Access Tuition

A-Level Physics

Induced Fission

Mark Scheme

Time available: 66 minutes
Marks available: 47 marks

1. (a) U-235 (absorbs) a neutron with added information ✓[1]

[1] Possible added information :

To become U-236

absorbs a slow moving neutron

absorbs a thermal neutron

If no marks awarded but the first two marking points are made without identifying the isotope give one mark

U-235/6 then divides/splits and gives out more neutrons ✓[2]

U-238 absorbs/scatters <u>neutrons</u> ✓[3]

[3] If the answer implies that U-238 in any way is involved in fission this mark is lost

3

(b) Substitution into or manipulation of the equation $N_t = N_0 e^{-\lambda t}$ to give the ratio $\frac{N_0}{N_t}$

with N_t for the present day and N_0 being in the past ✓[1a]

$$\left(\frac{N_0}{N_t} = e^{+\lambda t} = e^{+\left(1.54 \times 10^{-10} \times 2.0 \times 10^{9}\right)} = 1.36\right)$$

Mass of U-238 (= 1.36 × 0.993) = 1.35 kg (3 sf) ✓[2a]

OR working with half-lives

(Half life = 4.50×10^9 year)

Number of half-lives = 4/9 or 0.44 ✓[1b]

$$\left(\frac{N_0}{N_t} = 2^{(4/9)} = 1.36\right)$$

Mass of U-238 (= 1.36 × 0.993) = 1.35 kg (3 sf) ✓[2b]

Must be to 3 sig figs

Calculation may be in grams

[1b] Half life = $\ln 2 / 1.54 \times 10^{-10}$

= 4.50×10^9 (year)

Number of half-lives = $2.00 \times 10^9 / 4.50 \times 10^9$

2

(c) Ratio $\left(\frac{N_{235}}{N_{238}+N_{235}}\right)$ = 3.6% to 3.7%

so yes ✓ A valid calculation must be performed to gain the mark eg with an ecf from (b)

$$\left(\frac{N_{235}}{N_{238}+N_{235}} = \frac{52}{1400+52} \text{ using (b) data } = \frac{52}{1350+52}\right)$$

Condone using ratio $\frac{N_{235}}{N_{238}}$

$$\left(\frac{N_{235}}{N_{238}} = \frac{52}{1400} \text{ using (b) data } = \frac{52}{1350}\right)$$

= 3.7% to 3.9%

1

[6]

2. (a) To increase the probability/chance of fission (when neutron collides with fissile material/U-235)

Or

To allow the neutron to be absorbed by the fuel/U-235 ✓

Condone because thermal/slow moving neutrons are needed for fission to take place

'fuel' but not 'fuel rod' to be used in the alternative.

Reject inaccurate descriptions for example ones that imply the neutrons are undergoing fission.

1

(b) E_{final} = (1 – 0.63) E_{incident} or E_{final} = 0.37 E_{incident} ✓$_1$

(continuing this idea, E_1 = (1 – 0.63) E_0

E_2 = (1 – 0.63) E_1 so E_2 = (1 – 0.63)^2 E_0

and E_5 = (1 – 0.63)^5 E_0

E_5 = (1 – 0.63)^5 × 2.0 × 10^6))

= 1.4 × 10^4 eV ✓$_2$ (1.39 × 10^4 eV)

If no marks are scored a single mark can be given:

if the final answer that has a power of 10 error possibly by not using the M in the eV.

OR

using 0.63 rather than (1 – 0.63) in the calculation giving the answer 2(.0) × 10^5 (eV)

✓$_2$ *A correct final answer gains full marks*

2

(c) A link made between the change in kinetic energy or momentum to the masses of the (two) particles involved in the collision. ✓$_1$

A consistent argument that results in a statement ‘as nucleon number/number of nucleons in the nucleus increases more collisions are required. ✓$_2$

✓$_1$ Ref. to mass is needed.

{Essence of marking point: The mass determines how much KE/momentum is lost}

✓$_2$ Ref to nucleon number or equivalent needed but mass is not.

{Essence of marking point: If N is high then not much KE is lost so more collisions are needed}

An example of an argument could be:

More (kinetic) energy is lost when the mass of the moderator atom/nucleus is closer to the mass of the neutron

So the number of collisions needed increases with nucleon number

2

(d) Mass difference

= ($mass_U$ + $mass_n$) – ($mass_{Xe}$ + $mass_{Sr}$ + 4 $mass_n$)

= (235.044 + 1.0087) – (141.930 + 89.908 + 4 × 1.0087) ✓$_1$

= 0.180 u ✓$_2$ {if no unit present take u as the default unit}

(= 0.180 × 931.5)

= 168 (MeV) ✓$_3$

✓$_1$ Mark for word equation or substitution, one neutron may be cancelled from both parts of the subtraction. Condone any simple slip in transferring the numbers.

