Essential GCSE Physics 54.3

GCSE C C C A Level P P P

When a nucleus of $\mathrm{uranium\text{-}235}$ captures a neutron, fission takes place. One possible fission is:

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{95}_{36}\mathrm{Kr} + {}^{x}_{y}\mathrm{Ba} + 3\,{}^{1}_{0}\mathrm{n}$$

Part A x

Calculate x.

Part B y

Calculate y.

Essential GCSE Physics 56.2

GCSE C C C A Level P P P

$^{1}_{0}\mathrm{n}$	$0.016\,749\times10^{-25}\,\mathrm{kg}$	α	$6.645\times10^{-27}\,\mathrm{kg}$
$^{87}_{35}\mathrm{Br}$	$1.443\,031\times10^{-25}\,\mathrm{kg}$	$^{103}_{40}\mathrm{Zr}$	$1.708\,773\times10^{-25}\,\mathrm{kg}$
$^{134}_{54}\mathrm{Xe}$	$2.223\,061\times10^{-25}\,\mathrm{kg}$	$^{147}_{57}\mathrm{La}$	$2.439\,291\times10^{-25}\,\mathrm{kg}$
$^{189}_{81}\mathrm{Tl}$	$3.137\,255\times10^{-25}\,\mathrm{kg}$	$^{193}_{83}\mathrm{Bi}$	$3.203\,808\times10^{-25}\,\mathrm{kg}$
$^{206}_{82}\mathrm{Pb}$	$3.419\,541\times10^{-25}\,\mathrm{kg}$	$^{206}_{84}\mathrm{Po}$	$3.419\,623\times10^{-25}\,\mathrm{kg}$
$^{210}_{84}\mathrm{Po}$	$3.486\,084\times10^{-25}\,\mathrm{kg}$	$^{210}_{86}\mathrm{Rn}$	$3.486\,179\times10^{-25}\,\mathrm{kg}$
$^{212}_{83}\mathrm{Bi}$	$3.519\,444\times10^{-25}\,\mathrm{kg}$	$^{216}_{85}\mathrm{At}$	$3.586\,032\times10^{-25}\,\mathrm{kg}$
$^{234}_{90}\mathrm{Th}$	$3.885\,568\times10^{-25}\,\mathrm{kg}$	$^{235}_{92}\mathrm{U}$	$3.902\,162\times10^{-25}\,\mathrm{kg}$
$^{238}_{92}\mathrm{U}$	$3.952\,090\times10^{-25}\,\mathrm{kg}$	$^{239}_{94}\mathrm{Pu}$	$3.968\,700\times10^{-25}\,\mathrm{kg}$

When a uranium nucleus fissions, there are various products which can be made. One typical reaction is

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{147}_{57}\mathrm{La} + {}^{87}_{35}\mathrm{Br} + 2{}^{1}_{0}\mathrm{n}$$

Part A Reactant mass

Calculate the total mass of the reactants.

Part B Product mass

Calculate the total mass of the products.

Part C Lost mass

The mass 'lost' is the energy lost to the nuclei. This energy is released in the form of kinetic energy.

Calculate the lost mass.

Part D Energy lost

Use the equation $E = mc^2$ to work out how much energy has been lost from the nuclei (and gained in kinetic energy).

Part E Energy from $1.0\,\mathrm{kg}$

The energy you calculated in (d) was released when one nucleus of uranium was fissioned.

Use the mass of this nucleus to work out how much energy you could get out of $1.0\,\mathrm{kg}$ of uranium if you fissioned all of the nuclei.

Part F Power station output

A nuclear power station has a thermal power output of $3.0 \times 10^9\,\mathrm{W}$.

Calculate how much energy is generated in one year of continuous operation.

Part G Amount of fuel needed

Use your answers to (e) and (f) to calculate the minimum amount of uranium you would need to fuel the power station for a year.

Part H Two neutrons

Why is it important that the reaction makes at least two neutrons?

- So that the energy released is split between the neutrons and they travel slow enough to be captured by other nuclei.
- So the neutrons produced outnumber the elements produced by the reaction.
- So that one reaction can cause at least one further reaction.
- So that a sufficient amount of energy for electricity production is released.

