Grade 11 Physics Model Paper 3

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)** kg m s^{-2}

b. **(iii)** Both reach the ground at the same time.

c. **(ii)** The acceleration due to gravity is larger at the poles.

d. **(iii)** Along the tangent to the circle at the point where it was

e. **(iii)** It becomes 4 times as much.

f. **(ii)** $f = R/2$

g. **(ii)** They always form erect, diminished images and show a wide field of view.

h. **(iii)** 9 cm

i. **(ii)** 20 cm

j. **(iv)** $8F$

k. **(i)** The same number of protons

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

Question 2 — 5 marks

a. **Parallelogram law:** if two vectors acting at a point are represented in size and direction by the two adjacent sides of a parallelogram drawn from that point, their resultant is represented in size and direction by the diagonal of the parallelogram through that point. **[2]**

Resolution of a vector is splitting it into two or more component vectors whose sum is the vector, usually two at right angles, $A\cos\theta$ and $A\sin\theta$.

Marking scheme

- Parallelogram law stated (adjacent sides, resultant the diagonal from the same point).
- Resolution: splitting a vector into components (usually at right angles).

b. The two velocities are at right angles: **[2]**

$$v = \sqrt{4.0^2 + 3.0^2} = 5.0\ \text{m/s}, \quad \text{at } \tan^{-1}\frac{3.0}{4.0} = 37^\circ \text{ to the line straight across}$$

Only the 4.0 m/s carries it across: $t = \dfrac{80}{4.0} = 20$ s. In that time the river carries it $3.0 \times 20 = 60$ m downstream.

Marking scheme

- Resultant 5.0 m/s at 37° downstream of straight across.
- Time 20 s and drift 60 m.

c. Upstream, so that the upstream component of the boat's velocity cancels the river's: $4.0\sin\theta = 3.0$, so $\sin\theta = 0.75$ and $\theta = 49^\circ$ from the line straight across, towards upstream. **[1]**

Marking scheme

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- Upstream at about 49° to the straight-across line ($\sin\theta = 3/4$).

OR

a. The **moment of a force** about a point is the product of the force and the perpendicular distance of its line of action from that point; it measures the turning effect of the force (unit N m). **[2]**

Principle of moments: for a body in equilibrium, the sum of the clockwise moments about any point equals the sum of the anticlockwise moments about the same point.

Marking scheme

- Moment = force × perpendicular distance from the point to its line of action.
- Principle of moments: clockwise moments = anticlockwise moments in equilibrium.

b. Moments about the pivot: **[2]**

$$30g \times 1.5 = 45g \times d \quad \Rightarrow \quad d = \frac{45}{45} = 1.0\ \text{m}$$

The plank doesn't move up or down, so the pivot pushes up with the total weight: $(30 + 45) \times 9.8 = 735$ N.

1.0 m from the pivot; the pivot pushes up with 735 N.

Marking scheme

- Rohan sits 1.0 m from the pivot.
- Upward force of the pivot 735 N.

c. **No.** The moments are now $30g \times 2.0 = 60g$ N m on Diya's side and $45g \times 1.5 = 67.5g$ N m on Rohan's (about 588 N m against 662 N m). They are no longer equal, so Rohan's side goes down: moving both by the same distance adds a larger moment for the heavier child. **[1]**

Marking scheme

- No: the new moments (30 × 2.0 against 45 × 1.5, times g) are unequal, so Rohan's side goes down.

Question 3 — 5 marks

a. Steam condensing on the skin first gives out its large latent heat of vaporization (2.26 × 10⁶ J for every kilogram) at 100 °C, and only then cools as water. So the same mass of steam gives the skin far more heat than boiling water does. **[1]**

Marking scheme

- Steam gives out its large latent heat of vaporization as it condenses, so much more heat reaches the skin.

b. By the principle of calorimetry, heat lost by the lemonade = heat gained by the ice. **[3]**

Heat lost: $0.50 \times 4200 \times (30 - 10) = 42\,000$ J.

