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Centre number

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Candidate number

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Surname

StemUp Model Solution

Forename(s)

Candidate signature

I declare this is my own work.

AS PHYSICS

Paper 1

Wednesday 15 May 2024

Morning

Time allowed: 1 hour 30 minutes

Materials

For this paper you must have:

- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet
- a protractor.

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do all rough work in this book. Cross through any work you do not want to be marked.
- Show all your working.

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 70.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

For Examiner's Use

Question	Mark
1	
2	
3	
4	
5	
6	
TOTAL	



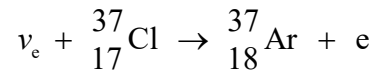
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Answer **all** questions in the spaces provided.

0 1

An electron neutrino interacts with a chlorine-37 nucleus to produce an argon-37 nucleus and an electron.

The interaction is represented by the equation:



0 1 . 1

Explain, with reference to appropriate conservation laws, why the electron is emitted in this interaction.

[2 marks]

Charge must be conserved: on the left the charge is $0 + 17 = +17$, the argon nucleus has one more proton ($+18$), so an electron of charge -1 must be emitted: $18 + (-1) = +17$.

Lepton number must be conserved: left side ν_e has $L = +1$ (Cl has 0), right side Ar has 0, so an electron with $L = +1$ is needed: $1 + 0 = 0 + 1$.

0 1 . 2

Calculate the specific charge of the argon-37 nucleus.

[2 marks]

$$\text{charge} = 18 \times 1.60 \times 10^{-19} = 2.88 \times 10^{-18} \text{ C}$$

$$\text{mass} = 37 \times 1.67 \times 10^{-27} = 6.18 \times 10^{-26} \text{ kg}$$

$$\text{specific charge} = \text{charge} / \text{mass}$$

$$= 2.88 \times 10^{-18} / 6.18 \times 10^{-26}$$

$$\text{specific charge} = \underline{4.66 \times 10^7} \text{ C kg}^{-1}$$

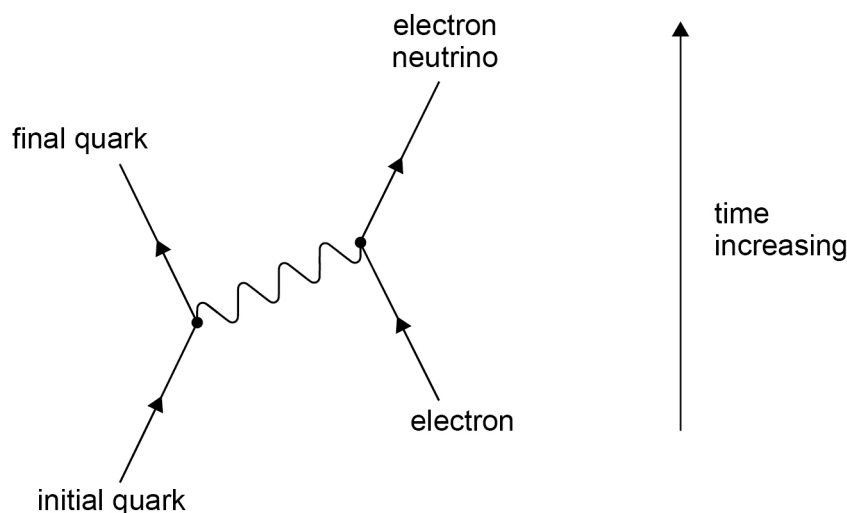


0 1 3

In a different interaction, the argon-37 nucleus interacts with an electron.

Figure 1 represents the interaction of a quark in a baryon of the nucleus.

Figure 1



Deduce the exchange particle and the effect on the baryon.
Give **one** reason to support each answer.

[4 marks]

exchange particle W^+ boson

reason It is the weak interaction (electron capture): a W boson is the exchange particle of the weak interaction.

The lepton changes flavour: the electron (-1) becomes an electron neutrino (0), so a W^+ must be absorbed at that vertex to conserve charge: $-1 + 1 = 0$.

effect on baryon A proton changes into a neutron (charge of the baryon decreases by 1, $uud \rightarrow udd$).

reason An up quark changes to a down quark (quark changes flavour, $uud \rightarrow udd$), which only happens in the weak interaction. Charge is conserved at the quark vertex: $u (+2/3) \rightarrow d (-1/3) + W^+ (+1)$.

Question 1 continues on the next page

Turn over ►



0 1 4

The argon-37 nucleus decays into a stable nucleus.

Describe the nature of the forces that act between nucleons and how these forces can maintain nuclear stability.

In your answer, describe:

- the forces of repulsion and attraction that act between nucleons
- exchange particles associated with these forces
- the role of these forces in keeping the nucleus stable.

[6 marks]

Repulsion: protons are positively charged so there is an electromagnetic (electrostatic) repulsion between protons. Attraction: there is a gravitational attraction between all nucleons, but it is negligible compared with the other forces.

