R1-2002 Q1(b)

b) U_{92}^{238} has a very long half life and decays through a series of daughter products ending with a stable isotope of lead. Very old samples of U_{92}^{238} ore, which have not undergone physical or chemical changes, would be expected to show an equilibrium between the daughter elements provided that their half life was considerably shorter than that of U_{92}^{238}. Analysis of an ore of U_{92}^{238} shows that for each 1.00 g of U_{92}^{238} there is 0.300 μ g o Ra_{88}^{226} . The half life of Ra_{88}^{226} is 1602 years.
What is the half life of U_{92}^{238} ? [8]

R1-2004 Q1(h)

h) According to the special theory of relativity a mass, m, with velocity v, relative to an observer, is given by:

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

where m_0 is the mass measured when $v = 0$. c is the speed of light.
A $^{238}_{92}U$ nucleus, mass of 2.21×10^5 Mev/c^2, stationary with respect to an observer, undergoes fission and breaks into two equal parts with a total kinetic energy of 200 Mev (1ev =1.60×10^{-19}J). If the two parts are brought to rest, what is the total decrease in mass in kg? What speed did the two masses have?

[8]

R1-2006 Q1(k)

(k) Using the data in Table 1.k, calculate the mass change and the energy released when 10.0 kg of ${}^{235}_{92}U$ undergoes the fission reaction (1u = 931 MeV):

$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3{}^{1}_{0}n$$

Nucleus	Mass / u
${}^{235}_{92}U$	235.04
${}^{141}_{56}Ba$	140.91
${}^{92}_{36}Kr$	91.91
${}^{1}_{0}n$	1.01

Table 1.k

[4]

R1-2007 Q1(a)

(a) How does the proton number, Z, and the nucleon number, A, of a nucleus change due to:

(i) the emission of an alpha particle ?
(ii) the emission of a beta particle ?
(iii) the fusion with a deuterium nucleus ?

[3]

R1-2007 Q1(g)

(g) A uranium bearing rock contains 9 uranium atoms to every 8 helium atoms. Assuming the decay process, which converts a uranium atom into a lead atom, involves the emission of 8 alpha particles, calculate the age of the rock. The half life of uranium is 4.5×10^9 years.

[5]

R1-2008 Q1(k)

(k) Determine the energy released when a deuterium, D, and a tritium, T, nucleus are fused together to yield a neutron, n, and a helium, He, nucleus. The masses of these particles are given in Table 1.j.

Particle	Mass
D	2.01410u
T	3.01605u
n	1.00867u
He	4.00260u

Table 1.k

$u = 1.66050 \times 10^{-27}$ kg. [4]

R1-2008 Q1(n)

(n) The present day abundances of the isotopes U^{238} and U^{235} are in the ratio 140:1. They have half lives, respectively, of 4.5×10^9 and 7.1×10^8 years. Estimate the age of the Earth assuming that equal amounts of each isotope existed at the formation of the Earth.

[7]

R1-2012 Q1(j)

(j) Determine the binding energy per nucleon, in MeV, of an alpha particle.

Mass of proton = 1.0080 u
Mass of neutron = 1.0087 u
Mass of alpha particle = 4.0026 u
1 u = 930 MeV/c^2

[3]

R1-2012 Q1(m)

(m) A radioactive substance, with a half-life of T, contains a particular nucleus that has NOT decayed over an observational period of $5T$. What is the probability that it will decay over a further period of (i) T and (ii) $3T$?

[4]

R1-2013 Q1(d)

(d) Determine the half-life, T, of a substance with activity that decreases by 1.00 % in 10^8 s (approximately 3 years).

[5]

R1-2013 Q1(k)

(k) Sketch, on the same diagram, the paths of three alpha particles, of the same energy, which are directed towards a fixed nucleus so they are deflected through (i) 10^o, (ii) 90^o, and (iii) 180^o. If the nucleus in (iii) is not fixed, what is the relative velocity of the two particles at the distance of closest possible approach?

[5]

R1-2011 Q1(f)

f) The potassium isotope $^{42}K_{19}$ disintegrates into $^{42}Ca_{20}$.

