AQA A-LEVEL PHYSICS · 7408

PHYSICS



EXAM QUESTION PACK

3.12.2 WAVE-PARTICLE DUALITY

SCORE	PERCENTAGE
/78	%

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Q1.

Figure 1 shows a modern version of the apparatus used by Hertz to investigate the properties of electromagnetic waves. Electromagnetic waves are continuously emitted from a dipole transmitter. The electromagnetic waves are detected by a dipole receiver.

An oscilloscope is used to display the amplitude of the detected signal at the dipole receiver.

Figure 1

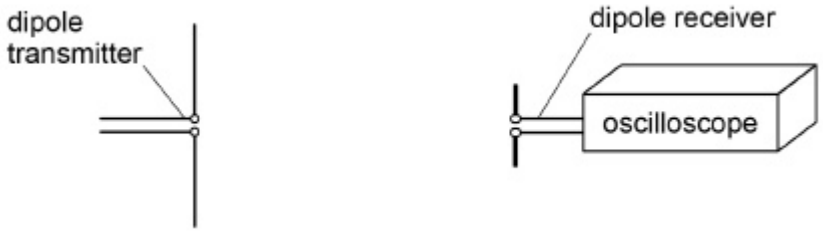


Figure 2 shows the same apparatus when the dipole receiver has been rotated through an angle of 90°

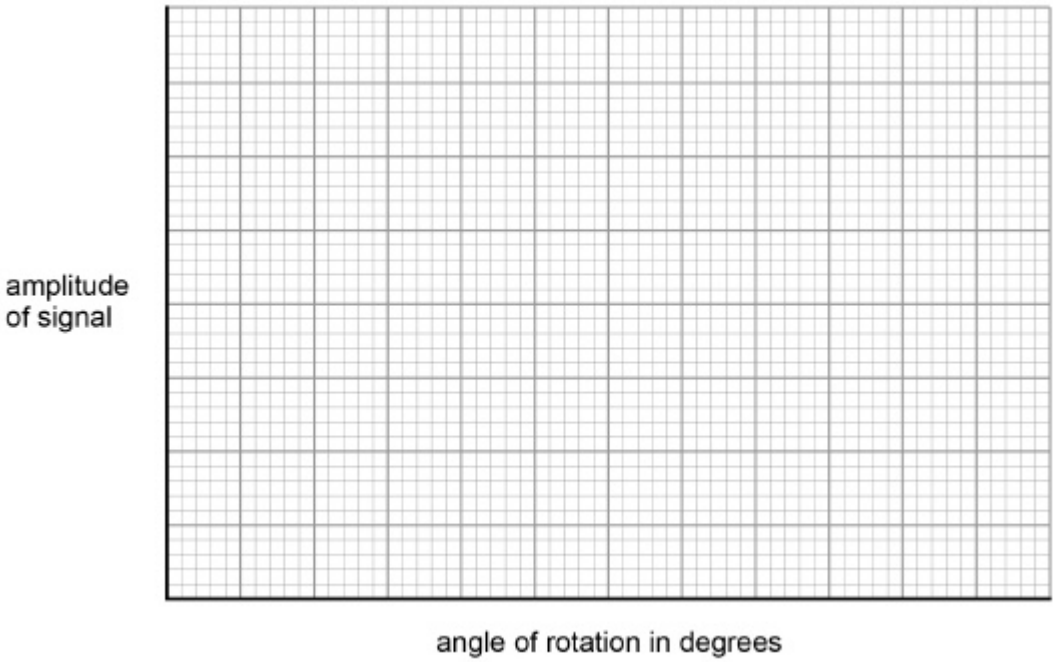
Figure 2



(a) Sketch a graph on **Figure 3** to show how the amplitude detected by the dipole receiver varies with angle of rotation as the receiver is turned through 360° Start your graph from the position shown in **Figure 1**.

Figure 3

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(3)

(b) Maxwell derived the equation $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ for the speed c of electromagnetic waves, where μ_0 is the permeability of free space and ε_0 is the permittivity of free space.

Explain, using a suitable calculation, why this equation led to the conclusion that light is an electromagnetic wave.

