

HU Collection

ESAT Mock Set D: Physics

Worked Solutions

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Answer key

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

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

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

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 A.

Track the charges in nC. Step 1: A and B share $+24 - 8 = +16$, so each has $+8$. Step 2: B and C share $+8$, so each has $+4$. Step 3: C goes from $+4$ to 0. Step 4: A ($+8$) and C (0) share, so each has $+4$. Step 5: C again goes from $+4$ to 0.

Both times it was earthed, C was positive, that is, short of electrons, so electrons flowed from the earth onto C to neutralise it (protons stay in their nuclei). The total charge neutralised is 8 nC, which is

$$\frac{8 \times 10^{-9}}{1.6 \times 10^{-19}} = 5.0 \times 10^{10}$$

electrons, all from earth to C.

2.5×10^{10} counts only one earthing; 1.0×10^{11} comes from sharing $24 + 8 = 32$ nC in step 1, ignoring the sign of the charge on B.

Question 2. Answer B.

Add up the mechanical energy lost in both stages and convert once. Slowing down: $\frac{1}{2} \times 1200 \times (30^2 - 20^2) = 600 \times 500 = 300$ kJ. On the hill the speed is constant, so no kinetic energy is lost, but the brakes must absorb all the gravitational energy released: $1200 \times 10 \times 50 = 600$ kJ.

The discs receive 80% of 900 kJ, which is 720 kJ, and their heat capacity is $24 \times 500 = 12\,000$ J K⁻¹, so the rise is $720\,000/12\,000 = 60$ K.

20 K comes from thinking that braking at constant speed transfers no energy. Using $(30 - 20)^2$ instead of $30^2 - 20^2$ gives 4 K for the first stage and 44 K in total. Ignoring the 80% gives 75 K, and 76 K uses the whole kinetic energy at 30 m s⁻¹.

Question 3. Answer B.

Frequency is fixed by the source and does not change on refraction (each crest arriving at the boundary produces one crest beyond it), so II is false. Only the speed and wavelength change, in proportion.

I: in air the wavelength is $440 \times \frac{3.0}{2.0} = 660$ nm. Colour is set by frequency, equivalently by the wavelength in a vacuum or air, so this is red light. The 440 nm measured inside the glass would suggest violet or blue, which is the trap. True.

III: from glass to water the frequency is still unchanged, so $\lambda_{\text{water}} = 440 \times \frac{2.25}{2.0} = 495 \text{ nm}$. True.

So I and III only.

Question 4. Answer A.

Let each lamp have resistance r and the battery p.d. be V . With S open, Q and R are in parallel: they have the same p.d., so they carry equal currents, and together they carry twice the current of one lamp. The pair therefore behaves like a resistance $\frac{1}{2}r$, the total is $\frac{3}{2}r$, the current is $\frac{2V}{3r}$ and P has $\frac{2}{3}V$ across it.

The switch joins the two ends of Q with a wire. But R is connected between those same two points, so the switch short-circuits R as well, and both Q and R go out: I is true. Now P has all of V across it, and the current rises from $\frac{2V}{3r}$ to $\frac{V}{r}$, a factor of $\frac{3}{2}$ rather than 2: II is false. The power in P is proportional to the square of its p.d., which rises by the factor $\frac{3}{2}$, so the power rises by the factor $\frac{9}{4}$: III is true.

Question 5. Answer F.

The spring stores $\frac{1}{2}kx^2 = \frac{1}{2} \times 1200 \times 0.050^2 = 1.5 \text{ J}$. The trolleys start at rest, so by conservation of momentum they leave with momenta of equal size p in opposite directions.

Kinetic energy can be written as $\frac{p^2}{2m}$, so with equal momenta the energy is shared in inverse proportion to mass. A is a third of the mass of B, so it takes three times the energy: A gets $\frac{3}{4} \times 1.5 = 1.125 \text{ J}$. It rises until this is all gravitational potential energy: $h = \frac{1.125}{0.50 \times 10} = 0.225 \text{ m}$.

