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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.

A-level PHYSICS

Paper 3

Section B Turning points in physics

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 35.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

Time allowed: The total time for both sections of this paper is 2 hours. You are advised to spend approximately 50 minutes on this section.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
TOTAL	



Section B

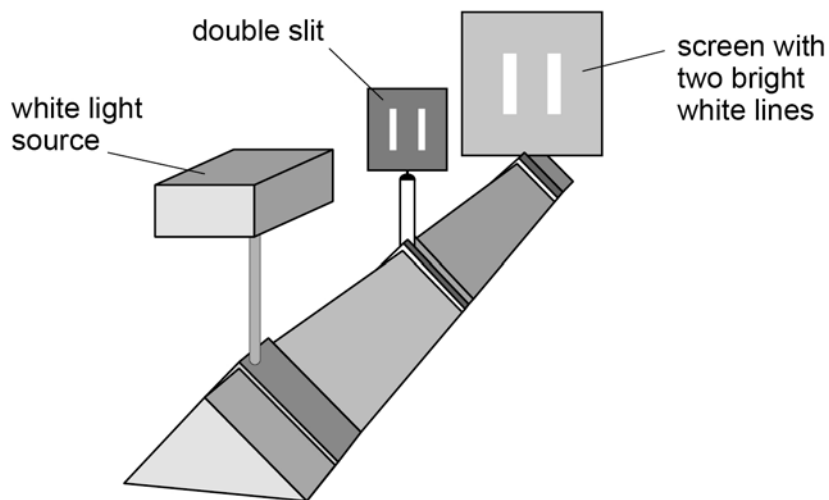
Answer **all** questions in this section.

0 1

In the 17th century, Isaac Newton proposed a theory to explain some of the properties of light. An alternative theory of light was proposed by Christiaan Huygens at about the same time.

A student uses the arrangement in **Figure 1** to investigate the two theories.

Figure 1



0 1 . 1

The student observes two bright white lines on the screen.

Explain how this observation supports Newton's theory of light.

[2 marks]

Newton's corpuscular theory says light consists of particles (corpuscles) that travel in straight lines.

So the light passes straight through the two slits and forms sharp shadows with sharp edges; only two distinct bright lines are seen on the screen, with no diffraction or spreading.

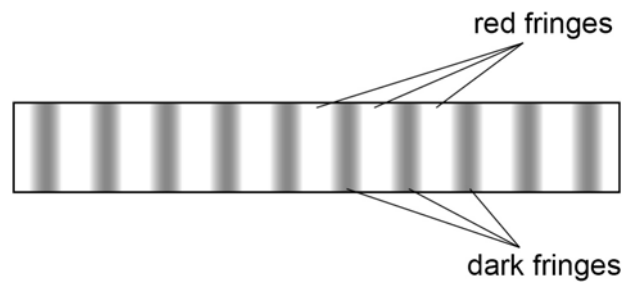


0 1 2

The student makes alterations to the apparatus in **Figure 1**.

Figure 2 shows the red and dark fringes that the student now observes on the screen.

Figure 2



Identify the alterations made by the student and explain how the observations in **Figure 2** support Huygens' theory of light.

In your answer you should:

- identify alterations made to the apparatus in **Figure 1**
- outline the key features of Huygens' theory
- explain how the result of this experiment supports Huygens' theory.

[6 marks]

Alterations: the student replaced the white light source with a monochromatic (red) light source, e.g. a red filter or a laser, and placed a single slit in front of the double slit so that the light reaching the double slit is coherent (a laser is already coherent and monochromatic).

The slits were also made narrower and moved closer together, so that the slit width and slit separation are comparable to the wavelength of the light, and the screen is far from the slits.

Huygens' theory: light is a wave. Every point on a wavefront acts as a source of secondary wavelets, and the new wavefront is the envelope (tangent) of these secondary wavelets.

Explanation: when the wavefront reaches the slits, each point in each slit produces secondary wavelets, so the light spreads out (diffracts) from each slit and the wavelets from the two slits overlap on the screen.