The ice first melts at 0 °C, then the melted water warms from 0 °C to 10 °C:

$$m \times 3.36 \times 10^5 + m \times 4200 \times 10 = m \times 378\,000\ \text{J}$$

$$m \times 378\,000 = 42\,000 \quad \Rightarrow \quad m = 0.11\ \text{kg}$$

About 0.11 kg (111 g) of ice.

Marking scheme

- Heat lost by the lemonade 42 000 J.
- Heat gained by the ice: $mL + mc\Delta\theta$ (melting and then warming to 10 °C).
- $m \approx 0.11$ kg.

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c. **No, much less.** The ice takes in 336 000 J for every kilogram to melt before its temperature rises at all; water at 0 °C only warms up. Most of the cooling by the ice comes from its latent heat. **[1]**

Marking scheme

- No: ice also takes in its latent heat of fusion, so it absorbs far more heat.

Question 4 — 5 marks

a. **Boyle's law:** at constant temperature, the volume of a fixed mass of gas is inversely proportional to its pressure, $PV = \text{constant}$. **[3]**

Charles's law: at constant pressure, the volume of a fixed mass of gas is directly proportional to its absolute temperature, $V \propto T$ (it changes by $\frac{1}{273}$ of its volume at 0 °C for each degree).

An **ideal gas** is one that obeys the gas laws, $PV = nRT$, exactly at all pressures and temperatures: its molecules have no volume of their own and exert no forces on one another except when they collide. Real gases behave nearly so at low pressure and high temperature.

Marking scheme

- Boyle's law stated (constant temperature, PV constant).
- Charles's law stated (constant pressure, $V \propto T$).
- Ideal gas: obeys $PV = nRT$ exactly (no molecular volume or attraction).

b. **[2]**

$$c_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3 \times 8.31 \times 300}{0.032}} = \sqrt{2.34 \times 10^{5}} = 483 \ \text{m/s}$$

$c_{rms} \propto \sqrt{T}$, so doubling it needs four times the absolute temperature: $4 \times 300 = 1200$ K, which is 927 °C.

Marking scheme

- $c_{rms} \approx 483$ m/s (with $T = 300$ K).
- 1200 K (927 °C), since $c_{rms} \propto \sqrt{T}$.

Question 5 — 5 marks

a. It is the increase in volume per unit original volume for each degree rise in temperature: $\gamma = \dfrac{\Delta V}{V_0 \, \Delta\theta}$. **[1]**

Marking scheme

- Increase in volume per unit volume per degree rise in temperature.

b. The flask expands too, so only the apparent expansion overflows. $\gamma_r = \gamma_a + \gamma_g$, so **[3]**

$$\gamma_a = 1.8 \times 10^{-4} - 0.27 \times 10^{-4} = 1.53 \times 10^{-4} \ \text{K}^{-1}$$

$$\Delta V_a = V_0 \, \gamma_a \, \Delta\theta = 500 \times 1.53 \times 10^{-4} \times 80 = 6.1 \ \text{cm}^3$$

About 6.1 cm³ overflows.

Marking scheme

- The overflow is the apparent expansion: $\gamma_a = \gamma_r - \gamma_g$.
- $\gamma_a = 1.53 \times 10^{-4}$ K⁻¹.
- Overflow about 6.1 cm³.

c. **Yes.** The overflow is the apparent expansion, $V_0(\gamma_r - \gamma_g)\Delta\theta$. If $\gamma_g = \gamma_r$, the flask's space grows exactly as much as the mercury, and nothing overflows; if $\gamma_g > \gamma_r$, the apparent expansion is negative, so the flask grows more than the mercury and the level falls. **[1]**

Marking scheme

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- Yes: overflow $= V_0(\gamma_r - \gamma_g)\Delta\theta$, zero when the expansivities are equal and negative (level falls) when the flask's is larger.

Question 6 — 5 marks

a. **Angular dispersion** is the angle between the violet and the red rays coming out of a prism: $\delta_v - \delta_r$. **[2]**

Dispersive power ω of a material is the ratio of the angular dispersion to the mean deviation (of yellow light): $\omega = \dfrac{\delta_v - \delta_r}{\delta} = \dfrac{\mu_v - \mu_r}{\mu - 1}$.

