Radioactivity

Radioactivity is a spontaneous process, during which an unstable nucleus of a certain element transforms into more stable nucleus of a different element. During the process, loosened particles are emitted from the nucleus in the form of radiation.

Whether the nucleus is stable or unstable is decided by so called **valley of stability**, which is defined by ratio of protons and neutrons in nucleus. For nuclides with lower mass number, the stable ratio is around 1 : 1. With higher mass number the ratio changes towards 2 : 3 (P : N). If the ratio of a nuclide deviates from the valley of stability ratio, the said nuclide is considered unstable.

Nucleus

The nucleus of an atom is a particle with a radius of approximately 10^{-15} m and is decisive in determining the total mass of an atom. All nuclei contain **nucleons** - nuclear particles of two types with almost the same mass but differing in charge - protons and neutrons. The nucleon number tells us the total number of nucleons in the nucleus, denoted as A.

Proton is a nuclear particle with a positive charge equal to so called elementary charge (1,6 * 10^{-19} C). Number of protons in the nucleus is represented as **atomic number** (Z).

Neutron is a nuclear particle without any charge. As opposed to the proton, the neutron is unstable. As itself it decays into the proton and into other particles. The amount of neutrons in the nucleus is represented with **neutron number** (N).

A chemical element is defined by amount of its protons and neutrons. From the structure of the nucleus we can assume its stability and mass. Probability of the decay depends on the ratio of N and Z.

Nuclides

A nuclide is an atomic species defined by the specific constitution of its nucleus, i.e., by its number of protons Z and its number of neutrons N.

Carbon, as an example, is found as a mix of two isotopes, ^{12}C and ^{13}C. In tables, the relative atomic mass of carbon is 12,011 which corresponds to this natural mix of isotopes instead of 12,000 which would be relative atomic mass of pure ^{12}C.

Isotopes

Isotopes are variants of a particular chemical element which differ in neutron number. All isotopes of a given element have the same number of protons in each atom. They differ in physical but not chemical characteristics. The main differences are in mass and stability which is direct consequence of different neutron number. As an example, isotope of carbon ^{12}C, which is the most common (98,9%), is stable. Isotope ^{13}C, whose nucleus contains one more neutron, is still stable, but not as common (1,1%). Isotope ^{14}C with two more neutrons in its nucleus is already unstable and that's why we call it radionuclide. **Radionuclide** is an isotope which decays while emitting radiation.

Isotopes almost do not differ in their chemical attributes. One minor difference might be in speed of their reactions. Heavier isotopes are usually slower in their reactions.

Isobars

Isobars are atoms of different chemical elements which have the same number of nucleons but different atomic number. An example of isobars would be ^{40}S, ^{40}Cl, ^{40}Ar, ^{40}K, and ^{40}Ca. The nuclei of these nuclides contain 40 nucleons but they contain different numbers of protons and neutrons. $N + Z = const.$

Isotones

Isotones are atoms of different chemical elements which have the same number of neutrons but different atomic and mass number. As an example we can use ^{12}B and ^{13}C. Borium has 5 protons, carbon has 6 protons but both have 7 neutrons. The biggest groups of isotones are with 50 neutrons (^{86}Kr,^{88}Sr,^{89}Y,^{90}Zr,^{92}Mo) and with 82 neutrons (^{138}Ba,^{139}La,^{140}Ce,^{141}Pr,^{142}Nd,^{144}Sm). No stable isotones have 19, 21, 35, 39, 45, 61, 71, 89, 115, 123 or 127 neutrons.

Binding and Separation Energy

The stability of a nucleus depends on the binding energy, which is the energy that must be supplied—or, if you prefer, the work that must be done—to break the nucleus into individual nucleons. However, one works more with the separation energy, which is the binding energy calculated per nucleon. The $^{56}_{26}Fe$ isotope has the highest separation energy. It can therefore be said that this isotope of iron is the most stable isotope ever - the same applies to the nuclide of this substance.