Answer space for this question continues on the next page

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For a point on the screen there is a path difference between the distances from the two slits, and this path difference introduces a phase difference between the waves arriving there.

Bright (red) fringes form where the path difference is a whole number of wavelengths, so the waves arrive in phase and superpose constructively.

Dark fringes form where the path difference is an odd number of half wavelengths, so the waves arrive in antiphase and cancel.

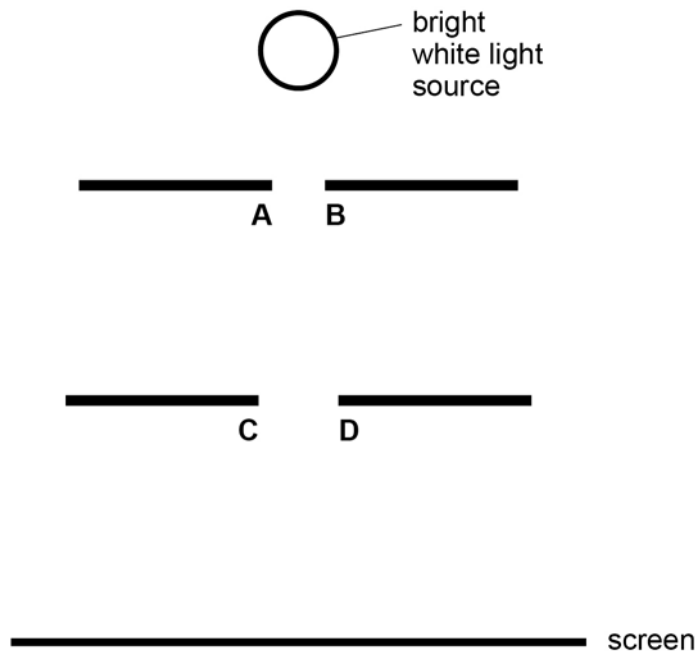
This gives the pattern of equally spaced red and dark fringes in Figure 2. Newton's corpuscular theory cannot explain the dark fringes (adding more corpuscles cannot produce darkness), so the observation supports Huygens' wave theory.



0 1 3

Shortly before the work of Newton and Huygens, Francesco Grimaldi carried out an experiment into the behaviour of light. **Figure 3** shows Grimaldi's arrangement.

Figure 3



A bright white light source is used to illuminate a small circular aperture, **AB**. The light from this aperture illuminates a second, slightly larger circular aperture, **CD**.

The light passing through both apertures arrives at a screen.

Newton's theory and Huygens' theory make different predictions about the appearance of the light on the screen.

Discuss these differences in appearance.

[3 marks]

Most of the screen is dark in both cases.

Newton's theory predicts a bright central spot (a sharp image of the aperture) surrounded by a region of partial shadow, with no fringes, because the corpuscles travel in straight lines.

Huygens' theory predicts that the light diffracts at the apertures, so there is a bright region with fringes around its edge, and with white light the edge of the bright region (the fringes) is coloured, since different colours have different wavelengths.

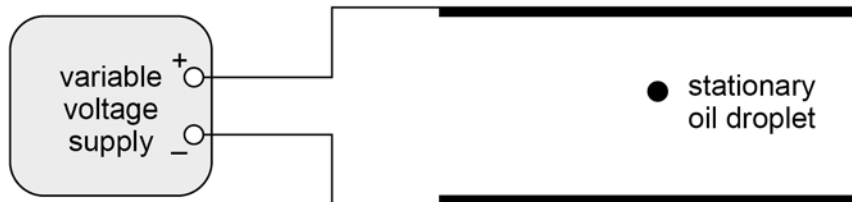


0 2

Robert Millikan experimented with oil drops to determine a value for the electronic charge.

Figure 4 shows a stationary oil droplet between two horizontal metal plates. The plates are connected to a variable voltage supply so that the upper plate is positive. The oil droplet has mass m and charge Q .

Figure 4



0 2 . 1

State and explain the sign of the charge on the oil droplet.

[1 mark]

The electric force must be upwards, opposite to the weight. The field is downwards (top plate positive), and the drop is attracted towards the positive plate, so Q is negative.