Equal shares give 15 cm, giving A all the energy gives 30 cm, and sharing in proportion to mass gives 7.5 cm. 2.5 cm is the height reached by B, and 45 cm uses kx^2 for the spring's energy.

Question 6. Answer B.

I: by $pV = \text{constant}$ the pressure doubles. The temperature is unchanged, so the particles move with the same average speed and each collision gives the wall the same average push; the only way to double the pressure is to double the collision rate on each unit of wall area. (Equivalently, there are twice as many particles in each cubic centimetre next to the wall, moving just as fast.) True.

II: the temperature of boiling water stays at 100°C , and temperature measures the average kinetic energy of the particles, so that does not change. The energy supplied is the latent heat, which separates the particles. False: this is the heat versus temperature confusion.

III: turning 1 kg of water at 100°C into steam at 100°C takes in the specific latent heat of vaporisation, and that energy stays in the steam's particles. True.

IV: the particles that escape from the surface are the ones moving fast enough to break away from their neighbours, so those left behind are, on average, slower: the liquid cools. Only energy flowing in from the surroundings can make up for this. True, and it is why sweating cools you.

So I, III and IV only.

Question 7. Answer F.

Draw the boundary in the right place: to find the force in a coupling, treat everything behind it as one object. Let each wagon have mass m and the deceleration be a .

Statement I is true. In case 1 the wagons have no brakes, so the only horizontal force that can slow each group of wagons is a backward push from the coupling in front of it. Every coupling is in compression: the wagons run in against the locomotive.

Statement II is false. C_1 must decelerate all three wagons, so it pushes with $3ma$. C_2 only has to decelerate the two wagons behind it, so its force is $2ma$. The ratio is $\frac{3}{2}$, not 3; the factor 3 compares C_1 with C_3 .

Statement III is true. In case 2 the braking force on each vehicle is in proportion to its mass, so every vehicle would decelerate at the same rate on its own. No coupling needs to transmit any force.

The answer is I and III only.

Question 8. Answer A.

Experiment 1: paper stops alpha but not beta or gamma. Gamma is uncharged and goes straight to R. Beta-minus particles are negative, so they are attracted towards the positive upper plate; they are very light, so they are deflected strongly, to P. (Without the paper, alpha would be pulled gently down to S: twice the charge, but about 7000 times the mass.)

Experiment 2: all three reach the field. Gamma again goes to R. For alpha, the conventional current is in its direction of motion, to the right; with the field into the page, Fleming's left-hand rule gives a force upwards, and alpha's large mass makes the deflection small: Q. Beta-minus particles carry negative charge, so their conventional current is to the left and the force is downwards, with a large deflection: T.

The wrong options come from treating the magnetic field like the electric one, sending beta towards the negative plate, letting paper stop beta as well, failing to stop alpha, or swapping which of alpha and beta paper stops.

Question 9. Answer C.

The rod never touches the magnet, but it still pushes on it. The magnetic force on the rod is exerted by the magnet, so by Newton's third law the rod exerts an equal and opposite force on the magnet. The extra 2.4 g means the magnet is pushed down by $0.0024 \times 10 = 0.024$ N, so the rod is pushed up by 0.024 N, and

$$B = \frac{F}{IL} = \frac{0.024}{4.0 \times 0.050} = 0.12 \text{ T.}$$

Reversing the current reverses both forces, and 6.0 A makes them $\frac{6}{4}$ as large: 0.036 N, equivalent to 3.6 g, now acting upwards on the magnet. The reading is $312.0 - 3.6 = 308.4$ g.

312.0 g assumes a magnet that is not touched cannot change the reading; 315.6 g ignores the reversal; 0.012 T forgets to multiply the mass by g ; 1.2 T takes 5.0 cm as 0.0050 m.

Question 10. Answer C.

The rate of energy loss is proportional to the surface area A , and by $E = mc\Delta T$ the energy needed per kelvin is proportional to the mass, so to the volume V . Hence, at any given temperature, the rate of fall of temperature is proportional to A/V .

