

**Nuclear and Atomic Physics Part I**  
**Past Examination Questions**

**Past Year I Questions:**

**1997 PH1.2: 1a)** Find the wavelength of light associated with photons of energy 3 eV. What is the energy of electrons whose de Broglie wavelength is the same? [4]

**b)** An electron in a hydrogen atom has principal quantum number  $n = 2$ . What are the possible values of the angular momentum quantum number  $l$ ? Calculate the maximum value of the  $z$ -component of its angular momentum. [3]

**c)** Explain briefly why the radius  $R$  of a nucleus of mass number  $A$  is given approximately by the formula

$$R = R_0 A^{\frac{1}{3}}$$

where  $R_0$  is a constant. [3]

**1998 PH1.2: 1a)** An electron has a kinetic energy of 3.0 eV. Calculate its momentum and de Broglie wavelength. [2]

**b)** An electron on a hydrogen atom has principal quantum number  $n = 3$ . What are the possible values for the angular momentum quantum number  $l$ ? For each value of  $l$  calculate the magnitude of the orbital angular momentum. [3]

**c)** In a photo-electric cell, light of wavelength 250 nm shines in a metal surface whose work function is 2.0 eV. Calculate the maximum kinetic energy of the emitted electrons. [2]

**d)** Calculate the frequency and wavelength of the light emitted when an electron moves from a state with an energy of -3.4 eV to a state of energy -13.6 eV. [3]

**1998 PH1.2: 3a)** The Binding Energy of a nucleus mass  $M$  is written

$$\text{BE} = (Nm_n + Zm_H - M) c^2.$$

Define all the terms used on the right hand side of this equation. [5]

**b)** Describe the features of the strong nuclear force which binds the nucleus and contrast it with the Coulomb force which binds electrons in atoms. [5]

**c)** The volume of a nucleus is found to be proportional to  $A$ , or its radius is proportional to  $A^{\frac{1}{3}}$ , and the binding energy is found to be approximately proportional to  $A$  when  $A \geq 50$ . Show that the features of the strong nuclear force can explain these observations. [5]

d) Compare and contrast nuclear fission and nuclear fusion in the context of nuclear binding energies. [5]

**1998 EP1.2: 1a)** Describe the photoelectric effect and state why the explanation of this was important to the development of modern physics. [4]

b) How are the sharp lines in X-ray spectra produced? [2]

c) Outline the process of nuclear fusion which release energy in the sun. Why has it been so hard to develop fusion for use in power stations on earth? [4]

**1998 EP1.2: 2a)** List the four quantum numbers which label the electrons in an atom, and state the restrictions imposed by quantum physics on the values of these numbers. [6]

b) Explain how the Pauli exclusion principle and the range of quantum number values discussed above yield an understanding of the electronic structure of the atoms in shells and sub-shells when arranged in the periodic table of elements. [7]

c) List the quantum numbers for the three electrons in a lithium atom, and for the eleven electrons in a sodium atom. Lithium and sodium are among the alkali metals. How does your list help you explain their properties and chemistry? [7]

**1999 Physics Ep1.2 3a)** What is the mass defect for an atomic nucleus? Discuss the relationship between the binding energy of the nucleus and the mass defect. [4]

b) Calculate the average binding energy per nucleon for the Lithium isotope  ${}^6_3\text{Li}$ , using the following data:  $M_1\text{H} = 1.007825u$ ,  $m_n = 1.008665u$ ,  $M_6\text{Li} = 6.01512u$ , and  $1u = 931.5 \text{ MeV/u}$ . [7]

Draw a graph to indicate how the average binding energy per nucleon depends upon the mass number  $A$  of a nucleus. Outline why this energy is reduced by the Coulomb force for nuclei with large values of  $A$ , and by the surface effects for nuclei with small  $A$  values. [7]

Describe the process of nuclear fission for very heavy isotopes, and use your graph from the previous part of this question to explain why the process leads to a release of energy. Outline how a chain reaction occurs, and briefly describe how this leads to the concept of a critical mass for the fissionable isotope. [7]

### Past Year II Questions:

**1997 Physics 2.1: 1a)** In the Stern-Gerlach experiment a beam of neutral silver atoms was split into two by a non-uniform magnetic field. Explain the significance of this result. [3]

**b)** What experimental observations on the nuclear  $\beta$ -decay necessitate the existence of the neutrino? [4]

**c)** Explain briefly, with the aid of a graph, how the Binding Energy per Nucleon in a nucleus varies with  $A$  value. [4]

**1997 Physics 2.1: 2a)** Explain the physical significance of each of the four quantum numbers which characterise the eigenstates of the electron in a hydrogen atom. What are the allowed values for each? [8]

**b)** Describe the changes in the energy levels of the hydrogen atom when it is placed in a uniform magnetic field. [6]

**c)** The splitting of the energy levels is given by  $\Delta E = \mu_B B (m_l + 2m_s)$ . Explain the meaning of each of the symbols and the significance of the factor 2. Show that this implies that the total magnetic moment and the total angular momentum are not anti-parallel. [6]

**1997 Physics 2.1: 3b)** Compare and contrast the processes of  $\alpha$  and  $\beta$  decay, paying particular attention to the types of nuclei which are unstable with respect to these decays, and the interaction responsible. How would you expect the energy of the emitted particle to depend on the lifetime of the parent nucleus? [10]

**1995 Physics 1: 1a)** With the aid of a suitable diagram, describe the characteristic features of the X-ray spectra emitted by atoms of high atomic number. [5]

**1995 Physics 1: 2a)** Explain why in an alkali metal with atomic number  $Z$ , the potential energy of an electron at large  $r$  is:

$$V(r) = \frac{-e^2}{4\pi\epsilon_0 r}$$

and at small radius  $r$ :

$$V(r) = \frac{-Ze^2}{4\pi\epsilon_0 r}$$

**b)** How does the orbital angular momentum of an electron influence the value of its total energy? [5]

**1995 Physics 1: 3a)** Draw a sketch of the magnitude of the binding energy per nucleon of atomic nuclei as a function of nucleon number. Indicate the appropriate scale on each of the axes.

With reference to your sketch, give a brief explanation of fission and fusion processes. [10]

**b)** In the Semi-Empirical Mass Formula (SEMF), the coulomb term is proportional to  $Z^2/A^{1/3}$ . Explain the form of this  $Z$  and  $A$  dependence. [5]

**1996 Physics 1: 2a)** Define the terms *Binding Energy* of an atomic nucleus, *Q-value* of a nuclear reaction.

Show how the  $Q$  value is related to the binding energies of the nuclei involved in a nuclear reaction. [6]

**b)** Sketch a graph of the variation of the binding energy per nucleon (BEPN) with the atomic mass number  $A$  of the nucleus. The liquid drop model of the nucleus leads to the Semi-Empirical mass formula (SEMF) which is a good representation of the BEPN curve. Describe the nuclear properties modeled in each of the five terms of the SEMF. [10]

**1996 Physics 1: 3a)** Describe the four quantum numbers normally used to label the states of the electron in the Hydrogen atom. [4]

**b)** The electron configuration for the sodium ( $^{11}\text{Na}$ ) atom is written  $1s^2 2s^2 2p^6 3s^1$ . Explain the meaning of the symbols  $s$  and  $p$  in this configuration and show how it is a direct consequence of the Pauli Exclusion Principle. [6]