# Unit 1 Area of study 2: Nuclear and radioactivity physics

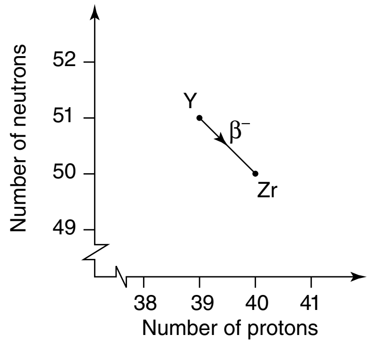
## Chapter 4

## Radiation from the nucleus

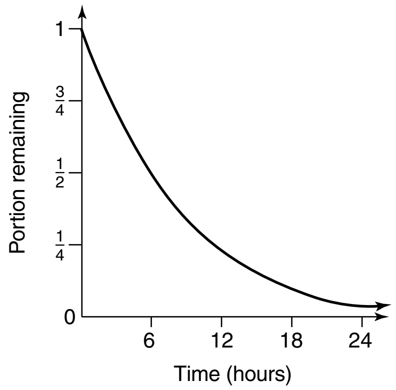
1. (a) 30 protons, 36 neutrons
   (b) 90, 140
   (c) 20, 25
   (d) 14, 17
2. (a) ${}^{4}_{2}\mathrm{He}$
   (b) ${}^{13}_{7}\mathrm{N}$
   (c) ${}^{234}_{91}\mathrm{Pa}$
3. (a) Gold: 79 protons, 118 neutrons
   (b) Bismuth: 83 protons, 127 neutrons
   (c) Lead: 82 protons, 128 neutrons
4. The number of nucleons (protons + neutrons) does not determine the element a particular atom may be. It is the number of protons that determines an element.
5. (a) A radioisotope is an unstable isotope of an atom that can become more stable by emitting radiation from its nucleus.
6. $\alpha$ and $\beta$ particles and $\gamma$-rays are emitted from the nucleus.
7. (a) $\gamma, \beta^-, \alpha$ (b) $\alpha, \beta^-, \gamma$
8. (a) $\beta^-$: a neutron has transformed into a proton and a $\beta^-$ is released.
   (b) $\beta^-$: a neutron has transformed into a proton and a $\beta^-$ is released.
   (c) $\alpha$: the released particle has two protons and two neutrons.
9. $\alpha$ decay
   (a) ${}^{226}_{88}\mathrm{Ra} \rightarrow {}^{4}_{2}\alpha + {}^{222}_{86}\mathrm{Rn}$ + energy
   (radon)
   (b) ${}^{214}_{84}\mathrm{Po} \rightarrow {}^{4}_{2}\alpha + {}^{210}_{82}\mathrm{Pb}$ + energy
   (lead)
   (c) ${}^{241}_{95}\mathrm{Am} \rightarrow {}^{4}_{2}\alpha + {}^{237}_{93}\mathrm{Np}$ + energy
   (neptunium)
10. $\beta^-$ decay
    (a) ${}^{60}_{24}\mathrm{Co} \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{60}_{25}\mathrm{Mn}$ + energy
    (manganese)
    (b) ${}^{90}_{38}\mathrm{Sr} \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{90}_{39}\mathrm{Y}$ + energy
    (yttrium)
    (c) ${}^{32}_{15}\mathrm{P} \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{32}_{16}\mathrm{S}$ + energy
    (sulfur)
11. ${}^{24}_{12}\mathrm{Mg}^* \rightarrow \gamma + {}^{24}_{12}\mathrm{Mg}$
12. (a) ${}^{Z}_{A}\mathrm{X} \rightarrow {}^{4}_{2}\alpha + {}^{z-4}_{A-2}\mathrm{D}$ + energy
    (b) ${}^{Z}_{A}\mathrm{X} \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{Z}_{A+1}\mathrm{E}$ + energy
    (c) ${}^{Z}_{A}\mathrm{X}^* \rightarrow {}^{Z}_{A}\mathrm{X} + \lambda$
    (d) ${}^{27}_{13}\mathrm{Al} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{28}_{14}\mathrm{Si} + {}^{1}_{0}\mathrm{n}$ + energy
    (e) ${}^{22}_{11}\mathrm{Na} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{25}_{12}\mathrm{Mg} + {}^{1}_{1}\mathrm{H}$ + energy
13. $1\ \mathrm{eV} = 1.6 \times 10^{-19}\ \mathrm{J}$

