7.1 Discrete energy and radioactivity

Singly-ionized helium (He^+)is said to be "hydrogen-like" in that it only has one electron (although it has two protons and two neutrons). The energy levels differ from those of hydrogen as shown in the following table:

Energy level (n)	Energy/eV
1	−54.4
2	−13.6
3	−6.0
4	−3.4
5	−2.2

a) Explain why the ground state has a much higher energy level than that of hydrogen (−13.6 eV).

a) The hydrogen atom has a single proton in the nucleus but the helium ion has two. This means the attractive force between the nucleus and an electron is greater for the helium nucleus. The helium electron is more tightly bound to the nucleus and, therefore, requires more energy to remove it to infinity.

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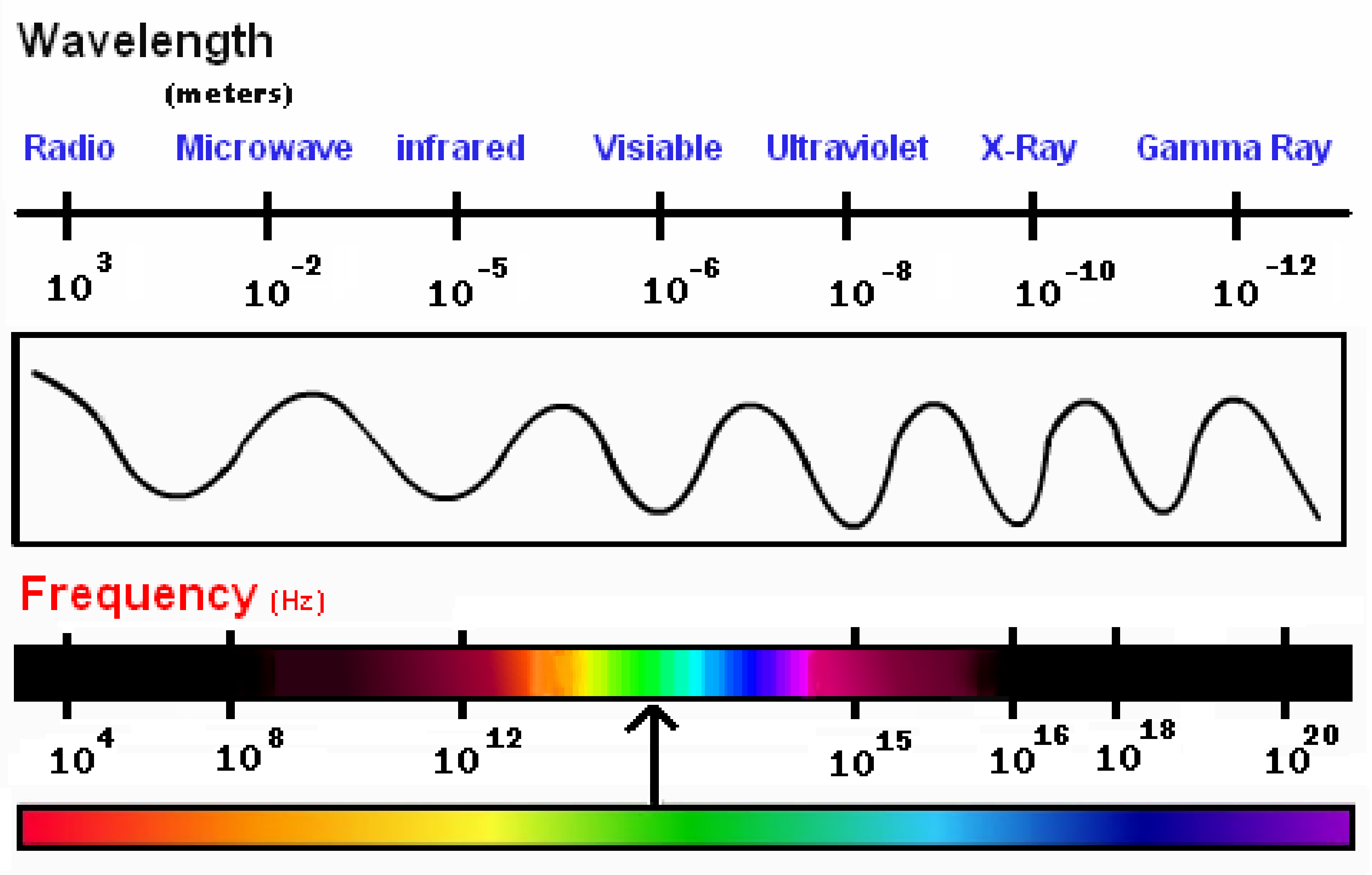
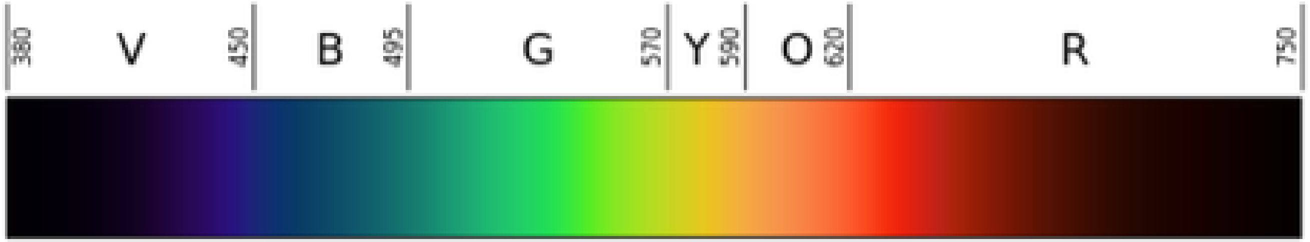
b) (i) Determine the frequency of the photon emitted by an electron transition from energy level 4 to energy level 2.

