Chapter 11. Nuclear Chemistry

Introduction to Inorganic Chemistry
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Contact me trough phone or e-mail if you have questions
Online Tests on Following days
March 24, 2017: Test 1 (Chapters 1-3)
April 10, 2017 : Test 2 (Chapters 4-5)
April 28, 2017: Test 3 (Chapters 6,7 &8)
May 12, 2017 : Test 4 (Chapters 9, 10 &11)
May 15, 2017: Make Up Exam: Chapters 1-11)
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Chapter 11

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Section 11.1

Stable and Unstable Nuclides

Nuclear Reaction

- A reaction in which changes occur in the nucleus of an atom (not ordinary chemical reactions).
- Nuclide – an atom with a specific atomic number and a specific mass number.
- Atomic Number (*Z*) – number of protons
- Mass Number (*A*) – sum of protons and neutrons $^{A}_{Z}X$

Section 11.1

Stable and Unstable Nuclides

- Stable nuclide – nuclide with a stable nucleus; does not readily undergo change.
- Unstable nuclide – nuclide with an unstable nucleus; spontaneously undergoes change.

Section 11.1

Stable and Unstable Nuclides

Radioactivity

- Radiation spontaneously emitted from an unstable nucleus.
- Radioactive nuclide (radionuclide) – a nuclide with an unstable nucleus from which radiation is spontaneously emitted.

Section 11.1

Stable and Unstable Nuclides

Radioactive Stability

- There is a correlation between nuclear stability and the total # of nucleons found in a nucleus.
- Nuclides with 84 or more protons are unstable.

Section 11.1

Stable and Unstable Nuclides

Radioactive Stability

- There is a correlation between nuclear stability and neutron-to-proton ratio in a nucleus.
- Light nuclides are stable when *Z* equals *A* – *Z* (neutron/proton ratio is 1).
- For heavier elements the neutron/proton ratio required for stability is greater than 1 and increases with *Z*.

Section 11.2

The Nature of Radioactive Emissions

Understanding Radioactivity

1. Certain nuclides possess unstable nuclei.
2. Nuclides with unstable nuclei spontaneously emit energy (radiation).

Section 11.2

The Nature of Radioactive Emissions

Alpha Particle

- A particle in which two protons and two neutrons are present that is emitted by certain radioactive nuclei.

Section 11.2

The Nature of Radioactive Emissions

Beta Particle

- Particle whose charge and mass are identical to those of an electron that is emitted by certain radioactive nuclei.

Section 11.2

The Nature of Radioactive Emissions

Gamma Ray

- Form of high-energy radiation without mass or charge that is emitted by certain radioactive nuclei.

Section 11.3

Equations for Radioactive Decay

Radioactive Decay

- Process by whereby a radionuclide is transformed into a nuclide of another element as a result of the emission of radiation from its nucleus.
- Parent nuclide – nuclide that undergoes decay
- Daughter nuclide – nuclide that is produced

Section 11.3

Equations for Radioactive Decay

How Nuclear Equations Differ From Chemical Equations

1. The symbols in nuclear equations stand for nuclei rather than atoms.
2. Mass numbers and atomic numbers (nuclear charge) are always specifically included in nuclear equations.
3. The elemental symbols on both sides of the equation frequently are not the same in nuclear equations.

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Section 11.3

Equations for Radioactive Decay

- Alpha Particle Decay (α):

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

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Section 11.3

Equations for Radioactive Decay

- Beta Particle Decay (β):

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

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Section 11.3

Equations for Radioactive Decay

- Gamma Ray Emission (γ):

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

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Section 11.3

Equations for Radioactive Decay

Concept Check

Which of the following produces a β particle?

a) $^{68}_{31}\text{Ga} + {}^{0}_{-1}\text{e} \rightarrow {}^{68}_{30}\text{Zn}$

b) $^{62}_{29}\text{Cu} \rightarrow {}^{0}_{+1}\text{e} + {}^{62}_{28}\text{Ni}$

c) $^{212}_{87}\text{Fr} \rightarrow {}^{4}_{2}\text{He} + {}^{208}_{85}\text{At}$

d) $^{129}_{51}\text{Sb} \rightarrow {}^{0}_{-1}\text{e} + {}^{129}_{52}\text{Te}$

