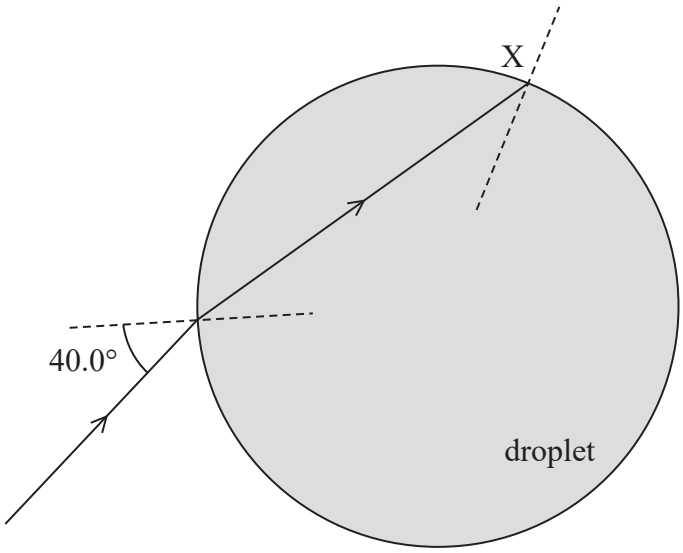
14 Lighthouses are located along coastlines to aid navigation. A lighthouse emits an intense beam of light. In clear weather the beam is visible for long distances, but in foggy weather the visibility of the beam is limited.

(a) The beam is refracted by water droplets in the air.

A light ray in the beam is incident on a spherical water droplet with an angle of incidence of 40.0°. The ray passes through the droplet and meets the water-air boundary at X as shown.

Diagram **NOT** to scale



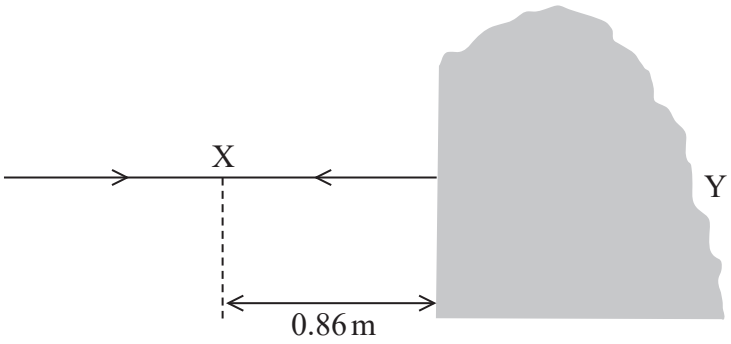
Deduce whether the ray leaves the water droplet at point X.

speed of light in water = $2.25 \times 10^8\,\text{m s}^{-1}$

(4)

(b) A lighthouse is also fitted with a foghorn to emit a loud sound in foggy weather.

A sound wave is incident normally on a large rock and is reflected. The reflected wave meets the incoming wave, creating a standing wave. The closest node to the rock is at point X, 0.86 m from the rock as shown.



(i) Calculate the speed of the sound wave.

frequency of sound wave = 200 Hz

(3)

Speed of sound wave = ...

(ii) The rock is about 2 m wide and 2 m high.

Explain why sound would be heard at point Y behind the rock.

(2)

(Total for Question 14 = 9 marks)

15 The Planck constant is an important universal constant used in the study of wave–particle duality.

(a) In a demonstration of the photoelectric effect, ultraviolet radiation with a frequency of 2.8×10^{16} Hz is incident on the surface of clean zinc. Electrons are released from the surface of the zinc.

Calculate the maximum velocity of the released electrons.

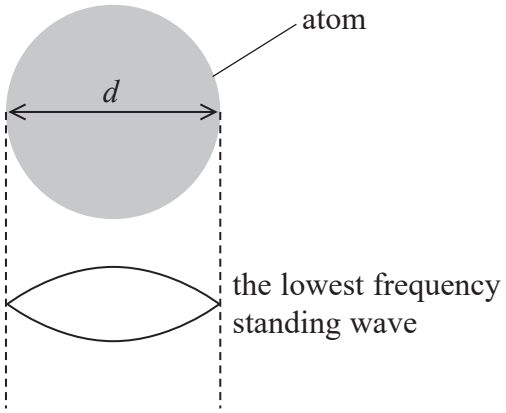
work function of zinc = 6.9×10^{-19} J

(2)

Maximum velocity = ...