Part I Coal power plant

The combustion of one carbon atom $(\mathrm{mass} = 2.0 \times 10^{-26}\,\mathrm{kg})$ releases $6.6 \times 10^{-20}\,\mathrm{J}$ of energy.

Calculate the mass of carbon (e.g. coal) which would need to be burnt each day to have the same thermal power output as the $3.0 \times 10^{9}\,\mathrm{W}$ nuclear station.

Part J Nuclear power plant

The mass of nuclear waste produced in one year by the nuclear power station will be very similar to your answer to (g). If the material had a density of $6000\,\mathrm{kg/m^3}$, work out the volume of high level nuclear waste produced by the power station in one year's operation.

Part K Length of cube

A cube-shaped underground chamber is to hold the waste produced by the power station over its 20 year operating lifetime. Use your answer to (j) to work out the side-length of the cube.

Part L Fission Products

Since fission products absorb too many neutrons, nuclear fuel has to be removed from a reactor when only $5\,\%$ of the fissile uranium has been used. Repeat part (k) on the assumption that a country does not 'reprocess' its nuclear fuel to remove the fission products, and that fuel is thrown away when only $5\,\%$ of it has been used up.

Part M Mass of waste products

Work out the mass of the waste products of burning the coal in (i). When you burn $12\,\mathrm{g}$ of carbon, you need $32\,\mathrm{g}$ of oxygen, and so for every $12\,\mathrm{g}$ of carbon burnt, $44\,\mathrm{g}$ of waste is made.

Part N Volume of oxygen required

Work out the volume of oxygen required to burn the coal in (i). Assume that every $12\,\mathrm{g}$ of carbon needs $32\,\mathrm{g}$ of oxygen to burn, and that $32\,\mathrm{g}$ of oxygen gas has a volume of $0.024\,\mathrm{m}^3$.

Gameboard:
STEM SMART Physics 36 - Nuclear Energy

Essential Pre-Uni Physics J4.5

A Level

P P P

Mass defects, binding energies or energy yields in nuclear equations require high precision data as calculations involve subtracting two very similar numbers. Use the data here (and on page iv of the book) to all significant figures given. Take $c = 2.998 \times 10^8\,\mathrm{m\,s^{-1}}$, and the electronic charge as $1.602 \times 10^{-19}\,\mathrm{C}$.

Mass of neutron (m_n)	$1.67493 \times 10^{-27}\,\mathrm{kg}$
Mass of neutron (m_n)	$1.00867\,\mathrm{u}$
Mass of proton (m_p)	$1.67262 \times 10^{-27}\,\mathrm{kg}$
Mass of proton (m_p)	$1.00728\,\mathrm{u}$
Mass of electron (m_e)	$9.10938 \times 10^{-31}\,\mathrm{kg}$
Mass of electron (m_e)	$5.48580 \times 10^{-4}\,\mathrm{u}$
Atomic mass unit (u)	$1.66054 \times 10^{-27}\,\mathrm{kg}$

One nuclear fusion reaction is ${}^2_1\mathrm{H} + {}^3_1\mathrm{H} \rightarrow {}^4_2\mathrm{He} + {}^1_0\mathrm{n}$. The masses of the **nuclei** are given below:

$$\text{Deuterium } ({}^2\mathrm{H}) \text{ mass } 2.01355\,\mathrm{u}$$

$$\text{Tritium } ({}^3\mathrm{H}) \text{ mass } 3.01550\,\mathrm{u}$$

$$\text{Helium } ({}^4\mathrm{He}) \text{ mass } 4.00151\,\mathrm{u}$$

Calculate the energy released by this reaction in MeV (it appears as the kinetic energy of the reaction products). Give your answer to 4 sig fig.

Gameboard:

STEM SMART Physics 36 - Nuclear Energy

Essential Pre-Uni Physics J4.1

A Level

P P P

Mass defects, binding energies or energy yields in nuclear equations require high precision data as calculations involve subtracting two very similar numbers. Use the data here (and on page iv of the book) to all significant figures given. Take $c = 2.998 \times 10^8\,\mathrm{m\,s^{-1}}$, and the electronic charge as $1.602 \times 10^{-19}\,\mathrm{C}$.

