

Please write clearly in block capitals.

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.

INTERNATIONAL AS PHYSICS

Unit 2 Electricity, waves and particles

Thursday 16 January 2020

07:00 GMT

Time allowed: 2 hours

Materials

For this paper you must have:

- a Data and Formulae Booklet as a loose insert
- a ruler with millimetre measurements
- a scientific calculator, which you are expected to use where appropriate.

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.
- All working must be shown.
- 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.

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 80.

For Examiner's Use	
Question	Mark
1	
2	
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4	
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11–24	
TOTAL	

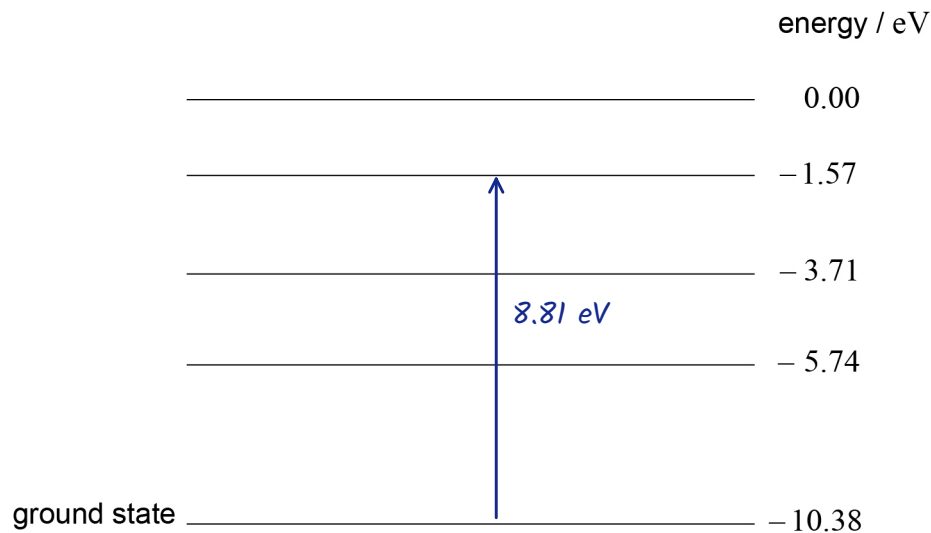


J A N 2 0 P H 0 2 0 1

Section A

Answer **all** questions in this section.

0 1

Figure 1 shows some of the energy levels of a single atom.**Figure 1**

0 1 . 1

The atom is in its ground state. A photon of energy 8.81 eV is incident on the atom.

Describe a likely outcome of this event.

[2 marks]

The photon is absorbed and the atom is excited: an electron is raised from the ground state to the -1.57 eV level, because $-10.38 + 8.81 = -1.57$ eV, exactly the energy difference between the two levels.

0 1 . 2

Multiple atoms, with the same energy levels as shown in **Figure 1**, return to the ground state.

State how many different photon wavelengths can be observed.

[1 mark]number of wavelengths = 6

3



0 2

Light passing from glass to water has a critical angle of 61° .

0 2 . 1

State what is meant by critical angle.

[1 mark]

The critical angle is the angle of incidence (in the glass) for which the angle of refraction is 90° : the maximum angle of incidence at which refraction occurs.

0 2 . 2

Glass has a refractive index of 1.52

Calculate the speed of light in water.

[3 marks]

$$\sin \theta_c = n_2 / n_1$$

$$n_{\text{water}} = 1.52 \times \sin 61^\circ = 1.33$$

$$n = c / v, \text{ so } v = c / n_{\text{water}}$$

$$v = 3.00 \times 10^8 / 1.33 = 2.26 \times 10^8 \text{ m s}^{-1}$$

speed = 2.3×10^8 m s^{-1}

4

Turn over for the next question

Turn over ►

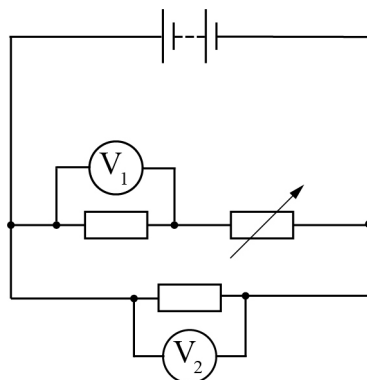


0 3

Figure 2 shows a circuit containing two fixed resistors, a variable resistor and a battery with negligible internal resistance.

Voltmeters V_1 and V_2 are connected across the fixed resistors.

Figure 2



The resistance of the variable resistor is increased.

State and explain how the readings on V_1 and V_2 are affected by this change.

[4 marks]

V_1 *V_1 decreases. The fixed resistor and the variable resistor are in series, so the emf is shared between them in the ratio of their resistances. The variable resistor now takes a larger share of the pd, so V_1 falls (also the current in that branch falls, and $V = IR$ with R fixed).*

V_2 *V_2 stays the same. The branches are in parallel and independent of each other, and with negligible internal resistance the pd across the lower branch is still equal to the emf of the battery.*

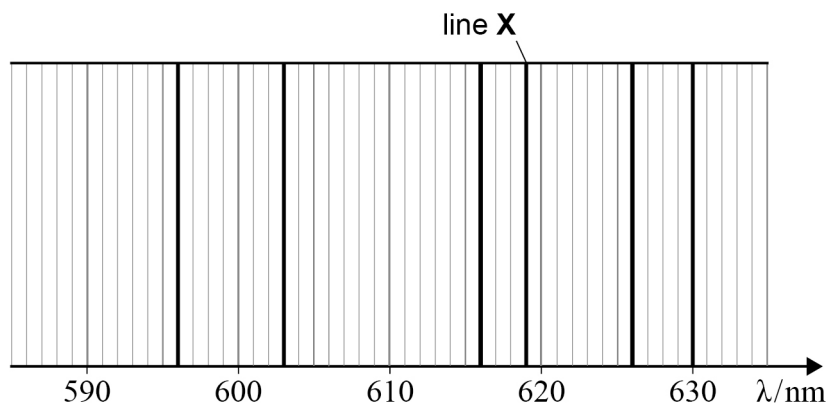
4



0 4

Figure 3 shows part of the line spectrum for light emitted from a neon lamp. A wavelength scale is shown.

