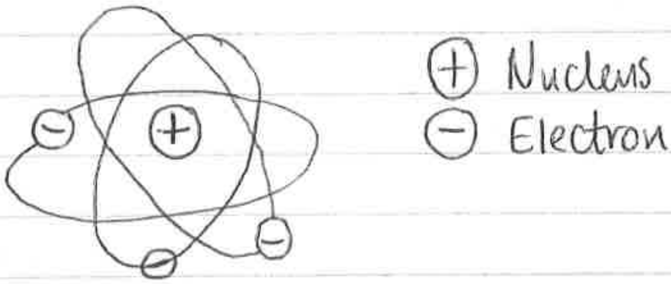
Higher Physics
Unit 2: Particles and Waves
Nuclear Reactions

Rutherford's Model

1. The alpha particles are positively charged and are repelled by the positively charged nucleus, so they change direction (are scattered) and in a few cases are reflected back from the foil.

2. The Rutherford Model of the atom shows that an atom is mostly empty space, with electrons orbiting a fixed, positively charged nucleus in set, predictable paths. The nucleus has all of the mass of the atom.



Radioactive Decay

3. a. $^{226}_{88}Ra \rightarrow {}^{222}_{86}R + {}^{4}_{2}He$

b. $^{234}_{92}U \rightarrow {}^{230}_{90}Th + {}^{4}_{2}He$

c. $^{234}_{91}Pa \rightarrow {}^{234}_{92}U + {}^{0}_{-1}e$

d. $^{210}_{82}Pb \rightarrow {}^{210}_{83}Bi + {}^{0}_{-1}e$

4. a. $^{228}_{90}Th \rightarrow ^{228}_{91}Ra + ^{0}_{-1}e$

b. $^{220}_{86}Rn \rightarrow ^{216}_{84}Po + ^{4}_{2}He$

c. $^{211}_{82}Pb \rightarrow ^{211}_{83}Bi + ^{0}_{-1}e$

d. $^{223}_{88}Ra \rightarrow ^{219}_{86}Rn + ^{4}_{2}He$

5. $^{238}_{92}U \rightarrow ^{234}_{92}U + ^{4}_{2}\alpha + 2^{0}_{-1}\beta$

Uranium-234

6. $^{232}_{90}Th \rightarrow ^{224}_{87}Fr + 2^{4}_{2}\alpha + ^{0}_{-1}\beta$

7. $^{235}_{92}U \rightarrow ^{231}_{90}Th \rightarrow ^{231}_{91}Pa \rightarrow ^{227}_{89}Ac$

a. Uranium-235, Thorium-231, Protactinium-231, Actinium-227

b. If gamma is emitted then this can't be shown in the equation as it is energy (a photon), and does not have a relative atomic mass number etc

$E=mc^2$

8. a. $E=mc^2$ $m = 3.25 \times 10^{-28}$ kg
$E = 3.25 \times 10^{-28} \times (3 \times 10^8)^2$ $c = 3 \times 10^8$ m/s
$E = 2.925 \times 10^{-11}$ J

b. $E=mc^2$ $m = 2.01 \times 10^{-28}$ kg
$E = 2.01 \times 10^{-28} \times (3 \times 10^8)^2$ $c = 3 \times 10^8$ m/s
$E = 1.809 \times 10^{-11}$ J

c. $E = mc^2$ $m = 1.62 \times 10^{-28}$ kg

$E = 1.62 \times 10^{-28} \times (3 \times 10^8)^2$ $c = 3 \times 10^8$ m/s

$E = \underline{1.458 \times 10^{-11} J}$

d. $E = mc^2$ $m = 2.85 \times 10^{-28}$ kg

$E = 2.85 \times 10^{-28} \times (3 \times 10^8)^2$ $c = 3 \times 10^8$ m/s

$E = \underline{2.565 \times 10^{-11} J}$

9. ${}^3_1H + {}^2_1H \rightarrow {}^4_2He + {}^1_0n$

a.

mass before reaction (kg)		mass after reaction (kg)	
${}^3_1H$	5.00890×10^{-27}	He	6.64632×10^{-27}
${}^2_1H$	3.34441×10^{-27}	n	1.67490×10^{-27}
	8.35331×10^{-27}		8.32122×10^{-27}

mass defect $= 3.209 \times 10^{-29}$ kg

b. $E = mc^2$ $m = 3.209 \times 10^{-29}$ kg

$E = 3.209 \times 10^{-29} \times (3 \times 10^8)^2$ $c = 3 \times 10^8$ m/s

$E = \underline{2.8881 \times 10^{-12} J}$

c. Nuclear Fusion

d. $P = \frac{E}{t}$

$P = 25 \times 10^6$ W $E = 2.8881 \times 10^{-12}$ J

$t = 1$ s

$\Rightarrow \frac{25 \times 10^6}{2.8881 \times 10^{-12}} = 8.65621 \times 10^{18}$ reactions per second.

