**neutron than the parent element. Thus the sum of the protons and neutrons in the daughter element** remains the same as in the parent element. Due to the formation of one more proton, the atomic number of the daughter element is increased by one unit.

**Soddy-Fajans and Russel group displacement law (1913)**

This law tells us about the nature and the new periodic position of the element produced when a radioactive element loses an α-particle or a β-particle, or a positron or gains an electron. The element losing or gaining the particle is called *parent element* and the element which is produced after the loss or gain of the particle is called *daughter element* or *daughter product*. This law can be studied under the following heads.

(*i*) **Emission of an alpha particle, α or $^4_2He$.** We know that an α-particle is a helium nucleus whose mass number is 4 and nuclear charge (*i.e.*, atomic number) is +2. Thus this particle is represented as $^{4}_{+2}He$ or simply as $^4_2He$. When a radioactive element emits an α-particle ($^4_2He$), the mass number of the daughter element is decreased by 4 units (since the mass number of helium nucleus is 4) and atomic number gets decreased by 2 units (since the charge or atomic number of helium nucleus is +2). Due to the decrease in atomic number by two units, the daughter element gets shifted two places to the left in the periodic table. For example :

$$\underset{\text{Group VIA}}{^{215}_{84}Po_{131}} \xrightarrow{-^4_2He} \underset{\text{Group IVA}}{^{211}_{82}Pb_{129}} + {^4_2He}$$

*Explanation.* We know that a helium nucleus ($^4_2He$) has mass number equal to 4 and atomic number equal to 2. Thus this nucleus contains 2 protons and 4 – 2 = 2 neutrons ($^4_2He_2$). Thus the above nuclear reaction can be written as

$$^{215}_{84}Po_{131} \xrightarrow{-^4_2He_2} {^{211}_{82}Pb_{129}} + {^4_2He_2}$$

The presence of two protons and two neutrons in helium nucleus implies that when the nucleus of $^{215}_{84}Po_{131}$ loses an α-particle, 2 protons and 2 neutrons are lost by it, *i.e.*, the number of protons (or atomic number) in the daughter element becomes 84 – 2 = 82 and the number of neutrons becomes equal to 131 – 2 = 129 and consequently the mass number becomes equal to 82 + 129 = 211. Thus the loss of 2 protons implies that the atomic number of the daughter element is two units less than that of the parent element while the loss of (2 protons + 2 neutrons) suggests that the mass number of the daughter element becomes four units less than that of the perent element.

(*ii*) **Emission of a beta particle, β or $^{0}_{-1}e$.** We know that a β-particle is an electron which has mass number equal to zero and its charge or atomic number is –1. Thus it is represented as $^{0}_{-1}e$ or β. When a radioactive element emits one $^{0}_{-1}e$ (or β-particle), the mass number of the daughter element remains the same (since the mass number of $^{0}_{-1}e$ is zero) but its atomic number is increased by one unit (since the charge or atomic number of $^{0}_{-1}e$ is –1). Due to the increase in atomic number by one unit, the newly-formed element gets shifted one place to the right in the periodic table. For example :

$$\underset{\substack{\text{(Radioactive)}\\\text{(Group IA)}}}{^{24}_{11}Na_{13}} \xrightarrow{-^{0}_{-1}e} \underset{\substack{\text{(Stable)}\\\text{(Group IIA)}}}{^{24}_{12}Mg_{12}} + {^{0}_{-1}e} \text{ or } \bar{\beta}$$

$$\underset{\text{(Group Zero)}}{^{23}_{10}Ne_{13}} \xrightarrow{-^{0}_{-1}e} \underset{\text{(Group IA)}}{^{24}_{12}Na_{12}} + {^{0}_{-1}e} \text{ or } \bar{\beta}$$

*Explanation.* We know that nucleus does not contain ${}_{-1}^{0}e$ (β-particle) as such. Then how is $\overline{\beta}$-particle produced in the nuclear reactions like those as given above? In order to explain its production, it is assumed that one of the neutrons (${}_{0}^{1}n$) present in the parent element is converted into a proton (${}_{1}^{1}H$ or ${}_{1}^{1}p$) and in this conversion process, one ${}_{-1}^{0}e$ (β-particle) and one anti-neutrino (${}_{0}^{0}\nu$) are also produced, *i.e.*,

$$ {}_{0}^{1}n \rightarrow {}_{1}^{1}H \text{ or } {}_{1}^{1}p + {}_{-1}^{0}e \text{ or } \beta + {}_{0}^{0}\nu \qquad \text{... } (i) $$

