

HU Collection

ESAT Mock Set E: Physics

Worked Solutions

Kevin Hu 28 October 2026

Answer key

Q	1	2	3	4	5	6	7	8	9	10
Ans	B	E	A	D	C	E	A	C	F	F

Q	11	12	13	14	15	16	17	18	19	20
Ans	D	C	C	A	E	F	F	B	D	D

Q	21	22	23	24	25	26	27			
Ans	B	B	A	C	E	B	A			

Each solution gives an intended route and names the trap the question was built around. Diagrams show the configuration each solution works with.

Question 1. Answer **B**.

Work each statement from $v = f\lambda$ and distance = speed $\times$ time.

I is correct: in bone $\lambda = v/f = 4000/(2.0 \times 10^6) = 2.0 \times 10^{-3}$ m. (Using the soft tissue speed gives 0.75 mm.)

II is wrong. The frequency is fixed by the source: each wave that arrives at the boundary carries on into the bone, so waves leave the boundary at the rate they arrive. The speed and the wavelength change together.

IV is correct: the front of the pulse is $1500 \times 2.0 \times 10^{-6} = 3.0 \times 10^{-3}$ m ahead of its back.

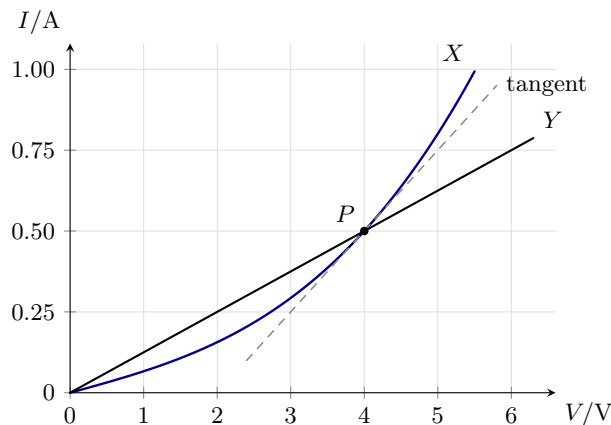
III is the trap. Comparing 2.0 mm with the 3.0 mm pulse length suggests overlap, but the echo from the deeper boundary travels the extra 2.0 mm twice, out and back. So it trails the first echo by 4.0 mm of path, which is more than the 3.0 mm length of each echo: in time, a gap of $2.7 \mu\text{s}$ against a pulse duration of $2.0 \mu\text{s}$. The echoes are separate, so III is false. The answer is I and IV only.

Question 2. Answer **E**.

Resistance is defined by $R = V/I$: it is the ratio of the coordinates of a point, so on an I against V graph it is 1 divided by the gradient of the line from the origin to that point, not of the tangent.

Statement I is correct. At P both components have $V = 4.0$ V and $I = 0.50$ A, so both have resistance 8.0Ω .

Statement II is the classic misconception. The curve is bending upwards, so its tangent at P is steeper than the line from the origin: its gradient is about 0.25 A V^{-1} , which would wrongly suggest 4Ω .



Statement III is correct. In series the two components carry the same current. At the current of P , 0.50 A , the p.d.s would add to $4.0 + 4.0 = 8.0\text{ V}$, so with only 6.0 V the current is smaller. Below P the curve lies below the line, so at any such current X needs a larger p.d. than Y to drive it. The answer is I and III only.

Question 3. Answer A.

Write the acceleration of a ball of mass m and weight mg as

$$a = \frac{mg - D}{m} = g - \frac{D}{m},$$

where D is the air resistance, which depends only on the speed here.

Statement I is false. At release the speed is zero, so $D = 0$ and both balls accelerate at g . The larger weight of S is matched by its larger mass: more force, but also more inertia.

Statement II is true. At 5 m s^{-1} both balls feel the same D , and D/m is smaller for the heavier ball, so S has the greater acceleration.

Statement III is false. At terminal velocity D equals the weight, and S is heavier, so the air resistance on S is greater. It reaches this larger drag by falling faster, which is why its terminal velocity is higher.

The answer is II only. Choosing I and II only is the old belief that heavier objects simply fall faster; choosing II and III only forgets that drag depends on speed, which differs at the two terminal velocities.

Question 4. Answer D.

Count protons in the nucleus and electrons around it separately.

I is true. The polonium atom has 84 protons and 84 electrons. The alpha particle takes 2 protons and 2 neutrons out of the nucleus but no electrons, so the atom left behind has 82 protons and still 84 electrons: a net charge of $-2e$. (It is a lead ion, $^{206}_{82}\text{Pb}^{2-}$, until it sheds its two spare electrons.)

II is false. A beta-minus particle is an electron created in the nucleus when a neutron turns into a proton; it is not one of the orbiting electrons. The atom left behind has 84 protons but only the original 83 orbiting electrons, so its charge is $+e$.

III is true. In beta-minus decay the proton number rises by 1 and the mass number is unchanged: $^{210}_{83}\text{Bi} \rightarrow ^{210}_{84}\text{Po} + ^0_{-1}\text{e}$, and proton number 84 is polonium. (The popular slip is to lower the proton number, giving lead.)

The answer is I and III only.

Question 5. Answer C.

