

HU Collection

ESAT Mock Set C: Physics

Worked Solutions

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Answer key

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

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

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

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 C.

Charging by friction moves electrons and nothing else. The rod gained electrons, so the cloth lost them, and electrons have mass: the cloth's mass fell, by a tiny amount, so I is true.

In the metal sphere only electrons are free to move. The negative rod repels them towards the far side, and when the earth wire touches there, some of them are pushed down the wire to earth. Nothing positive moves, because protons are held in nuclei, so II is false (even though the conventional current in the wire points from earth to sphere). Once the wire is removed those electrons cannot return, so when the rod is taken away the sphere is left short of electrons: it is positively charged, and III is true.

Choosing III only comes from believing the cloth's mass cannot change; choosing II and III comes from picturing positive charge physically moving.

Question 2. Answer B.

The circulation is a convection current, so think about where dense and less dense water wants to go.

Statement I is true. Water warmed in the panel expands, becomes less dense and rises up the return pipe into the tank, while cooler, denser water from the tank sinks down the other pipe to replace it. The warm water can only rise into the tank if the tank is higher than the panel.

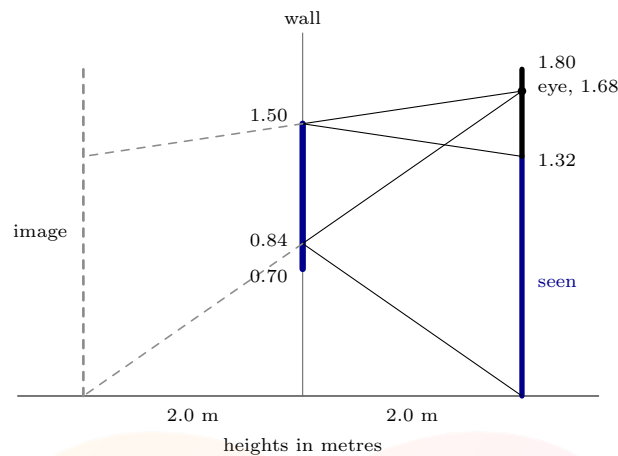
Statement II is true. A surface that is a good absorber of infrared is also a good emitter of it, and matt black is better at both than a light or shiny surface. The panel still gains overall because the sunlight it absorbs far outweighs what it emits.

Statement III is false. The coldest, densest water in the tank settles at the bottom, so the feed pipe to the panel should leave from near the bottom of the tank and the hot return pipe should enter near the top. Feeding the panel from the top would send the hottest water back to be heated and would oppose the natural circulation.

The answer is I and II only. The common slip is to choose I only, from believing that a black surface is good at absorbing but not at emitting.

Question 3. Answer A.

Use the image. Her image stands as far behind the mirror as she stands in front of it, so the line from her eye to the image of any point of her body crosses the mirror halfway between them horizontally. By similar triangles it meets the mirror at the height midway between her eye and that point, *whatever her distance from the mirror*.



Statement I. The top edge, at 1.50 m, serves the body point at height h with $\frac{1}{2}(1.68 + h) = 1.50$, so $h = 1.32$ m. True. (Her feet need the mirror point $\frac{1}{2}(1.68 + 0) = 0.84$ m, which is on the mirror, so she sees from her feet up to 1.32 m.)

Statement II. The midpoint rule does not involve her distance, so stepping back changes nothing. False, and a very common belief.

Statement III. To see all of herself she needs the mirror to cover heights from 0.84 m to $\frac{1}{2}(1.68 + 1.80) = 1.74$ m, a span of 0.90 m, which is half her height. Her mirror is only 0.80 m tall, so no placement can work. Raising it by 0.24 m brings the top edge to 1.74 m and her head into view, but the lower edge rises to 0.94 m and she now sees only from $2(0.94) - 1.68 = 0.20$ m upwards. False.

Only statement I is correct.

Question 4. Answer B.

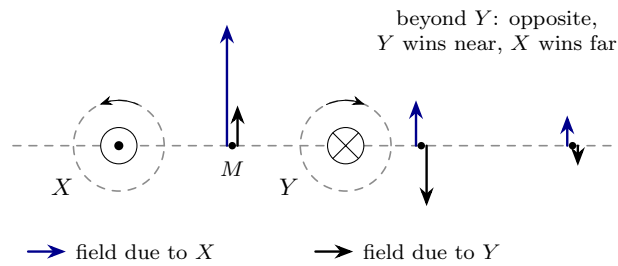
Let the balance measure the volumes. If nothing had overflowed, the container would now weigh $1000 + 300 = 1300$ g. It weighs 1180 g, so 120 g of water, that is 120 cm^3 , overflowed. The pores were already full, so the sample displaced its whole external volume: 120 cm^3 .