Statement I is true. For P , $\frac{A}{V} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{3}{r}$. For Q , $\frac{A}{V} = \frac{6(2r)^2}{(2r)^3} = \frac{3}{r}$. The cube is bigger and has corners, but it cools at the same rate.

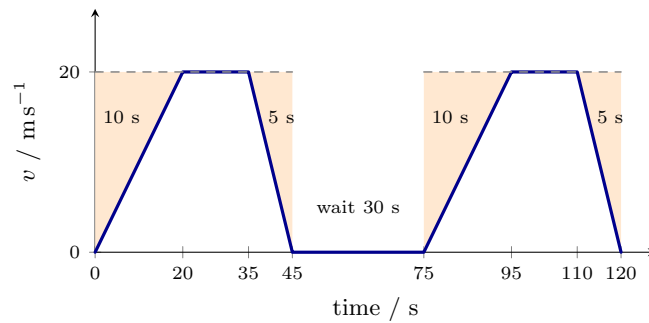
Statement II is false. Doubling the radius multiplies the area by 4 but the volume by 8, so R cools at half the rate of P , not a quarter.

Statement III is true. At every temperature on the way down, P is cooling twice as fast as R , so it passes through the whole range from 600°C to 500°C in half the time.

The answer is I and III only.

Question 11. Answer B.

Compare the tram with an imaginary one that travels at 20 m s^{-1} the whole way. Speeding up from rest at 1.0 m s^{-2} takes 20 s and, from $v^2 - u^2 = 2as$, covers 200 m, which the imaginary tram would cover in 10 s. So each start costs 10 s. Likewise each stop takes 10 s to cover 100 m, costing 5 s.



The extra stop adds one more stop and one more start, plus the wait: $5 + 10 + 30 = 45$ s. Each half of the route is 600 m, more than the 300 m needed to speed up and slow down, so the tram still reaches full speed. (The journey goes from 75 s to 120 s.)

30 s counts only the wait. 60 s adds the full 20 s and 10 s of the speed changes instead of the time they lose, and 40 s or 35 s count only one of the two. 120 s is the new journey time, not the increase.

Question 12. Answer D.

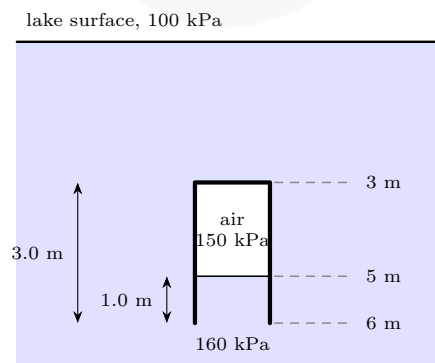
Translate the graph into coil positions. Around D, coils just to its left (such as C) are displaced to the right and coils just to its right (such as E) are displaced to the left, so coils crowd in on D: it is the centre of a compression. Around H the pattern is reversed and the coils spread out: a rarefaction. The crest B is not a compression; that is the transverse-wave picture misapplied.

For the motion, use the fact that the wave pattern moves to the right. A moment later, each coil has the displacement that the coil slightly to its left has now. Just left of H the displacement is negative, so H is moving left, and since the graph is steepest at H, its displacement is changing fastest. (Coil D moves right fastest, while B and F, at maximum displacement, are momentarily at rest.)

So the compression is at D and H is moving left fastest.

Question 13. Answer E.

First locate the bell. The trapped air was squeezed from 3.0 m to 2.0 m of the cylinder, so its pressure rose to $100 \times \frac{3}{2} = 150$ kPa. Each metre of water adds $\rho g \times 1 \text{ m} = 10$ kPa, so the water surface inside the bell is 5.0 m below the lake surface, and the open bottom is 1.0 m lower, at 6.0 m.



