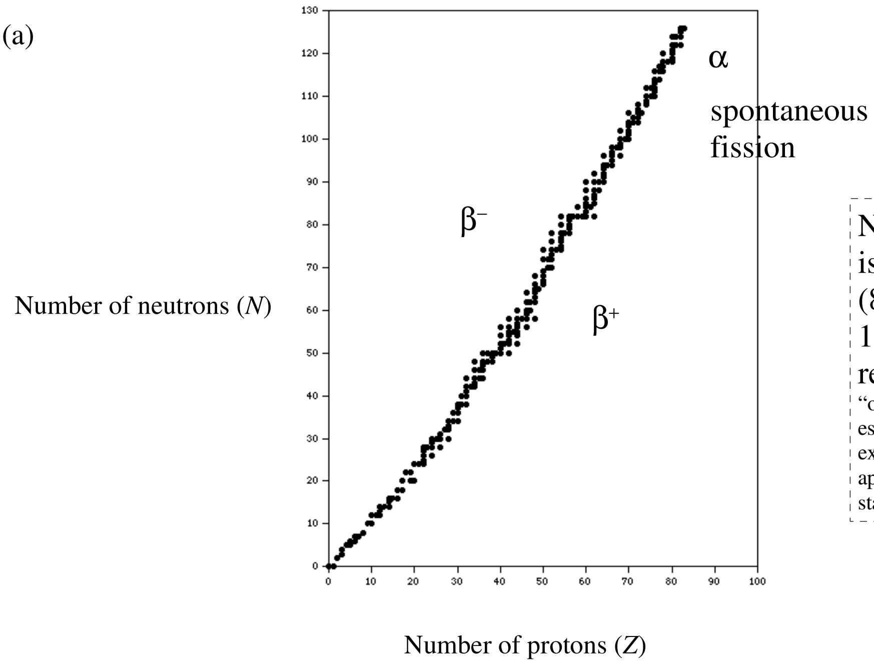
Radioactivity Assignment 1 ***SOLUTIONS***

1.

(a)



> NOTE: The heaviest stable isotope is bismuth-209 , at (83,126) with a half-life of 1.9×10^{19} years. The graph should respect this position.
> "over a billion times longer than the current estimated age of the universe. Owing to its extraordinarily long half-life, for nearly all applications bismuth can be treated as if it is stable and non-radioactive" - Wikipedia

(b) The attractive 'strong nuclear force' between nucleons acts over very small distances, whereas the electrostatic repulsive force acts over the whole nucleus. Bigger nuclei have protons further apart which therefore experience more repulsion than attraction. There must therefore be more neutrons compared to protons in order to overcome the repulsion over the larger distances.

(d) *alpha* and *spontaneous fission* are both due to the nucleus being too large (too many of both neutrons and protons), hence it gets rid of both neutrons and protons
beta minus is due to too many neutrons, so a neutron is converted into a proton by emitting an electron
beta plus is due to too many protons, so a proton is converted into a neutron by emitting an positron

2.

Type of emission	**Symbol**	**Charge**	**Mass**	**Charge number**	**Mass number**
Alpha	α	$+3.20\times10^{-19}$ C	6.645×10^{-27} kg	2	4
Beta minus	β^-	-1.60×10^{-19} C	9.11×10^{-31} kg	-1	0
Beta plus	β^+	$+1.60\times10^{-19}$ C	9.11×10^{-31} kg	1	0
Gamma	γ	0	0	0	0

3. Complete the following nuclear decay equations:

(a) ${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\alpha$

(b) ${}^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} + {}^{0}_{-1}\text{e} + {}^{0}_{0}\bar{\nu}$

(c) ${}^{40}_{19}\text{K} \xrightarrow{\beta^-} {}^{40}_{20}\text{X} + {}^{0}_{-1}\text{e} + {}^{0}_{0}\bar{\nu}$

(d) ${}^{210}_{83}\text{Bi} \rightarrow {}^{210}_{84}\text{Po} + {}^{0}_{-1}\text{e} + {}^{0}_{0}\bar{\nu}$

(e) ${}^{210}_{84}\text{Po} \rightarrow {}^{206}_{82}\text{Pb} + {}^{4}_{2}\text{He}$

(f) ${}^{212}_{82}\text{Pb} \rightarrow {}^{212}_{83}\text{Bi} + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$

4. All nuclei exist in discrete energy levels. Alpha particles break off from nuclei and therefore must also have a discrete energy.

5.

(a) 0 mass number since negligible mass compared to nucleons. -1 charge since the opposite charge of a proton on which the atomic number depends
(b) 0 mass number since negligible mass compared to nucleons. 1 charge since equal to the charge of a proton on which the atomic number depends
(c) 0 mass number since of negligible mass. 0 charge number since neutral.
(d) 0 mass number since of negligible mass. 0 charge number since neutral.
(e) 0 mass number since no mass. 0 charge number since no charge.

6.

(a)
(i) ${}^{1}_{0}\text{n} \rightarrow {}^{1}_{1}\text{p} + {}^{0}_{-1}\beta^{-} + {}^{0}_{0}\overline{\nu}$
(ii) ${}^{1}_{1}\text{p} \rightarrow {}^{1}_{0}\text{n} + {}^{0}_{1}\beta^{+} + {}^{0}_{0}\nu$

(b) Electrons and positrons must be produced in order to conserve charge number in each case.

Beta particles exhibit a range of energies and momenta, so another particle is needed to account for the difference. That is, a third particle (neutrino or antineutrino) which has zero mass and charge number.