(ii) State which region of the electromagnetic spectrum the emitted photon belongs to.

THE ELECTRO MAGNETIC SPECTRUM





Color	Wavelength	Frequency	Photon energy
violet	380–450 nm	668–789 THz	2.75–3.26 eV
blue	450–495 nm	606–668 THz	2.50–2.75 eV
green	495–570 nm	526–606 THz	2.17–2.50 eV
yellow	570–590 nm	508–526 THz	2.10–2.17 eV
orange	590–620 nm	484–508 THz	2.00–2.10 eV
red	620–750 nm	400–484 THz	1.65–2.00 eV

b) (i) $\Delta E = (-13.6) - (-3.4) = -10.2$ eV (the minus sign tells us that there is a loss of energy during the emission of photons).

$$10.2 \text{ eV} = 10.2 \times 1.6 \times 10^{-19} \text{ J}$$
$$= 1.6 \times 10^{-18} \text{ J}$$
$$E = hf \therefore f = \frac{E}{h} = \frac{1.6 \times 10^{-18}}{6.63 \times 10^{-34}}$$
$$= 2.4 \times 10^{15} \text{ Hz}$$

(ii) We have seen this energy for the hydrogen atom previously and so know that this frequency corresponds to ultraviolet. You can calculate the wavelength by dividing the speed of electromagnetic waves by your known frequency.

a) The element helium was first identified from the *absorption spectrum* of the Sun.

(i) Explain what is meant by the term *absorption spectrum*.

(ii) Outline how this spectrum may be experimentally observed.

a) **(i)** An absorption spectrum consists of a continuous spectrum that has a number of absorption lines crossing it. These lines correspond to the frequencies of the light in the emission spectrum of the elements within the substance that is absorbing the light.

