THE BIG IDEA

Certain elements radiate particles and turn into other elements.

The idea that atoms are indivisible changed in 1896 when the French physicist Henri Becquerel discovered that some unused photographic plates had been exposed by particles coming from a piece of uranium. Understanding how atoms can change requires looking deep into the structure of the atom—into the atomic nucleus.

39.1 The Atomic Nucleus

The principal role of the neutrons in an atomic nucleus is to act as a sort of nuclear cement to hold the nucleus together.

39.1 The Atomic Nucleus

It would take 30,000 carbon nuclei to stretch across a single carbon atom.

The nucleus is composed of particles called **nucleons**—electrically charged protons and electrically neutral neutrons.

Neutrons and protons have close to the same mass, with the neutron's being slightly greater.

Nucleons have nearly 2000 times the mass of electrons. The mass of an atom is practically equal to the mass of its nucleus alone.

39.1 The Atomic Nucleus

The positively charged protons in the nucleus hold the negatively charged electrons in their orbits.

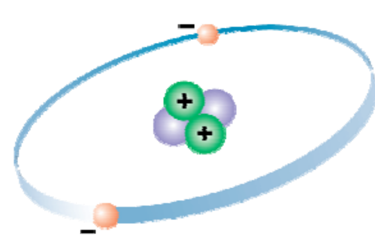
The number of protons in the nucleus therefore determines the chemical properties of that atom.

The positive nuclear charge determines the possible structures of electron orbits that can occur.

The number of neutrons has no direct effect on the electron structure, and hence does not affect the chemistry of the atom.

39.1 The Atomic Nucleus

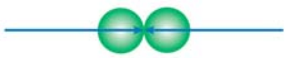
The number of electrons that surround the atomic nucleus is matched by the number of protons in the nucleus.



39.1 The Atomic Nucleus

Nucleons are bound together by an attractive nuclear force appropriately called the **strong force.**

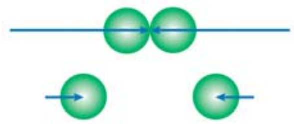
- The nuclear force of attraction is strong only over a very short distance (large force vectors).



39.1 The Atomic Nucleus

Nucleons are bound together by an attractive nuclear force appropriately called the **strong force.**

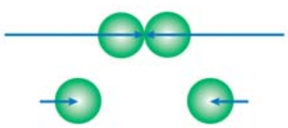
- The nuclear force of attraction is strong only over a very short distance (large force vectors).
- When two nucleons are just a few nucleon diameters apart, the nuclear force they exert on each other is nearly zero (small force vectors).



39.1 The Atomic Nucleus

Nucleons are bound together by an attractive nuclear force appropriately called the **strong force.**

- The nuclear force of attraction is strong only over a very short distance (large force vectors).
- When two nucleons are just a few nucleon diameters apart, the nuclear force they exert on each other is nearly zero (small force vectors).
- This means that if nucleons are to be held together by the strong force, they must be held in a very small volume.
- Nuclei are tiny because the nuclear force is very short-range.



39.1 The Atomic Nucleus

Meanwhile, the electrical force acts as a repulsive force between protons that are not in direct contact with one another.

Stability is due to a tension between the strong force's tendency to hold the nucleus together and the electrical force's tendency to blow it apart.

A nucleus needs a certain balance of neutrons and protons for stability.

39.1 The Atomic Nucleus

Although the nuclear force is strong, it is only barely strong enough to hold a pair of nucleons together.

- For a pair of protons, which repel each other electrically, the nuclear force is not quite strong enough to keep them together.
- When neutrons are present, the attractive strong force is increased relative to the repulsive electrical force.
- The presence of neutrons adds to the nuclear attraction and keeps protons from flying apart.

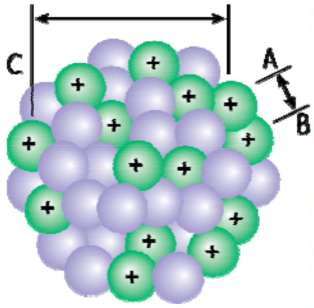
39.1 The Atomic Nucleus

The more protons there are in a nucleus, the more neutrons are needed to hold them together.

- For light elements, it is sufficient to have about as many neutrons as protons.
- For heavy elements, extra neutrons are required.
- For elements with more than 83 protons, even the addition of extra neutrons cannot completely stabilize the nucleus.

39.1 The Atomic Nucleus

A strong attractive nuclear force acts between nearby protons A and B, but not significantly between A and C. The longer-range electrical force repels protons A and C as well as A and B.



39.1 The Atomic Nucleus

CONCEPT CHECK **What is the role of neutrons in the nucleus?**

39.2 Radioactive Decay

The atoms of radioactive elements emit three distinct types of radiation called *alpha particles*, *beta particles*, and *gamma rays*.

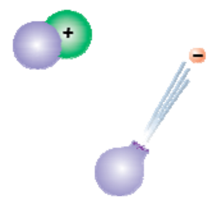
39.2 Radioactive Decay

One factor that limits how many stable nuclei can exist is the instability of the neutron.

A lone neutron will decay into a proton plus an electron (and also an antineutrino, a tiny particle we will not discuss here).

About half of a bunch of lone neutrons will decay in 11 minutes.

