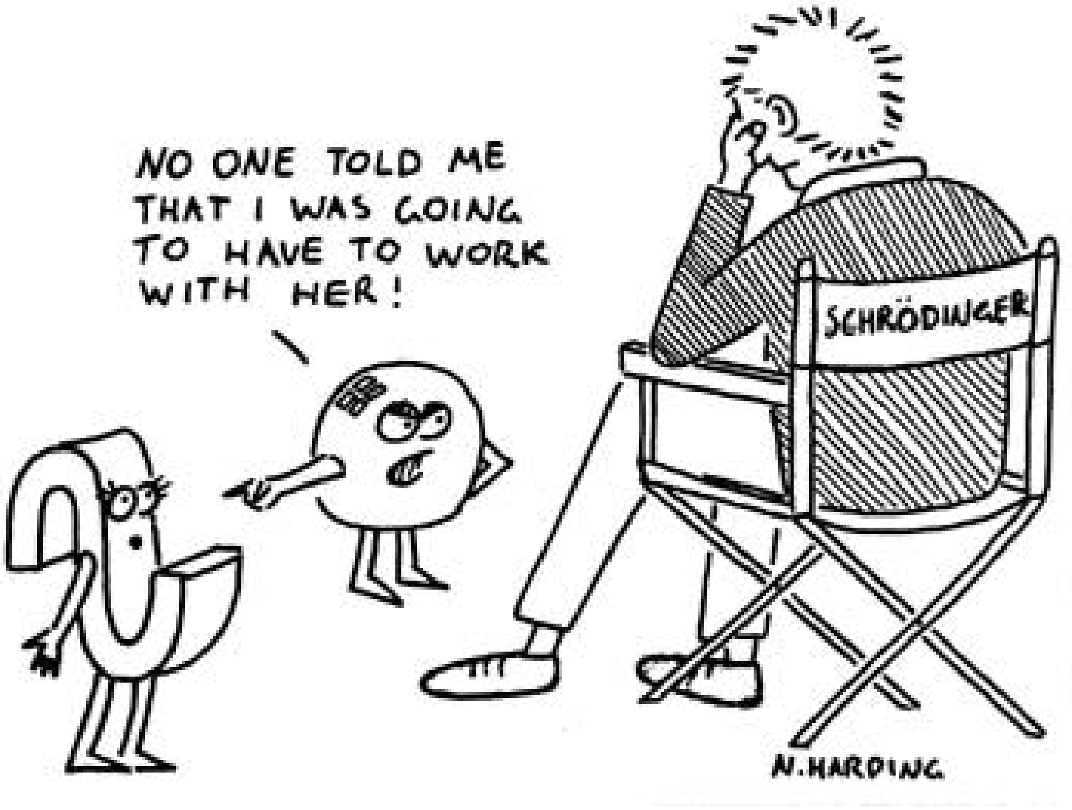
Advanced Higher Physics

Past Paper Questions

2.1 Quantum Theory



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.

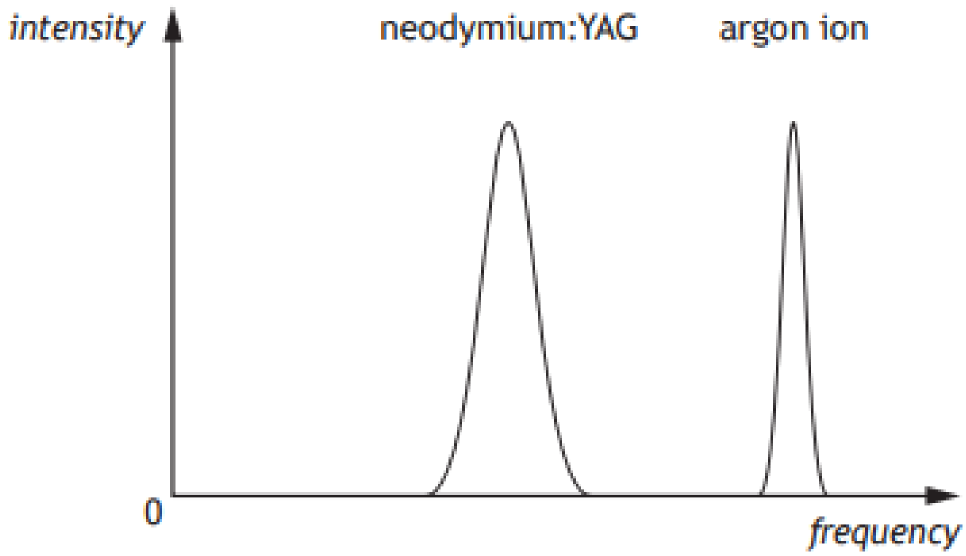


Figure 7A

(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**

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}.

