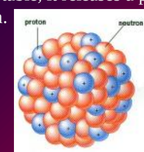
Nuclear Chemistry

Stability of isotopes is based on the ratio of neutrons and protons in its nucleus. Although most nuclei are stable, some are unstable and spontaneously decay, emitting radiation.

All the elements greater than Pb on the Periodic Table are radioactive.

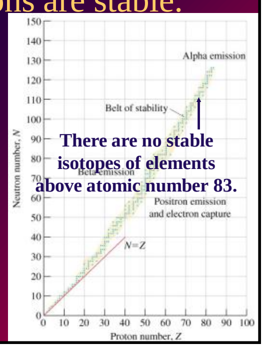
Most elements with a 1:1 ratio of protons to neutrons are stable.

When the nucleus is unstable, it releases a particle and energy which is called radiation.



Only certain combinations of protons and neutrons are stable.

A nuclide falling outside the "belt of stability" are radioactive. They spontaneously decay to form another element.



There are no stable isotopes of elements above atomic number 83.

Each radioactive isotope has a specific mode and rate of decay (half-life).

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

Regents Question: 01/03 #20

Which radioisotope is a beta emitter?

- ☑ (1) ^{90}Sr
- (2) ^{220}Fr
- (3) ^{37}K
- (4) ^{238}U

Regents Question: 06/03 #7

Alpha particles are emitted during the radioactive decay of

- (1) carbon-14
- (2) neon-19
- (3) calcium-37
- ☑ (4) radon-222

The half-life of a radioactive nuclide is the amount of time it takes for half of that nuclide to decay into a stable nuclide.

The half-life of Carbon-14 is 5730 years

After 5730 years, ½ the mass of an original sample of Carbon-14 remains unchanged.

After another 5730 years, ¼ (half of the half) of an original sample of Carbon-14 remains unchanged.

The half-life of a radioactive nuclide cannot be changed.

Regents Question: 06/02 #29

As a sample of the radioactive isotope ^{131}I decays, its half-life

(1) decreases

(2) increases

☑ (3) remains the same

Determining how much of a radioactive isotopes remains unchanged after a period of time.

- Determine how many half-lives have gone by (Time/half-life)
- Halve the mass of the starting material for each half-life period that goes by.
  - How much of a 20.g sample of ^{131}I remains unchanged after 24 days?
  - The half-life period is 8 days so 24 days is 3 half-lives. Half the mass three times.

20.g $\xrightarrow{\text{8 days}}$ 10.g $\xrightarrow{\text{8 days}}$ 5.0g $\xrightarrow{\text{8 days}}$ 2.5g

Regents Question: 06/02 #46

Exactly how much time must elapse before 16 grams of potassium-42 decays, leaving 2 grams of the original isotope?

(1) 8 x 12.4 hours

(2) 2 x 12.4 hours

☑ (3) 3 x 12.4 hours

(4) 4 x 12.4 hours

16 → 8 → 4 → 2

^{42}K	12.4 h	β^-	potassium-42

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.

A particle accelerator can be used to "shoot" charged particles at the nucleus of atoms.

Regents Question: 06/03 #34

What is the name of the process in which the nucleus of an atom of one element is changed into the nucleus of an atom of a different element?

(1) decomposition

☑ (2) transmutation

(3) Substitution

(4) reduction

Regents Question: 01/03 #29

Which equation is an example of artificial transmutation?

☑ (1) ${}^{9}_{4}Be + {}^{4}_{2}He \rightarrow {}^{12}_{6}C + {}^{1}_{0}n$

(2) $U + 3F_2 \rightarrow UF_6$

(3) $Mg(OH)_2 + 2\ HCl \rightarrow 2H_2O + MgCl_2$

(4) $Ca + 2\ H_2O \rightarrow Ca(OH)_2 + H_2$

The other choices are chemical reactions, not nuclear reactions.

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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, and ionizing power, and penetrating power.

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Regents Question: 08/02 #21

The spontaneous decay of an atom is called

(1) ionization

(2) crystallization

(3) combustion

☑ (4) transmutation

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The symbols used in nuclear chemistry can be found on Reference Table O.

