

ANSWERS TO REVIEW QUESTIONS

IMPORTANT NOTE: READ THIS FIRST.

There are three different kinds of answer here.

- The usual form for quantitative questions is a short entry giving the final numerical answer. Sometimes there will be also a brief indication of how to get to that result. The amount of detail given is usually much less than that required in a model answer. For descriptive answers ("bookwork") references to the text may be all that is given. These entries have no special label.
- **Model answers** are written out in full as a guide to the kind of response which would get full marks in an exam. However, a model answer given here, memorised and presented in an exam, may not score very well because it lacks originality.
- **Notes** are intended to indicate the features of a good answer or give a commentary on which an answer might be based. They often contain background information which would not need to be reproduced in a model answer.

1 The energy of a photon in terms of its wavelength is given by

$$E = \frac{hc}{\lambda} .$$

$$\frac{E_{500 \text{ nm}}}{E_{650 \text{ nm}}} = \frac{100 \times \frac{hc}{500 \text{ nm}}}{113 \times \frac{hc}{650 \text{ nm}}} = 1.15.$$

2 a) Rest mass of a particle is the mass that the particle has when it is at rest.

- b) Photon, neutrino.
c) Electron, proton, neutron, etc.

3 a) Electron diffraction : when electrons are fired through a thin crystal they produce a diffraction pattern of just the kind that classical waves give.

- b) Photoelectric effect : electrons are emitted when light of a frequency greater than a critical value is shone on a metal. The energy needed to free one electron must be delivered by a single photon!

4 Model Answer

a) The energy of a photon is hf and since the frequency f is related to wavelength by $c = f\lambda$,

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \text{ J.s} \times 3.0 \times 10^8 \text{ m.s}^{-1}}{500 \times 10^{-9} \text{ m}}$$

$$= 4.0 \times 10^{-19} \text{ J (or 2.5 eV)} .$$

b) For a material particle the de Broglie wavelength is given by $\lambda = \frac{h}{p}$.

But momentum $p = mv$ and kinetic energy $K = \frac{1}{2} mv^2$

$$\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{\frac{2K}{m}}} = \frac{h}{\sqrt{2Km}} .$$

$$\text{So } \lambda = \frac{6.63 \times 10^{-34} \text{ J.s}}{\sqrt{2 \times 2.0 \times 10^{-19} \text{ J} \times 9.11 \times 10^{-31} \text{ kg}}} = 1.1 \text{ nm}.$$

5 a) $m = \gamma m_0$

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

$$m = \left(1 - \left(\frac{1.8 \times 10^8 \text{ m.s}^{-1}}{3.0 \times 10^8 \text{ m.s}^{-1}}\right)^2\right)^{-\frac{1}{2}} \times 9.11 \times 10^{-31} \text{ kg}$$

$$= 1.1 \times 10^{-30} \text{ kg.}$$

b) $E = mc^2 = 1.0 \times 10^{-13} \text{ J.}$

7 See chapter AN2.

9 Model answer

a) 13.6 eV. This is the energy required to remove an electron from the ground state.

b) The energy difference between the states is

$$\Delta E = \frac{E_1}{3^2} - \frac{E_1}{2^2} = -\frac{5}{36} E_1$$

The frequency f of the radiation is given by $\Delta E = hf$ so

$$f = \frac{\Delta E}{h} = -\frac{5E_1}{36h}$$

$$= -\frac{5 \times (-13.6 \text{ eV})}{36 \times (4.14 \times 10^{-15} \text{ eV.s})}$$

$$= 4.6 \times 10^{-14} \text{ Hz.}$$

c) Yes. The electron will be removed from the atom. 13.6 eV goes into binding energy and there will be 1.4 eV of energy left over, which can appear as kinetic energy.

10 7.1 MeV.

12 Notes

a) A transition of an atom from one energy state to another lower state with no outside cause.

b) A transition of an atom from one energy state to another lower state which happens in the presence of a photon of an energy equal to the energy difference in the transition. This leads to two photons (the original one and that resulting from the stimulated emission) of that energy.

c) Radiation whose band of frequencies is very narrow.

13 a) See answer 12(b) above and §2-7.

b) See §2-7.