Mass of neutron (m_n)	$1.67493 \times 10^{-27}\,\mathrm{kg}$
Mass of neutron (m_n)	$1.00867\,\mathrm{u}$
Mass of proton (m_p)	$1.67262 \times 10^{-27}\,\mathrm{kg}$
Mass of proton (m_p)	$1.00728\,\mathrm{u}$
Mass of electron (m_e)	$9.10938 \times 10^{-31}\,\mathrm{kg}$
Mass of electron (m_e)	$5.48580 \times 10^{-4}\,\mathrm{u}$
Atomic mass unit (u)	$1.66054 \times 10^{-27}\,\mathrm{kg}$

Calculate the mass defect of $^{56}_{26}\mathrm{Fe}$ in $\mathrm{kilograms}$. The $^{56}\mathrm{Fe}$ $\mathbf{nucleus}$ has a mass of $55.92068\,\mathrm{u}$. Give your answer to 4 sig fig.

Gameboard:

STEM SMART Physics 36 - Nuclear Energy

Essential Pre-Uni Physics J4.7

A Level P P P

Mass defects, binding energies or energy yields in nuclear equations require high precision data as calculations involve subtracting two very similar numbers. Use the data here (and on page iv of the book) to all significant figures given. Take $c = 2.998 \times 10^8\ \mathrm{m\,s^{-1}}$, and the electronic charge as $1.602 \times 10^{-19}\ \mathrm{C}$.

Mass of neutron (m_n)	$1.674\,93 \times 10^{-27}\ \mathrm{kg}$
Mass of neutron (m_n)	$1.008\,67\ \mathrm{u}$
Mass of proton (m_p)	$1.672\,62 \times 10^{-27}\ \mathrm{kg}$
Mass of proton (m_p)	$1.007\,28\ \mathrm{u}$
Mass of electron (m_e)	$9.109\,38 \times 10^{-31}\ \mathrm{kg}$
Mass of electron (m_e)	$5.485\,80 \times 10^{-4}\ \mathrm{u}$
Atomic mass unit (u)	$1.660\,54 \times 10^{-27}\ \mathrm{kg}$

One nuclear fusion reaction is ${}^2_1\mathrm{H} + {}^3_1\mathrm{H} \rightarrow {}^4_2\mathrm{He} + {}^1_0\mathrm{n}$. The masses of the $\mathbf{nuclei}$ are given below:

$$\text{Deuterium } ({}^2\mathrm{H}) \text{ mass } 2.013\,55\ \mathrm{u}$$

$$\text{Tritium } ({}^3\mathrm{H}) \text{ mass } 3.015\,50\ \mathrm{u}$$

$$\text{Helium } ({}^4\mathrm{He}) \text{ mass } 4.001\,51\ \mathrm{u}$$

Part A Binding energy per nucleon of deuterium

Using the information in the tables above, calculate the binding energy per nucleon of deuterium. Give your answer to 4 sig fig.

Part B Energy released

Calculate the energy released in the fusion reaction above using the binding energy per nucleon calculated in Part A and the following data: Binding energy per nucleon of tritium is $2.8273\,\mathrm{MeV}$, and for helium-4 it is $7.0739\,\mathrm{MeV}$. Give your answer to 4 sig fig.

Gameboard:

STEM SMART Physics 36 - Nuclear Energy

Essential Pre-Uni Physics J4.8

A Level

Mass defects, binding energies or energy yields in nuclear equations require high precision data as calculations involve subtracting two very similar numbers. Use the data here (and on page iv of the book) to all significant figures given. Take $c = 2.998 \times 10^{8}\,\mathrm{m\,s^{-1}}$, and the electronic charge as $1.602 \times 10^{-19}\,\mathrm{C}$.

Mass of neutron (m_n)	$1.67493 \times 10^{-27}\,\mathrm{kg}$
Mass of neutron (m_n)	$1.00867\,\mathrm{u}$
Mass of proton (m_p)	$1.67262 \times 10^{-27}\,\mathrm{kg}$
Mass of proton (m_p)	$1.00728\,\mathrm{u}$
Mass of electron (m_e)	$9.10938 \times 10^{-31}\,\mathrm{kg}$
Mass of electron (m_e)	$5.48580 \times 10^{-4}\,\mathrm{u}$
Atomic mass unit (u)	$1.66054 \times 10^{-27}\,\mathrm{kg}$

One nuclear fission reaction is ${}^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{147}_{57}\mathrm{La} + {}^{87}_{35}\mathrm{Br} + 2{}^{1}_{0}\mathrm{n}$. The masses of the $\mathbf{atoms}$ are given in the table below.

