Introduction to Quantum Theory

2013 Revised AH Physics

Marks

10. The Bohr model of the atom suggests that the angular momentum of an electron orbiting a nucleus is quantised.

A hydrogen atom consists of a single electron orbiting a single proton. Figure 10A shows some of the possible orbits for the electron in a hydrogen atom.

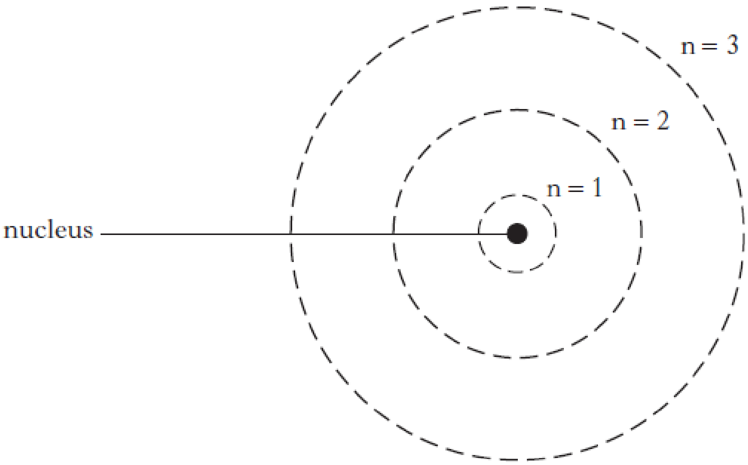

Figure 10A

The table shows the values of the radii for the first three orbits.

Orbit number, n	*Orbital radius*/10^{-10} m
1	0·53
2	2·1
3	4·8

(*a*) Calculate the speed of the electron in the orbit number 3. **2**

(*b*) Calculate the de Broglie wavelength associated with this electron. **2**

(*c*) Some of the limitations of the Bohr model of the atom are addressed by Quantum Mechanics.

(i) The position of an electron in a hydrogen atom was measured with an uncertainty of 0·15 nm.

Calculate the minimum uncertainty in its momentum. **2**

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6. In 1928 Davisson and Germer fired a beam of electrons through a very thin layer of nickel in a vacuum, which resulted in the production of a diffraction pattern.

(*a*) (i) What did they conclude from the results of their experiment? **1**

(ii) Give **one** example of experimental evidence that photons of light exhibit particle properties. **1**

(*b*) Calculate the de Broglie wavelength of an electron travelling at $4 \cdot 4 \times 10^6\,m\,s^{-1}$. **2**

(*c*) A 20 g bullet travelling at $300\,m\,s^{-1}$ passes through a 500 mm gap in a target.

Using the data given, explain why no diffraction pattern is observed. **2**

(*d*) (i) Describe the Bohr model of the hydrogen atom. **2**

(ii) Calculate the angular momentum of an electron in the third stable orbit of a hydrogen atom. **2**

(10)

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7. One of the key ideas in Quantum Theory is the Heisenberg Uncertainty Principle.

(*a*) The uncertainty in the position of a particle can be estimated as its de Broglie wavelength. An electron has an average speed of $3 \cdot 2 \times 10^6\,m\,s^{-1}$.

(i) Calculate the minimum uncertainty in the momentum of this electron. **3**

(ii) It is not possible to measure accurately the position of an electron using visible light. Describe the effect of using a beam of X-rays rather than visible light on the measurement of the electron's position and momentum. Justify your answer. **2**

(*b*) Polonium 212 decays by alpha emission. The energy required for an alpha particle to escape from the Polonium nucleus is 26 MeV. Prior to emission, alpha particles in the nucleus have an energy of 8·78 MeV. With reference to the Uncertainty Principle, explain how this process can occur. **2**

(7)

8. Werner Heisenberg is considered to be one of the pioneers of quantum mechanics.

He is most famous for his uncertainty principle which can be expressed in the equation

$$\Delta x \Delta p_x \geq \frac{h}{4\pi}$$

(a) (i) State what quantity is represented by the term Δp_x. **1**

(ii) Explain the implications of the Heisenberg uncertainty principle for experimental measurements. **1**

(b) In an experiment to investigate the nature of particles, individual electrons were fired one at a time from an electron gun through a narrow double slit. The position where each electron struck the detector was recorded and displayed on a computer screen.

