Oakland Schools Chemistry Resource Unit

Nuclear Chemistry

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Nuclear Chemistry

Content Statements:

C2.5x Nuclear Stability:

Nuclear stability is related to a decrease in potential energy when the nucleus forms from protons and neutrons. If the neutron/proton ratio is unstable, the element will undergo radioactive decay. The rate of decay is characteristic of each isotope: the time for half of the parent nuclei to decays is called the half-life. Comparison of the parent/daughter nuclei can be used to determine the age of the sample. Heavier elements are formed from the fusion of lighter elements in stars.

C3.5x Mass Defect:

Nuclear reactions involve energy changes many times the magnitude of chemical changes. In chemical reactions matter is conserved, but in nuclear reactions a small loss of matter (mass defect) will account for the tremendous release of energy. The energy released in nuclear reactions can be calculated from the mass defect: $E=mc^2$.

Content Expectations:

C2.5a Determine the age of materials using the ratio of stable and unstable isotopes of a particular type.

C2.r5b Illustrate how elements can change in nuclear reactions using balanced equations.

C2.r5c Describe the potential energy changes as two protons approach each other.

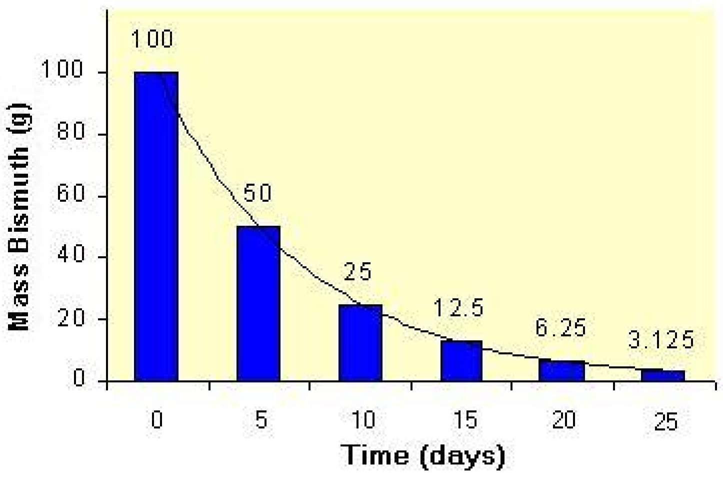
C2.r5d Describe how and where all the elements on earth were formed.

C3.5a Explain why matter is not conserved in nuclear reactions.

Instructional Background Information:

Half-Life:

Radioactive decay proceeds according to a principal called the half-life. The half-life ($T_{½}$) is the amount of time necessary for one-half of the radioactive material to decay. For example, the radioactive element bismuth (Bi-210) can undergo alpha decay to form the element thallium (Tl-206) with a reaction half-life equal to five days. If we begin an experiment starting with 100 g of bismuth in a sealed lead container, after five days we will have 50 g of bismuth and 50 g of thallium in the jar. After another five days (ten from the starting point), one-half of the remaining bismuth will decay and we will be left with 25 g of bismuth and 75 g of thallium in the jar. As illustrated, the reaction proceeds in halves, with half of whatever is left of the radioactive element decaying every half-life period.



Radioactive Decay of Bismuth-210 ($T_{½}$ = 5 days)

The fraction of parent material that remains after radioactive decay can be calculated using the equation:

$$\textbf{Fraction remaining} = \frac{1}{2^n} \textbf{(where n = \# half-lives elapsed)}$$

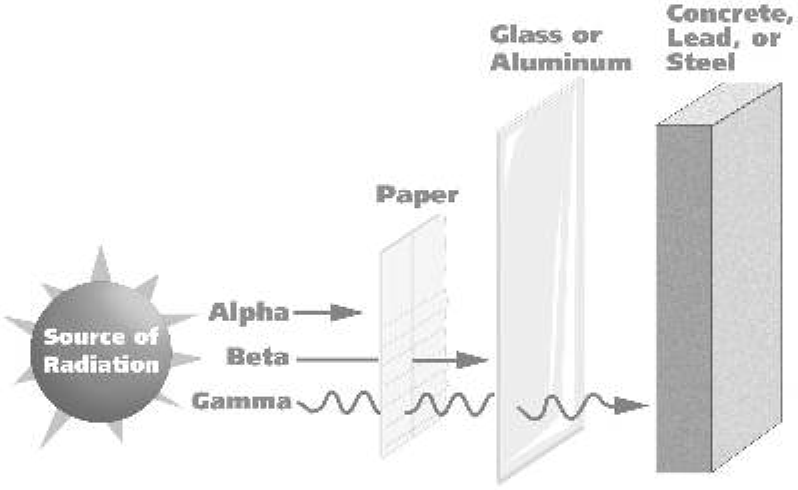
The amount of a radioactive material that remains after a given number of half-lives is therefore:

Amount remaining = Original amount * Fraction remaining

The decay reaction and $T_{½}$ of a substance are specific to the isotope of the element undergoing radioactive decay. For example, Bi-210 can undergo decay to Tl-206 with a $T_{½}$ of five days. Bi-215, by comparison, undergoes b decay to Po-215 with a $T_{½}$ of 7.6 minutes, and Bi-208 undergoes yet another mode of radioactive decay (called electron capture) with a $T_{½}$ of 368,000 years!
visionlearning.com
http://www.visionlearning.com/library/module_viewer.php?mid=59