(b) Atomic electrons are confined within the atom. One model of atomic electrons suggests that the wave associated with an atomic electron forms a standing wave that fits exactly into the diameter d of the atom.

(i) The diagram shows the lowest frequency standing wave that fits into the diameter of the atom.



Calculate the momentum of the electron.

$d = 2.00 \times 10^{-10}$ m

(3)

Momentum = ...

(ii) Electrons in an atom can only exist at discrete energy levels.

Explain how this standing wave model can account for this.

(2)

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(Total for Question 15 = 7 marks)

TOTAL FOR SECTION A = 60 MARKS

17 A photographer uses a light meter to measure the intensity of light entering a camera. A simple light meter consists of a light dependent resistor (LDR) connected in a circuit.

(a) The resistance of an LDR depends on the intensity of light incident on the LDR.

Explain how the change in resistance may be modelled in terms of conduction electrons.

(4)

(b) The light meter records an intensity of $1100\,W\,m^{-2}$. The LDR in the light meter has a surface area of $4.0 \times 10^{-5}\,m^2$.

Calculate the energy that is transferred to the LDR every 60 seconds.

(2)

Energy = ...

(c) The light incident on the camera lens is unpolarised. The photographer places a polarising filter in front of the camera lens.

Explain how the polarising filter affects the intensity of light incident on the camera lens.

(4)

(Total for Question 17 = 10 marks)

TOTAL FOR SECTION B = 20 MARKS
TOTAL FOR PAPER = 80 MARKS

SECTION A

Answer ALL questions.

All multiple choice questions must be answered with a cross in the box ☒ for the correct answer from A to D. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 The wavelength of light emitted from a laser can be determined using a diffraction grating. The equation used to calculate the wavelength is

$$n\lambda = d\sin\theta$$

Which row of the table shows possible units for n and d?

		n	d
☒	**A**	no unit	mm^{-1}
☒	**B**	no unit	mm
☒	**C**	mm	no unit
☒	**D**	mm^{-1}	no unit

(Total for Question 1 = 1 mark)

2 A student carries out an investigation to determine the Young modulus of a material.

Which of the following gives two measuring instruments the student should use?

☒ **A** calipers and stopwatch

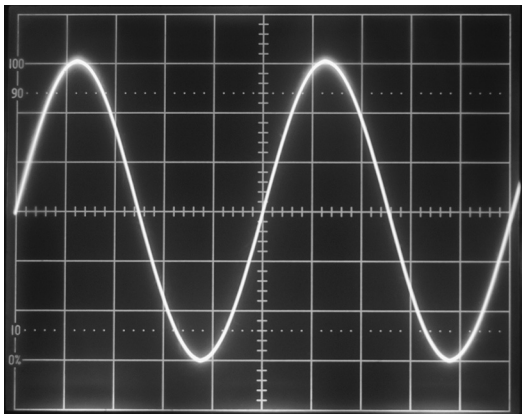
☒ **B** metre rule and micrometer

☒ **C** metre rule and stopwatch

☒ **D** micrometer and calipers

(Total for Question 2 = 1 mark)

3 A 2-beam oscilloscope is used to determine the speed of sound in air. The oscilloscope screen shown displays the signal used to produce the sound wave.



(Source: © Dorling Kindersley/UIG/SCIENCE PHOTO LIBRARY)

The time-base is set to 50 μs / division.

Which of the following gives the frequency, in Hz, of the signal?