Soaking added 30 g of water, so the pores have volume 30 cm^3 . The grains therefore occupy $120 - 30 = 90 \text{ cm}^3$ and have mass 270 g, giving a density of $270/90 = 3.0 \text{ g cm}^{-3}$.

2.25 g cm^{-3} is the dry bulk density $270/120$, which counts the pores as rock; 2.5 divides the soaked mass by the bulk volume; 3.3 divides the soaked mass by the grain volume; 1.8 adds the pore volume instead of subtracting it ($270/150$); 1.5 takes the overflow to be $1180 - 1000 = 180$ g.

Question 5. Answer F.

Use the right-hand grip rule. Seen from above, the current in X comes towards us, so its field lines circle anticlockwise; the current in Y goes away from us, so its field lines circle clockwise. The field lines round a wire spread out with distance, so each field weakens away from its wire, and at equal distances the 3 A wire gives the stronger field.



Between the wires both fields point the same way (up the page in the figure), so I is true. Beyond Y the two fields are opposite. Very close to Y, the field of Y is far stronger; a long way out the two distances are almost equal and the larger current in X wins. The resultant reverses along this line, so it must be zero somewhere in between: II is true. (Beyond X the nearer and larger current always wins, so there is no zero on that side.)

Statement III is the trap. The force of X on Y and the force of Y on X are a Newton's third law pair, so they are equal in size and opposite in direction whatever the two currents are. (Here the wires repel.)

Question 6. Answer A.

Track the proton number. P has 80 protons and $1.6 \times 80 = 128$ neutrons. Q, being an isotope, also has 80 protons, with $1.4 \times 80 = 112$ neutrons. As the proton number ends where it started, the mass number falls by exactly the fall in neutron number, 16.

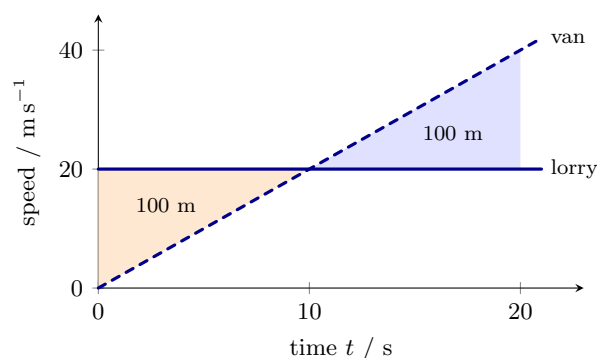
Only alpha emission changes the mass number (by 4 each time; beta-minus and gamma emission leave it unchanged), so there are $16/4 = 4$ alpha decays. These lower the proton number by 8. Each beta-minus decay turns a neutron into a proton and raises the proton number by 1, so returning to 80 protons needs 8 beta-minus decays.

Check with neutrons: the 4 alphas carry off 8 neutrons and the 8 beta decays convert 8 more, a fall of 16, as required. The other options come from counting alphas (4), all particles (12), the neutron drop (16), or assuming one beta per alpha (2).

Question 7. Answer B.

The gradient of the distance-between-them graph is the difference between the two speeds. At the peak the gradient is zero, so at $t = 10$ s the van has just reached the lorry's speed u .

Now draw both vehicles on one speed and time graph. The gap at $t = 10$ s is the area between the two lines, a triangle: $\frac{1}{2} \times 10 \times u = 100$, so $u = 20 \text{ m s}^{-1}$ and the van's acceleration is 2 m s^{-2} .



The van draws level when it has covered the same distance in the same time, so its average speed then equals the lorry's 20 m s^{-1} . Starting from rest with constant acceleration, its average speed is

half its final speed, so its final speed is 40 m s^{-1} , reached at $t = 20 \text{ s}$. On the graph, the second triangle cancels the first.