Thus in the nuclear reaction,

$$ {}_{11}^{24}Na_{13} \xrightarrow{-{}_{-1}^{0}e} {}_{12}^{24}Mg_{12} + {}_{-1}^{0}e $$

one of the 13 neutrons is converted into a proton and hence the newly-formed element has 13 − 1 = 12 neutrons and 11 + 1 = 12 protons and in this process one ${}_{-1}^{0}e$ (β-particle) and one anti-neutrino (${}_{0}^{0}\nu$) are also produced. Thus the newly-formed element is ${}_{12}^{24}Mg_{12}$ and hence the above reaction should be written as :

$$ {}_{11}^{24}Na_{13} \longrightarrow {}_{12}^{24}Mg_{12} + {}_{-1}^{0}e \text{ or } \beta + {}_{0}^{0}\nu $$

The discussion made above shows that since mass number of the parent element and of the daughter element are the same, these two elements are isobars to each other. Thus we can say that the emission of one or more β-particles (or ${}_{-1}^{0}e$) by a radioactive element produces its isobar(s).

β decay is common over the entire range of nuclides and amongst the naturally occuring heavy radioactive nuclides and in the fission products (see *Nuclear Fission*).

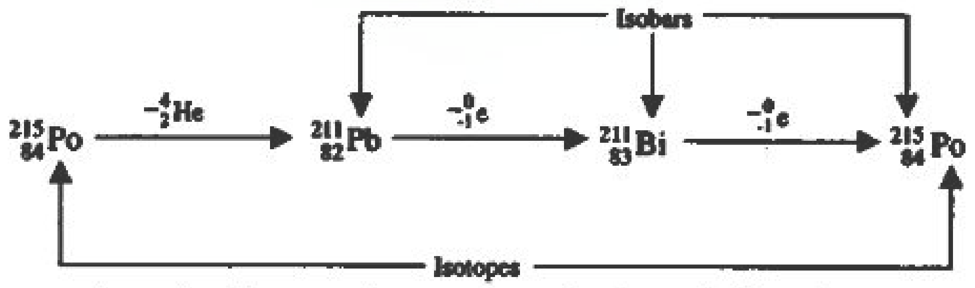
Equation (*i*) is balanced in so far as angular momentum values of different particles is concerned as shown below:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Equation : | ${}_{0}^{1}n$ | $\longrightarrow$ | ${}_{1}^{1}H$ | $-$ | ${}_{+1}^{0}e$ | $+$ | ${}_{0}^{0}\nu$ |
| Angular momentum values : | $+\dfrac{h}{4\pi}$ | | $+\dfrac{h}{4\pi}$ | $-$ | $\dfrac{h}{4\pi}$ | $+$ | $\dfrac{h}{4\pi}$ |

If ${}_{0}^{0}\nu$ is not supposed to be emitted in the above equation, then angular momentum values are not balanced as shown below:

| | | | | | |
|---|---|---|---|---|---|
| Equation : | ${}_{0}^{1}n$ | $\longrightarrow$ | ${}_{1}^{1}H$ | $+$ | ${}_{-1}^{0}e$ |
| Angular momentum values : | $+\dfrac{h}{4\pi}$ | | $+\dfrac{h}{4\pi}$ | $-$ | $\dfrac{h}{4\pi}$ |

*Formation of isotopes and isobars.* When a radioactive element emits one α-particle (${}_{2}^{4}He$) and two β-particles (${}_{-1}^{0}e$), the daughter element has the same atomic number as the parent element and hence these two elements are isotopes to each other. Thus the combined emission of one α-particle and two β-particles produces an isotope of the parent element, *e.g.*




It may be seen from the above nuclear reactions that the emission of one or more β-particles (${}_{-1}^{0}e$) by a radioactive element produces its isobar(s).