The strong nuclear force (strong interaction) acts between all nucleons (protons and neutrons). It is attractive from about 0.5 fm up to about 3 to 4 fm, so it only acts between neighbouring nucleons, and it is very strongly repulsive at separations less than about 0.5 fm.

Exchange particles: the electromagnetic force is carried by virtual photons; the strong interaction between nucleons is carried by pions (π^+ , π^- , π^0).

Stability: at typical nucleon separations (about 1 fm) the strong force attraction is much greater in magnitude than the electromagnetic repulsion between protons, so it dominates and holds the nucleons together. The short-range repulsion stops the nucleons getting closer than about 0.5 fm, so the nucleus does not collapse. The nucleons sit at the separation where the forces balance, giving a stable nucleus.



[illegible]

0 2

A tube contains a vapour of mercury atoms at low pressure. In an experiment, the vapour is bombarded by a beam of electrons.

An electron in the beam gains 6.7 eV of kinetic energy by moving through a potential difference V .

0 2

1

Deduce V .

[1 mark]

$$V = \underline{6.7} \text{ V}$$

The electron collides with a mercury atom. The atom subsequently emits a photon of ultraviolet radiation with an energy of 6.7 eV.

0 2

2

Calculate the wavelength of the emitted photon of this ultraviolet radiation.

[3 marks]

$$E = 6.7 \times 1.60 \times 10^{-19} = 1.07 \times 10^{-18} \text{ J}$$

$$E = hc/\lambda \text{ so } \lambda = hc/E$$

$$\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / (1.072 \times 10^{-18})$$

$$\lambda = 1.86 \times 10^{-7} \text{ m}$$

$$\text{wavelength} = \underline{1.9 \times 10^{-7}} \text{ m}$$



0 2 . 3

The experiment is repeated with a different gas.

Figure 2 shows the three lowest energy levels for an atom of the gas.

Figure 2

not to scale

−3.16 eV _____ energy level B

−4.96 eV _____ energy level A

−21.56 eV _____ ground state

When an electron in the beam collides with the gas atom, 18.4 eV of energy is transferred to the atom.

The atom subsequently emits a photon of visible light.

State and explain the energy transitions that are involved.

Support your answer with appropriate calculations.

[4 marks]

The 18.4 eV transferred excites an atomic electron from the ground state to level B: $-21.56 + 18.40 = -3.16$ eV, which is exactly level B.

The electron then de-excites from B to A, emitting a visible photon: $\Delta E = -3.16 - (-4.96) = 1.80$ eV $= 1.80 \times 1.60 \times 10^{-19} = 2.88 \times 10^{-19}$ J, so

$\lambda = hc/E = 6.63 \times 10^{-34} \times 3.00 \times 10^8 / 2.88 \times 10^{-19} = 6.9 \times 10^{-7}$ m,

which is visible (red). B to ground or A to ground give too much

energy, so too short a wavelength (UV).

8

Turn over ►



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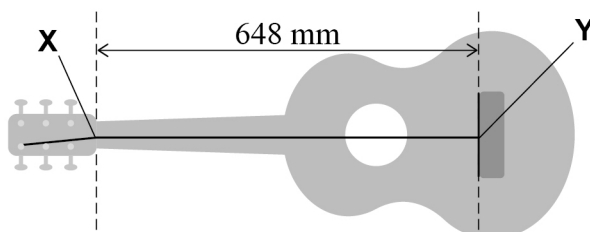
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0 3

Figure 3 shows a guitar with only one of its strings attached. The string is fixed at **X** and **Y**. The string is plucked and vibrates freely between **X** and **Y**. The distance **XY** is 648 mm.

Figure 3

0 3 . 1

The frequency of the first harmonic is 147 Hz.

Calculate the speed of the wave travelling in the string.

[2 marks]

$$\text{first harmonic: } \lambda = 2 \times XY = 2 \times 0.648 = 1.296 \text{ m}$$

$$v = f\lambda = 147 \times 1.296$$

$$v = 190.5 \text{ m s}^{-1}$$

speed of wave = 191 m s⁻¹

0 3 . 2

The tension in the string is 71 N.

Calculate the mass of the string between **X** and **Y**.

[3 marks]

