lost volts 0.25 V.
- Internal resistance grows with age: less current and terminal p.d., so the bulb is dimmer.

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Question 9 — 5 marks

a. In parallel, each capacitor has the same p.d. across it, and the total charge stored is the sum of their charges. Joining them in parallel is like increasing the area of the plates, so the total $C = C_1 + C_2$ is larger than either. **[1]**

Marking scheme

- Same p.d., charges add (like larger plates), so $C = C_1 + C_2$.

b. **[2]**

$$\text{Series: } \frac{1}{C} = \frac{1}{2.0} + \frac{1}{3.0} = \frac{5}{6} \Rightarrow C = 1.2\ \mu\text{F} \qquad \text{Parallel: } C = 2.0 + 3.0 = 5.0\ \mu\text{F}$$

Marking scheme

- Series 1.2 µF.
- Parallel 5.0 µF.

c. In series both carry the same charge: **[2]**

$$Q = CV = 1.2 \times 10^{-6} \times 10 = 1.2 \times 10^{-5}\ \text{C}\ (12\ \mu\text{C})$$

$$V_1 = \frac{Q}{C_1} = \frac{12}{2.0} = 6.0\ \text{V}, \qquad V_2 = \frac{12}{3.0} = 4.0\ \text{V}$$

The 2.0 µF capacitor has the larger p.d.: with the same charge, $V = Q/C$ is larger for the smaller capacitance.

Marking scheme

- Same charge, 12 µC, on each.
- 6.0 V across 2.0 µF and 4.0 V across 3.0 µF; the smaller capacitor has the larger p.d., since $V = Q/C$.

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

Question 10 — 8 marks

a. The **angle of friction** λ is the angle between the normal reaction R and the resultant of R and the limiting friction F: $\tan\lambda = \frac{F}{R} = \mu_s$. **[3]**

The **angle of repose** θ is the smallest angle of an inclined plane at which a body placed on it just begins to slide down.

At the angle of repose, the body is just about to slide, so friction is limiting. Along the slope, $F = mg\sin\theta$; perpendicular to it, $R = mg\cos\theta$. So

$$\mu_s = \frac{F}{R} = \frac{mg\sin\theta}{mg\cos\theta} = \tan\theta$$

and $\tan\lambda = \tan\theta = \mu_s$: the angle of repose equals the angle of friction.

Marking scheme

- Angle of friction defined (between R and the resultant of R and limiting friction).
- Angle of repose defined (the least slope at which a body begins to slide).
- $F = mg\sin\theta$, $R = mg\cos\theta$, so $\tan\theta = \mu_s = \tan\lambda$.

b. Along the slope, $ma = mg\sin\theta - \mu_k mg\cos\theta$, so **[2]**

$$a = g(\sin\theta - \mu_k\cos\theta) = 9.8 \times (0.60 - 0.25 \times 0.80) = 9.8 \times 0.40 = 3.9\ \text{m/s}^2$$

Marking scheme

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- $a = g(\sin\theta - \mu_k \cos\theta)$.
- $a \approx 3.9$ m/s².

c. The crate starts to slide if $\tan\theta > \mu_s$. Here $\tan 37^\circ = \frac{0.60}{0.80} = 0.75 > 0.50$, so **yes, it slides by itself**. **[3]**

The largest angle at which it stays at rest is the angle of repose: $\tan\theta = 0.50$, so $\theta = 27^\circ$ (26.6°).

A wet plank is more slippery, so μ_s is smaller and **the angle of repose is smaller**: the crate would slide on a gentler slope.

Marking scheme

- $\tan 37^\circ = 0.75 > 0.50$, so it slides.
- Largest angle about 27° ($\tan\theta = 0.50$).
- Wet plank: smaller μ_s, smaller angle.

Question 11 — 8 marks

a. On a flat road the centripetal force is supplied only by **friction** between the tyres and the road. If the car is too fast, or the road wet, friction may not be enough and the car skids outwards. **[2]**

On a **banked** road the normal reaction of the road is tilted towards the center, and its horizontal part supplies centripetal force, so the car can take the bend safely without relying on friction (at the speed the road is designed for).

Marking scheme

- Flat road: friction alone, which may be too small (skidding).
- Banking: the horizontal part of the normal reaction supplies centripetal force.

b. $v = 36$ km/h $= 10$ m/s. **[3]**

$$F = \frac{mv^2}{r} = \frac{1000 \times 10^2}{50} = 2000 \text{ N}$$

Friction must supply it: $\mu mg \geq \frac{mv^2}{r}$, so

$$\mu = \frac{v^2}{rg} = \frac{100}{50 \times 9.8} = 0.20$$

2000 N; coefficient of friction at least 0.20.

Marking scheme

- Speed in m/s: 10 m/s.
- Centripetal force 2000 N.
- Least $\mu = v^2/rg \approx 0.20$.

c. With no friction, $\tan\theta = \dfrac{v^2}{rg} = \dfrac{100}{50 \times 9.8} = 0.204$, so $\theta = 11.5^\circ$. **[3]**

At 72 km/h $= 20$ m/s, the friction needed is $\mu = \dfrac{v^2}{rg} = \dfrac{400}{490} = 0.82$. The wet road gives at most 0.40, less than half of this, so **no: the car would skid outwards**. (The safe speed is $\sqrt{\mu rg} = \sqrt{0.40 \times 50 \times 9.8} = 14$ m/s, about 50 km/h.)