$$\begin{aligned} 1.71\ \mathrm{MeV} &= 1.71 \times 10^{6}\ \mathrm{eV} \\ &= 1.7 \times 10^{6}\ \mathrm{eV} \times 1.6 \times 10^{-19}\ \mathrm{J/eV} \\ &= 2.74 \times 10^{-13}\ \mathrm{J} \end{aligned}$$

14. ${}^{90}_{39}\mathrm{Y} \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{90}_{40}\mathrm{Zr}$. See the following figure.



15. $\beta^-$ decay occurs when a neutron in the nucleus is transformed into a proton. In order for the neutral neutron to gain a positive charge and become a proton it must also release a particle with a negative charge equal in size to that of the proton. The particle released is an electron.
16. 2 hours: the time at which half of the protons remain. This can be read directly from the graph.
17.



18. Free radicals and ions are very chemically reactive and may result in new chemical reactions taking place. For example, the production of $H^+$ and $OH^-$ ions may react with molecules either causing damage to DNA (genetic mutations may be passed on) or to

mechanisms for controlling cell division (forming cancer), or interfering with the production of molecules necessary for the life of a cell (this may cause the cell to die).

19. Energy absorbed = absorbed dose × mass

$$\begin{aligned}\text{Energy absorbed} &= \text{absorbed dose} \times \text{mass}\\ &= 3 \times 10^{-3} \times 30\\ &= 9 \times 10^{-2}\text{ J}\end{aligned}$$

20. $$\begin{aligned}\text{Absorbed dose} &= \frac{\text{energy absorbed}}{\text{mass}}\\ &= \frac{9 \times 10^{-2}}{60}\\ &= 1.5 \times 10^{-3}\text{ Gy}\\ &= 1.5\text{ mGy}\end{aligned}$$

21. If $\gamma$ radiation ⇒ quality factor = 1

$$\begin{aligned}\text{dose equivalent} &= \text{absorbed dose} \times \text{quality factor}\\ &= 3 \times 10^{-3} \times 1\\ &= 3 \times 10^{-3}\text{ Sv}\end{aligned}$$

22. $$\begin{aligned}\text{Quality factor} &= 20\\ \text{dose equivalent} &= \text{absorbed dose} \times \text{quality factor}\\ &= 1.5 \times 10^{-3} \times 20\\ &= 30 \times 10^{-3}\text{ Sv}\\ &= 30\text{ mSv}\end{aligned}$$

23. Alpha ($\alpha$) particles cause a lot of localised damage. They give much of their energy quickly to nearby atoms (i.e. they are stopped over short distances).

24. Using table 4.3, p. 89: >40 Sv will cause death within 48 h.

As $\gamma$ radiation ⇒ quality factor = 1 ⇒ dose eq. = abs. dose

$$\begin{aligned}\text{energy absorbed} &= \text{absorbed dose} \times \text{mass}\\ &= 40 \times 80\\ &= 3200\text{ J}\end{aligned}$$

25. Safety precautions needed for isotopes producing $\alpha$ radiation:
    - Store in sealed cardboard boxes.
    - Handle with gloves.

    Safety precautions needed for isotopes producing $\beta$ radiation:
    - Store in aluminium containers with walls several millimetres thick.
    - Shield against, with aluminium of at least several millimetres thick.

    Safety precautions needed for isotopes producing $\gamma$ radiation:
    - Store in thick (several centimetres) lead containers.
    - Shield against, using lead which is several centimetres thick.