Particles that decay by spontaneously emitting charged particles and energy are said to be **radioactive.**



39.2 Radioactive Decay

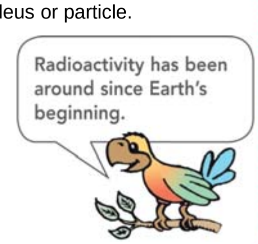
Radioactivity is governed by mass-energy equivalence.

- Particles decay spontaneously only when their combined products have less mass after decay than before.
- The mass of a neutron is slightly greater than the total mass of a proton plus electron (and the antineutrino).
- When a neutron decays, there is less mass.
- Decay will not spontaneously occur for reactions where more mass results. A proton decaying into a neutron can occur only with external energy input.

39.2 Radioactive Decay

All elements heavier than bismuth (atomic number 83) decay in one way or another, so these elements are radioactive.

Radiation is the name given to the charged particles and energy emitted by an unstable nucleus or particle.



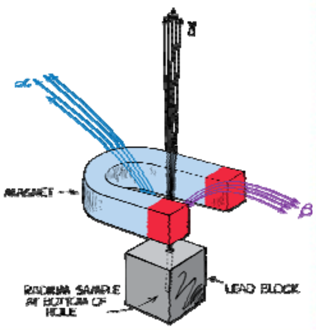
39.2 Radioactive Decay

The atoms of radioactive elements emit three distinct types of radiation called *alpha particles*, *beta particles*, and *gamma rays*.

- alpha particles have a positive electric charge
- beta particles are negative
- gamma rays are electrically neutral

39.2 Radioactive Decay

A magnetic field separates alpha and beta particles and gamma rays, all of which come from a radioactive source placed at the bottom of a hole drilled in a lead block.

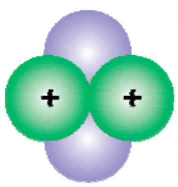


39.2 Radioactive Decay

An alpha particle is made of two protons and two neutrons and is identical to the nucleus of a helium atom.

A beta particle is simply an electron ejected from the nucleus when a neutron is transformed into a proton.

An electron does not exist in a neutron. The electron that pops out of the neutron is produced during an interaction.



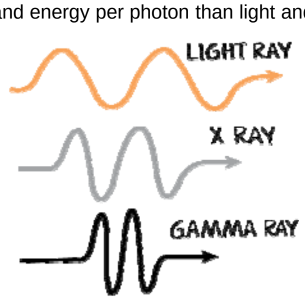
39.2 Radioactive Decay

A gamma ray is massless energy. Like visible light, gamma rays are simply photons, but of much higher frequency and energy.

- Visible light is emitted when electrons jump from one atomic orbit to another of lower energy.
- Gamma rays are emitted when nucleons do a similar sort of thing inside the nucleus.
- There are great energy differences in nuclear energy levels, so the photons emitted carry a large amount of energy.

39.2 Radioactive Decay

A gamma ray is simply electromagnetic radiation, much higher in frequency and energy per photon than light and X-rays.



39.2 Radioactive Decay

think!

The electrical force of repulsion between the protons in a heavy nucleus acts over a greater distance than the attractive forces among the neutrons and protons in the nucleus. Given this fact, explain why all of the very heavy elements are radioactive.

39.2 Radioactive Decay

think!

The electrical force of repulsion between the protons in a heavy nucleus acts over a greater distance than the attractive forces among the neutrons and protons in the nucleus. Given this fact, explain why all of the very heavy elements are radioactive.

Answer:

In a large nucleus, where protons such as those on opposite sides are far apart, electrical repulsion can exceed nuclear attraction. This instability makes all the heaviest atoms radioactive.

39.2 Radioactive Decay

CONCEPT CHECK **What types of radiation are emitted by the atoms of radioactive elements?**

39.3 Radiation Penetrating Power

The penetrating power of radiation depends on its speed and its charge.

39.3 Radiation Penetrating Power

There is a great difference in the penetrating power of the three types of radiation.

- Alpha particles are the easiest to stop. They can be stopped by a few sheets of thin paper.
- Beta particles go right through paper but are stopped by several sheets of aluminum foil.
- Gamma rays are the most difficult to stop and require lead or other heavy shielding to block them.

39.3 Radiation Penetrating Power

Alpha particles penetrate least and can be stopped by a few sheets of paper;

beta particles by a sheet of aluminum; gamma rays by a thick layer of lead.

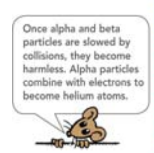
39.3 Radiation Penetrating Power

An alpha particle is easy to stop because it is relatively slow and its charge interacts with the molecules it encounters along its path.

It slows down as it shakes many of these molecules apart and leaves positive and negative ions in its wake.

Even when traveling through nothing but air, an alpha particle will come to a stop after only a few centimeters.

It soon grabs up a couple of stray electrons and becomes nothing more than a harmless helium atom.



39.3 Radiation Penetrating Power

A beta particle normally moves at a faster speed than an alpha particle and carries only a single negative charge.

It is able to travel much farther through the air.

Most beta particles lose their energy during the course of a large number of glancing collisions with atomic electrons.

Beta particles slow down until they become a part of the material they are in, like any other electron.

39 The Atomic Nucleus and Radioactivity
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39.3 Radiation Penetrating Power

Gamma rays are the most penetrating of the three because they have no charge.

A gamma ray photon interacts with the absorbing material only via a direct hit with an atomic electron or a nucleus.

Unlike charged particles, a gamma ray photon can be removed from its beam in a single encounter.