☒ **A** $5 \times 50 \times 10^{-6}$

☒ **B** $2.5 \times 50 \times 10^{-6}$

☒ **C** $\dfrac{1}{5 \times 50 \times 10^{-6}}$

☒ **D** $\dfrac{1}{2.5 \times 50 \times 10^{-6}}$

(Total for Question 3 = 1 mark)

4 A ball bearing falling freely through a liquid reaches terminal velocity. The terminal velocity is determined by measuring the time taken for the ball bearing to fall a measured distance.

The measured distance has a percentage uncertainty X.

The measured time has a percentage uncertainty Y.

Which of the following gives the percentage uncertainty in the value for the terminal velocity of the ball bearing?

☒ **A** X + Y

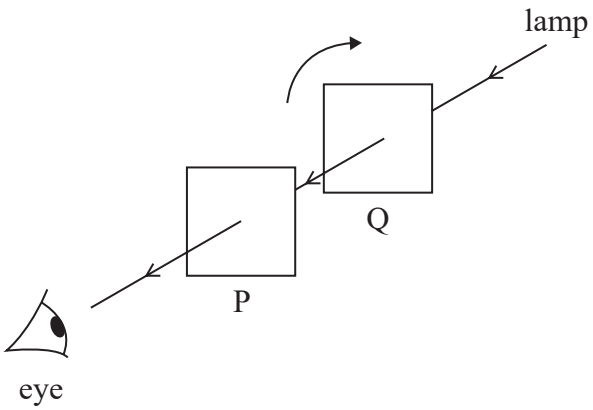
☒ **B** XY

☒ **C** $\dfrac{X}{Y}$

☒ **D** X – Y

(Total for Question 4 = 1 mark)

5 A lamp is switched on and viewed through two polarising filters P and Q, as shown.



The lamp appears dark when viewed through P and Q.
Q is rotated through 180°.

Which row of the table gives the appearance of the lamp after Q has rotated by 90° from its original position and by 180° from its original position?

		Angle of rotation of 90°	Angle of rotation of 180°
☒	**A**	dark	dark
☒	**B**	dark	bright
☒	**C**	bright	dark
☒	**D**	bright	bright

(Total for Question 5 = 1 mark)

6 A textbook describes waves as having oscillations of different wavelengths in multiple planes. The oscillations are perpendicular to the direction of energy transfer.

Which of the following is being described?

☒ **A** stationary waves

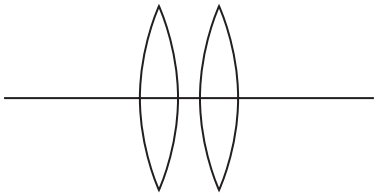
☒ **B** longitudinal waves

☒ **C** polarised transverse waves

☒ **D** unpolarised transverse waves

(Total for Question 6 = 1 mark)

7 Two thin converging lenses are placed next to each other as shown.



Each lens has a power of 4 D.

Which of the following is the total power of the combined lenses?

☒ **A** 1 D

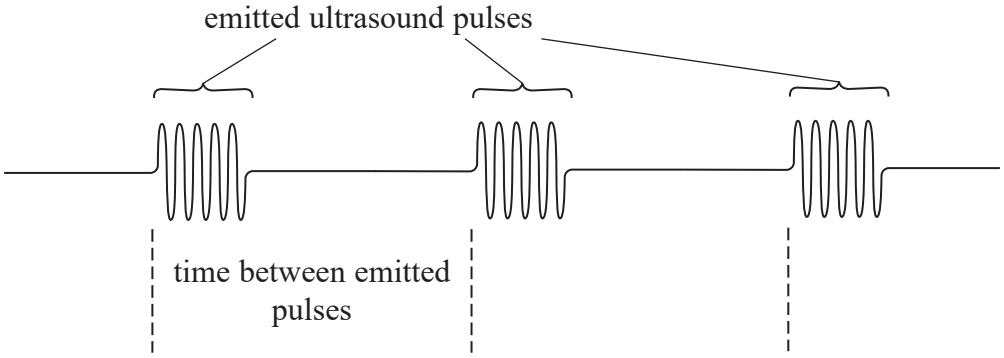
☒ **B** 2 D

☒ **C** 4 D

☒ **D** 8 D

(Total for Question 7 = 1 mark)

9 Bats use a pulse-echo technique to hunt for moths. The bat emits a series of ultrasound pulses as shown on the oscilloscope trace below.



