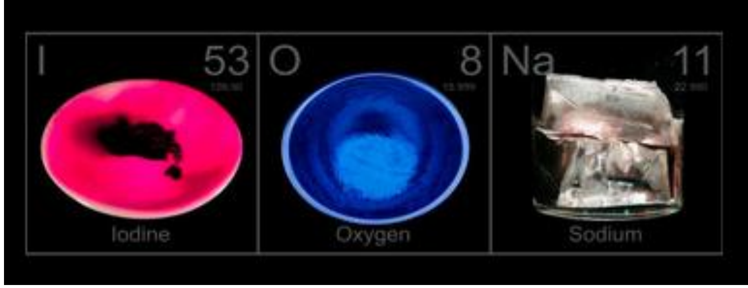
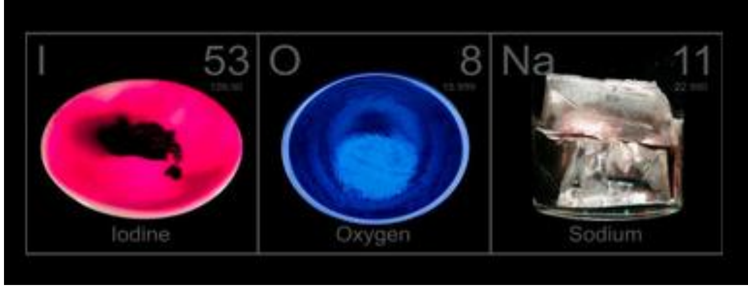
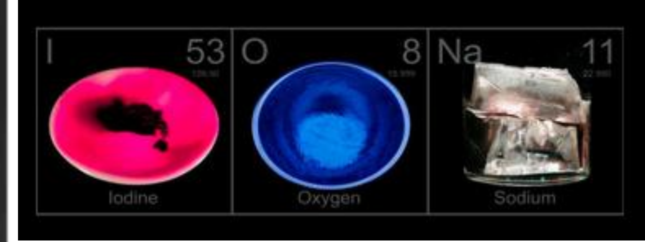


Nuclear Reactions

April 26 2011
SCH 4U1
Mr. Dvorsky

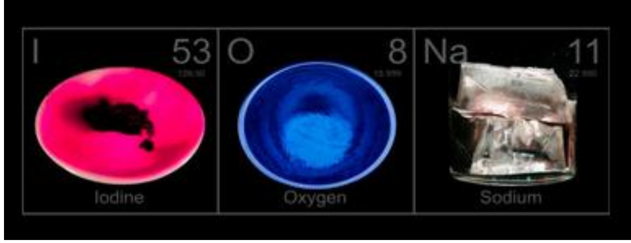


- Life on Earth is dependent on energy from the Sun.
- The Sun emits 3.8×10^{26} joules every second.
- How the Sun accomplishes this was a mystery to scientists for many years.
- Calculations showed that this could not be due to combustion or some normal chemical reaction – if so the Sun would have used up its fuel long ago.

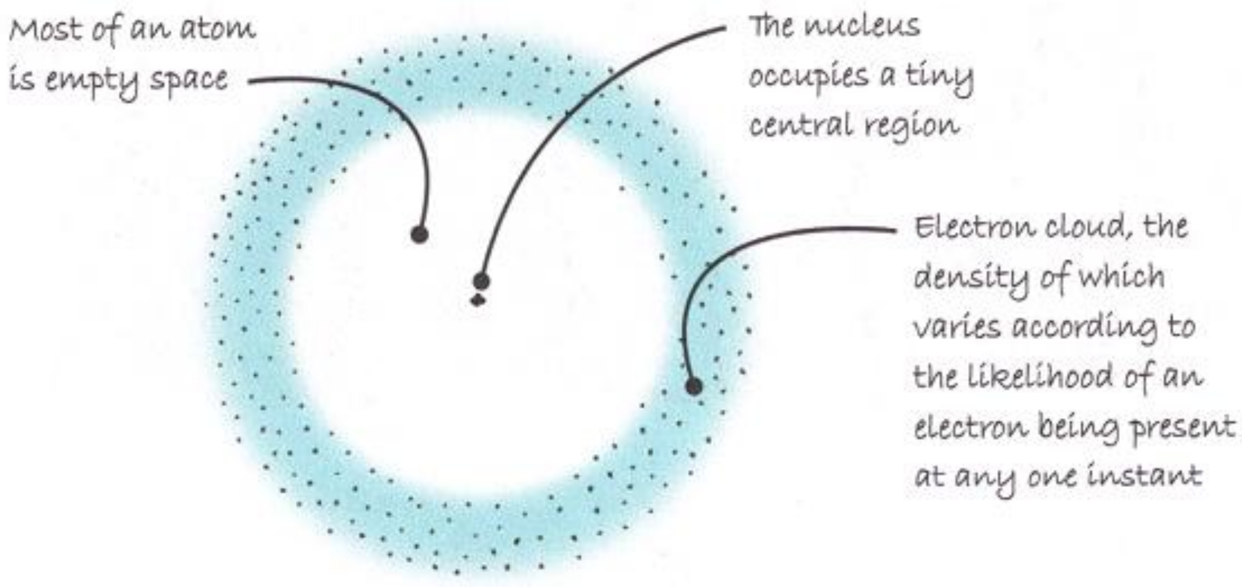


- Radioactivity was discovered by Henri Becquerel in 1896, thanks in large part to Rontgen discovering x-rays the year before
- Marie Sklodowska Curie isolated a radioactive element from uranium ores
- Rutherford studied the radioactive emissions and suggested there were several types.