Dense materials such as lead are good absorbers mainly because of their high electron density.

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39.3 Radiation Penetrating Power

think!

Pretend you are given three radioactive cookies—one alpha, one beta, and the other gamma. Pretend that you must eat one, hold one in your hand, and put the other in your pocket. Which would you eat, hold, and pocket if you were trying to minimize your exposure to radiation?

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39.3 Radiation Penetrating Power

think!

Pretend you are given three radioactive cookies—one alpha, one beta, and the other gamma. Pretend that you must eat one, hold one in your hand, and put the other in your pocket. Which would you eat, hold, and pocket if you were trying to minimize your exposure to radiation?

Answer:

If you must, then hold the alpha; the skin on your hand will shield you. Put the beta in your pocket; your clothing will likely shield you. Eat the gamma; it will penetrate your body anyway. (In real life, always use appropriate safeguards when near radioactive materials.)

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39.3 Radiation Penetrating Power

CONCEPT CHECK

What factors determine the penetrating power of radiation?

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39.4 Radioactive Isotopes

Isotopes of an element are chemically identical but differ in the number of neutrons.

39.4 Radioactive Isotopes

In a neutral atom, the number of protons in the nucleus determines the number of electrons surrounding the nucleus.

39.4 Radioactive Isotopes

In a neutral atom, the number of protons in the nucleus determines the number of electrons surrounding the nucleus.

If there is a difference in the number of electrons and protons, the atom is charged and is called an *ion.*

An ionized atom is one that has a different number of electrons than nuclear protons.

39.4 Radioactive Isotopes

The number of neutrons has no bearing on the number of electrons the atom may have or on the chemistry of an atom.

The common form of hydrogen has a bare proton as its nucleus.

There can be different kinds, or *isotopes*, of hydrogen, however, because there can be different numbers of neutrons in the nucleus.

An **isotope** is a form of an element having a particular number of neutrons in the nuclei of its atoms.

39.4 Radioactive Isotopes

In one isotope of hydrogen, the nucleus consists of a single proton.

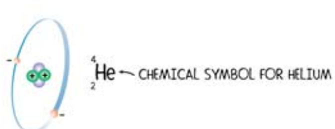
In a second isotope of hydrogen, the proton is accompanied by a neutron.

In a third isotope of hydrogen, there are two neutrons.

All the isotopes of hydrogen are chemically identical. The orbital electrons are affected only by the positive charge in the nucleus.

39.4 Radioactive Isotopes

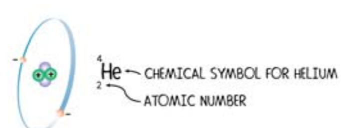
We distinguish between the different isotopes of hydrogen with the symbols $^1_1\mathbf{H}$, $^2_1\mathbf{H}$, and $^3_1\mathbf{H}$.



39.4 Radioactive Isotopes

We distinguish between the different isotopes of hydrogen with the symbols $^1_1\mathbf{H}$, $^2_1\mathbf{H}$, and $^3_1\mathbf{H}$.

The lower number in each notation is the **atomic number** or the number of protons.

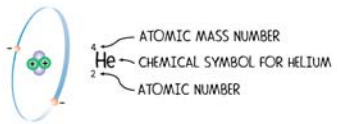


39.4 Radioactive Isotopes

We distinguish between the different isotopes of hydrogen with the symbols ^1_1H, ^2_1H, and ^3_1H.

The lower number in each notation is the **atomic number** or the number of protons.

The upper number is the **atomic mass number** or the total number of nucleons in the nucleus.



39.4 Radioactive Isotopes

The common isotope of hydrogen, ^1_1H, is a stable element.

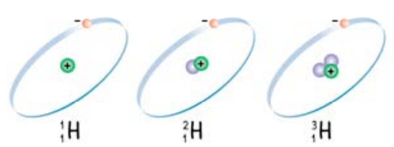
The isotope ^2_1H, called *deuterium,* is also stable.

The triple-weight hydrogen isotope ^3_1H, called *tritium,* however, is unstable and undergoes beta decay.

This is the radioactive isotope of hydrogen.

39.4 Radioactive Isotopes

The three isotopes of hydrogen have different numbers of neutrons in the nucleus. The varying number of neutrons changes the mass of the atom, but not its chemical properties.



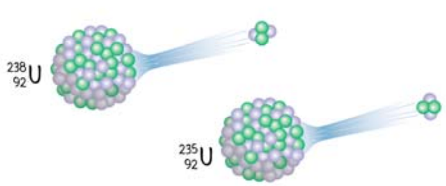
39.4 Radioactive Isotopes

The common isotope of uranium is $^{238}_{92}U$, or U-238 for short.

- It has 92 protons and 146 neutrons in its nucleus.
- It is radioactive, with a smaller decay rate than $^{235}_{92}U$, or U-235, with 92 protons and 143 neutrons in its nucleus.
- Any nucleus with 92 protons is uranium, by definition.
- Nuclei with 92 protons but different numbers of neutrons are simply different isotopes of uranium.

39.4 Radioactive Isotopes

All isotopes of uranium are unstable and undergo radioactive decay.



39.4 Radioactive Isotopes

think!

The nucleus of beryllium-8, ^8_4Be, undergoes a special kind of radioactive decay: it splits into two equal halves. What nuclei are the products of this decay? Why is this a form of alpha decay?

39.4 Radioactive Isotopes

think!