${}^{235}_{92}\mathrm{U}$	$3.90300 \times 10^{-25}\,\mathrm{kg}$
${}^{147}_{57}\mathrm{La}$	$2.43981 \times 10^{-25}\,\mathrm{kg}$
${}^{87}_{35}\mathrm{Br}$	$1.44335 \times 10^{-25}\,\mathrm{kg}$

Part A Binding energy

Using the information given, calculate the binding energy (in MeV) per nucleon of ${}^{235}\mathrm{U}$. Give your answer to 4 sig fig.

Part B Energy released in fission

Calculate the energy released in the fission reaction above using your binding energy per nucleon calculated in Part A and the following data: binding energy per nucleon for $^{147}\mathrm{La}$ is $8.2227\,\mathrm{MeV}$, and for $^{87}\mathrm{Br}$ is $8.6055\,\mathrm{MeV}$. Give your answer to 4 sig fig.

Gameboard:

STEM SMART Physics 36 - Nuclear Energy

Physics. You work it out.

Fusion Reactions

GCSE A Level

${}^{0}_{1}\mathrm{e}$	$9.1094 \times 10^{-31}\,\mathrm{kg}$	${}^{12}_{6}\mathrm{C}$	$1.99210 \times 10^{-26}\,\mathrm{kg}$
${}^{1}_{0}\mathrm{n}$	$1.6749 \times 10^{-27}\,\mathrm{kg}$	${}^{14}_{7}\mathrm{N}$	$2.32463 \times 10^{-26}\,\mathrm{kg}$
${}^{1}_{1}\mathrm{H}$	$1.6726 \times 10^{-27}\,\mathrm{kg}$	${}^{15}_{8}\mathrm{O}$	$2.49059 \times 10^{-26}\,\mathrm{kg}$
${}^{2}_{1}\mathrm{H}$	$3.3436 \times 10^{-27}\,\mathrm{kg}$	${}^{24}_{12}\mathrm{Mg}$	$3.98172 \times 10^{-26}\,\mathrm{kg}$
${}^{3}_{1}\mathrm{H}$	$5.0074 \times 10^{-27}\,\mathrm{kg}$	${}^{56}_{26}\mathrm{Fe}$	$9.28585 \times 10^{-26}\,\mathrm{kg}$
${}^{3}_{2}\mathrm{He}$	$5.0064 \times 10^{-27}\,\mathrm{kg}$	${}^{111}_{52}\mathrm{Te}$	$1.841405 \times 10^{-25}\,\mathrm{kg}$
${}^{4}_{2}\mathrm{He}$	$6.6447 \times 10^{-27}\,\mathrm{kg}$		

Using the nuclear masses above, calculate the energy released in each of the following fusion reactions. In this question take $c = 3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$.

Part A ${}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \longrightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$

$${}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \longrightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$$

Part B $4\,{}^{1}_{1}\mathrm{H} \longrightarrow {}^{4}_{2}\mathrm{He} + 2\,{}^{0}_{1}\mathrm{e}$

$$4\,{}^{1}_{1}\mathrm{H} \longrightarrow {}^{4}_{2}\mathrm{He} + 2\,{}^{0}_{1}\mathrm{e}$$

Part C $^{56}_{26}\mathrm{Fe} + ^{56}_{26}\mathrm{Fe} \longrightarrow ^{111}_{52}\mathrm{Te} + ^{1}_{0}\mathrm{n}$

$$^{56}_{26}\mathrm{Fe} + ^{56}_{26}\mathrm{Fe} \longrightarrow ^{111}_{52}\mathrm{Te} + ^{1}_{0}\mathrm{n}$$

Part D Difference with the last reaction

What is different about the last reaction?

- It releases significantly more energy than the rest.
- It takes in energy.
- Charge is not conserved.
- Mass is not conserved.