River of Stability

However, the stability of the nucleus can also be deduced without knowing the values of binding and separation energies. The so-called **stability river**, which is determined by the ratio of the number of protons and the number of neutrons, tells about the stability or instability of a nuclide. Particularly stable are nuclides with so-called "magic numbers", such as $^{4}_{2}He$, $^{16}_{8}O$, or $^{40}_{20}Ca$. Generally speaking, if the ratio of nucleon number to proton number is 2:1, it is a very stable nucleus. For heavier elements, neutrons tend to predominate over protons—probably to balance the repulsive electrostatic forces between like-charged protons—and the ratio approaches about 3:2. In light nuclei, on the contrary, there are fewer neutrons than protons - the electrostatic forces between p^+ are not so strong - and then the ratio is close to 1.5:1.

In simple terms, taking into account both previous paragraphs, it can be said that stable nuclei acquire A from 30 to 130. If a nuclide is outside the river of stability by its ratio, it is considered unstable. There are about 50 unstable nuclides in nature.

Radioactive Decay Series

There are four known radioactive decay series that describe the chain of transformations taking place in radioactive nuclides. Radioactive nuclides often do not decay directly into a stable nucleus, but again into a radioactive nucleus, which already has a lower energy, but it continues to decay until a stable nucleus is reached.

These radioactive decay series are: uranium-radium decay series, then uranium-actinium, thorium and neptunium decay series. . Using a few rules, it was determined that the A of individual 'intermediates' decay series can be easily generalized.

The uranium-radium radioactive decay series begins with the radioactive isotope $^{238}_{92}U$ and ends with the stable isotope $^{206}_{82}Pb$, A=4n+2.

The uranium-actinium radioactive decay series begins with the isotope $^{235}_{92}U$ and ends with the isotope $^{207}_{82}Pb$ A=4n+3 .

Thorium's radioactive decay series begins with $^{232}_{90}Th$ and ends with $^{208}_{82}Pb$, A=4n.

The neptunium radioactive decay series starts at $^{237}_{93}Np$ and ends at $^{209}_{83}Bi$ and A=4n+1.

Until recently, only three of these series - uranium-radium, uranium-actinium, thorium - were considered natural, because the starting nuclides were found in nature, while the neptunium series was considered an artificial series, because neptunium could not be found in nature. However, it has been shown to be present in trace amounts in uranium ores, so all radioactive decay series can be considered natural.

Types of Radiation

α-particles

α-particle constits of **two protons** and **two neutrons** which are bond together identically to the **nucleus of helium**. It has non-zero mass and because it contains two protons it has positive charge +2e. This radiation is emitted during the **α-decay of an isotope of a heavy element**. Emitted energy is equal to the loss of mass of the system.

Nuclide which is result of the α-decay has **lower atomic number by two** and mass number lower by four (it's shifted by two places to the left in the PTOE). The emitted particle has much lower mass than the original nucleus which means that the kinetic energy of the the new nucleus is negligible. The newly created nucleus returns back from the excited state by **emitting quantums of γ-radiation**. γ-radiation usually accompanies α particles during α-decay.

α-particles are **highly ionizing form** of particle radiation and they have very **low penetration depth**, which means they can be absorbed by just a few centimetres of air or by a sheet of paper. Superficial effect on human skin is negligible as all of the α-particles absorbed by cells squamous epithelium. Exposing inner epithelia to α-particles can lead to cancerous process as they can damage genetic material. α-particles can be used for medical purposes. In smaller doses they activate defense systems of the cells.

Among elements which undergo α-decay belongs for example **uranium**, **radium** or **radon**.

β-particles

β-particles are emitted by nuclei which undergo β-decay. They can be either positively β^+ (positrons) or negatively β^- (electrons) charged. **β^+-particles** are emitted during tranformation of proton into neutron inside the nucleus. The new element is shifted one place to the left in the PTOE. **β^--particles** are emitted during transformation of neutron into proton inside the nucleus. The new element is shifted one place to the right in the PTOE. β-particles are emitted at very high velocity and they have higher penetration depth than α-particles. They can penetrate materials with low density or low thiccness. As an example for shading of β-particles we can use a tin foil.