20 m s^{-1} is the speed at the greatest gap, not at drawing level. Treating the gap as $10u$ instead of a triangle gives $u = 10 \text{ m s}^{-1}$, which leads to 10 m s^{-1} if the van is assumed to draw level at equal speeds, or to $10\sqrt{2} \text{ m s}^{-1}$ if $v^2 = 2as$ is used with $a = 1 \text{ m s}^{-2}$ over 100 m . Using $v^2 = 2as$ with the correct $a = 2 \text{ m s}^{-2}$ but over the 200 m the lorry covers by $t = 10 \text{ s}$ gives $20\sqrt{2} \text{ m s}^{-1}$, and 60 m s^{-1} assumes the van draws level at $t = 30 \text{ s}$.

Question 8. Answer F.

Use scaling twice. At terminal speed the drag equals the weight. The weight is proportional to the volume, so to r^3 , while the drag is kr^2v^2 . Hence $kr^2v_t^2 \propto r^3$, giving $v_t^2 \propto r$ and $v_t \propto \sqrt{r}$. Making the radius 4 times larger doubles the terminal speed, so the large hailstone has $v_t = 20 \text{ m s}^{-1}$.

Drag is proportional to v^2 , so at half its terminal speed the large hailstone feels a quarter of the drag it would feel at terminal speed, which is a quarter of its weight. The resultant force is $\frac{3}{4}mg$, so the acceleration is $\frac{3}{4}g = 7.5 \text{ m s}^{-2}$.

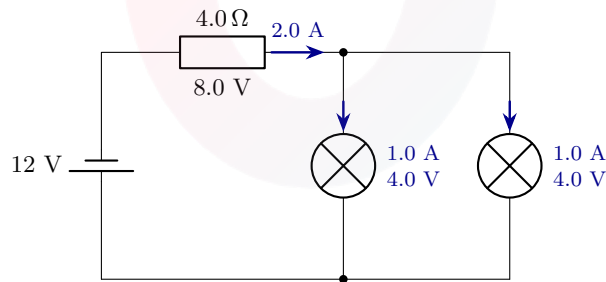
The answer 0 comes from assuming every hailstone has the same terminal speed. Taking $v_t \propto r$ gives 40 m s^{-1} and $g(1 - \frac{1}{16}) = 9.375 \text{ m s}^{-2}$. Treating drag as proportional to v gives 5.0 m s^{-2} , and 2.5 m s^{-2} comes from using the drag fraction instead of the resultant.

Question 9. Answer C.

A filament lamp is not ohmic, so there is no single resistance to use for it. Instead, let each lamp have p.d. V and current I . The resistor carries the current of both lamps, $2I$, so the series rule gives

$$V + 4.0 \times 2I = 12, \quad \text{that is} \quad V + 8I = 12.$$

Now test the table against this condition rather than guessing a resistance: the row $V = 4.0 \text{ V}$, $I = 1.00 \text{ A}$ gives $4 + 8 = 12$. As V increases, so does I , so $V + 8I$ only ever increases and this is the only possible operating point.



The resistor carries 2.0 A with 8.0 V across it, so its power is $(2.0)^2 \times 4.0 = 16 \text{ W}$.

Putting the current of one lamp, 1.0 A , through the resistor gives 4.0 W ; 8.0 W is the power in the two lamps; 24 W is the power supplied by the battery; 36 W wrongly puts all 12 V across the resistor; 12 W multiplies 12 V by 1.0 A .

Question 10. Answer C.

With reaction time t_r and deceleration a , the thinking distance is vt_r and, from $v^2 - u^2 = 2as$, the braking distance is $\frac{v^2}{2a}$. So the stopping distance has the form $d = \alpha v + \beta v^2$, and the job is to separate the two parts.

The data give $10\alpha + 100\beta = 16$ and $20\alpha + 400\beta = 52$. Doubling the first and subtracting removes the thinking distance: $200\beta = 20$, so $\beta = 0.1 \text{ s}^2 \text{ m}^{-1}$ and then $\alpha = 0.6 \text{ s}$. (Equivalently, d/v is linear in v : it is 1.6 at 10 and 2.6 at 20 .)

Halving the deceleration doubles β but leaves α alone, so from 30 m s^{-1}

$$d = 0.6 \times 30 + 0.2 \times 900 = 18 + 180 = 198 \text{ m}.$$

Doubling the whole dry distance of 108 m gives 216 m, which wrongly doubles the thinking distance too. 180 m forgets the thinking distance, and 234 m and 288 m come from scaling a whole stopping distance by v^2 and then doubling.

Question 11. Answer D.