The experiment continued until a clear pattern emerged on the screen as shown in Figure 8.

The momentum of each electron at the double slit is $6{\cdot}5 \times 10^{-24}$ kg m s^{-1}.

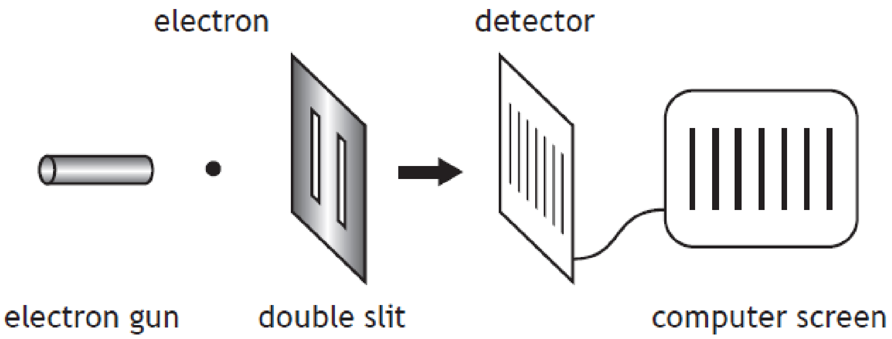

Figure 8 not to scale

(i) The experimenter had three different double slits with slit separations 0·1 mm, 0·1 μm and 0·1 nm.

State which double slit was used to produce the image on the screen.

You must justify your answer by calculation of the de Broglie wavelength. **4**

Space for working and answer

(ii) The uncertainty in the momentum of an electron at the double slit is $6{\cdot}5 \times 10^{-26}$ kg m s^{-1}.

Calculate the minimum absolute uncertainty in the position of the electron. **3**

Space for working and answer

(iii) Explain fully how the experimental result shown in Figure 8 can be interpreted. **3**

6. A student makes the following statement.

"Quantum theory — I don't understand it. I don't really know what it is. I believe that classical physics can explain everything."

Use your knowledge of physics to comment on the statement. **3**

7. Laser light is often described as having a single frequency. However, in practice a laser will emit photons with a range of frequencies.

Quantum physics links the frequency of a photon to its energy.

Therefore the photons emitted by a laser have a range of energies (ΔE). The range of photon energies is related to the lifetime (Δt) of the atom in the excited state.

A graph showing the variation of intensity with frequency for light from two types of laser is shown in Figure 7A.

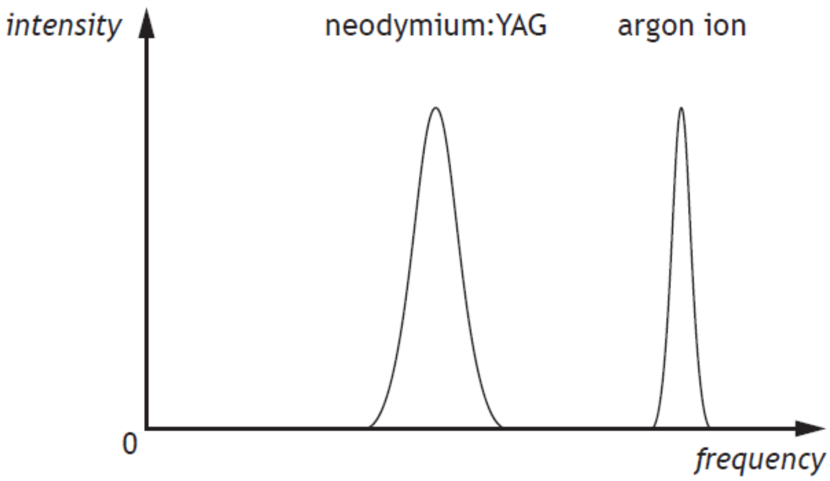

Figure 7A

(a) By considering the Heisenberg uncertainty principle, state how the lifetime of atoms in the excited state in the neodymium:YAG laser compares with the lifetime of atoms in the excited state in the argon ion laser.

Justify your answer. **2**

(b) In another type of laser, an atom is in the excited state for a time of $5{\cdot}0 \times 10^{-6}$ s.

(i) Calculate the minimum uncertainty in the energy (ΔE_{min}) of a photon emitted when the atom returns to its unexcited state. 3

(ii) Determine a value for the range of frequencies (Δf) of the photons emitted by this laser. 3