10. $4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2\,{}^{0}_{1}e^{+}$

mass before reaction (kg)		mass after reaction (kg)	
$4\,{}^{1}_{1}H$	$4 \times 1.673 \times 10^{-27}$	${}^{4}_{2}He$	6.646×10^{-27}
	6.692×10^{-27}		

mass defect = 4.6×10^{-29} kg

$E = mc^2$ $\quad m = 4.6 \times 10^{-29}$ kg

$E = 4.6 \times 10^{-29} \times (3 \times 10^8)^2$ $\quad c = 3 \times 10^8$ m/s

$E = 4.14 \times 10^{-12}$ J

11. ${}^{1}_{1}H + {}^{15}_{7}N \rightarrow {}^{12}_{6}C + {}^{4}_{2}He$

$E = mc^2$ $\quad E = 7.96662 \times 10^{-13}$ J

$7.96662 \times 10^{-13} = m \times (3 \times 10^8)^2$ $\quad c = 3 \times 10^8$ m/s

$m = \frac{7.96662 \times 10^{-13}}{(3 \times 10^8)^2}$

$m = 8.518 \times 10^{-30}$ kg

mass after reaction (kg) $= 20.1031 \times 10^{-27} + 6.69944 \times 10^{-27}$

$= 2.680254 \times 10^{-26}$ kg

mass before reaction (kg) = mass defect + mass after reactin

$= 8.8518 \times 10^{-30} + 2.680254 \times 10^{-26}$

$= 2.68114 \times 10^{-26}$ kg

mass of nitrogen particle = mass before reaction − mass of ${}^{1}_{1}H$

$= 2.68114 \times 10^{-26} - 1.68706 \times 10^{-27}$

$= 2.51243 \times 10^{-26}$ kg

12. ${}^{A}_{Z}X + {}^{2}_{1}H \rightarrow 2\,{}^{4}_{2}He + {}^{1}_{0}n$ + energy

a. ${}^{7}_{3}Li$ - Lithium

b. $E = mc^2$

$2.97\times10^{-12} = m \times (3\times10^{8})^2$

$m = \frac{2.97\times10^{-12}}{(3\times10^{8})^2}$

$m = 3.3\times10^{-29}$ kg (mass defect)

$E = 2.97\times10^{-12}$ J

$c = 3\times10^{8}$ m/s

mass after reaction (kg)	
$2\,{}^{4}_{2}He$	$2\times6.642\times10^{-27}$
${}^{0}_{1}n$	1.675×10^{-27}
	1.4959×10^{-26} kg

mass before reaction = mass defect + mass after reaction

$= 3.3\times10^{-29} + 1.4959\times10^{-26}$

$= 1.4992\times10^{-26}$ kg

mass of ${}^{7}_{3}Li$ = mass before reaction − mass of ${}^{2}_{1}H$

$= 1.4992\times10^{-26} - 3.342\times10^{-27}$

$= 1.165\times10^{-26}$ kg

13. ${}^{3}_{1}H + {}^{2}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$

a. Nuclear Fusion

b.

mass before reaction (kg)	
${}^{3}_{1}H$	5.005×10^{-27}
${}^{2}_{1}H$	3.342×10^{-27}
	8.347×10^{-27}

mass after reaction (kg)	
${}^{4}_{2}He$	6.642×10^{-27}
${}^{1}_{0}n$	1.675×10^{-27}
	8.317×10^{-27}

mass defect = 3×10^{-29} kg

$E = mc^2$

$E = 3\times10^{-29}\times(3\times10^{8})^2$

$E = 2.7\times10^{-12}$ J

$m = 3\times10^{-29}$ kg

$c = 3\times10^{8}$ m/s

14. $^{240}_{94}Pu \rightarrow ^{236}_{92}U + ^{4}_{2}He$

mass before reaction (kg)		mass after reaction (kg)	
Pu	398.626×10^{-27}	U	391.970×10^{-27}
		He	6.645×10^{-27}
			3.98615×10^{-25}

mass defect $= 1.1 \times 10^{-29}$ kg

$E = mc^2$ $\quad m = 1.1 \times 10^{-29}$ kg

$E = 1.1 \times 10^{-29} \times (3 \times 10^8)^2$ $\quad c = 3 \times 10^8$ m/s

$E = 9.9 \times 10^{-13}$ J

15. $^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{137}_{r}Cs + ^{s}_{37}T + 4\,^{1}_{0}n$

a. This is an induced reaction. The Uranium nucleus is struck by a neutron to cause fission.

b. $r = 55$
$s = 95$

c. The element represented by T is **rubidium**

d.

	mass before reaction (kg)		mass after reaction (kg)
$^{235}_{92}U$	390.219×10^{-27}	$^{137}_{55}Cs$	227.292×10^{-27}
$^{1}_{0}n$	1.675×10^{-27}	$^{95}_{37}T$	157.562×10^{-27}
	3.91894×10^{-25}	$4\,^{1}_{0}n$	$4 \times 1.675 \times 10^{-27}$
			3.91554×10^{-25}

mass defect $= 3.4 \times 10^{-28}$ kg

$E = mc^2$ $\quad m = 3.4 \times 10^{-28}$ kg

$E = 3.4 \times 10^{-28} \times (3 \times 10^8)^2$ $\quad c = 3 \times 10^8$ m/s

$E = 3.06 \times 10^{-11}$ J

16. $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{139}_{57}La + ^{r}_{42}Mo + 2^{1}_{0}n + s^{0}_{-1}e$

a. $r = 95$

$s = 7$

b. The total mass before fission is greater than the total mass of the products. Einstein suggested that mass was a form of energy, and that when there was a decrease in mass, an equivalent amount of energy was produced ($E=mc^2$).

c.

mass before reaction (kg)		mass after reaction (kg)	
$^{235}_{92}U$	390.173×10^{-27}	$^{139}_{57}La$	230.584×10^{-27}
$^{1}_{0}n$	1.675×10^{-27}	$^{95}_{42}Mo$	157.544×10^{-27}
		$^{1}_{0}n$	$2 \times 1.675 \times 10^{-27}$
	3.91848×10^{-25}		3.91478×10^{-25}

mass defect $= 3.7 \times 10^{-28}$ kg

$E = mc^2$

$E = 3.7 \times 10^{-28} \times (3 \times 10^8)^2$

$E = \underline{3.33 \times 10^{-11} J}$

$c = 3 \times 10^8$ m/s

$m = 3.7 \times 10^{-28}$ kg