14 $E = \frac{hc}{\lambda}$ but the maximum energy is given by $E = qV$.

$$\text{So } V = \frac{6.63 \times 10^{-34} \text{ J.s} \times 3.0 \times 10^8 \text{ m.s}^{-1}}{1.6 \times 10^{-19} \text{ C} \times 0.154 \times 10^{-9} \text{ m}} = 8.1 \text{ kV.}$$

15 $N = N_0 e^{-\mu x}$ so $x = -\frac{1}{\mu} \ln \frac{N}{N_0}$

$$\ln \frac{N}{N_0} = \ln(0.01 \times 10^{-2}) = -9.21$$

$$\text{For concrete: } x = -\frac{-9.21}{36 \text{ m}^{-1}} = 0.26 \text{ m.}$$

$$\text{For lead: } x = 2.6 \text{ mm.}$$

16 See §6-2 and figure 6.2. (Numerical details of the curve are not required.)

17 Notes

- a) See §4-1.
 b) Secondary photons or charged particles may continue to carry some of the energy.

$$18 \quad \frac{A}{A_0} = \left(\frac{1}{2}\right)^{\frac{t}{\tau}}$$

Take logarithms of both sides:

$$\begin{aligned} \log \frac{A}{A_0} &= \frac{t}{\tau} \log\left(\frac{1}{2}\right) \text{ so} \\ t &= \tau \frac{\log\left(\frac{A}{A_0}\right)}{\log(0.5)} \\ &= 5.7 \times 10^3 \text{ y} \times \frac{\log(0.75)}{\log(0.5)} \\ t &= 2.4 \times 10^3 \text{ y.} \end{aligned}$$

19 Model answer

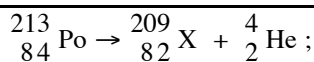
- a) The activity of a radioactive sample decays exponentially with time, i.e. it always takes the same time for the activity to decrease by any fixed fraction. The time taken for the activity of a sample of radioactive material to fall to one half its original value is called the half life.
 b) The same exponential law applies to the concentration N of atoms after time interval t :

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

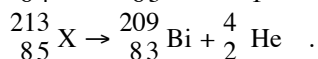
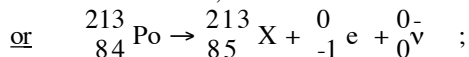
Here τ is the half life and N_0 is the original concentration of carbon-14 atoms.

$$\begin{aligned} \log\left(\frac{N}{N_0}\right) &= \frac{t}{\tau} \log\left(\frac{1}{2}\right) \text{ so} \\ t &= \tau \frac{\log\left(\frac{N}{N_0}\right)}{\log(0.5)} \\ &= 5.7 \times 10^3 \text{ y} \times \frac{\log\left(\frac{1.0 \times 10^{-14}}{1.0 \times 10^{-13}}\right)}{\log(0.5)} \\ t &= 19 \times 10^3 \text{ y.} \end{aligned}$$

The burnt wood is about 20 thousand years old.

20

Atomic number 82, mass number 209.



Atomic number 85; mass number 213.

[Note. Only the first of these chains occurs in nature.]

21

Z : number of protons.

A : number of nucleons (protons plus neutrons)

- a) Z decreases by 2; A decreases by 4.
 b) Z increases by 1; A is unchanged.
 c) Both Z and A are unchanged.

22 a) See answer to Q19(a).

$$b) \quad \frac{1}{16} = \frac{1}{2^4} .$$

So it will take 4 half-lives, 32 days, for the activity to fall to $\frac{1}{16}$ of its original value.

23 a) See §5-4.

b) To change the small signal (a photon) from the scintillator to a measurable voltage pulse.

c) e.g. photographic emulsion : see chapter AN5.

24 a) A high energy photon.

b) Gamma-ray emission follows an alpha or beta-ray emission which has left a nucleus in an excited state. A transition of the nucleus to a lower energy state is accompanied by the emission of the excess energy as a gamma-ray photon.

c) See §§ 4-3, 4-4, 4-6.