Compare front and back. Let the wave speed be v , the dipper speed u and the time between dips $T = 0.20 \text{ s}$. Between two dips a crest moves vT forward while the dipper follows it by uT , so the spacing ahead is $(v - u)T$. Behind, the dipper moves away from the previous crest, so the spacing is $(v + u)T$.

Half the sum of the two spacings is the undisturbed wavelength $vT = \frac{1}{2}(0.8 + 3.2) = 2.0 \text{ cm}$, so $v = 2.0/0.20 = 10 \text{ cm s}^{-1}$. Half the difference is $uT = \frac{1}{2}(3.2 - 0.8) = 1.2 \text{ cm}$, so $u = 6 \text{ cm s}^{-1}$.

Ahead, crests 0.8 cm apart reach the stationary cork at 10 cm s^{-1} , so they pass it at $10/0.8 = 12.5 \text{ Hz}$. The frequency at the cork is not the dipping frequency: that is the whole point of the Doppler effect. 12 cm s^{-1} forgets to halve the difference; 10 cm s^{-1} is the wave speed; 5.0 Hz ignores the Doppler effect; 3.1 Hz is the frequency behind; 20 Hz scales 5.0 Hz by the ratio $3.2/0.8$ of the spacings.

Question 12. Answer A.

There is no need to find the speed. The force $F = BIL$ is constant and acts over 0.80 m, and with no friction or air resistance all the work it does ends up as gravitational potential energy at the top of the ramp:

$$BIL \times 0.80 = mgh \quad \Rightarrow \quad 0.50 \times I \times 0.040 \times 0.80 = 0.010 \times 10 \times 1.6.$$

So $0.016 I = 0.16$ and $I = 10 \text{ A}$.

For the direction use Fleming's left-hand rule: first finger along the field (up), thumb along the force (east). The second finger then points north, so the current flows through the rod from south to north.

20 A and 5.0 A come from gaining or losing a factor of 2 by going through $\frac{1}{2}mv^2$ and $v^2 = 2gh$; the other directions come from using the right hand or swapping the roles of the fingers.

Question 13. Answer E.

Three stages, each with its own conservation law. Falling: $v^2 = 2gh = 100$, so the hammer arrives at 10 m s^{-1} with kinetic energy 20 kJ.

Impact: the collision is inelastic, so energy is not conserved but momentum is. $400 \times 10 = 500V$ gives $V = 8.0 \text{ m s}^{-1}$, and the kinetic energy just after impact is $\frac{1}{2} \times 500 \times 64 = 16 \text{ kJ}$. A fifth of the energy has already gone into sound, heat and deformation.

Penetration: over the 0.10 m the ground's force R removes this kinetic energy and also the gravitational potential energy released, $500 \times 10 \times 0.10 = 500 \text{ J}$. So $0.10R = 16\,000 + 500$, giving $R = 165 \text{ kN}$.

Forgetting the extra potential energy gives 160 kN. Ignoring the loss in the collision and using the full 20 kJ gives 205 kN or 200 kN. Using only the hammer's kinetic energy after impact, 12.8 kJ, gives 133 kN or 128 kN.

Question 14. Answer E.

Let the diameter be d and the length ℓ . The resistance is proportional to ℓ/d^2 and the curved surface area to $d\ell$. At the melting point the heating power I^2R matches the maximum rate of heat loss, so

$$I^2 \frac{\ell}{d^2} \propto d\ell \quad \Rightarrow \quad I^2 \propto d^3.$$

The length cancels: doubling it doubles the heating and the cooling alike, so the 6.0 cm is a distraction. The current must rise by a factor of 8, so I^2 rises by $64 = 4^3$ and the diameter must rise by a factor of 4, to 0.80 mm.

Taking the current proportional to the diameter gives 1.6 mm; forgetting that the resistance depends on the diameter ($I^2 \propto d$) gives 12.8 mm; letting the extra length raise the resistance but not the cooling gives about 1.0 mm; taking the current proportional to the cross-sectional area gives about 0.57 mm; 0.40 mm comes from $I \propto d^3$.

Question 15. Answer A.

First find how the arrangement stretches, from first principles. The whole spring has stiffness $6.0/0.12 = 50 \text{ N m}^{-1}$. Under a given force every coil stretches by the same amount, so a quarter of the spring extends a quarter as much and has stiffness 200 N m^{-1} .

