Nuclear Reactions : Notes/W.S. - 70

A **chemical reaction** is one that involves a change in the electronic structure of an atom.

A **nuclear reaction** is one that involves a change in the nucleus of an atom.

In this type of reaction, an enormous amount of energy can be released. A typical chemical reaction may release 1,000 kJ of energy per mol of reactant. But a nuclear reaction may release 10^6 times as much energy as this.

In nuclear reactions, charge is always conserved. Atomic mass is almost (but not quite) conserved. Some mass is converted to energy. The amount of energy can be found from Einstein's equation, $E = mc^2$ (m is the mass converted in kg, and c is the speed of light which is 3.0×10^8 m/s).

The main particles involved in nuclear reactions are :

1) $^1n_0$ = the neutron

2) $^1H_1$ = the proton

3) $^4He_2$ = the helium nucleus (alpha particle, Q = +2e)

4) $^0e_{-1}$ = the beta particle (high speed electron, Q = -1e)

5) $^0g_0$ = the gamma ray (high energy electromagnetic radiation)

The superscript in the above symbols indicates the mass number. The subscript indicates the charge in units of e (elementary charge).

There are several types of nuclear reactions.

1) **Radioactive decay** : A radioactive nucleus emits an alpha particle, a beta particle, a gamma ray, or a combination of the three. e.g.:

$^{226}Ra_{88} \rightarrow {}^{222}Rn_{86} + {}^4He_2 + {}^0g_0$

$^{214}Pb_{82} \rightarrow {}^{214}Bi_{83} + {}^0e_{-1} + {}^0g_0$

Note: The sums of the superscripts (mass numbers) on each side are equal. The sums of the subscripts (charge) on each side are also equal. Total mass number and charge are conserved.

If a beta particle (electron) is ejected from a nucleus, a neutron in the nucleus changed into a proton. An isolated neutron will decay into a proton and an electron.

2) **Fission** : In this reaction, the nucleus splits into two parts that have approximately equal masses. This may be spontaneous or induced (in a lab). This reaction occurs in nuclear reactors and nuclear bombs that use uranium. e.g.:

$^{256}Fm_{100} \rightarrow {}^{116}Ag_{47} + {}^{138}I_{53} + 2\ {}^{1}n_{0}$ (spontaneous)

$^{235}U_{92} + {}^{1}n_{0} \rightarrow {}^{141}Ba_{56} + {}^{92}Kr_{36} + 3\ {}^{1}n_{0}$ (induced)

3) **Fusion** : In this type of nuclear reaction, two nuclei "fuse", or join together to form a heavier nucleus, with the release of a lot of energy. This type of reaction occurs in the sun and in nuclear bombs that use hydrogen. e.g.:

$^{2}H_{1} + {}^{3}H_{1} \rightarrow {}^{4}He_{2} + {}^{1}n_{0}$ + energy

4) **Artificial Transmutation** : This nuclear reaction occurs when a nucleus is bombarded with a particle forming a new atom. e.g.:

$^{14}N_{7} + {}^{4}He_{2} \rightarrow {}^{17}O_{8} + {}^{1}H_{1}$

Problems :

1) What is a nuclear reaction ?

2) A nuclear reaction releases up to _____ times the energy of a chemical reaction.

3) What two things are conserved in a nuclear reaction ?

4) Using the Einstein equation, find the amount of energy released when one gram of matter is converted into energy.

5) Write down the symbols for the five main particles involved in nuclear reactions. (there are others)

6) Name and describe briefly the four main types of nuclear reactions.

7) Balance the following nuclear reactions. (fill in the blanks)

a) _____ + $^{4}He_{2}$ -> $^{7}Be_{4}$

b) $^{209}Po_{84}$ + $^{1}n_{0}$ -> $^{4}He_{2}$ + _____

c) $^{226}Ra_{88}$ -> _____ + $^{4}He_{2}$

d) $^{14}C_{6}$ -> $^{14}N_{7}$ + _____

e) _____ + $^{0}e_{-1}$ -> $^{7}Li_{3}$

f) $^{238}U_{92}$ -> _____ + $^{4}He_{2}$ + $^{0}e_{-1}$

g) $^{16}O_{8}$ + $^{1}n_{0}$ -> $^{15}N_{7}$ + _____

h) $^{235}U_{92}$ + $^{1}n_{0}$ -> $^{141}Ba_{56}$ + $^{92}Kr_{36}$ + _____

i) $^{2}H_{1}$ + _____ -> $^{3}He_{2}$ + $^{1}n_{0}$

j) $^{3}H_{1}$ -> _____ + $^{0}e_{-1}$

k) _____ + $^{12}C_{6}$ -> $^{254}No_{102}$ + 4 $^{1}n_{0}$

l) $^{59}Co_{27}$ + $^{1}n_{0}$ -> _____

m) $^{60}Co_{27}$ -> $^{60}Ni_{28}$ + $^{0}e_{-1}$ + _____

n) $^{3}H_{1}$ -> _____ + $^{0}g_{0}$

o) _____ + $^{4}He_{2}$ -> $^{12}C_{6}$ + $^{1}n_{0}$

8) Which of the above reactions are examples of :

a) radioactivity _____

b) fission _____

c) fusion _____

d) artificial transmutation _____

Answers : 1) It is a reaction that involves a change in the nucleus., 2) 10^6, 3) charge and mass number, 4) $9.0x10^{13}J$, 5) see text above, 6) see text above, 7a) $^{3}He_{2}$, b) $^{206}Pb_{82}$, c) $^{222}Rn_{86}$, d) $^{0}e_{-1}$, e) $^{7}Be_{4}$, f) $^{234}Pa_{91}$, g) $^{2}H_{1}$, h) 3 x $^{1}n_{0}$, i) $^{2}H_{1}$, j) $^{3}He_{2}$, k) $^{246}Cm_{96}$, l) $^{60}Co_{27}$, m) $^{0}g_{0}$, n) $^{3}H_{1}$, o) $^{9}Be_{4}$, 8)a) c, d, f, j, m, n., b) h, c) a, i., d) b, e, g, k, l, o.