When the bell is full of air with the inside water level at the open bottom, the air pressure equals the water pressure there: $100 + 60 = 160$ kPa. Count the air in units of pV , with V_0 the volume of the bell: there is now $160V_0$ and there was originally $100V_0$, so $60V_0$ must be added. At 100 kPa that is a volume of $0.60V_0 = \frac{3}{5}V_0$.

$\frac{1}{2}$ uses 150 kPa for the full bell, forgetting that the inside level drops by 1.0 m; $\frac{8}{15}$ just fills the 1.0 m of water space with air at 160 kPa, forgetting that the air already inside must also be raised

from 150 to 160 kPa; $\frac{1}{3}$ ignores compression altogether; $\frac{8}{5}$ is the total air, not the extra; $\frac{3}{10}$ uses the pressure at the top of the bell.

Question 14. Answer E.

First turn each reading into a resistance. The two components carry the same current, so their p.d.s are in the ratio of their resistances. Lamp off: 9.0 V across the LDR and 3.0 V across 6.0 k Ω , so the LDR is 18 k Ω . Lamp at 1.0 m: 4.0 V and 8.0 V, so 3.0 k Ω . Target: 7.5 V and 4.5 V, so 10 k Ω .

The key is that intensity is proportional to $1/R$, so it is $1/R$, not R , that adds. In units of (k Ω)⁻¹ the background contributes $\frac{1}{18}$. The lamp at 1.0 m contributes $\frac{1}{3} - \frac{1}{18} = \frac{5}{18}$, and at the new distance it must contribute $\frac{1}{10} - \frac{1}{18} = \frac{2}{45}$. The ratio is $\frac{5}{18} \div \frac{2}{45} = \frac{25}{4}$, so the intensity from the lamp must fall by a factor of $\frac{25}{4}$ and its distance must grow by a factor of $\frac{5}{2}$: the lamp goes 2.5 m away.

(A slicker route: the current is $(12 - V)/6$ in mA, so $\frac{1}{R} = \frac{12-V}{6V} = \frac{2}{V} - \frac{1}{6}$. Differences in $1/R$ are therefore proportional to differences in $1/V$, and the ratio is $(\frac{1}{4} - \frac{1}{9}) \div (\frac{1}{7.5} - \frac{1}{9}) = \frac{25}{4}$ directly.)

Ignoring the background, so that $R \propto d^2$, gives $\sqrt{10/3} \approx 1.8$ m; scaling the distance with the voltmeter reading gives about 1.9 m; $R \propto d$ gives about 3.3 m; forgetting the square root gives 6.25 m; thinking a higher reading means more light gives 0.40 m.

Question 15. Answer D.

Watch the motion from inside the car. When the lamp comes loose it has the same velocity as the car, so relative to the floor it starts from rest. Its acceleration is 10 m s⁻² downwards and the floor's is 2.5 m s⁻² downwards, so the gap closes with a constant relative acceleration of $10 - 2.5 = 7.5$ m s⁻². The car's speed of 5.0 m s⁻¹ is irrelevant.

Apply $v^2 - u^2 = 2as$ to the relative motion: $v^2 = 2 \times 7.5 \times 2.4 = 36$, so $v = 6.0$ m s⁻¹.

The trap is the direction of the acceleration: a car moving up but slowing down is accelerating downwards, which makes the lamp seem lighter, not heavier. Using $10 + 2.5$ gives $2\sqrt{15}$, and ignoring the car's acceleration gives $4\sqrt{3}$. The fall takes 0.8 s, after which the lamp is moving down at 3.0 m s⁻¹ relative to the building and the floor is moving up at 3.0 m s⁻¹; 3.0 m s⁻¹ is the speed relative to the building. Adding or subtracting 5.0 m s⁻¹ gives 11 or 1.0.

Question 16. Answer E.

Coil 1 sees exactly the same motion as before, so the first pair of pulses is unchanged in every graph. Three separate ideas then fix the pair from coil 2.