Figure 3



0 4 . 1

Outline how a diffraction grating can produce a line spectrum.

[2 marks]

Light diffracts (spreads out) as it passes through each slit of the grating.

Waves from different slits overlap and interfere: maxima where they arrive in phase (path difference $n\lambda$, so $n\lambda = d \sin \theta$).

Each wavelength has its maxima at a different angle, so each wavelength appears as a separate bright line.

0 4 . 2

Calculate the energy of the photon responsible for line **X** in the spectrum in **Figure 3**.

[3 marks]

from Figure 3, line X: $\lambda = 619 \text{ nm} = 6.19 \times 10^{-7} \text{ m}$

$$E = hc / \lambda = 6.63 \times 10^{-34} \times 3.00 \times 10^8 / 6.19 \times 10^{-7}$$

$$E = 3.21 \times 10^{-19} \text{ J}$$

photon energy = 3.2×10^{-19} J

5

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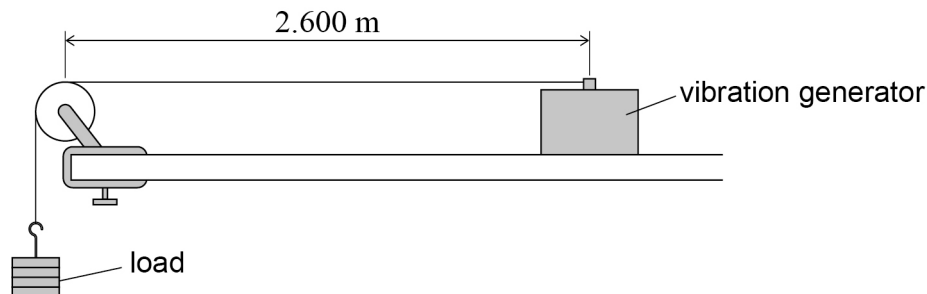


0 5

Figure 4 shows the apparatus used to investigate stationary waves on a string.

The frequency of the vibration generator is adjusted until the first-harmonic stationary wave is observed on the string. This is repeated for different loads.

Figure 4



0 5 . 1

Show that the frequency f of the first harmonic is related to the tension T in the string by the following equation:

$$f^2 = \left(\frac{1}{4lm} \right) T$$

where l = length of the vibrating part of the string
 m = mass of the vibrating part of the string.

[2 marks]

first harmonic: $l = \lambda / 2$, so $\lambda = 2l$

wave speed $c = f\lambda = \sqrt{T / \mu}$, where μ = mass per unit length = m / l

$f = (1 / 2l) \sqrt{T / \mu} = (1 / 2l) \sqrt{Tl / m}$

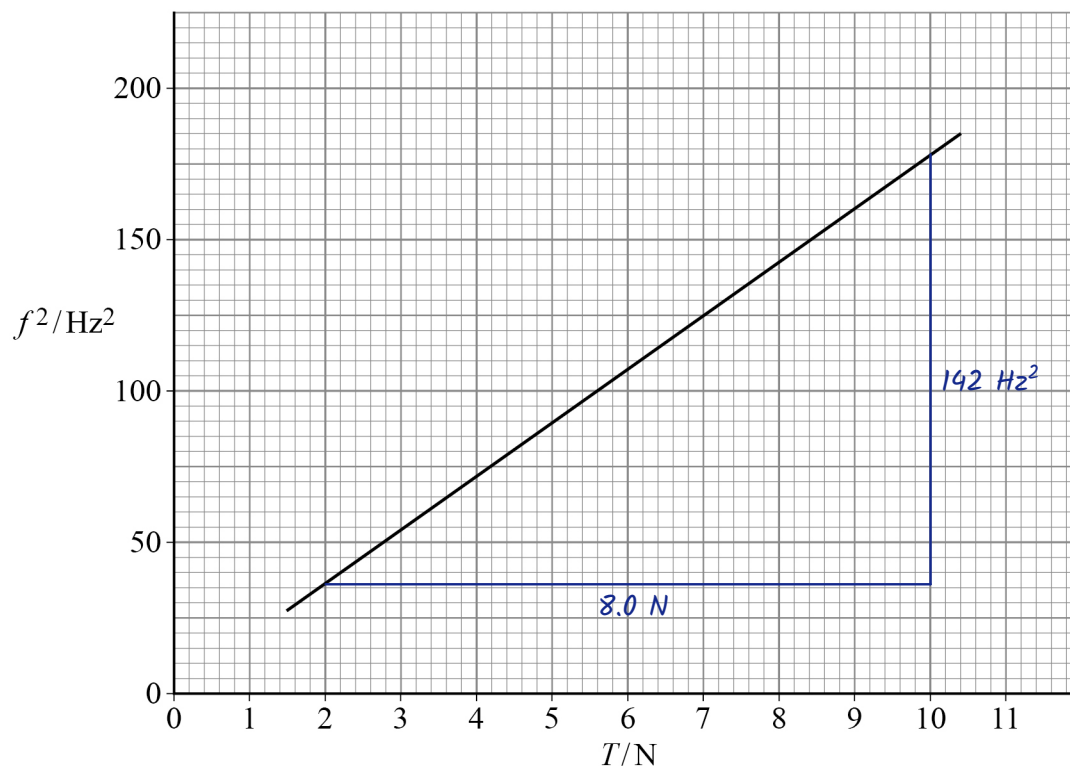
squaring: $f^2 = (1 / 4l^2) \times (Tl / m)$

so $f^2 = (1 / 4lm) T$



0 5 . 2 Figure 5 is a graph showing the variation of f^2 with T for this investigation.

