HYDROGEN ATOM, PROPERTIES OF NUCLEUS, RADIOACTIVITY, NUCLEAR FISSION & FUSION AND APPLICATIONS

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CONTENTS:

Spectra Series of Hydrogen Atom Cont'd

Bohr Model

- electrons exist only in *orbits* with specific amounts of energy called energy levels
- Therefore…
- electrons can only gain or lose certain amounts of energy
- only certain *photons* are produced

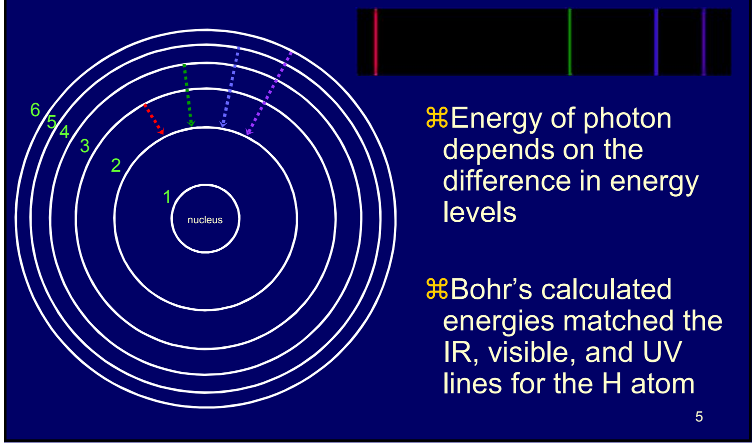
Spectra Series of Hydrogen Atom Cont'd

- It is known that the energy of the outer orbit is greater than the energy of the inner ones.

- When the hydrogen atom is subjected to external energy, the electron jumps from lower energy state to a higher energy state i.e., the hydrogen atom is excited.

- The excited state is not stable hence the electron returns to its ground state in about 10^{-8} seconds.

Spectra Series of Hydrogen Atom Cont'd



⌘Energy of photon depends on the difference in energy levels

⌘Bohr's calculated energies matched the IR, visible, and UV lines for the H atom

Spectra Series of Hydrogen Atom Cont'd

•Consider a transition from orbit n_2 (for upper orbit) to a smaller orbit n_1 (for lower orbit), $n_1 < n_2$, or equivalently, from a higher energy level n_2 to a lower energy level n_1 .

•Then, the energy $\frac{hc}{\lambda}$: of the emitted photon of the wavelength λ is equal to $E_{n_2} - E_{n_1}$.

Spectra Series of Hydrogen Atom Cont'd

•Noting that $E_n = -\frac{hcR}{n^2}$, then, the wavelength of the photon emitted in a transition from n_2 to a lower energy level n_1 is obtained as :

- $$\bar{\nu} = \frac{1}{\lambda} = R\left(\frac{1}{n_1{}^2} - \frac{1}{n_2{}^2}\right),$$

where R is called the Rydberg constant,

$R = \frac{me^4}{8\epsilon_0^2 h^3 c}$ = 1.097 X 10^7 m^{-1} = 1.0967758 X 10^{-3} Å^{-1},

for hydrogen, Z = 1,

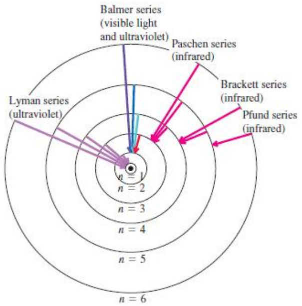
$\bar{\nu}$ is the emitted wave number.

Spectra Series of Hydrogen Atom Cont'd

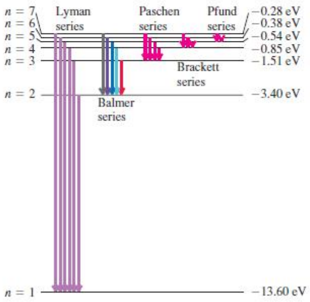
•For the hydrogen spectral series, the transitions are:

- Lyman Series: n_1 = 1, n_2 = 2, 3, 4, . . .∞ (Ultraviolet)
- Balmer Series: n_1 = 2, n_2 = 3, 4, 5, ... ∞ (Visible light & Ultraviolet)
- Paschen Series: n_1 = 3, n_2 = 4, 5, 6, ... ∞ (Infrared)
- Bracket Series: n_1 = 4, n_2 = 5, 6, 7, ... ∞ (Infrared)
- Pfund Series: n_1 = 5, n_2 = 6, 7, 8, ... ∞ (Infrared)

Spectra Series of Hydrogen Atom Cont’d



(a) Permitted orbits of an electron in the Bohr model of a hydrogen atom (not to scale). Arrows indicate the transitions responsible for some of the lines of various series.



(b) Energy-level diagram for hydrogen, showing some transitions corresponding to the various series

Illustrative Examples

EXAMPLE 1:

The wavelength of the first line of Balmer series of hydrogen is 6563 X 10^{-10} m. Calculate the wavelength of its second line.