Radiometric Dating:
Radioactive elements such as uranium (U) and thorium (Th) decay naturally to form different elements or isotopes of the same element. (Isotopes are atoms of any elements that differ in mass from that element, but possess the same general chemical and optical properties.) This decay is accompanied by the emission of radiation or particles (alpha, beta, or gamma rays) from the nucleus, by nuclear capture, or by ejection of orbital electrons. A number of isotopes decay to a stable product, a so-called daughter isotope, in a single step (for example, carbon-14), whereas other series involve many steps before a stable isotope is formed. Multistep radioactive decay series include, for example, the uranium-235, uranium-238, and thorium-232 families. If a daughter isotope is stable, it accumulates until the parent isotope has completely decayed. If a daughter isotope is also radioactive, however, equilibrium is reached when the daughter decays as fast as it is formed.
cartage.org
http://www.cartage.org.lb/en/themes/sciences/chemistry/NuclearChemistry/NuclearReactions/Radiometricdating/RadiometricDating%20.html

Alpha, Beta, Gamma particles:
What is radioactivity?
Atoms are not all stable. The excess energy contained in an unstable atom is released in one of a few basic particles and energetic waves. The Greek alphabet is used to name the particles (in the order of their discovery).



ALPHA PARTICLES

The alpha particle is the heaviest. It is produced when the heaviest elements decay. Alpha and beta rays are not waves. They are high-energy particles that are expelled from unstable nuclei. In the case of alpha radiation, the high energy particles leave the nucleus. The alpha particle is a helium atom and contains two neutrons and two protons. It leaves the nucleus of an unstable atom at a speed of 16,000 kilometers per second, around a tenth the speed of light. The alpha particles are relatively large and heavy. As a result, alpha rays are not very penetrating and are easily absorbed. A sheet of paper or a 3-cm layer of air is sufficient to stop them. Its energy is transferred within a short distance to the surrounding media. However, its short flight knocks about 450,000 electrons out of the surrounding atoms. The alpha particle emitter will not penetrate the outer layer of our skin, but is dangerous if inhaled or swallowed. The delicate internal workings of the living cell forming the lining of the lungs or internal organs, most certainly will be changed (mutated) or killed outright by the energetic alpha particle. The number of lung cancer cases among uranium miners from inhaled and ingested alpha sources is much higher than those of the public at large. Radon, the gas produced by the decay of radium-226, also emits alpha particles, which poses a hazard to lungs and airways when inhaled. Homes built in areas with high ground radioactivity should be tested for radon buildup in enclosed basement spaces.

1. An example of an a transmutation takes place when uranium decays into the element thorium (Th) by emitting an alpha particle, as depicted in the following equation:

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

BETA PARTICLES

Beta rays are much lighter energy particles. The beta particle is an energetic electron given off by the nucleus of unstable isotopes to restore an energy balance. They leave the nucleus at a speed of 270,000 kilometers per second. They can be stopped, for instance, by an aluminum sheet a few millimeters thick or by 3 meters of air. The RS-500 can detect most energetic beta particles through the case. Weaker beta particles can be detected through the tube window. Although the beta particle is around 8000 times smaller than the alpha particle, it is capable of penetrating much deeper into living matter. Each encounter with a living cell, and there may be many before the beta energy is dissipated, is likely to dam age some of the chemical links between the living molecules of the cell or cause some permanent genetic change in the cell nucleus. If the damage occurs within the generative cells of the ovaries or testes, the damage may be passed to new generations. The normal background radiation level must contribute to the mutation of the gene pool. Most mutations are undesirable with a very few leading to "improvements". Any increase in the background level of radiation should be considered harmful.

1. An example of this is the decay of the isotope of carbon named carbon-14 into the element nitrogen:

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

GAMMA RAYS

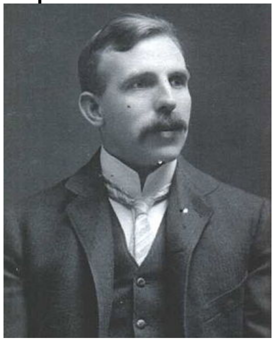
The next "particle" is the very high energy "X-ray" called the gamma ray. It is an energetic photon or light wave in the same electromagnetic family as light and x-rays, but is much more energetic and harmful. It is capable of damaging living cells as it slows down by transferring its energy to surrounding cell components. The RS-500 detects energetic gamma rays through the case walls. Gamma ray sources are used to find flaws in pipes and vessels and to check the integrity of welds in steel.

oasisllc.com

http://www.oasisllc.com/abgx/radioactivity.htm

Ernest Rutherford, 1st Baron Rutherford of Nelson,

(30 August 1871 – 19 October 1937) was a physicist who became known as the "father" of nuclear physics. He pioneered the orbital theory of the atom through his discovery of Rutherford scattering off the nucleus with his gold foil experiment. He was awarded the Nobel Prize in Chemistry in 1908.



