Quantum Physics

Q1. When a clean metal surface in a vacuum is irradiated with ultraviolet radiation of a certain frequency, electrons are emitted from the metal.

(a) (i) Explain why the kinetic energy of the emitted electrons has a maximum value.

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(2)

(ii) Explain with reference to the work function why, if the frequency of the radiation is below a certain value, electrons are not emitted.

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(2)

(iii) State a unit for work function.

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(1)

(b) Light energy is incident on each square millimetre of the surface at a rate of 3.0×10^{-10} J s^{-1}. The frequency of the light is 1.5×10^{15} Hz.

(i) Calculate the energy of an incident photon.

answer = ... J

(2)

(ii) Calculate the number of photons incident per second on each square millimetre of the metal surface.

answer = ...

(2)

(c) In the wave theory model of light, electrons on the surface of a metal absorb energy from a small area of the surface.

(i) The light striking the surface delivers energy to this small area at a rate of 3.0×10^{-22} J s^{-1}.

The minimum energy required to liberate the electron is 6.8×10^{-19} J.
Calculate the minimum time it would take an electron to absorb this amount of energy.

answer = ... s

(1)

(ii) In practice the time delay calculated in part c (i) does not occur. Explain how this experimental evidence was used to develop the particle model for the behaviour of light.

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(2)
(Total 12 marks)

Q2. When light of a certain frequency is shone on a particular metal surface, electrons are emitted with a range of kinetic energies.

(a) Explain

- in terms of photons why electrons are released from the metal surface, and
- why the kinetic energy of the emitted electrons varies upto a maximum value.

The quality of your written communication will be assessed in this question.

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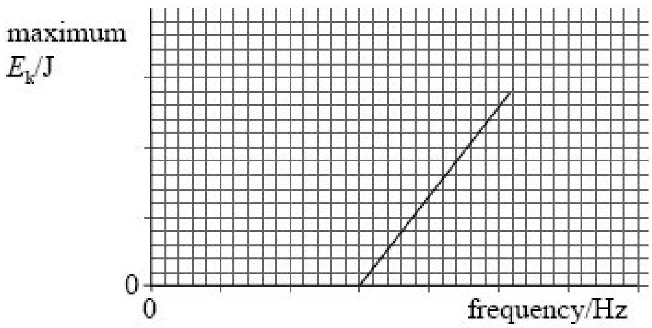
(6)

(b) The graph below shows how the maximum kinetic energy of the electrons varies with the frequency of the light shining on the metal surface.



(i) On the graph mark the *threshold frequency* and label it f_0.

(1)

(ii) On the graph draw a line for a metal which has a higher threshold frequency.

(2)

(iii) State what is represented by the gradient of the graph.

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(1)

(c) The threshold frequency of a particular metal surface is 5.6×10^{14} Hz. Calculate the maximum kinetic energy of emitted electrons if the frequency of the light striking the metal surface is double the threshold frequency.

answer = ... J

(3)

(Total 13 marks)

Q3. (a) The photoelectric effect suggests that electromagnetic waves can exhibit particle-like behaviour. Explain what is meant by threshold frequency and why the existence of a threshold frequency supports the particle nature of electromagnetic waves.

The quality of your written communication will be assessed in this question.

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(6)

(b) (i) An alpha particle of mass 6.6×10^{-27} kg has a kinetic energy of 9.6×10^{-13} J. Show that the speed of the alpha particle is 1.7×10^{7} m s^{-1}.

(3)

(ii) Calculate the momentum of the alpha particle, stating an appropriate unit.

answer = ...

(3)

(iii) Calculate the de Broglie wavelength of the alpha particle.

answer = ... m

(2)
(Total 14 marks)

Q4. When monochromatic light is shone on a clean metal surface, electrons are emitted from the surface due to the photoelectric effect.

(a) State and explain the effect on the emitted electrons of

(i) increasing the frequency of the light,

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(2)

(ii) increasing the intensity of the light.

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(2)

(b) The wave model was once an accepted explanation for the nature of light. It was rejected when validated evidence was used to support a particle model of the nature of light. Explain what is meant by **validated evidence**.

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(2)

(c) The threshold frequency of lithium is 5.5×10^{14} Hz.

(i) Calculate the work function of lithium, stating an appropriate unit,

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answer ....