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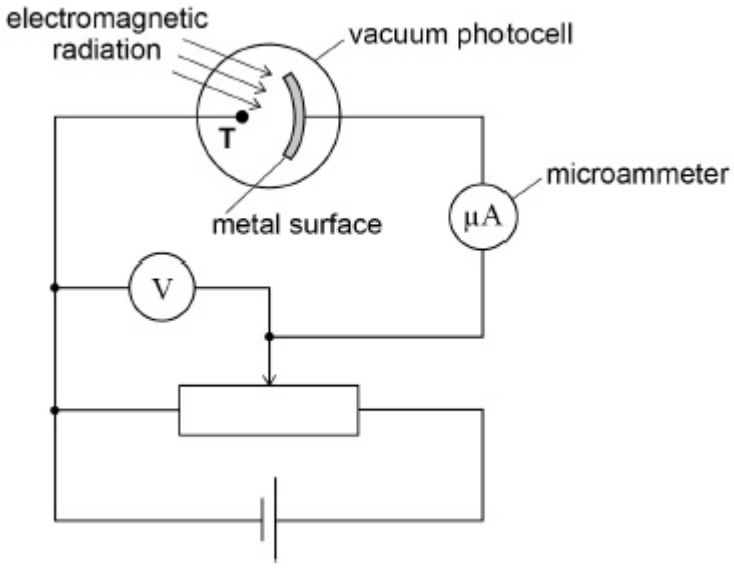
(2)

(Total 5 marks)

Q2.

The diagram shows a vacuum photocell in which a metal surface is illuminated by electromagnetic radiation of a single wavelength. Electrons emitted from the metal surface are collected by terminal **T** in the photocell. This results in a photocurrent, I, which is measured by the microammeter.

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The potential divider is adjusted until the photocurrent is zero.

The potential difference shown on the voltmeter is 0.50 V

The work function of the metal surface is 6.2 eV

(a) Calculate the wavelength, in nm, of the electromagnetic radiation incident on the metal surface.

wavelength = _____ nm

(3)

(b) The intensity of the electromagnetic radiation is increased. No adjustment is made to the potential divider.

The classical wave model and the photon model make different predictions about the effect on the photocurrent.

Explain the effect on the photocurrent that each model predicts and how experimental observations confirm the photon model.

_____

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(3)

(c) The potential divider in the diagram is returned to its original position so that a photocurrent is detected by the microammeter.
The potential divider is then adjusted to increase the potential difference shown on the voltmeter.

Explain why the photocurrent decreases when this adjustment to the potential divider is made.

(2)

(d) The apparatus shown in the diagram above is used to investigate three different metal surfaces **A**, **B** and **C**.
The table shows, for each of the three surfaces, a voltmeter reading V and the corresponding photocurrent I. The same source of electromagnetic radiation is used throughout the investigation.

	V/V	I/μA
Metal surface **A**	1.5	56
Metal surface **B**	2.5	56
Metal surface **C**	2.5	78

Which conclusion about the relationship between the work functions of **A**, **B** and **C** is correct?

Tick (✓) the correct box.

A > B > C. ☐

A < B < C. ☐

B > A > C. ☐

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B < A < C. ☐

(1)

(Total 9 marks)

Q3.

Which statement suggests that electrons have wave properties?
Tick (✓) the correct answer.

Electrons are emitted in photoelectric effect experiments. ☐

Electrons are released when atoms are ionised. ☐

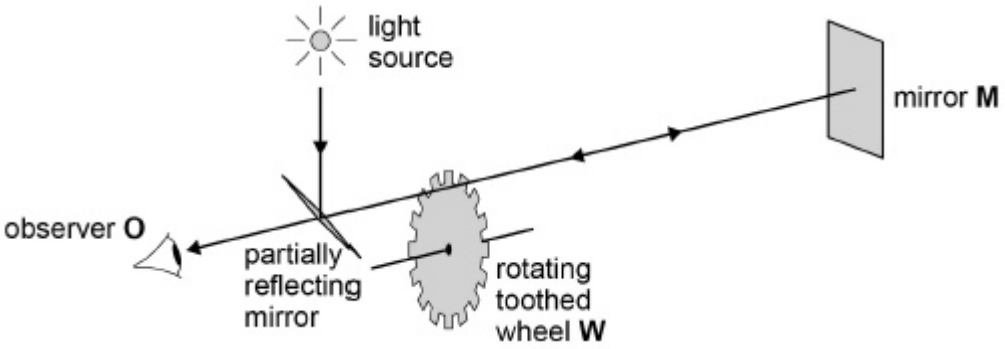
Electrons produce dark rings in diffraction experiments. ☐

Electron transitions in atoms produce line spectra. ☐

(Total 1 mark)

Q4.