Also the mark can be awarded for giving or comparing the mass on the LHS with the RHS.

✓$_2$ Only allow correct answer.

✓$_3$ This mark can stand alone for the conversion of any number of u converted to MeV. 2 sig figs is acceptable.

The conversion mark can come from any part of this question not just the final line.

{1 kg = 6.02 × 10^{26}}

A correct answer gains all 3 marks.

3

(e) 1. (Small amounts of fossil fuel used) so little greenhouse gas emissions/less global warming/less CO_2/less climate change. {not no greenhouse gas}

2. (Less fossil fuel used) so cleaner air.

3. Small amounts of fuel consumed to get the same/large amount of power/energy.

4. Nuclear power can be produced continuously{condone use of constant} (whereas renewables are dependent on sunlight/wind etc).

5. Some (but not all) nuclear power stations can adjust their output quickly.

6. Benefit of producing medical isotopes.

✓ ✓ ✓ any three points

Just one of the examples may be from the following:

At present nuclear fuel is obtained from stable allied countries (as opposed to oil/gas).

Facilitates nuclear weapon production.

(Less fuel used) so less transportation needed.

Examples of rejected ideas because they are incomplete or wrong:

Produces more energy.

There is more uranium than fossil fuel.

Damages the environment less.

Provides jobs.

More efficient than others.

Reference to cost.

It's a renewable source.

3

[11]

3. (a) (moderator) - the neutron undergoes an elastic collision / bounces off with less speed / kinetic energy ✓ (Any reference to absorption loses the mark)

Must have the idea that the neutron slow because of collisions

1

(b) (control rod) – the neutron is absorbed ✓

'stopped' will not get the mark.

If alternatives are given all must be correct to gain mark.

1

(c) the neutron is absorbed/U-236 is formed ✓
(causing) the nucleus (of fuel / uranium) to split into (two smaller) daughter nuclei / nuclei / fragments ✓
releasing (several fast-moving) neutrons ✓

1st mark can use words like absorbed / takes in /

*2nd mark: alternative words for nuclei are **not** acceptable (eg daughter ~~products~~)*

3rd mark 'neutrons' must be plural.

3

(d)

Descriptor	(Bullet point headings are detailed at the bottom end of the table)	Mark
High Level – Good to Excellent All three bullet points must be addressed. The source must be identified and two stages in the treatment sequence must be given. Finally three problems encountered in the treatment of waste and how the problems are overcome should be stated. (Note discussion of a problem will often cover a stage of the treatment). *The information presented as a whole should be well organised using appropriate specialist vocabulary. There should only be one or two spelling or grammatical errors for this mark.*	6 marks = At least 6 points made coming from all three of the bullet point headings. (note some written points may count as answers to bullet point headings 2 and 3) 5 marks = 5 points made coming from all three of the bullet point headings. To be in this top band communication skills must be good and the ideas easy to follow.	5-6
Intermediate Level – Modest to Adequate All three bullet points must be addressed. The source must be identified as well a stage in the treatment along with a problem encountered in the treatment of waste and how it is dealt with. One additional piece of information must be made from any of the bullet points listed below to be at the top of this band. *The grammar and spelling may have a few shortcomings but the ideas must be clear.*	4 marks = 4 points made coming from at least 2 bullet point headings. 3 marks = 3 points made coming from at least 2 bullet point headings. To be in this moderate band communication skills must be good enough to understand the ideas easily even if the order is a little unclear.	3-4
Low Level – Poor to Limited To be at the top of this band two bullet points must be addressed which must include a problem encountered in the treatment of waste and how it is dealt with. A single mark is awarded if any of the information given in the bullet points listed below is given. *There may be many grammatical and spelling errors and the information may be poorly organised.*	2 marks = Two points made from any bullet point heading. 1 mark = any point made coming from any bullet point heading. Or the script as a whole shows some basic understanding of the issues.	1-2
The description expected in a competent answer should include: **1st bullet point** The (highly radioactive/ most dangerous)		