(i) What are the likely source/s of radiation produced?
(ii) How many protons, neutrons and electrons are present in an atom of the daughter nucleus $^{42}Ca_{20}$?

[3]

R1-2012 Q1(b)

(b) The energy levels, E_n, of the hydrogen atom are given by

$$E_n = \frac{-2.16 \times 10^{-18}}{n^2} \text{ J, where } n \text{ is a positive integer.}$$

(i) What is the ionization energy of the atom?
(ii) What is the wavelength of the H_α line, which is due to transitions from the $n = 3$ to $n = 2$ level?

[4]

R1-2012 Q1(i)

(i) The electron gun of a cathode ray tube consists of a small hot filament F which is located at $x = 0$, Figure 1.i, and which produces electrons in the x-y plane of the page with a *very small* range of velocities. A typical electron has velocity components v_x and v_y. Between $x = 0$ and $x = d$ there is a horizontal uniform electric field, E, which accelerates the electrons produced at the filament to velocities which are much greater than v_x and v_y. The electrons emerge from the field, beyond $x = d$, travelling in straight lines. Show that the paths of the emerging electrons, when projected back, appear to have come from a point along the axis at approximately $x = -d$.

[6]

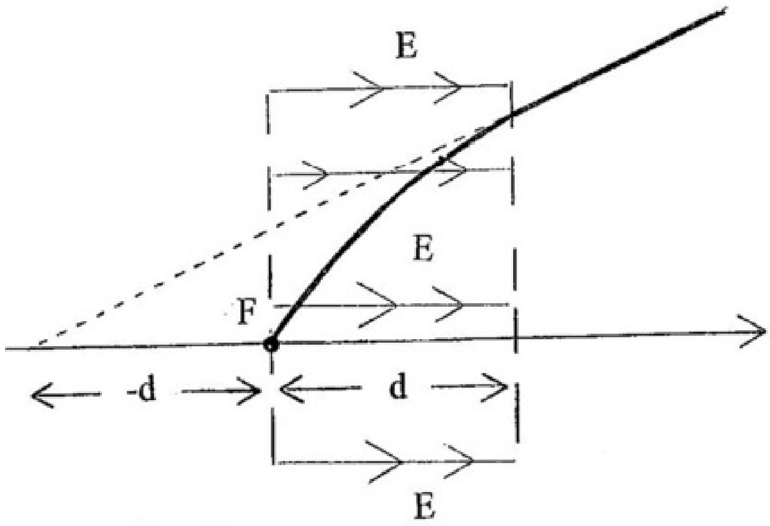

Figure 1.i

R1-2009 Q1(o)

(o) An electron and a positron annihilate each other to produce two γ-rays. Calculate the minimum energy of the photons ?

[3]

R1-2009 Q4

(a) (i) Determine the relationship between the decay constant λ and the half life τ of a radioactive source ?

(ii) How long would it take for 87.5% of the atoms in Pb^{209}, with a half life of 3.3 hours, to decay ?

[8]

(b) A small volume of solution, containing a radioactive isotope of sodium, has an activity of 1200 disintegrations per minute when injected the blood stream of a patient. After 30 hours the activity of a 1.00 cc sample of the blood is 0.50 disintegrations per minute. If the half life of the sodium isotope is 15 hours, determine the volume of blood in the patient's body.

[5]

(c) A point source of γ- rays has a half life of 30 minutes. The initial count rate, determined by a Geiger counter placed 2.0 m from the source, is 360 s^{-1}. The distance between the counter and the source is changed. After 90 minutes the count rate is 5.0 s^{-1}. What is distance between the source and the counter ?