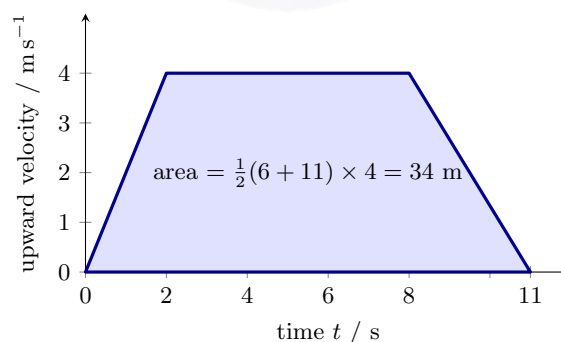
Hang a force F on the arrangement. The rod stays horizontal, so the three upper pieces have equal extensions and each carries $\frac{1}{3}F$, extending by $\frac{F}{600}$. The lower piece carries the full F and extends by $\frac{F}{200}$. The total extension is $\frac{F}{600} + \frac{3F}{600} = \frac{F}{150}$, so the arrangement behaves like one spring of stiffness 150 N m^{-1} .

Now use energy. The greatest elastic energy is stored at the lowest point, where the weight is momentarily at rest, so all the gravitational energy lost has become elastic energy: $Wx = \frac{1}{2}kx^2$, giving $x = \frac{2W}{k} = 0.08 \text{ m}$, twice the equilibrium extension. The energy stored is $Wx = 6.0 \times 0.08 = 0.48 \text{ J}$. 0.12 J is the energy at the equilibrium position, and 0.24 J is W times the equilibrium extension. 1.44 J is the answer for the uncut spring, and 1.92 J comes from forgetting that cutting the spring makes each piece stiffer. Letting each upper piece carry the whole weight gives 0.72 J.

Question 16. Answer B.

The reading tells us the resultant force: an excess of 1 kg on the display is an extra 10 N upwards on a 60 kg student, an acceleration of $\frac{1}{6} \text{ m s}^{-2}$. For the first 2 s the excess is +12 kg, so the lift accelerates upwards at 2 m s^{-2} and reaches 4 m s^{-1} upwards.

The duration of the last stage is not given, but the lift starts and ends at rest, so the total change in momentum is zero. The area between the reading graph and the 60 kg line must therefore cancel: $12 \times 2 = 8 \times T$, giving $T = 3 \text{ s}$. The lift stops at $t = 11 \text{ s}$.



The distance is the area under the velocity and time graph, a trapezium with parallel sides 6 s and 11 s and height 4 m s^{-1} : $\frac{1}{2}(6 + 11) \times 4 = 34 \text{ m}$, upwards because the first reading was above 60 kg. Taking the last stage to last 2 s or 4 s gives 32 m or 36 m, and leaving out the slowing or speeding stage gives 28 m or 30 m. Choosing downwards confuses an increased reading with downward motion.

Question 17. Answer F.

Read the gradient correctly. Adding a small volume ΔV to the top of the liquid raises the top surface by $\Delta V/A$, where A is the cross-section at that level, and so raises the base pressure by $\rho g \Delta V/A$: the gradient is $\rho g/A$. The kink at 4 litres is where the water reaches the narrow section (the gradient rises from 0.5 to 2.0 kPa per litre); the kink at 5 litres is where the oil begins.

From 4 to 7 litres the top surface is always in the same narrow section, so the gradients there are in the ratio of the densities: $\rho_{\text{oil}} = 1000 \times \frac{1.6}{2.0} = 800 \text{ kg m}^{-3}$. Comparing 1.6 with 0.5 mixes two different areas, giving the impossible 3200 (it would sink, not float); inverting the ratio gives 1250.

For the depth, add the layers using $p = \rho gh$ for each. The water in the lower section gives 2.0 kPa, so it is 0.20 m deep; the water in the upper section gives another 2.0 kPa, another 0.20 m; the oil gives 3.2 kPa, so its depth is $3200/(800 \times 10) = 0.40 \text{ m}$. Total: 0.80 m.

Dividing the final 7.2 kPa by $\rho_{\text{water}}g$ gives 0.72 m, wrongly treating the oil as water; 0.50 m puts the oil in the wide section.

Question 18. Answer A.

Subtract readings to cancel the unknown background. Write the readings as $B + A$, $B + Ar$ and $B + Ar^2$, where B is the background and r is the fraction of the source's activity left after each 6 hours. The differences are

$$670 - 190 = 480 = A(1 - r), \quad 190 - 70 = 120 = Ar(1 - r),$$

so $r = 120/480 = \frac{1}{4}$: two half-lives every 6 hours, a half-life of 3 hours. The differences themselves shrink by the same factor, so the next one is $120/4 = 30$ and the reading at 18 hours is $70 - 30 = 40$ counts per minute.