Table O
Symbols Used in Nuclear Chemistry

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

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Regents Question: 06/02 #24

Which product of nuclear decay has mass but no charge?

(1) alpha particles

☑ (2) neutrons

(3) gamma rays

(4) beta positrons

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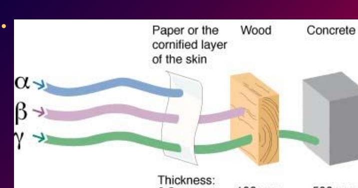
Alpha particles have the lowest penetrating power, gamma the highest.

Alpha particles won't pass through paper.



Alpha particles have the highest ionizing power. They knock off electrons and leave a trail of ions as they pass through the air.

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Regents Question: 08/02 #26

Which type of emission has the highest penetrating power?

(1) alpha

(2) beta

(3) positron

☑ (4) gamma

Regents Question: 06/03 #32

Which type of radioactive emission has a positive charge and weak penetrating power?

☑ (1) alpha particle

(2) beta particle

(3) gamma ray

(4) neutron

Modes of radioactive decay

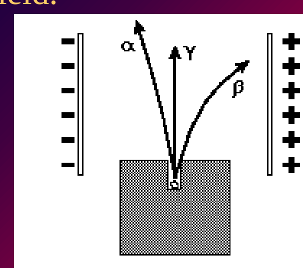
- Alpha Decay (α)
  - 2 protons 2 neutrons $^{4}_{2}$He nucleus
- Beta Particle (β^-)
  - Electron emitted from the nucleus $^{0}_{-1}e$
- Positron Particle (β^+)
  - Mass of an electron but positive charge $^{0}_{+1}e$
- Gamma radiation
  - High energy radiation (higher than x-ray)
  - No mass and no charge

Alpha, Beta and Gamma can be separated using an electric or magnetic field.

Positively charged alpha (α) particles move toward the negative.

Negatively charged beta (β^-) particles move toward the positive.

Gamma rays and neutrons do not bend in the electric field.

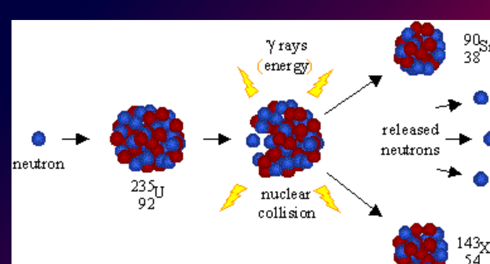


Nuclear reactions include natural and artificial transmutation, fission, and fusion.

- Transmutation – changing one element into another.
- Fission – breaking an atom into two smaller atoms
- Fusion – combining small atoms into a larger atom

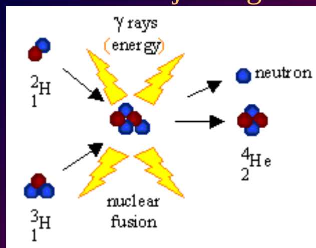
Nuclear reaction take place in the nucleus of an atom.

Nuclear fission – splitting the atom.



More neutrons are released to keep the reaction going.

Nuclear fusion – joining small atoms.



$^2H + ^3H \longrightarrow ^4He + ^1n$

Hydrogen atoms combine to form helium in a star.

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Regents Question Jan 2012 #49

Given the balanced equation representing a nuclear reaction:

$$^2_1H + ^3_1H \rightarrow ^4_2He + ^1_0n$$

Which phrase identifies and describes this reaction?

(1) fission, mass converted to energy
(2) fission, energy converted to mass
(3) fusion, mass converted to energy
(4) fusion, energy converted to mass

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Regents Question: 08/02 #43

Given the fusion reaction: $^2_1H + ^2_1H \rightarrow X + \text{energy}$

Which particle is represented by X?

