QUESTION ONE: LIGHT FANTASTIC (8 marks)

Planck's constant = 6.63×10^{-34} J s
Speed of light = 3.00×10^{8} m s^{-1}

(a) When viewing white light from a glowing source through a spectroscope, a spectrum is seen. If a gas is now placed between the source and the spectroscope the spectrum shows dark absorption lines. Explain fully how these lines are formed.

(b) Discuss how diffraction and the photoelectric effect demonstrate the wave / particle nature of light.

(c) By using sensible estimates for the physical quantities involved, calculate how many visible photons per second are emitted by a 100 watt hot filament light bulb.

(d) Cold fusion, the supposed fusion of two deuterium nuclei at about room temperature, is thought to be unlikely. Discuss.

(8)

QUESTION TWO

Explain what is meant by the term **wave–particle duality**, provide a description of experimental evidence supporting the wave nature of light, and a further description supporting the particle nature of light.

QUESTION THREE: PHOTONS AND ELECTRONS

The distance between the surfaces of the Earth and Moon	$= 3.80 \times 10^{8}$ m
The charge on the electron	$= -1.60 \times 10^{-19}$ C
Speed of light	$= 3.00 \times 10^{8}$ m s^{-1}
Planck's constant	$= 6.63 \times 10^{-34}$ J s
Mass of the electron	$= 9.11 \times 10^{-31}$ kg

(a) Monochromatic light of wavelength 375 nm is incident on a metal surface. A potential difference of 1.31 V is required to cut off the flow of photoelectrons.

Calculate the work function of the metal.

(b) A 0.450 mW laser, of wavelength 581 nm, is pointing at the Moon. The laser beam spreads out at an angle of 1.65×10^{-3} radians.

Calculate the maximum number of photons arriving per second per square metre on the Moon.

(c) A photon of frequency f_1 and wavelength λ_1, is scattered by a stationary electron. The photon has a momentum, given by the de Broglie relationship, of $\frac{h}{\lambda_1}$.

Due to the interaction, a photon of frequency f_2 and wavelength λ_2 results. It travels in the opposite direction to the initial photon, and the electron gains energy of 4.00 keV, with velocity v in the same direction as the incident photon.

Calculate the value of λ_1.

The effects of special relativity can be assumed to be negligible.

(d) The number of electrons in a 1 gram sample of hydrogen is approximately twice the number of electrons in a 1 gram sample of any other light element (of atomic number less than 8).

Explain.

(8)

QUESTION FOUR: PARTICLES AND WAVES

(a) (i) Describe the photoelectric effect.

In your answer you should include a derivation of the relationship between the incident photon's frequency and the electron's kinetic energy, and how these relate to the work function of the metal.

(ii) The photoelectric effect was unable to be fully explained using classical physics.

Comment on this statement.

(b) Describe the similarities and the differences between the orbit of the Moon around the Earth and the orbit of an electron around a proton in a hydrogen atom.

(c) Sound from a small loudspeaker L reaches a point P by two paths, which differ in length by 1.2 m. When the frequency of the sound is gradually increased, the resultant intensity at P goes through a series of maxima and minima. A maximum occurs when the frequency is 1000 Hz, and the next maximum occurs at 1200 Hz.

(i) Explain what causes the maxima and minima to occur.

(ii) Calculate the speed of sound in the medium between L and P.

(8)

QUESTION FIVE: MODERN PHYSICS

(a) Albert Einstein and Niels Bohr provided explanations for the **photoelectric effect** and the **emission spectrum** of the hydrogen atom.

Explain in detail the key underlying physics of each explanation, and describe the fundamental physical connection between these two phenomena.

(b) With reference to the data below, explain how fission and fusion processes differ in their release of energy.

Binding energies per nucleon:

Deuterium	$^{2}_{1}H$	=	1.12 MeV
Helium	$^{4}_{2}He$	=	7.08 MeV
Iron	$^{56}_{26}Fe$	=	8.79 MeV
Uranium	$^{238}_{92}U$	=	7.57 MeV

$1eV = 1.6 \times 10^{-19}$ J

(c) Visible radiation with a continuous spectrum of wavelengths passes through hydrogen gas before passing through a diffraction grating. A series of dark lines (absorption spectrum) is produced in the resulting interference pattern.