Solution: For the first line of the Balmer series, we have

$$\bar{\nu}_1 = \frac{1}{\lambda_1} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = \frac{5}{36}R$$

For the second line

$$\bar{\nu}_2 = \frac{1}{\lambda_2} = R\left(\frac{1}{2^2} - \frac{1}{4^2}\right) = \frac{3}{16}R$$

Dividing the first equation by second equation,

Illustrative Examples Cont’d

we have that : $\frac{\lambda_2}{\lambda_1} = \frac{20}{27}$ $or\ \lambda_2 = \frac{20}{27}\lambda_1$

and $\lambda_2 = \frac{20 \times 6563 \times 10^{-10}}{27} = 4861 \times 10^{-10} m$

EXAMPLE 2.

Calculate the frequency of the electron in the first Bohr’s orbit in hydrogen atom. Work out the Solution.

Assignments

Question 1.

The wavelength difference between the longest lines in the Balmer and Lyman series for hydrogen is 534.7nm. Calculate Rydberg constant for hydrogen.

Question 2.

Determine, in angstroms, the shortest and longest wavelengths of the Lyman series of hydrogen.

Properties of nucleus

- The nucleus of an atom consists of protons and neutrons, which are collectively referred to as nucleons.
- The neutron was discovered in 1932 by Chadwick (James Chadwick 1891 – 1974).
- The neutron carries no electrical charge and has a mass that is slightly larger than that of a proton.

Properties of nucleus Cont’d

- The number of protons in the nucleus is different in different elements and is given by the atomic number Z.
- In an electrically neutral atom, the number of nuclear protons equals the number of electrons in orbit around the nucleus, the number of neutrons in the nucleus is N.

Properties of nucleus Cont’d

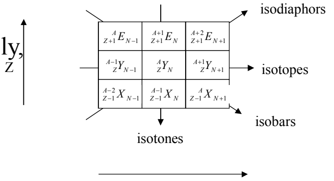
- The total number of protons and neutrons is referred to as the atomic mass number A; A = Z + N. Sometimes, A is also called the nucleon number.
- For example, the nuclei of all naturally occurring aluminum atoms have A = 27, and the atomic number for aluminum is Z = 13, the that the number of neutrons in an aluminum nucleus is N = 14.

Properties of nucleus Cont’d

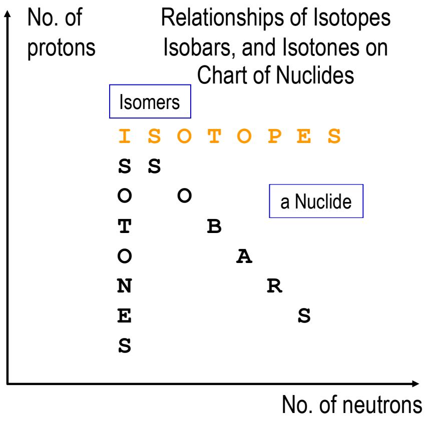
- Generally, $^{A}_{Z}X$ where X is the chemical symbol, A and Z have their usual meaning. For a proton the symbol is, $^{1}_{1}H$ since the proton is the nucleus of a hydrogen atom.
- For a neutron the symbol is $^{1}_{0}n$. Nuclei that contain the same number of protons, but a different number of neutrons are known as isotopes. For example, same Z ^{40}Ca, ^{42}Ca, ^{44}Ca.

Properties of nucleus Cont’d

- Also,
  - **Isotones**: same *N* ^{40}Ca, ^{42}Ti, ^{44}Cr
  - **Isobars**: same *A* ^{42}Ca, ^{42}Ti, ^{42}Cr
  - **Isodiaphors**: same neutron excess ^{42}Ca, ^{46}Ti, ^{50}Cr
- Diagrammatically,



Isotopes Isotones, and Isobars Relationships



Recognize the locations of
isobars isotones
isomers Isotopes
on the chart of nuclides
helps you remember
meaning of these terms,
and interpret the
transformation of nuclides
in nuclear decays and
nuclear reactions.

Properties of nucleus Cont’d

The electric charges and masses of the particles are:

Particle	Electric Charge (C)	Mass (Kg)	Mass (u)
Electron	-1.6×10^{-19}	9.109×10^{-31}	0.00054858 0
Proton	$+1.6 \times 10^{-19}$	1.672623×10^{-27}	1.007276
Neutron	0	1.674929×10^{-27}	1.008665

$1U = 1.66053886 \times 10^{-27}\,Kg = 931.5\,MeV/c^2$

Interactions

- Electromagnetic: e$^-$ (lepton) bound in the atoms by the electromagnetic force
- Weak interaction: Neutrino observed in beta decay.
- Strong interaction: Quarks are bound in together by the strong force in nucleons. Nuclear forces bind nucleons into nuclei.
- Gravitation: Gravitational interaction between the elementary particles is in practice very small compared to the other three.