$$v = \sqrt{T/\mu} \text{ so } \mu = T/v^2$$

$$\mu = 71 / 190.5^2 = 1.956 \times 10^{-3} \text{ kg m}^{-1}$$

$$m = \mu \times l = 1.956 \times 10^{-3} \times 0.648$$

$$m = 1.27 \times 10^{-3} \text{ kg}$$

mass = 1.3×10^{-3} kg

Question 3 continues on the next page

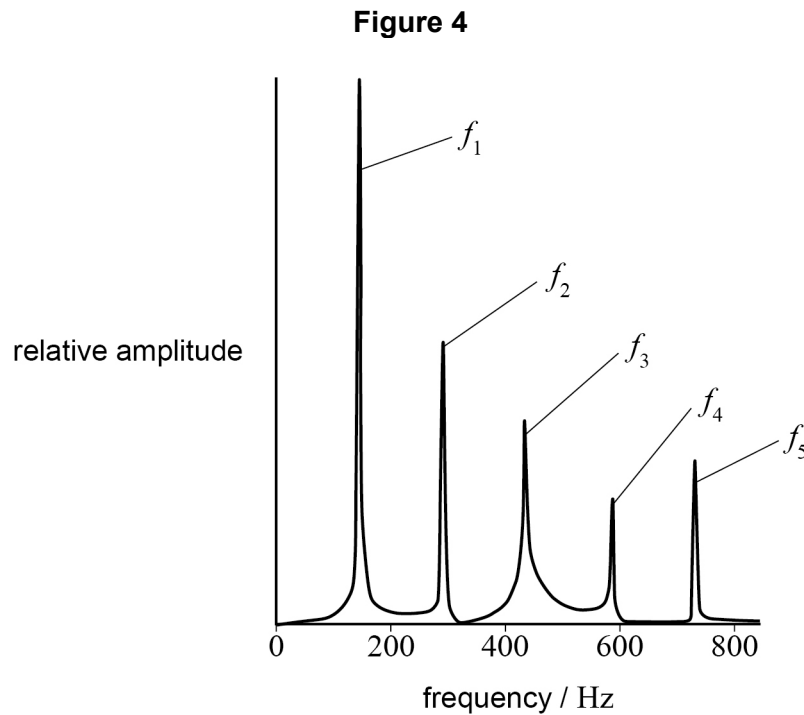
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The sound produced by the guitar is analysed.

The sound is the superposition of the first harmonic f_1 with harmonics f_2, f_3, f_4 and f_5 of the stationary waves that exist on the string.

Figure 4 shows the frequencies of these harmonics and their relative amplitudes.

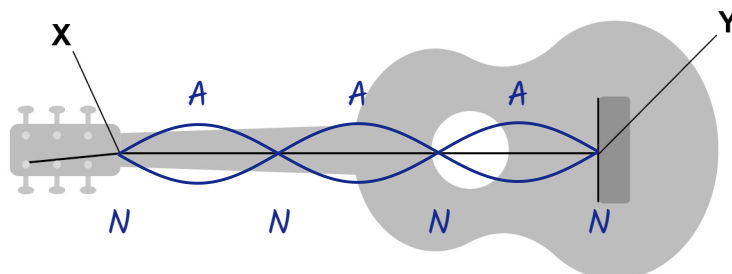


0 3 . 3 Draw, on **Figure 5**, the stationary wave that produces the harmonic f_3 .

Label the positions of all nodes **N** and all antinodes **A**.

[3 marks]

Figure 5



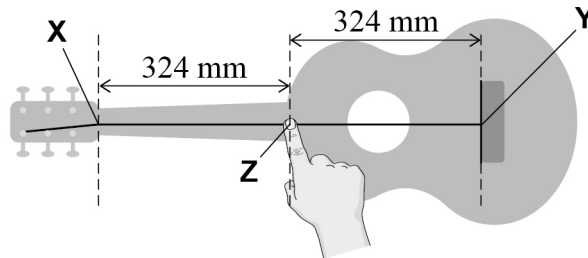
0 3 4

The string is vibrating freely.

The player then touches the string lightly at its midpoint **Z** as shown in **Figure 6**. This prevents the string from vibrating at **Z**.

The sections **XZ** and **ZY** of the string continue to vibrate.

Figure 6



The sound produced by the guitar is analysed.

Deduce, with reference to frequency, how the harmonics present in this sound compare with the harmonics present in **Figure 4**.

[3 marks]

Touching the string at its midpoint forces a node there, so only stationary waves with a node at the midpoint can exist.

The odd harmonics f_1 , f_3 and f_5 (about 150, 450 and 750 Hz) need an antinode at the midpoint, so they cannot exist and are no longer present.

The even harmonics f_2 and f_4 have a node at the midpoint, so they are still present: about 300 Hz and 600 Hz (v/λ with $\lambda = 0.648$ m gives 294 Hz, and 588 Hz).

So the sound only contains f_2 and f_4 : the lowest frequency is double the original fundamental.

11

Turn over for the next question

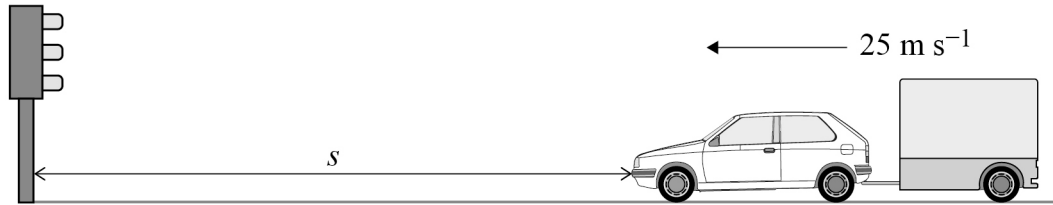
Turn over ►



0 4

In this question, assume that all forces are coplanar.