The nucleus of beryllium-8, $^{8}_{4}Be$, undergoes a special kind of radioactive decay: it splits into two equal halves. What nuclei are the products of this decay? Why is this a form of alpha decay?

Answer:

When beryllium-8 splits into equal halves, a pair of nuclei with 2 protons and 2 neutrons is created. These are nuclei of helium-4, $^{4}_{2}He$, also called alpha particles. So this reaction is a form of alpha decay.

39.4 Radioactive Isotopes

CONCEPT CHECK

How are the isotopes of an element similar? How do they differ?

39.5 Radioactive Half-Life

Rates of radioactive decay appear to be absolutely constant, unaffected by any external conditions.

39.5 Radioactive Half-Life

Since some radioactive nuclei are more stable than others, they decay at different rates.

A relatively stable isotope will decay slowly, while an unstable isotope will decay in a shorter period of time.

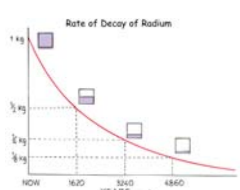
The radioactive decay rate is measured in terms of a characteristic time, the *half-life.*

The **half-life** of a radioactive material is the time needed for half of the radioactive atoms to decay.

39.5 Radioactive Half-Life

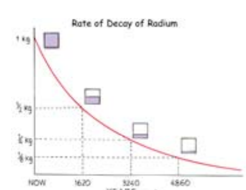
Graphing Decay Rates

Radium-226, for example, has a half-life of 1620 years.



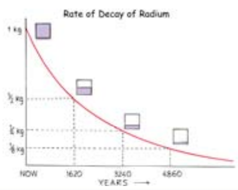
39.5 Radioactive Half-Life

- This means that half of any given specimen of Ra-226 will have undergone decay by the end of 1620 years.
- In the next 1620 years, half of the remaining radium decays, leaving only one fourth the original of radium atoms.



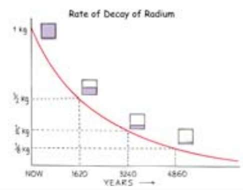
39.5 Radioactive Half-Life

- The rest are converted, by a succession of disintegrations, to lead.



39.5 Radioactive Half-Life

- After 20 half-lives, an initial quantity of radioactive atoms will be diminished to about one millionth of the original quantity.



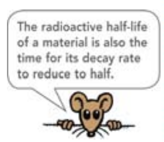
39.5 Radioactive Half-Life

The isotopes of some elements have a half-life of less than a millionth of a second.

U-238 has a half-life of 4.5 billion years.

Each isotope of a radioactive element has its own characteristic half-life.

Rates of radioactive decay appear to be absolutely constant, unaffected by any external conditions.



39.5 Radioactive Half-Life

Constancy of Decay Rates

High or low pressures, high or low temperatures, strong magnetic or electric fields, and even violent chemical reactions have no detectable effect on the rate of decay of an element.

Any of these stresses, however severe by ordinary standards, is far too mild to affect the nucleus deep in the interior of the atom.

39.5 Radioactive Half-Life

Measuring Decay Rates

The half-life is determined by calculating the number of atoms in a sample and the rate at which the sample decays.

The half-life of an isotope is related to its rate of disintegration.

The shorter the half-life of a substance, the faster it disintegrates, and the more active is the substance.

The half-life can be computed from the rate of disintegration, which can be measured in the laboratory.

39.5 Radioactive Half-Life

a. A Geiger counter detects incoming radiation by its ionizing effect on enclosed gas in the tube.

a

39.5 Radioactive Half-Life

a. A Geiger counter detects incoming radiation by its ionizing effect on enclosed gas in the tube.

b. Lab workers wear film badges to measure their accumulated radiation exposure.

a b

39.5 Radioactive Half-Life

think!

If a sample of a radioactive isotope has a half-life of 1 year, how much of the original sample will be left at the end of the second year? What happens to the rest of the sample?

39.5 Radioactive Half-Life

think!

If a sample of a radioactive isotope has a half-life of 1 year, how much of the original sample will be left at the end of the second year? What happens to the rest of the sample?

Answer:

One quarter of the original sample will be left. The three quarters that underwent decay became other elements.

39.5 Radioactive Half-Life

CONCEPT CHECK **How do external conditions affect rates of radioactive decay?**

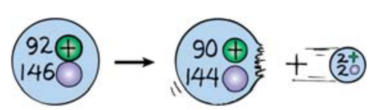
39.6 Natural Transmutation of Elements

When a radioactive isotope undergoes alpha or beta decay, it changes to an isotope of a different element.

39.6 Natural Transmutation of Elements

The changing of one element to another is called **transmutation.** Consider common uranium.

- Uranium-238 has 92 protons and 146 neutrons. The nucleus loses two protons and two neutrons—an alpha particle.
- The 90 protons and 144 neutrons left behind are the nucleus of a new element.
- This element is *thorium.*



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

39.6 Natural Transmutation of Elements

Alpha Decay

An arrow is used to show that the $^{238}_{92}U$ changes into the other elements.

Energy is released in three forms: gamma radiation, kinetic energy of the alpha particle, and kinetic energy of the thorium atom.

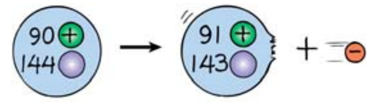
In the nuclear equation, the mass numbers at the top balance and the atomic numbers at the bottom also balance.

