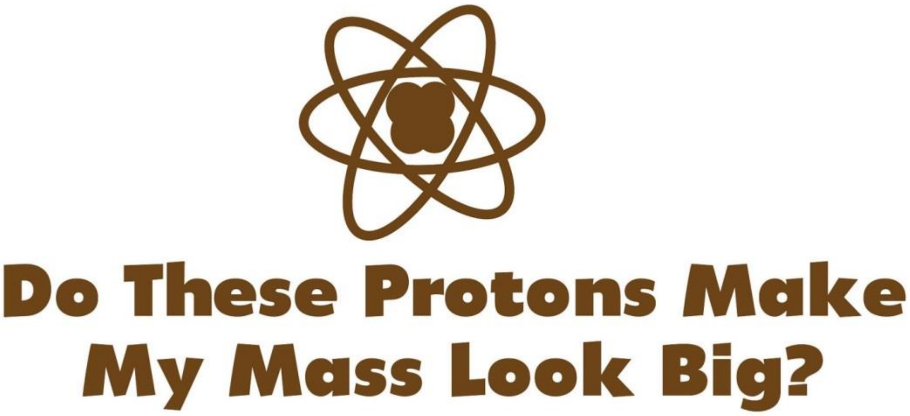
Name:

Regents Chemistry:

Notes: Unit 13 Nuclear Chemistry



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KEY IDEAS:

- Stability of isotopes is based in the ratio of neutrons and protons in its nucleus. Although most nuclei are stable, some are unstable and spontaneously decay, emitting radiation. (3.1o)
- Each radioactive isotope has a specific mode and rate of decay (half-life). (4.4a)
- A change in the nucleus of an atom that converts it from one element to another is called transmutation. This can occur naturally or can be induced by the bombardment of the nucleus by high-energy particles. (5.3a)
- Spontaneous decay can involve the release of alpha particles, beta particles, positrons, and/or gamma radiation from the nucleus of an unstable isotope. These emissions differ in mass, charge, ionizing power, and penetrating power. (3.1p)
- Nuclear reactions include natural and artificial transmutation, fission, and fusion. (4.4b)
- There are benefits and risks associated with fission and fusion reactions. (4.4f)
- Nuclear reactions can be represented by equations that include symbols which represent atomic nuclei (with the mass number and atomic number), subatomic particles (with mass number and charge), and/or emissions such as gamma radiation. (4.4c).
- Energy released in a nuclear reaction (fission or fusion) comes from the fractional amount of mass converted into energy. Nuclear changes convert matter into energy. (5.3b)
- Energy released during nuclear reactions is much greater than the energy released during chemical reactions. (5.3c)
- There are inherent risks associated with radioactivity and the use of radioactive isotopes. Risks can include biological exposure, long-term storage and disposal, and nuclear accidents. (4.4e)
- Radioactive isotopes have many beneficial uses. Radioactive isotopes are used in medicine and industrial chemistry, e.g., radioactive dating, tracing chemical and biological processes, industrial measurement, nuclear power, and detection and treatment of disease. (4.4d)

Vocabulary:

Word	**Definition**
Alpha Particle	A form of radioactive decay equivalent to a Helium-4 nucleus.
Artificial transmutation	Changing one element into another by bombarding it with particle bullets in a particle accelerator.
Atomic Mass	The weighted average of all naturally occurring isotopes of an element.
Atomic Mass Unit (amu)	1/12 the mass of a C-12 atom, the approximate mass of protons and neutrons.
Atomic number	The number that identifies an element, equal to an atom's number of protons.
Beta Particle	A form of radioactive decay equivalent to an electron.
Deflect	Change in direction due to an outside force.
Emit	To give off something.
Gamma Radiation	A high energy form of radioactive decay with no mass or charge.
Half-life	The time it takes for half the mass of a sample of radioactive isotope to undergo decay. The period of time in which any given nucleus has a 50% chance of undergoing radioactive decay.
Isotope	Atoms of the same element that contain different numbers of neutrons and therefore differ in atomic mass as well.
Mass defect	The mass that was lost during a nuclear change that was converted into energy via $E=mc^2$.
Mass number	The sum total of the protons and neutrons in an atom.
Natural radioactivity (Radioactive Decay)	The spontaneous breakdown of an unstable nucleus into a more stable nucleus and a decay particle (alpha, beta-negative, beta-positive or gamma).
Neutron	The particle that has no charge and has a mass of 1 a.m.u.
Nuclear charge	The net positive charge of the nucleus, equal to the number of protons in the nucleus.
Nuclear fission	The process whereby a large nucleus is split by artificial transmutation into smaller nuclei with the release of a large amount of energy derived from the conversion of a tiny bit of mass into energy.
Nuclear fusion	The process whereby two small nuclei are combined to form one larger nucleus with release of a huge amount of energy derived from the conversion of a tiny bit of mass into energy.
Nucleon	A particle that exists in the nucleus (protons and neutrons.)
Nucleus	The central core of the atom, consists of protons and neutrons and has a net positive charge.
Particle accelerator	A device that uses electromagnetic fields to accelerate charged particles.
Proton	A particle that represents a unit charge of +1 and a mass of 1 a.m.u.
Radioisotope	An isotope of an element which is radioactive (undergoes spontaneous decay).
Transmutation	A change to the nucleus of an element which produces a new element.

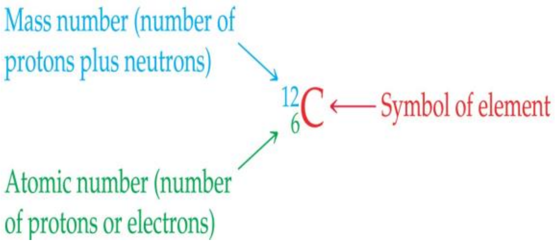
Lesson 1: Radioactive Decay

Objective:

- ***Construct nuclear equations for the spontaneous decay of radioactive nuclides.***

ISOTOPES are atoms of the same element that have the same # of PROTONS but different # of NEUTRONS or mass.

Atomic Notation:



Subtract atomic number from mass number to find the NEUTRONS

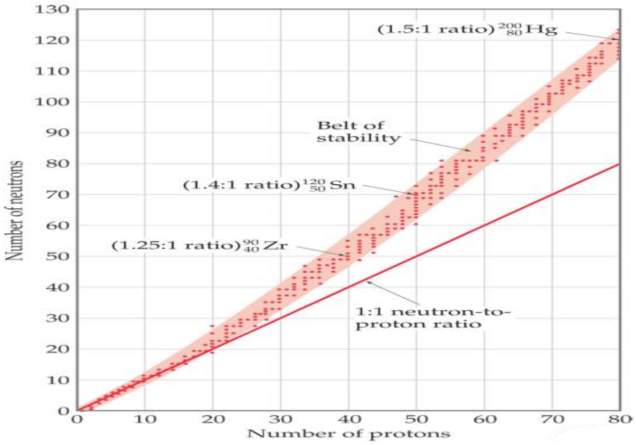
RADIOACTIVE DECAY:

- The process by which nuclei emit particles and change into new elements (called Transmutation).
- Only deals with PROTONS and NEUTRONS (these are in the nucleus).
    - Identity of an element changes due to change in number of protons

NATURAL RADIOACTIVITY (Transmutation):

- Occurs when **UNSTABLE** atoms (radioactive) decay into new atoms.
- **ALWAYS TURNS INTO A MORE STABLE ELEMENT**

RADIOACTIVITY: Is due to the proton-neutron ratio. The band of stability refers to atoms that are stable due to stable proton-neutron ratios.