Marking scheme

- Angular dispersion: angle between the violet and red rays ($\delta_v - \delta_r$).
- Dispersive power: angular dispersion ÷ mean deviation.

b. A lens behaves like a set of small prisms. Its refractive index is larger for violet than for red, so violet light is focused closer to the lens than red: white light has no single focus, and the image has colored edges. **[1]**

Marking scheme

- Different refractive index for each color, so the colors focus at different points.

c. For no chromatic aberration, $\dfrac{\omega}{f} + \dfrac{\omega'}{f'} = 0$: **[2]**

$$\frac{0.020}{20} + \frac{0.040}{f'} = 0 \quad \Rightarrow \quad f' = -40\ \text{cm}$$

$$\frac{1}{F} = \frac{1}{20} + \frac{1}{-40} = \frac{1}{40} \quad \Rightarrow \quad F = 40\ \text{cm}$$

The concave lens: focal length 40 cm (−40 cm); the doublet: a converging lens of 40 cm.

Marking scheme

- Concave lens $f' = -40$ cm.
- Doublet $F = +40$ cm (converging).

OR

a. 1. The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane. **[2]**
2. **Snell's law:** for a given pair of media and a given color of light, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant: $\dfrac{\sin i}{\sin r} = {}_1\mu_2$.

Marking scheme

- First law: incident ray, refracted ray and normal in one plane.
- Second law (Snell's): $\sin i / \sin r$ constant for a pair of media.

b. Light from the part under the water bends away from the normal as it leaves the water, so that part seems to come from a point nearer the surface (it is apparently raised), and the pencil looks bent where it enters the water. **[1]**

Marking scheme

- Refraction at the surface: the part under water appears raised, so the pencil looks bent.

c. **[2]**

$$\sin r = \frac{\sin i}{\mu} = \frac{\sin 30^\circ}{1.5} = \frac{0.5}{1.5} = 0.333 \quad \Rightarrow \quad r = 19.5^\circ$$

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$$v = \frac{c}{\mu} = \frac{3.0 \times 10^8}{1.5} = 2.0 \times 10^8 \ \text{m/s}$$

Marking scheme

- Angle of refraction about 19.5°.
- Speed in glass 2.0×10^8 m/s.

Question 7 — 5 marks

a. An **equipotential surface** is a surface on which every point is at the same potential. **[2]**

Work done in moving a charge q between two points is q × their potential difference, which is zero on an equipotential surface, so **no work** is done. That means the field has no component along the surface: the field lines cross every equipotential surface **at right angles**.

Marking scheme

- Equipotential surface: all points at the same potential.
- Zero potential difference, so no work; field lines perpendicular to it.

b. At the midpoint, 0.20 m from each charge, the potentials add as scalars: **[3]**

$$V = k\left(\frac{9.0 \times 10^{-9}}{0.20} + \frac{-3.0 \times 10^{-9}}{0.20}\right) = \frac{9.0 \times 10^9 \times 6.0 \times 10^{-9}}{0.20} = 270 \ \text{V}$$

Work $= qV = 1.0 \times 10^{-9} \times 270 = 2.7 \times 10^{-7}$ J.

Yes. At x meters from A,

$$\frac{9.0}{x} - \frac{3.0}{0.40 - x} = 0 \quad \Rightarrow \quad 3.6 - 9x = 3x \quad \Rightarrow \quad x = 0.30 \ \text{m}$$

The potential is zero **30 cm from A** (10 cm from B), though the field there is not zero.

Marking scheme

- Potential at the midpoint 270 V.
- Work 2.7×10^{-7} J.
- Zero potential 30 cm from A.

Question 8 — 5 marks

a. **Coulomb's law:** the force between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them, acting along the line joining them: $F = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r^2}$. **[2]**

The **relative permittivity** of a medium is the ratio of its permittivity to that of free space, $\varepsilon_r = \varepsilon/\varepsilon_0$: it tells how many times weaker the force between two charges is in the medium than in a vacuum.