The variable voltage supply is set to zero volts. The oil drop falls. The constant speed v_1 of the falling oil droplet is found to be $3.8 \times 10^{-5} \text{ m s}^{-1}$ and the following measurements are recorded:

density of oil = 910 kg m^{-3}
viscosity of air = $1.8 \times 10^{-5} \text{ N s m}^{-2}$

0 2 . 2

Show that the mass m of the oil droplet is about $8 \times 10^{-16} \text{ kg}$.

[3 marks]

At terminal speed: weight = viscous drag, $mg = 6\pi\eta rv_1$

$m = \text{volume} \times \text{density} = \frac{4}{3}\pi r^3 \rho$, so $\frac{4}{3}\pi r^3 \rho g = 6\pi\eta rv_1$

$r^2 = 9\eta v_1 / (2\rho g) = (9 \times 1.8 \times 10^{-5} \times 3.8 \times 10^{-5}) / (2 \times 910 \times 9.81)$

$r^2 = 3.45 \times 10^{-13} \text{ m}^2$, $r = 5.9 \times 10^{-7} \text{ m}$

$m = \frac{4}{3}\pi (5.87 \times 10^{-7})^3 \times 910$

$m = 7.7 \times 10^{-16} \text{ kg}$ ($\approx 8 \times 10^{-16} \text{ kg}$)



0 2 . 3

The variable voltage supply is adjusted so that the oil droplet rises at a constant speed v_2 . The potential difference (pd) across the plates is V and the distance between the plates is d .

In his experiment, Millikan measured the constant speed v_1 of a falling droplet when the pd was zero. He compared this with the speed v_2 of the same droplet when the droplet was made to rise.

Show that
$$\frac{v_2}{v_1} = \frac{VQ}{dmg} - 1$$

[2 marks]

Rising at constant speed: electric force = weight + drag

$$VQ / d = mg + 6\pi\eta rv_2, \text{ so } VQ / d - mg = 6\pi\eta rv_2$$

Falling ($V = 0$): $mg = 6\pi\eta rv_1$. Divide: $v_2 / v_1 = (VQ / d - mg) / mg$

$$\text{so } v_2 / v_1 = VQ / (dmg) - 1$$

0 2 . 4

The following measurements are made for the droplet in Question 02.2 when it is rising at constant speed.

$$V = 715 \text{ V}$$

$$v_2 = 1.1 \times 10^{-4} \text{ m s}^{-1}$$

The separation of the plates $d = 11.6 \text{ mm}$.

Deduce, using the equation in Question 02.3, whether the value of the charge for this droplet is consistent with the currently accepted value of the electronic charge.

[3 marks]

$$Q = (v_2 / v_1 + 1) \times dmg / V$$

$$v_2 / v_1 = 1.1 \times 10^{-4} / 3.8 \times 10^{-5} = 2.89$$

$$Q = (2.89 + 1) \times (11.6 \times 10^{-3} \times 7.7 \times 10^{-16} \times 9.81) / 715$$

$$Q = 4.8 \times 10^{-19} \text{ C}$$

$$Q / e = 4.8 \times 10^{-19} / 1.6 \times 10^{-19} = 3.0$$

Q is a whole-number multiple of e ($3e$), so it is consistent with the accepted value of the electronic charge.

Question 2 continues on the next page

Turn over ►



0 2 . 5

After Millikan published his results, it was found that he had used a value for the viscosity of air that was smaller than the actual value.

Discuss the effect this error had on Millikan's value of the electronic charge.

[3 marks]

The value of the viscosity is used to calculate the radius and so the mass of the droplet (from $mg = 6\pi\eta rv_1$ with $m = \frac{4}{3}\pi r^3\rho$).

A smaller value of viscosity gives a smaller viscous force on the droplet, so a smaller calculated radius, weight and mass ($r \propto \sqrt{\eta}$).

From $Q = (v_2 / v_1 + 1) dm g / V$ (or weight = EQ for a stationary drop), $Q \propto m$, so as the mass is smaller Q is smaller: Millikan's value of e was too small.