wikipedia.org

http://en.wikipedia.org/wiki/Ernest_Rutherford

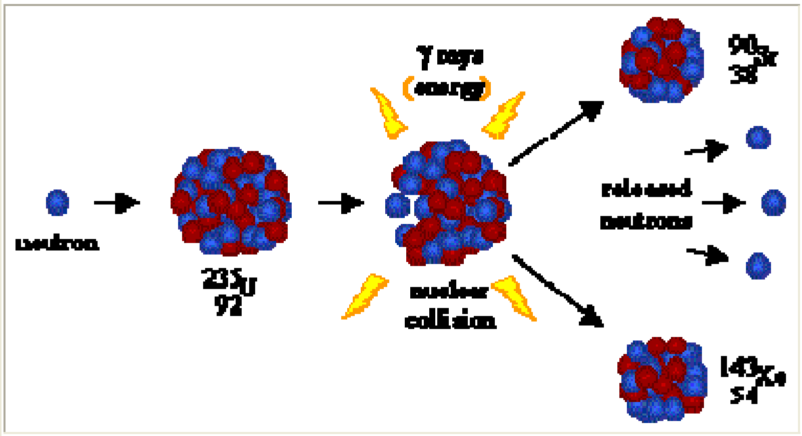
Balancing Nuclear Reactions:

Fission:

Stimulated Nuclear Reactions

While many elements undergo radioactive decay naturally, nuclear reactions can also be stimulated artificially. Although these reactions also occur naturally, we are most familiar with them as stimulated reactions. There are two such types of nuclear reactions:

1. Nuclear fission: reactions in which an atom's nucleus splits into smaller parts, releasing a large amount of energy in the process. Most commonly this is done by "firing" a neutron at the nucleus of an atom. The energy of the neutron "bullet" causes the target element to split into two (or more) elements that are lighter than the parent atom.



The Fission Reaction of Uranium-235

During the fission of U235, three neutrons are released in addition to the two daughter atoms. If these released neutrons collide with nearby U235 nuclei, they can stimulate the fission of these atoms and start a self-sustaining nuclear chain reaction. This chain reaction is the basis of nuclear power. As uranium atoms continue to split, a significant amount of energy is released from the reaction. The heat released during this reaction is harvested and used to generate electrical energy.

visionlearning.com

http://www.visionlearning.com/library/module_viewer.php?mid=59

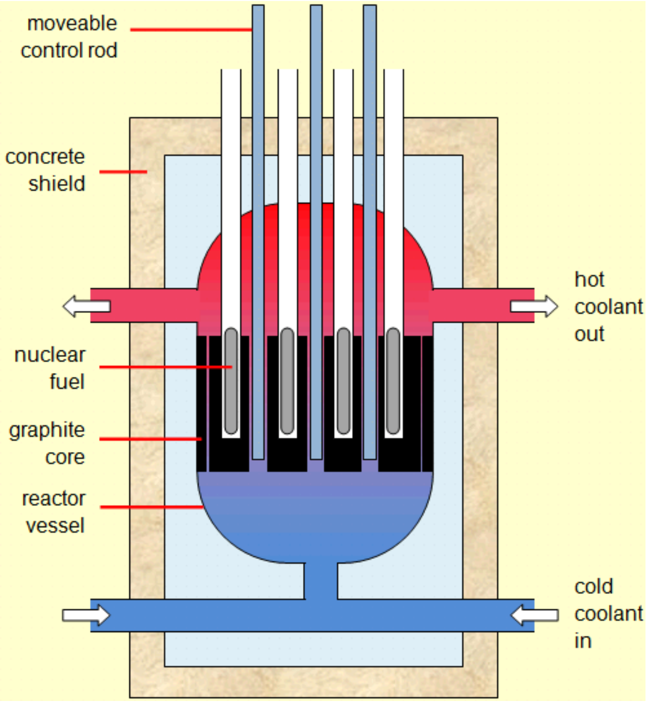
Nuclear fission---controlled reaction

Nuclear power stations use the heat released by nuclear reactions to boil water to make steam. The type of nuclear reaction used is called nuclear fission. In nuclear fission:

- a neutron collides with an uranium nucleus (which is large and unstable)
- the uranium nucleus splits into two similar-sized smaller nuclei
- more neutrons are released
- these neutrons can then collide with more uranium nuclei.

These processes are repeated continuously, forming a chain reaction.

In a nuclear explosion, the chain reaction is allowed to run out of control, releasing large amounts of energy very quickly. In a nuclear reactor, the reaction is controlled so that energy is released at a steady rate.

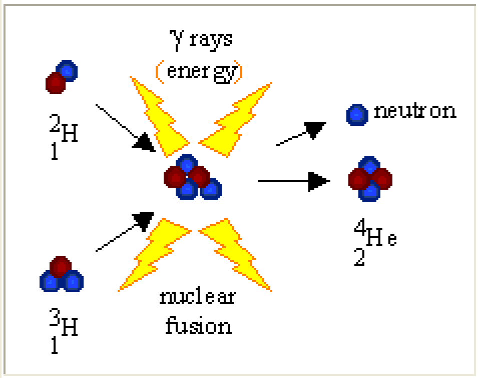


Outline of a nuclear reactor

The nuclear fuel (usually uranium oxide) is held in metal containers called fuel rods. These are lowered into the reactor core. A coolant - usually water or carbon dioxide - is circulated through the reactor core to remove the heat. Control rods are also lowered into the core. These absorb neutrons and control the rate of the chain reaction. They are raised to speed it up, or lowered to slow it down.