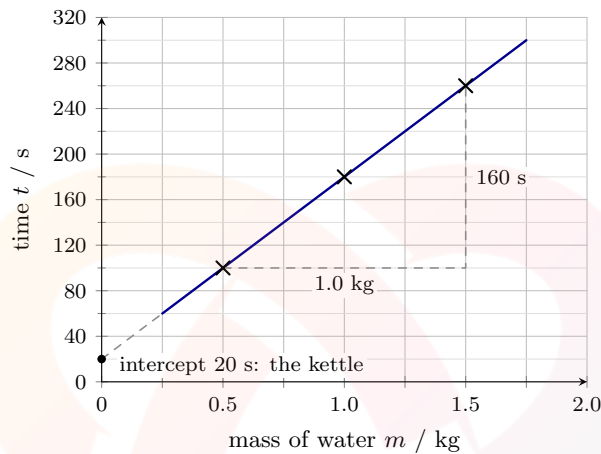
Let the element have power P and let the kettle need C joules per kelvin. With $\Delta T = 80$ K,

$$Pt = (C + mc) \Delta T \implies t = \frac{c \Delta T}{P} m + \frac{C \Delta T}{P}.$$

So the graph is a straight line: the gradient belongs to the water and the intercept belongs to the kettle. Dividing one by the other, P and ΔT cancel:

$$\frac{\text{intercept}}{\text{gradient}} = \frac{C}{c}.$$

In other words the intercept, measured in kilograms along the line, is the mass of water that would need as much energy as the kettle.



The gradient is $(260 - 100)/(1.5 - 0.5) = 160 \text{ s kg}^{-1}$ and the intercept is $100 - 0.5 \times 160 = 20 \text{ s}$. So the kettle behaves like $20/160 = 0.125 \text{ kg}$ of water, and

$$C = 0.125 \times 4200 = 525 \text{ J K}^{-1}.$$

(As a check, $P = 4200 \times 80/160 = 2100 \text{ W}$ and $C = 2100 \times 20/80 = 525 \text{ J K}^{-1}$.)

Taking the start of the drawn line, 60 s, as the intercept gives 1575 J. Reading 80 s per 0.5 kg as the gradient gives 1050 J. Dividing the kettle's 42 000 J by 100 K instead of 80 K gives 420 J, while 2100 is the power and 42 000 J is the kettle's energy for the whole 80 K rise.

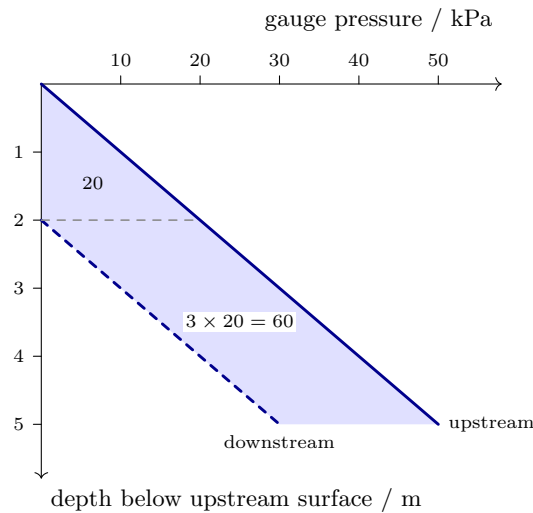
Question 6. Answer E.

Use the average pressure. Atmospheric pressure pushes equally on both faces of the gate, so only the extra pressure ρgh due to the water matters. This rises steadily from 0 at the surface to ρgh at the floor, so over a wetted face of depth h the average is $\frac{1}{2}\rho gh$, and the force on that face is

$$F = \frac{1}{2}\rho gh \times (\text{area}) = \frac{1}{2}\rho gwh^2.$$

Upstream: $\frac{1}{2} \times 1000 \times 10 \times 6.0 \times 5.0^2 = 750 \text{ kN}$. Downstream: $\frac{1}{2} \times 1000 \times 10 \times 6.0 \times 3.0^2 = 270 \text{ kN}$. The resultant is $750 - 270 = 480 \text{ kN}$, towards the downstream side.

Equivalently, the force per metre width is the area between the two pressure against depth lines below: a triangle over the top 2 m, where only the upstream water presses, and then a constant difference of 20 kPa over the bottom 3 m.

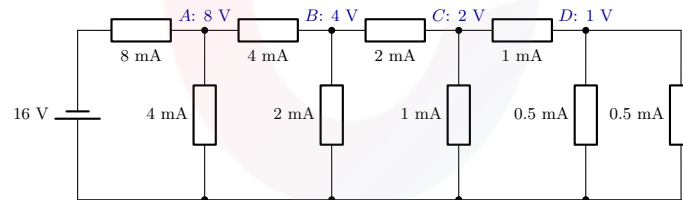


That area is $20 + 60 = 80$ kN per metre, and $80 \times 6.0 = 480$ kN. Taking the 20 kPa difference over the whole 5 m gives 600 kN; using the floor pressures instead of the averages gives 960 kN; $\frac{1}{2}\rho g w(5.0 - 3.0)^2 = 120$ kN squares the difference instead of taking the difference of the squares.

Question 7. Answer A.

Working forwards from the battery is hopeless without combining resistors. Instead, work backwards from the far end. Call the p.d. across the right-most resistor v (in volts), so it carries $v/2$ mA.

The vertical resistor at D has the same p.d., so it also carries $v/2$ mA. Together these currents, v mA, flow through the 1.0 k Ω resistor between C and D , whose p.d. is therefore v . So the p.d. at C is $2v$, the vertical resistor at C carries v mA, and $2v$ mA flows from B to C , giving a p.d. of $4v$ at B . The pattern repeats: each step towards the battery doubles the p.d. and the current.