12



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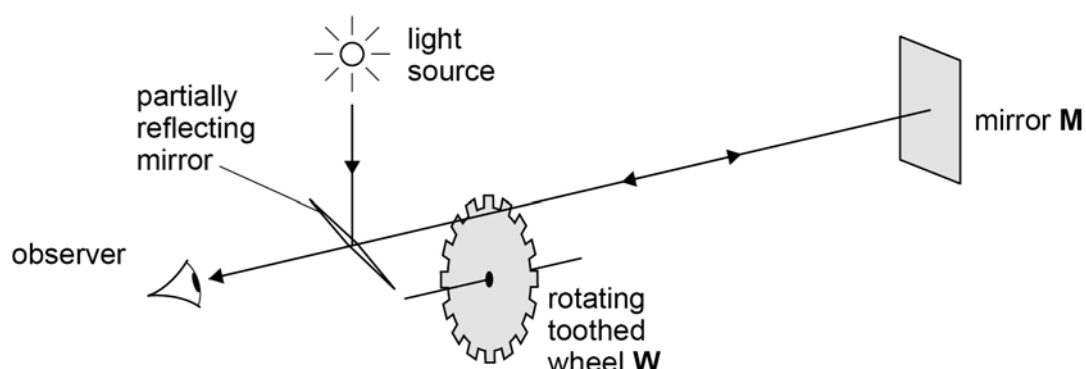
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0 3

Figure 5 shows the arrangement used by Fizeau to determine the speed of light.

Figure 5



The toothed wheel **W** is rotated and the reflected light from a distant mirror **M** is observed.

The speed of light is calculated from the equation

$$c = 4dnf_0$$

where d is the distance from **W** to **M** and
 n is the number of teeth on the rotating wheel **W**.

0 3 . 1

State what f_0 represents in the equation.

[2 marks]

f_0 is the (lowest) frequency of rotation of the wheel **W** at which no reflected light is seen by the observer.

It is the lowest such frequency: light passing through a gap returns to find the next tooth blocking it.



0 3 . 2

The experiment is attempted using a rotating wheel with 720 teeth that can be rotated at up to 620 revolutions per minute.

The distance between **W** and **M** is 8.5 km.

Deduce whether the speed of light can be determined with this particular arrangement.

[2 marks]

$$\text{Maximum frequency} = 620 / 60 = 10.3 \text{ rev s}^{-1} \text{ (Hz)}$$

$$\text{Largest } c \text{ measurable} = 4dnf = 4 \times 8500 \times 720 \times 10.3$$

$$= 2.5 \times 10^8 \text{ m s}^{-1}$$

$$\text{OR } f_0 \text{ needed} = c / 4dn = 3.0 \times 10^8 / (4 \times 8500 \times 720)$$

$$= 12.3 \text{ Hz} = 735 \text{ rev min}^{-1}$$

No: the largest speed it can measure is less than the speed of light (it needs $f_0 >$ the maximum frequency).

0 3 . 3

The determination of the speed of light took on extra significance when Maxwell derived the wave-speed equation

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

State how ϵ_0 and μ_0 are related to the types of field in the wave.

[2 marks]

ϵ_0 related to the electric field strength (due to a charged object) in free space (a vacuum): the permittivity of free space.

μ_0 related to the magnetic flux density (due to a current-carrying wire) in free space: the permeability of free space.

Turn over ►



0 4 . 1

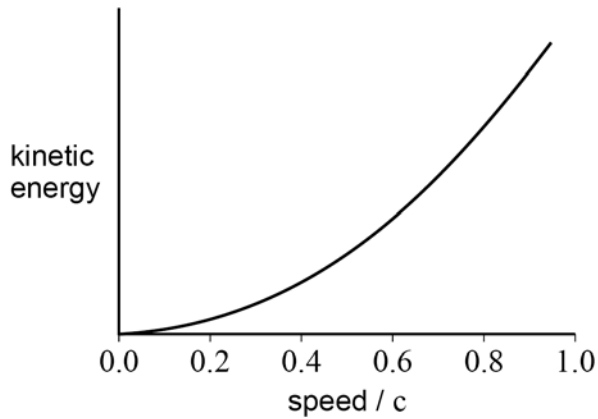
Bertozzi investigated how the kinetic energy of electrons varies with speed.