To determine the product of radioactive decay of an unstable nucleus, use Tables N and O…

TABLE N: DECAY MODES -- look up nuclide to get type of decay

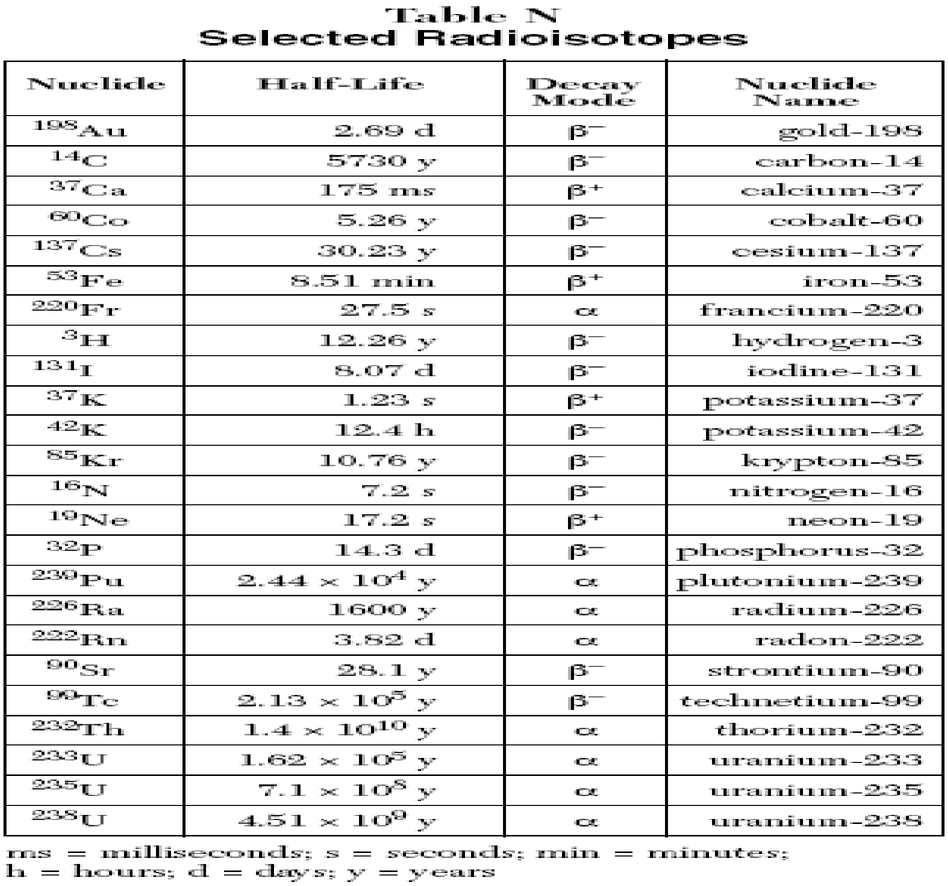


Table N
Selected Radioisotopes

Nuclide	Half-Life	Decay Mode	Nuclide Name
^{198}Au	2.69 d	β^-	gold-198
^{14}C	5730 y	β^-	carbon-14
^{37}Ca	175 ms	β^+	calcium-37
^{60}Co	5.26 y	β^-	cobalt-60
^{137}Cs	30.23 y	β^-	cesium-137
^{53}Fe	8.51 min	β^+	iron-53
^{220}Fr	27.5 s	α	francium-220
^{3}H	12.26 y	β^-	hydrogen-3
^{131}I	8.07 d	β^-	iodine-131
^{37}K	1.23 s	β^+	potassium-37
^{42}K	12.4 h	β^-	potassium-42
^{85}Kr	10.76 y	β^-	krypton-85
^{16}N	7.2 s	β^-	nitrogen-16
^{19}Ne	17.2 s	β^+	neon-19
^{32}P	14.3 d	β^-	phosphorus-32
^{239}Pu	2.44×10^4 y	α	plutonium-239
^{226}Ra	1600 y	α	radium-226
^{222}Rn	3.82 d	α	radon-222
^{90}Sr	28.1 y	β^-	strontium-90
^{99}Tc	2.13×10^5 y	β^-	technetium-99
^{232}Th	1.4×10^{10} y	α	thorium-232
^{233}U	1.62×10^5 y	α	uranium-233
^{235}U	7.1×10^8 y	α	uranium-235
^{238}U	4.51×10^9 y	α	uranium-238