26. $t_{\frac{1}{2}} = 5730$ years

$$1\text{ g} \rightarrow \underset{t_{\frac{1}{2}}}{\tfrac{1}{2}\text{ g}} \rightarrow \underset{2\,t_{\frac{1}{2}}}{\tfrac{1}{4}\text{ g}} \rightarrow \underset{3\,t_{\frac{1}{2}}}{\tfrac{1}{8}\text{ g}}$$

⇒ 3 half-lives to get from 1 g to $\frac{1}{8}$ g

∴ 3 × 5730 years = 17 190 years.

27. It would be more dangerous to stand next to a source of high activity (decays per second) and short half-life since exposure would be significant in a short time frame.

28. Dose equivalent takes into account the different types of damage caused by different forms of ionising radiation.

29. In its early stages, the foetus consists only of a few cells which divide to form the rest of the baby. If these cells are damaged, the foetus may not be able to form properly.

30. Suggested lifestyle changes might include not flying in planes, avoiding certain medical procedures (e.g. X-rays), living closer to sea level, not smoking and staying away from smokers.

31. One possible reason for the difference in health problems are the differences in exposure (amount and type).

32. $t_{\frac{1}{2}} = 120\text{ s} = 2\text{ min}$

Method 1:

$$\begin{aligned}2\text{ pm} &\rightarrow 1\ \mu\text{g} = 1 \times 2^{0}\ \mu\text{g}\\ 1{:}58 &\rightarrow 2\ \mu\text{g} = 1 \times 2^{1}\ \mu\text{g}\\ 1{:}56 &\rightarrow 4\ \mu\text{g} = 1 \times 2^{2}\ \mu\text{g}\\ 1{:}54 &\rightarrow 8\ \mu\text{g} = 1 \times 2^{3}\ \mu\text{g}\\ 1{:}52 &\rightarrow 16\ \mu\text{g} = 1 \times 2^{4}\ \mu\text{g}\end{aligned}$$

$x$ half-lives before 2 pm, amount is $1 \times 2^{x}\ \mu\text{g}$

⇒ at 1:30 pm, 15 half-lives before 2 pm, amount is $1 \times 2^{15}\ \mu\text{g} = 33\text{ mg}$

Method 2:

$$\begin{aligned}A_0 &= ? & A_F &= A_0 2^{\frac{-t}{t_{\frac{1}{2}}}}\\ A_F &= 1\ \mu\text{g} = 1 \times 10^{-6}\text{ g} & 1 \times 10^{-6} &= A_0 2^{\frac{-30}{2}}\\ t &= 30\text{ min} & 2^{-15} \times 1 \times 10^{-6} &= A_0\\ t_{\frac{1}{2}} &= 2\text{ min} & A_0 &= 33\text{ mg}\end{aligned}$$

33. ${}^{238}_{92}\text{U} \rightarrow {}^{206}_{82}\text{Pb} + ?$

The release of $\beta$ particles does not result in a change in mass number. As mass number changes from 238 to 206 ⇒ $\alpha$ decay is involved. 238 − 206 = 32, therefore a change of 32 nucleons. Each $\alpha$ particle released reduces mass number by 4, therefore 8 $\alpha$ particles released.

Each $\alpha$ particle released reduces atomic number by 2, therefore 8 $\alpha$ particles reduces atomic number by 16, ⇒ new atomic number of 76. This is 6 too few for ${}_{82}\text{Pb}$, therefore 6 extra protons result from $\beta$ decay.

Therefore, to change from ${}^{238}_{92}\text{U}$ to ${}^{206}_{82}\text{Pb}$, the atom releases 8 $\alpha$ particles and 6 $\beta$ particles.

34. Assume $\gamma$ radiation and dose equivalent of 30 mSv annually (from p. 87 of text).

$$\begin{aligned}\text{absorbed dose} &= \frac{\text{equivalent dose}}{\text{quality factor}}\\ &= \frac{30 \times 10^{-3}}{20}\\ &= 1.5 \times 10^{-3}\text{ Gy}\\ \text{absorbed energy} &= \text{absorbed dose} \times \text{mass}\\ &= 1.5 \times 10^{-3} \times 0.5\\ &= 7.5 \times 10^{-4}\text{ J}\end{aligned}$$