[7]

R1-2005 Q3

An element A is radioactive, with decay constant λ_1, and decays to element B. B decays, with decay constant λ_2, where $\lambda_2 >> \lambda_1$, to the stable element C. At time t the number of atoms of A is $N_1(t)$ and the number of atoms of B is $N_2(t)$. N_0 is the total number of atoms. The ratio $R = (N_2/N_0)$ can be shown to be given by

$$R = \frac{\lambda_1}{(\lambda_2 - \lambda_1)}\left[e^{-\lambda_1 t} - e^{-\lambda_2 t}\right].$$

a) Sketch a graph of R as a function of t. [3]

b) Obtain the approximate variation of R with t for:

(i) t is small

(ii) λ_2, knowing λ_1? [6]

d) From the equation for R above deduce the approximate relationship

$$N_2\lambda_2 = N_1\lambda_1 .$$

State the conditions under which it is valid. [5]

e) Sketch the behaviour of $N_3(t)$, the number of C atoms, against t. [2]

Useful relation for small x

$e^x = 1 + x + \ldots$

R1-2005 Q7

a) The relativistic energy E of an electron with momentum p is given by

$$E^2 = p^2c^2 + m_e^2c^4.$$

(i) What is understood by the rest energy of the electron?

(ii) Deduce an expression for the kinetic energy, T, of the electron.

[4]

b) A photon of frequency f is scattered through an angle of 90^0 by an initially stationary electron. After the collision the photon has a frequency f'. The electron acquires relativistic momentum p directed at an angle θ to the incident photon.

(i) Write down the conservation equations for this collision.

(ii) Prove that

$$c^2p^2 = h^2(f^2 + f'^2)$$

and

$$f' = \left(1 + \frac{hf}{m_ec^2}\right)^{-1} f.$$

[13]

Momentum of a photon, frequency f, is hf/c.

c) What can be deduced about f', θ and p when $hf << m_ec^2$? [3]

Useful relationship: $\sin^2\theta + \cos^2\theta = 1.$

R1-2006 Q6

Q6.

(a)

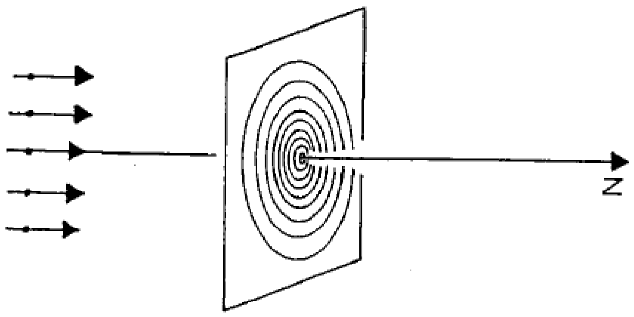

Figure 6.1

A uniform parallel beam, of alpha particles, number per unit volume ρ and velocity u, each consisting of two protons and two neutrons, travels along the z-axis. Consider a plane perpendicular to the z-axis consisting of concentric circles, centres on the z-axis, with radii nt, where the constant t is the radial distance between adjacent circles and n is an interger (0, 1, 2, 3…), Figure 6.1.

(i) Determine the number N of alpha particles per second that pass through an annulus between the nth and $(n+1)th$ circle.

(ii) Sketch the graph of N against n.

[3]

(b) The beam of alpha particles encounters a **fixed** gold nucleus, along the z-axis, consisting of 79 protons and 118 neutrons, Figure 6.2.

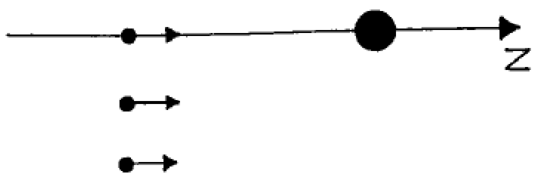

Figure 6.2.

(i) Sketch the trajectories of the three alpha particles indicated in Figure 6.2.

(ii) Why are relatively few particles scattered through large angles?

(iii) What is the largest angle through which a particle is scattered?

(iv) Why do bound electrons, in orbit around the gold nucleus, have a negligible influence on the alpha particle trajectories?

[5]

(c)

(i) Determine the distance of closest approach, r_1, of an alpha particle to the nucleus.

(ii) If the gold nucleus is free to move and initially at rest, what is the velocity of an alpha particle *relative* to the gold nucleus at the distance of closest approach, r_2? Determine r_2 in this case.

Assume the masses of the neutron and proton are both equal to m.