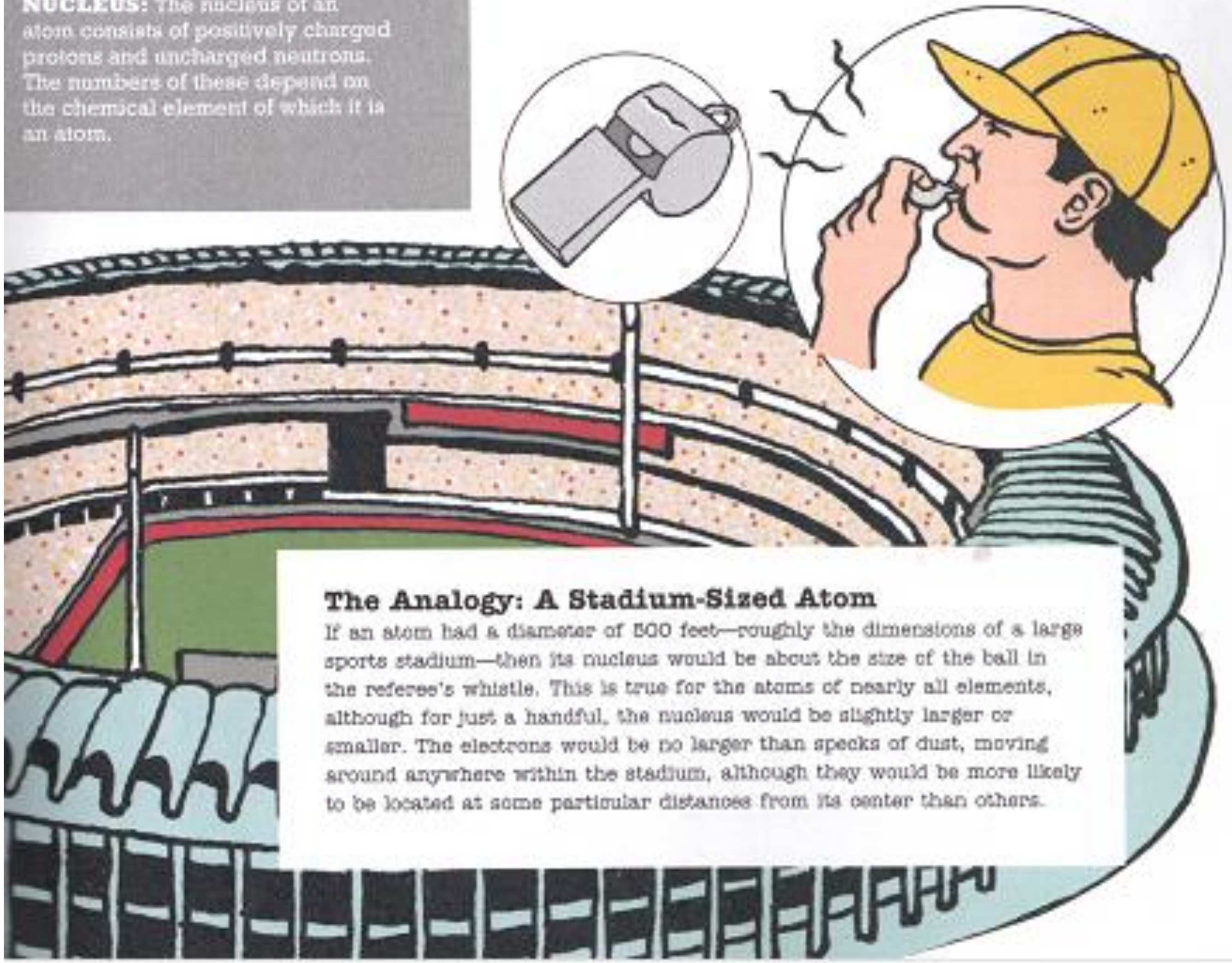
Some review...



Recall the modern model of the atom:

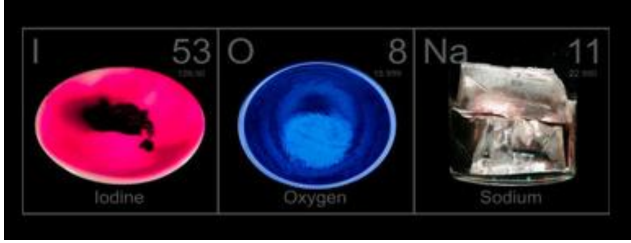


NUCLEUS: The nucleus of an atom consists of positively charged protons and uncharged neutrons. The numbers of these depend on the chemical element of which it is an atom.



The Analogy: A Stadium-Sized Atom

If an atom had a diameter of 500 feet—roughly the dimensions of a large sports stadium—then its nucleus would be about the size of the ball in the referee's whistle. This is true for the atoms of nearly all elements, although for just a handful, the nucleus would be slightly larger or smaller. The electrons would be no larger than specks of dust, moving around anywhere within the stadium, although they would be more likely to be located at some particular distances from its center than others.

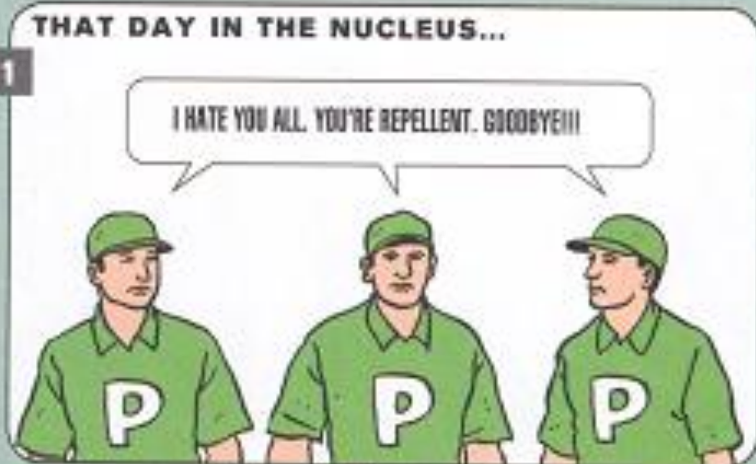


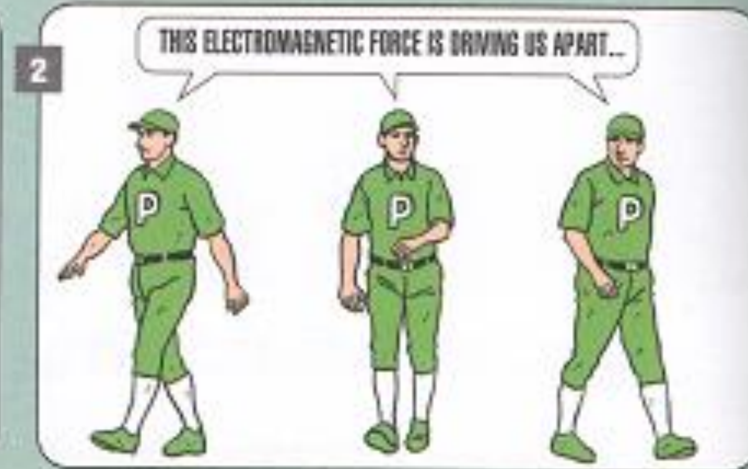
What Holds Atoms Together?