Interactions Cont'd

The forces of elementary particle physics are associated with the exchange of particles. An interaction between particles is characterized by both its strength and its range.

forces	strength	range (fm)	exchange particle	mass (eV)	charge	spin
gravitational	6×10^{-39}	infinite	graviton?	0	0	2
weak	1×10^{-6}	2×10^{-3}	$W\pm$, Z	91×10^{9}	$\pm 1,0$	1
electromagnetic	7×10^{-3}	infinite	photon	0	0	1
strong	1	1.5	pion	35×10^{6}	0	1

$1 \text{ fm} = 10^{-15} \text{ m}$

Force between two objects can be described as exchange of a particle – particle transfers momentum and energy between the two objects, and is said to mediate the interaction

graviton – not yet observed
pions or pi mesons – between nucleons

Radioactivity

- ***Introduction:*** Radioactivity was discovered by Becquerel in 1896 when he noticed that some photographic plates placed close to some uranium salt were blackened.
- He found that the radiation from the uranium salt could penetrate not only paper but also glass & even aluminum.
- He concluded that such radiation was similar to x-rays which were discovered in 1895 by Rontgen.
- Slightly over year later, Marie & Pierre Curie succeeded in isolating radium and polonium, two highly radioactive substances. *[Marie Curie; Nobel Laureate in Chemistry and Physics]*

Radioactivity Cont'd

- **Natural and Artificial Radioactivity**
- Radioactivity is the spontaneous decay or disintegration of the nucleus of the atom of an element during which α,β – particles or γ-rays or a combination of any or all the three, and energy or heat are released.
- Radioactive elements are those elements that spontaneously emit radiation from their nucleus, e.g Radium, Thorium , Radon etc.
- There are two classes of radioactivity: the natural & the artificial.

Radioactivity Cont'd

- **Natural radioactivity** is the spontaneous disintegration of the nucleus of an atom during which α or β – particles or γ-rays or a combination of them and heat are released.
- Sometimes, radioactivity can be induced in an element by irradiation with for example, neutron. By irradiation, we mean exposure to radiation either by accident or intent.
- Such radioactivity that is induced is called **Artificial radioactivity**. In artificial radioactivity, an ordinary atom is made radioactive by bombarding it with radioactive particles.

Radioactivity Cont’d

- **Types of Radioactive Radiation**
- The radiation form radioactive substances can be grouped under alpha (α) particles, beta (β) particles (β^{-1}, β^{+1} & electron capture) and gamma (γ) rays.

- **α – Particles:**
- i. α – particles are Helium nuclei ${}^{4}_{2}He$, hence they are positively charged.
- ii. Alpha particles emitted from a source have the same energy, in the range of a few MeV. The speed of α – particles is about $\frac{1}{200}$ that of light.

Radioactivity Cont’d

- iii. α – particles are deflected by a strong magnetic field from the direction of deflection, it can be deduced that the α-particles are positively charged.

- . iv. Since they are positively charged, they are deflected by an electric field.

- v. They have high ionizing power, producing a large number of ion pairs for each unit distance of its path.

Radioactivity Cont’d

- vi. The range of α particle in air is about 5cm; they are easily stopped by a piece of paper.

- vii. They cause substances like zinc-sulfide to fluoresce and also blacken photographic plates.

Radioactivity Cont’d

Alpha decay.

- Occurs when the nucleus is too large.
- An alpha particle is emitted, reducing the size of the nucleus.
- The daughter nucleus has an atomic number 2 less and an atomic mass 4 less than the parent nucleus.

(Unstable Atom) **(more stable Atom)** **(Alpha particle)**

$$ {}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He $$

- Illustrative Examples :

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

Radioactivity Cont’d

$$^{234}_{92}\text{U} \longrightarrow {}^{230}_{90}\text{Th} + {}^{4}_{2}\text{He}$$

$$^{230}_{90}\text{Th} \longrightarrow {}^{226}_{88}\text{Ra} + {}^{4}_{2}\text{He}$$

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

$$^{218}_{84}\text{Po} \longrightarrow {}^{214}_{82}\text{Pb} + {}^{4}_{2}\text{He}$$

Radioactivity Cont’d

- **β – Particles**
- i. β – particles are electrons with energy of a few MeV.
- ii. They have high speeds of up to about $\frac{2}{3}$ the speed of light.
- iii. They are easily deflected by a magnetic field. From the direction of deflection, it was deduced that β – particles are negatively charged.
- iv. They are also deflected by an electric field.

Radioactivity Cont’d

- v. The ionization power of β – particles is about $\frac{1}{10}$ that of α – particles.
- vi. Their range is about 10 times that of α – particles, they are stopped only by a few millimeter thickness of aluminum.
- vii. They cause certain materials to fluoresce and also blacken photographic plates.