Figure 5



Length l is 2.600 m.

Determine, using **Figure 5**, an accurate value for m .

[3 marks]

$$\text{gradient} = (178 - 36) / (10.0 - 2.0) = 142 / 8.0 = 17.75 \text{ Hz}^2 \text{ N}^{-1}$$

$$\text{gradient} = 1 / (4lm), \text{ so } m = 1 / (4 \times \text{gradient})$$

$$m = 1 / (4 \times 2.600 \times 17.75)$$

$$m = 5.42 \times 10^{-3} \text{ kg}$$

$$m = \underline{5.42 \times 10^{-3}} \text{ kg}$$

Question 5 continues on the next page

Turn over ►



0 5 . 3

To measure the length of 2.600 m, a metre ruler or a 5 m tape measure may be used. Both the metre ruler and the tape measure have a 1 mm resolution.

Explain the advantage of using the 5 m tape measure.

[2 marks]

The tape measure gives a smaller uncertainty in the length.

The 2.600 m can be measured in a single reading, whereas the metre ruler must be used three times (moved along), so its ± 1 mm reading uncertainty is added each time it is used.

7



Turn over for the next question

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0 6

Electrons are accelerated from rest through a potential difference V as part of an electron-diffraction experiment.

0 6 . 1

Each electron gains a kinetic energy of 1.5×10^{-15} J.

Calculate V .

[2 marks]

$$W = QV, \text{ so } V = E_k / e$$

$$V = 1.5 \times 10^{-15} / 1.60 \times 10^{-19} = 9375 \text{ V}$$

$$V = \underline{9400} \text{ V}$$

0 6 . 2

Show that the momentum of an electron after acceleration is approximately $5 \times 10^{-23} \text{ kg m s}^{-1}$.

[3 marks]

$$E_k = \frac{1}{2}mv^2, \text{ so } v = \sqrt{2E_k / m}$$

$$v = \sqrt{2 \times 1.5 \times 10^{-15} / 9.11 \times 10^{-31}} = 5.74 \times 10^7 \text{ m s}^{-1}$$

$$p = mv = 9.11 \times 10^{-31} \times 5.74 \times 10^7$$

$$p = 5.2 \times 10^{-23} \text{ kg m s}^{-1} \approx 5 \times 10^{-23} \text{ kg m s}^{-1}$$



0 6 . 3

The electrons are then incident on a graphite crystal. The crystal diffracts the electrons, creating a second-order maximum at an angle of 10° to the zero-order maximum.

The crystal can be modelled as a diffraction grating where the gap between each layer in the crystal behaves like the slit spacing of the grating.

Calculate the effective slit spacing of this diffraction grating.

[4 marks]

de Broglie wavelength: $\lambda = h / p$

$$\lambda = 6.63 \times 10^{-34} / 5.23 \times 10^{-23} = 1.27 \times 10^{-11} \text{ m}$$

$$n\lambda = d \sin \theta, \text{ with } n = 2 \text{ and } \theta = 10^\circ$$

$$d = 2\lambda / \sin 10^\circ = 2 \times 1.27 \times 10^{-11} / \sin 10^\circ$$

$$d = 1.46 \times 10^{-10} \text{ m}$$

slit spacing = 1.5×10^{-10} m

9

Turn over for the next question

Turn over ►



07.1

State what is meant by the threshold frequency of radiation in the photoelectric effect.

[2 marks]

The threshold frequency is the minimum frequency of the incident radiation (photons) needed for a photoelectron to be emitted from the metal surface.

07.2

Monochromatic light with a photon energy of $3.7 \times 10^{-19} \text{ J}$ is incident on a metal surface.

Photoelectrons with a maximum kinetic energy of $5.7 \times 10^{-20} \text{ J}$ are emitted from the surface.

Calculate, in eV, the work function of the metal.

[2 marks]

$$hf = \phi + E_{k(max)}, \text{ so } \phi = hf - E_{k(max)}$$

$$\phi = 3.7 \times 10^{-19} - 5.7 \times 10^{-20} = 3.13 \times 10^{-19} \text{ J}$$

$$\phi = 3.13 \times 10^{-19} / 1.60 \times 10^{-19} = 1.96 \text{ eV}$$

work function = 2.0 eV



0 7 . 3

The total power of the monochromatic light incident on the surface is $1.3 \times 10^{-2} \text{ W}$.

Calculate the maximum number of photoelectrons that can be emitted from the surface per second.

[2 marks]

number of photons per second = total power / energy of one photon

$$N = 1.3 \times 10^{-2} / 3.7 \times 10^{-19}$$

$$N = 3.5 \times 10^{16} \text{ s}^{-1} \text{ (one photon releases at most one electron)}$$

$$\text{maximum number per second} = 3.5 \times 10^{16} \text{ s}^{-1}$$

0 7 . 4

The light is replaced with a different monochromatic light with half the wavelength but the same incident power.