39.6 Natural Transmutation of Elements

Beta Decay

Thorium-234 is also radioactive.

- When it decays, it emits a beta particle, an electron ejected from the nucleus.
- When a beta particle is ejected, a neutron changes into a proton.
- The new nucleus then has 91 protons and is no longer thorium.
- It is the element *protactinium.*



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

39.6 Natural Transmutation of Elements

The atomic number has increased by 1 in this process but the mass number remains the same.

The beta particle (electron) is written as $^{0}_{-1}e$.

- The -1 is the charge of the electron.
- The 0 indicates that its mass is insignificant when compared with the mass of nucleons.
- Beta emission has hardly any effect on the mass of the nucleus; only the charge changes.

39.6 Natural Transmutation of Elements

Transmutation and the Periodic Table

When an atom ejects an alpha particle, the mass number of the resulting atom decreases by 4, and the atomic number by 2. The resulting atom belongs to an element two spaces back in the periodic table.

When an atom ejects a beta particle from its nucleus, it loses no nucleons, its atomic number *increases* by 1. The resulting atom belongs to an element one place forward in the periodic table.

Thus, radioactive elements decay backward or forward in the periodic table.

39.6 Natural Transmutation of Elements

A nucleus may emit gamma radiation along with an alpha particle or a beta particle.

Gamma emission does not affect the mass number or the atomic number.

39.6 Natural Transmutation of Elements

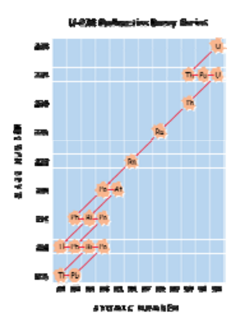
Radioactive Decay Series

The radioactive decay of $^{238}_{92}U$ to an isotope of lead, $^{206}_{82}Pb$, occurs in steps.

On a graph of the decay series, each arrow that slants downward toward the left shows an alpha decay.

Each arrow that points to the right shows a beta decay.

Some of the nuclei in the series can decay either way.



39.6 Natural Transmutation of Elements

think!

Complete the following nuclear reactions.

a. $^{228}_{88}\text{Ra} \rightarrow ^{?}_{?}? + ^{0}_{-1}e$

b. $^{209}_{84}\text{Po} \rightarrow ^{205}_{82}\text{Pb} + ^{?}_{?}?$

39.6 Natural Transmutation of Elements

think!

Complete the following nuclear reactions.

a. $^{228}_{88}\text{Ra} \rightarrow ^{?}_{?}? + ^{0}_{-1}e$

b. $^{209}_{84}\text{Po} \rightarrow ^{205}_{82}\text{Pb} + ^{?}_{?}?$

Answer:

a. $^{228}_{88}\text{Ra} \rightarrow ^{228}_{89}\text{Ac} + ^{0}_{-1}e$

b. $^{209}_{84}\text{Po} \rightarrow ^{205}_{82}\text{Pb} + ^{4}_{2}\text{He}$

39.6 Natural Transmutation of Elements

think!

What finally becomes of all the uranium-238 that undergoes radioactive decay?

39.6 Natural Transmutation of Elements

think!

What finally becomes of all the uranium-238 that undergoes radioactive decay?

Answer:

All the uranium-238 will ultimately become lead. On the way to becoming lead, it will exist as a series of other elements.

39.6 Natural Transmutation of Elements

CONCEPT CHECK

How is the chemical identity of a radioactive isotope affected by alpha or beta decay?

39.7 Artificial Transmutation of Elements

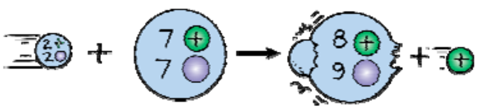
The elements beyond uranium in the periodic table—the *transuranic* elements—have been produced through artificial transmutation.

39.7 Artificial Transmutation of Elements

New Zealander Ernest Rutherford, in 1919, was the first physicist to succeed in artificially transmuting a chemical element.

He bombarded nitrogen nuclei with alpha particles and found traces of oxygen and hydrogen that were not there before.

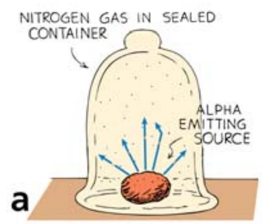
Rutherford accounted for the presence of the oxygen and hydrogen with the nuclear equation



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

39.7 Artificial Transmutation of Elements

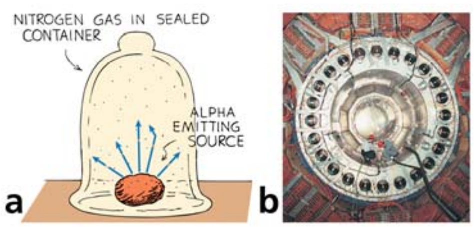
a. When nitrogen gas is exposed to alpha particles, some of the nitrogen becomes oxygen and hydrogen.



39.7 Artificial Transmutation of Elements

a. When nitrogen gas is exposed to alpha particles, some of the nitrogen becomes oxygen and hydrogen.

b. A particle accelerator's high energies easily transmute elements.



39.7 Artificial Transmutation of Elements

Many such nuclear reactions followed—first with natural bombarding particles from radioactive elements.

Later, scientists used more energetic particles hurled by giant atom-smashing particle accelerators.

The elements beyond uranium in the periodic table have been produced through artificial transmutation.