Radioactivity Cont’d

Beta Decay

β^-: change a neutron to a proton

$$^{A}_{Z}X_N \rightarrow {}^{A}_{Z+1}Y_{N-1} + \beta^- + \bar{\nu}$$

β^- is an electron, $\bar{V}$ is called antineutrino

β^+: change a proton to a neutron

$$^{A}_{Z}X_N \rightarrow {}^{A}_{Z-1}Y_{N+1} + \beta^+ + \nu$$

β^+ is an anti-electron or positron, V is called neutrino

EC: electron capture, change a proton to a neutron, V is the neutrino

$$^{A}_{Z}X_N + e^- \rightarrow {}^{A}_{Z-1}Y_{N+1} + \nu$$

Radioactivity Cont’d

(β^-) Decay

- Electron is created when a neutron decays into a proton and an electron, when this occurs, the proton number of the parent nucleus increases from Z to Z +1 and the nucleon number remains unchanged.
- β- decay can occur whenever the mass of the original neutral atom is longer than that of the final atom.
- In general, a β- decay can be expressed as

Radioactivity Cont’d

(β^-) Decay

$${}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z+1}Y_{N-1} + \beta^{-} + \bar{\nu}$$

Neutron rich nuclei;
Large N/Z ratio

$${}^{90}_{38}Sr \rightarrow {}^{90}_{39}Y + \beta^{-} + \overline{\upsilon}$$

$${}^{32}_{15}P \rightarrow {}^{32}_{16}S + \beta^{-} + \overline{\upsilon}$$

$${}^{234}_{90}Th \rightarrow {}^{234}_{91}P + \beta^{-} + \overline{\upsilon}$$

$${}^{12}_{5}B \rightarrow {}^{12}_{6}C + \beta^{-} + \overline{\upsilon}$$

$${}^{1}_{0}n \rightarrow {}^{1}_{1}H + \beta^{-} + \overline{\upsilon}$$

Radioactivity Cont’d

Positron (β^+) Decay

- A β+ decay sometimes occurs; in this process the particle emitted by the nucleus is a positron, rather than an electron.
- A positron, also, called a β+ particle has the same mass as an electron, but carries a change of positive instead of negative.
- In β+ decay, a proton is converted into a neutron.

Radioactivity Cont’d

Positron (β^+) Decay

β+: change a proton to a neutron

$${}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z-1}Y_{N+1} + \beta^{+} + \nu$$

β+ is an anti-electron, or positron, V is the neutrino

$${}^{22}_{11}Na \rightarrow {}^{22}_{10}Ne + \beta^{+} + \upsilon$$

$${}^{11}_{6}C \rightarrow {}^{11}_{5}B + \beta^{+} + \upsilon$$

$${}^{12}_{7}N \rightarrow {}^{12}_{6}C + \beta^{+} + \upsilon$$

$${}^{13}_{7}N \rightarrow {}^{13}_{6}C + \beta^{+} + \upsilon$$

$${}^{1}_{1}H \rightarrow {}^{1}_{0}n + \beta^{+} + \upsilon$$

Radioactivity Cont’d

Electron Capture

- The 3rd type of β decay is the electron capture.
- There are a few nuclides for which β+ emission is not energetically possible but in which an orbital electron (usually in the K Shell) can combine with a proton in the nucleus and the neutrino is emitted.
- In electron capture a proton is converted into a neutron. An electron capture process can be written as

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Radioactivity Cont’d

EC: electron capture, change a proton to a neutron

$${}^{A}_{Z}X_{N} + e^{-} \rightarrow {}^{A}_{Z-1}Y_{N+1} + \nu$$

excited
nucleus

e^{-} = x-rays or Auger electrons
+ inner bremsstrahlung

$$e^{-} + {}^{7}_{4}Be \rightarrow {}^{7}_{3}Li + \upsilon$$

$$e^{-} + {}^{1}_{1}H \rightarrow {}^{1}_{0}n + \upsilon$$

The neutrino were postulated by Pauli in 1931 to explain an otherwise unaccountable loss of energy and angular momentum in β^{-} and β^{+}decay Processes, respectively

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Radioactivity Cont’d

- **<u>γ – Rays</u>**
- i. γ – rays are electromagnetic radiation of wavelength stronger than those of X-rays
- ii. They are not deflected by magnetic or electric fields, this shows that γ – rays are not charged (i.e. neutral)
- iii. Among the three types of radioactive radiation, γ – rays have the strongest penetration power. γ – rays are stopped only by a few centimeter thickness of lead.
- iv. The ionization power of γ – rays is about $\frac{1}{1000}$ that of α – particles.

Radioactivity Cont’d

Gamma Decay

- In a gamma decay, a nucleus initially in an excited state makes a transition to a lower energy state and in the process emits a photon, called a γ-ray.
- It is found that the γ – ray emerge with discrete energies, which shows that nuclei possess discrete energy levels. The energy of the γ-ray photon is given by $E_i - E_f = hf$

Radioactivity Cont'd

Gamma Decay

- Because γ-ray photons carry number charge or mass, the charge and atomic number of the nucleus do not change in γ-decay. The γ-decay process is written as follows:

$$^{A}_{Z}P^{*} \rightarrow {}^{A}_{Z}P + \gamma$$

Parent nucleus in excited energy state

Parent nucleus in lower energy state

γ rays

- γ decay does not cause a transmutation of one element into another. Often, γ ray emission accompanies α or β decay.

Radioactivity Cont'd

Gamma Decay

- It is worthy of note that; in both α and β decays, the Z value of a nucleus changes and the nucleus of one element becomes the nucleus of a different element.
- In γ-decay, the element does not change; the nucleus merely goes from an excited state to a less excited state.