Describe and explain any effect on the photoelectrons.

[3 marks]

*The photoelectrons are emitted with a higher maximum kinetic energy
(higher maximum speed),*

*because halving the wavelength doubles the frequency, so each photon
has double the energy ($E = hc/\lambda$), and $E_{k(\max)} = hf - \phi$ increases.*

Half as many photoelectrons are emitted per second,

*because the power is the same but each photon carries twice the
energy, so half the number of photons are incident on the surface per
second.*

9

Turn over ►



0 8 . 1

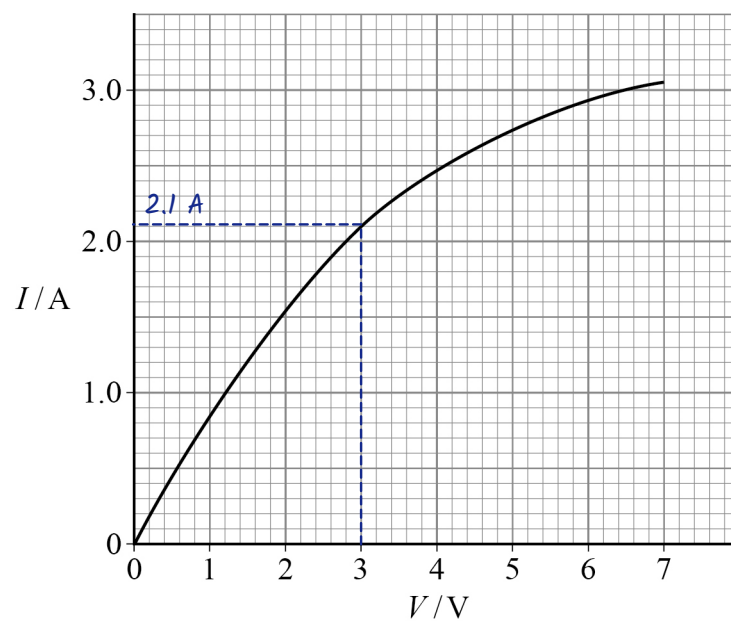
Define electrical resistance.

[1 mark]

Resistance is the ratio of the potential difference across a component to the current through it: $R = V / I$.

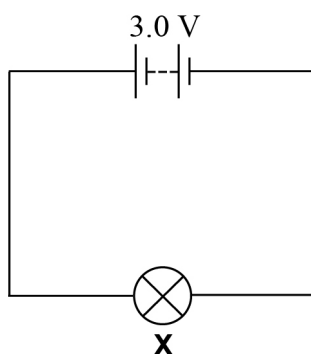
Figure 6 shows the I - V characteristic of a filament lamp **X**.

Figure 6



0 8 . 2

Figure 7 shows a battery of emf 3.0 V and negligible internal resistance connected to **X**.

Figure 7

Calculate the resistance of **X** in the circuit shown in **Figure 7**.

[2 marks]

from Figure 6, at $V = 3.0 \text{ V}$: $I = 2.1 \text{ A}$

$$R = V / I = 3.0 / 2.1$$

$$R = 1.43 \, \Omega$$

resistance = 1.43 Ω

0 8 . 3

Calculate the power dissipated by **X** in this circuit.
State the unit for your answer in fundamental (base) units.

[3 marks]

$$P = IV = 2.1 \times 3.0$$

$$P = 6.3 \text{ W}$$

$$\text{W} = \text{J s}^{-1} = \text{N m s}^{-1} = (\text{kg m s}^{-2}) \times \text{m s}^{-1} = \text{kg m}^2 \text{ s}^{-3}$$

power = 6.3 W unit = $\text{kg m}^2 \text{ s}^{-3}$

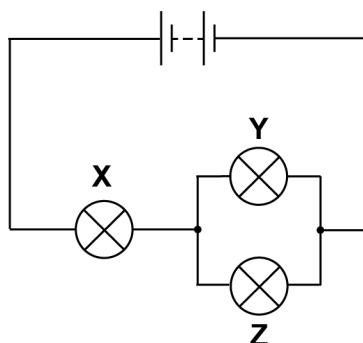
Question 8 continues on the next page

Turn over ►



0 8 . 4

Figure 8 shows **X** connected to two other lamps, **Y** and **Z**. All three lamps have identical I - V characteristics.

Figure 8

Explain for this circuit how the resistance of **Y** compares with the resistance of **X**. Calculations are **not** required.

[3 marks]

The current through X splits between Y and Z, so the current through Y is less than the current through X, and the pd across Y is less than the pd across X.

At lower current and pd the filament is at a lower temperature, so there are fewer collisions between the electrons and the metal ions: the ratio V/I is smaller.

Therefore Y has a lower resistance than X.

9

END OF SECTION A

Turn over for the next question

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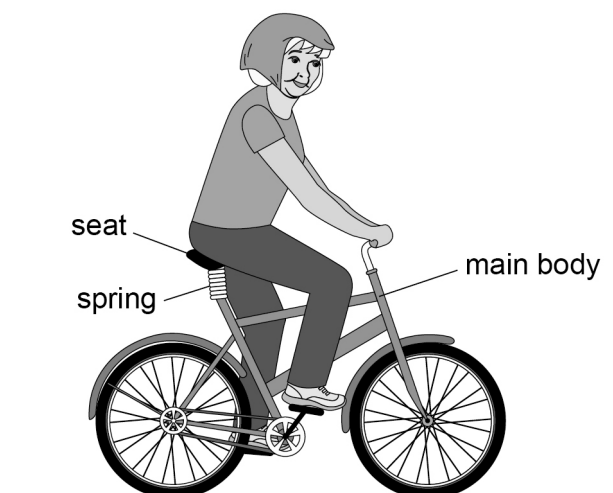
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ANSWER IN THE SPACES PROVIDED**

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Section BAnswer **all** questions in this section.**0 9**

The seat of a bicycle is attached to the main body of the bicycle by a single vertical spring, as shown in **Figure 9**.