Direction: coil 2 is wound the other way, so the same motion of the magnet induces a p.d. of the opposite sign, and its pair of pulses is negative then positive. Size: the magnet is accelerating, so it moves through coil 2 faster, and the induced p.d. is larger when the field through the coil changes faster, so the pulses are taller. Duration: at the higher speed the magnet takes less time to pass through coil 2, so the pulses are narrower. Only graph E shows an inverted pair that is both taller and narrower.

Graph C ignores the winding direction; graph F forgets that the faster magnet spends less time in the coil; graph D has the magnet slowing down; graphs A and B ignore the acceleration altogether.

Question 17. Answer A.

In an ideal transformer every turn on the core links the same changing magnetic field, so every turn contributes the same p.d.: the *volts per turn* is the same for the primary, the secondary and any extra winding. (This is just $V_s/V_p = n_s/n_p$ rearranged as $V_s/n_s = V_p/n_p$.)

The 40 reversed turns subtract from the output, lowering it by $12.0 - 10.0 = 2.0$ V, so each turn is worth 0.050 V. Raising the output from 12.0 V to 15.0 V needs $3.0 \div 0.050 = 60$ extra turns in the correct sense, and the primary has $230 \div 0.050 = 4600$ turns. (The original secondary has 240 turns.)

Comparing 10.0 V with the 14.0 V that a correct winding would have given leads to 0.10 V per turn, and the pair 30 and 2300; thinking the reversed turns also cancel 40 of the original turns gives

0.025 V per turn, and the pair 120 and 9200; 20 assumes the 40 turns were kept and rewound.

Question 18. Answer F.

Use $P = Fv$ at the two speeds. At top speed without the caravan the driving force equals the drag, so the drag on the car at 30 m s^{-1} is $36\,000/30 = 1200 \text{ N}$.

At half that speed the driving force doubles to 2400 N , while the drag on the car falls to a quarter, 300 N . The caravan's drag is also 300 N . For the whole train, the resultant force is $2400 - 600 = 1800 \text{ N}$ on 1800 kg , so $a = 1.0 \text{ m s}^{-2}$.

Now take the caravan alone. The tow bar must overcome its drag and also give it this acceleration: $T = 300 + 600 \times 1.0 = 900 \text{ N}$.

Taking drag as proportional to speed gives 1000 N . Ignoring the caravan's drag altogether gives 700 N , and remembering it for the acceleration but not in the caravan's own equation gives 600 N . Keeping the drag at its top-speed value gives 1200 N , and forgetting that the driving force doubles gives 500 N .

Question 19. Answer C.

Decode the four stages. From 0 to 84 s there is no liquid: the ice is warming from -40 to 0°C . From 84 to 420 s the liquid mass rises: melting. From 420 to 840 s it is constant at 0.50 kg : the water is warming from 0 to 100°C . After 840 s it falls: boiling.

The heater power is fixed, so energy is proportional to time. The warming water stage calibrates it: $0.50 \times 4200 \times 100 = 210\,000 \text{ J}$ in 420 s, so the power is 500 W . Then for the ice, $500 \times 84 = 0.50 c_{\text{ice}} \times 40$, giving $c_{\text{ice}} = 2100 \text{ J kg}^{-1}^\circ\text{C}^{-1}$. Without the power at all: the ice took $\frac{1}{5}$ of the time for $\frac{2}{5}$ of the temperature rise, so $c_{\text{ice}} = 4200 \times \frac{1/5}{2/5} = 2100$.

During boiling, 0.20 kg leaves in 900 s, taking $500 \times 900 = 450\,000 \text{ J}$, so $L_v = 450\,000/0.20 = 2.25 \text{ MJ kg}^{-1}$.

840 ignores the different temperature rises; 336 uses their ratio upside down; 1.5 divides by the 0.30 kg remaining; 0.90 divides by the whole 0.50 kg .

Question 20. Answer B.