So the p.d. at A is $8v$, the first resistor carries $8v$ mA and has p.d. $8v$, and the battery supplies $16v = 16$ V. Hence $v = 1.0$ V and the power is

$$P = \frac{v^2}{R} = \frac{1.0^2}{2000} \text{ W} = 0.50 \text{ mW}.$$

Taking the p.d. at D as 2 V (stopping one halving too early) gives 2.0 mW, and using 1.0 k Ω instead of 2.0 k Ω gives 1.0 mW.

Question 8. Answer C.

Conservation of energy for each shot, with compression x and fixed friction loss E_f :

$$\frac{1}{2}kx^2 = mgh + E_f \implies h = \frac{k}{2mg}x^2 - \frac{E_f}{mg}.$$

So h is a linear function of x^2 , and equal steps in x^2 give equal steps in h . There is no need to find k , m or E_f .

Going from 2.0 cm to 4.0 cm, x^2 rises from 4 to 16 (a step of 12) and h rises by 1.50 m. Going from 4.0 cm to 6.0 cm, x^2 rises from 16 to 36 (a step of 20), so h rises by $1.50 \times \frac{20}{12} = 2.50$ m, giving

$$h = 1.80 + 2.50 = 4.30 \text{ m.}$$

(The friction loss is equivalent to 0.20 m of height on every shot.)

Scaling 1.80 m by $(6/4)^2$ gives 4.05 m and scaling 0.30 m by 3^2 gives 2.70 m: both ignore the fixed loss. A straight line through the two points in x gives 3.30 m. Using only the x^2 term without subtracting the loss gives 4.50 m.

Question 9. Answer F.

The power is $P = V^2/R$, which is the same whether the induced p.d. is positive or negative. In one revolution the p.d. reaches a positive maximum and a negative maximum, so the power peaks *twice* per revolution. The peaks on the graph are 10 ms apart, so one revolution takes 20 ms: the coil was turning at 50 revolutions per second, and now turns at $1.5 \times 50 = 75$ revolutions per second. Reading the 10 ms spacing as the period of rotation gives the 150 options.

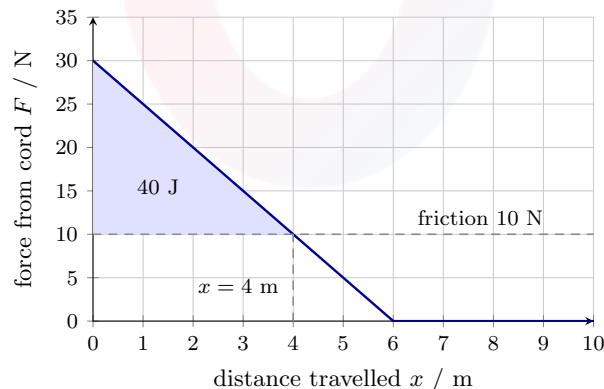
The induced p.d. is proportional to the rate at which the coil cuts the field, so its peak value rises by a factor of 1.5. Then

$$P_{\max} \propto \frac{V_{\max}^2}{R} \Rightarrow P_{\max} = 8 \text{ W} \times \frac{1.5^2}{2} = 9 \text{ W.}$$

Forgetting the new resistor gives 18 W; treating the power as proportional to the speed gives 12 W or 6 W.

Question 10. Answer F.

The sled speeds up while the cord's pull exceeds friction and slows down once it is less. So the speed is greatest where the resultant force is zero, at $F = 10$ N, which is at $x = 4.0$ m (not where the cord goes slack).



The net work done up to that point is the area between the force line and the friction line, a triangle of area $\frac{1}{2} \times 4 \times 20 = 40$ J. So $\frac{1}{2}(5.0)v^2 = 40$ and $v = 4.0 \text{ m s}^{-1}$.

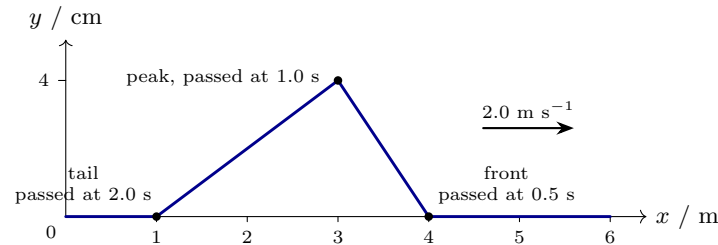
For the stopping point, the cord does $\frac{1}{2} \times 6 \times 30 = 90$ J of work in total and friction must remove all of it: $10d = 90$, so $d = 9.0$ m. The sled is still moving when the cord goes slack, with $90 - 60 = 30$ J of kinetic energy, which carries it a further 3.0 m.

Taking the greatest speed at $x = 6$ m gives 30 J and $2\sqrt{3} \text{ m s}^{-1}$. Ignoring friction gives 80 J up to $x = 4$ m, or 90 J up to $x = 6$ m. Stopping at $x = 6$ m assumes the sled halts when the pull ends.

Question 11. Answer D.

Track individual features of the pulse. A feature that passed the sensor at time τ has since travelled $2.0(2.5 - \tau)$ metres, so at $t = 2.5$ s it is at $x = 2.0(2.5 - \tau)$.