0 4 . 1

Figure 7 shows a car and trailer moving at 25 m s^{-1} at a distance s from traffic lights.**Figure 7**

The driver applies the brakes so that the car and trailer stop at the lights.

The car and trailer undergo a constant deceleration of 2.8 m s^{-2} .Calculate s .**[2 marks]**

$$v^2 = u^2 + 2as \text{ with } v = 0$$

$$s = u^2 / 2a = 25^2 / (2 \times 2.8)$$

$$s = 111.6 \text{ m}$$

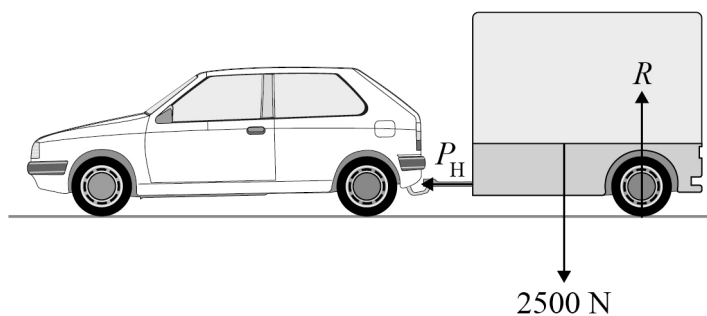
 $s =$ 112 m


The car and trailer accelerate from rest along a horizontal road.

Figure 8 shows:

- that the car exerts a horizontal force P_H on the trailer
- that the trailer has a weight of 2500 N
- the reaction force R on the wheels of the trailer.

Figure 8



0 4 . 2 Initially, there are no resistive forces and the trailer accelerates at 1.5 m s^{-2} .

Calculate the initial value of P_H .

[2 marks]

$$m = W/g = 2500 / 9.81 = 254.8\text{ kg}$$

$$F = ma = 254.8 \times 1.5$$

$$P_H = 382\text{ N}$$

$$P_H = \underline{\quad 380 \quad} \text{ N}$$

Question 4 continues on the next page

Turn over ►



Air resistance D acts on the trailer when it is moving. D increases as the velocity v of the trailer increases.

Figure 9 shows how D varies with v .

Figure 9

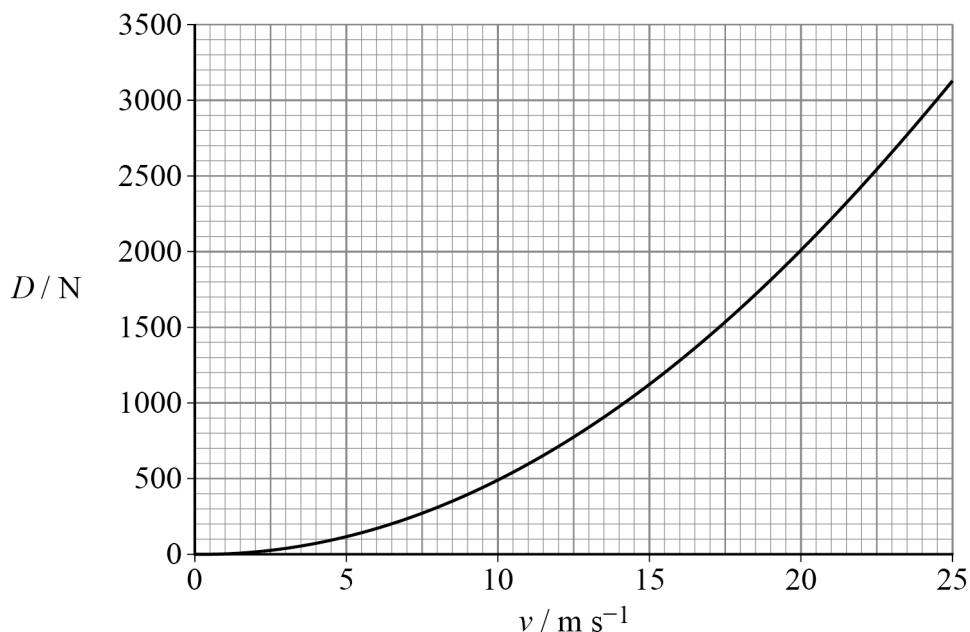
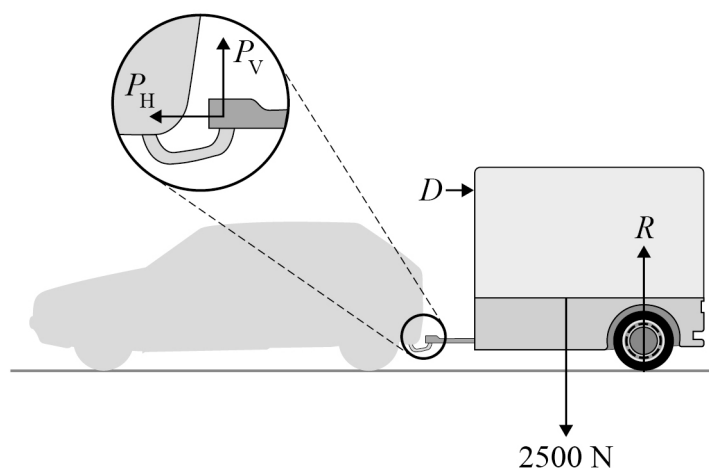


Figure 10 shows the forces acting on the trailer when it is travelling at a constant horizontal velocity.

