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### The Site you have Requested ...

## Atomic Alchemy: Nuclear Processes

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A ThinkQuest Internet Challenge 1998 Entry



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## Languages :

## Site Description

*With the help of chemistry and physics, modern scientists can produce more energy with a tiny radioactive pellet than they can with several tons of coal, gas, or oil. Come visit this well-documented and researched tutorial on atomic science. There is a nice Periodic Table of the Elements. An excellent site and well worth the visit.*

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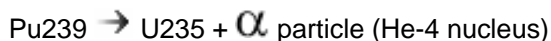
# Radioactivity

## Introduction:

Radioactivity is the spontaneous disintegration of atomic nuclei. The nucleus emits  $\alpha$  particles,  $\beta$  particles, or electromagnetic rays during this process.

## Alpha ( $\alpha$ ) Decay:

Alpha decay occurs when the nucleus spontaneously ejects an  $\alpha$  particle. An  $\alpha$  particle is really 2 protons and 2 neutrons, or an He nucleus. So when an atom undergoes  $\alpha$  decay, its atomic number decreases by 2 and its atomic mass decreases by 4.  $\alpha$  particles do not penetrate much material, for they can be stopped by paper. An example of  $\alpha$  decay is the following:



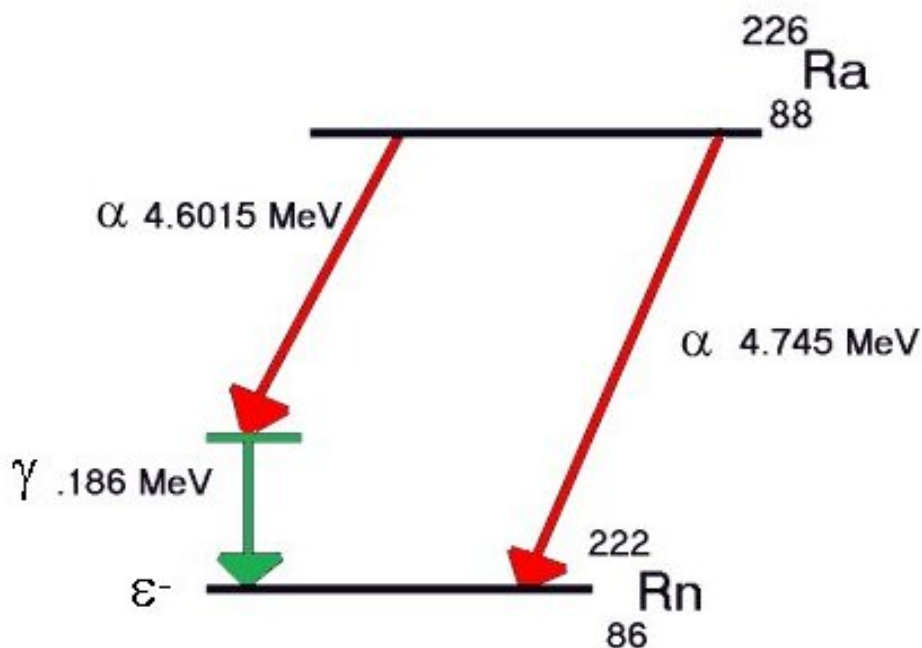
**$\alpha$  (Alpha) Particle and  
Gamma Rays Are Released**

**235U**

## Home

There is a difference in mass between the original nucleus and the sum of the mass of the  $\alpha$  particle and resulting nucleus. This lost mass is converted into energy using the formula  $E = mc^2$ ; the energy would equal the kinetic energy of the  $\alpha$  particle and the recoil energy of the resulting nucleus.

$\alpha$  particles are usually mono-energetic, but they can have different energies, as in the case of  $^{226}\text{Ra}$ . This isotope of radium has a small percentage of  $\alpha$  particles that don't have their full energy; instead the nucleus is left excited and emits gamma rays. Some of these rays will transfer energy to an orbital electron in the process [internal conversion](#).

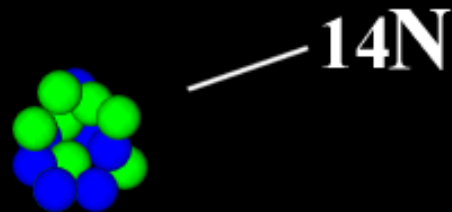


## Beta( $\beta$ )<sup>-</sup> Decay:

There are two types of  $\beta$  decay;  $\beta^+$  and  $\beta^-$  decay. An excess of neutrons in an atom's nucleus will make it unstable, and a neutron is converted into a proton to change this ratio. During this process, a  $\beta$  particle is released, and it has the same mass and charge as an electron. The resulting atom and the  $\beta$  particle have a total mass which is less than the mass of the original atom, and one would think that the  $\beta$  particles should have the energy equivalent to the mass lost ( $E = mc^2$ ). But  $\beta$  particles aren't mono-energetic, and have a broad energy spectrum from zero to the maximum energy predicted. So the  $\beta$  particle is accompanied by virtually massless and chargeless particles called neutrinos, whose kinetic energy makes up for the energy difference still remaining. As a result of  $\beta^-$  decay, the atomic number of the atom increases by 1.

