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THE OPEN UNIVERSITY OF SRI LANKA
DEPARTMENT OF PHYSICS
B.SC. DEGREE PROGRAMME – 2011/2012
LEVEL 05
ATOMIC AND NUCLEAR PHYSICS – PHU 3143/PHE 5143
FINAL EXAMINATION

Time allowed: Two hours (2 hrs.)

Date: 15th November 2012 **Time: 1.30 pm – 3.30 pm**

Answer FOUR (04) questions only.

(Useful Date:

Charge on an electron, $e = 1.6\times10^{-19}\,C$

Permittivity of free space $\varepsilon_0 = 8.85\times10^{-12}\,C^2N^{-1}m^{-2}$

$$\frac{1}{4\pi\varepsilon_0} = 9\times10^{9}\,Nm^2C^{-2},$$

$$1fm = 10^{-15}\,m,$$

Avogadro's number $= 6.02\times10^{23}$ atoms per mole,

$$1u = 931.5\text{ MeV}$$

Mass of an electron $m_e = 9.1\times10^{-31}\,kg$

Planck's constant $h = 6.63\times10^{-34}\,Js,$

$$\hbar = \frac{h}{2\pi} = 1.06\times10^{-34}\,Js,$$

$$1eV = 1.6\times10^{-19}\,J,$$

Velocity of light $C = 3\times10^{8}\,ms^{-1}$)

(01) (a) Derive the decay law $N = N_0e^{-\lambda t}$

(b) At a certain instant, a piece of radioactive material contains 10^{12} atoms. The half life of the material is 30 days.

(i) Calculate the number of disintegrations in the first second.
(ii) What time will elapse before 10^4 atoms remain?

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(c) Assume that all the ^{206}Pb found in a given sample of uranium ore resulted from decay of ^{238}U and that the ratio of $^{206}Pb/^{238}U$ is 0.60. How old is the ore? (Half-life of $^{238}U = 4.47\times10^{9}$ years)

(d) A small amount of solution containing ^{24}Na radionuclide with activity 2.0×10^{3} Bq was injected in the blood stream of a man. The activity of $1\ cm^{3}$ of blood sample taken 5 hours later turned out to be 16 disintegration per minute per cm^{3}. The half-life of ^{24}Na is 15 hours. Estimate the volume of the man's blood.

(02) (a) What are the properties of α, β and γ radiations.

(b) (i) The ^{226}Ra nucleus undergoes alpha decay according to equation given below.

$$^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

Calculate the Q value for this process.

(The Atomic masses are:

$$^{226}_{88}Ra = 226.025403u$$

$$^{222}_{86}Rn = 222.017570u$$

$$^{4}_{2}He = 4.002605u\,).$$

(ii) Suppose you measured the kinetic energy of the alpha particle from this decay. Would you measure 4.87 MeV?

(c) Show that ^{55}Fe may undergo electron capture, but not β^{+} decay.
The two possible reactions are:

$$^{55}_{26}Fe \rightarrow {}^{55}_{25}Mn + \beta^{+} + \nu^{-} \leftarrow \beta^{+} \text{ decay}$$

$$^{55}_{26}Fe + e^{-} \rightarrow {}^{55}_{25}Mn + \nu \leftarrow \text{Electron cupture}$$

(The Atomic masses are:

$$^{55}_{26}Fe = 54.938298u$$

$$^{55}_{25}Mn = 54.938050u$$

$$m_{e} = 0.000549u)$$

(d) $^{20}_{9}F$ decays to the ground state of $^{20}_{10}Ne$ as follows.

$$^{20}_{9}F \rightarrow ^{20}_{10}Ne^{*} + e^{-} + \bar{\nu}$$
$$\quad\quad\quad\quad\quad\quad \llcorner\; ^{20}_{10}Ne + \gamma$$

Where $^{20}_{10}Ne^{*}$ is an excited state of $^{20}_{10}Ne$
If the maximum kinetic energy of the emitted electrons is 5.4 MeV and γ - ray energy is 1.6 MeV determine the mass of $^{20}_{9}F$.
[Atomic mass of Ne = 19.99244u]

(03) (a) Consider a chain disintegration which starts with a pure radioactive source containing N_0 parent nuclei at time t = 0. If N_1 and N_2 are the number of parent and daughter nuclei at a time t, show that

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_0 \left[e^{-\lambda_1 t} - e^{-\lambda_2 t} \right]$$

Where λ_1 and λ_2 are the decay constants of the parent and daughter nuclei, respectively. Further, if $\lambda_1 << \lambda_2$ and the half-life of the parent nucleus is very long as compared to t, then show that the daughter nucleus approaches a constant value given by $N_2 = \frac{\lambda_1}{\lambda_2} N_0$

(b) It has been experimentally observed that uranium minerals that are sufficiently old to have attained radioactive secular equilibrium contain one atom of radium for every 2.8×10^6 atoms of ^{238}U. If the half-life of radium is 1620 years, calculate that of uranium.