The front of the pulse passed at $\tau = 0.5$ s, so it is now at $x = 4.0$ m. The peak passed at $\tau = 1.0$ s, so it is at $x = 3.0$ m. The tail passed at $\tau = 2.0$ s, so it is at $x = 1.0$ m.



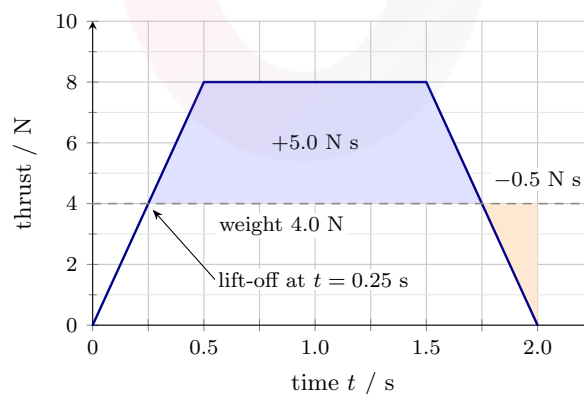
So the rope rises gradually from $x = 1$ to a peak at $x = 3$ and drops steeply to zero at $x = 4$: Graph D. The key point is that the part of the pulse that reaches the sensor first is now furthest along the rope, so the snapshot is the time trace reversed left to right and stretched by the wave speed.

Graphs A and E copy the time trace without reversing it. Graph B reverses it but forgets the factor 2.0 m s^{-1} , and Graph F simply relabels the time axis as distance. Graph C puts the front at $x = 2.0 \times 2.5 = 5.0$ m, as if the pulse had passed the sensor at $t = 0$.

Question 12. Answer C.

Use impulse: the change of momentum equals the area under the graph of resultant force against time. The trap is the launch pad.

The weight is 4.0 N , and the rocket cannot move until the thrust exceeds it, which happens at $t = 0.25$ s. Before then the pad pushes up with whatever is needed, the resultant force is zero and the momentum stays zero. After lift-off the resultant force is thrust minus weight, so the impulse is the area between the thrust graph and the line at 4.0 N , from 0.25 s to 2.0 s.



Above the line there is a trapezium of area $\frac{1}{2}(1.5 + 1.0) \times 4 = 5.0 \text{ N s}$. After $t = 1.75$ s the thrust is less than the weight, and the small triangle below the line has area $\frac{1}{2} \times 0.25 \times 4 = 0.5 \text{ N s}$, which counts as negative. Net impulse 4.5 N s , so

$$v = \frac{4.5}{0.40} = 11.25 \text{ m s}^{-1}.$$

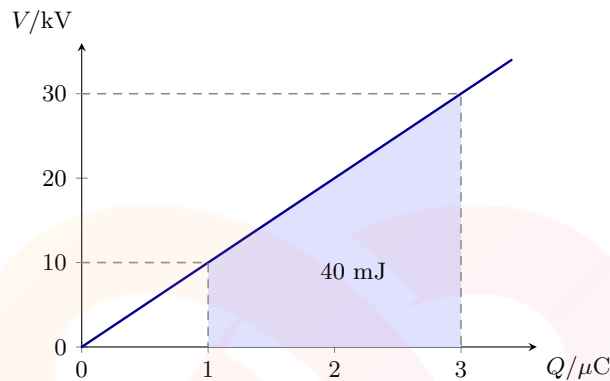
Subtracting the weight's impulse from $t = 0$ gives $(12 - 8)/0.40 = 10.0 \text{ m s}^{-1}$: that pretends the rocket could sink into the pad. Starting the weight at lift-off but keeping all 12 N s of thrust gives

12.5, and the reverse mix gives 8.75. Forgetting the weight after lift-off gives 28.75, and forgetting it entirely gives 30.0.

Question 13. Answer **C**.

The charge on the drum is $3.0 \mu\text{C}$ at 30 kV and $1.0 \mu\text{C}$ at 10 kV, so each spark carries $2.0 \mu\text{C}$ to earth. Replacing it at $0.50 \mu\text{C}$ per second takes 4.0 s. (The 6.0 s options give the time to the very first spark.)

The energy is the subtle part. $E = QV$ applies to charge moved through a fixed p.d., but here the p.d. falls steadily as the charge leaves. Each small piece of charge ΔQ gives up $V \Delta Q$, so the energy is the area under the graph of V against Q between $1.0 \mu\text{C}$ and $3.0 \mu\text{C}$, a trapezium:



$$E = \frac{1}{2} (30 + 10) \text{ kV} \times 2.0 \mu\text{C} = 20 \text{ kV} \times 2.0 \mu\text{C} = 40 \text{ mJ}.$$

Using 30 kV for all the charge gives 60 mJ, using 10 kV gives 20 mJ, and subtracting QV values $(90 - 10)$ gives 80 mJ. The value 45 mJ would be released only if the drum discharged completely.

Question 14. Answer **A**.

Treat each ejection on its own, in the frame moving with the tug just before that ejection. In that frame the total momentum is zero. If the remaining craft (mass M) gains speed Δv , the package moves backwards at $6.0 - \Delta v$, so

$$M \Delta v = 20(6.0 - \Delta v) \implies \Delta v = \frac{20 \times 6.0}{M + 20}.$$

The denominator is the total mass *before* the ejection.

First ejection: $\Delta v_1 = 120/100 = 1.2 \text{ m s}^{-1}$. Second ejection, from a craft of 80 kg: $\Delta v_2 = 120/80 = 1.5 \text{ m s}^{-1}$. The final speed is $1.2 + 1.5 = 2.7 \text{ m s}^{-1}$.