**(*iii*) Emission of a positron, ${}_{+1}^{0}e$.** We know that a positron is an anti-particle of an electron (${}_{-1}^{0}e$), *i.e.*, a positron has mass number equal to zero (its actual mass = 0.0005486 *amu*) and its charge or atomic number is +1. Thus positron is represented as $_{+1}^{0}e$. This particle was discovered by Iren Curie and her husband (name-Frederick Jiolet) in 1934. They bombarded $_{13}^{27}Al$ nuclide (non-radioactive isotope) with α-particles so that it was converted into radioactive $_{15}^{30}P$ isotope with the emission of a neutron ($_{0}^{1}n$).

$$_{13}^{27}Al + _{2}^{4}He \longrightarrow _{15}^{30}P \text{ (Radioactive)} + _{0}^{1}n$$

Being radioactive $_{15}^{30}P$ disintegrates to give stable $_{14}^{30}Si$ isotope and a positron ($_{+1}^{0}e$)

$$_{15}^{30}P \text{ (Radioactive)} \longrightarrow _{14}^{30}Si \text{ (Stable istope)} + _{+1}^{0}e \textit{ (positron)}$$

It is evident from the above nuclear reaction that when a radioactive element emits a positron, the mass number of the daughter element remains the same (since the mass number of $_{+1}^{0}e$ is zero) but its atomic number is decreased by one unit (since the charge or atomic number of $_{+1}^{0}e$ is +1). Due to the decrease in the atomic number by one unit, the newly-formed element gets shifted one place to the left in the periodic table. This fact is also evident form the following nuclear reactions:

$$\underset{\text{(Group IIA)}}{_{12}^{23}Mg_{11} \text{ (Radioactive)}} \xrightarrow{-_{+1}^{0}e} \underset{\text{(Group IA)}}{_{11}^{23}Na_{12} \text{ (Stable)}} + _{+1}^{0}e \textit{ (positron)}$$

$$\underset{\text{(Group IA)}}{_{11}^{22}Na_{11} \text{ (Radioactive)}} \xrightarrow{-_{+1}^{0}e} \underset{\text{(Group zero)}}{_{10}^{22}Ne_{12} \text{ (Stable)}} + _{+1}^{0}e \textit{ (positron)}$$

*Explanation:* How is the positron produced in a nuclear reaction has been explained by assuming that one of the protons ($_{1}^{1}p$ or $_{1}^{1}H$) present in the nucleus of the parent element is converted into a neutron ($_{0}^{1}n$) and in this process one positron ($_{+1}^{0}e$) and one neutrino ($_{0}^{0}\nu$) are also produced, *i.e.*,

$$_{1}^{1}H \rightarrow _{0}^{1}n + _{+1}^{0}e + _{0}^{0}\nu$$

Thus in the nuclear reaction

$$_{12}^{23}Mg_{11} \xrightarrow{-_{+1}^{0}e} _{11}^{23}Na_{12} + _{+1}^{0}e,$$

one of the 12 protons is converted into a neutron and hence the daughter element has 12 – 1= 11 protons and 11+ 1 = 12 neutrons and in this process one positron ($_{+1}^{0}e$) and one neutrino ($_{0}^{0}\nu$) are also produced. Thus the daughter element is $_{11}^{23}Na_{12}$ and hence the above equation should be written as :

$$_{12}^{23}Mg_{11} \longrightarrow _{11}^{23}Na_{12} + _{+1}^{0}e + _{0}^{0}\nu$$

Since the mass number of the parent element and the daughter element are the same, these two elements are isobars to each other. Thus, we see that the emission of one or more positrons ($_{+1}^{0}e$) by a radioactive element produces its isobar(s).

**(iv) Addition of an electron: Electron - capture process.** In this process an electron from the K or L shell is captured by a proton of the nucleus and this proton is converted into a neutron. In this process a neutrino ($_{0}^{0}\nu$) is also produced.

$$_{1}^{1}H + _{-1}^{0}e \longrightarrow _{0}^{1}n + _{0}^{0}\nu$$

The following nuclear reactions are electron-capture reactions.

$$_{26}^{55}Fe_{29} + _{-1}^{0}e \longrightarrow _{25}^{55}Mn_{30} + _{0}^{0}\nu \quad ...(i)$$

$$_{56}^{131}Ba_{75} + _{-1}^{0}e \longrightarrow _{55}^{131}Cs_{76} + _{0}^{0}\nu$$