(04) (a) What is meant by fusion and fission? Give one specific example of each kind of reaction, explaining how each is induced.

(b) When an atom of ^{235}U undergoes fission in a reactor, about 200 MeV of energy is liberated. Suppose that a reactor using ^{235}U has an output of 700 MW and is 20% efficient.

(i) How many uranium atoms does it consume in one day?
(ii) What mass of uranium does it consume each day?

(c) Consider the fusion reaction

$$6\ {}^{2}_{1}H \rightarrow 2\ {}^{4}_{2}He + 2p + 2n + Q$$

$$Q = 43\ MeV$$

Determine the amount of energy that will be generated by fusing all the nuclei in 1 kg of deuterium in such a reaction.

(05) (a) What are the Bohr's postulates?

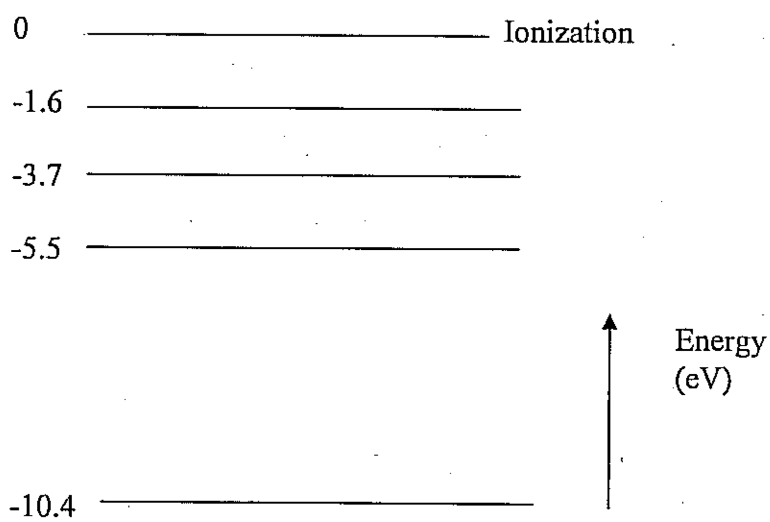
(b) The quantization condition of Bohr's theory of the hydrogen atom is,

$$m_e v_n r_n = n\hbar = \frac{nh}{2\pi}$$

Where, v_n – The velocity of an electron in the n^{th} orbit.
r_n - The radius of the n^{th} orbit.

Use Bohr's quantization condition and classical mechanics to find the total energy of the n^{th} orbit in the hydrogen atom. Express the ground state energy in terms of physical constants.

(c) The diagram shows some of the outer energy levels of the mercury atom.



(i) Calculate the ionization energy in joules for an electron in the – 10.4 eV level.

(ii) An electron has been excited to the – 1.6 eV energy level. Show on the diagram all the possible ways it can return to the – 10.4 eV level.

(iii) Which change in energy levels will give rise to a yellowish line $(\lambda = 600nm)$ in the mercury spectrum?

(06) (a) What is the difference between Rutherford's model and the Bohr's atom model.

(b) A beam of alpha particles of energy 8.2 MeV is scattered by a thin gold foil. (For gold Z = 79)

(i) Find the distance of closest approach for the alpha particles.
(ii) What is the corresponding impact parameter for a scattering angle of 10°.

(c) In Rutherford's analysis of the scattering of alpha particles by thin foils the angle of deflection of an incident particle, ϕ, is given by,

$$\cot\frac{\phi}{2} = \left(\frac{4\pi\varepsilon_0}{ZeQ}\right).mv^2b$$

Where m, v and Q are the mass, velocity and charge of the alpha particle respectively. b is the impact parameter. Use this expression to derive a relation for the probability that the particle should be deflected through an angle greater than ϕ on passing through a thin foil. If this probability is 10^{-3} for 10 MeV alpha particles, what is it for 5 MeV protons passing through the same foil?