Edexcel Physics Unit 5

Topic Questions from Papers

Nuclear Decay

12 Radioisotopes are often used for medical applications. ^{131}I is a β^--emitter, and can be used to treat an overactive thyroid gland. When a small dose of ^{131}I is swallowed, it is absorbed into the bloodstream. It is then concentrated in the thyroid gland, where it begins destroying the gland's cells.

(a) Patients are advised that radiation detection devices used at airports may detect increased radiation levels up to 3 months after the treatment. Explain how it is possible for the activity of the ^{131}I to be detected outside the body.

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(b) (i) The half-life of ^{131}I is 8 days. What fraction of the original number of iodine atoms will have decayed after a period of 24 days?

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Fraction = ...

(ii) Doctors wish to prescribe a sample of ^{131}I of activity 1.5 MBq. The sample is prepared exactly 24 hours before it is due to be swallowed by the patient. Calculate the activity that the sample should have when it is prepared.

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Activity = ... MBq

(Total for Question 12 = 7 marks)

14 Ionisation smoke detectors contain a small amount of the radioactive isotope americium. ^{241}Am is an α-emitter. It has a half-life of 432 years, and the activity from the source in a new smoke detector is about 3.5×10^4 Bq.

(a) Explain why the radiation produced by a smoke detector does not pose a health hazard.

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(b) (i) Complete the nuclear equation for the decay of americium.

(2)

$$^{241}_{\dots}\mathrm{Am} \rightarrow {}^{\dots}_{93}\mathrm{Np} + {}^{\dots}_{\dots}\alpha$$

(ii) Using data from the table, calculate the energy, in MeV, of α-particles released when a nucleus of americium-241 undergoes alpha decay.

(3)

Nuclide	**Mass/u**
Am	241.056 822
Np	237.048 166
α-particle	4.002 603

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Energy = ... MeV

(c) An ionisation smoke detector is sold with the guarantee that it "lasts a lifetime". Comment on the appropriateness of this guarantee, based on its use of americium-241.

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(Total for Question 14 = 7 marks)

17 In September 1987, two youngsters in Brazil removed a stainless steel cylinder from a machine in an abandoned clinic. Five days later they sold the cylinder to a scrap dealer who prised open a platinum capsule inside to reveal a glowing blue powder. The powder was found to contain caesium-137 and had an activity of 5.2×10^{13} Bq.

Caesium-137 is a β^--emitter with a half-life of 30 years.

*(a) Discuss the dangers to the youngsters of possessing this cylinder for 5 days.

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(b) Complete the equation to represent the decay of caesium-137 into barium.

(2)

$$^{137}_{55}\text{Cs} \rightarrow \,^{\cdots}_{\cdots}\text{Ba} + \,^{\cdots}_{\cdots}\beta^-$$

(c) (i) The decay of caesium into barium is a random process. Why is the decay process described as random?

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(ii) Show that the decay constant for the caesium-137 is about 7×10^{-10} s^{-1}.

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(d) In September 2007, 20 years after the cylinder was removed from the machine, the substance was still highly radioactive. Calculate the number of caesium-137 atoms remaining in the powder.

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Number = ...

(e) Caesium-137 is one of the products from the nuclear fission of uranium-235 in a nuclear reactor.

(i) Complete the equation for this reaction and show the number of neutrons released.

(1)

$$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{137}_{55}\text{Cs} + {}^{95}_{\dots}\text{Rb} + \dots\,{}^{1}_{0}\text{n}$$

(ii) Explain the significance to the operation of the reactor of the number of neutrons emitted in each fission.

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(Total for Question 17 = 15 marks)

16 Polonium-210 is an alpha-emitter with a half-life of 138 days. It emits alpha particles of energy 5.3 MeV as it decays to a stable isotope of lead.

One small pellet of polonium-210 contains 1.3×10^{21} atoms.

(a) (i) Show that the initial activity of this polonium pellet is about 8×10^{13} Bq.

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(ii) Hence show that the rate of energy release by the pellet is more than 60 W.

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17 Fission and fusion are both nuclear processes that release energy. About 20% of the UK's energy need is currently provided by the controlled fission of uranium. Intensive research continues to harness the energy released from the fusion of hydrogen.

(a) (i) Fission of uranium-235 takes place after the absorption of a thermal neutron. Assume such neutrons behave as an ideal gas at a temperature of 310 K.

Show that the square root of the mean square speed of the neutrons is about 3000 m s^{-1}.

mass of neutron = 1.0087u

(3)

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(ii) Complete the equation for the fission of uranium-235.