Electrons, being negatively charged, are held in atoms by electrostatic attraction toward the nucleus, which is positively charged because of the presence of protons. The nucleus itself is held together by the mighty nuclear force.

How is it that protons, which should not hang out together at close quarters, do so in the nucleus of every atom?

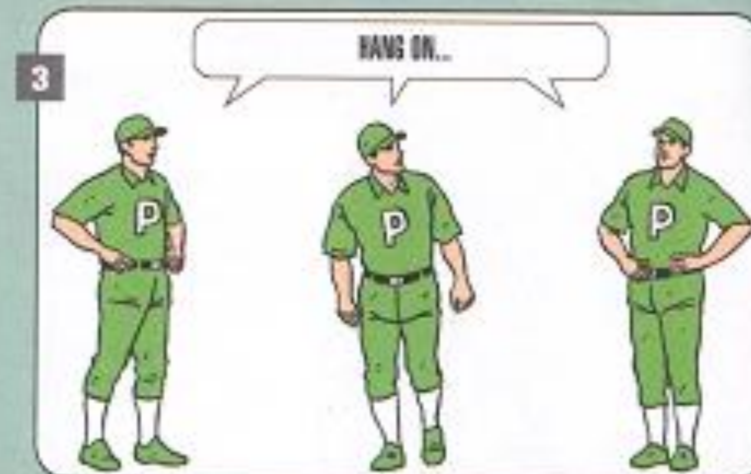
Inside an atomic nucleus, an intense conflict plays out between two powerful forces. These are the electromagnetic force—which causes like charges (such as protons) to repel and unlike charges to attract—and the nuclear force, which pulls protons and neutrons together. Normally, the nuclear force wins out...

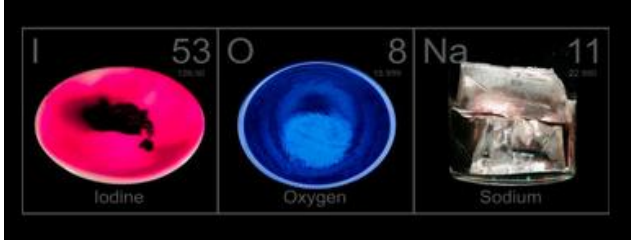




EFFECTS OF THE ELECTROMAGNETIC FORCE

Because the electromagnetic force causes like electrical charges (positive-positive or negative-negative) to repel, the positively charged protons in the nucleus are constantly pushing away from each other.





EFFECTS OF THE NUCLEAR FORCE

Fortunately, the even more powerful nuclear force overrides the electromagnetic force and pulls all the protons and neutrons together. If this didn't happen, the world as we know couldn't exist, because any atoms that formed would immediately break up. The nuclear force is closely linked to (some physicists consider it a "leakage" of) yet another force that operates inside protons and neutrons known as the "strong" force (see Composite Particles, page 23).

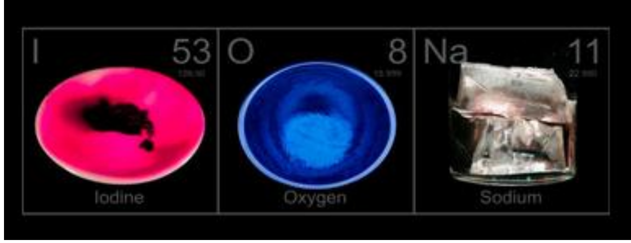
4

5

6

A LOVE-HATE RELATIONSHIP

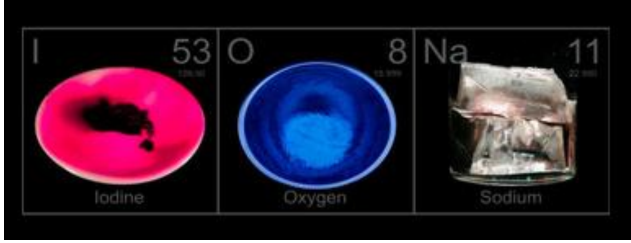
Thus, the protons and neutrons are held tightly in a compact ball. Most nuclei remain like this forever, or at least for billions of years. Only in a minority does the conflict between the electromagnetic and nuclear forces eventually cause the nucleus to break up, in what is called radioactive decay (see page 16).



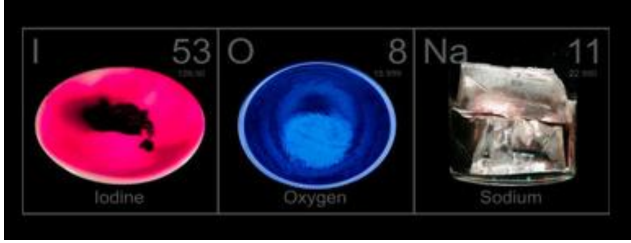
Radioactivity

Not all atoms are stable. While most are likely to last for hundreds of billions of years, some contain a particular combination of protons and neutrons in their nuclei that makes them unstable—this is because of conflicts between the forces operating inside the nuclei (see page 14). As a result, the nuclei of these atoms eventually disintegrate, or at least change in some way—in a process called radioactive decay.