Indeed $B = 30$ and the source contributes 640, 160, 40 and then 10. 17.5 quarters the whole reading, including background; 35 assumes a 6 hour half-life; 10 forgets to add the background back; 30 assumes the source has died away; 55 shrinks the last difference by 8 instead of 4.

Question 19. Answer E.

Energy per charge first. Each coulomb of ions gains 1000 J, so the beam carries kinetic energy away at $P = IV = 2.0 \times 1000 = 2000 \text{ W}$. Each ion gains $qV = 1.6 \times 10^{-16} \text{ J}$, so

$$\frac{1}{2} \times 2.0 \times 10^{-25} v^2 = 1.6 \times 10^{-16} \Rightarrow v^2 = 1.6 \times 10^9, \quad v = 4.0 \times 10^4 \text{ m s}^{-1}.$$

Let M be the mass of xenon leaving each second. The thrust is the momentum given to the beam each second, $F = Mv$, while the power is $P = \frac{1}{2}Mv^2$. Dividing,

$$F = \frac{2P}{v} = \frac{4000}{4.0 \times 10^4} = 0.10 \text{ N},$$

with no need to count ions. (The long way: $2.0/(1.6 \times 10^{-19}) = 1.25 \times 10^{19}$ ions leave each second, each with momentum $2.0 \times 10^{-25} \times 4.0 \times 10^4 = 8.0 \times 10^{-21} \text{ kg m s}^{-1}$.)

0.050 N uses $P = Fv$ as if for a car; 0.071 N comes from $qV = mv^2$; 0.20 N gives each ion a momentum change of $2mv$, as if it bounced; $3.2 \times 10^{-3} \text{ N}$ uses 1 V instead of 1000 V; $4.0 \times 10^3 \text{ N}$ forgets the square root.

Question 20. Answer D.

Use the reflection law in its rotating form: if a mirror turns through an angle θ while the incident beam stays fixed, the reflected beam turns through 2θ . (The normal turns by θ , so the angle of incidence changes by θ , and the reflected ray, on the other side of the normal, moves by θ more.)

With n faces, each face is in use while the prism turns through $360^\circ/n$, so each sweep covers $720^\circ/n$. The sweep is steady, so the fraction of time spent on the drum is the fraction of the sweep angle it occupies:

$$\frac{30^\circ}{720^\circ/n} = \frac{n}{24} = \frac{1}{3} \implies n = 8.$$

Each face gives one sweep, so there are $8 \times 50 = 400$ sweeps per second.

Forgetting the doubling gives a sweep of $360^\circ/n$ and $n = 4$; halving instead of doubling gives $n = 2$. 800 counts two sweeps per face, and 50 is just the rotation rate.

Question 21. Answer **C**.

The first instinct, $c = \frac{P}{\dot{m} \Delta T}$ for one run, gives 4600 from run 1 and 4000 from run 2. Two different answers show that the losses cannot be ignored.

The key is that the casing is at the same temperature in both runs, so the power lost to the surroundings, L , is the same each time. Each second,

$$P = L + \dot{m}c \Delta T.$$

Subtracting the two runs removes the unknown loss: the extra $600 - 276 = 324$ W heats the extra 3.0 g s^{-1} through 30 K. So

$$c = \frac{324}{0.0030 \times 30} = 3600 \text{ J kg}^{-1} \text{ K}^{-1}.$$

As a check, the loss is $L = 276 - 0.0020 \times 3600 \times 30 = 60$ W, and run 2 gives $600 - 540 = 60$ W too. Averaging the two naive values gives 4300, and adding the 60 W loss instead of subtracting it gives 5600 or 4400.

Question 22. Answer **B**.

Work with the current, not the voltage. At present the line voltage is $10 \text{ kV} \times \frac{2000}{1000} = 20 \text{ kV}$ and the power sent is $1.8 + 0.20 = 2.0$ MW, so the line current is $2.0 \text{ MW} \div 20 \text{ kV} = 100 \text{ A}$.