Marking scheme

- Coulomb's law stated (∝ product of charges, ∝ 1/r², along the line joining them).
- Relative permittivity: $\varepsilon/\varepsilon_0$, how many times weaker the force is in the medium.

b. **[3]**

$$F_e = \frac{9.0 \times 10^9 \times (1.6 \times 10^{-19})^2}{(5.3 \times 10^{-11})^2} = 8.2 \times 10^{-8} \ \text{N}$$

$$F_g = \frac{6.67 \times 10^{-11} \times 9.1 \times 10^{-31} \times 1.67 \times 10^{-27}}{(5.3 \times 10^{-11})^2} = 3.6 \times 10^{-47} \ \text{N}$$

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$$\frac{F_e}{F_g} = \frac{8.2 \times 10^{-8}}{3.6 \times 10^{-47}} = 2.3 \times 10^{39}$$

The electric force is about 10^{39} times stronger, so gravity plays no part inside the atom: atoms (and molecules and solids) are held together by electric forces. Gravity matters only for huge masses, which are nearly neutral.

Marking scheme

- Electric force 8.2×10^{-8} N.
- Gravitational force 3.6×10^{-47} N.
- Ratio about 2.3×10^{39}: electric forces hold atoms together.

Question 9 — 5 marks

a. In parallel each gets the full mains voltage, and each can be switched on or off without affecting the others; in series they would share the voltage, and one switched off or failing would break the circuit for all. **[1]**

Marking scheme

- Each gets the full voltage and works independently.

b. **[2]**

$$R_p = \frac{3.0 \times 6.0}{3.0 + 6.0} = 2.0\ \Omega, \qquad R = 2.0 + 4.0 = 6.0\ \Omega$$

$$I = \frac{V}{R} = \frac{12}{6.0} = 2.0\ \text{A}$$

Marking scheme

- Total resistance 6.0 Ω.
- Current 2.0 A.

c. The 4.0 Ω resistor carries the whole 2.0 A: $P = I^2R = 2.0^2 \times 4.0 = 16$ W, and the p.d. across it is 8.0 V. The pair has the remaining 4.0 V across it: **[2]**

$$P_{3\,\Omega} = \frac{V^2}{R} = \frac{4.0^2}{3.0} = 5.3\ \text{W}, \qquad P_{6\,\Omega} = \frac{4.0^2}{6.0} = 2.7\ \text{W}$$

(Total 24 W $= 12 \times 2.0$. ✓)

The 4.0 Ω resistor: it carries the whole current, so it has the largest share of the p.d. Of the two in parallel, the smaller 3.0 Ω gets more power, since with the same p.d. $P = V^2/R$ is larger for smaller R.

Marking scheme

- 16 W, 5.3 W and 2.7 W.
- The 4.0 Ω has the most (whole current, largest p.d.); in parallel the smaller resistor has more power.

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

Question 10 — 8 marks

a. The **slope** of a velocity–time graph is the acceleration; the **area** under it is the displacement. **[3]**

For a body whose velocity rises uniformly from u to v in time t, the graph is a straight line. Its slope is the acceleration:

$$a = \frac{v - u}{t} \quad \Rightarrow \quad v = u + at$$

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The area under it is a rectangle of height u and width t plus a triangle of base t and height $v - u = at$:

$$s = ut + \tfrac{1}{2} \times t \times at = ut + \tfrac{1}{2}at^2$$

Marking scheme

- Slope gives acceleration; area gives displacement.
- $v = u + at$ from the slope.
- $s = ut + \tfrac{1}{2}at^2$ from the area (rectangle plus triangle).

b. Top speed: $v = u + at = 0 + 2.0 \times 10 = 20$ m/s. **[2]**

Distances (areas under the graph):

$$s_1 = \tfrac{1}{2} \times 10 \times 20 = 100\ \text{m}, \quad s_2 = 20 \times 30 = 600\ \text{m}, \quad s_3 = \tfrac{1}{2} \times 8.0 \times 20 = 80\ \text{m}$$

Top speed 20 m/s; total 780 m.