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Section 11.3

Equations for Radioactive Decay

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Section 11.4

Rate of Radioactive Decay

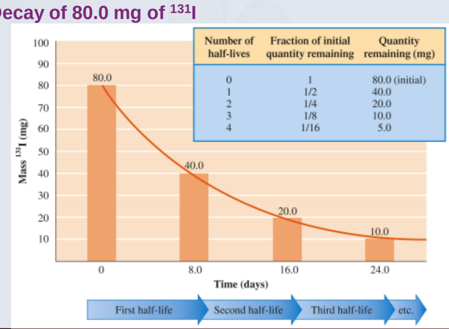
Half-Life

- Time required for one-half of a given quantity of a radioactive substance to undergo decay.
- The greater the decay rate for a radionuclide, the shorter its half-life.

Section 11.4

Rate of Radioactive Decay

Decay of 80.0 mg of ^{131}I

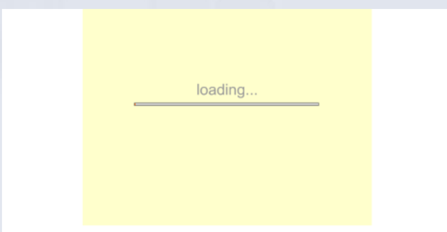


Number of half-lives	Fraction of initial quantity remaining	Quantity remaining (mg)
0	1	80.0 (initial)
1	1/2	40.0
2	1/4	20.0
3	1/8	10.0
4	1/16	5.0

Section 11.4

Rate of Radioactive Decay

Half-Life of Nuclear Decay



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Section 11.4

Rate of Radioactive Decay

Half-Life (*n*)

$$\left(\begin{array}{c}\text{Amount of radionuclide}\\ \text{undecayed after } n \text{ half-live}\end{array}\right) = \left(\begin{array}{c}\text{original amount}\\ \text{of radionuclide}\end{array}\right) \times \left(\frac{1}{2^n}\right)$$

Section 11.4

Rate of Radioactive Decay

Exercise

The half-life of technetium-99 is 5.98 hours. How much, in grams, of a 0.75-g sample of technetium-99 will remain undecayed after a period of 16 hours?

Section 11.4

Rate of Radioactive Decay

Exercise

The half-life of technetium-99 is 5.98 hours. How much, in grams, of a 0.75-g sample of technetium-99 will remain undecayed after a period of 16 hours?

0.12 g

$$(16 \text{ hours})\left(\frac{1 \text{ half-life}}{5.98 \text{ hours}}\right) = 2.68 \text{ half-lives}$$

$$(0.75 \text{ g})\left(\frac{1}{2^{2.68}}\right) = 0.12 \text{ g}$$

Section 11.5

Transmutation and Bombardment Reactions

Transmutation Reaction

- A nuclear reaction in which a nuclide of one element is changed into a nuclide of another element.

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Section 11.5

Transmutation and Bombardment Reactions

Bombardment Reaction

- A nuclear reaction brought about by bombarding stable nuclei with small particles traveling at very high speeds.
  – Always two reactants and two products.

$${}^{14}_{7}N + {}^{4}_{2}a \rightarrow {}^{17}_{8}O + {}^{1}_{1}p$$

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Section 11.5

Transmutation and Bombardment Reactions

Synthetic Elements

- Over 2000 bombardment-produced radionuclides are known.
- Transuranium elements – occur right after uranium on the periodic table (elements 93 to 118).
- All nuclides of all elements beyond bismuth (Z = 83) in the periodic table are radioactive.

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Section 11.6

Radioactive Decay Series

- A series of radioactive decay processes beginning with a long-lived radionuclide and ending with a stable nuclide of lower atomic number.

