PowerPoint Lectures
to accompany
Physical Science, 8e

Chapter 8
Atoms and Periodic Properties

*Core Concept

Different fields of study contributed to the development of a model of the atom.

- *Dalton - atoms indivisible
- *Thomson and Millikan experiments
  - *Electron mass very small, no measurable volume
  - *What is the nature of an atom's positive charge?
- *Thomson's "Plum pudding" model
  - *Electrons embedded in blob of positively charged matter like "raisins in plum pudding"

*Early Models of the Atom

*The Nucleus

Ernest Rutherford (1907)

* Scattered alpha particles off gold foil
* Most passed through without significant deflection
* A few scattered at large angles
* Conclusion: an atom's positive charge resides in a small, massive nucleus
* Later: positive charges = protons
* James Chadwick (1932): also neutral neutrons in the nucleus

*The Nuclear Atom

* Atomic number
  * Number of protons in nucleus
  * Elements distinguished by atomic number
  * 113 elements identified
  * Number of protons = number of electrons *in neutral atoms*
* Isotopes
  * Same number of protons; different number of neutrons

*Atomic Symbols and Masses

Mass number

* Number of protons + neutrons

Atomic mass units (u)

* 1/12 of carbon-12 isotope mass

Atomic weight

* Atomic mass of an element, averaged over naturally occurring isotopes

Predictions of classical theory
* Electrons orbit the nucleus
* Curved path = acceleration
* Accelerated charges radiate
* Electrons lose energy and spiral into nucleus
* Atoms cannot exist!

Experiment - atoms do exist
⇒ New theory needed

*Classical "Atoms"

*The Quantum Concept

* Max Planck (1900)
  * Introduced quantized energy
* Einstein (1905)
  * Light made up of quantized photons
* Higher frequency photons = more energetic photons

*Atomic Spectra

Blackbody radiation
* Continuous radiation distribution
* Depends on temperature of radiating object
* Characteristic of solids, liquids and dense gases

Line spectrum
* Emission at characteristic frequencies
* Diffuse matter: incandescent gases
* Illustration: Balmer series of hydrogen lines

*Bohr's Theory

Three rules:

1. Electrons only exist in certain allowed orbits
2. Within an orbit, the electron does not radiate
3. Radiation is emitted or absorbed when changing orbits

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Chapter 13
Nuclear Reactions

Nuclear reactions involve changes in the nucleus of the atom.

*Core Concept

*Nuclear Radioactivity

* Natural radioactivity
  * Spontaneous emission of particles or energy from an unstable nucleus
  * Discovered by Becquerel
* Three types of radioactive decay
  * Alpha decay (He-nucleus)
  * Beta decay (high energy electron)
  * Gamma decay (high energy electromagnetic radiation)

*Nuclear Equations

* Atomic number = number of protons in nucleus
* Isotopes: same atomic number; different number of neutrons
* Mass number = number of nucleons (protons and neutrons) in nucleus
* Nuclear reactions
  * Represented by balanced equations
  * Charge conserved
  * Mass number conserved

*The Nature of the Nucleus

* Strong nuclear force
  * Binds protons and neutrons
  * Very short ranged, less than 10^{-15} m
  * Overcomes proton-proton Coulomb repulsion
* Nuclear shell model
  * Nucleon quantum energy levels
  * Maximum stability for nucleon number = 2, 8, 20, 28, 50, 82 or 126
* Band of stability

Generalizations - Nuclear Stability

1. Atomic number > 83: unstable
2. Nucleon number = 2, 8, 20, 28, 50, 82 or 126: added stability
3. Pairs of protons and pairs of neutrons: added stability
   - Odd number of both protons and neutrons less stable
4. Neutron: proton ratios for added stability
   - 1:1 in isotopes with up to 20 protons
   - 1+increasing:1 with increasingly heavy isotopes

Types of Radioactive Decay

1. Alpha emission
   - Expulsion of helium nucleus
   - Least penetrating: stopped by paper

$$^{222}_{86}Rn \rightarrow \, ^{218}_{84}Po + \, ^{4}_{2}He$$

2. Beta emission
   - Expulsion of an electron
   - More penetrating: 1 cm of aluminum

$$^{14}_{6}C \rightarrow \, ^{14}_{7}N + \, ^{0}_{-1}e$$

3. Gamma decay
   - Emission of a high energy photon
   - Most penetrating: 5 cm of lead

$$^{222}_{86}Rn^{*} \rightarrow \, ^{222}_{86}Rn + \, ^{0}_{0}\gamma$$

Radioactive Decay Series

- One radioactive nucleus decays to a 2nd, which decays to a 3rd, which…
- Three naturally occurring series
  - Thorium-232 to lead-208
  - Uranium-235 to lead-207
  - Uranium-238 to lead-206

*Half-life

* Time required for 1/2 of a radioactive sample to decay
* Example: 1 kg of an unstable isotope with a one-day half-life
  * After 1 day: 500 g remain
  * After 2 days: 250 g remain
  * After 3 days: 125 g remain
* U-238 decay series: wide half-life variation

*Measurement of Radiation

Measurement methods

* Ionization counters
  * Detect ions produced by radiation
  * Example: Geiger counter
* Scintillation counters
  * Rely on flashes of light produced as radiation strikes a phosphor
  * Zinc sulfide: phosphor used in TV picture tubes

*Radiation Units

* Measured at the source
  * Activity: number of disintegrations per unit time
  * Units: Becquerel (SI unit), Curie, …
* Measured where absorbed
  * Human exposure: rem
  * SI unit: millisievert
  * rad: radiation absorbed dose (unit = gray)
  * Dosage related to effects on organism

*Radiation Exposure

* Natural radioactivity
  * 100-500 mrem/yr
  * Sources
    * Cosmic rays from outer space
    * Earth's residual radioactivity
    * Medical x-rays, TVs, …
* Consequences
  * DNA disruption
  * Free radical production
* Threshold versus linear exposure models

*Nuclear Energy

* Interconversion of mass and energy
* Mass defect
  * Difference between masses of reactants and products
* Binding energy
  * Energy required to break a nucleus into individual protons and neutrons
* Ratio: binding energy to nucleon number
  * Iron-56 = most stable nucleus

*Nuclear Fission

* Heavy nuclei splitting into lighter ones
* Chain reactions
  * Possible when one reaction can lead to others
  * One neutron in, two or more out
* Critical mass
  * Sufficient mass and concentration to produce a chain reaction

* Nuclear Power Plants

* Rely on controlled fission chain reactions
* Steel vessel contains fuel rods and control rods
* Full plant very intricate
  * Containment and auxiliary buildings necessary
* Spent fuel rods
  * Contain fissionable materials U-235, Pu-239
  * Disposal issues not settled

*Nuclear Fusion

* Less massive nuclei forming more massive nuclei
* Energy source for Sun and other stars
* Requirements for fusion
  * High temperature
  * High density
  * Sufficient confinement time
* Controlled fusion
  * Magnetic confinement
  * Inertial confinement

*Source of Nuclear Energy

* Ultimately connected to origins of the Universe and the life cycles of stars
* Big Bang theory
  * Incredibly hot, dense primordial plasma cools, creating protons and neutrons
  * Continued cooling leads to hydrogen atoms which collapse gravitationally into 1st generation stars
* Stellar evolution
  * Interior temperatures and densities suitable for fusion of heavy elements beyond hydrogen and helium
  * Certain massive stars explode in supernovae, spreading heavy elements (some radioactive)
* Ultimate source: gravitational attraction!