Fusion:

2. Nuclear fusion: reactions in which two or more elements "fuse" together to form one larger element, releasing energy in the process. A good example is the fusion of two "heavy" isotopes of hydrogen (deuterium: H2 and tritium: H3) into the element helium.



Nuclear Fusion of Two Hydrogen Isotopes

Fusion reactions release tremendous amounts of energy and are commonly referred to as thermonuclear reactions. Although many people think of the sun as a large fireball, the sun (and all stars) is actually enormous fusion reactors. Stars are primarily gigantic balls of hydrogen gas under tremendous pressure due to gravitational forces. Hydrogen molecules are fused into helium and heavier elements inside of stars, releasing energy that we receive as light and heat.

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http://www.visionlearning.com/library/module_viewer.php?mid=59

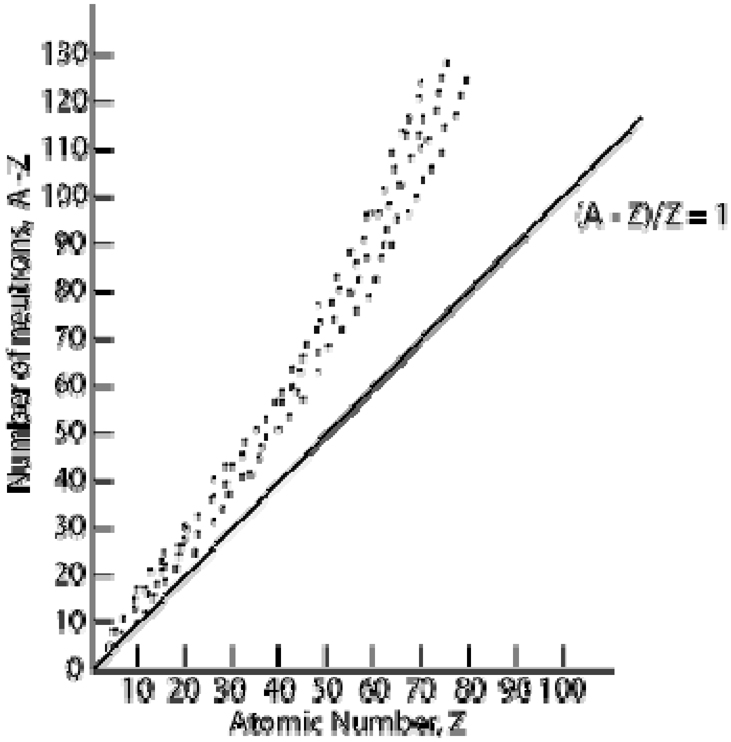
Isotope:

The number of neutrons in an atom can also vary. Two atoms of the same element that contain different numbers of neutrons are called **isotopes**. For example, normally hydrogen contains no neutrons. An isotope of hydrogen does exist that contains one neutron (commonly called deuterium). The atomic number (z) is the same in both isotopes; however the atomic mass increases by one in deuterium as the atom is made heavier by the extra neutron.

Nuclear Transmutation: A nucleus which undergoes alpha decay transforms into a new element. This process is called transmutation.

Band of stability:

Chemistry Graphs: The Band of Stability



Most elements have isotopes. For <u>stable</u> isotopes, an interesting plot arises when the number of neutrons is plotted versus the number of protons. Because the plot shows only the stable isotopes, this graph is often called the Nuclear Belt of Stability. The plot indicates that lighter nuclides (isotopes) are most stable when the neutron/proton ratio is 1/1. This is the case with any nucleus that has up to 20 protons. As the atomic number increases beyond 20, a different trend becomes apparent. In this range, it appears that a stable nucleus is able to accommodate more neutrons. Stable isotopes have a higher neutron to proton ratio, rising to 1.5/1 for elements having atomic numbers between 20 and 83.

algebralab.org
http://www.algebralab.org/practice/practice.aspx?file=Reading_TheBandOfStability.xml

Potential energy changes as protons approach each-other: As they approach each other the potential energy increases because they are both negatively charged.

How and where elements are formed:
The lightest elements (hydrogen, helium, deuterium, lithium) were produced in the Big Bang nucleosynthesis. According to the Big Bang theory, the temperatures in the early universe were so high that fusion reactions could take

place. This resulted in the formation of light elements: hydrogen, deuterium, helium (two isotopes), lithium and trace amounts of beryllium.

Nuclear fusion in stars converts hydrogen into helium in all stars. In stars less massive than the Sun, this is the only reaction that takes place. In stars more massive than the Sun (but less massive than about 8 solar masses), further reactions that convert helium to carbon and oxygen take place in successive stages of stellar evolution. In the very massive stars, the reaction chain continues to produce elements like silicon up to iron.