[12]

R1-2008 Q7

A radioactive source contains a mixture of two unrelated radioactive substances, A and B, with decay constants, λ_A and λ_B ; A has the larger decay constant. A counter which is 60% efficient at detecting all the decays of nuclei A, but only 11% efficient for those of substance B. At time $t = 0$, A and B produce N_A and N_B counts per minute, respectively. The results of the experimental measurements for the total counts are given in Table 7.1.

t Time / days	N Counts / min.
0.5	7000
2.0	620
5.0	142
9.0	76
15.0	28

Table 7.1

(a) (i) Write down the equation for N, the number of counts per minute detected by the counter.

(ii) Deduce the behaviour of N for large t.

(iii) Using (ii) plot a suitable graph in order to determine N_B and λ_B.

(iv) What is the initial number of B atoms present ?

[15]

(b)

(i) Extrapolate the graph to obtain a value of N at time $t = 0$ and hence determine N_A.

(ii) Using the first experimental result in Table 7.1, determine λ_A. [5]

R1-2004 Q9

Time (min)	R (counts/s)
4·00	392.2
68·00	65.5
132·00	10.9
196·00	1.86

a) The table shows some measurements of the decay rate of a sample of ^{128}I, a radionuclide often used medically as a trace to measure the rate at which iodine is absorbed by the thyroid gland.
Determine the disintegration constant λ and the half-life $T_{1/2}$ for this radionuclide.

[13]

b) Element A is an alpha particle emitter with a half life of 1.0×10^8 years. The decay product B has a half life of 60 s. It decays by beta decay to element C, which is stable. It is thought that A was formed in the supernova that produced the solar system. A sample of rock on Earth contains all three elements.

(i) What will happen to the proportions of A, B, and C during a year?

(ii) The ratio of the number of atoms of C to those of A is 1.0×10^{11}. When did the supernova occur?

(iii) What assumptions did you make to determine the date of the supernova?

[7]

R1-2008 Q8

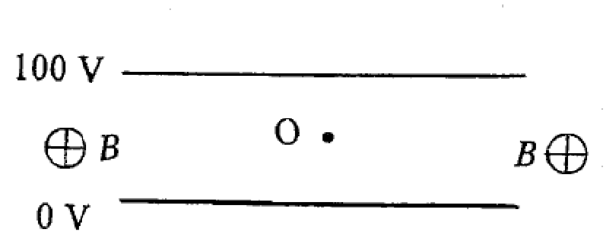

Figure 8.1 Side View

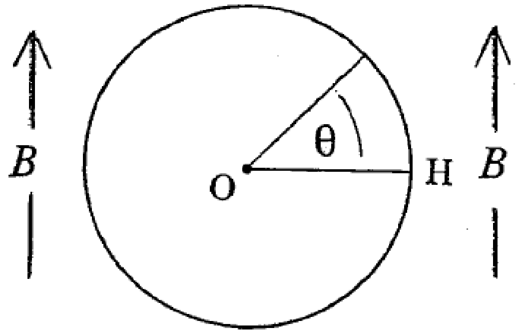

Figure 8.2 Plan

Two parallel circular conducting plates, 1.00 mm apart, are in an evacuated vessel. The plates are at a potential difference of 100 V and situated in a constant magnetic field of flux density B = 0.010 T parallel to the surface of the plates, Figures 8.1 and 8.2.

A radioactive source of beta particles , with maximum energy of 15.0 keV, is located, symmetrically, at the centre, O, of the gap between the plates.

(a) Determine using classical physics:

(i) the electric force on a beta particle
(ii) the order of magnitude of the ratio of the gravitational to the electric force on a beta particle
(iii) the maximum speed of the beta particle at O
(iv) the condition for beta particles, travelling in the horizontal plane through O, to emerge from the plates
(v) the range of speeds of the emerging beta particles from the plates
(vi) the angular range of θ, Figure 8.2, of the beta particles in (v) [15]

(b) (i) The calculations in (a) assume that the beta particles are not travelling with relativistic speeds. Is this assumption justified ? Give a quantitative answer.