Figure 9

The spring has a spring constant of $7.2 \times 10^4 \text{ N m}^{-1}$. The mass of the rider is 68 kg. Assume that the weight of the rider is fully supported by the spring and that the mass of the seat is negligible.

0 9 . 1

Show that the time period for free oscillations of the seat is approximately 0.2 s when the rider is sitting on it.

[2 marks]

$$T = 2\pi \sqrt{m / k}$$

$$T = 2\pi \sqrt{68 / 7.2 \times 10^4}$$

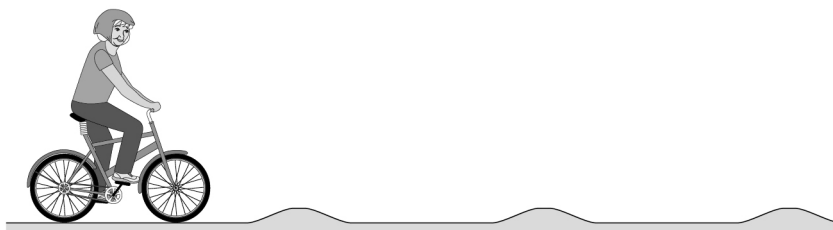
$$T = 0.193 \text{ s} \approx 0.19 \text{ s, which is approximately } 0.2 \text{ s}$$



0 9 . 2

Figure 10 shows the bicycle and rider approaching a series of speed bumps that are equally spaced.

Figure 10



When the bicycle travels over the speed bumps at a certain speed, the rider experiences large-amplitude vertical oscillations.

Identify and explain the effect that causes the large-amplitude oscillations.

[3 marks]

The effect is resonance.

The equally spaced speed bumps give the seat and rider a periodic driving force as the bicycle passes over them.

At this speed the driving frequency matches the natural frequency of the seat and spring (time between bumps = natural time period), so energy is transferred most efficiently and the amplitude is a maximum.

0 9 . 3

The rider experiences large-amplitude oscillations when the bicycle travels at 5.8 m s^{-1} .

Calculate the distance between adjacent speed bumps.

[2 marks]

time between bumps = natural time period = 0.193 s

distance = speed $\times$ time = 5.8×0.193

distance = 1.12 m

distance = 1.1 m

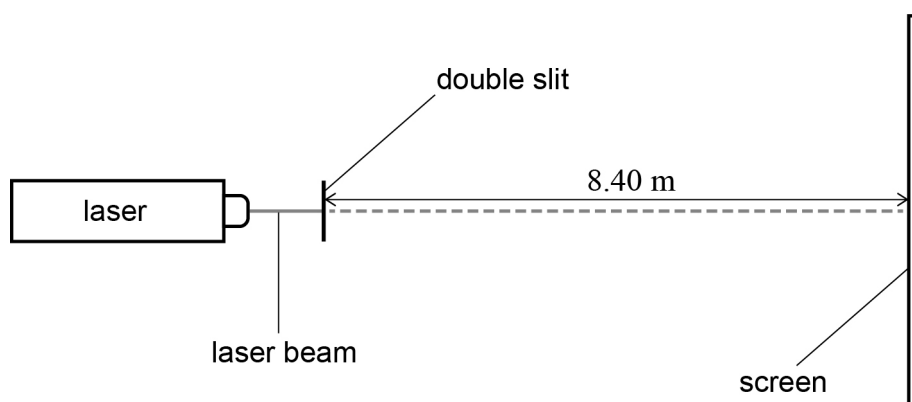
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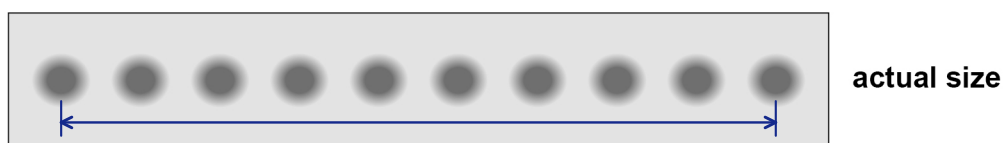
1 0

Figure 11 shows apparatus used to determine the wavelength of laser light using Young's double-slit method.

Figure 11

1 0 . 1

Figure 12 shows the actual size of part of the interference fringe pattern seen on the screen.

Figure 12

Determine, in mm, an accurate measurement for the fringe spacing w .

[2 marks]

*measure across 10 bright fringes (9 fringe spacings) with a ruler,
from the centre of the first fringe to the centre of the last:*

$$9w = 95 \text{ mm}$$

$$w = 95 / 9 = 10.6 \text{ mm}$$

$$w = \underline{10.6} \text{ mm}$$



1 0 . 2 Calculate the percentage uncertainty in your value for w .

[2 marks]

uncertainty in the ruler reading = ± 1 mm in 95 mm

% uncertainty = $(1 / 95) \times 100 = 1.05$ %

percentage uncertainty = 1.1 %

1 0 . 3 The distance between the slits is 0.420 mm with an uncertainty of ± 1.2 %.
The distance from the slits to the screen is 8.40 m with an uncertainty of ± 0.6 %.