Elements higher than iron cannot be formed through fusion as one has to supply energy for the reaction to take place. However, we do see elements higher than iron around us. So how did these elements form? The answer is supernovae. In a supernova explosion, neutron capture reactions take place (this is not fusion), leading to the formation of heavy elements. This is the reason why it is said that most of the stuff that we see around us come from stars and supernovae (the heavy elements part). If you go into technical details, then there are two processes of neutron capture called rapid process (r-process) and the slow process (s-process), and these lead to formation of different elements.
Curious.astro.cornell.edu

http://curious.astro.cornell.edu/question.php?number=345

Lack of matter conservation in nuclear reactions:
With nuclear reactions, the energies involved are so great that the changes in mass become easily measurable. One no longer can assume that mass and energy are conserved separately, but must take into account their interconversion via Einstein's relationship, $E = mc^2$. If mass is in grams and the velocity of light is expressed as $c = 3 \times 10^{10}$ cm sec^{-1}, then the energy is in units of g cm^2 sec^{-2}, or ergs. A useful conversion is from mass in amu to energy in million electron volts (MeV):

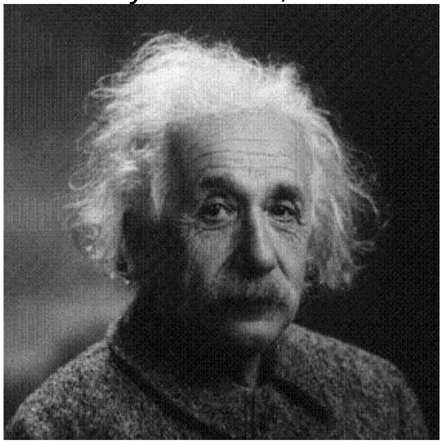
1 amu = 931.4 MeV

What holds a nucleus together? If we attempt to bring two protons and two neutrons together to form a helium nucleus, we might reasonably expect the positively charged protons to repel one another violently. Then what keeps them together in the ^4_2He nucleus? The answer, as we mentioned in Chapter 2, is that a helium atom is lighter than the sum of two protons, two neutrons, and two electrons. Some of the mass of the separated particles is converted into energy and dissipated when the nucleus is formed. Before the helium nucleus can be torn apart into its component particles, this dissipated energy must be restored and turned back into mass. Unless this energy is provided, the nucleus cannot be taken apart. This energy is termed the *binding energy* of the helium nucleus.

Theory of Relativity:

Theory of Relativity - The Basics

The Theory of Relativity, proposed by the Jewish physicist Albert Einstein (1879-1955) in the early part of the 20th century, is one of the most significant scientific advances of our time. Although the concept of relativity was not introduced by Einstein, his major contribution was the recognition that the speed of light in a vacuum is constant and an absolute physical boundary for motion. This does not have a major impact on a person's day to day life since we travel at speeds much slower than light speed. For objects traveling near light speed, however, the theory of relativity states that objects will move slower and shorten in length from the point of view of an observer on Earth. Einstein also derived the famous equation, $E = mc^2$, which reveals the equivalence of mass and energy. When Einstein applied his theory to gravitational fields, he derived the "curved space-time continuum" which depicts the dimensions of space and time as a two-dimensional surface where massive objects create valleys and dips in the surface. This aspect of relativity explained the phenomena of light bending around the sun, predicted black holes as well as the background radiation left from the Big Bang. For his work on relativity, the photoelectric effect and blackbody radiation, Einstein received the Nobel Prize in 1921.



Theory of Relativity - Inherent Limitations

For the past century, scientists have conducted a variety of experiments to verify the implications of the Theory of Relativity as well as advance fields such as cosmology and particle physics. However, there is some question as to the ability of Einstein's Theory of Relativity to describe as many physical phenomena as has been claimed - with some scientists arguing against it entirely. Regardless, as with any other scientific theory, it is not the absolute, entire and final description of the universe. Because it is a scientific theory, it contains certain assumptions and approximations of nature and ultimately, fails to describe several phenomena altogether (i.e. electromagnetism). Unfortunately, Einstein's Theory of Relativity, much like Darwin's Theory of Evolution, has become popularized as a "scientific truth" because it offers a simplified explanation to the complexity observed in the natural universe. In fact, Einstein himself spent the rest of his life attempting to develop a Unified Theory of Physics which would combine electromagnetism with relativity. He was unsuccessful and to date, this task has not been accomplished.

