Nuclear Chemistry

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I. Radioactivity

The spontaneous, uncontrollable change of a nucleus by the emission of rays and/or the emission or capture of particles. Discovery attributed to Becquerel about 1900.

A. Types

alpha (α) particles	2 protons and 2 neutrons	${}^{4}_{2}He$
beta (β) particles	1 electron	${}^{0}_{-1}e$
gamma rays	high energy electromagnetic radiation	γ
positron emission	1 positive electron	${}^{0}_{+1}e$
K capture (electron capture)	no particles emitted, 1 electron captured from outside nucleus	

alpha (α) particles	10% speed of light	stopped by a sheet of paper
beta (β) particles	90% speed of light	stopped by a thin sheet of Aluminum
gamma rays	speed of light	stopped by thick layers of lead or concrete

B. Nuclear Reactions

- **Balance mass number and atomic number.**

alpha particles

beta particles

positron emission

electron capture

C. Units and effects

1. Activity - disintegrations per s

Becquerel (1 nucleus/s) [Bq]
Curie (3.7 x 10^{10} nuclei/s) [Ci]

2. Absorbed dose - absorption of energy

rad (1.00 x 10^{-5} J/g) [rad]
Gray (1.00 J/kg) [Gy]

3. Biological effect or dose equivalent

rem [rem]
Sievert [Sv]

Estimates of exposure to radiation range from 200 to 400 mrems per year. Dosage and time exposed determine amount of harm --roughly 600 rem is fatal.

The effects can be broken into 2 categories

1. **Somatic effects - radiation rips through cells and breaks down water molecules into OH radicals which are very reactive and cause long-lasting and immediate health effects**
2. **Genetic effects - radiation causes changes in DNA sequencing in reproductive sperm and egg**

II. Nuclear stability

A. **Elements of even atomic numbers have more isotopes than those of odd atomic number. Most stable isotopes have an even number of neutrons.**

B. **All isotopes of elements beyond Bi (Atomic number 83) are radioactive.**

C. **If protons are positively charged, what holds the nucleus together? Part of the mass of the protons and neutrons in the nucleus has been converted into binding energy - this binding energy is a result of what is called the nuclear strong force - one of the 4 fundamental forces known**

Four fundamental forces

1. **Nuclear strong force - holds individual p and n together, also hold nucleus together**
2. **Nuclear weak force - responsible for some types of radioactive decay**
3. **Electromagnetic force - holds atom together, responsible for chemical properties**
4. **Gravity - holds solar system and universe together**

D. How do we compute the binding energy?

sum of masses of p and n in nucleus - mass of nucleus = mass defect

This mass defect is the amount of mass which has been converted into binding energy.

Einstein's $E = mc^2$ provides the conversion from mass units to energy units

From a graph of binding energy per nucleon we find that Fe is the most stable element. Heavy elements can fission to become more stable; light elements can fuse to become more stable.

III. Other Nuclear Reactions

A. Transmutations - collisions that make new elements

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

B. Fission - a collision that splits the atom

Only certain isotopes are readily fissionable : uranium-235 and plutonium 239. Uranium 238 does not fission and is the predominate isotope of uranium.

Many products are possible, the following reaction is one example.

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\ ^{1}_{0}n$$

Although all nuclear changes involve an energy change (like physical and chemical changes), fission produces a very large energy change.

$\Delta E = -2 \times 10^{10}$ **kJ/mole**

Nuclear Reactors make use of this reaction to produce steam which then produces electricity through a turbine. The U.S. does not have appreciable reserves of uranium and thus does not have very much uranium 235.

C. Fusion - collisions of <u>small</u> nuclei to make heavier nuclei

$$4\ {}^{1}_{1}H \longrightarrow {}^{4}_{2}He + 2\ {}^{0}_{1}e$$

This is how our sun produces energy. The energy production is -2.5 x 10^9 kJ. On an energy per mass basis, fusion is superior to fission. We have been unable to sustain this process for commercial use and have only used it in hydrogen bombs.

IV. Health applications

A. Radon

Radon is a product of the uranium decay series and is a gas. It moves through the soil and can accumulate in closed basements. Since it decays by alpha emission its major danger is by inhalation of the gas and the resulting damage by the alpha radiation and the decay product polonium radiation. The EPA level is 4 picocuries per liter.

B. Diagnostic (Internal)

1. Iodine-125 for thyroid gland, gamma emitter

2. Fluorine-18 for heart problems, positron emitter which forms gamma rays after colliding with an electron. This isotope is incorporated into a glucose molecule and is then administered. Using positrons in this way is called positron emission tomography (PET).

C. Therapeutic (External and Internal)

1. Cobalt-60 used externally to destroy cancer tissue, gamma emitter

2. Yttrium-90 used internally to destroy cancer tissue, beta emitter