The car exerts a vertical force P_V and a horizontal force P_H on the trailer when it is travelling at a constant horizontal velocity v_1 .

An enlarged view of P_V and P_H is also shown in **Figure 10**.

Figure 10



The horizontal force P_H is now greater than the value calculated in Question **04.2**.



0 4 3

The vertical force P_V is 762 N.

The resultant of P_H and P_V is 912 N.

Determine v_1 .

[3 marks]

$$P_H^2 + P_V^2 = 912^2$$

$$P_H = \sqrt{912^2 - 762^2} = \sqrt{251100} = 501 \text{ N}$$

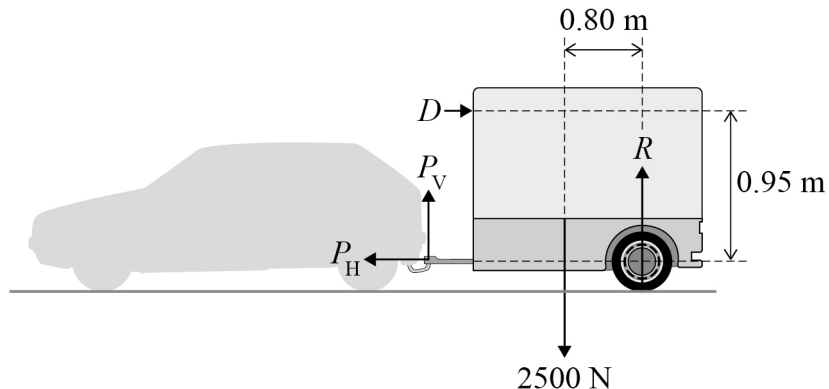
constant velocity so $D = P_H = 500 \text{ N}$

from Figure 9, $D = 500 \text{ N}$ when $v = 10 \text{ m s}^{-1}$

$$v_1 = \underline{\quad 10 \quad} \text{ m s}^{-1}$$

D can be considered to act at the position shown in **Figure 11**. For some of the forces, the distances of their lines of action from the centre of the trailer's wheel have been included.

Figure 11



0 4 4

Explain why P_H has no moment about the centre of the trailer's wheel in **Figure 11**.

[1 mark]

The line of action of P_H passes through the centre of the wheel, so its perpendicular distance from the centre is zero (moment = $F \times 0 = 0$).

Question 4 continues on the next page

Turn over ►



0 4 . 5

When the car and trailer travel with velocity v_2 , P_V is zero.

Determine v_2 .

[3 marks]

$P_V = 0$, take moments about the centre of the wheel:

$$D \times 0.95 = 2500 \times 0.80$$

$$D = 2000 / 0.95 = 2105 \text{ N} \approx 2100 \text{ N}$$

from Figure 9, $D = 2100 \text{ N}$ when $v = 20.5 \text{ m s}^{-1}$

$$v_2 = \underline{\quad 20.5 \quad} \text{ m s}^{-1}$$

0 4 . 6

The air resistance D acting on the trailer increases as the velocity v of the trailer increases.

Explain this increase in D with reference to the momentum of the air displaced by the trailer.

You should also refer to appropriate Newton's laws of motion.

[3 marks]

As v increases, the trailer displaces more air each second, and each air particle is given a greater velocity, so more air particles are given momentum each second and each gains more momentum.

So the rate of change of momentum of the air increases, and by Newton's 2nd law ($F = \Delta(mv)/\Delta t$) a greater force is exerted on the air by the trailer.

By Newton's 3rd law the air exerts an equal and opposite force on the trailer, so the air resistance D on the trailer increases.



0 4 . 7

The car has a maximum power output of 95 kW.

The maximum velocity of the car and trailer is 25 m s^{-1} .

At this velocity, the force D on the trailer is 3100 N.

The car exerts a horizontal force P_H on the trailer and the trailer exerts an equal and opposite force of magnitude P_H on the car.

Assume that air resistance and P_H are the only resistive forces acting on the car.

Calculate the air resistance acting on the car when it is travelling at a constant velocity of 25 m s^{-1} .