Theory of Relativity - Abused and Misused

In addition to being misrepresented as an undeniable fact, the Theory of Relativity has been misapplied to areas beyond gravitational phenomena even in the scientific community. Concerning the origin of the universe, Einstein's Theory of Relativity is the basis for the Big Bang Theory, a theory postulating on the origin of the universe. Likewise, Darwin's Theory of Evolution is a theory focused on the origin of species and, ultimately, the origin of man. Yet, these two theories are often discussed as though they are two ends of a larger unified theory. In reality, they are not theories on a continuum, but separate theories describing two completely different physical phenomena.
allaboutscience.org
http://www.allaboutscience.org/theory-of-relativity.htm

Nuclear Weapons:

Fission bomb: In a nuclear bomb there is a globe made of plutonium-239 or uranium-235. In this globe there is a neutron source which only effective when the TNT (trinitrotoluene) explodes. Because of the compression of the explosion the critical mass of the split material is overstepped. There are nuclear bomb which are build otherwise, but the principle is always the same. This both materials are very expensive, because on earth we find very little plutonium so it means that we must produce plutonium. To produce plutonium it is necessary to bombard the natural and very cheap uranium-238 with neutrons to make uranium-239. Uranium-239 decays to neptunium-239 and neptunium-239 decays after a certain time to plutonium-239. You can find uranium-235 in nature, but only in uranium-238. To split this uranium-235 from uranium-238 is very expensive, because their chemical properties are the same so it is not possible to split them in a chemical way. A nuclear bomb like this can have an explosion force of 20 kilotons (20000 tons). This means that an explosion of such a bomb is as effective as the explosion of 20 kilotons of TNT.
homepageofscientifictopics
http://www.hpwt.de/Kern2e.htm

Fusion bomb: Hydrogen bombs can reach an explosion force of 20 megatons (20 million tons). This bombs are also knows as three-phase fuses. The fission like in a nuclear bomb is only the first phase. In the second phase there is a fusion between deuterium and tritium. The temperature in the second phase is 200 to 300 million degrees Celsius (much hotter than the core of the sun). The third phase is the fission of uranium-238 which is of the outer side of the bomb. Under these conditions the fission of uranium-238 is possible. The principle of power plants is the same like in nuclear bombs, but without using TNT. The reason why nuclear power plants do not explodes is that there are control rods to control the number of the neutrons in the reactor. This is a controlled nuclear chain reaction opposed to the uncontrolled nuclear chain reaction in nuclear bombs. The nuclear power plants in the future will be fusion reactors which do not crack heavy atomic nucleus, but fuses light atomic nucleus. Fusion is possible today but the energy which you need for a fusion reaction is higher than the energy you get out and this is not the sense of nuclear fusions. With fusions the last elements of the "Periodic table of the elements" have been created, because they not on earth. In 1999 a few physicists thought that they have discovered the element 118 but two years later in 2001 they said that it was a mistake, so element 114 is the last know element. In stars there are also fusions. In our sun it is the proton cycle which you can find on the website of astronomy and astrophysics. Now I will give an answer why we get energy from these nuclear reactions. We must begin which Einstein's famous formula: $E=mc^2$ (E stands for energy, m stands for mass and c stands for the speed of light in the vacuum). This formula makes it possible to transform mass into energy. Atomic nuclei have different binding energies. The binding energy is the energy which holds the nucleons together. Because of this fact there is in every atomic nucleus a mass defect. A free proton and a free neutrons weighs more than deutrium (heavy hydrogen, consists of one proton and one neutron). Iron has got the highest binding energy and stands in the middle of the "Periodic table of the elements". When somebody goes closer to this middle with fissions or fusions a part will be transformed into energy.

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http://www.hpwt.de/Kern2e.htm

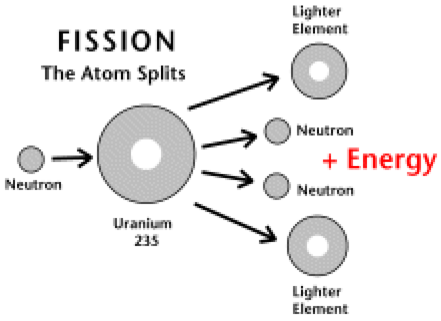
Atomic Energy:

Nuclear energy is energy in the nucleus (core) of an atom. Atoms are tiny particles that make up every object in the universe. There is enormous energy in the bonds that hold atoms together.

Nuclear energy can be used to make electricity. But first the energy must be released. It can be released from atoms in two ways: nuclear fusion and nuclear fission.

In **nuclear fusion**, energy is released when atoms are combined or fused together to form a larger atom. This is how the sun produces energy.

In **nuclear fission**, atoms are split apart to form smaller atoms, releasing energy. Nuclear power plants use nuclear fission to produce electricity.



Nuclear Fuel - Uranium

The fuel most widely used by nuclear plants for nuclear fission is uranium. Uranium is nonrenewable, though it is a common metal found in rocks all over the world. Nuclear plants use a certain kind of uranium, U-235, as fuel because its atoms are easily split apart. Though uranium is quite common, about 100 times more common than silver, U-235 is relatively rare. Most U.S. uranium is mined, in the Western United States. Once uranium is mined the U-235 must be extracted and processed before it can be used as a fuel.

During nuclear fission, a small particle called a neutron hits the uranium atom and splits it, releasing a great amount of energy as heat and radiation. More neutrons are also released. These neutrons go on to bombard other uranium atoms, and the process repeats itself over and over again. This is called a chain reaction.

Nuclear Power Plants Generate Electricity

Nuclear power accounts for about 19 percent of the total net electricity generated in the United States, about as much as the electricity used in California, Texas and New York, the three states with the most people. In 2006, there were 66 nuclear power plants (composed of 104 licensed nuclear reactors) throughout the United States.