The diagram shows the apparatus Fizeau used to determine the speed of light.



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.

(a) Explain these observations.

Observation A

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_____

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Observation B

(2)

(b) The table shows data from Fizeau's experiment at the instant when observation B is made.

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 the table are consistent with the present accepted value for the speed of light.

(2)

(c) 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.

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(2)

(d) Explain how the nature of light is implied by Maxwell's theory of electromagnetic waves and Fizeau's result.

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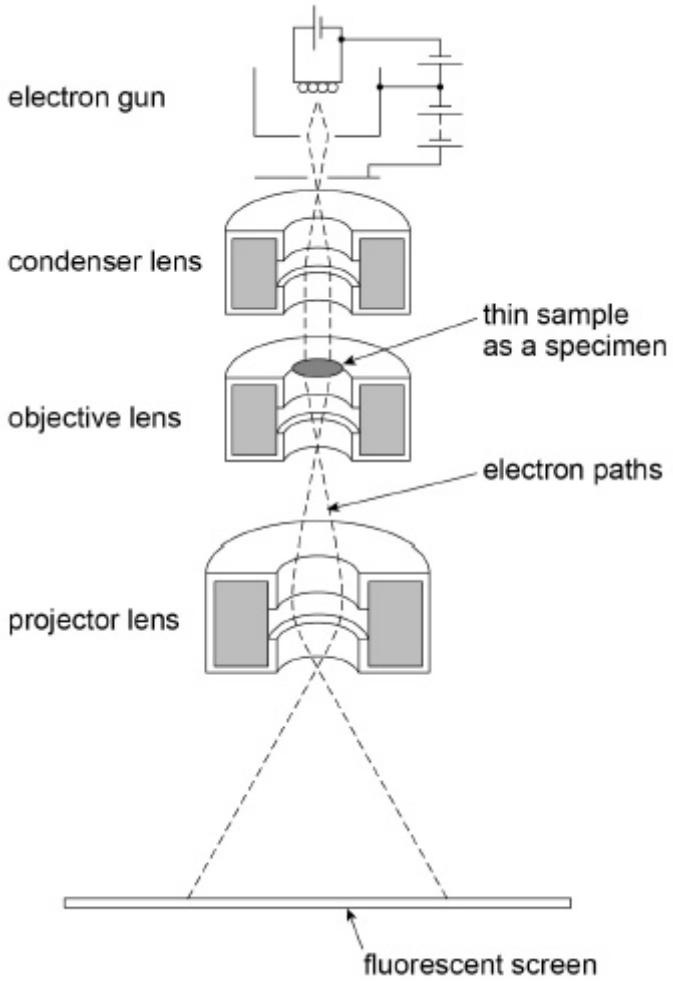
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(3)

(Total 9 marks)

Q5.

The diagram shows the main parts of a transmission electron microscope (TEM).



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

Beta particle emission	☐
Electron diffraction	☐
Photoelectric effect	☐
Thermionic emission	☐

(1)

(b) 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)

(c) 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.

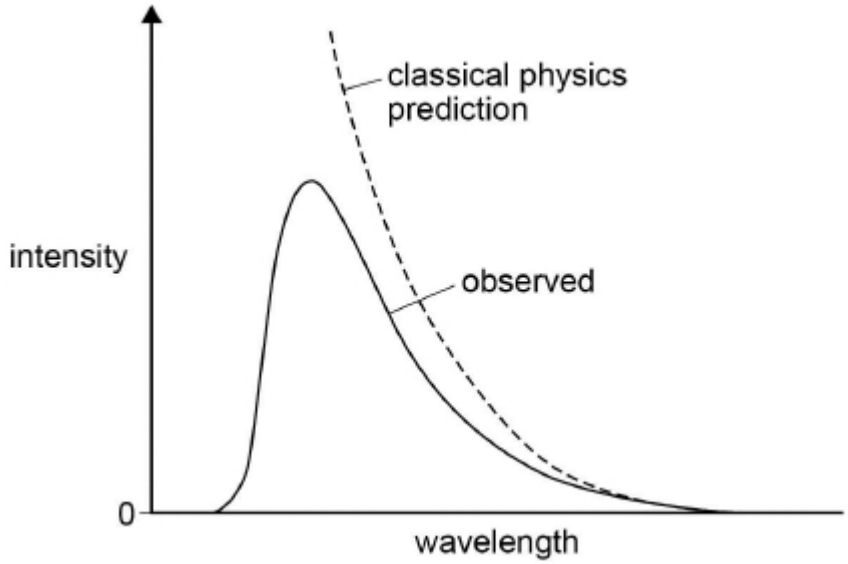
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(6)

(Total 10 marks)

Q6.