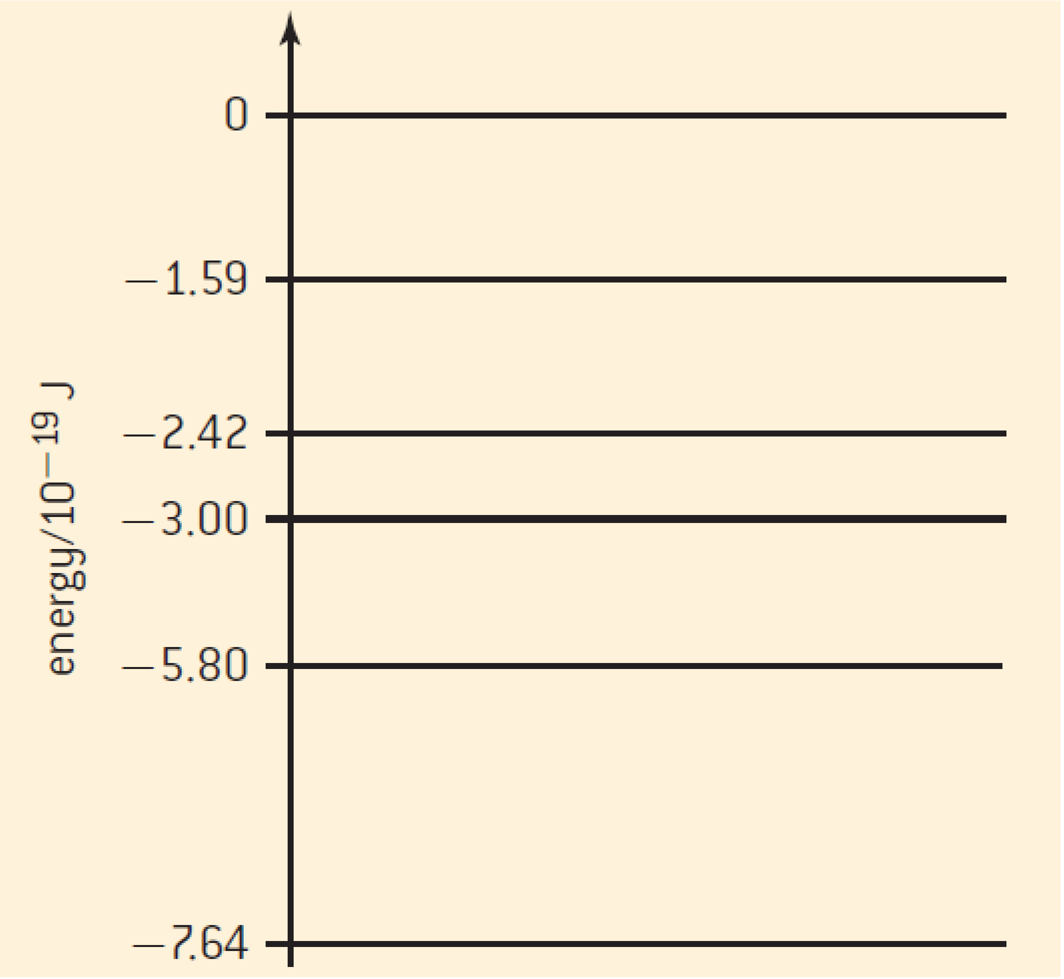
(ii) The light from the Sun can be projected onto a screen after passing through a diffraction grating or a prism in order to disperse it into its component wavelengths. This gives evidence about the elements in the gases in the outer part of the Sun.

b) One of the wavelengths in the absorption spectrum of helium occurs at 588 nm.

(i) Show that the energy of a photon of wavelength 588 nm is 3.38×10^{-19} J.

(ii) The diagram below represents some of the energy levels of the helium atom. Use the information in the diagram to explain how absorption at 588 nm arises.

(iii) Mark this transition on a copy of the energy level diagram below.



b) **(i)** $E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{588 \times 10^{-9}}$