(3)

(ii) Calculate the maximum kinetic energy of the emitted electrons when light of frequency 6.2×10^{14} HZ is incident on the surface of a sample of lithium.

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answer .... J

(3)

(Total 12 marks)

Q5. (a) When monochromatic light is shone on a clean cadmium surface, electrons with a range of kinetic energies up to a maximum of 3.51×10^{-20} J are released. The *work function* of cadmium is 4.07 eV.

(i) State what is meant by work function.

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(2)

(ii) Explain why the emitted electrons have a range of kinetic energies up to a maximum value.

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(4)

(iii) Calculate the frequency of the light. Give your answer to an appropriate number of significant figures.

answer = ... Hz

(4)

(b) In order to explain the photoelectric effect the wave model of electromagnetic radiation was replaced by the photon model. Explain what must happen in order for an existing scientific theory to be modified or replaced with a new theory.

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(2)
(Total 12 marks)

Q6. **Figure 1** shows the energy level diagram of a hydrogen atom. Its associated spectrum is shown in **Figure 2**.

The transition labelled **A** in **Figure 1** gives the spectral line labelled **B** in **Figure 2**.

Figure 1

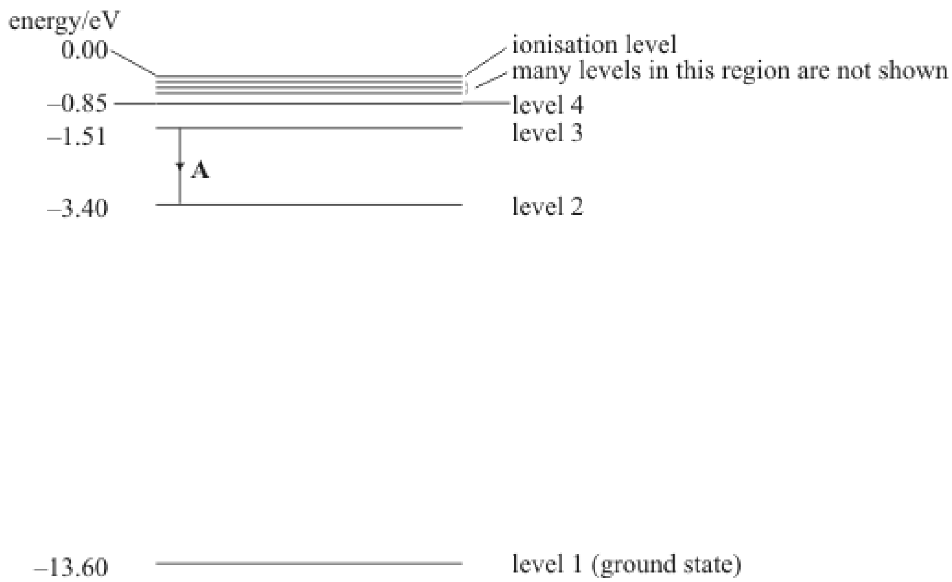
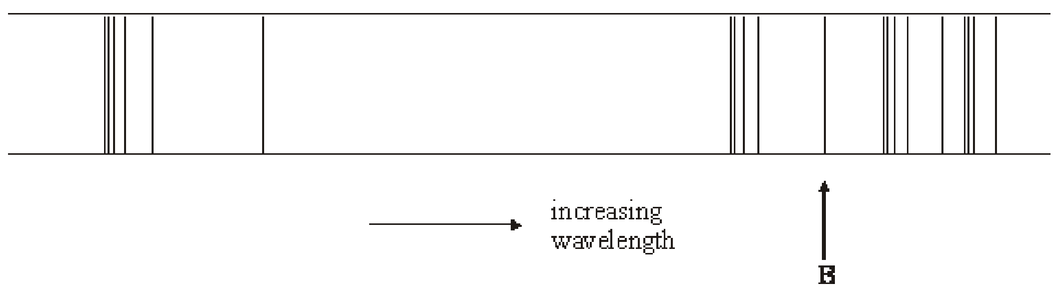


Figure 2

hydrogen spectrum showing some of the main spectral lines



(a) (i) Show that the frequency of spectral line B is about 4.6×10^{14} Hz.

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(ii) Calculate the wavelength represented by line B.

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(3)

(b) The hydrogen atom is excited and its electron moves to level 4.