Calculate, in nm, the wavelength of the laser light.

[2 marks]

$w = \lambda D / s$, so $\lambda = ws / D$

$\lambda = 10.6 \times 10^{-3} \times 0.420 \times 10^{-3} / 8.40$

$\lambda = 5.30 \times 10^{-7} \text{ m} = 530 \text{ nm}$

wavelength = 530 nm

1 0 . 4 Calculate the absolute uncertainty in your value for the wavelength.

[3 marks]

total % uncertainty = 1.1 % + 1.2 % + 0.6 % = 2.9 %

absolute uncertainty = $0.029 \times 530 \text{ nm} = 15.4 \text{ nm}$

absolute uncertainty = 15 nm

END OF SECTION B

Turn over ►



Section C

Each of the questions in this section is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown. 

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown. 

You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

1 1

A cell has an emf of 1.5 V and an internal resistance of 2.0 Ω .

A wire of negligible resistance is connected directly from one terminal of the cell to the other.

What is the energy dissipated in the cell in 5 minutes?

[1 mark]

A 5.6 J

☐

B 340 J

☒

C 900 J

☐

D 1400 J

☐


1 2

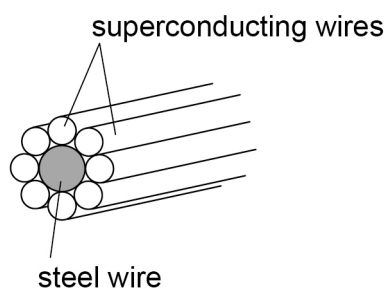
A metal wire has resistance R .

A second wire made from the same metal is 50% longer but has the same volume as the first wire.

What is the resistance of the second metal wire?

[1 mark]**A** $0.67R$ ☐**B** $1.5R$ ☐**C** $2.0R$ ☐**D** $2.3R$ ☒**1 3**

A cable consists of superconducting wires attached in parallel to a steel wire.



What is the purpose of the steel wire in the cable?

[1 mark]**A** to increase the critical temperature of the superconductor☐**B** to increase the strength of the cable☒**C** to reduce the resistance of the cable when it is superconducting☐**D** to reduce the current in the cable☐**Turn over ►**

1 4

Two resistors **X** and **Y** have resistances R_X and R_Y .
 R_Y is greater than R_X .

When **X** and **Y** are combined in parallel, the equivalent resistance is R_T .

Which is correct?

[1 mark]

A $R_T < R_X < R_Y$

☒

B $R_X < R_T < R_Y$

☐

C $R_X < R_Y < R_T$

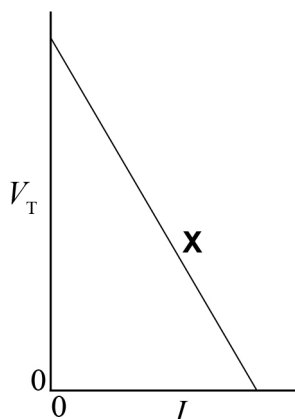
☐

D $R_T < R_Y < R_X$

☐

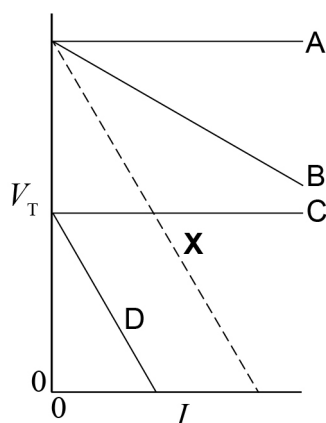
1 5

A battery **X** has emf ε and internal resistance r . The graph shows the variation of terminal pd V_T with current I for the battery.



The line for battery **X** is shown again below as a dashed line.

Which line shows the variation of V_T with I for a battery of emf $\frac{\varepsilon}{2}$ and negligible internal resistance?

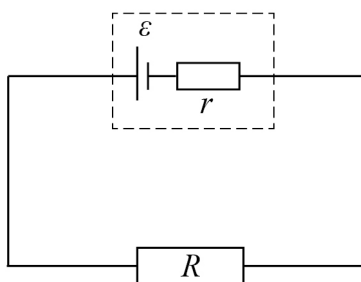
[1 mark]

- A** ☐
- B** ☐
- C** ☒
- D** ☐

Turn over ►

1 6

A resistor of resistance R is connected to a cell of emf ε and internal resistance r .
The current in the circuit is I .



What is the power dissipated in the resistor of resistance R ?

[1 mark]**A** $I\varepsilon$
☐
B $I^2(R + r)$
☐
C $\frac{\varepsilon^2}{R + r}$
☐
D $\frac{\varepsilon^2 R}{(R + r)^2}$
☒
1 7

Two pendulums have the same length and perform undamped small-angle oscillations with the same amplitude.