Which graph shows the variation of kinetic energy with speed?

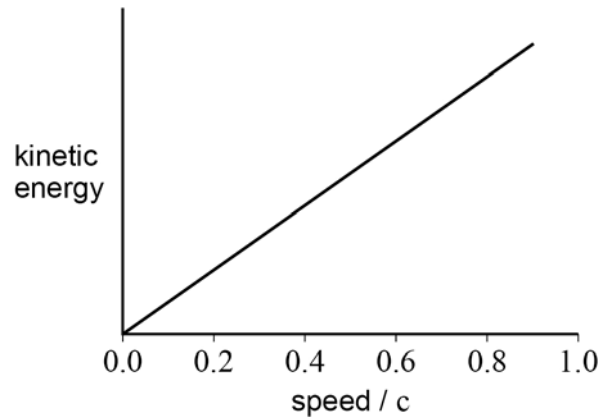
Tick (✓) **one** box.

[1 mark]

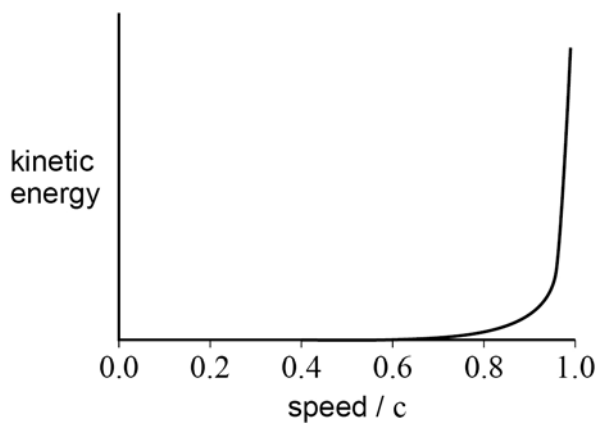
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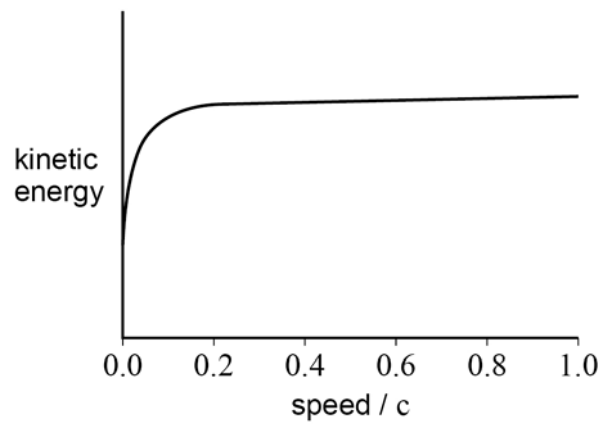
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C



D



A

☐

B

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C

☒

D

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0 4 . 2

Calculate the speed of a particle when its kinetic energy is equal to its rest energy.

[3 marks]*KE = total energy - rest energy, and KE = rest energy*

so $m_0 c^2 / \sqrt{1 - v^2/c^2} - m_0 c^2 = m_0 c^2$

$1 / \sqrt{1 - v^2/c^2} = 2, \quad 1 - v^2/c^2 = 0.25$

$v = \sqrt{0.75} c = 0.866c = 0.866 \times 3.00 \times 10^8$

$v = 2.6 \times 10^8 \text{ m s}^{-1}$

speed = 2.6 × 10⁸ m s⁻¹

0 4 . 3

Discuss the change in the observed mass of a spring when it is stretched.

[2 marks]*Mass and energy are equivalent, related by $E = mc^2$ ($\Delta E = \Delta mc^2$).**When the spring is stretched, work is done on it and it gains (stores)**elastic potential energy, so its observed mass increases, by $\Delta m = \Delta E/c^2$* *(a very small increase).***END OF QUESTIONS**

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