Kinds of Radioactivity

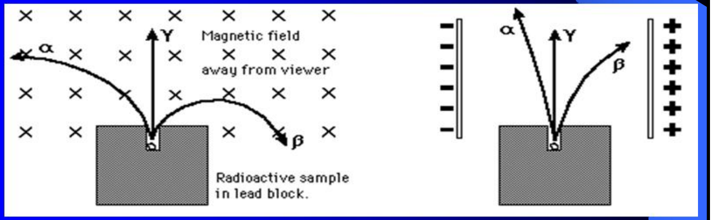
Summary of Radioactive Decay Processes

Type of Radioactive Decay	Particle Emitted	Change in Mass Number	Change in Atomic Number
Alpha Decay	Helium Nuclei	Decreases by 4	Decreases by 2
Beta Decay	Beta Particle	No Change	Increases by 1
Gamma Emission	Energy	No Change	No Change
Positron Emission	Positron	No Change	Decreases by 1
Electron Capture	X-ray Photon	No Change	Decreases by 1

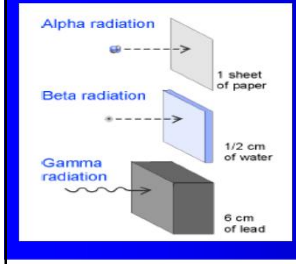
The three main decays are Alpha, Beta and Gamma

Radioactivity Cont'd

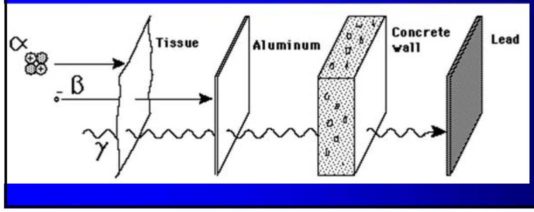
Positive and negative charged particles will be deflected in different directions. Neutral particles or rays go straight through.



Radioactivity Cont’d



Alpha particles may be completely stopped by a sheet of paper, beta particles by aluminum shielding. Gamma rays, however, can only be reduced by much more substantial obstacles, such as a very thick piece of lead.



Radioactivity Cont’d

Radiation and Radioactivity

- Radiation: Energy in transit, either as particles or electromagnetic waves
- Radioactivity: The characteristic of various materials to emit ionizing radiation
- Ionization: The removal of electrons from an atom. The essential characteristic of high energy radiations when interacting with matter.

Radiation
is energy in transit in the form of **high speed particles and electromagnetic waves**.

Ionizing radiation
is radiation **with enough energy** so that during an interaction with an atom, it can remove tightly bound electrons from their orbits, causing the atom to become charged or ionized (examples: gamma rays, neutrons)

Non-ionizing radiation
is radiation **without enough energy** to to separate molecules or remove electrons from atoms. Examples are visible light, radio and television waves, ultra violet (UV), and microwaves with a large spectrum of energies.

Radioactivity Cont’d

- **Radioactivity**
  is the **spontaneous transformation** of an **unstable** atom and often results in the **emission of radiation**. This process is referred to as a transformation, a decay or a disintegrations of an atom. These emissions are collectively **called ionizing radiations**. Depending on how the nucleus loses this excess energy either a lower energy atom of the same form will result, or a completely different nucleus and atom can be formed.
- **Ionization**
  is a particular characteristic of the radiation produced **when radioactive elements decay**. These radiations are of such high energy that when they interact with materials, they can **remove electrons from the atoms in the material.** This effect is the reason why ionizing radiation is **hazardous to health**.
- **Radioactive Material** is any material that contains radioactive atoms.
- **Radioactive Contamination**
  is radioactive material distributed over some area, equipment or person.

Radioactivity Cont’d

The ***activity*** of a radioactive sample is the rate at which atoms decay.

If N(t) is the number of atoms present at a time t, then the activity R is

$$R = -\frac{dN}{dt}.$$

dN/dt is negative, so the activity is a positive quantity.

The SI unit of activity is the becquerel: 1 becquerel = 1 Bq = 1 event/second.

Another unit of activity is the curie (Ci) defined by
1 curie = 1 Ci = 3.70×10^{10} events/s = 37 GBq.

Radioactivity Cont'd

Half-Life

Experimental measurements show that the activities of radioactive samples fall off exponentially with time.

Empirically: $\boxed{R = -R_0 e^{-\lambda t}.}$

λ is called the "decay constant" of the decaying nuclide. Each radioactive nuclide has a different decay constant.

Radioactivity Cont'd

The ***half-life***, $T_{½}$, is the time it takes for the activity to drop by ½. We can find a relationship between λ and $T_{½}$:

$$\frac{R_0}{2} = R_0\, e^{-\lambda T_{½}}$$

activity after $T_{½}$

original activity

$$\frac{1}{2} = e^{-\lambda T_{1/2}}$$

$$e^{+\lambda T_{1/2}} = 2 \qquad \lambda T_{1/2} = \ln(2) \qquad \boxed{\lambda = \frac{\ln(2)}{T_{1/2}} = \frac{0.693}{T_{1/2}}}$$

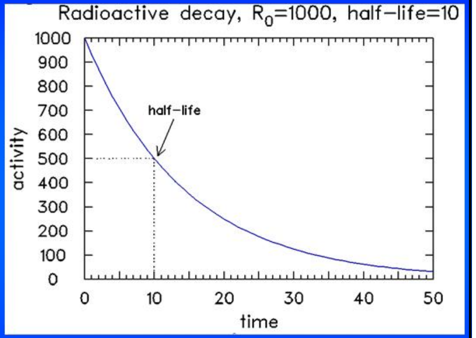
The mean lifetime of a nucleus is different from its half-life. It turns out that $\bar{T} = 1.44\, T_{1/2}$.