25 See §5-4.

$$\begin{aligned}
 26 \quad \text{Dose rate} &= \frac{\text{rate at which energy is absorbed}}{\text{mass}} \\
 &= \frac{\frac{1}{2} \times (\text{rate at which energy is emitted})}{\text{mass}} \\
 &= \frac{\frac{1}{2} \times (\text{activity} \times \text{energy of one decay})}{\text{mass}} \\
 &= \frac{\frac{1}{2} \times 2.0 \times 10^9 \text{ Bq} \times 0.14 \times 10^6 \text{ eV} \times 1.6 \times 10^{-19} \text{ J.(eV)}^{-1}}{50 \text{ kg}} \\
 &= 0.45 \mu\text{Gy.s}^{-1}
 \end{aligned}$$

27 a) See §5-7.

$$b) \quad \text{Dose } D = \frac{\text{energy deposited}}{\text{mass of patient}} .$$

$$\text{Energy deposited } E_{\text{dep}} = \frac{1}{2} \times 1 \% \times (\text{energy emitted}).$$

Energy emitted

$$\begin{aligned}
 E_{\text{em}} &= (\text{number of gamma ray photons emitted}) \times (\text{energy of one photon}) \\
 &= N E_{\gamma}
 \end{aligned}$$

Since the half-life is large compared with the exposure time interval t

$$N = \text{Activity} \times \text{exposure time} = At$$

Putting all this together we get

$$\begin{aligned}
 D &= \frac{\frac{1}{2} \times 1 \% \times At E_{\gamma}}{m} \\
 &= \frac{0.005 \times 8.4 \times 10^{13} \text{ Bq} \times 3 \text{ min} \times 1.25 \text{ MeV}}{60 \text{ kg}} \\
 &= \frac{0.005 \times 8.4 \times 10^{13} \text{ s}^{-1} \times 180 \text{ s} \times 1.25 \times 10^6 \times 1.60 \times 10^{-19} \text{ J}}{60 \text{ kg}} \\
 &= 0.25 \text{ Gy}
 \end{aligned}$$

29 Notes

a) Low health hazard; the alpha particles will be absorbed in the air or clothing.

b) High health hazard; especially if taken into bones; the energy will be absorbed in the cells near the radium atoms.

30 Model answer

a) The smallest energy difference between the K and L shells is $(69.6 - 12.1) \text{ keV} = 57.5 \text{ keV}$. So the lowest energy $K\alpha$ radiation can be excited when the accelerating voltage reaches 57.5 kV.

b) The shortest wavelength $K\alpha$ line is the one with the highest photon energy,

$E = (69.6 - 10.2)\text{keV} = 59.4 \text{ keV}$. Photon energy and wavelength are related by

$$E = \frac{hc}{\lambda}$$

so
$$\lambda = \frac{4.14 \times 10^{-15} \text{ eV}\cdot\text{s} \times 3.00 \times 10^8 \text{ m}\cdot\text{s}^{-1}}{59.4 \times 10^3 \text{ eV}}$$

$$= 21 \text{ pm}.$$

31 See chapter AN4.

32 See chapter AN4.

33 See chapter AN4.

34 a) See chapter AN4.

b) See figure 4.19. Describe the features of this graph. Mention minimum ionisation.

35 Notes

a) See §4-10. Range is determined by the initial speed and charge of the particle as well as the composition and density of the absorbing material. [Since it is not always convenient to specify the initial speed of a particle, the initial kinetic energy and the mass can be used instead.]

b) See chapter AN3. Each alpha decay mode releases a definite amount of kinetic energy with the alpha particle. [This happens because momentum and kinetic energy must be shared in definite proportions between the alpha particle and the daughter nucleus.] So all the alpha particles have the same speed and hence approximately the same range. [On the other hand beta decay releases two particles, usually an electron and an antineutrino, so the kinetic energy and momentum are shared in different proportions among the electron, antineutrino and daughter nucleus.] Beta particles have a variety of energies, so they also have a variety of ranges.

c) See chapter AN4. Each gamma ray photon has only one interaction before it is lost from a beam. That interaction is random so the ranges of the photons extend from practically nothing to a very long distance. The range of an individual photon cannot be predicted.

36 See §5-2. Include a diagram.

37 See §5-8 & §5-9.