ms = milliseconds; s = seconds; min = minutes;
h = hours; d = days; y = years

TABLE 0: TYPES OF DECAY – use to get mass and charge of decayed particle

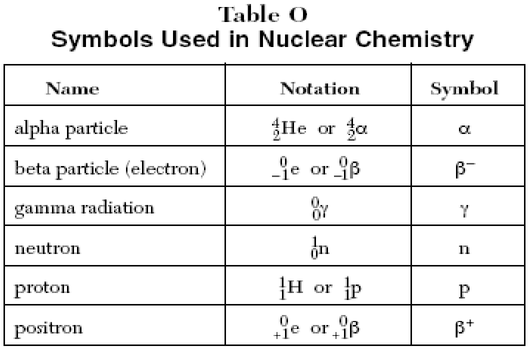


Table O
Symbols Used in Nuclear Chemistry

Name	Notation	Symbol
alpha particle	${}^{4}_{2}\text{He}$ or ${}^{4}_{2}\alpha$	α
beta particle (electron)	${}^{0}_{-1}\text{e}$ or ${}^{0}_{-1}\beta$	β^-
gamma radiation	${}^{0}_{0}\gamma$	γ
neutron	${}^{1}_{0}\text{n}$	n
proton	${}^{1}_{1}\text{H}$ or ${}^{1}_{1}\text{p}$	p
positron	${}^{0}_{+1}\text{e}$ or ${}^{0}_{+1}\beta$	β^+

Radioactivity: BETA DECAY

- Atoms above the stability belt have too many neutrons and beta decay due to this.

- The beta particle is an electron created when a neutron decays.

Example: *Beta decay:* ^{234}Th undergoes beta decay

- The total mass on the left must equal the total mass on the right (234 = 0 + 234)
- The total charge on the left must equal the total charge on the right (90 = -1 + 91)
- Find the new symbol using the charge (number of protons) for the atomic number

Example: ^{14}C undergoes Beta decay:

Radioactivity: POSITRON EMISSION

- Atoms below this belt have too many protons and positron decay.

- The positron is the opposite of a beta particle.

Example: *Positron emission*: ^{37}K undergoes positron decay

- The total of the mass numbers on the left must equal the total on the right (37 = 0 + 37)
- The total charge on the left must equal the total charge on the right (19 = 1 + 18)

Example: ^{37}Ca

Radioactivity: ALPHA DECAY

- Atoms with 82 or more protons alpha decay (too many protons and neutrons)
- Alpha particles are weak due to their mass.
- Alpha particles are the helium nuclei.

Example: *Alpha decay:* ^{238}U undergoes alpha decay

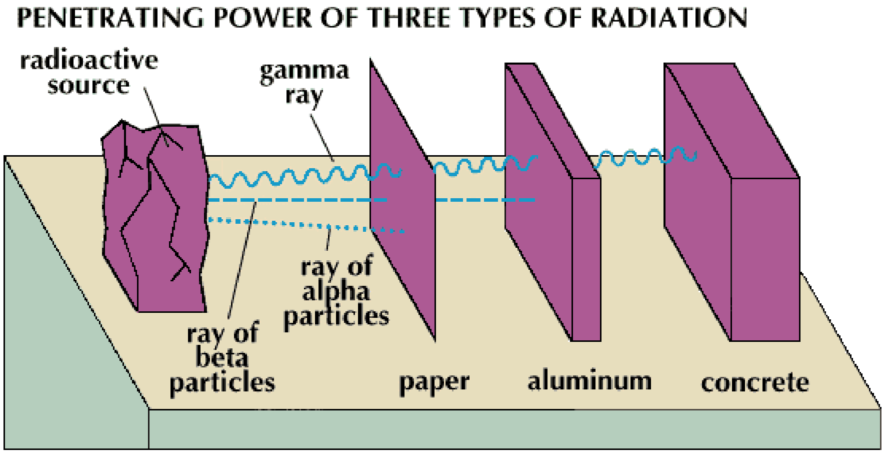
- The total mass on the left must equal the total mass on the right (238 = 4 + 234)
- The total charge on the left must equal the total charge on the right (92 = 2 + 90)

Example: Francium-220

Radioactivity: GAMMA DECAY

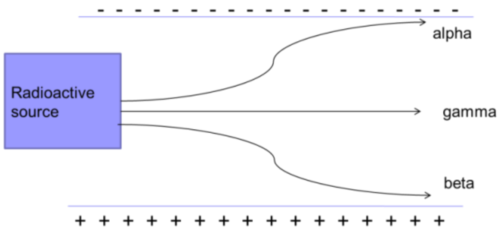
- Strongest particle.
- Accompanies most decay.
- Usually not written due to the fact that it cannot change the mass or charge of any of the species.

