Please write clearly in block capitals.

Centre number ☐☐☐☐☐ Candidate number ☐☐☐☐

Surname __________

Forename(s) __________

Candidate signature __________

A-level
PHYSICS

Paper 3
Section B Turning points in physics

Thursday 29 June 2017 Morning

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.

Materials

For this paper you must have:

- a pencil and a ruler
- a scientific calculator
- a Data and Formulae booklet.

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.
- 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.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
TOTAL	

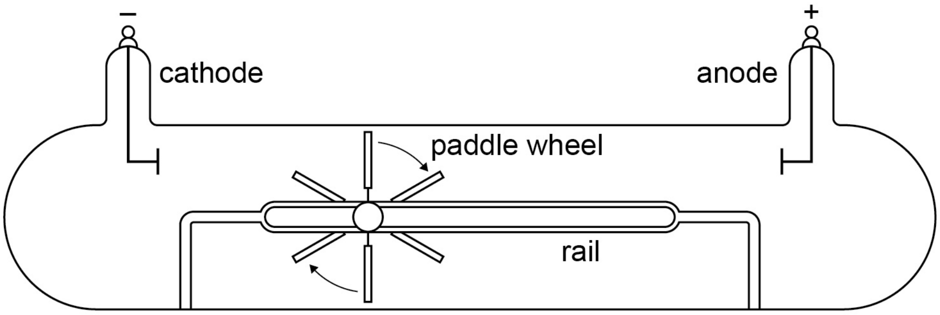
Section B

Answer **all** questions in this section.

0 1 **Figure 1** shows a gas discharge tube devised by William Crookes in one of his investigations.

When a large potential difference is applied between the cathode and anode the paddle wheel is seen to rotate and travel along the rail towards the anode.

Figure 1



0 1 . 1 Explain how this experiment led Crookes to conclude that cathode rays are particles and that these particles caused the movement of the paddle.

[2 marks]

- Electrons move from the cathode to the anode ✓
- The paddle wheel gains energy from the electrons ✓

0 1 . 2 Later experiments showed that cathode rays are electrons in motion.

Explain how cathode rays are produced in a gas discharge tube.

[3 marks]

- Gas atoms are ionised (they lose electrons) ✓
- Electrons are emitted from the cathode ✓
- Electrons are accelerated toward the anode ✓

0 1 . 3 In a particular gas discharge tube, air molecules inside the tube are absorbed by the walls of the tube.

Suggest the effect that this absorption may have on the motion of the paddle wheel.

Give a reason for your answer.

[2 marks]

Rotates More	Rotates Less
· The electrons move through with a higher kinetic energy ✓ · The paddle wheel rotates more ✓	· Fewer electrons collide with the paddle wheel ✓ · The paddle wheel rotates less ✓

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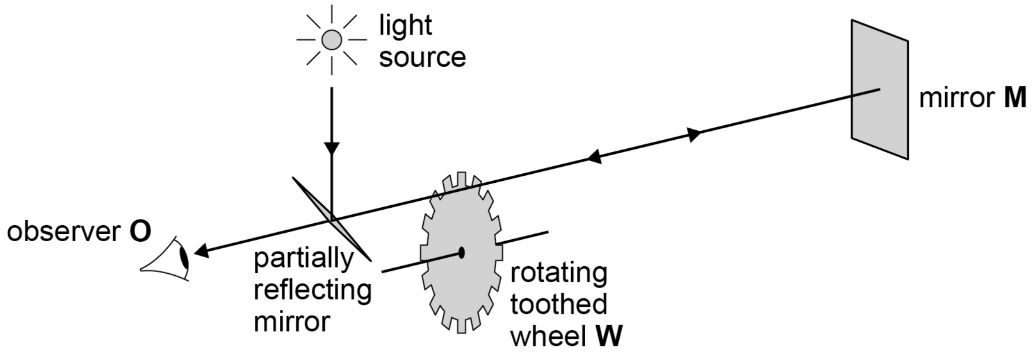
0 2 **Figure 2** shows the apparatus Fizeau used to determine the speed of light.

Figure 2



The following observations are made.

A When the speed of rotation is low the observer sees the light returning after reflection by the mirror **M**.

B When the speed of the wheel is slowly increased the observer continues to see the light until the wheel reaches a certain speed. At this speed the observer cannot see the light.

0 2 . 1 Explain these observations.

