## **SECTION B**

## Answer ALL questions.

- 15 (a) Solar sails are a form of propulsion for spacecraft. The sail is made of a thin sheet of reflective material. When photons of light from the Sun reflect from the material a force is exerted on the sail. The photons reflect with a momentum equal to their initial momentum but in the opposite direction.
  - (i) Show that a single photon of frequency  $1.5 \times 10^{15}$  Hz has a momentum of about  $3 \times 10^{-27}$  N s.

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(ii) Hence determine the momentum transferred to the solar sail by this photon.

**(1)** 

Momentum transferred =

(b) An alternative method of producing a momentum change is being investigated. Researchers have suggested that 'larger changes in momentum could be produced by directing laser light at graphene oxide'. Electrons are emitted from the graphene oxide surface, resulting in a force being exerted on the graphene oxide in the opposite direction.

A researcher has suggested that one possible mechanism for the emission of the electrons is the photoelectric effect.



photon of light of frequency $1.5 \times 10^{15}$ Hz is about $8 \times 10^{5}$ m s <sup>-1</sup> .	
work function of graphene oxide = $6.7 \times 10^{-19}  \text{J}$	(3)
(ii) Hence calculate the momentum of the photoelectron.	(2)
Momentum of photoelectron =	
e) Explain whether the suggestion in (b) that 'larger changes in momentum could be	
produced by directing laser light at graphene oxide' is true.	(2)
	(2)
(Total for Question 15 = 10 m	arks)



5 The diagram shows the lowest energy levels for a certain atom.

A photon with energy 3.2 eV is absorbed.

An electron could move from

- A ground state to level 1.
- **B** ground state to level 2.
- C level 1 to ground state.
- **D** level 2 to ground state.

(Total for Question 5 = 1 mark)

\*15 The behaviour of electromagnetic radiation can be described in terms of a photon model or a wave model.

In the photoelectric effect, electromagnetic radiation is incident on a metal plate and under certain conditions electrons are emitted.

It is observed that, for a given metal,

- no electrons are emitted if the frequency of the incident radiation is below a certain threshold frequency.
- electrons are emitted instantaneously if the frequency of the incident radiation is above a certain threshold frequency.
- the kinetic energy of the emitted electrons depends only on the frequency of the incident radiation.

Discuss how the photon model of electromagnetic radiation can explain these observations and why the wave model of electromagnetic radiation cannot.		
observations and why the wave moder of electromagnetic radiation cannot.	(6)	
(Total for Question 15 = 6	marks)	

**TOTAL FOR SECTION A = 60 MARKS** 



4 Einstein's photoelectric equation states

$$hf = \phi + \frac{1}{2} m v_{\text{max}}^2$$

The quantity denoted by  $\phi$  is the minimum

- $\ oxed{oxed}$  A amount of energy of a photon needed to release an electron.
- **B** amount of energy of an electron needed to release a photon.
- C frequency of a photon needed to release an electron.
- D frequency of an electron needed to release a photon.

(Total for Question 4 = 1 mark)