[3 marks]

$$P = Fv \text{ so driving force } F = 95 \times 10^3 / 25 = 3800 \text{ N}$$

$$\text{constant velocity: trailer } P_H = D = 3100 \text{ N}$$

$$\text{constant velocity: } F = \text{air resistance on car} + P_H$$

$$\text{air resistance on car} = 3800 - 3100$$

$$= 700 \text{ N}$$

air resistance on car = 700 N

17

Turn over for the next question

Turn over ►



0 5

Figure 12 shows a circuit for controlling the current I in a filament lamp L_1 . The battery has negligible internal resistance.

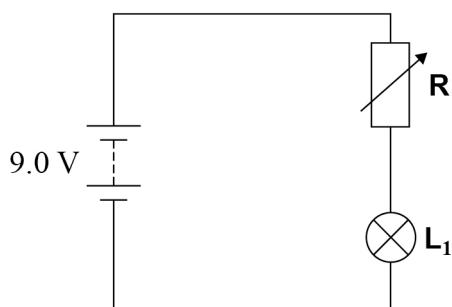
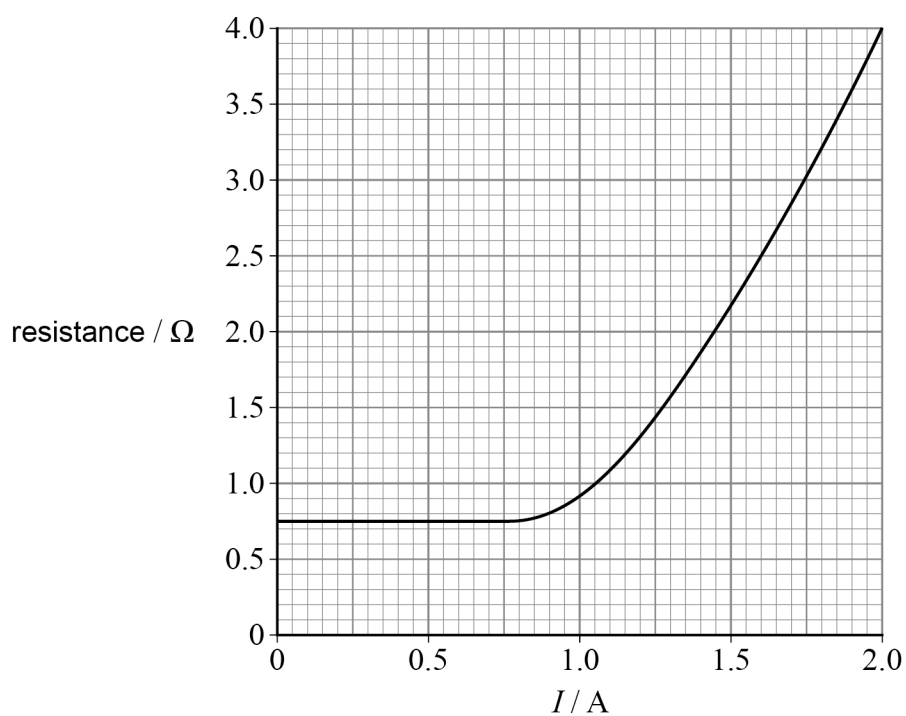
Figure 12

Figure 13 shows how the resistance of L_1 varies with I .

Figure 13

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0 5 . 1

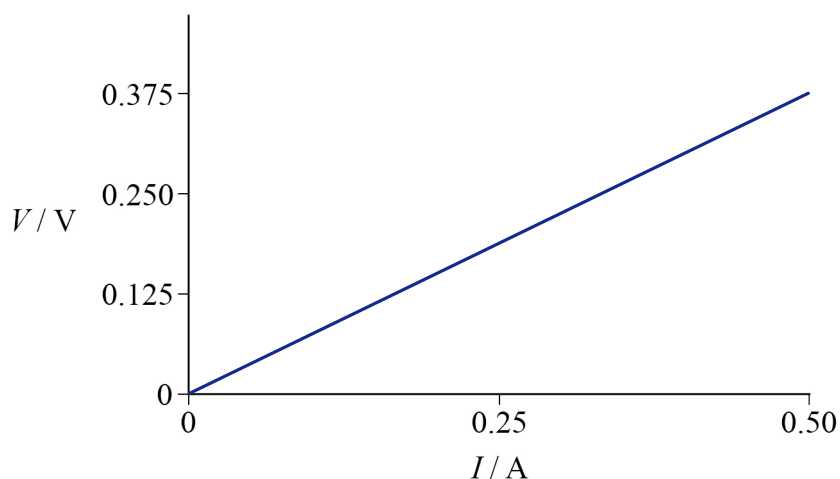
The current in L_1 is increased from 0 to 0.50 A.

The potential difference V across L_1 is 0.375 V when I is 0.50 A.

Draw, on **Figure 14**, a V - I graph for L_1 in the current range 0 to 0.50 A.

[1 mark]

Figure 14



0 5 . 2

Calculate the power dissipated in L_1 when I is 1.9 A.