Radioactive Decay

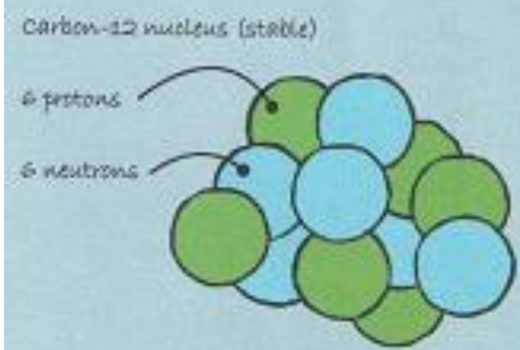


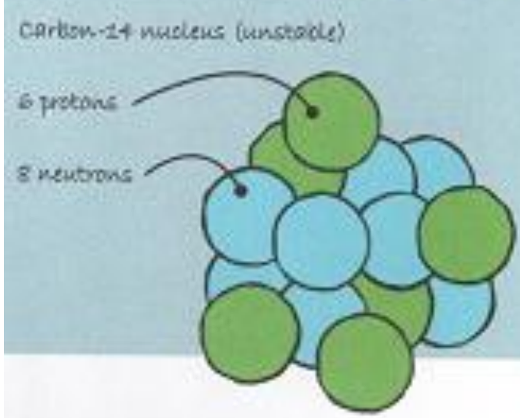
- Unstable atoms that are liable to undergo radioactive decay are called radioactive isotopes –isotopes being forms of chemical elements
- Most naturally occurring elements have several radioactive isotopes as well as one or more stable forms
- A few with particularly large atomic nuclei, such as uranium and radium exist only as radioactive isotopes

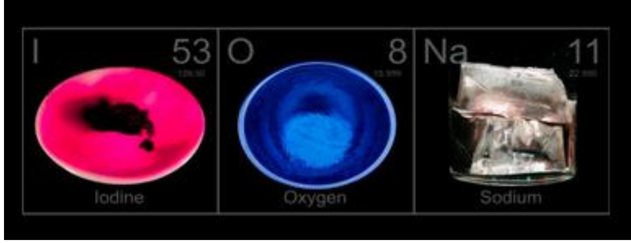


What are Isotopes?

Each chemical element can exist in a number of different forms called *isotopes*. These vary in having different numbers of neutrons in their atomic nuclei. Isotopes have names like oxygen-14 or lead-208—the number after the name of the element denotes the total number of protons and neutrons in the atomic nuclei of that isotope. Some isotopes are stable, others unstable. For example, carbon-12—by far the most common isotope of carbon—is stable, while carbon-14—a much less common isotope—is unstable and will eventually decay.

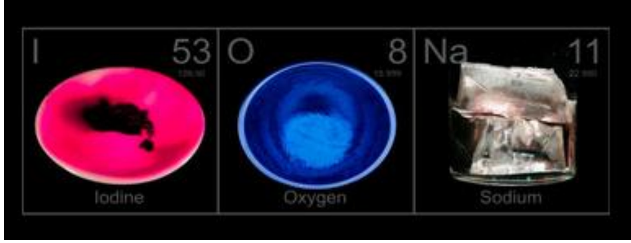






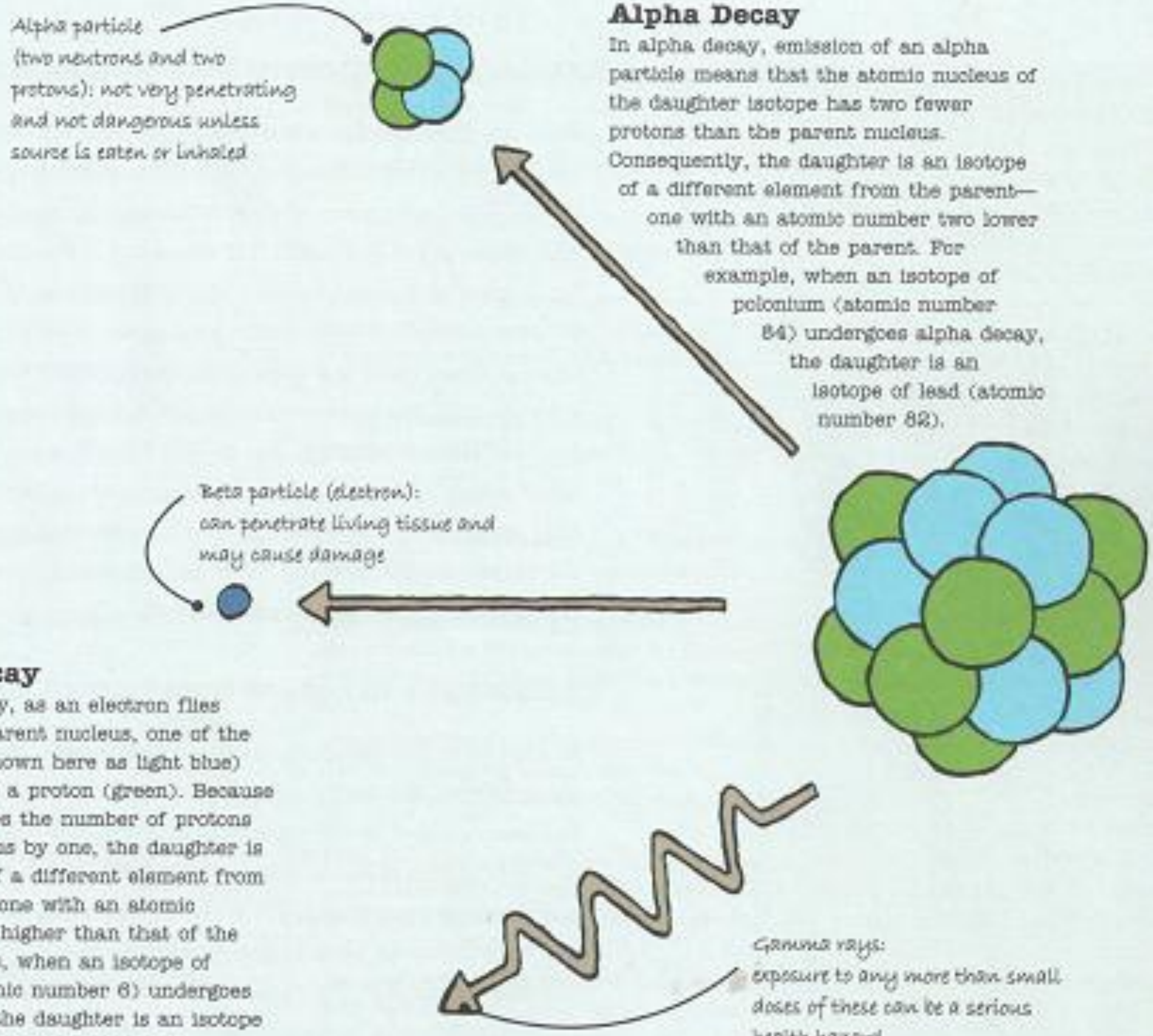
- When radioactive isotopes decay, they emit energetic particles and sometimes also emit some high-energy radiation.
- As they decay, they are sometimes transferred into the atoms of a different element, and often generate a lot of heat – a pellet of radium will glow in the dark and produce heat for centuries.