(1) ^1_1H	(3) ^3_2He
(2) ^3_1H	☑ (4) ^4_2He

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Regents Question: 06/03 #49

Given the nuclear reaction $^{239}_{93}Np \rightarrow ^{239}_{94}Pu + X,$

What does X represent?

(1) a neutron
(2) a proton
(3) an alpha particle
☑ (4) a beta particle

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There are benefits and risks associated with fission and fusion reactions.

- Benefits to making electricity with nuclear fission
  - A small amount of fuel makes a large amount of electricity
  - Not dependent on foreign oil
  - Using fusion instead of burning fossil fuels does not pollute the air
  - Cheap electricity
- Risks to making electricity using nuclear fission
  Exposure to radioactive material can cause cancer, mutations or death
  - Transportation and storage of fissionable material is dangerous
  - Nuclear accidents
  - Disposal of nuclear waste
  - Thermal pollution

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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.

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Alpha decay: mass decreases by four, atomic number decreases by two.

- ^{238}U undergoes alpha decay

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

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)

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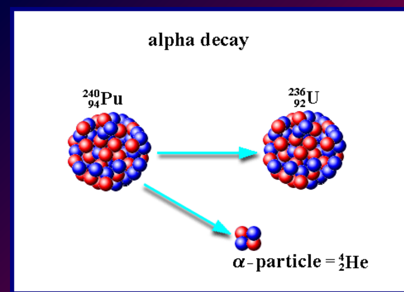
Alpha decay of Plutonium-240



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Beta (minus) decay: mass remains the same, atomic number increases by one.

- ^{234}Th undergoes beta decay

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

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)

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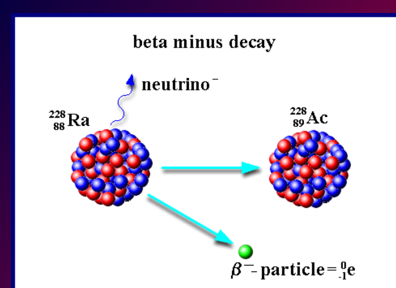
Radium-228 undergoes beta decay



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Positron (beta plus) decay: mass remains the same, atomic number decreases by one.

- ^{37}K undergoes positron decay

$$^{37}_{19}K \longrightarrow {}^{0}_{+1}e + {}^{37}_{18}Ar$$

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)

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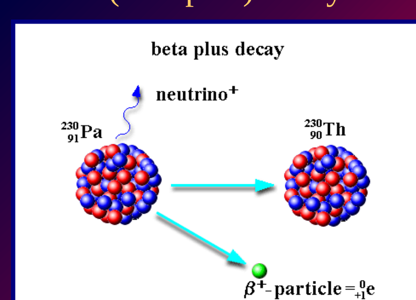
Protactinium-230 undergoes positron (beta plus) decay



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Regents Question: 08/02 #8

Which reaction represents natural nuclear decay?

(1) $H^+ + OH^- \rightarrow H_2O$
(2) $KClO_3 \rightarrow K^+ + ClO_3^-$
☑ (3) $^{235}_{92}U \rightarrow ^{4}_{2}He + ^{231}_{90}Th$
(4) $^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$

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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.

$E=mc^2$

The energy released is equal to the mass lost (m) times the speed of light (c) squared. A small amount of mass lost converts to a very large amount of energy.

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Energy released during nuclear reactions is much greater than the energy released during chemical reactions.

- Fission – used in nuclear reactors and atomic bombs
- Fusion – used in hydrogen bombs and the energy that powers the sun.

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Regents Question: 01/03 #56

Given the nuclear equation:

$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{142}_{56}Ba + ^{91}_{36}Kr + 3^{1}_{0}n$

a State the type of nuclear reaction represented by the equation. Fission

b The sum of the masses of the products is slightly less than the sum of the masses of the reactants. Explain this loss of mass. Lost mass is converted into energy

c This process releases greater energy than an ordinary chemical reaction does. Name another type of nuclear reaction that releases greater energy than an ordinary chemical reaction. Fusion

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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.

Exposure to radiation can cause cancer, mutations or death.