Marking scheme

- Top speed 20 m/s.
- Total distance 780 m.

c. Braking as before: $a = \frac{20}{8.0} = 2.5$ m/s². **[3]**

While he reacts the bus keeps moving: $20 \times 0.50 = 10$ m. Braking distance: $s = \frac{v^2}{2a} = \frac{20^2}{2 \times 2.5} = 80$ m. Total $10 + 80 = 90$ m, more than 70 m: **no, the bus doesn't stop in time.**

To stop within the remaining $70 - 10 = 60$ m: $a = \frac{v^2}{2s} = \frac{400}{120} = 3.3$ m/s².

Marking scheme

- Reaction distance 10 m and braking distance 80 m (deceleration 2.5 m/s²).
- 90 m > 70 m, so it doesn't stop in time.
- Needed deceleration about 3.3 m/s² (over 60 m).

Question 11 — 8 marks

a. At first the graph is a straight line through the origin: stress is proportional to strain (Hooke's law), up to the **proportional limit**. A little beyond it is the **elastic limit**: up to here the wire goes back to its original length when the load is removed. **[2]**

Past the elastic limit the wire is plastic: at the **yield point** it starts to stretch a lot for little extra stress and keeps a permanent extension. The stress then rises to its greatest value (the ultimate tensile stress), the wire narrows at one place, and it breaks at the **breaking point**.

Marking scheme

- Straight line (Hooke's law) up to the proportional limit; elastic limit: returns to its length up to here.
- Yield point: large plastic extension, permanent set, then ultimate stress and breaking.

b. **[3]**

$$\text{stress} = \frac{F}{A} = \frac{400}{2.0 \times 10^{-6}} = 2.0 \times 10^{8}\ \text{Pa}$$

$$\text{strain} = \frac{\text{stress}}{Y} = \frac{2.0 \times 10^{8}}{2.0 \times 10^{11}} = 1.0 \times 10^{-3}$$

$$x = \text{strain} \times L = 1.0 \times 10^{-3} \times 3.0 = 3.0 \times 10^{-3}\ \text{m} = 3.0\ \text{mm}$$

Marking scheme

- Stress 2.0×10^8 Pa.

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- Strain 1.0×10^{-3}.
- Extension 3.0 mm.

c. The energy stored is $W = \frac{1}{2}Fx$. The wire's volume is AL, so **[3]**

$$\frac{W}{AL} = \frac{1}{2}\frac{F}{A}\frac{x}{L} = \tfrac{1}{2} \times \text{stress} \times \text{strain}$$

For this wire: $\frac{1}{2} \times 2.0 \times 10^{8} \times 1.0 \times 10^{-3} = 1.0 \times 10^{5}$ J/m³. (Check: $W = \frac{1}{2} \times 400 \times 3.0 \times 10^{-3} = 0.60$ J in a volume of $2.0 \times 10^{-6} \times 3.0 = 6.0 \times 10^{-6}$ m³, which is 1.0×10^{5} J/m³. ✓)

Lateral strain $= \sigma \times$ longitudinal strain $= 0.30 \times 1.0 \times 10^{-3} = 3.0 \times 10^{-4}$: the diameter decreases by **0.03%** of itself.

Marking scheme

- $W/AL = \frac{1}{2}(F/A)(x/L) = \frac{1}{2}$ stress × strain.
- 1.0×10^{5} J/m³.
- Diameter decreases by 3.0×10^{-4} of itself (0.03%).

OR

a. **Principle:** if no external force acts on a system of bodies, its total linear momentum stays the same. **[2]**

Before firing, the gun and bullet are at rest, so their total momentum is zero. The explosion is an internal force, so the total stays zero after firing: the bullet's forward momentum must be balanced by an equal backward momentum of the gun, which therefore moves back (recoils).