[2 marks]

from Figure 13, $R = 3.6 \Omega$ at $I = 1.9 A$

$$P = I^2 R = 1.9^2 \times 3.6$$

$$P = 13.0 W$$

power dissipated = 13 W

Question 5 continues on page 21

Turn over ►



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0 5 . 3

The variable resistor **R** in **Figure 12** is adjusted until I is 1.5 A and V is 3.3 V.

Calculate the resistance of **R**.

[2 marks]

$$V_R = 9.0 - 3.3 = 5.7 \text{ V}$$

$$R = V/I = 5.7 / 1.5$$

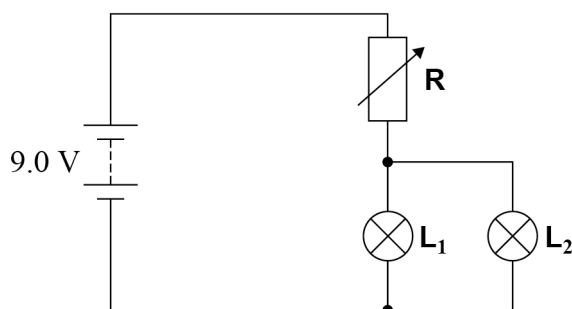
$$R = 3.8 \, \Omega$$

resistance of **R** = 3.8 Ω

0 5 . 4

Figure 15 shows a second lamp **L**₂, identical to **L**₁, connected to the circuit.

Figure 15



R is adjusted so that the potential difference across **L**₁ is again 3.3 V.

Deduce, without calculation, the change in the resistance of **R**.

[3 marks]

The resistance of R must decrease.

With L_2 in parallel and 3.3 V across each lamp, the current through each lamp is the same as before, so the total current through the lamps (and through R) is doubled (more current in the parallel section). The pd across R must still be $9.0 - 3.3 = 5.7 \text{ V}$, so to carry the larger current with the same pd a lower resistance of R is needed (the combined resistance of L_1 and L_2 is lower, so R must fall to keep the same ratio of pd division).

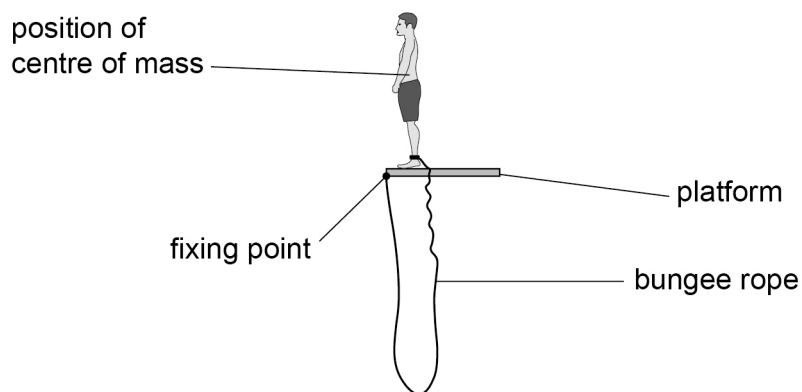


0 6

Figure 16 shows a boy of mass m standing on a platform about to perform a bungee jump. He steps off the platform and falls vertically. The tension in the rope increases as it stretches. The boy decelerates to rest at the lowest point of the jump. Assume that air resistance is negligible throughout this question.