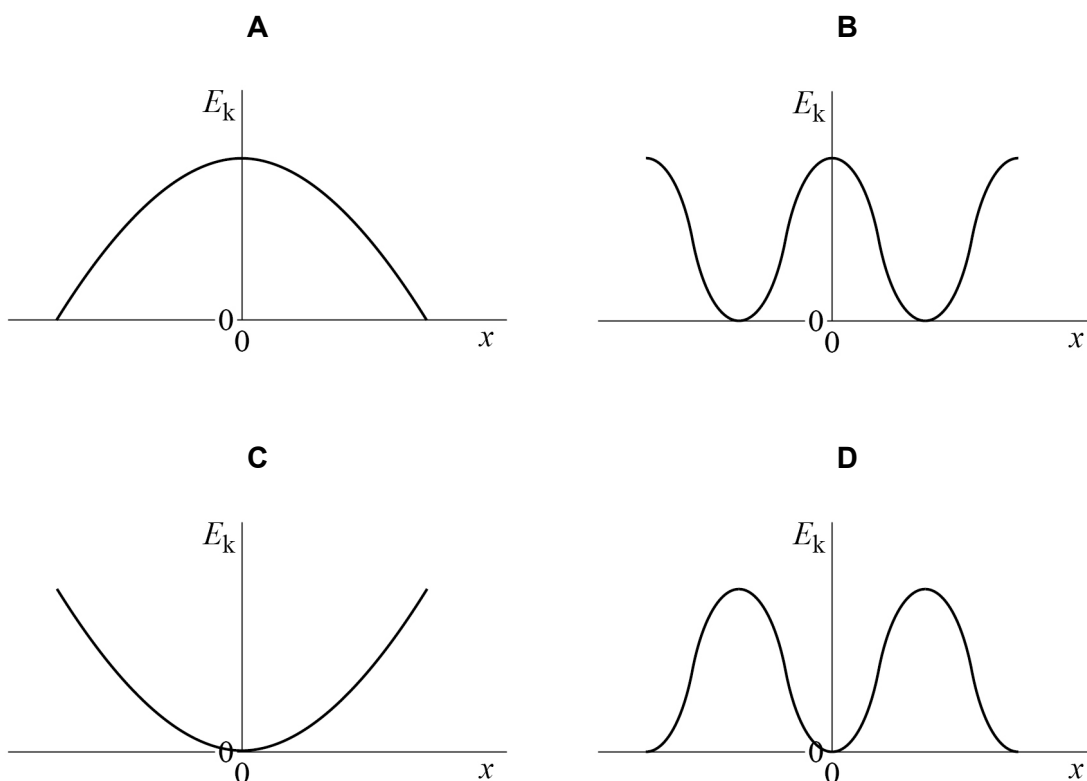
One pendulum bob has a greater mass than the other.

Which quantity is **not** the same for both pendulums?

[1 mark]**A** average speed
☐
B time period
☐
C total energy
☒
D maximum speed
☐


1 8

Which graph shows the variation of kinetic energy E_k with displacement x for a mass–spring system performing simple harmonic motion?

[1 mark]

A ☒

B ☐

C ☐

D ☐

1 9

What **cannot** be observed with sound waves?

[1 mark]

A diffraction ☐

B dispersion ☐

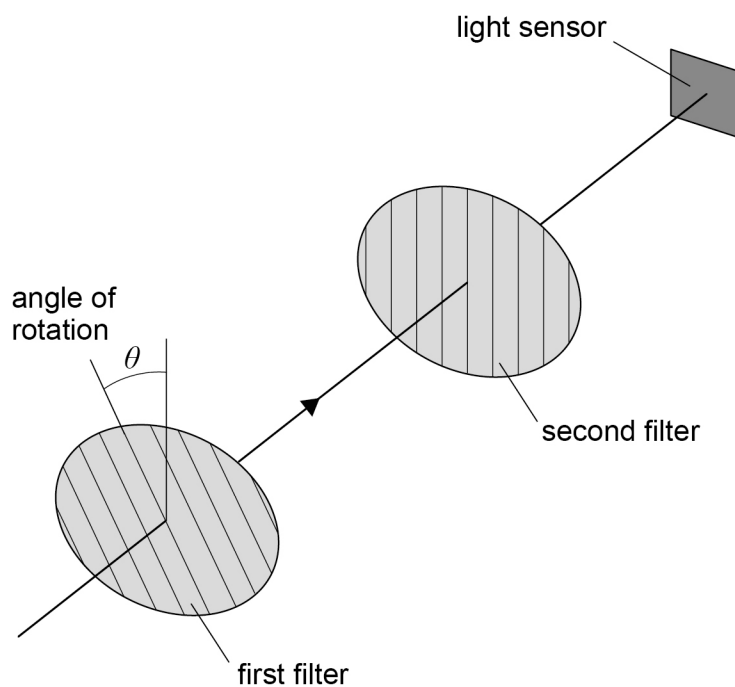
C polarisation ☒

D refraction ☐

Turn over ►

2 0

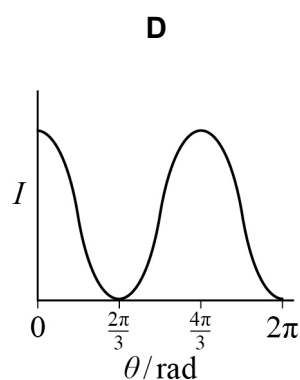
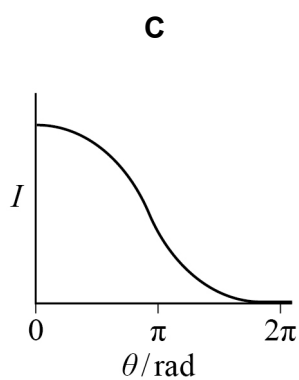
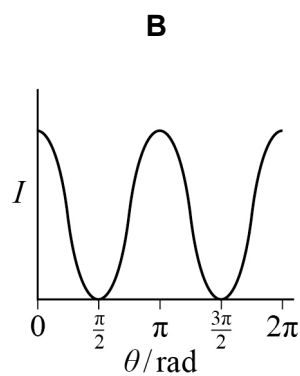
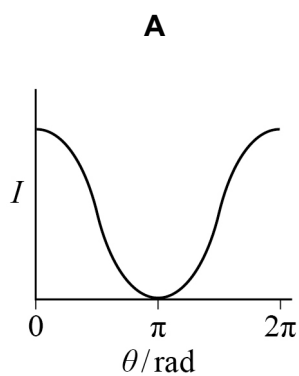
Unpolarised light passes perpendicularly through two polarising filters before reaching a sensor that detects its intensity I .