Radioactivity Cont'd

Here's a plot of the activity of a radionuclide.

The initial activity was chosen to be 1000 for this plot.

The half-life is 10 (in whatever time units we are using).



All decay curves look like this; only the numbers on the axes will differ, depending on the radionuclide (which determines the half-life) and the amount of radioactive material (which determines the initial activity).

Radioactivity Cont'd

- Example: The radioactive isotope decays by electron capture with a half – life of 272 days.
- (a) Find the decay constant of the lifetime.
- (b) If you have a radiation source containing , with activity 2.00μCi, how many radioactive nuclei does it contain?
- (c) What will be the activity of this source after one year?

Radioactivity Cont’d

Solution

(a) $T_{1/2} = (272 \text{ days}) \times 24 \times 60 \times 60 = 2.35 \times 10^7 \text{s}$

$$T_m = \frac{T_{1/2}}{0.693} = \frac{2.35 \times 10^7 \text{s}}{0.693} = 3.39 \times 10^7 \text{s}$$

Decay constant λ is:

$$\lambda = \frac{1}{T_m} = \frac{1}{3.39 \times 10^7 \text{s}} = 2.95 \times 10^{-8} s^{-1}$$

Alternatively,

$$\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{2.35 \times 10^7} = 2.95 \times 10^{-8} s^{-1}$$

Radioactivity Cont’d

(b) The activity $-\frac{dN}{dt} = \lambda N \quad A = -\frac{dN}{dt} = 2.00\mu\text{Ci}$

$$-\frac{dN}{dt} = 2.00\mu\text{Ci} = (2 \times 10^{-6})(3.7 \times 10^{10} s^{-1}) = 7.4 \times 10^4 \text{nuclei/s}$$

Recall $N = -\frac{1}{\lambda}\frac{dN}{dt} = \frac{7.40 \times 10^4 \text{ nuclei/s}}{2.95 \times 10^{-8}} = 2.51 \times 10^{12} \text{nuclei}$

$$N = N_o e^{-\lambda t} = N_o \times e^{-[2.95\times10^{-8}/s]\times 1\, year\, (s)}$$

(c)Note 1 year = (365 x 24 x 60 x 60)s

$$N = 0.394 N_o$$

the activity has decreased by this same factor

$$(0.394)(2.00\mu\text{Ci}) = 0.788\mu\text{Ci}$$

Radioactivity Cont’d

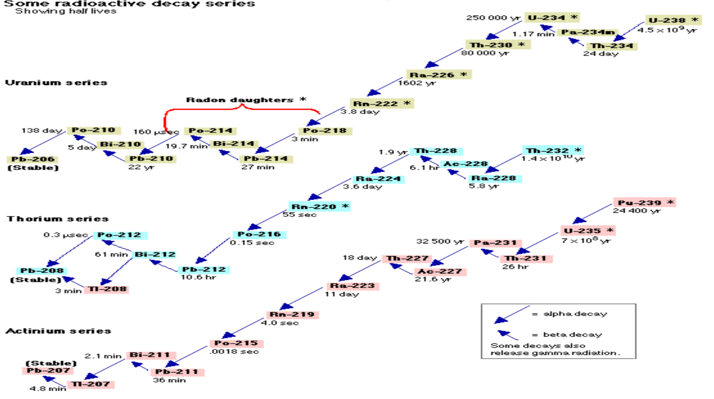
Radiocarbon example. A piece of wood has 13 disintegrations per minute per gram of carbon. The activity of living wood is 16 dpm per gram. How long ago did the tree die?

$$t = \frac{1}{\lambda} \ln \frac{R_0}{R}.$$

$$t = \frac{5760 \text{ years}}{0.693} \ln \frac{16}{13} = 1726 \text{ years}.$$

Radioactive Series

Radioactivity Cont’d



Notes:

1. In a uranium orebody, the U-238 series represents almost 95% of the radioactivity.
2. The level of radioactivity of an isotope is inversely proportional to its half life. The shorter-lived each kind of radioisotope, the more radiation it emits per unit mass. Th-232, U-235 and U-238 are thus virtually stable.

* Specifically mentioned in text or footnote.

Applications of radioactivity

- Many satellites use radioactive decay from isotopes with long half-lives for power because energy can be produced for a long time without refueling.
- Isotopes with a short half-life give off lots of energy in a short time and are useful in medical imaging, but can be extremely dangerous.
- The isotope carbon-14 is used by archeologists to determine age.