Marking scheme

- Total momentum constant when no external force acts.
- Total zero before and after firing, so the gun gets an equal and opposite momentum (recoil).

b. **[3]**

$$0 = mv + MV \quad \Rightarrow \quad V = -\frac{mv}{M} = -\frac{0.020 \times 400}{4.0} = -2.0\ \text{m/s}$$

The rifle recoils at **2.0 m/s**.

$$KE_{bullet} = \tfrac{1}{2} \times 0.020 \times 400^{2} = 1600\ \text{J}, \qquad KE_{rifle} = \tfrac{1}{2} \times 4.0 \times 2.0^{2} = 8.0\ \text{J}$$

Marking scheme

- Momentum equation, total zero.
- Recoil speed 2.0 m/s.
- Kinetic energies 1600 J and 8.0 J.

c. For equal momenta, $KE = \frac{p^{2}}{2m}$ is inversely proportional to the mass. The rifle is $\frac{4.0}{0.020} = 200$ times heavier, so it has $\frac{1}{200}$ of the bullet's kinetic energy. **[3]**

Held tightly, the rifle and his body recoil as one mass, $4.0 + 60 = 64$ kg:

$$V = \frac{0.020 \times 400}{64} = 0.125\ \text{m/s}$$

The kick is much gentler, and the rifle doesn't gain speed before hitting his shoulder.

Marking scheme

- $KE = p^{2}/2m$: with equal momenta, KE inversely proportional to mass (200 times).
- Held tight, the recoiling mass is 64 kg.
- Recoil speed about 0.13 m/s, so a gentle kick.

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Question 12 — 8 marks

a. In a single atom an electron can have only certain energy levels. In a solid, billions of atoms are packed close together and their outer electrons affect one another, so each level splits into a huge number of levels very close together: an **energy band**. Between the bands are **forbidden gaps**. **[3]**

- **Conductor:** the top band (the conduction band) is only partly full, or overlaps the valence band, so electrons can easily take a little energy and move: it conducts well.
- **Insulator:** the valence band is full and the conduction band empty, with a wide gap (5–10 eV) that electrons can't cross at room temperature: it doesn't conduct.
- **Semiconductor:** like an insulator, but with a small gap (about 1 eV), so at room temperature a few electrons jump into the conduction band, leaving holes: it conducts a little, and more when it is warmer.

Marking scheme

- Levels of many close atoms split into bands separated by forbidden gaps.
- Conductor: partly full band (or overlapping bands); insulator: full valence band and wide gap.
- Semiconductor: small gap (about 1 eV), a few electrons cross at room temperature.

b. **[3]**

$$E_4 = -\frac{13.6}{16} = -0.85\ \text{eV}, \qquad E_2 = -\frac{13.6}{4} = -3.40\ \text{eV}$$

$$\Delta E = -0.85 - (-3.40) = 2.55\ \text{eV} = 2.55 \times 1.6 \times 10^{-19} = 4.08 \times 10^{-19}\ \text{J}$$

$$\lambda = \frac{hc}{\Delta E} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{4.08 \times 10^{-19}} = 4.88 \times 10^{-7}\ \text{m} = 488\ \text{nm}$$

2.55 eV, 4.08×10^{-19} **J, about 488 nm** (blue-green light).

Marking scheme

- Photon energy 2.55 eV.
- 4.08×10^{-19} J.
- Wavelength about 488 nm (4.88×10^{-7} m).

c. The photon has 2.55 eV: **more than silicon's 1.1 eV**, so it can lift an electron across the gap, and silicon absorbs the light. It is **less than diamond's 5.5 eV**, so it can't, and nothing in diamond takes in its energy. **[2]**

No photon of visible light (about 1.6–3.1 eV) has the 5.5 eV needed, so diamond absorbs none of it and lets it through: it is transparent. Every visible photon has more than silicon's 1.1 eV, so silicon absorbs all visible light and is opaque.

Marking scheme

- Yes for silicon (2.55 > 1.1 eV); no for diamond (2.55 < 5.5 eV).
- Visible photons can't cross diamond's gap, so it is transparent; they all cross silicon's, so it absorbs them.

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