Most power plants burn fuel to produce electricity, but not nuclear power plants. Instead, nuclear plants use the heat given off during fission as fuel. Fission takes place inside the reactor of a nuclear power plant. At the center of the reactor is the core, which contains the uranium fuel.

The uranium fuel is formed into ceramic pellets. The pellets are about the size of your fingertip, but each one produces the same amount of energy as 150 gallons of oil. These energy-rich pellets are stacked end-to-end in 12-foot metal fuel rods. A bundle of fuel rods is called a fuel assembly.

Fission generates heat in a reactor just as coal generates heat in a boiler. The heat is used to boil water into steam. The steam turns huge turbine blades. As they turn, they drive generators that make electricity. Afterward, the steam is changed back into water and cooled in a separate structure at the power plant called a cooling tower. The water can be used again and again.

Nuclear Power and the Environment

Compared to electricity generated by burning fossil fuels, nuclear energy is clean. Nuclear power plants produce no air pollution or carbon dioxide but a small amount of emissions result from processing the uranium that is used in nuclear reactors.

Like all industrial processes, nuclear power generation has by-product wastes: spent (used) fuels, other radioactive waste, and heat. Spent fuels and other radioactive wastes are the principal environmental concern for nuclear power. Most nuclear waste is low-level radioactive waste. It consists of ordinary tools, protective clothing, wiping cloths and disposable items that have been contaminated with small amounts of radioactive dust or particles. These materials are subject to special regulations that govern their disposal so they will not come in contact with the outside environment.

On the other hand, the spent fuel assemblies are highly radioactive and must initially be stored in specially designed pools resembling large swimming pools (water cools the fuel and acts as a radiation shield) or in specially designed dry storage containers. An increasing number of reactor operators now store their older and less spent fuel in dry storage facilities using special outdoor concrete or steel containers with air cooling. The United States Department of Energy's long range plan is for this spent fuel to be stored deep in the earth in a geologic repository, at Yucca Mountain, Nevada.

eia.doe.gov
http://www.eia.doe.gov/kids/energyfacts/sources/non-renewable/nuclear.html

Natural vs. man-made elements (synthetic elements):
Synthetic elements, in chemistry, radioactive elements that were not discovered occurring in nature but as artificially produced isotopes. They are technetium (at. no. 43), which was the first element to be synthesized, promethium (at. no. 61), astatine (at. no. 85), francium (at. no. 87), and the transuranium elements (at. no. 93 and beyond in the periodic table). Some of these elements have since been shown to exist in minute amounts in nature, usually as short-lived members of natural radioactive decay series (see radioactivity).

The synthetic elements through atomic number 100 (fermium) are created by bombarding a heavy element, such as uranium or plutonium, with neutrons or alpha particles. The synthesis of the transfermium elements (elements with atomic number 101 or greater) is accomplished by the fusion of the nuclei of two lighter elements. Elements 101 through 106 were first produced by fusing the nuclei of slightly lighter elements, such as californium, with those of light elements, such as carbon. Elements 107 through 112 were first produced by fusing the nuclei of medium-weight elements, such as bismuth or lead, with those of other medium-weight elements, such as iron, nickel, or zinc. Element 114 was first produced by fusing the nuclei of plutonium and calcium and subsequently by fusing the nuclei of lead and krypton, as was element 116. Element 115 was produced by bombarding americium with calcium, and element 113 resulted from the radioactive decay of element 115. The claim by Lawrence Berkeley National Laboratory to have created element 118 has been retracted.)

The transfermium elements are produced in very small quantities (one atom at a time), and identification is therefore very difficult because of half-lives ranging from minutes to milliseconds and the need to identify the products by methods other than known chemical separations. This has led to controversy over reported discoveries and over the naming of the elements. It has been predicted that one isotope of element 114—containing 114 protons and 184 neutrons—would be very stable because its nucleus would have a full complement of protons and neutrons. Termed an “island of stability,” its half-life might be measured in years. However, none of the three isotopes of element 114 synthesized as yet have as many as 184 neutrons, and their half-lives are still in the millisecond range.

infoplease.com
http://www.infoplease.com/ce6/sci/A0847507.html

Terms and Concepts

Atomic Number
Atomic Mass
Decay Rate
Electron
Element
Isotope
Neutron
Neutron Mass to Energy Conversion
Nuclear Reaction
Nucleus
Photon
Proton
Radioactive Dating
Radioactive Isotope
Strong Force

Nuclear Chemistry

Activity #1 - Fission: Breaking Up is Hard to Do

Fusion: Why Can't We Just Get Together?

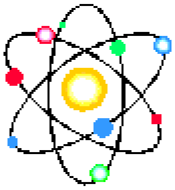
Questions:

Motivation for Learning

What is the difference between fission and fusion? What type of reaction is currently used in nuclear power plants? What type of reaction is used by a star? Are all nuclear reactions dangerous?