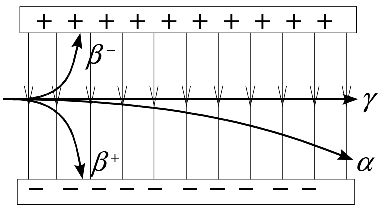
7. A nucleus is sometimes left in an excited state after alpha or beta decay. As it returns to the ground state, it emits gamma radiation. Since there are discrete energy levels in a nucleus, there are corresponding discrete gamma energies.

8.

	Alpha	**Beta**	**Gamma**
Penetration	Very small	Moderate	Large

9.

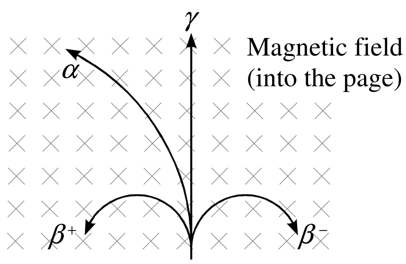
(a)



Electric field
(between parallel plates)

Paths of deflection are parabolic

(b)



Paths of deflection are circular

Radioactivity Assignment 2 ***SOLUTIONS***

1.

(a) (any three)

- **radioactive nucleus:** alpha, beta, gamma
- **x-ray device:** x-rays
- **nuclear reactor:** neutron
- **cyclotron:** proton, deuteron

(b) Ionising radiation can break chemical bonds in living matter (since it alters the electronic configuration of atoms it interferes with), and this can kill cells. It can also change the genetic material in cells (for example causing cancer or mutations).

(c)

- increasing the distance from the source
- limiting the time of exposure
- using adequate shielding (for example wearing a lead apron)

2. 66 minutes is 3 half-lives so $n = 3$

$N = N_0\left(\frac{1}{2}\right)^n$

$= 2.0\times10^9 \times\left(\frac{1}{2}\right)^3$

$= 2.5\times10^8$

There are 2.5×10^8 nuclei remaining after 66 minutes.

3.

(a) $A = A_0\left(\frac{1}{2}\right)^n$

$\therefore 6.25 = 100\left(\frac{1}{2}\right)^n$

$\therefore 0.0625 = \left(\frac{1}{2}\right)^n$

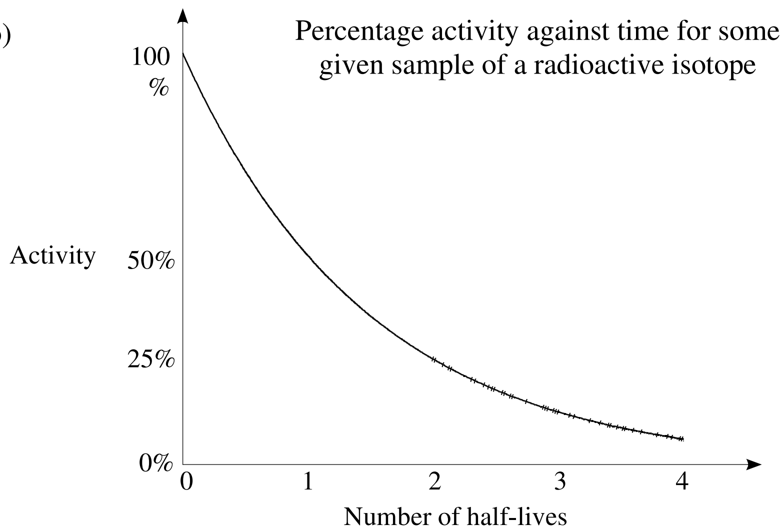
$0.0625 = \frac{1}{16} = \left(\frac{1}{2}\right)^4$ $\left\{\log(0.0625) = n\log\left(\frac{1}{2}\right) \text{ could also be used here}\right\}$

$\therefore n = 4$

$4\times432 = 1728$

They must wait 1728 years.

(b)



(c) It will have no effect. This is because the probability of decay is independent of the physical state of the material.

4. Once every five minutes is once every 60×5 = 300 seconds. So 1÷300 = 0.003 Bq (1 s.f.)

5.

(a) Beta plus decay involves emission of a positron. The positron is very likely to make contact with an electron which is its antiparticle. The two annihilate, converting their mass into energy as gamma photons. There must be two photons in opposite directions since otherwise there would be a change in momentum, and momentum must be conserved.

(b) Total mass of a positron and an electron is $2 \times 9.11 \times 10^{-31} = 1.822 \times 10^{-30}$ kg

$\therefore$ Total energy $E = mc^2 = 1.822 \times 10^{-30} \times (3.00 \times 10^8) = 1.64 \times 10^{-13}$ J

$1.64 \times 10^{-13} \div 1.60 \times 10^{-19} \div 10^6 = 1.02$ MeV

So energy of each photon is $1.02 \div 2 = 0.512$ MeV

6.

(a) ^{18}FDG can concentrate within the heart since the body treats it as glucose and uses it as fuel.

^{18}FDG can concentrate within tumours, since they use glucose at greater rates than regular tissue.

(b) When a person is undergoing a PET scan they are lying flat, surrounded by a ring of detectors. When a positron–electron annihilation occurs at the location of the radioisotope two photons are emitted in opposite directions. They are detected on opposite sides of the detector and therefore form a coincidence line. Once multiple annihilations have occurred, coincidence lines intersect to show the position of the tracer.

(c) The radioisotopes used in PET scans have short half lives, but the radiopharmaceutical must continue to undergo radioactive decay after it has been ingested by the patient, so this ingestion must occur soon after the radioisotope has been produced.

(d)

(i) used to create a radioactive form of water to trace blood flow

(ii) used to create a radioactive glucose which has multiple uses e.g. finding cancerous tumours