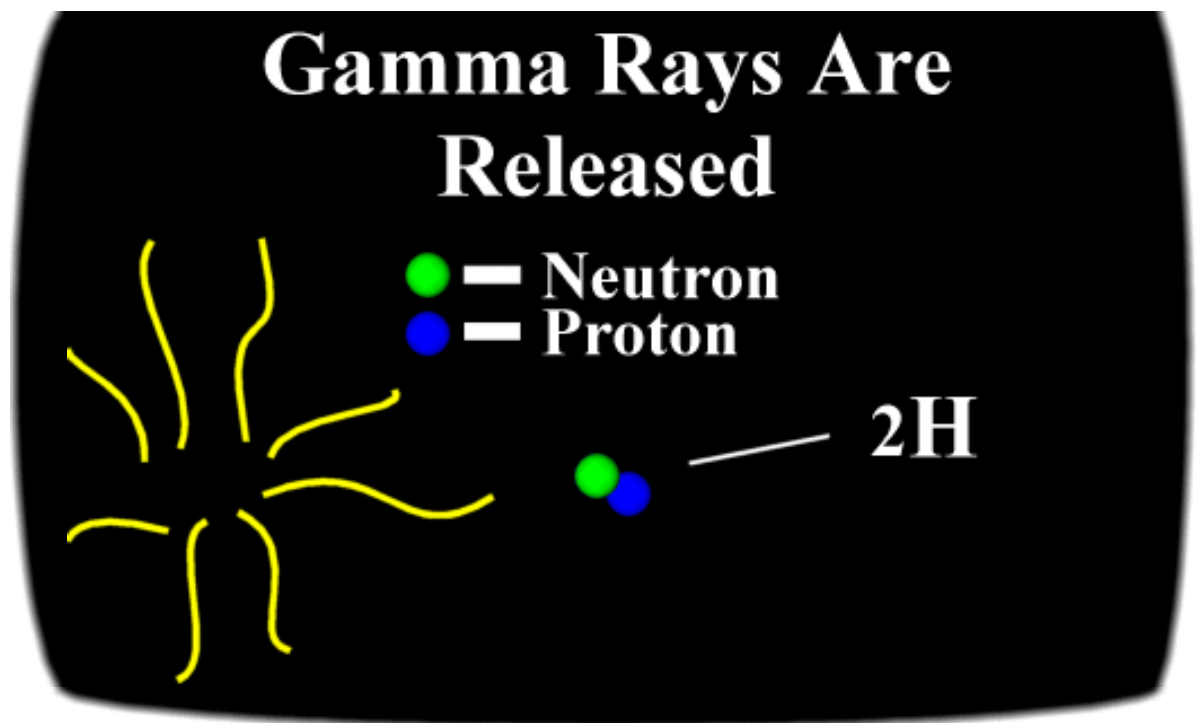
## Electron and Anti-Neutrino Are Released

● — Neutron  
● — Proton



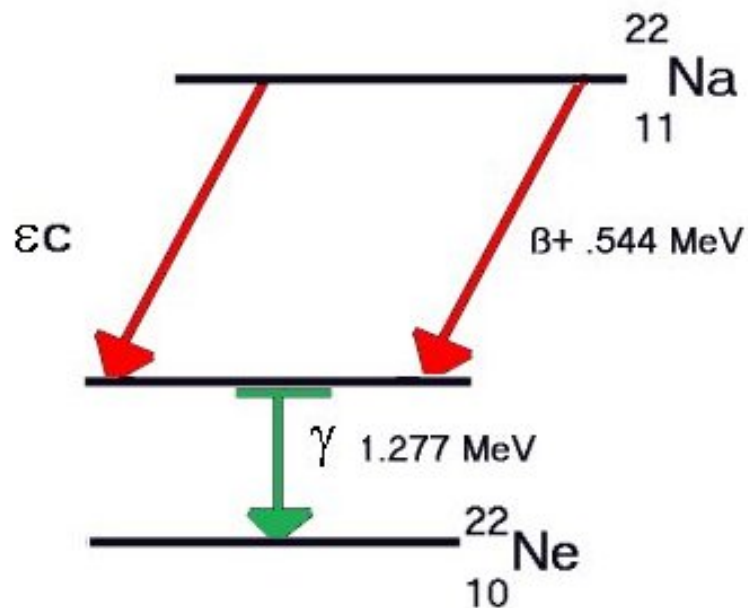
### $\beta^+$ Decay:

When there is an excess of protons in the nucleus, and it is not energetically possible to emit an  $\alpha$  particle,  $\beta^+$  decay occurs. This is where the nucleus becomes stable by converting a proton into a neutron. During  $\beta^+$  decay, a positron (a particle with the same mass as an electron but with positive charge), and a neutrino are released. Positrons interact with electrons, causing both to be completely destroyed. Two gamma ray photons with the same energy as the mass of the positron and electron are released.