$$= 3.38 \times 10^{-19}\ \text{J}$$

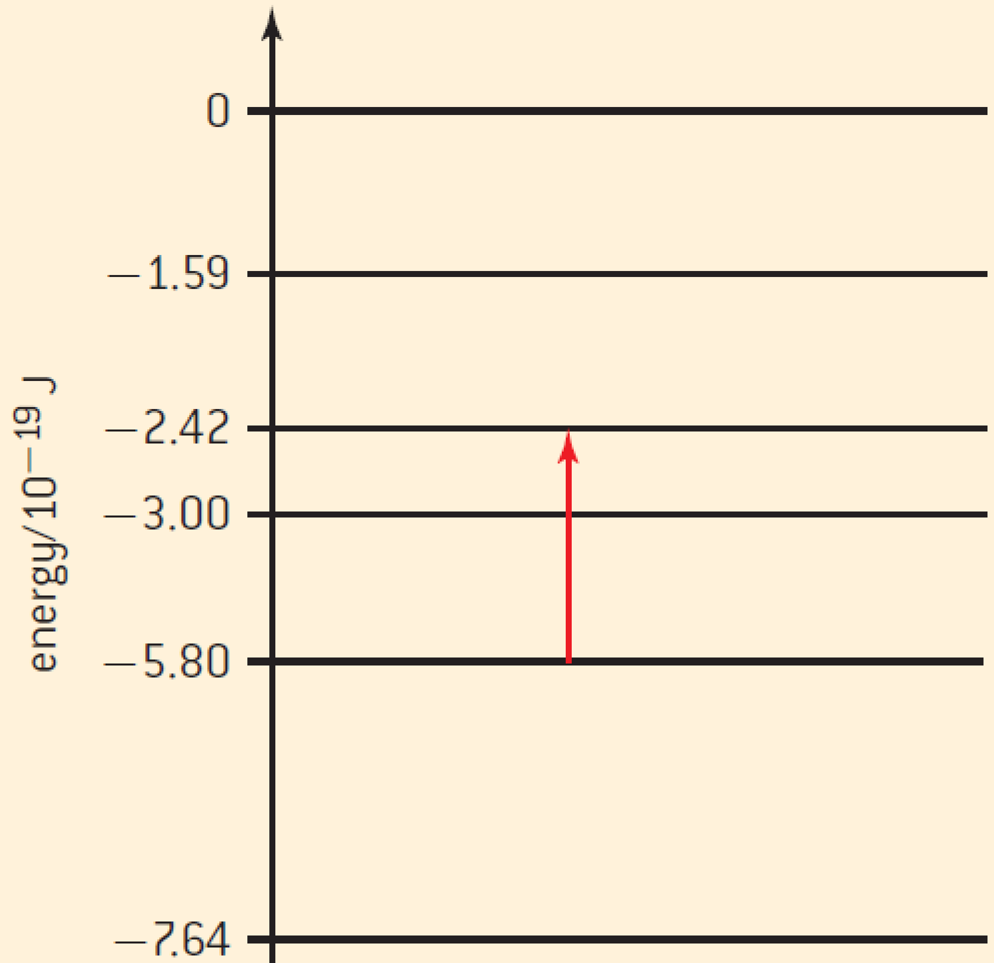
(ii) As this is absorption, the electron is being raised to a higher energy level. The difference between the levels must be equal to 3.38×10^{-19} J and so this is between (-5.80×10^{-19} J) and (-2.42×10^{-19} J) levels, i.e.,

$(-2.42 \times 10^{-19}\ \text{J}) - (-5.80 \times 10^{-19}\ \text{J})$

$= (+)3.38 \times 10^{-19}$ J

Note that the energy levels are given in joules and so there is no need to do a conversion from electronvolts in this question.

(iii) The transition is marked in red.



A nucleus of strontium-90 ($^{90}_{38}Sr$) decays into an isotope of yttrium (Y) by negative beta emission. Write down the nuclear equation for this decay.

This is a normal beta negative decay so the equation will be:

$$^{90}_{38}Sr \rightarrow \, ^{0}_{-1}e + \, ^{90}_{39}Y + \, ^{0}_{0}\overline{\nu}$$

Under certain circumstances a nucleus can capture an electron from the innermost shell of electrons surrounding the nucleus. When the iron-55 ($^{55}_{26}Fe$) nucleus captures an electron in this way the nucleus changes into a manganese (Mn) nucleus. Write a nuclear equation to summarise this.

This is a case of balancing a nuclear equation with the electron being identical to a negative beta particle. The electron is present before the interaction and so appears on the left-hand side of the equation giving:

$$^{55}_{26}\mathrm{Fe} + {}^{0}_{-1}\mathrm{e} \rightarrow {}^{55}_{25}\mathrm{Mn}$$

Actinium-227 ($^{227}_{89}Ac$), decays into thorium-227 ($^{227}_{90}Th$). Thorium-227 has a half-life of 18 days and undergoes α-decay to the nuclide radium-223. On a particular detector a sample of thorium-227 has an initial count rate of 32 counts per second.

a) Define the terms **(i)** nuclide and **(ii)** half-life.

b) Copy and complete the following reaction equation. $^{227}_{89}Ac \rightarrow {}^{227}_{90}Th + \ldots\ldots\ldots + \ldots\ldots\ldots$

a) **(i)** A nuclide is a nucleus with a particular number of protons and neutrons.