Ejecting both together would give only $240/100 = 2.4 \text{ m s}^{-1}$ (as would assuming each ejection adds the same 1.2). One at a time does better because the second package pushes against a lighter craft, which is the idea behind multi-stage rockets.

The other options treat 6.0 m s^{-1} as the package's speed relative to the station: $1.5 + 1.5 = 3.0$, $1.5 + 2.0 = 3.5$, a correct first step followed by a second step done this way giving 3.6, or both together giving $240/60 = 4.0 \text{ m s}^{-1}$.

Question 15. Answer **E**.

The mass is not given, and it is not needed: work per kilogram, and use the fact that at 55°C the wax loses energy at the same rate whether it is liquid, freezing or solid.

Just before freezing, the tangent falls from 75°C to 45°C in 15 minutes, a gradient of 2.0 K min^{-1} . So each kilogram loses energy at $3000 \times 2.0 = 6000 \text{ J per minute}$.

Freezing lasts from 10 to 40 minutes. The temperature stays at 55°C, so the loss is still 6000 J per minute per kilogram, all of it supplied by the latent heat:

$$L = 6000 \times 30 = 180\,000 \text{ J kg}^{-1} = 180 \text{ kJ kg}^{-1}.$$

Just after freezing, the tangent falls from 55°C to 30°C in 10 minutes, 2.5 K min⁻¹. The same 6000 J per minute per kilogram now gives the faster fall, so

$$c_s = \frac{6000}{2.5} = 2400 \text{ J kg}^{-1} \text{ K}^{-1}.$$

A steeper fall for the same energy loss means a *smaller* heat capacity; 3750 = 3000 × 2.5/2.0 gets the ratio upside down. 225 kJ kg⁻¹ uses the solid's gradient with the liquid's heat capacity, and 240 kJ kg⁻¹ uses the time at which freezing ends, 40 minutes, instead of its duration.

Question 16. Answer F.

Call the height of the duct h (along the current), its width w (along the field) and the length of the pumping section L . The current crosses a height h of sodium, perpendicular to the field. Splitting it into many parallel strands spread along the 30 cm makes no difference, since the forces on the strands simply add, so the total force is $F = BIh$ and the length L plays no part.

The force pushes on a cross-section of area hw , so

$$\Delta p = \frac{BIh}{hw} = \frac{BI}{w} = \frac{0.40 \times 1700}{0.040} \text{ Pa} = 17 \text{ kPa}.$$

The height of the duct cancels: only the width measured along the field matters. The column it supports satisfies $\Delta p = \rho gH$, so

$$H = \frac{17\,000}{850 \times 10} \text{ m} = 2.0 \text{ m}.$$

Using 30 cm as the length of wire in $F = BIL$ gives 6.0 m, and using 4.0 cm gives 0.80 m. Dividing by the area of the side wall or of the top wall gives 0.27 m or 0.67 m, and forgetting g gives 20 m.

Question 17. Answer F.

The layers are in series, like resistors: the same energy flow passes through each, and the temperature differences across them add, just as p.d.s do. So each layer's share of the 20 K drop tells you its share of the wall's total opposition to conduction, without working out any conductivities.

From the graph, the board takes 20 − 4 = 16 K of the drop and the brick takes 4 K. So the board provides $\frac{4}{5}$ of the opposition and the brick $\frac{1}{5}$.

For a fixed material, the temperature difference needed for a given flow is proportional to thickness, so doubling the board doubles its opposition from $\frac{4}{5}$ to $\frac{8}{5}$. The total becomes $\frac{8}{5} + \frac{1}{5} = \frac{9}{5}$ of the original. With the same overall 20 K across the wall, the rate of loss is

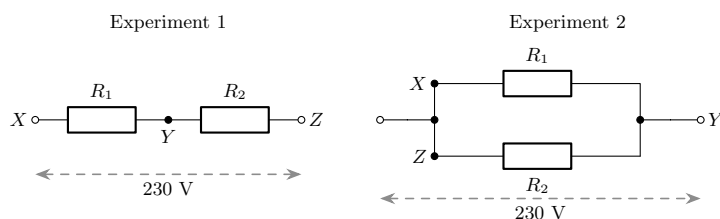
$$\frac{1}{9/5} = \frac{5}{9}$$

of its original value. (Check: the brick now takes $\frac{1}{9}$ of the drop, about 2.2 K, which matches a flow of $\frac{5}{9}$ of the original through the unchanged brick.)

The answer $\frac{1}{2}$ ignores the brick. The answer $\frac{5}{6}$ comes from total thickness, 25 cm to 30 cm, as though both materials conducted equally well. $\frac{4}{9}$ is the fraction by which the loss falls, not what remains. $\frac{17}{33}$ comes from reading the steeper gradient as the better conductor, which gets the 16 : 1 ratio the wrong way round. $\frac{9}{5}$ is the factor upside down.

Question 18. Answer B.

Decode the experiments. In experiment 1 the elements are in series; in experiment 2 each element has the full 230 V across it, so they are in parallel. Work with powers rather than resistances: let a and b be the powers of the XY and YZ elements each on its own across the mains, so $a = V^2/R_1$ and $b = V^2/R_2$.