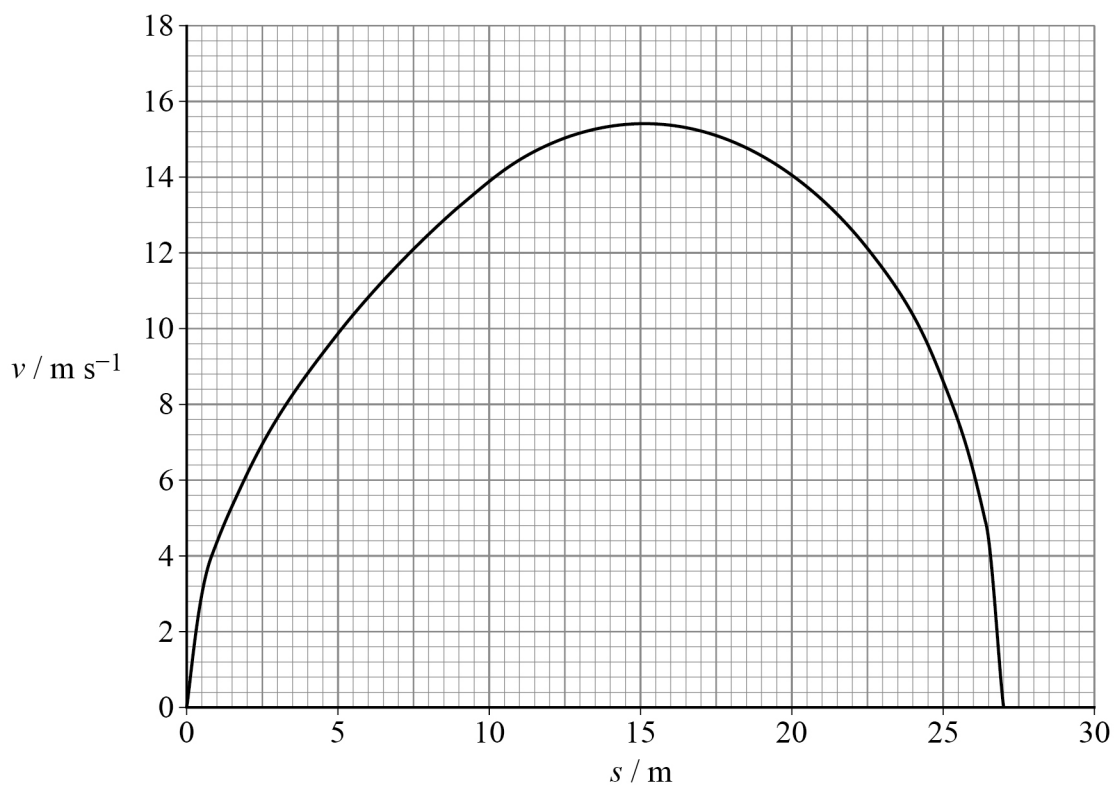
Figure 16

not to scale



During the jump, s is the vertical displacement moved by the boy's centre of mass. The lowest point of the jump occurs when s is 27 m.

Figure 17 shows the variation of his velocity v with s during the jump.

Figure 17

0 6 . 1

The boy experiences freefall when he steps off the platform.

During which part of the jump does the boy's acceleration begin to decrease?

Tick (✓) **one** box.

[1 mark]

between $s = 0$ and $s = 7.5$ m

☐

between $s = 7.5$ m and $s = 15$ m

☒

between $s = 15$ m and $s = 22.5$ m

☐

between $s = 22.5$ m and $s = 27$ m

☐

0 6 . 2

When the boy's centre of mass has moved through a distance s of 15.0 m the change in his gravitational potential energy is 9.56 kJ.

Calculate the mass m of the boy.

[2 marks]

$$\Delta E_p = mg\Delta h \text{ so } m = \Delta E_p / g\Delta h$$

$$m = 9.56 \times 10^3 / (9.81 \times 15.0)$$

$$m = 65.0 \text{ kg}$$

$$m = \underline{65.0} \text{ kg}$$

Question 6 continues on the next page

Turn over ►



The bungee rope has a stiffness k of 110 N m^{-1} and obeys Hooke's law.

0 6 . 3 The maximum kinetic energy of the boy is 7.71 kJ .

Calculate, by considering the energy transfers, the extension ΔL of the bungee rope when the kinetic energy of the boy is at a maximum.

[3 marks]

loss of GPE = gain of KE + elastic energy stored in rope

elastic energy = $9.56 - 7.71 = 1.85 \text{ kJ} = 1850 \text{ J}$

$E = \frac{1}{2}k\Delta L^2$ so $\Delta L = \sqrt{2E/k}$

$\Delta L = \sqrt{(2 \times 1850 / 110)} = \sqrt{33.6}$

$\Delta L = 5.80 \text{ m}$

$\Delta L =$ 5.80 m

0 6 . 4 Deduce the tension in the rope when the kinetic energy of the boy is at a maximum. Give a reason to support your answer.

[2 marks]

KE is maximum when acceleration = 0, so $T = mg$

$T = 65.0 \times 9.81 = 638 \text{ N}$

(check: $T = k\Delta L = 110 \times 5.80 = 638 \text{ N}$)

tension = 640 N

reason At maximum KE the velocity stops increasing, so the resultant force (and acceleration) is zero: tension equals weight.



The original rope is replaced with a second rope and the boy repeats the jump.

Table 1 contains information about the original rope and the second rope. Both ropes obey Hooke's law.

Table 1

	Young modulus	Cross-sectional area	Unstretched length
original rope	E	A	L
second rope	$1.2E$	A	$1.2L$

The Young modulus is given by:

$$\text{Young modulus} = \frac{\text{stiffness} \times \text{unstretched length}}{\text{cross-sectional area}}$$

0 6 . 5 Show that each rope has the same stiffness.

[1 mark]

$k = EA/L$. original rope: $k = EA/L$

second rope: $k = (1.2E \times A)/(1.2L) = EA/L$, the same stiffness

0 6 . 6 Deduce whether the boy's maximum velocity is increased when using the second rope.

[3 marks]

Yes. Maximum velocity is when tension = weight; k is the same, so the extension and the elastic energy stored at maximum velocity are the same.

The second rope's unstretched length is greater ($1.2L$), so he has a longer free fall and a greater velocity before the rope stretches; total distance fallen to maximum velocity is greater.

By conservation of energy, more GPE is lost but the same energy is stored in the rope, so he gains more kinetic energy: his maximum velocity is increased.

END OF QUESTIONS



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