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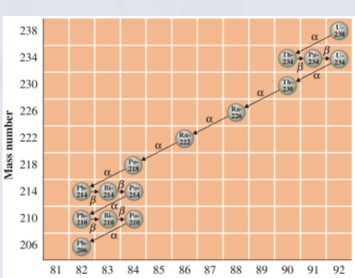
Section 11.6

Radioactive Decay Series

Radioactive Decay Series Example



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Section 11.7

Chemical Effects of Radiation

- Photographic plates
- Geiger counter

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Section 11.7

Chemical Effects of Radiation

Film Badges Are Used to Determine a Person's Exposure to Radiation

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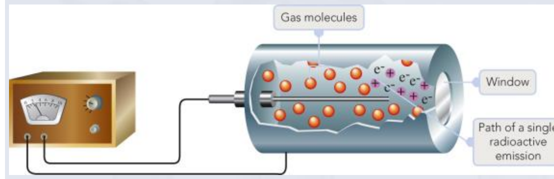
Section 11.7

Chemical Effects of Radiation

Geiger Counter



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Section 11.8

Biochemical Effects of Radiation

Two Things Can Happen to an Electron Subjected to Radiation

- Excitation – occurs when radiation, through energy release, excites an electron from an occupied orbital into an empty, higher-energy orbital.
- Ionization –occurs when the radiation carries enough energy to remove an electron from an atom or molecule.

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Section 11.8

Biochemical Effects of Radiation

Nonionizing Radiation vs. Ionizing Radiation

- Nonionizing radiation – radiation with insufficient energy to remove an electron from an atom or molecule.
  - Examples: radiowaves, microwaves, infrared light, and visible light
- Ionizing radiation – radiation with sufficient energy to remove an electron from an atom or molecule.
  - Examples: cosmic rays, X rays, and UV light

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Section 11.8

Biochemical Effects of Radiation

Ion Pair Formation

- Incoming radiation transfers sufficient energy into a molecule to knock an electron out of it, converting the molecule into a positive ion.
  - H_2O^+, e^-

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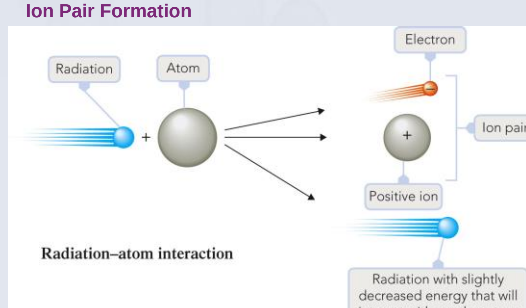
Section 11.8

Biochemical Effects of Radiation

Ion Pair Formation



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Section 11.8

Biochemical Effects of Radiation

Free Radical Formation

- Usually accompanies ion pair formation.
- Free radical – an atom, molecule, or ion that contains an unpaired electron; usually a very reactive species.

• H_2O^+ or • OH

Section 11.9

Detection of Radiation

Alpha Particle Effects

- Have low penetrating power and cannot penetrate the body's outer layers of skin.
- Major damage occurs when alpha-emitting radionuclides are ingested (contaminated food).

Section 11.9

Detection of Radiation

Beta Particle Effects

- Can penetrate much deeper than alpha particles and can cause severe skin burns if their source remains in contact with the skin for an appreciable amount of time.
- Internal exposure to beta radiation is as serious as internal alpha exposure.

Section 11.9

Detection of Radiation

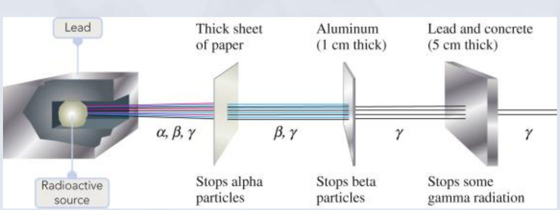
Gamma Radiation Effects

- Readily penetrate deeply into organs, bone, and tissue.

Section 11.9

Detection of Radiation

Alpha, Beta, and Gamma Radiation Differ in Penetrating Ability



Section 11.10

Sources of Radiation Exposure

Background Radiation

- Radiation that comes from natural sources to which living organisms are exposed on a continuing basis.

Section 11.10

Sources of Radiation Exposure

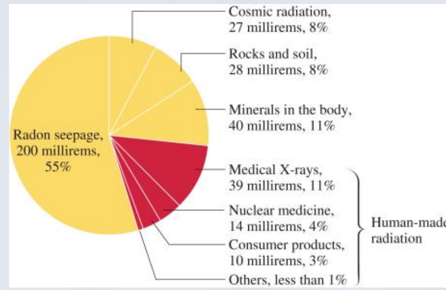
Sources of Background Radiation

- Cosmic radiation
- Rocks and minerals
- Food and drink
- Radon seepage in buildings

Section 11.10

Sources of Radiation Exposure

Components of the Estimated Annual Radiation Exposure



Section 11.11

Nuclear Medicine

- A field of medicine in which radionuclides are used for diagnostic and therapeutic purposes.