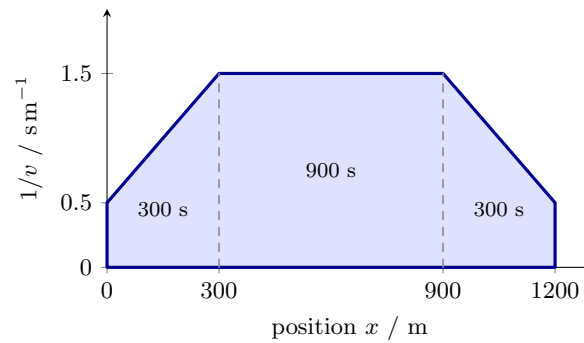
Strip off the background, then let the two halvings act independently. The source's own contribution was $230 - 30 = 200$ counts per minute through 0.60 mm at installation, and is now $55 - 30 = 25$ counts per minute.

After 5.2 years, two half-lives, the same 0.60 mm sheet would give only $200/4 = 50$ counts per minute from the source. The actual 25 is half of that, so the sheet is one halving thickness thicker: $0.60 + 0.20 = 0.80 \text{ mm}$.

Ignoring the decay compares 25 with 200, three halvings, giving 1.20 mm ; multiplying by 4 instead of dividing gives 1.60 mm ; allowing for only one half-life gives 1.00 mm . Forgetting the background compares 55 with $230/4 \approx 57$ and suggests about 0.60 mm ; reading half the expected count as half a halving the wrong way gives 0.40 mm .

Question 21. Answer A.

The motion is not uniformly accelerated, so the equations of motion are no use. Instead read the graph the right way. Over a short distance Δx the speed is nearly constant, so the time taken is $\Delta x/v = \frac{1}{v} \times \Delta x$, the area of a thin strip under the graph. Adding the strips: the area under a graph of $1/v$ against x is the time taken.



The area is $\frac{1}{2}(0.5 + 1.5) \times 300 + 1.5 \times 600 + \frac{1}{2}(1.5 + 0.5) \times 300 = 300 + 900 + 300 = 1500$ s. The average speed is total distance over total time, $1200/1500 = 0.80$ m s⁻¹.

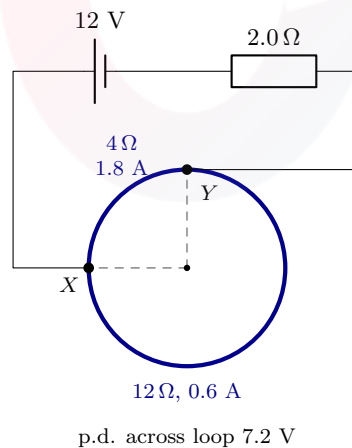
Averaging the speeds at the corners of the graph, 2 , $\frac{2}{3}$, $\frac{2}{3}$ and 2 m s⁻¹, gives $\frac{4}{3}$ m s⁻¹, and averaging speeds over distance gives 1.0 m s⁻¹. Both ignore the fact that the gauge spends longer in the slow sections. 1.25 is the mean of $1/v$ without taking the reciprocal, and $\frac{2}{3}$ and 1.5 misread single points of the graph.

Question 22. Answer **F**.

The two arcs between X and Y are in parallel. The $2.0\ \Omega$ resistor has $2.4 \times 2.0 = 4.8$ V across it, so by the series rule the loop has $12 - 4.8 = 7.2$ V across it, and both arcs share this p.d. Let the arcs have resistances R_1 and R_2 , with $R_1 + R_2 = 16\ \Omega$. Their currents add up to the battery current:

$$\frac{7.2}{R_1} + \frac{7.2}{R_2} = 2.4 \Rightarrow \frac{3}{R_1} + \frac{3}{R_2} = 1 \Rightarrow 3(R_1 + R_2) = R_1 R_2.$$

So the arcs have sum 16 and product 48: they are $4\ \Omega$ and $12\ \Omega$. The shorter arc is a quarter of the loop, so $\theta = 90^\circ$.



Check: the arcs carry 1.8 A and 0.6 A, which add to 2.4 A.