The solid line on the graph below shows how the intensity of radiation from a black body varies with wavelength at a particular temperature. The dotted line shows the variation as predicted by classical physics.



(a) Explain why the difference between the predicted and experimental curves is called the ultraviolet catastrophe.

(2)

(b) Describe the difference between the classical physics view and the quantum theory proposal made by Max Planck that enabled the distribution of the shape of the intensity−wavelength graph to be correctly predicted.

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(2)

(c) Discuss the evidence that the photoelectric effect provides in support of the quantum theory.

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(3)

(Total 7 marks)

Q7.

In a transmission electron microscope (TEM) electrons are accelerated by a potential difference V between a cathode and anode. The de Broglie wavelength λ of the accelerated electrons depends on V.

(a) Identify which of the following represents the relationship between λ and V. Ignore relativistic effects.

Tick (✓) the correct answer in the right−hand column

	✓ if correct
$\lambda \propto \sqrt{V}$	
$\lambda \propto V$	
$\lambda \propto \frac{1}{V}$	
$\lambda \propto \frac{1}{\sqrt{V}}$	

(1)

(b) TEMs operate using wavelengths of about 0.1 nm.

Explain why operation at such wavelengths makes the instrument such an important research tool.

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(2)

(c) State and explain **two** factors that limit the detail in the image produce by a TEM.

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2. _____

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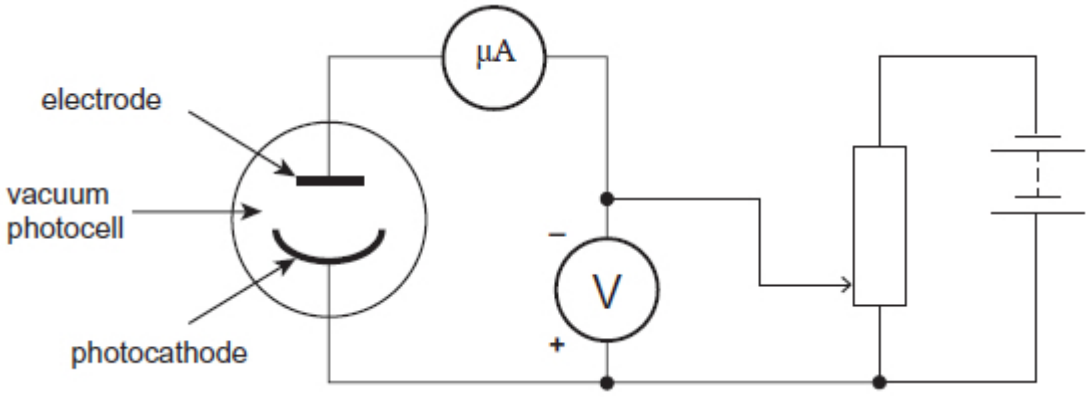
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(4)

(Total 7 marks)

Q10.

(a) The arrangement shown in the diagram is used by a student in a photoelectric effect experiment.



Monochromatic light falls on the photocathode. A current is recorded when the potential difference (pd) between the photocathode and the electrode is zero.
The student gradually increases the magnitude of the pd between the photocathode and electrode and makes observations of the effect this has on the current.

Describe and explain the observations that you would expect the student to make. In your answer you should refer to:

- the stopping potential
- the kinetic energy of the photoelectrons

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- how Einstein's photoelectric equation applies to this experiment.

The quality of your written communication will be assessed in your answer.

(6)

(b) Using the circuit in the diagram, the stopping potential recorded is 0.24 V when light of wavelength 490 nm is incident on the surface of the photocathode.

(i) Calculate the work function of the surface material.

work function = _____ J

(3)

(ii) The polarity of the battery in the diagram is now reversed and light of 490 nm is incident on the photocathode. The energy of the light falling on the surface of the photocathode each second is 6.1 μJ.

Calculate the maximum current that the microammeter could record.

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maximum current = _____ μA

(2)

(Total 11 marks)

Q11.

(a) Maxwell predicted the existence of electromagnetic waves that travelled in free space.

Identify the **two** quantities that vary in an electromagnetic wave and state the phase relationship between them.