β^- radiation

This is a stream of electrons emanating from the nucleus. Electrons really come from the nucleus, because the neutron decays into a proton and an electron. Protons remain in the nucleus during this reaction, only electrons fly out. In addition to these electrons, an electrically uncharged particle with a small mass - an antineutrino - also flies out of the nucleus. There is a **shift** in the periodic table **one place to the right**.

This reaction can be written as: ^1_0n -> ^1_1p+ $^0_{-1}e$ + antineutrino.

The reaction within the entire atom is then written approximately as follows: ^A_ZX -> $^A_{Z+1}Y$ + $^0_{-1}e$

β^+ radiation

β^+ radiation is much more difficult to observe. This is because it is a stream of positrons from the nucleus. A positron is a particle opposite to an electron. Like the electron, it has a small mass and an elementary charge, however positive. Positrons are found in antimatter, which is the opposite of matter found all around us. β^+ is difficult to observe because when matter meets antimatter, annihilation (complete release of energy) occurs, which is observed as an explosion. Positrons can only be observed in particle accelerators, or in this case the reaction of artificial nuclides. During β^+ radiation, a proton decays into a positron and a neutron. Everything is supplemented with neutrinos. The neutron remains in the nucleus and the positron flies out of it analogously to β^- radiation. So there is a **shift** in the periodic table **one place to the left**.

Everything can be written roughly like this: ^1_1p -> ^1_0n + $^0_{+1}e$ + neutrino.

Events throughout the core are described as: ^A_ZX -> $^A_{Z-1}Y$ + < sup>0$_{+1}$e

γ radiation

γ radiation is electromagnetic radiation with very short wavelength, great amount of energy and high penetration rate. Unlike α a β radiation, which are corpuscular, the γ radiation permeates into matter with more ease and its perfect shading is almost impossible (the intensity of radiation can be lowered by using layers of materials containing heavy elements, for instance lead).

Radionuclides are unstable nuclides. We distinguish natural radionuclides (found in nature) and synthetic radionuclides (created via nuclear reactions). From this we also distinguish natural and artificial radioactivity.

Natural radioactivity

It is spontaneous transition of unstable nuclei to their stable forms. During this process the nuclei are emitting radiation. Natural radioactivity was discovered by H. Becquerel in 1896 and studied by Marie and Pierre Curie.

Induced radioactivity

Transformation of atoms caused by nucleus reactions. This was discovered by Frederic and Irene Curie in 1934 during the test based on strafing aluminium with alfa particles.

Radioactive balance

Condition ,when is during some time converted the same amount of atoms in radioactive isotopes line.

A - there is no balance. Physical transfiguration half-life of mother-element (T1) is shorter then transfiguration half-life of the daughter-element (T2)

B - transient radioactive balance, T1 is longer then T2

C - permanent radioactive balance, transfiguration half-life T1 is much longer then T2 element

Nucleus instability

Not every atom nuclei are stable. Most of them transform spontaneously into different nuclei.

Radioactive transmutation half-life

During this process, unstable atoms beams their energy (as electromagnetic wave or as a particle).

Physical half-life
during this period, is half of original nuclei transformed
Biological half-life

during this time is half of particular element separate out of the body
Effective half-life
combination of biological and physical half-life. It means, that it is period, during which is radioactivity lowered to half, thanks to physical and biological transition.

Protection against the harmful effects of radioactive radiation

For more information see Protection against the harmful effects of radioactive radiation.

Usage of radioactivity

Nuclear energetics

Nuclear reactions are based on transmutation of the nuclei with higher bounding energy to the nuclei with the lower bounding energy. Difference between these energies is excited and used. Bounding energy is value characterising the stability of the nucleus. Most stable nuclei have nucleic number between 30 to 130. It is energy, released during the creation of the nucleus from two nucleons.