(ii) Half-life is the time for the count rate to halve in value **OR** the time for half the number of nuclei to decay into nuclei of another element.

b) The proton number has increased by one so this must be negative beta decay.

$$^{227}_{89}\text{Ac} \rightarrow {}^{227}_{90}\text{Th} + {}^{0}_{-1}\text{e} + {}^{0}_{0}\overline{\nu}$$

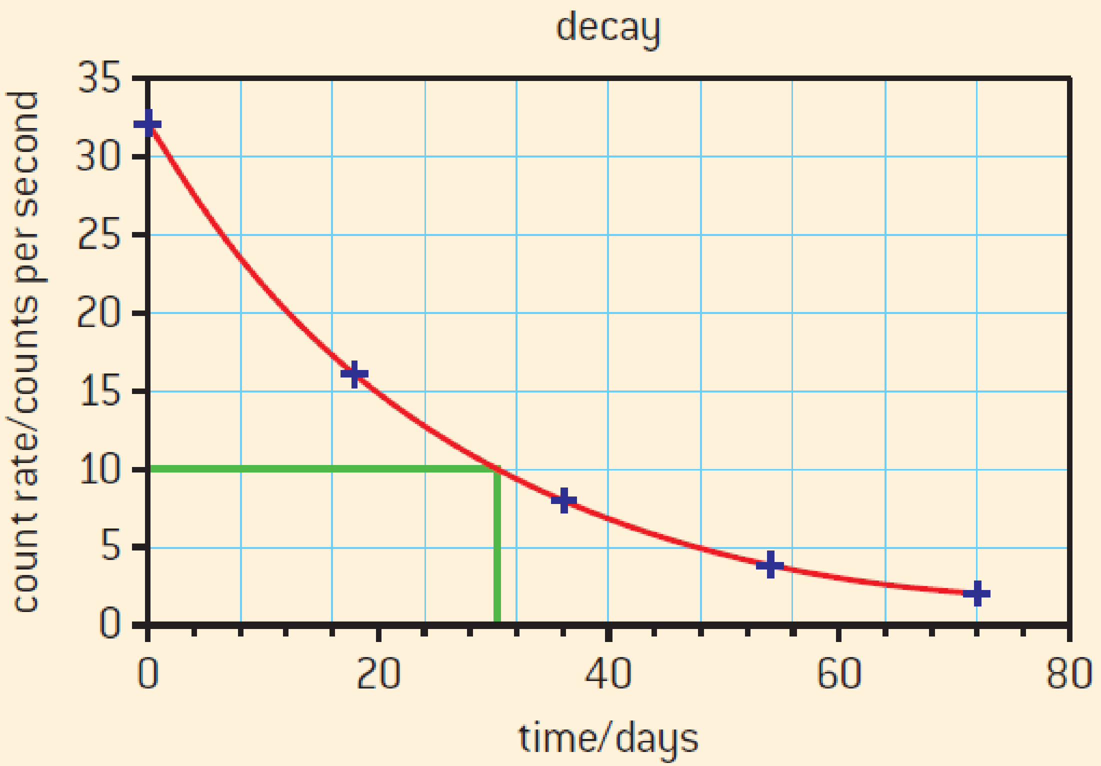
Actinium-227 ($^{227}_{89}Ac$), decays into thorium-227 ($^{227}_{90}Th$). Thorium-227 has a half-life of 18 days and undergoes α-decay to the nuclide radium-223. On a particular detector a sample of thorium-227 has an initial count rate of 32 counts per second.

c) **(i)** Draw a graph to show the variation with time t (for $t = 0$ to $t = 72$ days) of the number of nuclei in a sample of thorium-227

(ii) Determine, from your graph, the count rate of thorium after 30 days.

(iii) Outline the experimental procedure to measure the count rate of thorium-227.

c) (i)



(ii) Marked on the graph in green – the activity is 10 units. *There is likely to be a little tolerance on this type of question in an examination.*

(iii) You would not be expected to give great detail in this sort of question. You should include the following points:

- Use of a G–M tube as detector.
- Measuring the average background count rate in counts per second (this can be done by timing for 100 seconds with no source nearby). This should be done three times, averaged and divided by 100 to give the counts per second.
- Measuring the count rate three times with the source close to the detector.
- Correcting the count rate by subtracting the background count rate from the count rate with the source in position.