These elements have half-lives much less than the age of Earth.

39.7 Artificial Transmutation of Elements

CONCEPT CHECK

Which elements have been produced through artificial transmutation?

39.8 Carbon Dating

Scientists can figure out how long ago a plant or animal died by measuring the ratio of carbon-14 to carbon-12 in the remains.

39.8 Carbon Dating

Earth's atmosphere is continuously bombarded by *cosmic rays*—mainly high-energy protons—from beyond Earth.

This results in the transmutation of atoms in the upper atmosphere.

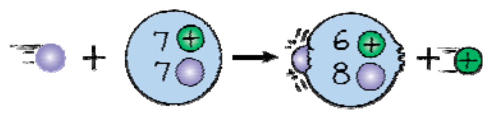
Protons quickly capture stray electrons and become hydrogen atoms in the upper atmosphere.

39.8 Carbon Dating

Neutrons keep going for long distances because they have no charge and do not interact electrically with matter.

Many of them collide with the nuclei of atoms in the lower atmosphere.

When nitrogen-14 is hit by a neutron (^1_0n), carbon-14 and hydrogen are produced.



$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{14}_{6}C + ^{1}_{1}H$$

39.8 Carbon Dating

Most of the carbon that exists on Earth is stable carbon-12.

In the air, it appears mainly in the compound carbon dioxide.

Because of the cosmic bombardment, less than one-millionth of 1% of the carbon in the atmosphere is carbon-14.

Like carbon-12, it joins with oxygen to form carbon dioxide, which is taken in by plants.

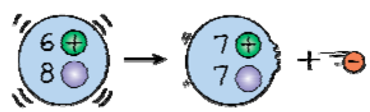
39.8 Carbon Dating

All plants have a tiny bit of radioactive carbon-14 in them.

All living things contain some carbon-14.

The ratio of carbon-14 to carbon-12 in living things is the same as the ratio of carbon-14 to carbon-12 in the atmosphere.

Carbon-14 is a beta emitter and decays back into nitrogen.



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

39.8 Carbon Dating

In a living plant, a radioactive equilibrium is reached where there is a fixed ratio of carbon-14 to carbon-12.

When a plant or animal dies, it stops taking in carbon-14 from the environment.

Then the percentage of carbon-14 decreases—at a known rate.

The longer an organism has been dead, the less carbon-14 that remains.

39.8 Carbon Dating

Scientists can find how long ago a plant or animal died by measuring the ratio of carbon-14 to carbon-12 in the remains.

The half-life of carbon-14 is 5730 years.

Half of the carbon-14 atoms that are now present in the remains of a body, plant, or tree will decay in the next 5730 years.

The radioactivity of once-living things gradually decreases at a predictable rate.

39.8 Carbon Dating

The radioactive carbon isotopes in the skeleton diminish by one half every 5730 years. The red arrows symbolize relative amounts of carbon-14.

39.8 Carbon Dating

Archeologists use the carbon-14 dating technique to establish the dates of wooden artifacts and skeletons.

Because of fluctuations in the production of carbon-14 through the centuries, this technique gives an uncertainty of about 15%.

For many purposes, this is an acceptable level of uncertainty.

If greater accuracy is desired, then other techniques must be employed.

39.8 Carbon Dating

think!

A gram of carbon from an ancient bone measures between 7 and 8 beta emissions per minute. A gram of carbon extracted from a fresh piece of bone gives off 15 betas per minute. Estimate the age of the ancient bone. Now suppose the carbon sample from the ancient bone were only one fourth as radioactive as a gram of carbon from new bone. Estimate the age of the ancient bone.

39.8 Carbon Dating

think!

A gram of carbon from an ancient bone measures between 7 and 8 beta emissions per minute. A gram of carbon extracted from a fresh piece of bone gives off 15 betas per minute. Estimate the age of the ancient bone. Now suppose the carbon sample from the ancient bone were only one fourth as radioactive as a gram of carbon from new bone. Estimate the age of the ancient bone.

Answer:

Since beta emission for the first old sample is one half that of the fresh sample, about one half-life has passed, 5730 years. In the second case, the ancient bone is two half-lives of carbon-14 or about 11,460 years old.

39.8 Carbon Dating

CONCEPT CHECK

How can scientists determine the age of carbon-containing artifacts?

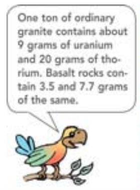
39.9 Uranium Dating

The dating of very old, nonliving things is accomplished with radioactive minerals, such as uranium.

39.9 Uranium Dating

The naturally occurring isotopes U-238 and U-235 decay very slowly and ultimately become isotopes of lead.

- U-238 decays through several stages to become Pb-206.
- U-235 finally becomes the isotope Pb-207.
- Most of the lead isotopes 206 and 207 that exist were at one time uranium.
- The older the uranium-bearing rock, the higher the percentage of these lead isotopes.



39.9 Uranium Dating

You can calculate the age of a rock from the half-lives of the uranium isotopes and the percentage of lead isotopes in the rock.

Rocks dated in this way have been found to be as much as 3.7 billion years old.

Samples from the moon, where there has been less obliteration of early rocks than on Earth, have been dated at 4.2 billion years.

39.9 Uranium Dating

CONCEPT CHECK **How do scientists date very old, nonliving things?**

39.10 Radioactive Tracers

Scientists can analyze biological or mechanical processes using small amounts of radioactive isotopes as tracers.