[2 marks]

Observation A

The wheel does not rotate quickly enough for a tooth to be in the way when light returns after rebounding from mirror M ✓

Observation B

Eventually the wheel is spinning fast enough that light passes through on its way out to mirror M, but the reflected light hits an adjacent tooth on the way back ✓

0 2 . 2 **Table 1** shows data from Fizeau's experiment at the instant when observation B is made.

Table 1

d, distance from **M** to **W**	8.6 km
f, number of wheel revolutions per second	12
n, number of teeth in the wheel	720

It can be shown that the speed of light c is given by the equation

$$c = 4dnf$$

Discuss whether the data in **Table 1** are consistent with the present accepted value for the speed of light.

[2 marks]

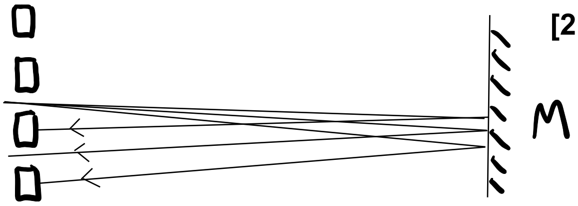
$4 \times 8.6 \times 10^3 \times 12 \times 720 = 2.97 \times 10^8 \text{ms}^{-1}$ ✓

The present value is $3.0 \times 10^8 \text{ms}^{-1}$. Since the value from the data rounds to this, it is consistent. ✓

0 2 . 3 The speed of the wheel is further increased.

Deduce the value of f when the observer would next be unable to see light returning from the mirror.

[2 marks]



- The light must go past a gap and to the next tooth ✓
- The value of f must be $3 \times 12 = 36 \text{s}^{-1}$ ✓

Question 2 continues on the next page

0 2 . 4 Explain how the nature of light is implied by Maxwell's theory of electromagnetic waves and Fizeau's result.

[3 marks]

- A value for the speed of electromagnetic waves was predicted by Maxwell's theory of electromagnetic waves ✓
- The result obtained from Fizeau's experiment is close to the predicted value ✓
- The similarity of this result implies that light is an electromagnetic wave ✓

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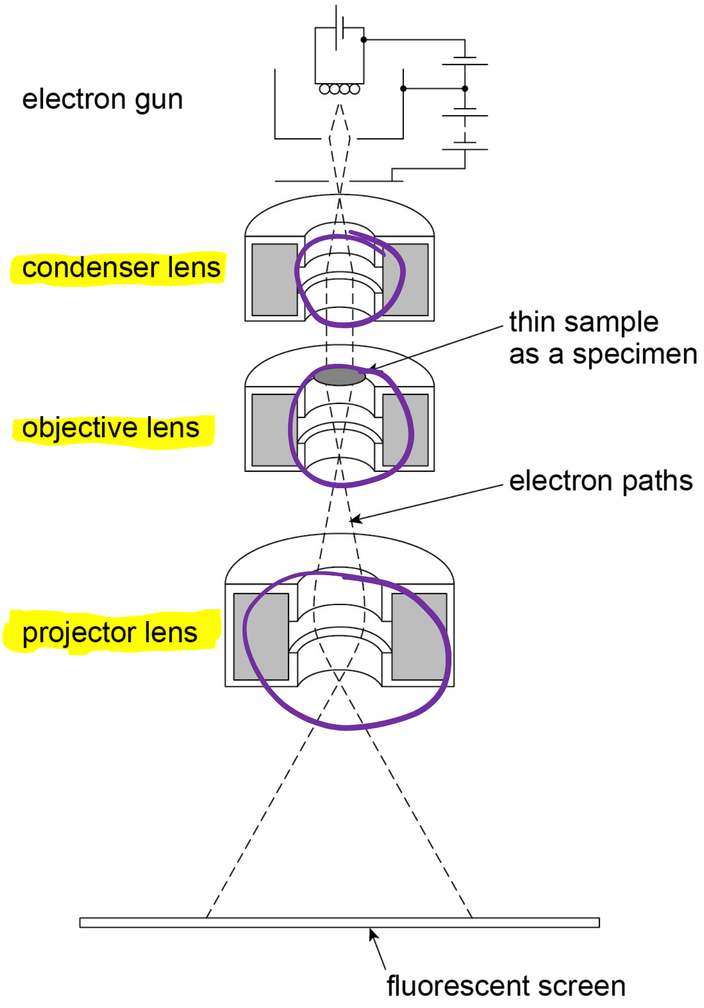
Turn over for the next question

Turn over ►

0 3 **Figure 3** shows the main parts of a transmission electron microscope (TEM).

Figure 3



0 3 . 1 What is the process by which electrons are produced in an electron gun?
Tick (✓) the correct box.