Decay Reactions



Types of Radioactive Decay

When radioactive isotopes decay, their nuclei usually emit one of two types of particles, called alpha and beta particles. They may also give off gamma rays. These three types of emission vary in how energetic, penetrating, and hazardous to health they can be.



Alpha Decay

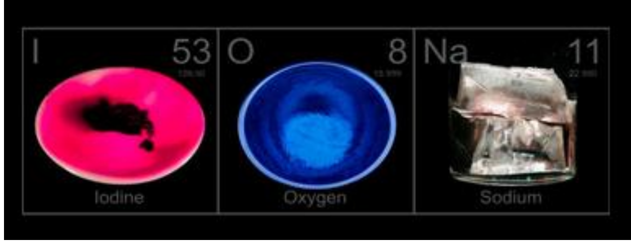
In alpha decay, emission of an alpha particle means that the atomic nucleus of the daughter isotope has two fewer protons than the parent nucleus. Consequently, the daughter is an isotope of a different element from the parent—one with an atomic number two lower than that of the parent. For example, when an isotope of polonium (atomic number 84) undergoes alpha decay, the daughter is an isotope of lead (atomic number 82).

Beta Decay

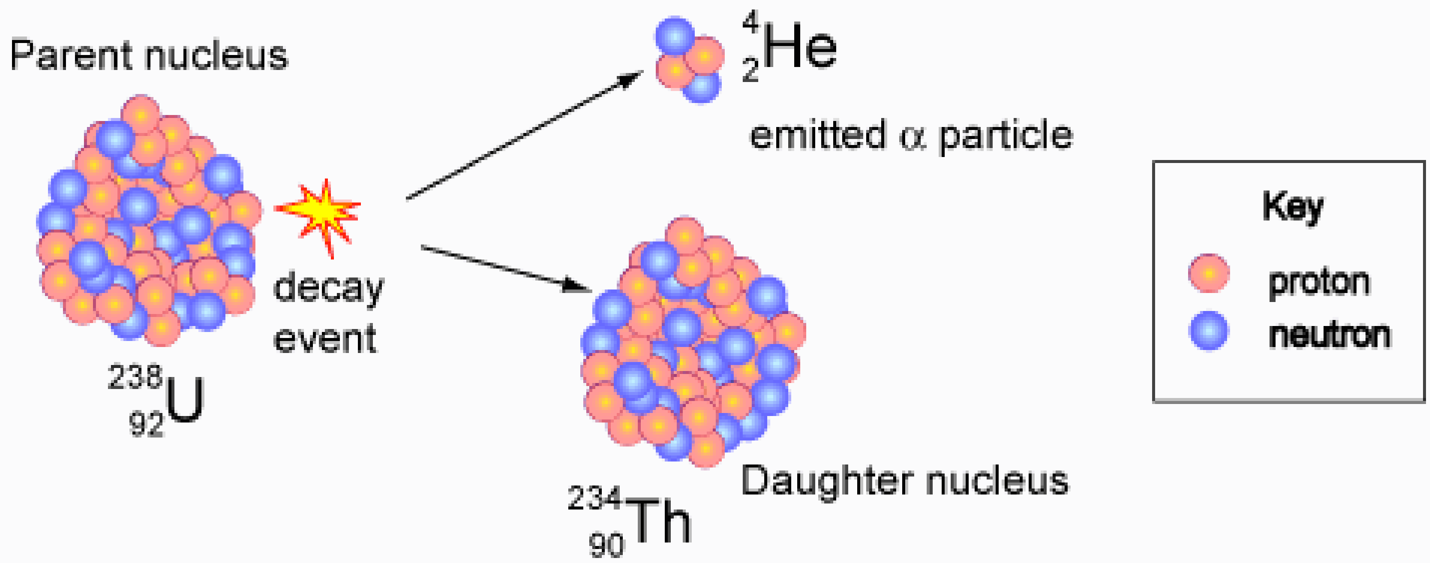
In beta decay, as an electron flies out of the parent nucleus, one of the neutrons (shown here as light blue) changes into a proton (green). Because this increases the number of protons in the nucleus by one, the daughter is an isotope of a different element from the parent—one with an atomic number one higher than that of the parent. Thus, when an isotope of carbon (atomic number 6) undergoes beta decay, the daughter is an isotope of nitrogen (atomic number 7).

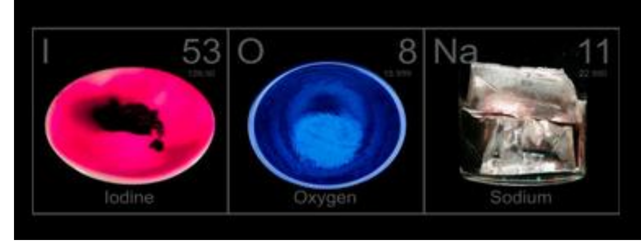
Gamma Decay

Gamma radiation is a highly energetic form of electromagnetic radiation (see page 32)—a type of wave rather than a particle. Radioactive isotopes never emit gamma rays on their own but frequently emit them alongside alpha or beta particles. Unlike alpha and beta decay, the emission of gamma radiation has no effect on the number of protons or neutrons left in the nucleus. Instead, gamma ray emission converts the nucleus from a higher, unstable energy state into a lower, more stable one.