(2)

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{\cdots\cdots}_{92}\text{U} \rightarrow ^{138}_{\cdots\cdots}\text{Cs} + ^{96}_{37}\text{Rb} + \cdots\cdots\ ^{1}_{0}\text{n}$$

(iii) Calculate the energy released in a single fission. Hence determine the rate of fission necessary to maintain a power output of 2.5 GW.

Mass / u	
^{235}U	235.0439
^{138}Cs	137.9110
^{96}Rb	95.9343

(4)

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Fission rate = ...

(b) *(i) State the conditions for fusion and hence explain why it has proved difficult to maintain a sustainable reaction in a practical fusion reactor.

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(ii) The nuclear reaction below represents the fusion of two deuterium nuclei. Complete the equation and identify particle X.

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$$^{2}_{1}D + ^{2}_{1}D \rightarrow ^{3}_{1}H + ^{\cdots\cdots}_{\cdots\cdots}X$$

Particle X is a ....

(iii) Despite the difficulties, the quest for a practical fusion reactor continues.

State **two** advantages fusion power might have over fission power.

(2)

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(Total for Question 17 = 16 marks)

18 The radioactive isotope carbon-14 undergoes decay with a half-life of 5730 years. While an organism is living, it takes in carbon from the atmosphere and the ratio of carbon-14 to the stable isotope carbon-12 in the organism is constant. After death the ratio changes, as the carbon-14 continues to decay but no more carbon is taken in. This is the basis of radiocarbon dating.

Archaeologists have used radiocarbon dating to pinpoint the date of construction of Stonehenge, an ancient stone circle in south west England. The archaeologists unearthed dead organic material from under the stones and sent a sample of it to Oxford University for analysis. Scientists at the university determined that the ratio of carbon-14 to carbon-12 in the sample was only 60% of that found in living organisms.

(a) Explain what is meant by a radioactive isotope.

(2)

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(b) Radioactive decay is a random process. Explain what this means.

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(c) Calculate the decay constant of carbon-14 and hence the time since Stonehenge was constructed.

(6)

Time = ...

(d) The rate of production of carbon-14 in the atmosphere has decreased since Stonehenge was constructed. Explain how this would affect the scientists' calculations of when Stonehenge was constructed.

(3)

(Total for Question 18 = 13 marks)

18 In a demonstration to her class, a teacher pours popcorn kernels onto a hot surface and waits for them to pop. The kernels pop one by one. There is a large rate of popping at first and this rate decreases as time goes on. However, the order in which the kernels pop cannot be predicted.

*(a) How realistic is this demonstration as an analogy to radioactive decay? Consider aspects of the demonstration that are similar to radioactive decay and aspects that are different.

(4)

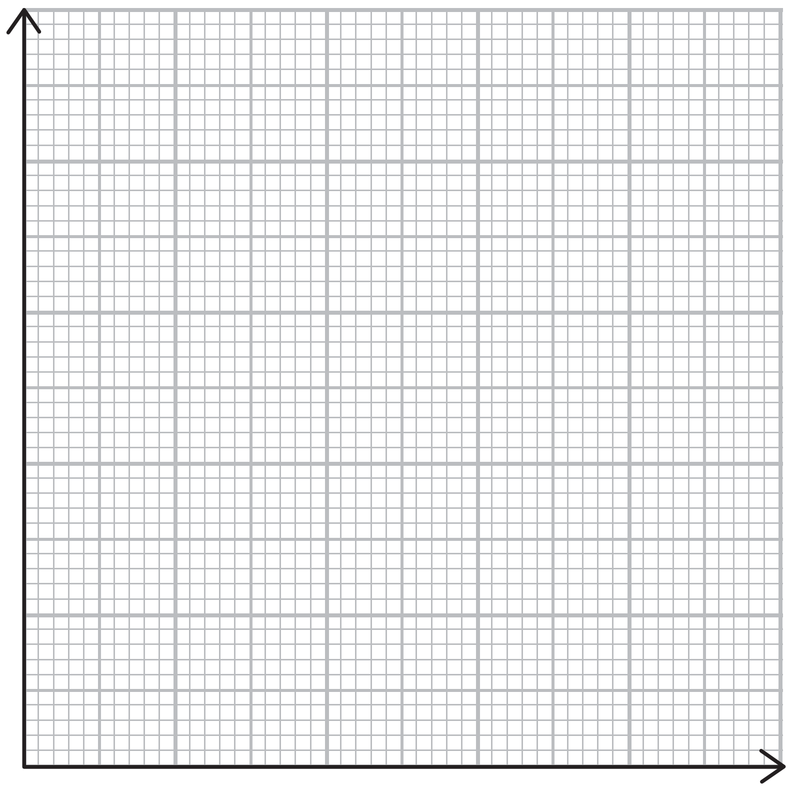
(b) In another demonstration, bags of popcorn are placed in a microwave oven for different lengths of time. Initially, each bag contains the same number of kernels. Once the bags are removed from the oven they are opened and the number of unpopped kernels counted. Assume that the popcorn obeys a similar rule to radioactive decay.