(a) A stationary bat emits an ultrasound pulse that is reflected from a moth. The bat detects the reflected pulse 36 ms later.

Calculate the distance between the bat and the moth.

speed of sound = 340 m s^{-1}

(3)

Distance = ...

(b) The bat flies towards the moth.

Explain why the bat must change the time between the emitted pulses as the distance between the bat and the moth decreases.

(3)

(Total for Question 9 = 6 marks)

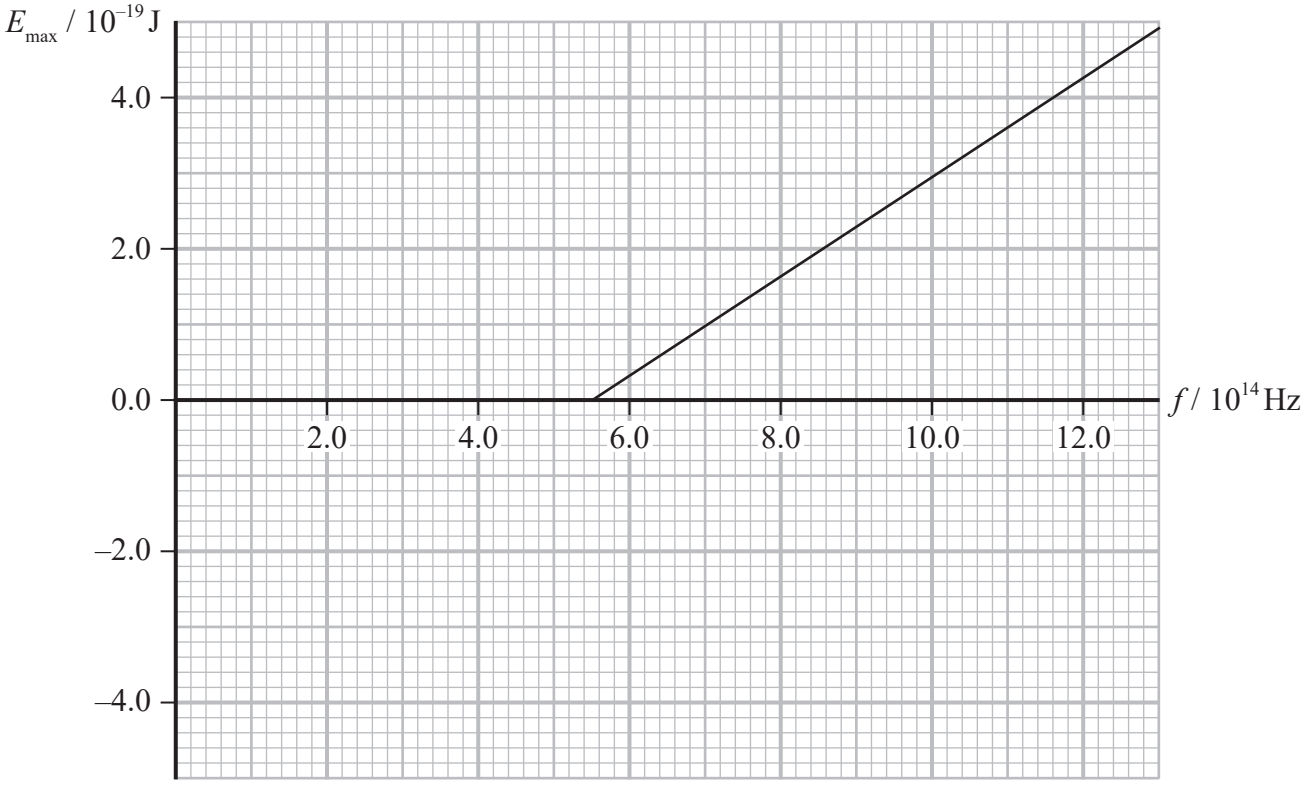
11 In a demonstration of the photoelectric effect, electromagnetic radiation of frequency f was incident on the surface of a metal. The maximum kinetic energy E_{max} of the emitted photoelectrons was determined for increasing values of f.