(i) How many different wavelengths of electromagnetic radiation may be emitted as the atom returns to its ground state?

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(ii) Calculate the energy, in eV, of the longest wavelength of electromagnetic radiation emitted during this process.

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(2)

(c) In a fluorescent tube, explain how the mercury vapour and the coating of its inner surface contribute to the production of visible light. You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.

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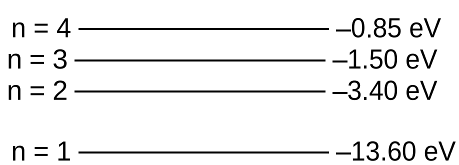
(3)
(Total 8 marks)

Q7. The diagram below shows part of an energy level diagram for a hydrogen atom.



(a) The level, n = 1, is the ground state of the atom.
State the ionisation energy of the atom in eV.

answer = ... eV

(1)

(b) When an electron of energy 12.1 eV collides with the atom, photons of three different energies are emitted.

(i) On the diagram above show with arrows the transitions responsible for these photons.

(3)

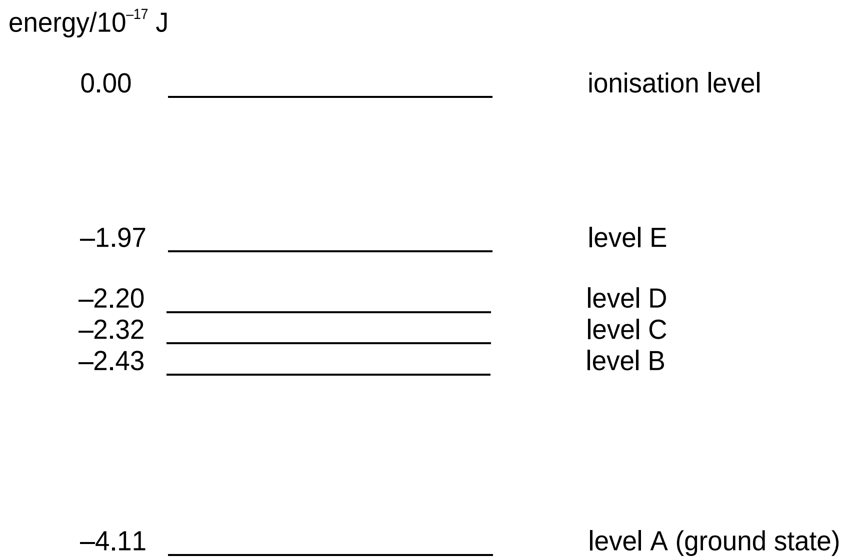
(ii) Calculate the wavelength of the photon with the smallest energy. Give your answer to an appropriate number of significant figures.

answer =............................. m

(5)

(Total 9 marks)

Q8. Some of the energy levels of an atom are shown below. The atom may be *ionised* by electron impact.



(a) (i) State what is meant by the ionisation of an atom.

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(ii) Calculate the minimum kinetic energy, in eV, of an incident electron that could ionise the atom from its ground state.

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(2)

(b) You may be awarded marks for the quality of written communication in your answer to parts (b)(i) and (b)(ii).

The atom in the ground state is given 5.00×10^{-17} J of energy by electron impact.

(i) State what happens to this energy.

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(ii) Describe and explain what could happen subsequently to the electrons in the higher energy levels.

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(4)

(c) Identify **two** transitions between energy levels that would give off electromagnetic radiation of the same frequency.

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and

__________ to __________

(2)
(Total 8 marks)

Q9. (a) When free electrons collide with atoms in their *ground state*, the atoms can be excited or ionised.

(i) State what is meant by ground state.

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(1)

(ii) Explain the difference between excitation and ionisation.

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(3)

(b) An atom can also become excited by the absorption of photons. Explain why only photons of certain frequencies cause excitation in a particular atom.

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(4)

(c) The ionisation energy of hydrogen is 13.6 eV. Calculate the minimum frequency necessary for a photon to cause the ionisation of a hydrogen atom. Give your answer to an appropriate number of significant figures.

answer ....Hz

(4)
(Total 12 marks)

Q10. (a) A fluorescent tube is filled with mercury vapour at low pressure. In order to emit electromagnetic radiation the mercury atoms must first be *excited*.

(i) What is meant by an excited atom?