The results from the demonstration are shown in the table:

Time in oven / s	Number of unpopped kernels, N	ln (N)
0	100	4.61
30	78	4.36
60	61	4.11
90	47	3.85
120	37	3.61
150	29	3.37

(i) Use the data to draw a graph to show that the half-life of this process is about 80 s.

(6)



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Half-life of popcorn = ...

(ii) A bag of popcorn is placed in the microwave oven until three quarters of the kernels have popped.

Determine the time for which the bag is in the oven.

(1)

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Time = ...

(Total for Question 18 = 11 marks)

12 All living organisms contain ^{12}C and radioactive ^{14}C. The concentration of ^{14}C in the organism is maintained whilst the organism is alive, but starts to fall once death has occurred.

(a) The count rate obtained from wood from an old Viking ship is 14.7 min^{-1} per gram of wood, after being corrected for background radiation. The corrected count rate from similar living wood is 16.5 min^{-1} per gram of wood.

Calculate the age of the ship in years.

^{14}C has a half life of 5700 years.

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Age of ship = ... years

(b) The concentration of ^{14}C in living organisms might have been greater in the past.

Explain how this would affect the age that you have calculated.

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(Total for Question 12 = 6 marks)

18 On 1st November 2006, the former Russian spy Alexander Litvinenko fell ill. Twenty one days later he died from the radiation effects of polonium-210. Experts suggest that as little as 0.89 μg of polonium-210 would be enough to kill, although Mr Litvinenko's death was linked to a much larger dose of the radioactive isotope. Traces of the isotope were later found in washrooms at five locations around London visited by the Russian.

Polonium-210 has a half life of 138 days.

(a) (i) In a 0.89 μg sample of polonium-210 there are 2.54×10^{15} atoms of polonium. Show that the decay constant for polonium-210 is about 6×10^{-8} s^{-1}, and hence calculate the activity of a sample of this size.

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Activity = ...

(ii) Calculate the fraction of polonium-210 nuclei that have decayed after a time of 21 days.

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Fraction decayed = ...

(b) Polonium-210 emits alpha particles. Explain why polonium-210 is virtually harmless unless it is taken into the body.

(2)

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(c) (i) Complete the equation below for the decay of polonium.

(2)

$$^{210}_{84}\text{Po} \rightarrow \,^{\dots}_{\dots}\text{Pb} + \,^{\dots}_{\dots}\alpha$$

(ii) State why the Pb nuclei would recoil from the alpha particles emitted during the decay.

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(d) Radioactive decay is said to occur spontaneously and randomly. Explain what is meant by spontaneous and random in this context.

(2)

Spontaneous ....

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Random ....

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(e) Suggest why traces of the isotope were found in locations visited by the Russian.

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(Total for Question 18 = 16 marks)

TOTAL FOR SECTION B = 70 MARKS

TOTAL FOR PAPER = 80 MARKS

17 Positron emission tomography (PET) is a nuclear medicine imaging technique. Pairs of gamma rays, produced when positrons from a radioisotope annihilate with electrons, are detected to form the image.

Radioisotopes used in PET scanning are typically isotopes with short half-lives such as carbon-11. Carbon-11 has a half-life of 1220 s and decays by positron emission to stable boron-11. Positrons are the antiparticles to electrons.

(a) Explain what is meant by a radioactive atom.

(2)

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(b) Complete the equation for the decay of carbon-11.

$$^{11}_{6}\text{C} \rightarrow \,^{\cdots}_{\cdots}\text{B} + \,^{\cdots}_{\cdots}\text{e}^{+} + \,^{0}_{0}\nu_{e}$$

(2)

(c) Calculate the energy in joules released in a positron decay of carbon-11.

	Mass / MeV/c^2
positron	0.511
carbon	10 253.6
boron	10 252.2

(3)

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Energy = ... J

(d) Explain why carbon-11 is a relatively safe radioisotope to use within the body.

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(e) A patient was injected intravenously with a radioactive compound containing carbon-11 with an activity of 1.58×10^6 Bq.

The sample was prepared 3600 s before it was administered to the patient.

Calculate the activity of the sample when it was prepared.

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Activity of the sample = ...