Taking the loop's overall $3\ \Omega$ as the resistance of the shorter arc gives 67.5° ; using the ratio $4 : 12$ of the arcs as the fraction of the loop gives 120° ; 45° halves the correct angle; 135° uses a product of 48 but forgets the sum, as in 6×8 ; about 53° puts the 4.8 V across the loop instead of 7.2 V.

Question 23. Answer **D**.

Work in heat capacities (energy per kelvin): X has $2.0 \times 4200 = 8400$ J K⁻¹, Y has 4200 J K⁻¹ and the block has $2.8 \times 500 = 1400$ J K⁻¹, in the ratio $6 : 3 : 1$.

First visits. In X the common temperature is the weighted mean $\frac{6 \times 80 + 1 \times 10}{7} = 70^\circ\text{C}$. In Y it is $\frac{1 \times 70 + 3 \times 10}{4} = 25^\circ\text{C}$, so $\Delta_1 = 15\text{ K}$.

The end of the process. Iterating visit by visit is hopeless, so use conservation of energy for the whole closed system. Each visit narrows the temperature differences, and after very many visits X , Y and the block all end at the same temperature, which must be the weighted mean of the starting temperatures of all three:

$$\frac{6 \times 80 + 3 \times 10 + 1 \times 10}{10} = 52^\circ\text{C}.$$

So $\Delta = 42\text{ K}$ and $\Delta_1/\Delta = 15/42 = 5/14$.

Leaving the block out of the final mean gives $56\frac{2}{3}^\circ\text{C}$ and $\frac{9}{28}$. Assuming the block leaves X at 80°C gives Y at 27.5°C and $\frac{5}{12}$, and making both slips gives $\frac{3}{8}$. Taking the final temperature as the plain average of 80 and 10 gives $\frac{3}{7}$, and $\frac{15}{52}$ divides by the final temperature instead of the rise.

Question 24. Answer **E**.

Recognise the equation of motion. Let x be the distance from the coast. The depth is proportional to x , $d = 250 \times \frac{x}{50000}$, so

$$v^2 = gd = 0.05x.$$

This is exactly $v^2 = 2ax$ with $a = 0.025\text{ m s}^{-2}$: a crest moving in from the shelf edge behaves like a body decelerating uniformly from $v = \sqrt{10 \times 250} = 50\text{ m s}^{-1}$ to rest at the coast. Under uniform deceleration the average speed is half the initial speed, 25 m s^{-1} , so the time is $50000/25 = 2000\text{ s}$ (about 33 minutes). Using the initial speed throughout gives 1000 s.

The wave is refracted by the changing depth, but its frequency, and so its period, stays the same. Where $d = 62.5\text{ m}$, $v = \sqrt{625} = 25\text{ m s}^{-1}$, so $\lambda = vT = 25 \times 900 = 22500\text{ m} = 22.5\text{ km}$. Keeping the shelf-edge wavelength $50 \times 900\text{ m} = 45\text{ km}$ assumes the wavelength is unchanged; 11.25 km scales the wavelength with the depth rather than with its square root.

Question 25. Answer **C**.

The natural first move, working out what is inside, is a dead end, because the readings do not decide it. A 12Ω resistor in parallel with a branch made of a 4Ω resistor and the diode fits them; so does a 3Ω resistor in series with a 9Ω resistor that the diode bypasses when it conducts. Happily it does not matter. For a given polarity the diode either conducts or it does not, and then the box is just a network of resistors, in which doubling the applied p.d. doubles every current. So the diode's state depends only on the polarity, and for each polarity the box behaves as a fixed resistance: $6.0/2.0 = 3.0\Omega$ with P positive and $6.0/0.50 = 12\Omega$ with Q positive.