(a) No photoelectrons are emitted when the frequency of the radiation is below a certain value.

Explain why.

(3)

(b) The graph shows the variation of E_{max} with f.



(i) A photon with frequency 10.0×10^{14} Hz is incident on the metal surface causing a photoelectron to be released.

Calculate the maximum possible velocity v_{max} of the photoelectron.

(2)

.....

.....

.....

v_{max} = ...

(ii) The table shows the work function ϕ for three metals.

Metal	**ϕ / eV**
caesium	2.2
zinc	4.3
beryllium	5.0

Deduce which metal was used in this demonstration.

(3)

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.....

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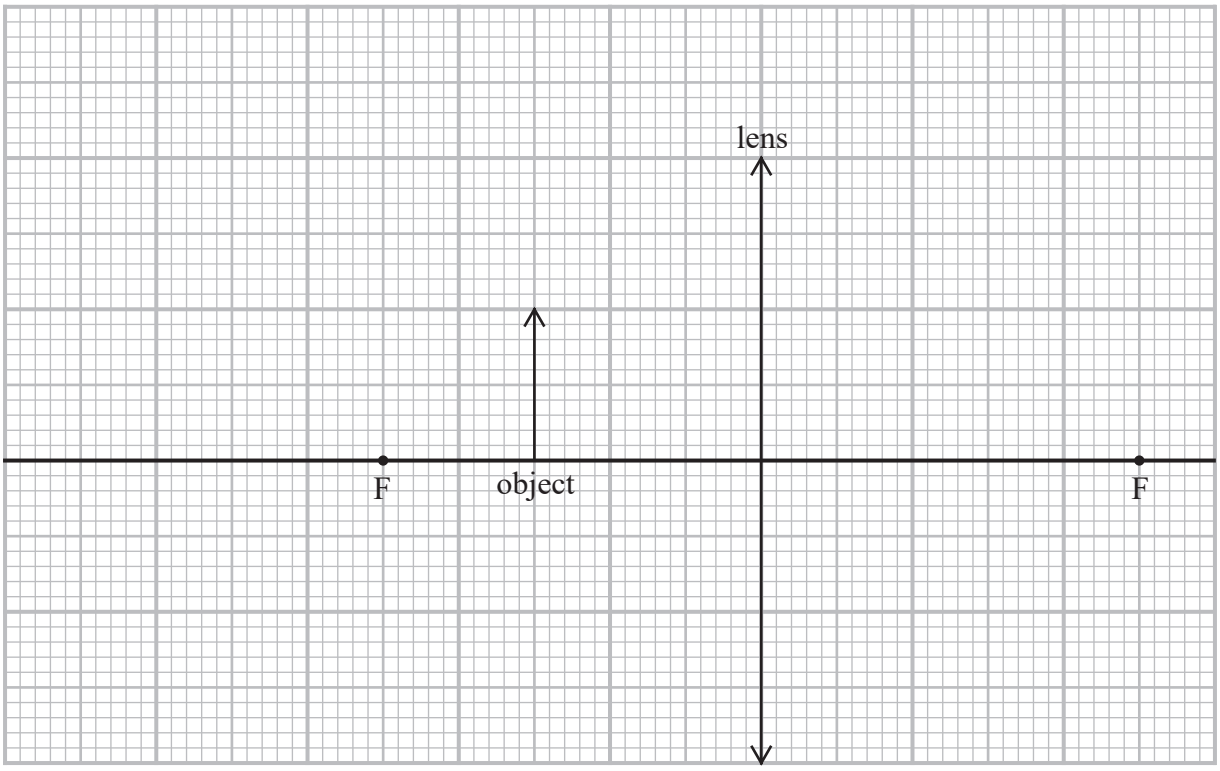
.....