(Total for Question 17 = 13 marks)

List of data, formulae and relationships

Acceleration of free fall	$g = 9.81\ \text{m s}^{-2}$	(close to Earth's surface)
Boltzmann constant	$k = 1.38 \times 10^{-23}\ \text{J K}^{-1}$	
Coulomb's law constant	$k = 1/4\pi\varepsilon_0$	
	$= 8.99 \times 10^{9}\ \text{N m}^2\ \text{C}^{-2}$	
Electron charge	$e = -1.60 \times 10^{-19}\ \text{C}$	
Electron mass	$m_e = 9.11 \times 10^{-31}\ \text{kg}$	
Electronvolt	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$	
Gravitational constant	$G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$	
Gravitational field strength	$g = 9.81\ \text{N kg}^{-1}$	(close to Earth's surface)
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\ \text{F m}^{-1}$	
Planck constant	$h = 6.63 \times 10^{-34}\ \text{J s}$	
Proton mass	$m_p = 1.67 \times 10^{-27}\ \text{kg}$	
Speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \text{m s}^{-1}$	
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$	
Unified atomic mass unit	$u = 1.66 \times 10^{-27}\ \text{kg}$	

Unit 1

Mechanics

Kinematic equations of motion	$v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
Forces	$\Sigma F = ma$ $g = F/m$ $W = mg$
Work and energy	$\Delta W = F\Delta s$ $E_k = \frac{1}{2}mv^2$ $\Delta E_{grav} = mg\Delta h$

Materials

Stokes' law	$F = 6\pi\eta rv$
Hooke's law	$F = k\Delta x$
Density	$\rho = m/V$
Pressure	$p = F/A$
Young modulus	$E = \sigma/\varepsilon$ where Stress $\sigma = F/A$ Strain $\varepsilon = \Delta x/x$
Elastic strain energy	$E_{el} = \frac{1}{2}F\Delta x$

Unit 2

Waves

Wave speed	$v = f\lambda$
Refractive index	${}_1\mu_2 = \sin i / \sin r = v_1/v_2$

Electricity

Potential difference	$V = W/Q$
Resistance	$R = V/I$
Electrical power, energy and efficiency	$P = VI$ $P = I^2R$ $P = V^2/R$ $W = VIt$

$$\% \text{ efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times 100$$

$$\% \text{ efficiency} = \frac{\text{useful power output}}{\text{total power input}} \times 100$$

Resistivity	$R = \rho l/A$
Current	$I = \Delta Q/\Delta t$ $I = nqvA$
Resistors in series	$R = R_1 + R_2 + R_3$
Resistors in parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Quantum physics

Photon model	$E = hf$
Einstein's photoelectric equation	$hf = \phi + \frac{1}{2}mv^2_{max}$

Unit 4

Mechanics

Momentum	$p = mv$
Kinetic energy of a non-relativistic particle	$E_k = p^2/2m$
Motion in a circle	$v = \omega r$ $T = 2\pi/\omega$ $F = ma = mv^2/r$ $a = v^2/r$ $a = r\omega^2$

Fields

Coulomb's law	$F = kQ_1Q_2/r^2$ where $k = 1/4\pi\varepsilon_0$
Electric field	$E = F/Q$ $E = kQ/r^2$ $E = V/d$
Capacitance	$C = Q/V$
Energy stored in capacitor	$W = \frac{1}{2}QV$
Capacitor discharge	$Q = Q_0 e^{-t/RC}$
In a magnetic field	$F = BIl \sin\theta$ $F = Bqv \sin\theta$ $r = p/BQ$
Faraday's and Lenz's Laws	$\varepsilon = -d(N\phi)/dt$

Particle physics

Mass-energy	$\Delta E = c^2 \Delta m$
de Broglie wavelength	$\lambda = h/p$

Unit 5

Energy and matter

Heating	$\Delta E = mc\Delta\theta$
Molecular kinetic theory	$\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$
Ideal gas equation	$pV = NkT$

Nuclear Physics

Radioactive decay	$\mathrm{d}N/\mathrm{d}t = -\lambda N$
	$\lambda = \ln 2/t_{\frac{1}{2}}$
	$N = N_0 e^{-\lambda t}$

Mechanics

Simple harmonic motion	$a = -\omega^2 x$ $a = -A\omega^2 \cos \omega t$ $v = -A\omega \sin \omega t$ $x = A \cos \omega t$ $T = 1/f = 2\pi/\omega$
Gravitational force	$F = Gm_1m_2/r^2$

Observing the universe

Radiant energy flux	$F = L/4\pi d^2$
Stefan-Boltzmann law	$L = \sigma T^4 A$ $L = 4\pi r^2 \sigma T^4$
Wien's Law	$\lambda_{max} T = 2.898 \times 10^{-3}$ m K
Redshift of electromagnetic radiation	$z = \Delta\lambda/\lambda \approx \Delta f/f \approx v/c$
Cosmological expansion	$v = H_0 d$