39.10 Radioactive Tracers

Radioactive isotopes of the elements have been produced by bombarding the elements with neutrons and other particles.

These isotopes are inexpensive, quite available, and very useful in scientific research and industry.

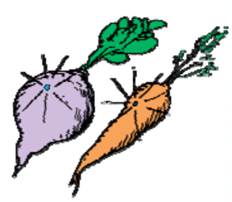
Scientists can analyze biological or mechanical processes using small amounts of radioactive isotopes as tracers.

39.10 Radioactive Tracers

For example, researchers mix a small amount of radioactive isotopes with fertilizer before applying it to growing plants.

Once the plants are growing, the amount of fertilizer taken up by the plant can be easily measured with radiation detectors.

From such measurements, researchers can tell farmers the proper amount of fertilizer to use.



39.10 Radioactive Tracers

Tracers are used in medicine to study the process of digestion and the way in which chemicals move about in the body.

Food containing a tiny amount of a radioactive isotope is fed to a patient.

The paths of the tracers in the food are then followed through the body with a radiation detector.

39.10 Radioactive Tracers

There are hundreds more examples of the use of radioactive isotopes.

- Radioactive isotopes can prevent food from spoiling quickly by killing the microorganisms that normally lead to spoilage.

39.10 Radioactive Tracers

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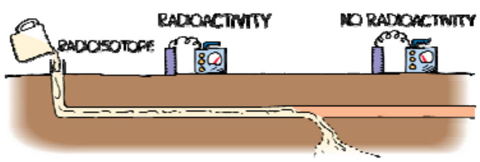
- Radioactive isotopes can also be used to trace leaks in pipes.



39.10 Radioactive Tracers

There are hundreds more examples of the use of radioactive isotopes.

- Radioactive isotopes can prevent food from spoiling quickly by killing the microorganisms that normally lead to spoilage.
- Radioactive isotopes can also be used to trace leaks in pipes.
- Engineers study automobile engine wear by making the cylinder walls in the engine radioactive and measuring particles that wear away with a radiation detector.

39.10 Radioactive Tracers

The shelf life of fresh strawberries and other perishables is markedly increased when the food is subjected to gamma rays from a radioactive source.

39.10 Radioactive Tracers

CONCEPT CHECK **How can scientists use radioactive isotopes to analyze biological or mechanical processes?**

39.11 Radiation and You

Sources of natural radiation include cosmic rays, Earth minerals, and radon in the air.

39.11 Radiation and You

Radioactivity has been around longer than humans have.

- It is as much a part of our environment as the sun and the rain.
- It is what warms the interior of Earth and makes it molten.
- Radioactive decay inside Earth heats the water that spurts from a geyser or that wells up from a natural hot spring.
- Even the helium in a child's balloon is the result of radioactivity. Its nuclei are nothing more than alpha particles that were once shot out of radioactive nuclei.

39.11 Radiation and You

Sources of natural radiation include cosmic rays, Earth minerals, and radon in the air.

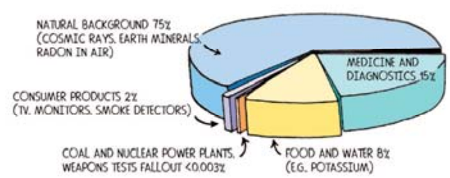
Radiation is in the ground you stand on, and in the bricks and stones of surrounding buildings.

Even the cleanest air we breathe is slightly radioactive.

If our bodies could not tolerate this natural background radiation, we wouldn't be here.

39.11 Radiation and You

The pie chart shows origins of radiation exposure for an average individual in the United States.



39.11 Radiation and You

Cosmic Rays

Much of the radiation we are exposed to is cosmic radiation streaming down through the atmosphere.

Most of the protons and other atomic nuclei that fly toward Earth from outer space are deflected away.

The atmosphere, acting as a protective shield, stops most of the rest.

39.11 Radiation and You

Some cosmic rays penetrate the atmosphere, mostly in the form of secondary particles such as muons.

Two round-trip flights between New York and San Francisco expose you to as much radiation as in a chest X-ray.

The air time of airline personnel is limited because of this extra radiation.

39.11 Radiation and You

Neutrinos

We are bombarded most by what harms us least—neutrinos.

- Neutrinos are the most weakly interacting of all particles.
- They have near-zero mass, no charge, and are produced frequently in radioactive decays.
- They are the most common high-speed particles known.
- About once per year on the average, a neutrino triggers a nuclear reaction in your body.
- We don't hear much about neutrinos because they ignore us.

39.11 Radiation and You

Gamma Rays

Of the types of radiation we have focused upon in this chapter, gamma radiation is by far the most dangerous.

It emanates from radioactive materials and makes up a substantial part of the normal background radiation.

39.11 Radiation and You

When gamma radiation encounters molecules in the body, it produces damage on the atomic scale.

These altered molecules are often harmful. Altered DNA molecules, for example, can produce harmful genetic mutations.

39.11 Radiation and You

Radiation Safety

Cells can repair most kinds of molecular damage if the radiation they are exposed to is not too intense.

On the other hand, people who work around high concentrations of radioactive materials must be protected to avoid an increased risk of cancer.

Whenever possible, exposure to radiation should be avoided.

39.11 Radiation and You

This is the internationally used symbol to indicate an area where radioactive material is being handled or produced.