Marking scheme

- Banking angle about 11.5°.
- At 20 m/s the friction needed is $\mu \approx 0.82$.
- More than 0.40, so not safe: the car skids.

OR

a. The work done by a **conservative** force in moving a body between two points doesn't depend on the path, and it is zero round any closed path; the energy can be got back (gravity, the spring force). **[2]**

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The work done by a **non-conservative** force depends on the path, and it is not zero round a closed path; the energy is turned into heat and can't be got back as mechanical energy (friction, air resistance).

Marking scheme

- Conservative: work independent of path, zero round a closed path (e.g. gravity).
- Non-conservative: work depends on the path (e.g. friction).

b. **[3]**

$$W = mgh = 500 \times 9.8 \times 20 = 9.8 \times 10^4 \text{ J}$$

$$P = \frac{W}{t} = \frac{9.8 \times 10^4}{5.0 \times 60} = \frac{98\,000}{300} = 327 \text{ W}$$

Work 98 kJ; useful power about 330 W.

Marking scheme

- $W = mgh$.
- $W = 9.8 \times 10^4$ J.
- Power about 327 W (time in seconds).

c. **[3]**

$$\text{Input power} = \frac{\text{useful power}}{\text{efficiency}} = \frac{327}{0.70} = 467 \text{ W}$$

A 0.5 hp motor gives $0.5 \times 746 = 373$ W, less than 467 W. **No**: it would take longer than 5 minutes (about $98\,000/(0.70 \times 373) = 375$ s), or he needs a motor of at least about 0.63 hp (in practice a 1 hp one).

The other 30% of the input is turned into heat (and sound) by friction in the pump and the pipes, and by the resistance of the motor's windings.

Marking scheme

- Input power needed about 467 W.
- 0.5 hp = 373 W is less, so not enough (or it takes longer).
- The wasted energy goes to heat and sound (friction, resistance).

Question 12 — 8 marks

a. The **redshift** $z = \frac{\Delta\lambda}{\lambda_0}$ is the fractional increase in the wavelength of a galaxy's light, compared with the same line measured in a laboratory: its lines are shifted towards the red end of the spectrum. **[3]**

Light from almost every galaxy is redshifted, so they are all moving **away from us**, and the farther a galaxy is, the larger its redshift. That is what we would see if space itself were stretching, carrying the galaxies apart from one another: the universe is expanding.

Hubble's law: the recessional speed of a galaxy is directly proportional to its distance from us, $v = H_0 d$.

Marking scheme

- Redshift: the fractional increase in wavelength, $z = \Delta\lambda/\lambda_0$.
- Nearly all galaxies redshifted, farther ones more: they move apart, the universe expands.
- Hubble's law: $v = H_0 d$.

b. **[3]**

$$z = \frac{\Delta\lambda}{\lambda_0} = \frac{669.4 - 656.3}{656.3} = \frac{13.1}{656.3} = 0.020$$

$$v = zc = 0.020 \times 3.0 \times 10^8 = 6.0 \times 10^6 \text{ m/s} = 6000 \text{ km/s}$$

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$$d = \frac{v}{H_0} = \frac{6000}{70} = 86\ \mathrm{Mpc}$$

Marking scheme

- Redshift 0.020.
- Speed 6.0×10^6 m/s (6000 km/s).
- Distance about 86 Mpc.

c. If every galaxy has moved at a steady speed since they were all together, the time since then is $T_0 = \frac{d}{v} = \frac{1}{H_0}$. In SI units, **[2]**

$$H_0 = \frac{70 \times 10^3\ \mathrm{m/s}}{3.09 \times 10^{22}\ \mathrm{m}} = 2.27 \times 10^{-18}\ \mathrm{s^{-1}}$$

$$T_0 = \frac{1}{H_0} = 4.4 \times 10^{17}\ \mathrm{s} = \frac{4.4 \times 10^{17}}{3.16 \times 10^7} = 1.4 \times 10^{10}\ \mathrm{years}$$

About 14 billion years.

Marking scheme

- $T_0 = 1/H_0$, with H_0 in $\mathrm{s^{-1}}$ ($2.27 \times 10^{-18}\ \mathrm{s^{-1}}$).
- About 1.4×10^{10} years.

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