## Electron Capture:

Sometimes it is not energetically feasible to convert a proton into a neutron by emitting a positron ( $\beta^+$  decay). In these cases, electron capture, or K capture occurs. This is where the nucleus captures an electron from an inner orbital, usually K orbital, and converts a proton into a neutron with it. The difference in mass is converted into a gamma ray and a neutrino.



## Internal Conversion:

In the process internal conversion, a gamma ray is emitted from the nucleus and strikes an orbital electron. The electron absorbs the energy and is then ejected from the atom.

## Gamma Radiation:

Gamma ray emission usually occurs with  $\alpha$  and  $\beta$  emission. Gamma rays have no charge or mass, so their emission doesn't change the chemical composition of the atom. Instead, it results in a loss of radiant energy. Gamma ray emission occurs because the nucleus is often unstable after  $\alpha$  and  $\beta$  decay. There are cases where pure gamma emission occurs, and this is where an isotope exists in two forms (nuclear isomers). They have the same atomic and mass numbers, but have different nuclear-energy content. So gamma emission occurs when the isomer goes from a higher to a lower energy form. The isotope protactinium-234 exists in two different energy states, and it emits gamma rays when undergoing transition to the lower-energy state.

## Half Life:

A sample of a radioactive substance will decay into various particles. The rate of decay is measured by how long it takes for half the sample to decay. The decay of an individual atom is totally random, but for a large sample size, we can get a good prediction of the half life.

### ***Half Life Information*** (Javascript must be enabled)

**Select Isotope:**

**Half-Life (years):**

Note: "5E9" means "5 x 10<sup>9</sup>"

**Description:**

### ***Test Conditions*** (Javascript must be enabled)

**Initial amount (g):**

**Number of years elapsed:**

**Amount left:**

## Decay Chains:

A radioactive decay series is the chain of decays that occur starting with a radioactive isotope. An example of this is the uranium-radium series:

Uranium-238  $\alpha$  decays  $\rightarrow$  thorium-234

Thorium-234 decays  $\rightarrow$  protactinium-234

Protactinium-234  $\beta$  decays to form uranium-234

Uranium-234  $\alpha$  decays  $\rightarrow$  thorium-230

Thorium  $\alpha$  decays  $\rightarrow$  radium-226

Radium-226 goes through five more  $\alpha$  decays and four more  $\beta$  decays to yield the non-radioactive isotope  $^{206}\text{Pb}$ , or lead. This series is also called the  $4n+2$  series, because the mass numbers of each of the isotopes in the series can be represented by  $4n+2$ , where  $n$  is an integer. The thorium series is a  $4n$  series; it starts at thorium-232 and the end result is  $^{208}\text{Pb}$ . The actinium series, or  $4n+3$  series, begins with uranium-235 and ends at  $\text{Pb-207}$ .

## Biological Effects of Radiation:

Ionizing radiation causes physical damage to cells and DNA. Ionizing radiation has energy that results in the formation of excited molecules. This radiation can excite DNA and result in the destruction on the DNA backbone. DNA is also damaged by other molecules that are produced by radiation, such as hydrogen peroxide from water. At high doses of radiation (10,000 - 15,000 rads), death occurs in a few hours because of neurological and cardiovascular breakdown (Central Nervous Syndrome). Medium doses, 500 - 1200 rads, causes death to occur in a few days because of the destruction of the gastrointestinal mucosa. Lower doses, 250 - 500 rads, causes death to occur after several weeks due to damage of the blood forming organs (hematopoietic syndrome).

## Units of Radioactivity:

**Roentgen (R)** - Defined as the amount of ionizing radiation which produces  $2.08 \times 10^9$  ion pairs in  $1\text{cm}^3$  of air.

**RAD (Radiation Absorbed Dose)** - A rad is the amount of radiation that puts  $10\text{ J}$  of energy in  $1\text{kg}$  of absorbing material.

**RBE (Relative Biological Effectiveness)** - The biological risk  $\alpha$ ,  $\beta$ , and  $\gamma$  radiation differ; The RBE factor compares the number of rads of x-radiation or  $\gamma$  radiation that produce the same biological damage as a rad of the radiation used.

**REM (Roentgen Equivalent in Man)** - Product of amount of rad and the RBE factor.

**Gray (Gy)** - 100 rads.

**Sievert (Sv)** - 100 rem.

## Quiz (Feel free to refer the above material while completing the quiz):

What is an  $\alpha$  (Alpha) Particle?

What is a  $\beta$  particle?

What is a positron?

What are the two ways for which it is possible that an isotope can undergo  $\alpha$  decay?

Briefly describe both types of  $\beta$  decay, and the particles involved in each.

If you have a 1000g sample of U-238, how much will be left after 2,500,000,000 years?

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