The first filter is rotated through an angle θ about an axis parallel to the light beam.

Which graph on page 29 shows the variation of intensity I with angle θ ?

[1 mark]

**A****B****C****D**

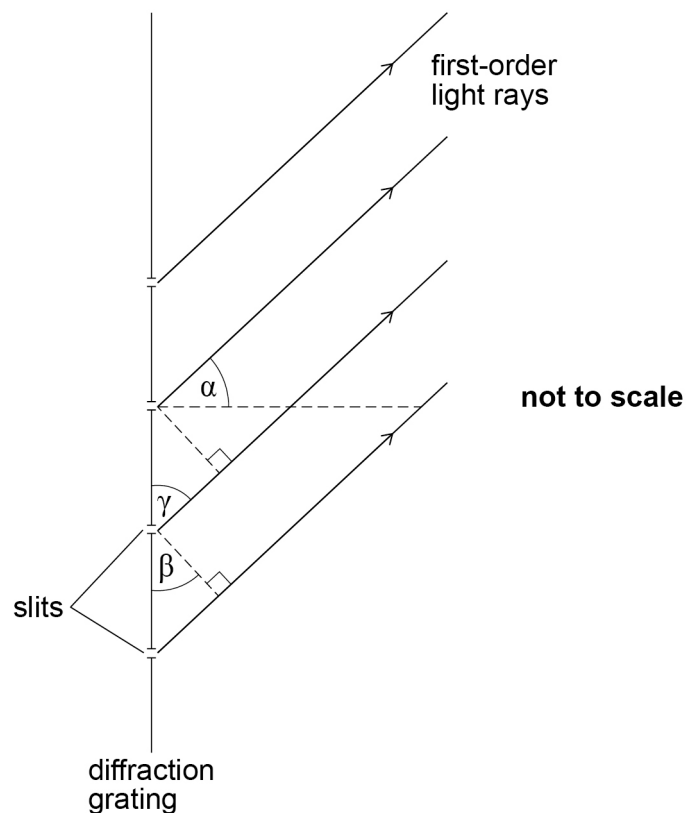
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2 1

In the derivation of the diffraction grating equation $n\lambda = d \sin \theta$, a diagram similar to the one below can be used.



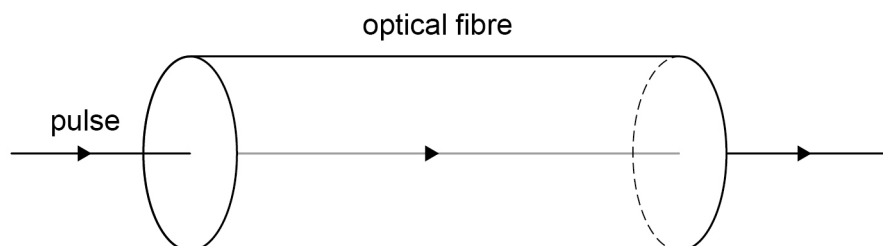
Which of the labelled angles α , β or γ is equivalent to the angle θ in the equation?

[1 mark]

A α only
☐
B α and β only
☒
C γ only
☐
D β and γ only
☐


2 2

A pulse of white light passes along the axis of a straight optical fibre. The pulse is broader when it leaves the optical fibre.



What causes this effect?

[1 mark]

A absorption

☐

B attenuation

☐

C material dispersion

☒

D modal dispersion

☐
2 3

Light crosses the boundary from air into a substance that has a refractive index of 2

What happens to the speed, frequency and wavelength of the light as it crosses the boundary?

[1 mark]

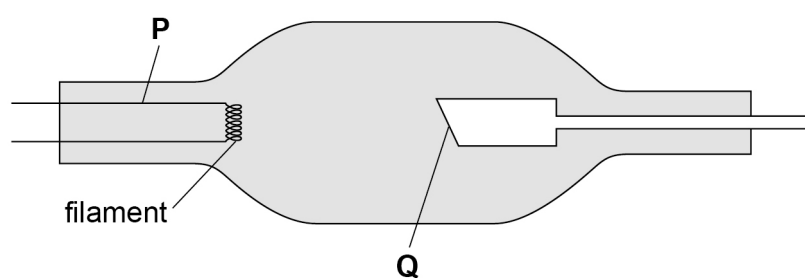
	Speed	Frequency	Wavelength	
A	halves	stays the same	halves	☒
B	doubles	stays the same	doubles	☐
C	doubles	doubles	stays the same	☐
D	halves	halves	doubles	☐

Turn over ►



2 4

The diagram shows an X-ray tube.

Which row identifies parts **P** and **Q**, and the direction of travel of the electrons?**[1 mark]**

	P	Q	Direction of electron travel	
A	anode	cathode	from P to Q	☐
B	anode	cathode	from Q to P	☐
C	cathode	anode	from P to Q	☒
D	cathode	anode	from Q to P	☐

14**END OF QUESTIONS**

There are no questions printed on this page

**DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED**



[illegible]

[illegible]



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