In parallel the powers add: $a + b = 2500$. In series the resistances add, $R_1 + R_2 = V^2/400$, and dividing by V^2 gives

$$\frac{1}{a} + \frac{1}{b} = \frac{1}{400} \Rightarrow \frac{a+b}{ab} = \frac{1}{400} \Rightarrow ab = 400 \times 2500 = 10^6.$$

So a and b are the roots of $t^2 - 2500t + 10^6 = 0$, that is $(t - 2000)(t - 500) = 0$, giving 2000 W and 500 W.

Experiment 3 shows that the YZ element is the 2000 W one, so the answer is 500 W. The value 2100 W comes from subtracting the powers, 1000 W from taking the square root of the product, and 1250 W from halving the parallel power as if the elements were identical.

Question 19. Answer D.

Do not try to find the half-life. Remove the background: the sample itself gives 6000 counts in the first hour and 4000 in the second, so $6000 \times 2000 = 1.2 \times 10^7$ and $4000 \times 2000 = 8.0 \times 10^6$ nuclei decay in those hours.

The number of decays in an hour is proportional to the number of undecayed nuclei at its start, so the number of nuclei falls by the same fraction every hour. As the second hour's decays are $\frac{2}{3}$ of the first hour's, the number of undecayed nuclei is multiplied by $\frac{2}{3}$ each hour: each hour a third of the nuclei present decay.

Let N be the number at the end of the second hour. Then the number at the end of the first hour was $\frac{3}{2}N$, and the second hour's decays are

$$\frac{3}{2}N - N = \frac{1}{2}N = 8.0 \times 10^6, \quad \text{so} \quad N = 1.6 \times 10^7.$$

Check: every remaining nucleus decays eventually, and the future hourly counts $\frac{2}{3} \times 4000$, $(\frac{2}{3})^2 \times 4000$, ... add up to 8000, which is $8000 \times 2000 = 1.6 \times 10^7$ nuclei. The number at the start, 3.6×10^7 , and the second hour's decays alone, 8.0×10^6 , are the commonest slips; 2.1×10^7 comes from forgetting the background, and 8.0×10^3 from forgetting that only one decay in 2000 is counted.

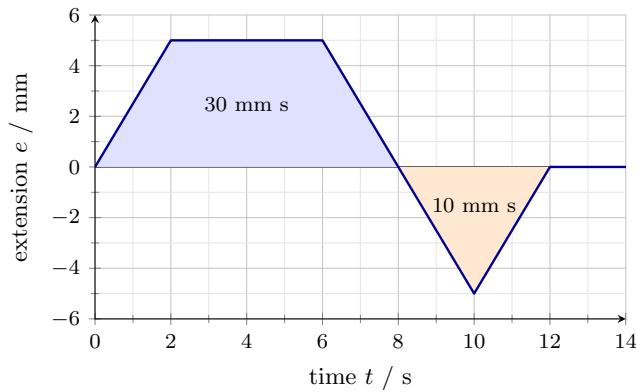
Question 20. Answer D.

The calibration replaces the unknown k and m . Hanging at rest, $k \times 0.025 = mg$, so

$$\frac{k}{m} = \frac{g}{0.025} = 400 \text{ s}^{-2}.$$

In the car the spring alone accelerates the mass, so $ke = ma$ and $a = 400e$. The graph of e against t is therefore the acceleration-time graph with a new scale, and the area under it, times 400, is the change in velocity.

The car speeds up while $e > 0$ and slows down while $e < 0$, so its greatest speed is at $t = 8$ s, where e crosses zero. It is not at $t = 6$ s: the acceleration is decreasing there but is still positive.



The area from 0 to 8 s is a trapezium, $\frac{1}{2}(8 + 4) \times 5 = 30 \text{ mm s} = 0.030 \text{ m s}$, so

$$v_{\max} = 400 \times 0.030 = 12 \text{ m s}^{-1}.$$

The negative triangle, 10 mm s, then removes 4 m s^{-1} , leaving 8.0 m s^{-1} at $t = 12 \text{ s}$, which is the final speed, not the greatest.

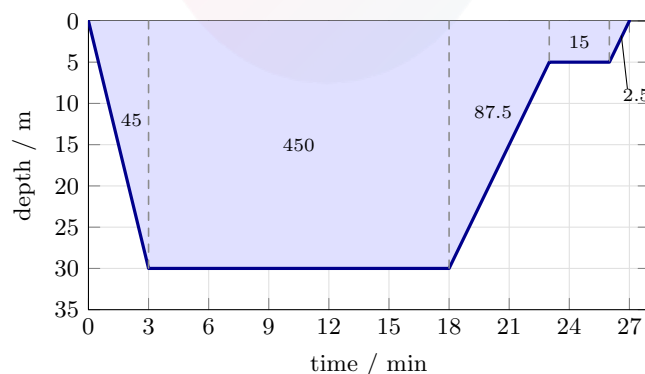
Stopping at $t = 6 \text{ s}$ or at $t = 10 \text{ s}$ (the most negative reading) gives 10 m s^{-1} . Treating each millimetre as 1 m s^{-2} gives 30 m s^{-1} , and a slip of a factor of 10 in converting 25 mm gives 1.2 m s^{-1} .

Question 21. Answer B.

Measure all the air at 100 kPa. At constant temperature pV is fixed, so 20 litres at depth h metres, where the pressure is $100(1 + h/10)$ kPa, would fill $20(1 + h/10)$ litres at 100 kPa. Her usage, in litres at 100 kPa, is therefore

$$20 \int \left(1 + \frac{h}{10}\right) dt = 20 \left(T + \frac{1}{10} \times \text{area under the depth graph}\right),$$

where $T = 27$ minutes is the length of the dive.