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Regents Question: 08/02 #58

a State one possible advantage of using nuclear power instead of burning fossil fuels.

Reduce air pollution, cheaper electricity, do not depend on foreign oil.

b State one possible risk of using nuclear power.

Nuclear accident releasing radioactive materials into the environment., thermal pollution, disposing of nuclear waste.

c If animals feed on plants that have taken up Sr-90, the Sr-90 can find its way into their bone structure. Explain one danger to the animals.

Radiation can cause cancer, mutations or death.

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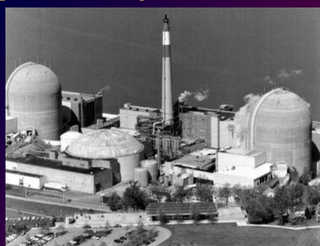
Residents around nuclear power plants worry about the health risks.



- Accidents releasing radioactive material into the environment
- Disposing of radioactive waste
- Transporting radioactive materials
- Attack by terrorists

The Indian Point nuclear power plant provides electricity for New York City.

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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.

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Uses of radioactive isotopes

- ^{14}C (Carbon 14) – radioactive dating of organic material
- ^{238}U (Uranium-238) radioactive dating of geological formations
- ^{235}U (Uranium-235) and ^{239}Pu (Plutonium-239) Nuclear reactors and atomic bombs
- ^{131}I (Iodine-131) Detection and treatment of thyroid diseases
- ^{60}Co (Cobalt-60) Treatment of cancer

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Regents Question: 06/03 #39

Which isotope is most commonly used in the radioactive dating of the remains of organic materials?

☑ (1) ^{14}C

(2) ^{16}N

(3) ^{32}P

(4) ^{37}K

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Regents Questions 29 and 30 June 2011

Energy is released during the fission of Pu-239 atoms as a result of the

(1) formation of covalent bonds
(2) formation of ionic bonds
(3) conversion of matter to energy
(4) conversion of energy to matter

Atoms of I-131 spontaneously decay when the

(1) stable nuclei emit alpha particles
(2) stable nuclei emit beta particles
(3) unstable nuclei emit alpha particles
(4) unstable nuclei emit beta particles

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Regents Question #50 June 2011

Which balanced equation represents natural transmutation?

(1) $^{9}_{4}Be + ^{1}_{1}H \rightarrow ^{6}_{3}Li + ^{4}_{2}He$

(2) $^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$

(3) $^{239}_{94}Pu + ^{1}_{0}n \rightarrow ^{144}_{58}Ce + ^{94}_{36}Kr + 2^{1}_{0}n$

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

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Jan 2011 #28-30

What is one benefit associated with a nuclear fission reaction?

(1) The products are not radioactive.
(2) Stable isotopes are used as reactants.
(3) There is no chance of biological exposure.
(4) A large amount of energy is produced.

Which balanced equation represents a fusion reaction?

(1) ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{93}_{36}\text{Kr} + {}^{140}_{56}\text{Ba} + 3{}^{1}_{0}\text{n}$

(2) ${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n}$

(3) ${}^{14}_{7}\text{N} + {}^{4}_{2}\text{He} \rightarrow {}^{17}_{8}\text{O} + {}^{1}_{1}\text{H}$

(4) ${}^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$

Which radioisotope emits alpha particles?

(1) Fe-53
(2) Sr-90
(3) Au-198
(4) Pu-239

Other uses of radioactive isotopes

- Radiation therapy
  - gamma rays kill cancer cells
- Irradiated food
  - gamma rays kill bacteria
- Radioactive tracers
  - Use a radioactive isotope in a chemical reaction or biological process and determine where that atom ends up at the end of the reaction.

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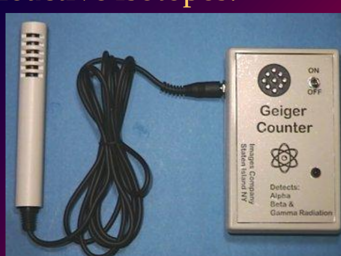
A Geiger Counter can be used to detect radiation given off by radioactive isotopes.



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