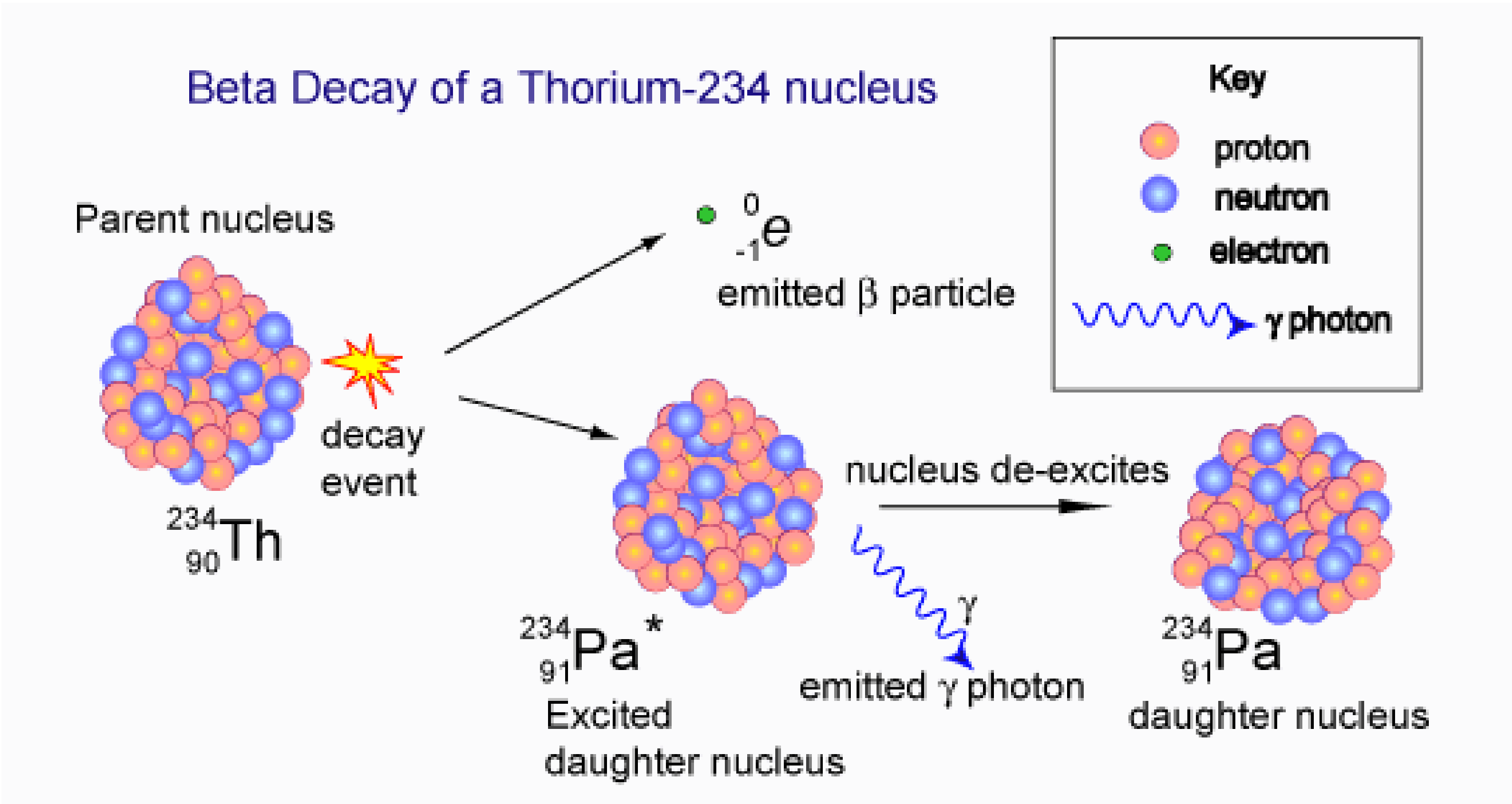


Alpha Decay of a Uranium-238 nucleus



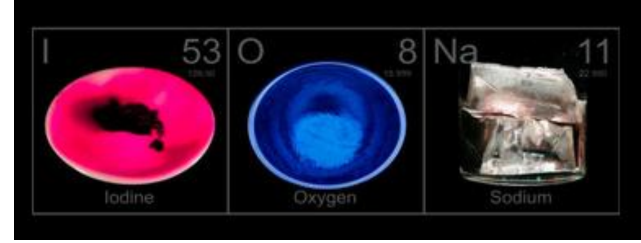


I 53
Iodine
O 8
Oxygen
Na 11
Sodium



Beta Decay of a Thorium-234 nucleus
Key
proton
neutron
electron
γ photon
Parent nucleus
$^{234}_{90}Th$
decay event
$^{0}_{-1}e$
emitted β particle
$^{234}_{91}Pa^{*}$
Excited daughter nucleus
nucleus de-excites
γ
emitted γ photon
$^{234}_{91}Pa$
daughter nucleus

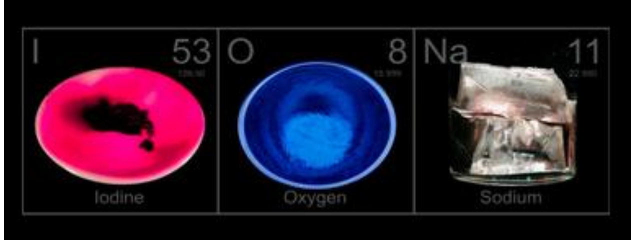
Bombardment Reactions



- Bombardment reactions involve the nucleus of the atom being bombarded with particles from the nucleus or an entire nucleus. – examples of particles are neutrons.
- These reactions usually give off a different particle than the one that they were bombarded with.

$$^{9}_{4}Be + ^{4}_{2}He \longrightarrow ^{12}_{6}C + ^{1}_{0}n$$

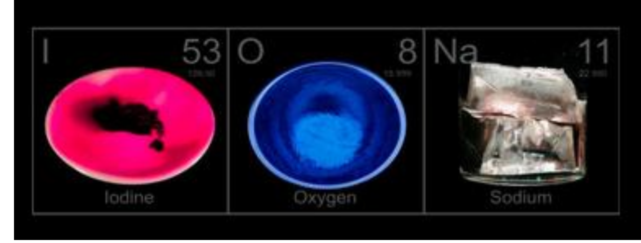
Transmutation Reaction



1) **TRANSMUTATION REACTIONS**: This type of reaction involves an element changing into another element.