The area under the depth graph is $45 + 450 + 87.5 + 15 + 2.5 = 600$ metre minutes, so she uses $20(27 + 60) = 1740$ litres at 100 kPa.

At the start the tank holds the equivalent of $15 \times 20\,000/100 = 3000$ litres at 100 kPa, so 1260 litres remain, and in the 15 litre tank these are at $1260 \times 100/15 = 8400$ kPa.

11 600 kPa is the fall in pressure, not the final reading. Ignoring depth altogether gives 16 400 kPa; leaving out atmospheric pressure (counting only $h/10$) gives 12 000 kPa; taking the whole dive at 30 m gives 5600 kPa.

Question 22. Answer **B**.

Ask what the transformer and loudspeaker look like from the amplifier. If the primary p.d. is V_p , then $V_s = V_p/10$, the secondary current is $I_s = V_s/8.0 = V_p/80$, and since $V_p I_p = V_s I_s$, $I_p = I_s/10 = V_p/800$. So the primary circuit behaves exactly like an $800\ \Omega$ resistor: the transformer multiplies the load resistance by the *square* of the turns ratio, 8.0×10^2 .

With one loudspeaker, the 40 V is shared equally between the internal $800\ \Omega$ and the effective $800\ \Omega$, so $V_p = 20\ \text{V}$, $V_s = 2.0\ \text{V}$ and the loudspeaker receives $2.0^2/8.0 = 0.50\ \text{W}$.

With two loudspeakers in parallel, the secondary current doubles for the same V_s , so the effective resistance halves to $400\ \Omega$. Then $I_p = 40/1200 = \frac{1}{30}\ \text{A}$, and the power passed on by the ideal transformer is

$$I_p^2 \times 400 = \frac{400}{900}\ \text{W} \approx 0.44\ \text{W}.$$

Adding a loudspeaker *reduces* the total power, because more of the 40 V is now dropped across the internal resistor.

Doubling to 1.0 W ignores the internal resistor's effect, 2.0 W and 4.0 W ignore the internal resistor altogether, and 0.17 W and 0.091 W come from scaling the resistance by the turns ratio instead of its square. 1.0 W and 1.3 W are the powers taken from the source, including the internal resistor.

Question 23. Answer **A**.

Work is force times the distance moved by the point where the force acts, in the direction of the force. So look at the force the steps exert, and at how far the steps themselves move while each passenger is on them.

Each passenger has constant velocity, so the resultant force on each is zero. The step surfaces are horizontal, so the steps push straight up with a force equal to the weight, 600 N, on both passengers.

Statement I is true: each rises 12 m and gains $600 \times 12 = 7200\ \text{J}$.

Statement II is true. X rises at $0.50\ \text{m s}^{-1}$ and is on the escalator for 24 s, during which the steps rise 12 m: work 7200 J. Y rises at $1.0\ \text{m s}^{-1}$ and is on for only 12 s, during which the steps under her rise just 6 m: work $600 \times 6 = 3600\ \text{J}$. The other 3600 J comes from her own muscles as she climbs the steps.

Statement III is false. For both passengers the escalator's rate of working is force times the vertical speed of the steps, $600 \times 0.50 = 300\ \text{W}$. Y receives less energy from the escalator only because she is on it for less time.

The answer is I and II only. Choosing I only comes from assuming the escalator must supply all of the gain in potential energy; choosing I and III only comes from thinking a faster passenger makes the escalator work harder.

Question 24. Answer **C**.

Replace each wall by a mirror-image bat. The echoes from a wall are exactly the clicks that would be heard from the bat's image behind that wall, which moves at the bat's speed u in the mirror-image direction.

For the wall ahead, the image approaches the bat. Successive clicks leave the image 45 ms apart, while it moves $u \times 45\ \text{ms}$ closer, so in the air they are $(v - u) \times 45\ \text{ms}$ apart, where $v = 340\ \text{m s}^{-1}$. The bat runs into them at a closing speed $v + u$, so they arrive at intervals of

$$45 \times \frac{v - u}{v + u} = 40\ \text{ms}, \quad \text{so} \quad \frac{v - u}{v + u} = \frac{8}{9}.$$

For the wall behind, the image recedes and the bat runs away from the sound, so u simply changes sign: the interval is

$$45 \times \frac{v + u}{v - u} = 45 \times \frac{9}{8} = 50.6\ \text{ms}.$$

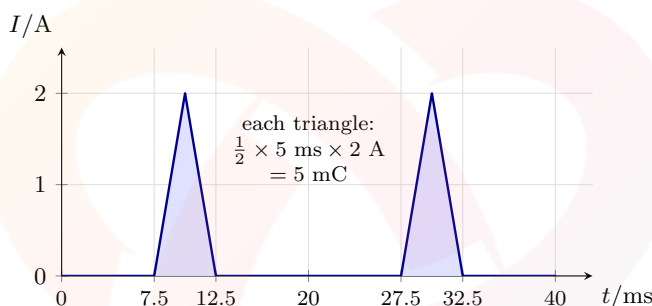
The speed of sound is not needed. (It gives $u = 20 \text{ m s}^{-1}$, and indeed $45 \times 360/320 = 50.6$.) The symmetric guess $45 + 5 = 50.0 \text{ ms}$ is wrong, because the stretch factor is the reciprocal of the squeeze factor, not its mirror about 1; 47.6 ms allows for the image moving away, which spreads the clicks out, but not for the bat running away from them.