International symbol of radioactivity

Nuclear energy can be divided into two types:

- Nucleus synthesis (Thermonuclear reaction) – Heavier nuclei are made of the lighter nuclei and huge amount of energy is emitted during this process. The conditions for this reaction are very high temperature and pressure (for example in the stars).
- Nucleus fission (Fission reaction) – Two mid-weighted atoms nuclei are created while few neutrons and energy is released. Recently created neutrons are used to another fission reaction. We have two types of reactions, controlled and uncontrolled. During the controlled reaction, the neutrons are used one by one step wisely. We use this process in power station to transform nuclear energy to electric energy. On the other hand, the uncontrolled reaction cause chain reaction and created neutrons release the energy immediately which why it is used in nuclear weapons.

Nuclear powerplants

Nuclear fission reaction is taking place in nuclear reactor. Whole process is compound of various parts, in order to prevent leak of radiation. Released thermal energy starts to boil water and flowing water steam runs a turbine. Heavy water (deuterium oxide) is used here as moderator for slowing down fission of neutrons. For controlling velocity of nuclear reaction are used cadmium control rods (are able to absorb generated neutrons) or boric acid.

The fission reaction takes place in a nuclear reactor, the entire block consists of several circuits to prevent the release of radioactivity. The released thermal energy heats the steam, which then drives the turbine. Heavy water (deuterium oxide) = moderator is used to slow down the fission neutrons. To control the rate of a nuclear reaction, cadmium control rods are used, which like to absorb the resulting neutrons and boric acid.

Neutron Radiation

In nuclear power plants, so-called neutron radiation is used to obtain energy.

As the name suggests – it is a stream of neutrons. Due to the nuclear forces, it is not easy to release a neutron from a nucleus, however, if it can be done, it has significant advantages. Neutron, as a particle without a charge - does not react very easily with the surrounding atoms, it only reacts with their nuclei. This radiation is not deflected in an electric or magnetic field and does not itself ionize the surroundings.

Neutrons can be released from nuclei in particle accelerators or by the decay of heavy transuranium nuclei (californium, A=252), we do not find them in nature. In practice, beryllium is most often used, which is irradiated with α radiation, which knocks a neutron out of the Be nucleus. Due to their small size and the small size of the nucleus, neutrons have to "meet" many particles before they finally react.

Neutron radiation can react with its surroundings in two ways. The first way is the so-called **elastic collisions**, in which the neutron transfers part of its energy and continues further with reduced energy - speed. The greatest effect of energy transfer is for hydrogen nuclei, i.e. for particles with a mass closest to a neutron, so light elements are suitable for slowing down neutrons. In the nuclei of heavy elements, less energy is transferred. Therefore, a so-called moderator is mainly used to slow down neutrons, which can be, for example, heavy water (= deuterium oxide).

In **inelastic collisions**, the neutron hits the nucleus and stays in it. The nuclei formed in this way are usually very unstable, which is why they often disintegrate themselves when emitting β- and γ radiation, or these particles just emit. Inelastic collisions work very well especially with slow neutrons. Boron or cadmium capture neutrons very well, which is why they are used as regulators in nuclear reactors.

This reaction can be written approximately as follows: ${}^{1}_{0}n + {}^{A}_{Z}X \rightarrow {}^{A+1}_{Z}Y$.

Nuclear weapons

For more information see Use of radioactivity.

Radiotherapy

Radiotherapy is a conservative method, which is used for curing malignant tumors. Using various types of ionizing radiation, affected tissue is facing it in order to cause necrosis of the tumor. The goal, except eliminating the affected tissue, is to cause as little damage to the healthy tissue as possible. Selection of the type and intenzity used radiation is based on the character of the tumor. **Brachytherapy** requires placing the source of radiation on the surface of the tumor or in the tumor. **Teletherapy** is carried out with source situated outside of the organism. From the physical point of view we distinguish two types of used ionizing radiation - electromagnetic and corpuscular. Electromagnetic includes radiation X (rtg) and γ. Corpuscular radiation includes particles such as protons, neutrons, α-particles and electrons (β-particles). According to the source there is wide range of methods - proton therapy, linear or circular accelerators treatment (X radiation) or cobalt therapy (γ radiation).