Section 11.11

Nuclear Medicine

Criteria Used in Selecting Radionuclides

- At low concentrations, the radionuclide must be detectable by instrumentation placed outside the body.
- Radionuclide must have a short half-life.
- Radionuclide must have a known mechanism for elimination from the body.
- The chemical properties of the radionuclide must be such that it is compatible with normal body chemistry.

Section 11.11

Nuclear Medicine

Diverse Uses of Radionuclides in the Human Body

- Determination of blood volume.
- Location of sites of infection.
- Diagnosis of impaired heart muscle.
- Location of impaired circulation.
- Assessment of thyroid activity.
- Determination of tumor size and shape.

Section 11.11

Nuclear Medicine

Therapeutic Uses for Radionuclides

- Selectively destroy abnormal (usually cancerous) cells.
- The radionuclide is often, but not always, placed within the body.

Section 11.12

Nuclear Fission and Nuclear Fusion

Fission Reactions

- A nuclear reaction in which a large nucleus (high atomic number) splits into two medium-sized nuclei with the release of several free neutrons and a large amount of energy.
- Basis for operation of nuclear power plants.
  - Uranium-235

Section 11.12

Nuclear Fission and Nuclear Fusion

Characteristics of the U-235 Fission Reaction

1. There is no unique way in which the U-235 nucleus splits.
2. Very large amounts of energy are emitted during this process.
3. Neutrons, which are reactants in the fission process, are also produced as products.

Section 11.12

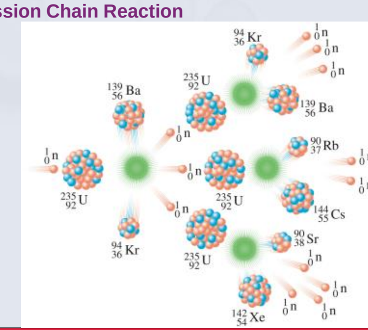
Nuclear Fission and Nuclear Fusion

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow \begin{cases} ^{135}_{53}\mathrm{I} + ^{97}_{39}\mathrm{Y} + 4\,^{1}_{0}\mathrm{n} \\ ^{139}_{56}\mathrm{Ba} + ^{94}_{36}\mathrm{Kr} + 3\,^{1}_{0}\mathrm{n} \\ ^{131}_{50}\mathrm{Sn} + ^{103}_{42}\mathrm{Mo} + 2\,^{1}_{0}\mathrm{n} \\ ^{139}_{54}\mathrm{Xe} + ^{95}_{38}\mathrm{Sr} + 2\,^{1}_{0}\mathrm{n} \end{cases}$$

Section 11.12

Nuclear Fission and Nuclear Fusion

A Fission Chain Reaction



Section 11.12

Nuclear Fission and Nuclear Fusion

Fusion Reactions

- A nuclear reaction in which two small nuclei are collided together to produce a larger nucleus and a large amount of energy.
- Opposite of nuclear fission.
- How the sun generates its energy.

Section 11.13

Nuclear and Chemical Reactions Compared

Table 11.6 Differences Between Nuclear and Chemical Reactions

Chemical Reaction	Nuclear Reaction
1. Different isotopes of an element have identical chemical properties.	1. Different isotopes of an element have different nuclear properties.
2. The chemical reactivity of an element depends on the element's state of combination (free element, compound, etc.).	2. The nuclear reactivity of an element is independent of the state of chemical combination.
3. Elements retain their identity in chemical reactions.	3. Elements may be changed into other elements during nuclear reactions.
4. Energy changes that accompany chemical reactions are relatively small.	4. Energy changes that accompany nuclear reactions are a number of orders of magnitude larger than those in chemical reactions.
5. Reaction rates are influenced by temperature, pressure, catalysts, and reactant concentrations.	5. Reaction rates are independent of temperature, pressure, catalysts, and reactant concentrations.