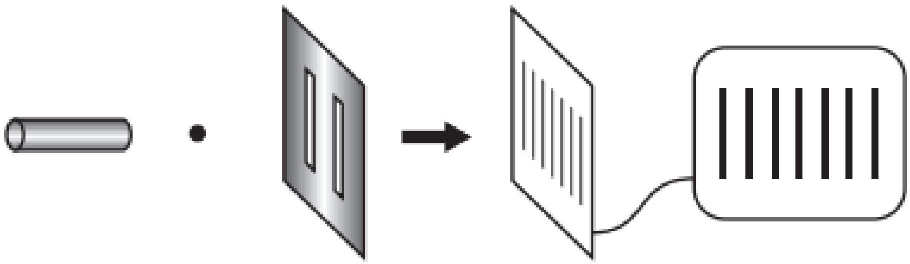


Figure 8 not to scale

(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**

(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**

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

2015

6. The Bohr model of the hydrogen atom consists of a single electron orbiting a single proton. Due to the quantisation of angular momentum, in this model, the electron can only orbit at particular radii.

Figure 6A shows an electron with principal quantum number n = 1.

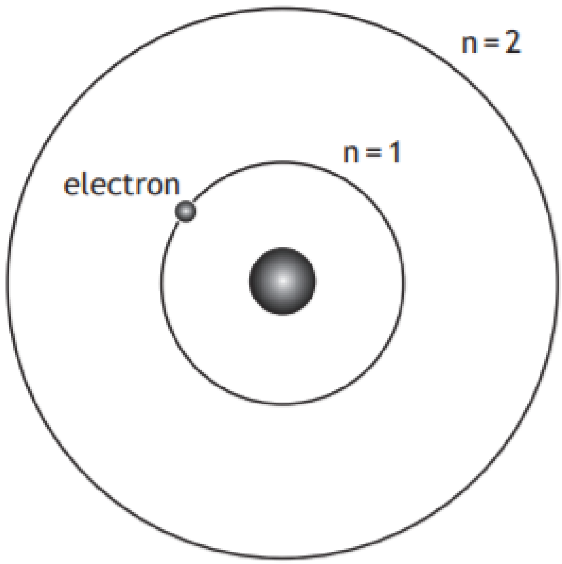


Figure 6A

(a) Explain what gives rise to the centripetal force acting on the electron. **1**

(b) (i) Show that the kinetic energy of the electron is given by

$$E_k = \frac{e^2}{8\pi\varepsilon_0 r}$$

where the symbols have their usual meaning. **2**

(ii) Calculate the kinetic energy for an electron with orbital radius 0·21 nm. **2**

(c) Calculate the principal quantum number for an electron with angular momentum $4{\cdot}22 \times 10^{-34}$ kg m^{2}s^{-1}. **3**

(d) Heisenberg's uncertainty principle addresses some of the limitations of classical physics in describing quantum phenomena.

(i) The uncertainty in an experimental measurement of the momentum of an electron in a hydrogen atom was determined to be $\pm 1{\cdot}5 \times 10^{-26}$ kg m s^{-1} .

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

(ii) In a scanning tunnelling microscope (STM) a sharp metallic tip is brought very close to the surface of a conductor. As the tip is moved back and forth, an electric current can be detected due to the movement ("tunnelling") of electrons across the air gap between the tip and the conductor, as shown in Figure 6B.

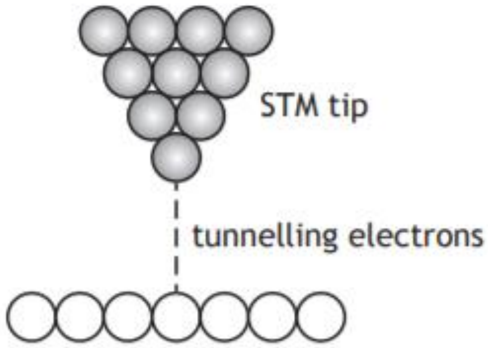


Figure 6B

According to classical physics, electrons should not be able to cross the gap as the kinetic energy of each electron is insufficient to overcome the repulsion between electrons in the STM tip and the surface.

Explain why an electron is able to cross the gap. **3**

11. The Nobel prize winning physicist Richard Feynman once stated "things on a small scale behave nothing like things on a large scale".

Using your knowledge of physics, comment on his statement. **3**

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)

Revised Advanced Higher2014

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**

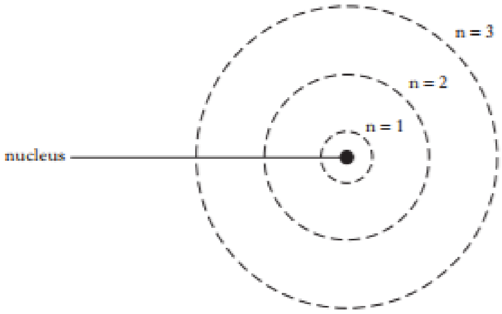
(*d*) (i) Describe the Bohr model of the hydrogen atom. **2**

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

(10)

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.