Question 25. Answer **E**.

The diode only lets current flow clockwise, into the positive terminal of the battery. Going round the loop, the p.d.s across the resistor and the battery must add up to the generator's p.d., so a forward current needs V to exceed the battery's 6.0 V , and then

$$I = \frac{V - 6.0}{3.0}.$$

When V is below 6.0 V the battery would push current backwards, which the diode blocks, so $I = 0$. V changes by 24 V in 10 ms , that is 2.4 V per ms , so it spends 2.5 ms rising from 6 V to 12 V and 2.5 ms falling back. In each 20 ms cycle the current is a triangular pulse lasting 5.0 ms and peaking at $(12 - 6)/3.0 = 2.0 \text{ A}$. Charge is the area under the current against time graph:



Each pulse delivers $\frac{1}{2} \times 5.0 \text{ ms} \times 2.0 \text{ A} = 5.0 \text{ mC}$, so the mean current is $5.0 \text{ mC}/20 \text{ ms} = 0.25 \text{ A}$ and the time is

$$\frac{1800 \text{ C}}{0.25 \text{ A}} = 7200 \text{ s} = 120 \text{ minutes}.$$

Ignoring the battery, so that $I = V/3.0$ whenever $V > 0$, gives a mean of 1.0 A and 30 minutes . Using $I = V/3.0$ only while $V > 6 \text{ V}$ gives 0.75 A and 40 minutes ; treating each pulse as a steady 2.0 A gives 60 minutes ; counting only the rising half of each pulse gives 240 minutes .

Question 26. Answer **B**.

Three readings of the graph do all the work.

First, the mass of B . The spring pushes the gliders with equal and opposite forces for the same time, so their momentum changes are equal and opposite. A goes from 0.80 to -0.40 m s^{-1} , a change of $0.20 \times 1.20 = 0.24 \text{ kg m s}^{-1}$, while B goes from 0 to 0.40 m s^{-1} . So $m_B = 0.24/0.40 = 0.60 \text{ kg}$.

Second, the compression. The area under a velocity-time graph is a displacement, so the area between the two curves is how much further A has moved than B : the amount by which the spring has been squashed. Up to t_1 , A is faster and the gap keeps closing; at t_1 the velocities are equal, so this is the greatest compression, 4.0 mm .

Third, the energy. At t_1 both gliders move at 0.20 m s^{-1} (as the graph shows, and as momentum requires: $0.16/0.80$). Their kinetic energy is then $\frac{1}{2}(0.80)(0.20)^2 = 0.016 \text{ J}$, compared with $\frac{1}{2}(0.20)(0.80)^2 = 0.064 \text{ J}$ at the start. The spring stores the difference, 0.048 J , so

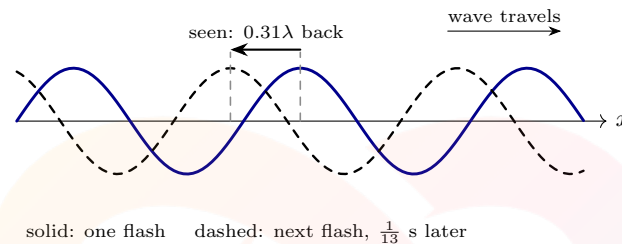
$$\frac{1}{2}k(0.004)^2 = 0.048 \implies k = \frac{0.096}{1.6 \times 10^{-5}} = 6000 \text{ N m}^{-1}.$$

Dropping the $\frac{1}{2}$ in the elastic energy gives 3000; storing all 0.064 J gives 8000; assuming the gliders have equal mass (common velocity 0.40 m s^{-1} , stored energy 0.032 J) gives 4000; taking the stored energy to be the kinetic energy remaining at t_1 , 0.016 J, gives 2000; dropping the $\frac{1}{2}$ in the kinetic energies but not in the elastic energy gives 12 000.

Question 27. Answer A.

Count wavelengths moved between flashes. In a time t the wave moves ft wavelengths, where f is the generator frequency; the eye sees only how far this is from the nearest whole number of wavelengths. Stationary at 12 flashes per second means $f/12$ is a whole number, so f is 36, 48 or 60 Hz.

At 13 flashes per second, between flashes the wave moves $f/13$ wavelengths. If n is the nearest whole number, the pattern appears to move $(f/13 - n)$ wavelengths per flash, so its apparent velocity is $13(f/13 - n)\lambda = (f - 13n)\lambda$.



For $f = 36$: $n = 3$, apparent velocity $(36 - 39) \times 0.40 = -1.2 \text{ m s}^{-1}$. For $f = 48$: $n = 4$, $(48 - 52) \times 0.40 = -1.6 \text{ m s}^{-1}$. For $f = 60$: $n = 5$, $(60 - 65) \times 0.40 = -2.0 \text{ m s}^{-1}$. The minus sign means back towards the generator, so $f = 48 \text{ Hz}$ and

$$v = f\lambda = 48 \times 0.40 = 19.2 \text{ m s}^{-1}.$$

4.8 and 5.2 m s^{-1} treat a flash rate as the wave frequency; 14.4 and 24.0 m s^{-1} are the other two candidates; 20.8 m s^{-1} is 52×0.40 , using $13n$ in place of f .