Penetrating Power of Radiation



Alpha is least penetrating then beta. Gamma is most penetrating.

Radiation is charged: can be separated by a magnetic field



Objective:

- ***Calculate the half-lives of selected nuclides***

HALF LIVES:

- The time it takes for half the atoms in a given sample of an element to decay.
- Radioactive substances decay at a rate that is NOT dependent on temperature, pressure, or concentration

Calculating Half Lives:

- After one half life 50% or ½ the radioactive element is still present.
- After two half lives 25% or ¼ the radioactive element is still present.
- After three half lives 12.5% or 1/8 the radioactive element is still present.
- This continues forever, the number will never be zero.
- The half lives are listed on **Table N.**

- The SHORTER THE HALF LIFE of an isotope the LESS STABLE it is.
- The LONGER THE HALF LIFE of an isotope the MORE STABLE it is.

CALCULATING HALF LIFE PROBLEMS

Example: Amount Remaining

If a sample of I-131 has an original mass of 52.0g what mass will remain after 40 days?

1. Look up half life of I-131 ________________ and determine how many half lives have passed by dividing the time passed by the half life.
   40/8.021 = 5 half life periods
2. Cut the original mass in half by the # of half life periods

#Half Lives	Mass	Fraction
0	52.0g	1
1		
2		
3		
4		
5		

After 40 days 1.63 grams of I-131 is left

Example: Fraction Remaining

If a sample of I-131 has an original mass of 52.0g what fraction will remain after 40 days?

Same set up as above, but now start with the whole (1) and cut that in half each half life.

After 40 days 1/32 of I-131 is left

Example: Number of Half Lives

How many half-life periods will it take for 50 grams of Tc-99 to decay to 6.25g?

1. Find the number of half lives by halving the original mass until you get to the final mass
   50/2 = 25/2 = 12.5/2 = 6.25
   = 3 Half Lives

Can also do in table form:

#Half Lives	Mass	Fraction
0	50g	1
1	25	1/2
2	12.5	1/4
3	6.25	1/8

Example: Half Life

What is the half-life of a 500 gram sample of a radioactive element if 125 grams remains after 20 hours?

1. Find the number of half lives by halving the original mass until you get to the final mass
   500/2 = 250/2 = 125 2 HL
2. Divide the time elapsed by the number of half lives you calculated.
   20 hours/2 = <u>10 Hour half life.</u>

Example: Original Mass

The half like of Tc-99 (used in brain tumors) is 6 hours. If 10 micrograms are left after 24 hrs, how much was administered to the patient originally?

1. Divide the times to obtain your amount of half lives
   24/6 = 4 half lives
2. Start with the ending mass and instead of halving, you double your amount the number of half lives you calculated, since we are going backwards!
   10*2*2*2*2 = <u>160 micrograms</u>

Example: Time Elapsed

How long will it take for a 400 grams sample of P-32 to decay to 50 grams?

1. Find the half lives by dividing the original mass in half until it hits your final mass.
   400/2 = 200/2 = 100/2 = 50 3 half lives
2. Look up the half live on table N and multiple that time by the number of half lives you calculated.
   14.3 days * 3 = <u>42.9 days</u>

Lesson 3: Nuclear Fusion and Fission

Objective:

- ***Determine the type of nuclear reaction***
- ***Determine benefits and risks associated with fission and fusion reactions***

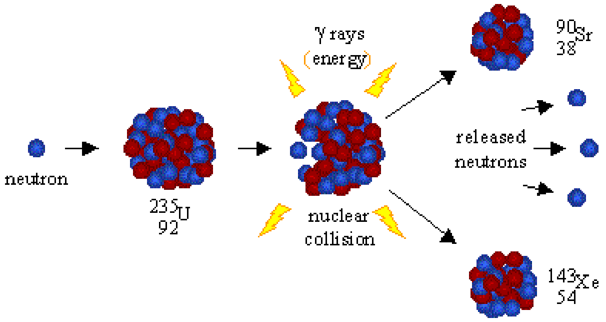
ARTIFICAL TRANSMUTATION:

Involves a high speed particle bombarding the nucleus. This occurs in particle accelerators.