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(1)

(ii) Describe the process by which mercury atoms become excited in a fluorescent tube.

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(3)

(iii) What is the purpose of the coating on the inside surface of the glass in a fluorescent tube?

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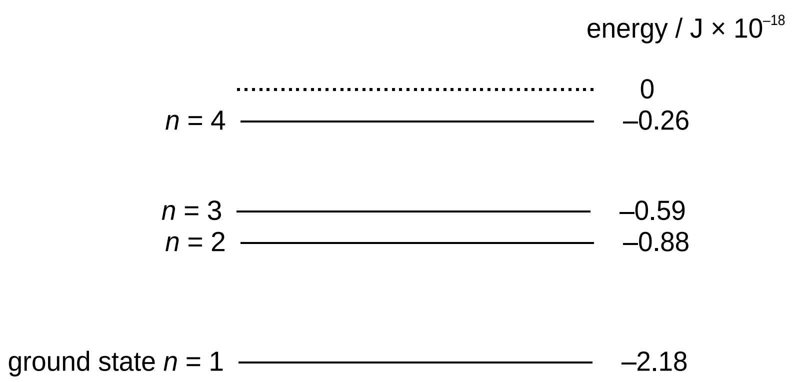
(3)

(b) The lowest energy levels of a mercury atom are shown in the diagram below. The diagram is **not** to scale.



(i) Calculate the frequency of an emitted photon due to the transition level $n = 4$ to level $n = 3$.

answer = ... Hz

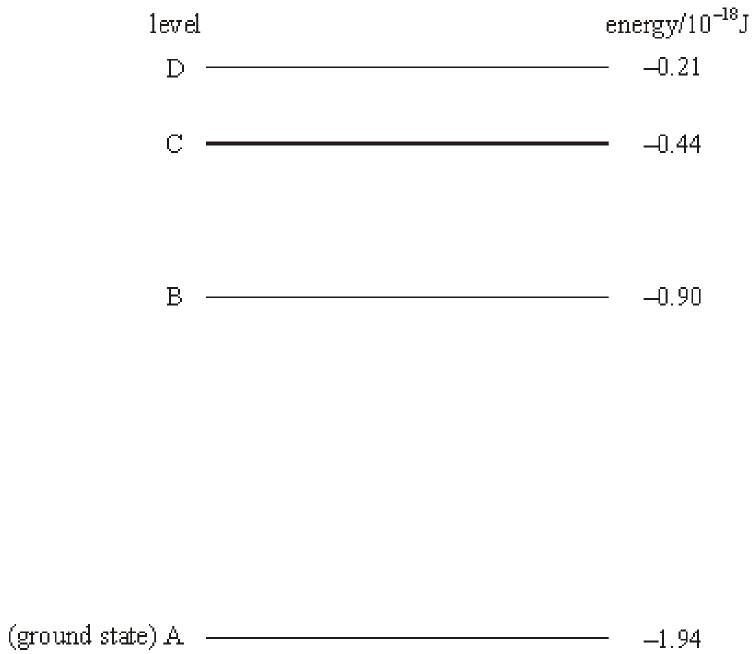
(3)

(ii) Draw an arrow on the diagram above to show a transition which emits a photon of a longer wavelength than that emitted in the transition from level $n = 4$ to level $n = 3$.

(2)

(Total 12 marks)

Q11. The diagram shows some of the electron energy levels of an atom.



An incident electron of kinetic energy 4.1×10^{-18} J and speed 3.0×10^{6} m s^{-1} collides with the atom represented in the diagram and excites an electron in the atom from level B to level D.

(a) For the incident electron, calculate

(i) the kinetic energy in eV,

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(ii) the de Broglie wavelength.

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(4)

(b) When the excited electron returns directly from level D to level B it emits a photon. Calculate the wavelength of this photon.

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(3)
(Total 7 marks)

Q12. A proton and an electron have the same velocity. The de Boglie wavelength of the electron is 3.2×10^{-8} m.

(a) Calculate,

(i) the velocity of the electron,

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(ii) the de Broglie wavelength of the proton.

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(4)

(b) (i) State what kind of experiment would confirm that electrons have a wave-like nature. Experimental details are not required.

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(ii) State why it is easier to demonstrate the wave properties of electrons than to demonstrate wave properties of protons.

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(2)
(Total 6 marks)