(Total for Question 11 = 8 marks)

13 A jeweller inspects the quality of a diamond. She uses a converging lens to produce a magnified image of the diamond.

(a) Complete the ray diagram to show how a converging lens produces a magnified image of the object shown.

(2)



(b) With the naked eye, the jeweller can detect a scratch that has a width of 0.1 mm or greater.

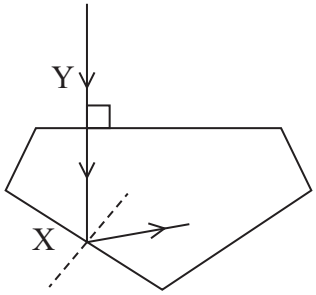
The diamond has a scratch that is 10 μm wide. The jeweller holds the diamond 0.012 m from the converging lens and views the image of the diamond.

Deduce, by calculation, whether the scratch is detectable by the jeweller using the lens.

power of lens = 45 D

(5)

(c) A ray of light enters the diamond along the normal at point Y as shown.



Not to scale

The ray is incident at the diamond-air interface at X with an angle of incidence equal to 40°.

Deduce whether the ray follows the path at X, as shown.

speed of light in diamond = $1.25 \times 10^8\,\text{m s}^{-1}$

(4)

(Total for Question 13 = 11 marks)

SECTION B

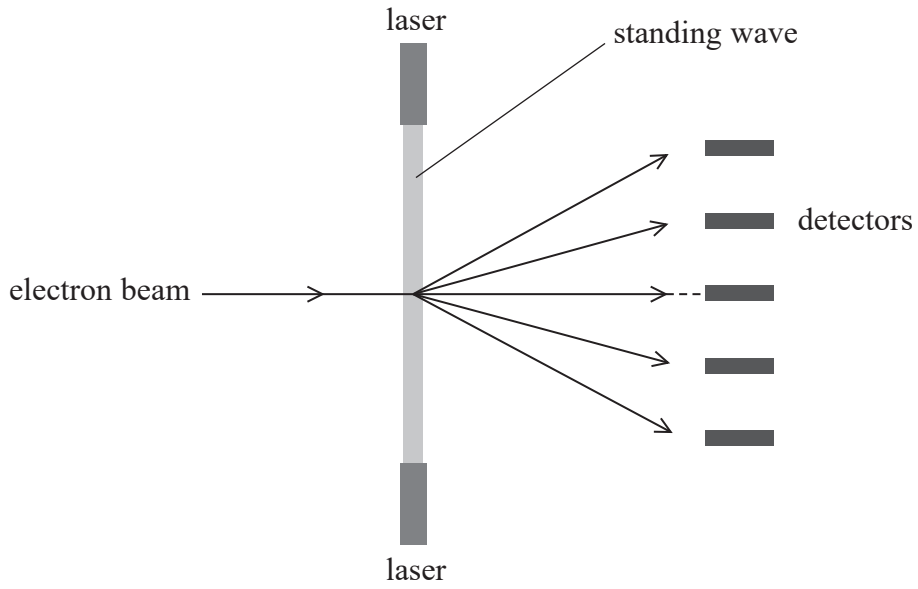
Answer ALL questions in the spaces provided.

15 Read the extract and answer the questions that follow.

In 1933 it was predicted that a standing light wave could act as a diffraction grating that could diffract electrons. The prediction was tested 70 years later due to the development of powerful lasers.

Two identical lasers, emitting coherent light, were pointed towards each other to create the standing wave. A narrow beam of electrons passed through the standing wave. The nodes in the standing wave acted like gaps in a diffraction grating.

The pattern of the diffracted electrons was observed by detectors placed behind the standing wave as shown.



(a) Describe how a standing wave can be created from the light emitted by the two lasers.

(5)

(b) A diffraction pattern is detected 0.24 m from the grating created by the laser light. The distance between the central maximum and the 1st order maxima of the diffraction pattern is 55 μm.

Calculate the wavelength of the electrons in the beam that passes through the standing wave created by the laser light.

wavelength of light from laser = 532 nm

(3)

Wavelength = ...