Explain, in detail, why this occurs.

(8)

QUESTION SIX: MODERN PHYSICS (8 marks)

Charge on the electron = -1.6×10^{-19} C

Speed of light = 3.00×10^{8} m s^{-1}

In an experiment to investigate the photoelectric effect, light of wavelength λ is incident on a metal surface and a current is produced. The current is reduced by applying a potential difference V between the metal surface and the collecting plate.

(a) (i) When the current is reduced to zero, derive an equation relating λ, V and the work function, ϕ, of the metal.

Provide a full explanation of the derivation.

(ii) A classical wave explanation fails to explain the experimental results of the photoelectric effect.

Discuss this statement.

(b) (i) A nucleus of mass 3.93×10^{-25} kg, which is stationary with respect to an observer, undergoes fission. The nucleus breaks into two equal parts with total kinetic energy of 200 MeV.

The two parts are brought to rest.

Calculate the total decrease in the mass in kg and therefore calculate the individual rest mass of the two equal masses.

(ii) According to Einstein's special theory of relativity, the mass m of an object with a velocity v, relative to an observer, is given by:

$$m = m_0 \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}$$

where c is the speed of light, and m_0 (the rest mass) is the mass measured when $v = 0$ m s^{-1}.

Discuss the physical significance of this relationship.

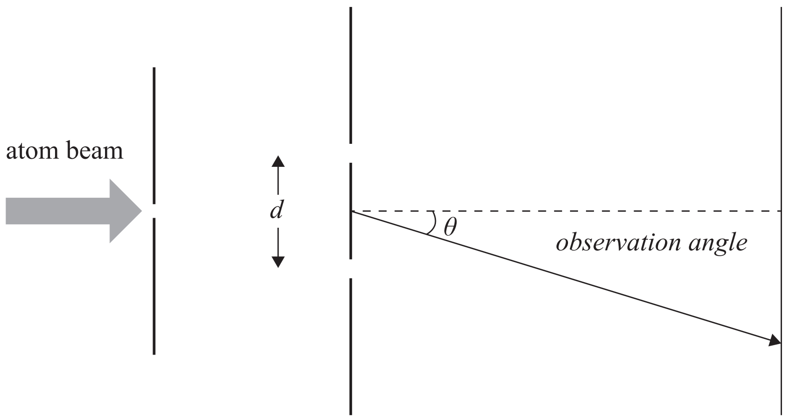
(iii) By considering the effects of the special theory of relativity, calculate the speed of the two masses in part (i) above, before they are brought to rest.

(8)

QUESTION SEVEN: WAVE/PARTICLE DUALITY (8 marks)

Matter, as well as light, can demonstrate wave-like behaviour and particle-like behaviour. The de Broglie relationship $\lambda = \frac{h}{p}$, where λ is the wavelength, p is the momentum and h is Planck's constant, can be verified by the experimental observation of the diffraction of atoms.

In the experiment below, a beam of atoms is incident on a double slit with slit separation d.



(a) Show that the de Broglie wavelength of an atom of mass m is related to its kinetic energy, E, by the following expression $\lambda = \frac{h}{\sqrt{2mE}}$.

(b) (i) Starting from $d\sin\theta = n\lambda$, derive an expression for the intensity maxima of the atom waves diffracted through the double slit, as a function of kinetic energy.

(ii) State the corresponding expression for the intensity minima.

One experimental difficulty is that the incident atoms have a range of kinetic energies. Assume that they have a range of energies distributed between $E + \Delta E$ and $E - \Delta E$, so that the mean energy is E.

(c) Explain why a range of energies will lead to poorly defined intensity maxima.

(d) The atom beam is incident on a diffraction grating. If the energy range $2\Delta E$ is too large, the interference fringe of the first order maximum will overlap the second order maximum.

Derive an expression for ΔE such that the first and second fringes have no overlap.

(8)