Quantity 1 _____

Quantity 2 _____

_____

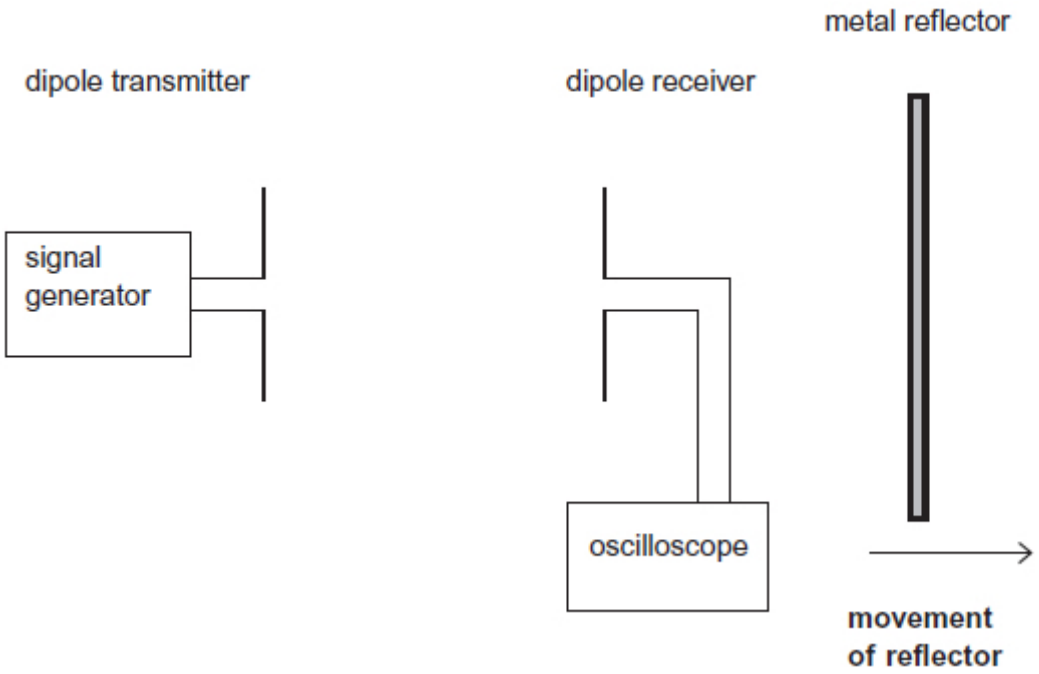
Phase relationship

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(2)

(b) Hertz determined the speed of electromagnetic waves and found that they travelled at 3.0×10^8 m s^{-1}. The diagram shows an arrangement using radio waves that is similar to that used by Hertz in his determination.



The dipole transmitter radiates an electromagnetic wave of frequency 2.2 GHz.
A signal is detected by the dipole receiver.
When the metal reflector is moved in the direction shown in the diagram, the detected signal strength alternates between maximum and minimum intensities.

(i) Explain why the detected signal strength changes from a maximum to a minimum as the metal reflector is moved.

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(3)

(ii) Determine the least distance the reflector has to move for the detected signal strength to change from a maximum to a minimum to confirm Hertz's value for the speed of electromagnetic radiation.

least distance = _____ m

(2)

(iii) Which **one** of the following observations originally led to the conclusion that light is an electromagnetic wave?

Place a tick (✓) in the right-hand column to show the correct answer.

	✓ if correct
Light is diffracted when it falls on a narrow slit.	
Light travels at 3×10^8 m s^{-1} in free space.	
Light changes speed when it enters a medium of different optical density.	
Light can be polarised when it passes through Polaroid.	

(1)

(Total 8 marks)

Q12.

(a) (i) Describe how Newton used the corpuscular theory to explain the refraction of light as it passes from one substance into a substance of higher optical density.

_____

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(3)

(ii) Huygens used a wave theory to explain refraction.

Explain why the corpuscular theory was rejected in favour of a wave theory to explain refraction.

(2)

(iii) Describe and explain the difference in the appearance of the fringes in Young's double-slit experiment that are predicted by the corpuscular theory and by the wave theory for light.

(2)

(b) Electromagnetic waves and matter are now known to exhibit both particle and wave behaviour. The photons for a particular X-ray wavelength have energy 5.0 keV.

Calculate the potential difference through which an electron has to be accelerated so that its de Broglie wavelength is the same as that of this X-ray.

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(4)
(Total 11 marks)

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