39.11 Radiation and You

CONCEPT CHECK **What are sources of natural radiation?**

Assessment Questions

1. In the nucleus of an atom, the strong force is a relatively
   a. short-range force.
   b. long-range force.
   c. unstable force.
   d. neutralizing force.

39 The Atomic Nucleus and Radioactivity
Conceptual Physics

Assessment Questions

1. In the nucleus of an atom, the strong force is a relatively
   a. short-range force.
   b. long-range force.
   c. unstable force.
   d. neutralizing force.

Answer: A

Assessment Questions

2. Which of the following do electric or magnetic fields not deflect?
   a. alpha particles
   b. beta particles
   c. gamma rays
   d. Magnetic and electric fields deflect alpha particles, beta particles, and gamma rays.

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Conceptual Physics

Assessment Questions

2. Which of the following do electric or magnetic fields not deflect?
   a. alpha particles
   b. beta particles
   c. gamma rays
   d. Magnetic and electric fields deflect alpha particles, beta particles, and gamma rays.

Answer: C

Assessment Questions

3. Which of these is the most penetrating in common materials?
   a. alpha particles
   b. beta particles
   c. gamma rays
   d. all are equally penetrating

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Conceptual Physics

Assessment Questions

3. Which of these is the most penetrating in common materials?
   a. alpha particles
   b. beta particles
   c. gamma rays
   d. all are equally penetrating

Answer: C

Assessment Questions

4. Uranium-235, uranium-238, and uranium-239 are different
   a. elements.
   b. ions.
   c. isotopes.
   d. nucleons.

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Assessment Questions

4. Uranium-235, uranium-238, and uranium-239 are different
   a. elements.
   b. ions.
   c. isotopes.
   d. nucleons.

Answer: C

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Assessment Questions

5. The half-life of carbon-14 is about 5730 years. Which of the following statements about the amount of carbon present in your bones is accurate?
   a. The present amount of carbon in your bones will reduce to zero when you die.
   b. The present amount of carbon in your bones will reduce to zero in about 5730 years.
   c. The present amount of carbon in your bones will reduce to zero in 11,460 years.
   d. The present amount of carbon in your bones will never reach zero, as the amount of carbon will continue to decrease by half of the amount remaining.

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Assessment Questions

5. The half-life of carbon-14 is about 5730 years. Which of the following statements about the amount of carbon present in your bones is accurate?
   a. The present amount of carbon in your bones will reduce to zero when you die.
   b. The present amount of carbon in your bones will reduce to zero in about 5730 years.
   c. The present amount of carbon in your bones will reduce to zero in 11,460 years.
   d. The present amount of carbon in your bones will never reach zero, as the amount of carbon will continue to decrease by half of the amount remaining.

Answer: D

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Assessment Questions

6. A certain element emits 1 alpha particle, and its products then emit 2 beta particles in succession. The atomic number of the resulting element is changed by
   a. zero.
   b. minus 1.
   c. minus 2.
   d. minus 3.

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Assessment Questions

6. A certain element emits 1 alpha particle, and its products then emit 2 beta particles in succession. The atomic number of the resulting element is changed by
   a. zero.
   b. minus 1.
   c. minus 2.
   d. minus 3.

Answer: A

Assessment Questions

7. Atoms can
   a. only transmute into completely different atoms in nature.
   b. only transmute into completely different atoms in laboratories.
   c. transmute into completely different atoms in both nature and laboratories.
   d. never transmute into completely different atoms.

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Assessment Questions

7. Atoms can
   a. only transmute into completely different atoms in nature.
   b. only transmute into completely different atoms in laboratories.
   c. transmute into completely different atoms in both nature and laboratories.
   d. never transmute into completely different atoms.

Answer: C

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Assessment Questions

8. Carbon-14 is a radioactive isotope of carbon that is primarily produced by cosmic radiation in the
   a. atmosphere.
   b. food we eat.
   c. interior of Earth.
   d. fallout of nuclear bomb tests.

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Assessment Questions

8. Carbon-14 is a radioactive isotope of carbon that is primarily produced by cosmic radiation in the
   a. atmosphere.
   b. food we eat.
   c. interior of Earth.
   d. fallout of nuclear bomb tests.

Answer: A

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Assessment Questions

9. To date the age of the oldest materials, scientists turn to the radioactivity of
   a. carbon.
   b. uranium.
   c. lead.
   d. nitrogen.

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Assessment Questions

9. To date the age of the oldest materials, scientists turn to the radioactivity of
   a. carbon.
   b. uranium.
   c. lead.
   d. nitrogen.

Answer: B

Assessment Questions

10. Radioactive tracers
    a. are beneficial only in agriculture.
    b. are harmful when used to extend the shelf life of perishables.
    c. have broad and beneficial applications in many fields.
    d. are always harmful.

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Conceptual Physics

Assessment Questions

10. Radioactive tracers
    a. are beneficial only in agriculture.
    b. are harmful when used to extend the shelf life of perishables.
    c. have broad and beneficial applications in many fields.
    d. are always harmful.

Answer: C

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Assessment Questions

11. Most of the radiation in Earth's biosphere
    a. is the result of military activities.
    b. originates from nuclear power plants.
    c. occurs as natural background radiation.
    d. is in the form of cosmic rays.

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Assessment Questions

11. Most of the radiation in Earth's biosphere
    a. is the result of military activities.
    b. originates from nuclear power plants.
    c. occurs as natural background radiation.
    d. is in the form of cosmic rays.

Answer: C