The power dissipated in the line is $I^2 R$, so a quarter of the loss needs half the current, 50 A. The loss is then 0.050 MW, so the power sent must be $1.8 + 0.05 = 1.85$ MW, and the line voltage must be

$$\frac{1.85 \text{ MW}}{50 \text{ A}} = 37 \text{ kV}.$$

The primary has 10 kV across 1000 turns, which is 10 V per turn, so the secondary needs 3700 turns.

The tempting 4000 doubles the voltage to halve the current, forgetting that less power has to be sent once less is wasted. 3600 divides only the town's 1.8 MW by 50 A; 3800 assumes the loss halves when the current halves; 8000 treats the loss as inversely proportional to the voltage; 7250 quarters the current instead of halving it.

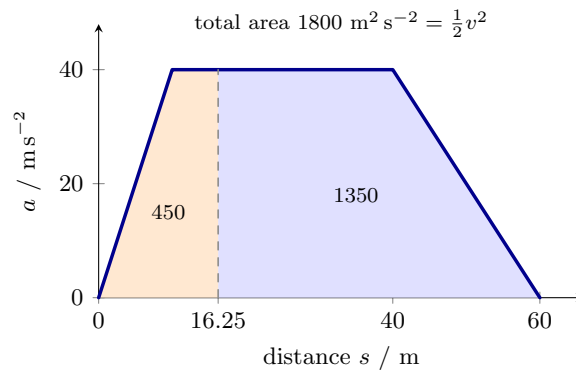
Question 23. Answer **E**.

This is not a velocity and time graph, and the area under it is not a change in speed. Multiply the acceleration by the sled's mass m : the area under a force and distance graph is the work done, which equals the gain in kinetic energy. So

$$m \times (\text{area under the } a \text{ and } s \text{ graph}) = \frac{1}{2}mv^2, \quad \text{that is} \quad \text{area} = \frac{1}{2}v^2.$$

This is the varying-acceleration version of $v^2 - u^2 = 2as$.

The total area is $\frac{1}{2} \times 10 \times 40 + 30 \times 40 + \frac{1}{2} \times 20 \times 40 = 200 + 1200 + 400 = 1800 \text{ m}^2 \text{ s}^{-2}$, so the final speed is 60 m s^{-1} . Half that speed means a quarter of the kinetic energy, so a quarter of the area: 450. The first triangle supplies 200, and the remaining 250 needs $250/40 = 6.25 \text{ m}$ of the flat section.



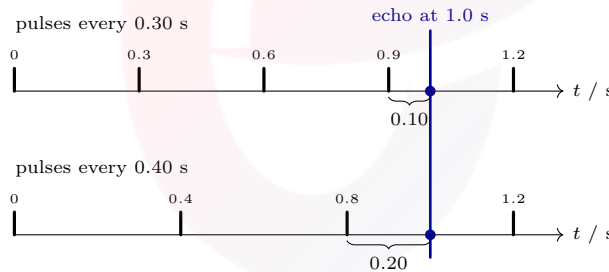
So the sled reaches 30 m s^{-1} at $s = 16.25 \text{ m}$. Half the area gives 27.5 m (treating speed as proportional to area), and half the distance gives 30 m . Assuming $a = 40 \text{ m s}^{-2}$ from the very start gives $900 = 80s$, so 11.25 m .

Question 24. Answer C.

Treat the display as a remainder. If the true round-trip time of a pulse is t , the echo arrives t after its own pulse, so the display shows what is left of t after removing whole pulse intervals. Hence

$$t = 0.10 + 0.30a = 0.20 + 0.40b \quad \text{for some whole numbers } a, b \geq 0.$$

The first list is $0.1, 0.4, 0.7, 1.0, 1.3, 1.6, 1.9, 2.2, \dots$ and the second is $0.2, 0.6, 1.0, 1.4, 1.8, 2.2, \dots$ seconds. The common values are $1.0 \text{ s}, 2.2 \text{ s}, 3.4 \text{ s}, \dots$, repeating every 1.2 s (the lowest common multiple of the two intervals).



The sea bed is at depth $\frac{1}{2} \times 1500t$, giving $750 \text{ m}, 1650 \text{ m}, \dots$; only 750 m lies within the charted range.