Detection of Radioactive Radiations

- The following detectors can be used in detecting the radioactive radiations:
- Scintillation counter
- Cloud and bubble chamber
- Geiger-Muller counter
- Solid State detector
- Photographic plates

NUCLEAR REACTION

- A nuclear reaction is an induced change involving a spontaneous decay of a nucleus from highly excited state.
- It requires the bombardment of a nucleus by high energy particles such as those from a particle accelerator or by gamma radiation which result in their capture and the subsequent decay of a compound nucleus.
- Nuclear reactions are indicated in equation form:

$$\mathit{Projectile} + \mathit{Target\ nucleus} \rightarrow \mathit{Residual\ nucleus} + \mathit{Detected\ nucleus}$$

Nuclear Reaction Cont'd

Or in condensed form

$$\mathit{Target}\ (\mathit{Projectile}, \mathit{Detected\ particle})\ \mathit{Residual\ nucleus}$$

Examples:

$${}^{16}_{8}\mathrm{O}\ (\mathrm{d},\mathrm{t})\ {}^{15}_{8}\mathrm{O} \quad \text{or} \quad {}^{16}_{8}\mathrm{O} + \mathrm{d} \rightarrow {}^{15}_{8}\mathrm{O} + \mathrm{t}$$

$${}^{23}_{11}\mathrm{Na}\ (\mathrm{d},\mathrm{p})\ {}^{24}_{11}\mathrm{Na} \quad \text{or} \quad {}^{23}_{11}\mathrm{Na} + \mathrm{d} \rightarrow {}^{24}_{11}\mathrm{Na} + \mathrm{p}$$

$${}^{14}_{7}\mathrm{N}\ (\alpha,\mathrm{p})\ {}^{17}_{8}\mathrm{O} \quad \text{or} \quad {}^{14}_{7}\mathrm{N} + \alpha \rightarrow {}^{17}_{8}\mathrm{O} + \mathrm{p}$$

$${}^{41}_{20}\mathrm{Ca}\ (\mathrm{h},\alpha)\ {}^{40}_{20}\mathrm{Ca} \quad \text{or} \quad {}^{41}_{20}\mathrm{Ca} + \mathrm{h} \rightarrow {}^{40}_{20}\mathrm{Ca} + \alpha$$

Nuclear Reaction Cont'd

where the following notations have been used:

Particle	Notation
Neutron	$n;\ ^1_0n$
Proton	$p;\ ^1_1H$
Deuteron	$d;\ ^2_1H$
Triton	$t;\ ^3_1H$
Helium-3	$h;\ ^3_2He$
Helium- 4	$\alpha;\ ^4_2He$

Nuclear reactions are subject to several conservation laws. The classical conservation principles for charge, momentum, angular momentum and energy are obeyed in all nuclear reactions. An additional conservation law, not anticipated by classical physics, is conservation of the total number of nucleons.

Nuclear Fission

- The splitting of a nucleus into ***smaller*** fragments is called nuclear **fission.** Heavy atoms (mass number>60) tend to break into smaller atoms, thereby increasing their ***stability***.
- or the disintegration of a massive nucleus into two fragments with comparative masses, sufficient excitation energy for the nucleus to split may be provided spontaneously or by particles bombardment.
- The two nuclei produced will be in the medium mass nuclear range so that the final value of E (binding energy per nucleon) is greater than the original values.
- Nuclear fission releases a large amount of ***energy***.

Nuclear Fission - splitting of heavier nuclei into lighter nuclei.

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{137}_{56}Ba + ^{84}_{36}Xe + 15\,^{1}_{0}n + \text{energy}$$

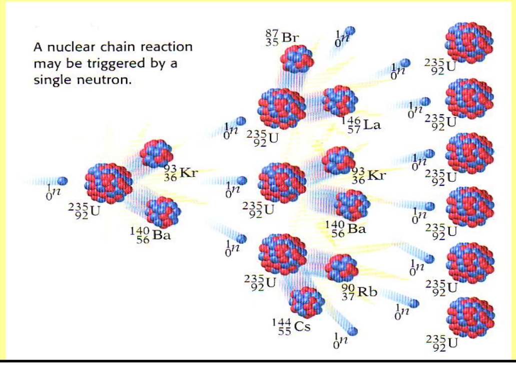
How much energy? E=mc^2

Energy = mass x (speed of light)^2 c=3.0x10^8

E=mc^2 explains mass defect (total mass of nucleus is less than sum of individual particles)

Nuclear Chain Reactions:

- Nuclear fission releases more neutrons which trigger more fission reactions
- The number of neutrons released determines the success of a chain reaction

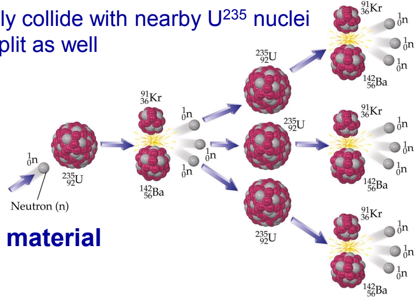


A nuclear chain reaction may be triggered by a single neutron.