[1 mark]

Beta particle emission ☐

Electron diffraction ☐

Photoelectric effect ☐

Thermionic emission ☑ ✓

↳ Process by which a metal is heated up and delocalised electrons are brought to the surface

0 3 . 2 The electrons in a particular TEM have a kinetic energy of 4.1×10^{-16} J. Relativistic effects are negligible for this electron energy.

Suggest, with a calculation, whether the images of individual atoms can, in principle, be resolved in this TEM.

[3 marks]

Planck constant, 6.626×10^{-34} Js

$$\lambda = \frac{h}{\sqrt{2mE}} = \frac{6.626\times10^{-34}}{\sqrt{2\times9.11\times10^{-31}\times4.1\times10^{-16}}} ✓$$

wavelength of electron

mass of electron, 9.11×10^{-31} kg

kinetic energy of electron

$$= 2.4\times10^{-11}\,\text{m} ✓$$

This wavelength is smaller than the width of an atom, 0.1nm, so images can be resolved. ✓

Question 3 continues on the next page

0 3 . 3 A typical TEM can accelerate electrons to very high speeds and form high resolution images.

Explain:

- the process of image formation, and
- the factors that affect the quality of, and the level of detail in, the image.

[6 marks]

Image Formation

- Electrons moving through the centre of the lens will not change direction (similar to light in a glass lens), but electrons further from the centre line will, due to magnetic fields
- The condenser lens deflects the electrons into a wide parallel beam, ready to pass through the sample
- The objective lens focuses the parallel beam in to form an image
- The projector lens redirects the electrons one more time to cast an image onto the fluorescent screen

Quality and Detail of Image

- Slower electrons have a larger wavelength, and therefore provide less detail
- There will be a range of emitted electron speeds, based on a temperature distribution in the cathode
  - → Electrons of different speeds will be deflected by different amounts in the lenses, causing aberration
- A thicker sample slows the electrons more, increasing their wavelengths and reducing the image detail

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Turn over for the next question

0 4 . 1

A student models a spacecraft journey that takes one year. The spacecraft travels directly away from an observer at a speed of $1.2 \times 10^{7}\ \mathrm{m\ s^{-1}}$. The student predicts that a clock stationary relative to the observer will record a time several days **longer** than an identical clock on the spacecraft.

Comment on the student's prediction. Support your answer with a time dilation calculation.

[4 marks]

One year = 365 x 24 x 3600 = 31,536,000s

dilated time

$$t = \frac{t_0}{\sqrt{1-v^2/c^2}}$$

t_0 — proper time (outside of spacecraft)

c — speed of light

v — speed of spacecraft

$$t = \frac{31,536,000}{\sqrt{1-\frac{(1.2\times10^7)^2}{(3\times10^8)^2}}}$$

$= 31,561,259\mathrm{s}$ ✓

Dilation = 31,561,259 − 31,536,000

= 25,259s ≃ 7 hours ✓

The time observed on the stationary clock will be longer, ✓ but by less than several days. ✓

0 4 . 2

In practice, the gravitational field of the Sun affects the motion of the spacecraft and it does not travel directly away from the Earth throughout the journey.

Explain why this means that the theory of special relativity cannot be applied to the journey.

[2 marks]

The Theory of Special Relativity requires objects moving relative to each other to not be accelerating ✓

If the spacecraft is not always moving directly away from the Earth, it must be accelerating at some points (changing direction) ✓

6

0 5 Cosmic rays detected on a spacecraft are protons with a total energy of 3.7×10^9 eV.

Calculate the velocity of the protons as a fraction of the speed of light.

[3 marks]

$$3.7\times10^{9}\times\underbrace{1.6\times10^{-19}}_{\text{charge on electron in coulombs}} = 5.9\times10^{-10}\,J \quad ✓$$

energy

speed of light

$$E = mc^2$$

relativistic mass

rest mass of proton $= 1.67\times10^{-27}$ kg

$$= \frac{m_0c^2}{\sqrt{1-v^2/c^2}}$$

$$\Rightarrow v = \sqrt{c^2\left(1-\left(\frac{E}{m_0c^2}\right)^2\right)} \quad ✓$$

$$= \sqrt{(3\times10^8)^2\left(1-\left(\frac{3.7\times10^9}{1.67\times10^{-27}\times(3\times10^8)^2}\right)^2\right)} = 2.901\times10^8\,ms^{-1}$$

proton velocity = 0.97 ✓ c

3

END OF QUESTIONS

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