During the $+12\text{ V}$ half the total resistance is 9Ω , the current is $\frac{4}{3}\text{ A}$ and the 6.0Ω resistor dissipates $6 \times \frac{16}{9} = \frac{32}{3}\text{ W}$. During the -12 V half the total is 18Ω , the current is $\frac{2}{3}\text{ A}$ and the power is $6 \times \frac{4}{9} = \frac{8}{3}\text{ W}$. The halves last equally long, so the mean power is

$$\frac{1}{2} \left(\frac{32}{3} + \frac{8}{3} \right) = \frac{20}{3}\text{ W} \approx 6.7\text{ W}.$$

$\frac{16}{3}\text{ W}$ assumes the diode stops all current in the reverse half; $\frac{32}{3}\text{ W}$ uses 3.0Ω for the box throughout; 6 W squares the mean size of the current, 1 A , instead of averaging the power; $\frac{2}{3}\text{ W}$ squares the mean signed current, $\frac{1}{3}\text{ A}$; $\frac{40}{3}\text{ W}$ adds the two powers without averaging.

Question 26. Answer **C**.

Build the scaling law from the model rather than chasing numbers. In each second a column of air of length v is driven down, so the mass of air per second is ρAv .

Hovering: the momentum given to the air per second is $(\rho Av)v$, so $W = \rho Av^2$ and $v = \sqrt{W/(\rho A)}$.

Power: the kinetic energy given per second is $\frac{1}{2}(\rho Av)v^2 = \frac{1}{2}Wv$. Combining,

$$P = \frac{1}{2}W\sqrt{\frac{W}{\rho A}} \propto \frac{W^{3/2}}{\sqrt{\rho}}.$$

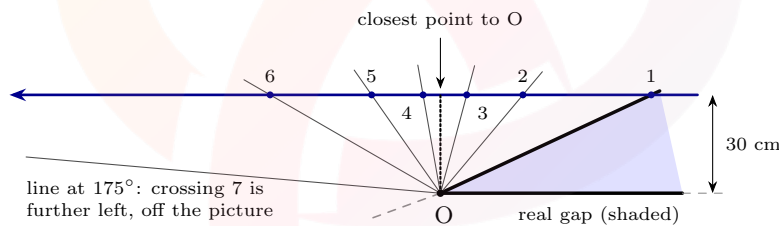
The weight rises by a factor $\frac{9}{4}$ and the density falls by a factor 0.64, so

$$P = 320 \times \left(\frac{9}{4}\right)^{3/2} \times \frac{1}{\sqrt{0.64}} = 320 \times \frac{27}{8} \times \frac{5}{4} = 1350 \text{ W}.$$

Forgetting the thinner air gives 1080 W, and dividing by $1/\sqrt{0.64}$ instead of multiplying gives 864 W. Assuming the air speed stays the same makes $P \propto W$ and gives 900 W. Assuming the mass of air per second stays the same makes $v \propto W$ and $P \propto W^2$, giving 2025 W, while $P \propto \sqrt{W}$ gives 600 W.

Question 27. Answer D.

Unfold the mirrors instead of following the beam. After the beam reflects from a mirror, its path is the mirror image, in that mirror, of the path it would have taken straight on. So reflect the whole gap in the mirror that is hit, then reflect that copy in its far mirror, and so on: the copies are fans of angle 25° around O, bounded by lines from O at $25^\circ, 50^\circ, 75^\circ, \dots$ to the lower mirror. In this unfolded picture the beam simply continues in a straight line, parallel to the lower mirror and 30 cm from it, and each line it crosses is one reflection.



A straight line parallel to the lower mirror, and 30 cm from it, crosses every line from O making an angle between 0° and 180° with the lower mirror once, and never meets the line at 180° . The lines it crosses are at $25^\circ, 50^\circ, \dots, 175^\circ$: that is 7 reflections, since 200° is too far.

Reflection in a line through O does not change distances from O, so the real beam is always exactly as far from O as the corresponding point of the straight line. The least distance is the perpendicular distance from O to that line, 30 cm, reached between the third and fourth reflections.

4 reflections comes from assuming the beam turns back as soon as its angle with the mirror passes 90° ; 8 rounds $180/25$ up. Angle chasing confirms 7: the beam meets successive mirrors at $25^\circ, 50^\circ, \dots, 175^\circ$ to their surfaces.