Artificial Transmutation	Natural Transmutation
• Always 2 reactants $^{27}_{13}Al + ^{4}_{2}He \rightarrow ^{30}_{15}P + ^{1}_{0}n$	• Always 1 reactant $^{226}_{88}Ra \rightarrow ^{4}_{2}He + ^{222}_{86}Rn$

FISSION REACTIONS:

A **NEUTRON** is shot at a radioactive source which splits producing **ENERGY**.

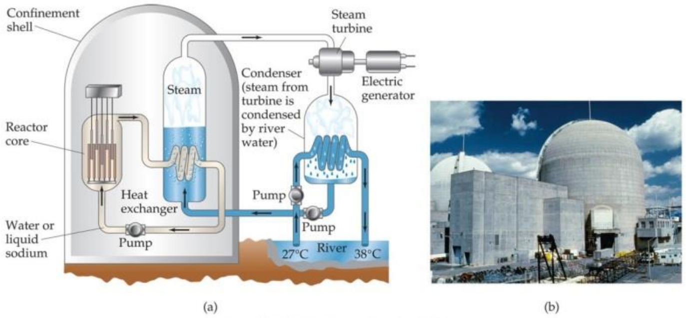


- If the number OF NEUTRONS released is not controlled a <u>**CHAIN REACTION**</u> will occur.
- This is the type of reaction used in <u>**nuclear**</u> <u>**bombs**</u>.

FISSION REACTORS:

The reaction's energy is converted to steam which turns and turbine system, creating electrical energy from nuclear energy.

- Fuel rods contain the fissionable radioactive source.
- CONTROL RODS can regulate the neutrons absorbed.
- Cooling Fluid acts as a moderator, slowing neutrons down.



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NUCLEAR POWER:

- In America, about 20% electricity generated by nuclear fission
- Imagine:
  - Nuclear-powered car
  - Fuel = pencil-sized U-cylinder
  - Energy = 1000 20-gallon tanks of gasoline
  - Refuel every 1000 weeks (about 20 years)

FUSION REACTIONS:

- Involves **THE COMBINING OF NUCLEI** to produce **HEAVIER ONES**.
- Ex. $^{2}\mathrm{H} + {}^{3}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + {}^{1}\mathrm{n}$

Fusion Reactions:

Advantages	**Disadvantages**
• Produces more energy • Materials more readily available • Less waste • Less danger (no chain reaction)	• Too Expensive

EXAMPLE: Which represents artificial Transmutation?

1. ${}_{92}U^{238} \longrightarrow {}_{2}He^{4} + {}_{90}Th^{234}$
2. ${}_{13}Al^{27} + {}_{2}He^{4} \longrightarrow {}_{15}P^{30} + {}_{0}n^{1}$
3. ${}_{6}C^{14} \longrightarrow {}_{7}N^{14} + e^{0}$
4. ${}_{88}Ra^{226} \longrightarrow {}_{2}He^{4} + {}_{86}Ra^{222}$

Lesson 4: Benefits and Risks of Nuclear Reactions

Objective:

- ***Determine benefits and risks associated with fission and fusion reactions***

BENEFITS OF RADIOACTIVE ISOTOPES

DATING MATERIALS:

- **CARBON-14** used to date organic remains
- **URANIUM** used to date rocks

MEDICAL APPLICATIONS:

- Must have A **SHORT HALF LIFE** and quickly eliminated from body
- **IODINE-131** (treat hyperthyroidism)
- **COBALT-60** used to treat cancer
- **TC-99** used to detect tumors

DANGERS/RISKS OF RADIOACTIVE ISOTOPES

- Damage to **TISSUE**
- Gene **MUTATIONS**
- **ACCIDENTS** due to radioactive wastes
- **RADIATION** from nuclear reactors