waste are the fission fragments from the fission of uranium-235 or from (spent) fuel rods. **2nd bullet point** The waste is initially placed in cooling ponds/water (close to the reactor for a number of years) plutonium/uranium is separated to be recycled high level waste is vitrified/made solid into (pyrex) glass then placed in (stainless) steel/lead/concrete cylinders/containers/bunkers to be stored **<u>deep</u>** underground (simply stating buried/underground is not enough) **3rd bullet point** (the problem and its solution must both be given, <u>some</u> examples are given below) the waste is (initially) is very hot/generates heat so has to be placed in water/cooling ponds (to remove the heat) the waste (initially) is highly radioactive and needs to be screened in water/cooling ponds (to absorb the radiation) the waste (initially) is highly radioactive and needs to be remotely handled (to avoid human contact with the waste). In liquid form the (high level) waste may leak hence the need to vitrify (and barrel in steel) The waste will be radioactive for hundreds/thousands of years so storage needs to be stable in a container hence the need to vitrify (and barrel in stainless steel) The waste will be radioactive for hundreds/thousands of years so long term storage needs to be in geologically stable areas (deep underground). Transporting waste presents a potential danger to the public so waste is transported enclosed in impact/crash resistant/extra thick and strong casings Or processed onsite or nearby.		

[11]

4. (a) the amount of energy required to separate a nucleus ✓
into its separate neutrons and protons / nucleons ✓
(or energy released on formation of a nucleus ✓
from its separate neutrons and protons / constituents ✓)

1st mark is for correct energy flow direction

2nd mark is for binding or separating nucleons (nucleus is in the question but a reference to an atom will lose the mark)

ignore discussion of SNF etc

both marks are independent

2

(b) (i) $2\,{}^{1}_{0}\text{n}$ or ${}^{1}_{0}\text{n} + {}^{1}_{0}\text{n}$ ✓

must see subscript and superscripts

1

(ii) binding energy of U
= 235 × 7.59 ✓ (= 1784 (MeV))
binding energy of Tc and In
= 112 × 8.36 + 122 × 8.51 ✓
(= 1975 (MeV))
energy released (= 1975 – 1784) = 191 (MeV) ✓ (allow 190 MeV)

1st mark is for 235 × 7.59 seen anywhere

2nd mark for 112 × 8.36 + 122 × 8.51 or 1975 is only given if there are no other terms or conversions added to the equation (ignore which way round the subtraction is positioned)
correct final answer can score 3 marks

3

(iii) energy released
= 191 × 1.60 × 10^{-13} ✓
(= 3.06 × 10^{-11} J)
loss of mass (= E / c^2)
= 2.91 × 10^{-11} / (3.00 × 10^{8})^2)
= 3.4 × 10^{-28} (kg) ✓
or
= 191 / 931.5 u ✓ (= 0.205 u)
= 0.205 × 1.66 × 10^{-27} (kg)
= 3.4 × 10^{-28} (kg) ✓

allow CE from (ii)
working must be shown for a CE otherwise full marks can be given for correct answer only

note for CE

answer = (ii) × 1.78 × 10^{-30}

(2.01 × 10^{-27} is a common answer)

2

(c) (i) line or band from origin, starting at 45° up to Z approximately = 20 reading $Z = 80$, $N = 110 \rightarrow 130$ ✓

initial gradient should be about 1 (ie Z = 20 ; N = 15 → 25) and overall must show some concave curvature. (Ignore slight waviness in the line)
if band is shown take middle as the line
if line stops at N > 70 extrapolate line to N = 80 for marking

1

(ii) fission fragments are (likely) to be above / to the left of the line of stability ✓
fission fragments are (likely) to have a larger *N* / *Z* ratio than stable nuclei
or
fission fragments are neutron rich owtte ✓
and become neutron or β^- emitters ✓

ignore any reference to α emission
a candidate must make a choice for the first two marks
stating that there are more neutrons than protons is not enough for a mark
1st mark reference to graph
2nd mark – high N / Z ratio or neutron rich
3rd mark beta minus
note not just beta

3

[12]

5. (a) insert control rods (further) into the nuclear core / reactor ✓

a change must be implied for 2 marks
marks by use of (further) or (more)
allow answers that discuss shut down as well as power reduction

which will absorb (more) neutrons (reducing further fission reactions) ✓

If a statement is made that is wrong but not asked for limit the score to 1 mark (e.g. wrong reference to moderator)

2

(b) fission fragments / daughter products or spent / used fuel / uranium rods (allow) plutonium (produced from U-238) ✓

not uranium on its own

1

(c) (i) γ (electromagnetic radiation is emitted) ✓

A reference to α or β loses this first mark

as the energy gaps are large (in a nucleus) as the nucleus de-excites down discrete energy levels to allow the nucleus to get to the ground level / state ✓
mark for reason

2nd mark must imply energy levels or states

2

(ii) momentum / kinetic energy is transferred (to the moderator atoms)
or
a neutron slows down / loses kinetic energy (with each collision) ✓

(eventually) reaching speeds associated with thermal random motion or reaches speeds which can cause fission (owtte) ✓

2

[7]