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**

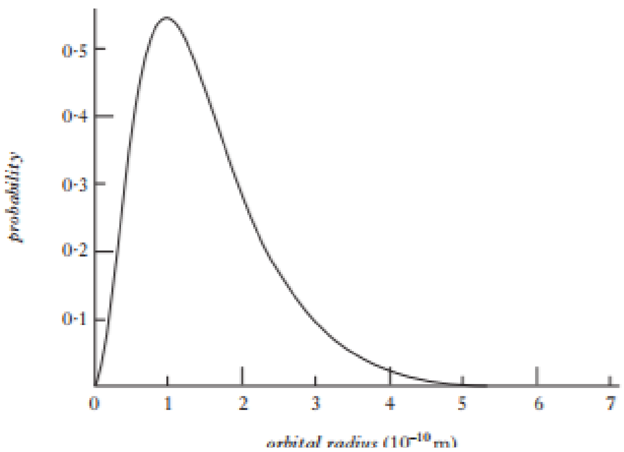
(*b*) Calculate the de Broglie wavelength associated with this electron. **2**

(*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**

(ii) A diagram of electron probability distribution for the hydrogen atom is shown in Figure 10B.



Comment on the position of the electron in this orbital. **2**

1. (*a*) A beta particle travelling at high speed has a relativistic mass 1·8 times its rest mass.

   (i) Calculate the speed of the beta particle. 2

   (ii) Calculate the relativistic energy of the beta particle at this speed. 2

   (iii) Name the force associated with beta decay. 1

   (*b*) Electrons exhibit both wave-like and particle-like behaviour.

   (i) Give **one** example of experimental evidence which suggests an electron exhibits wave-like behaviour. 1

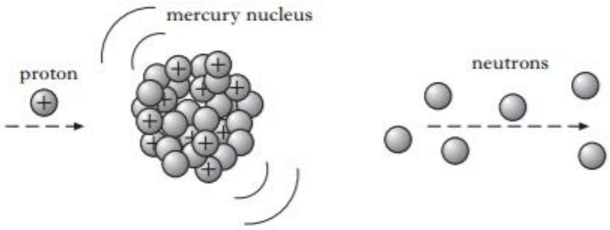
   (ii) Give **one** example of experimental evidence which suggests an electron exhibits particle-like behaviour. 1

(7)

Traditional 2011

Marks

1. In a process called "spallation", protons are accelerated to relativistic speeds and collide with mercury nuclei. Each collision releases neutrons from a mercury nucleus as shown in Figure 1.



(*a*) (i) The energy of a proton is $2{\cdot}08 \times 10^{-10}$ J. Calculate the relativistic mass of this proton. 2

(ii) Calculate the speed of this proton. 2

(*b*) A neutron produced in the spallation process is slowed to a non-relativistic speed, resulting in a kinetic energy of $3{\cdot}15 \times 10^{-21}$ J.

(i) Show that the momentum of the neutron is $3{\cdot}25 \times 10^{-24}$ kg m s^{-1}. 2

(ii) Calculate the de Broglie wavelength of this neutron. 2

(*c*) In a mercury nucleus, protons experience electrostatic repulsion, yet the nucleus remains stable.

(i) Name the force responsible for this stability. 1

(ii) Up to what distance is this force dominant? 1

(iii) Name the fundamental particles that make up protons and neutrons. 1

(11)

Traditional 2009

Marks

7. The Bohr model of the hydrogen atom states that the angular momentum of an electron is quantised.

(a) (i) Calculate the minimum angular momentum of the electron in a hydrogen atom. 2

(ii) When the electron has its minimum angular momentum it is in an orbit of radius $5 \cdot 3 \times 10^{-11}$ m. Calculate the linear momentum of the electron in this orbit. 2

(iii) Calculate the de Broglie wavelength of the electron in this orbit. 2

(b) One of the limitations of the Bohr model is that an orbiting electron is constantly accelerating and therefore should continuously emit electromagnetic radiation.

(i) What would happen to the orbit of the electron if electromagnetic radiation were to be continuously emitted? 1

(ii) What is the name of the branch of physics that provides methods to determine the electron's position in terms of probability? 1

(8)

Traditional 2008

Marks

4. (a) Electrons can exhibit wave-like behaviour. Give **one** example of evidence which supports this statement. 1

(b) The Bohr model of the hydrogen atom suggests a nucleus with an electron occupying one of a series of stable orbits.

A nucleus and the first two stable orbits are shown in Figure 6.

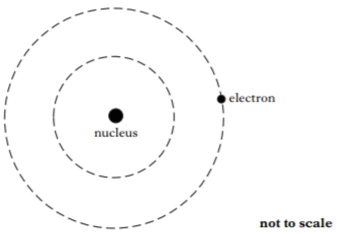


Figure 6

(i) Calculate the angular momentum of the electron in the second stable orbit. 2

(ii) Starting with the relationship

$$mrv = \frac{nh}{2\pi}$$

show that the circumference of the second stable orbit is equal to two electron wavelengths. 2

(iii) The circumference of the second stable orbit is $1 \cdot 3 \times 10^{-9}$ m.

Calculate the speed of the electron in this orbit. 2

(7)