The relativistic mass m of the electrons is given by

$$m = m_0 \ (1 - v^2 / c^2)^{-1/2} ,$$

where $m_0 = m_e$, the rest mass of the electron, and v is the speed of the electron.

(ii) How does the kinetic energy of a relativistic electron differ from that of a non-relativistic particle ?

[5]

R1-2010 Q7

(a) The abundances of U^{238} and U^{235} are in the ratio, respectively, of 140:1. Equal amounts of each isotope existed in the Earth's crust at its formation. Estimate the age of the Earth. The half-lives are: U^{238} 4.5×10^9 years, U^{235} 7.1×10^8 years.

[6]

(b) A steel compression ring for the piston of a car is irradiated with neutrons until it has a uniformly distributed activity of 4×10^5 Bq due to the formation of Fe^{59}. The ring is immediately installed in the engine. After the engine has been running for 30 days, a 100 cm^3 of the engine oil is taken out and 126 disintegrations are recorded from it during a 10 min counting period. If the total volume of the oil is 5.0×10^{-3} m^3, what fraction of the ring has worn away during the running period? Assume all the metal worn away is in suspension in the oil.

(1 Bq is one disintegration per sec., half-life Fe^{59} = 45 days)

[6]

(c) A radioactive detector is used to measure the count rate of a single radioactive source. It initially registered 82 counts s^{-1}, which dropped after 210 s to 19 counts s^{-1}. The half life of the substance was 70 s. Verify that the count rate does *not* satisfy an exponential decay law. A constant background radiation was present during the measurements. Determine its count rate.

[5]

(d) If in (c) the anomaly was due to the presence of a radioactive substance, with a much greater half life than the source, how would one deduce its half life from experimental measurements?

[3]

R1-2011 Q9

a) A rock sample has 1.0×10^{23} uranium nuclei which are in radioactive equilibrium with radium nuclei. How many radium nuclei are present? The half lives of uranium and radium are respectively 1.4×10^{17}s and 5.1×10^{10}s.

[3]

b) The window of a gamma-ray detector, area of 4.0×10^{-4} m^2, is situated horizontally so that it lies 2.0 m vertically above a point source of gamma rays. The detector records 60 photons per min. A sheet of a gamma-ray absorber is introduced between the source and the detector. The count rate can only be maintained by moving the gamma- ray detector vertically down by 0.2 m.

Calculate:

(i) The rate of emission of gamma-rays from the source.
(ii) The percentage of gamma-rays absorbed.

[5]

Living wood takes in radioactive carbon 14 from the atmosphere during the process of photosynthesis; the proportion of carbon 14 to carbon 12 being 1.25×10^{-12}. When the wood dies the carbon 14 decays, its half life being 5600 years. 4.00 g of carbon from a piece of dead wood gave a total count of 20.0 disintegrations per minute, with an uncertainty of 0.4 in the value.

Determine:

(i) The age of the wood.
(ii) The uncertainty in the age.

[12]

R1-2012 Q8

The scattering of photons (Compton scattering) can be used to identify the composition of materials by the intensity of the scattered radiation. The scattered radiation is at a different frequency and in this problem you are asked to find out what happens when a photon is scattered off at an angle.

An incident photon, frequency f, momentum (hf/c), is scattered by a stationary electron producing a scattered photon of frequency (f - Δf) , where Δf is small compared with f. This photon travels in a direction that makes an angle θ with the direction of the incident photon. The electron, mass m_e , acquires a non-relativistic speed v.

(a) Draw a labelled vector triangle of the momenta of the particles.

[3]

(b) Write down the equation relating the magnitude of the momentum of the electron to that of the photons.

[4]

(c) Obtain the equation for energy conservation.

[2]

(d) Deduce an equation for Δf. When Δf is much less than f and hf much less than $m_e c^2$, obtain the approximation,

$$\Delta f = \frac{hf^2(1 - \cos\theta)}{m_e c^2}$$

[7]

(e) Sketch graphs of:
- (i) Δf against f for constant θ
- (ii) Δf against θ for constant f.

For what angle(s) is Δf greatest? State the value(s) of Δf.

[4]