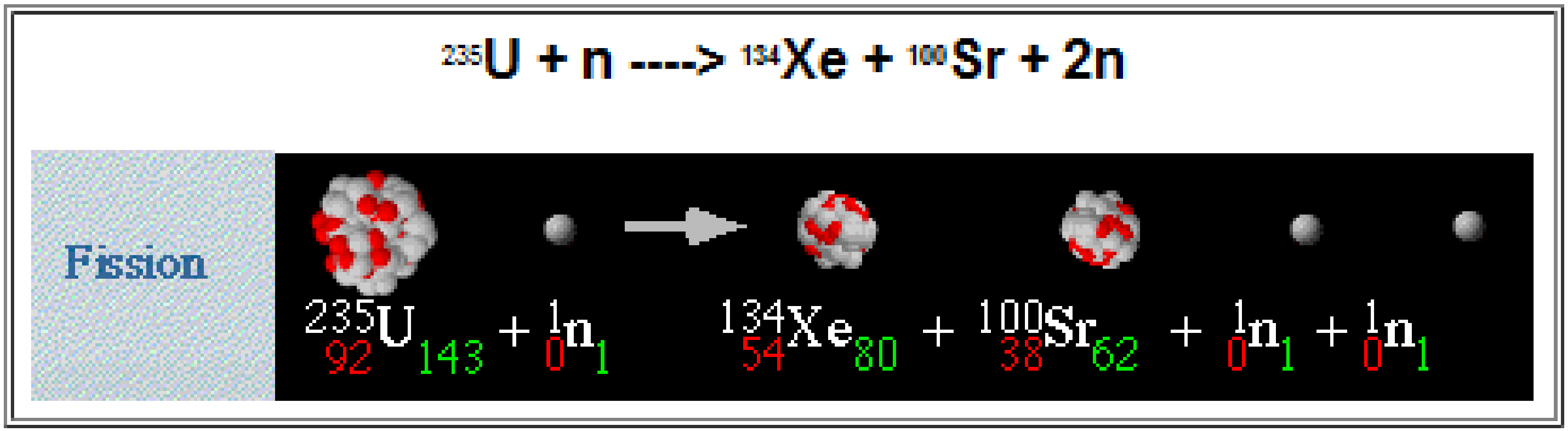
Element 1 ⟶ Element 2

e.g.	$^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$	Curie (1900)
e.g.	$^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{17}_{8}O + {}^{1}_{1}H$	Rutherford (1910)
e.g.	$^{9}_{4}Be + {}^{4}_{2}He \rightarrow {}^{12}_{6}C + {}^{1}_{0}n$	Chadwick (1932)



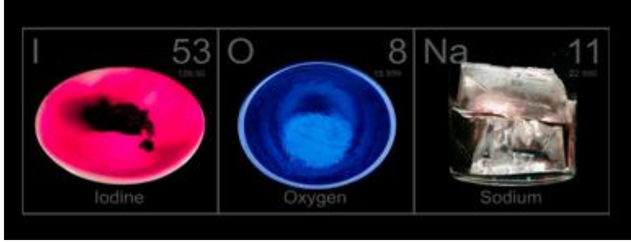
Fission

- Fission is a nuclear process in which a nucleus splits into two smaller nuclei.

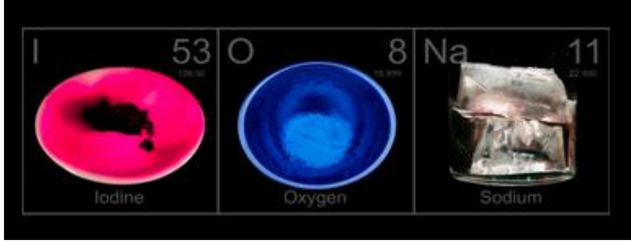


- A great number of products are possible, so long
- as the number of protons and neutrons in the products add up to those in the initial fissioning nucleus.

Fission (continued)

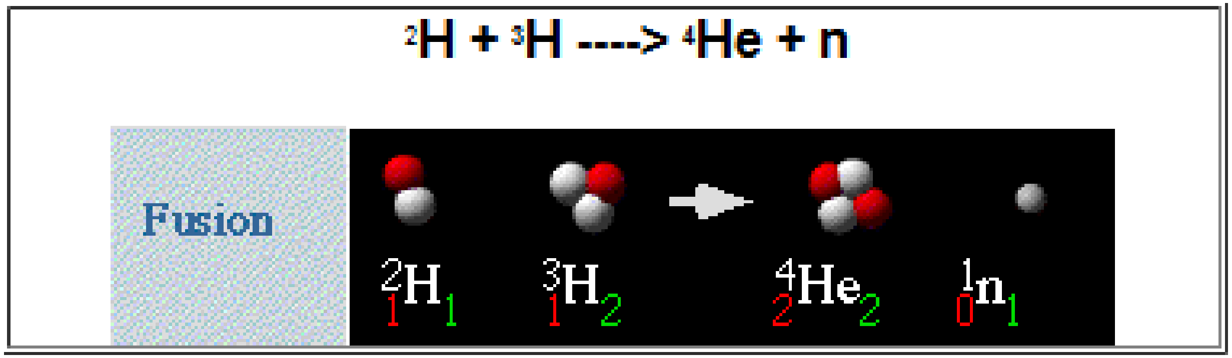


- A great amount of energy is released through fission as the heavier nuclei has a greater mass than the summed masses of the lighter product nuclei.