(c) The wavelength of monochromatic light can be determined using a diffraction grating with about 500 lines per mm.

Explain why the wavelength of electrons can **not** be determined using this diffraction grating.

(2)

*(d) A laser produces light with discrete wavelengths.

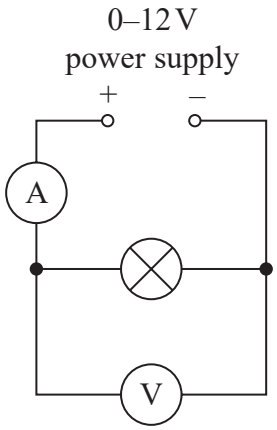
The laser contains a gas. A current in the gas causes the atoms in the gas to move to an excited state.

Explain why the excited atoms emit light with discrete wavelengths.

(6)

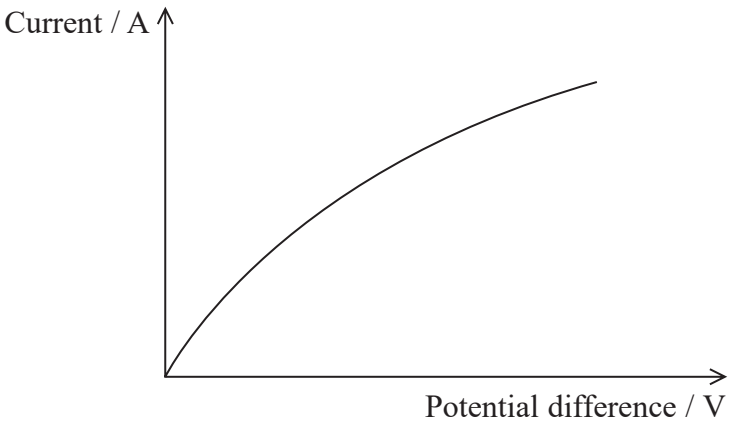
(Total for Question 15 = 16 marks)

16 A student investigated the current-potential difference relationship for a filament bulb.
She set up the circuit as shown.



The student increased the output from the power supply from 0 V to 12 V in steps of 2 V.
She recorded corresponding currents from the ammeter.

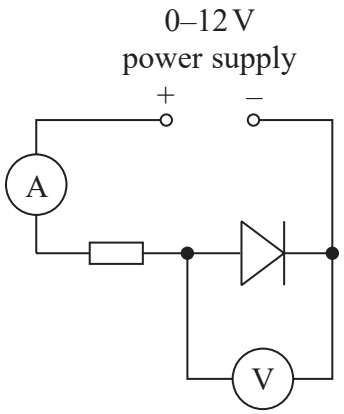
(a) A graph of her results is shown.



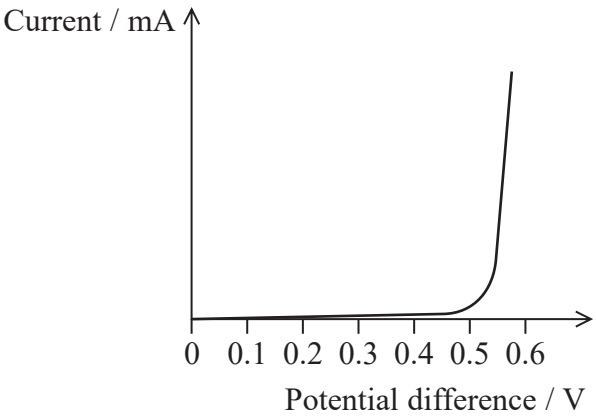
Explain the shape of the graph.

(4)

(b) The student replaced the bulb in the circuit with a diode in forward bias and a resistor as shown.



The graph shows how current varies with potential difference for a diode in forward bias.



Describe how the student could adapt her method to plot the variation of current with potential difference for the diode in forward bias.

You should include any changes to the circuit.

(3)

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(Total for Question 16 = 7 marks)

TOTAL FOR SECTION B = 23 MARKS
TOTAL FOR PAPER = 80 MARKS