Radiosensitivity of cells describes ability to react to radiation. Stem cells are more likely to be sensitive to radiation than mature or highly differentiated cells are.

Radiotherapy is a conservative method used to treat malignant tumors in the human body. The affected tissue is irradiated, when we use various types of ionizing radiation. The goal is to destroy the tumor and damage the surrounding healthy tissue as little as possible. Depending on the nature of the tumor, a different intensity and type of radiation is chosen. In **teletherapy**, irradiation is carried out using a source located outside the body. **Brachytherapy** requires placing the source on the surface of the tumor or directly inside the tumor. From a physical point of view, the ionizing radiation used is of two types - electromagnetic and corpuscular. Electromagnetic includes X-rays (x-rays) and γ-rays. Corpuscular radiation, also particle radiation, contains protons, neutrons, α-particles and electrons (β-particles). Depending on the source, there are a number of methods - proton treatment, treatment using a linear or circular accelerator (X-radiation) or deep therapy using cobalt (γ-radiation).

Cell **radiosensitivity** is a property that characterizes a cell's ability to respond to radiation. A minimally differentiated cell shows greater sensitivity to radiation than cells that are mature or highly differentiated.

Age analysis of archeological findings

Age determination of archeological findings is done with **radiocarbon method of dating**. [1]

Carbon is able to create 3 base isotopes - ^{12}C, ^{13}C a ^{14}C. Isotope ^{14}C is radioactive, that means radionuclide with half-life 5730 years. There are all 3 isotopes in a constant ratio in nature. We are able to determine age of dead organism based on number of decays per minute in 1 g of radioactive carbon. When an organism dies its shift of carbon supplies stops and in that moment the ratio of carbon isotopes is same as in nature. But immediately after that redionuclides start to decay and the ratio between isotopes growths.

Carbon is able to form three basic isotopes - ^{12}C, ^{13}C and ^{14}C. (See Isotopes) The ^{14}C isotope is radioactive, a so-called radionuclide with a half-life of 5730 years. All three isotopes are present in nature and in a constant ratio. It follows from this that when the organism dies, i.e. when the supply of carbon stops, the ratio of isotopes is the same as in the surrounding nature. The radionuclide begins to decay and the ratio between the isotopes increases. According to the number of decays per minute in 1 g of radioactive carbon, it is possible to determine the age of the find.

History

For more information see History of discoveries in the field of radioactivity.

As first discoverer of radioactivity is considered Henry Becquerel in 1896. When he placed fluorescence material between photographic panels and they were untouched, he found out that minerals emitting more than light radiation. Then at the start of 20th century Marie Curie Sklodowska was researching radioactivity and besides everything else she discovered new elements (radium and polonium). She were trying to find out why uranium ore is more radioactive than pure uranium. After four years she discovered polonium (named after her homeland) then she discovered even more radioactive radium. M. R. Sklodowska was the first woman to win a Nobel prize. First nuclear reactor was put into operation in 1942 in USA. First nuclear power station was opened in 1956 in Great Britain.

Henry Becquerel was the first to discover radioactivity in 1896 by discovering that minerals emit radiation other than light when he placed fluorescent material between photographic plates and the photographic plates were untouched. Subsequently, Marie Curie Sklodowská researched radioactivity at the beginning of the 20th century and, among other things, discovered new elements (radium and polonium). She researched why uranium ore is more radioactive than uranium itself. Four years later, she discovered polonium (she named it after her homeland), then she discovered the even more radioactive radium. M. R. Sklodowska was the first woman to win the Nobel Prize in Physics. The first nuclear reactor was commissioned in the USA in 1942. The first nuclear power plant was opened in 1956 in Great Britain.

Links

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