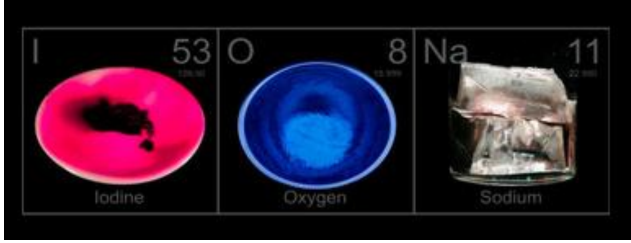


Fusion

- Fusion is a nuclear process in which two lighter nuclei combine to form a single heavier nucleus. An example important to humans is the reaction between two different hydrogen istopes to form an isotope of helium



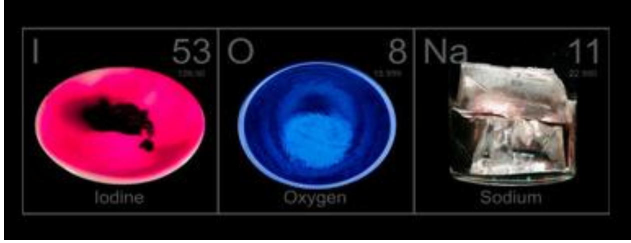
Half-Life



Half-Lives

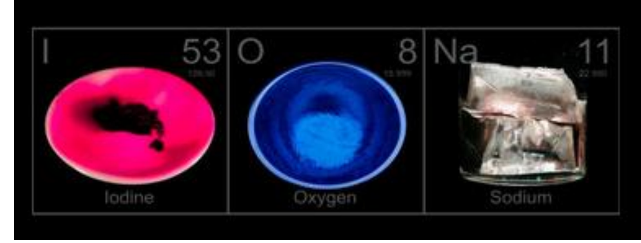
Different radioactive isotopes vary enormously in how unstable they are and therefore how quickly they decay. A standard way of categorizing the stability (or instability) of a particular isotope is by reference to its *half-life*. The atoms of a radioactive isotope don't all decay at once after a set amount of time. Instead, they decay one by one, in a random pattern. The half-life of an isotope is the time that can be expected for half of a collection of its atoms to decay. Very unstable isotopes have extremely short half-lives, measured in fractions of a second, while the more stable ones have half-lives measured in thousands, millions, or even billions of years.

There is a real problem with what to do with material containing long half-life isotopes produced as waste by nuclear reactors. This is because the material remains radioactive—and therefore potentially hazardous—for such a long period of time.



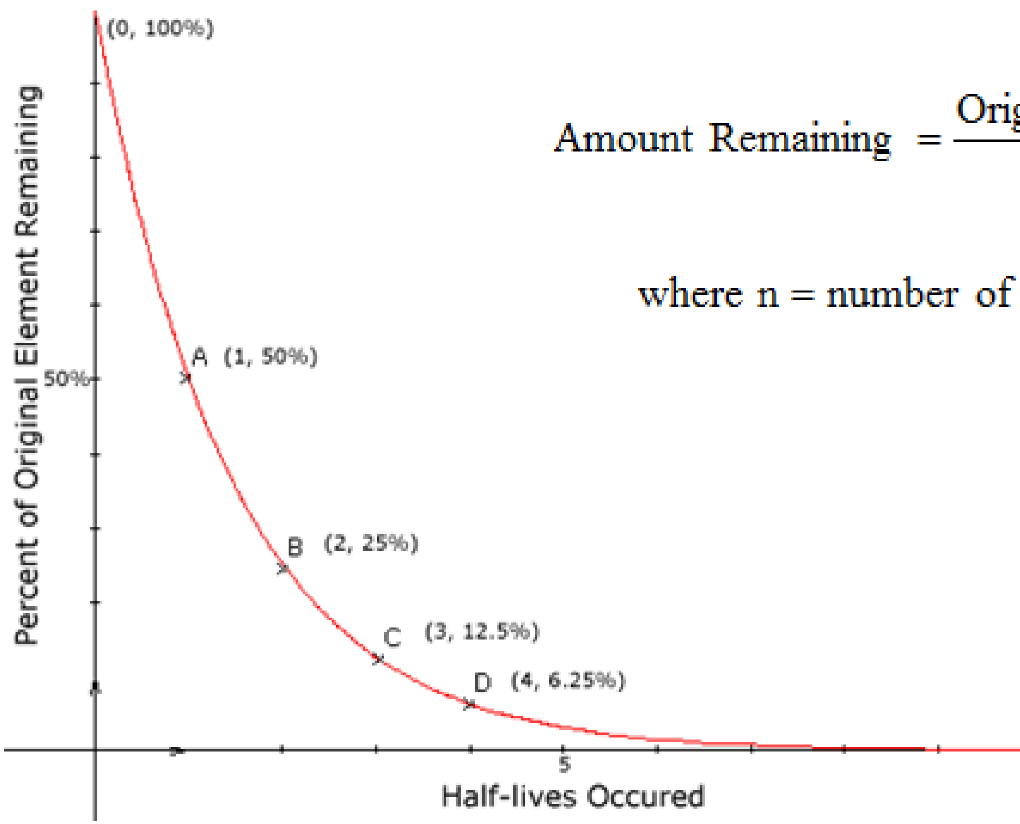
Half-Life is the time required for half the amount of a radioisotope to decay (i.e. release radiation and form a new element).

Radioisotope	Half life
Polonium-214	0.000164 s
Sodium-25	60 seconds
Tritium (H-3)	12.33 years
Carbon-14	5730 years
Uranium-238	4.47×10^9 years



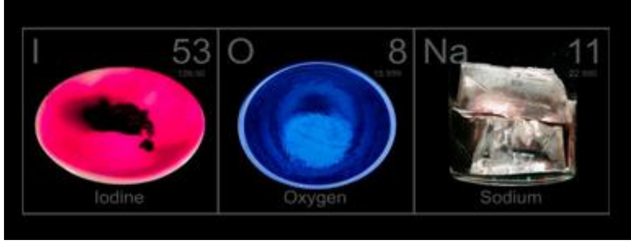
Consider the decay of Tritium:

Half Lives	0	1	2	3	100
Time (years)	0	12.3	24.7	36.0	1,233
Amount Remaining	100 g	50 g	25 g	12.5 g	8.7×10^{-17} g



$$\text{Amount Remaining} = \frac{\text{Original Amount}}{2^n}$$

where n = number of half lives



- Nuclear Binding Energy Calculations (see handout)