Neutrons may:

1 - Cause another fission by colliding with a U^{235} nucleus

- Creates two smaller nuclides and free neutrons
- The free neutrons potentially collide with nearby U^{235} nuclei
- May cause the nuclide to split as well



Each split (fission) is accompanied by a large quantity of **E-N-E-R-G-Y**

2 - Be absorbed in other material

3 - Lost in the system

If sufficient neutrons are present, we may achieve a **chain reaction**

Nuclear Fission Cont'd

- When the product has a greater number of neutrons than the number of bombardment neutrons.
- The excess neutrons go on to produce further fission reaction thereby resulting in a self-sustaining chain reaction, this process then provides a greater source of energy.
- The rate at which fission reaction occur is regulated by controlled rods, which can easily absorb neutrons.
- When each fission produces less than one-further fission, the reaction is sub-critical.

Nuclear Fission Cont'd

- When it produces one-further fission, the reactor becomes critical and the reaction is self-sustaining.
- When it produces well above its one-further fission, it is super-critical.
- A chain reaction can only occur if the starting material has enough mass to sustain a chain reaction. This amount is called the critical mass.
- Nuclear Fission is what occurs in Nuclear Reactors and Atomic Bombs.
- The Nuclear reactor is a ***controlled*** fission reaction, the bomb is not.

- **Nuclear Fission Cont'd**

Applications of Controlling Chain Reactions

1. Atomic Bomb (fission bomb) – Triggering a chain reaction in U-235 or Pu-239 (when operates under a super-critical condition)
   - Must have a minimum amount of radioactive isotope to sustain a chain reaction = CRITICAL MASS
2. Nuclear Power Plants – Convert heat energy from fission chain reaction into electricity.

Control chain reaction with control rods that absorb neutrons emitted after fission reaction.

Nuclear Fusion

- The combining of atomic nuclei to form a ***larger*** atom is called **fusion,** that is, when two or more small light nuclei come together, or fuse, to form a large nucleus.
- Nuclear fusion occurs in the sun where hydrogen atoms fuse to form helium

$$4\,{}^{1}_{1}H + 2\,{}^{0}_{-1}e^{-} \rightarrow {}^{4}_{2}He + \text{energy}$$

Fusion

- Fusion reactions also release very large amount of energy but require extremely high temperatures to start.
- Nuclear fusion also occurs in new stars and is how all of our elements were made.

$${}^{4}_{2}He + {}^{4}_{2}He \rightarrow {}^{8}_{4}Be + \text{energy}$$

$${}^{4}_{2}He + {}^{8}_{4}Be \rightarrow {}^{12}_{6}C + \text{energy}$$

Other Fusion Reactions

- Hydrogen Bomb or possible Fusion nuclear reactor reaction
- ${}^{3}_{1}H + {}^{2}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$
- New elements discovered:
- ${}_{20}Ca + {}_{95}Am \rightarrow {}_{115}Uup$
- ${}_{115}Uup \rightarrow {}_{113}Uut + {}^{4}_{2}He$

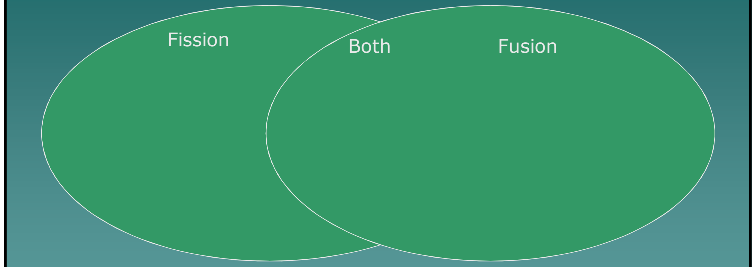
Balancing Nuclear Equations

- Mass numbers and Atomic numbers must add up on both sides of the reaction arrow.
- $^{256}_{100}\mathrm{Fm} \rightarrow {}^{140}_{54}\mathrm{Xe} + \underline{^{112}_{46}\mathrm{Pd}} + 4\,{}^{1}_{0}\mathrm{n}$

For Atomic numbers $100 = 54 + X$
$X = 46$

For Mass Numbers: $256 = 140 + X + 4$
$X = 112$

Complete the Venn diagram by listing one thing that fission & fusion have in common, one thing that applies only to fission, & one thing that applies only to fusion,



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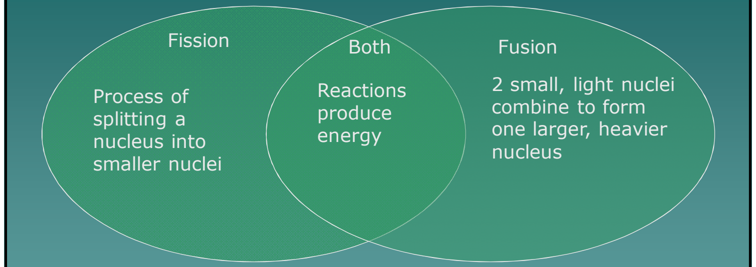

Process of splitting a nucleus into smaller nuclei

Reactions produce energy

2 small, light nuclei combine to form one larger, heavier nucleus