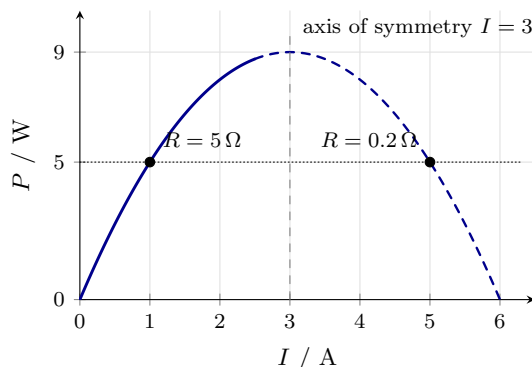
525 m ($t = 0.7 \text{ s}$) and 975 m (1.3 s) fit only the first reading; 450 m (0.6 s) and 1050 m (1.4 s) fit only the second; 1500 m forgets that the sound travels down and back.

Question 25. Answer D.

Let the hidden source have p.d. E and the internal resistor resistance r . With current I , the series rule puts a p.d. of $E - Ir$ across the variable resistor, so

$$P = I(E - Ir).$$

The graph is part of a parabola through the origin. Two points read from it, $(1.0, 5.0)$ and $(2.0, 8.0)$, give $E - r = 5$ and $E - 2r = 4$, so $r = 1.0 \Omega$ and $E = 6.0 \text{ V}$. Now $P = I(6 - I)$, which is zero at $I = 0$ and at $I = 6 \text{ A}$ (a short circuit, with all the power in the internal resistor), and is symmetric about $I = 3 \text{ A}$.



So the other current giving 5.0 W is the mirror image of 1.0 A in the line $I = 3$ A, namely 5.0 A, and then $R = P/I^2 = 5.0/25 = 0.20 \Omega$. A neat check: the two settings satisfy $R_1 R_2 = r^2$, and $5.0 \times 0.20 = 1.0$.

1.0 Ω uses P/I instead of P/I^2 ; 1.2 Ω divides E by 5.0 A, forgetting the internal resistor; 7.2 Ω ignores the internal resistor altogether, so that $P = 6I$; 0.31 Ω reflects in the end of the drawn curve, $I = 2.5$ A, instead of in the peak; 0.80 Ω takes the current at the end of the drawn curve.

Question 26. Answer D.

First the mass flow. Each hour a layer of water 0.090 m deep lands on 20 m², which is 1.8 m³ or 1800 kg, so rain enters the wagon at 0.50 kg s⁻¹. The wagon's horizontal motion does not change this, because the rain falls vertically onto a horizontal opening.

Statement I is true. The rain arrives with no horizontal momentum and must be brought up to 4.0 m s⁻¹. Using $F = \Delta p / \Delta t$, each second 0.50 kg gains $0.50 \times 4.0 = 2.0$ kg m s⁻¹, so the force is 2.0 N.

Statement II is true. The locomotive's power is $Fv = 8.0$ W, but the kinetic energy rises at only $\frac{1}{2} \times 0.50 \times 4.0^2 = 4.0$ W. The other half is dissipated as each raindrop slides and splashes to rest relative to the wagon, the signature of a perfectly inelastic capture.

Statement III is false. Water falling vertically relative to the wagon leaves it with the wagon's horizontal velocity, 4.0 m s⁻¹. Each second 0.50 kg still arrives with zero horizontal momentum and leaves with 2.0 kg m s⁻¹, so the same 2.0 N is needed. Keeping the mass constant does not remove the need to speed up the water passing through.

The answer is I and II only.

Question 27. Answer F.

Do not iterate; ask when the pump stops working. At the end of every push stroke the dead space holds 4 cm³ of gas at atmospheric pressure, because any excess has just escaped through the outlet valve. As the piston is withdrawn, this trapped gas expands; by $pV = \text{constant}$ it would reach $100 \times \frac{4}{500} = 0.80$ kPa at full withdrawal.

The inlet valve opens only if the cylinder pressure falls below the vessel pressure. Once the vessel pressure is 0.80 kPa or less, that never happens: the cylinder simply breathes its own dead-space gas in and out, and nothing more is taken from the vessel. So 0.80 kPa is the limit.

(While the vessel pressure p is above this, one stroke takes the vessel and dead-space gas together into 2500 cm³, so the new pressure is $p' = \frac{2000p+400}{2500}$ in kPa. Then $p' - 0.8 = \frac{4}{5}(p - 0.8)$: the pressure approaches 0.80 kPa from above but never goes below it.)

0.20 and 0.16 kPa expand the dead-space gas into the vessel, or the vessel and cylinder, instead of the cylinder; 6.4 Pa applies the ratio $4/500$ twice; an ideal pump with no dead space really could approach zero, but this one cannot.