Radiochemistry

Is the branch of chemistry concerned with the chemistry of radioisotopes, elements, and substances, the laws governing the physicochemical behavior of this radioactive matter, the chemistry of nuclear transformations, and the physicochemical processes that accompany these transformations, because of the topics, methods, and objects of its investigations, can be subdivided into general radio-chemistry, the chemistry of nuclear transformations, the chemistry of radioactive elements, and applied radiochemistry.

General radiochemistry studies the physicochemical regularities in the behavior of radioisotopes and elements. Radioisotopes, which differ little in their chemical properties from nonradioactive isotopes, are present, though in extremely low concentrations, in ores and other natural substances, in products obtained synthetically, and in the solutions formed after processing raw materials. The decay these isotopes undergo is accompanied by nuclear radiation. Most natural radioisotopes are daughter isotopes, that is, products of the decay of ^{238}U,

ISOTOPES

Atoms that have the same atomic number (number of protons), but different mass numbers (number of protons and neutrons) are called isotopes. There are naturally occurring isotopes and isotopes that are artificially produced. Isotopes are separated through mass spectrometry

An isotope is one of two or more species of atoms of a chemical element with the same atomic number (same number or protons in the nucleus) and position in the periodic table and nearly identical chemical behavior but with different atomic masses and physical properties. Every chemical element has one or more isotopes.

Species of atomic nuclei

The term nucleon is used to designate both protons and neutrons in the nucleus. The mass number A is the total number of nucleons (mass number). Thus

$$A = N + Z$$

where Z is the number of protons (equal the atomic number) and N is the number of neutrons.

$$^{A}_{Z}X$$

for example, carbon has two naturally occurring isotopes, $^{12}_{6}C$ and $^{13}_{6}C$. Because both of these isotopes have 6 protons, they are often written as ^{12}C and ^{13}C. ^{12}C has 6 neutrons, and ^{13}C has 7 neutrons.

Q // Find the number of protons and neutrons in the following isotopes:

a) ^{20}Ne, ^{21}Ne, ^{22}Ne; b) ^{84}Sr, ^{86}Sr, ^{87}Sr, ^{88}Sr; c) ^{102}Pd, ^{104}Pd, ^{105}Pd, ^{106}Pd, ^{108}Pd,

if you know the atomic weight of Ne = 10 , Sr = 38 and Pd = 46.

Classification of isotopes

Isotopes utilized in nuclear medicine fall into two broad categories: Stable and Unstable.

1. **Stable isotopes** show no tendency to undergo radioactive decomposition and are therefore used in mass spectrometry. A "stable isotope" is any of two or more forms of an element whos nuclei contains the same number of protons and electrons, but a different number of neutrons. Stable isotopes remain unchanged indefinitely. Stable isotopes are tools used by researchers worldwide in the diagnosis of disease.

2. **Unstable (radioactive) isotopes** are atoms that decay until they reach stability. By emitting a nuclear electron (β particle) or a helium nucleus (α particle), and radiation (γ rays) unstable isotopes disintegrate at measurable rates. Unstable or radioactive isotopes are used as tracers, and as radiation or energy sources.

Radioactive decay

Many nuclei are radioactive. This means they are unstable, and will eventually decay by emitting a particle, transforming the nucleus into another nucleus, or into a lower energy state. A chain of decays takes place until a stable nucleus is reached.

During radioactive decay, principles of conservation apply. Some of these we've looked at already, but the last is a new one:

- conservation of energy
- conservation of momentum (linear and angular)
- conservation of charge
- conservation of nucleon number

Conservation of nucleon number means that the total number of nucleons (neutrons + protons) must be the same before and after a decay.

There are three common types of radioactive decay, alpha, beta, and gamma. The difference between them is the particle emitted by the nucleus during the decay process.

Alpha decay

In alpha decay, the nucleus emits an alpha particle; an alpha particle is essentially a helium nucleus, so it's a group of two protons and two neutrons. A helium nucleus is very stable.

An example of an alpha decay involves uranium-238:

$$^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

Alpha particles do not travel far in air before being absorbed; this makes them very safe for use in smoke detectors, a common household item.

Beta decay

A beta particle is often an electron, but can also be a positron, a positively-charged particle that is the anti-matter equivalent of the electron. If an electron is involved, the number of neutrons in the nucleus decreases by one and the number of protons increases by one. An example of such a process is:

$$^{234}_{90}\text{Th} \longrightarrow {}^{234}_{91}\text{Pa} + {}^{0}_{-1}\text{e}$$

In terms of safety, beta particles are much more penetrating than alpha particles, but much less than gamma particles

Gamma decay

The third class of radioactive decay is gamma decay, in which the nucleus changes from a higher-level energy state to a lower level. Similar to the energy levels for electrons in the atom, the nucleus has energy levels.

When an electron changes levels, the energy involved is usually a few eV, so a visible or ultraviolet photon is emitted. In the nucleus, energy differences between levels are much larger, typically a few hundred keV, so the photon emitted is a gamma ray.

$$^{238}_{92}\text{U} \rightarrow {}^{4}_{2}\text{He} + {}^{234}_{90}\text{Th} + 2{}^{0}_{0}\gamma$$

Gamma rays are very penetrating; they can be most efficiently absorbed by a relatively thick layer of high-density material such as lead.

Q// Complete the following nuclear reaction by filling in the missing particle.

$${}^{210}_{86}Rn \longrightarrow {}^{4}_{2}He + X$$

$${}^{168}_{77}Ir \longrightarrow {}^{4}_{2}\alpha + X$$

$${}^{46}_{20}Ca \longrightarrow {}^{0}_{-1}\beta + X$$

Q// Write each of the following nuclear reactions.

a) ${}^{14}_{6}C$ decays by beta emission.

b) ${}^{238}_{92}U$ decays by alpha emission.

c) ${}^{40}_{19}K$ decays by beta emission.

d) ${}^{40}_{18}Ar$ decays by Gamma emission.

Applications of Radioactive isotopes

In medicine, for example, cobalt-60 is extensively employed as a radiation source to arrest the development of cancer. Other radioactive isotopes are used as tracers for diagnostic purposes as well as in research on metabolic processes. When a radioactive isotope is added in small amounts to comparatively large quantities of the stable element, it behaves exactly the same as the ordinary isotope chemically; it can, however, be traced with a Geiger counter or other detection device. Iodine-131 has proved effective in treating hyperthyroidism. Another medically important radioactive isotope is carbon-14, which is used in a breath test to detect the ulcer-causing bacteria Heliobacter pylori.

In industry, radioactive isotopes of various kinds are used for measuring the thickness of metal or plastic sheets; their precise thickness is indicated by the strength of the radiations that penetrate the material being inspected. They also may be employed in place of large X-ray machines to examine manufactured metal parts for structural defects. Other significant applications include the use of radioactive isotopes as compact sources of electrical power—e.g., plutonium-238 in spacecraft. In such cases, the heat produced in the decay of the radioactive isotope is converted into electricity by means of thermoelectric junction circuits or related devices.