Objectives:

Students will

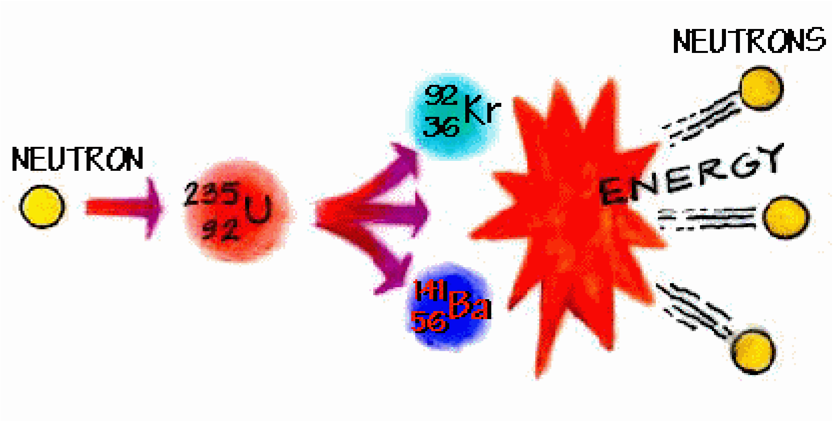


- visualize the process of nuclear fusion;
- visualize the process of nuclear fission;
- identify the products of fusion and fission;
- relate nuclear reactions to the Law of Conservation of Matter and Energy.

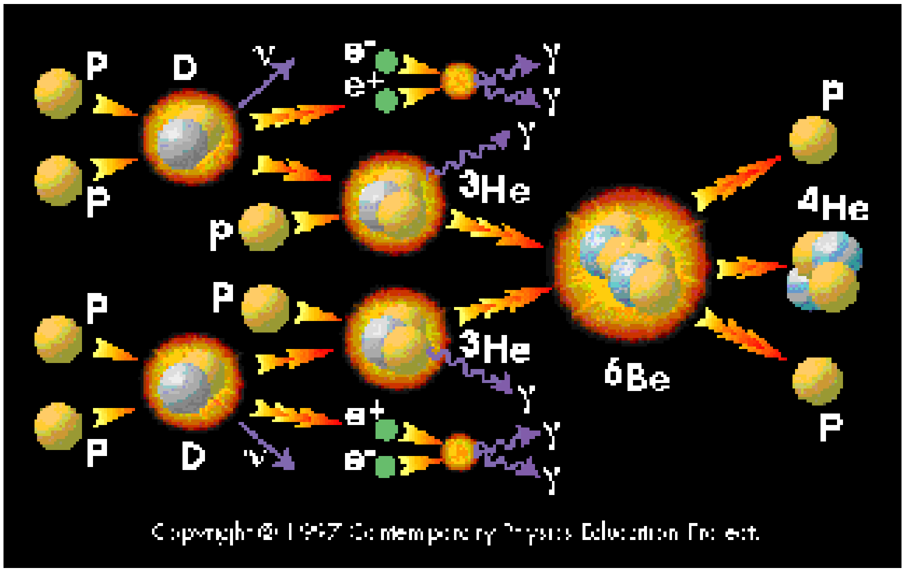
Teacher Notes:

Background Information

Isotopes of elements having atomic numbers greater than 80 are capable of undergoing fission. In nuclear fission, the nucleus splits apart generating enormous amounts of energy. When uranium 235 absorbs a neutron, fission can occur and it breaks apart to produce two smaller nuclei, several neutrons, and a great amount of energy. A chain reaction is produced as fission continues and the neutrons emitted bombard more uranium 235 nuclei. Fission is utilized in nuclear power plants and weapons.



Fusion is the joining of two light nuclei to produce a heavier one. Fusion is the process that powers the sun and the stars. To make fusion occur, the atoms must be heated to very high temperatures to have sufficient energy to fuse. Scientists are trying to develop practical ways to use fusion for electric power generation. If successful, the energy source would be environmentally friendly, producing no combustion products or greenhouse gases. While fusion is a nuclear process, the main products of the fusion reaction (helium and a neutron) are not radioactive.



Student Activity

Materials

- Chocolate flavored cereal puffs
- Corn flavored cereal puffs
- Small paper cups to hold cereal
- Paper plates to place cereal pieces on during fusion/fission process

Source:
http://galileo.phys.virginia.edu/outreach/8thGradeSOL/NuclearReactionsST.htm

Procedure

Fusion Model

1. Take 2 protons (chocolate puffs), and bring them together. In the process of fusing, one proton decays into a neutron and gives off energy. Take 1 proton away and change it into a neutron and energy by eating the chocolate puff (energy for you!) and placing a corn puff neutron next to the chocolate puff proton. This is an isotope of hydrogen called deuterium.
2. Make another atom of deuterium by the fusion process in step 1.
3. Each deuterium nucleus now fuses with another proton (add a chocolate puff to each nuclei). The result is an isotope of Helium called He-3.
4. Now fuse the two He-3 nuclei together (you should have 4 protons and 2 neutrons in your model). This is beryllium-6, but it is unstable and disintegrates into two individual protons and a He-4 nucleus which has 2 protons and 2 neutrons and is known as an alpha particle (represented by the Greek letter alpha: α). Energy in the form of gamma rays (represented by the Greek letter gamma: γ) is also given off in the process.
5. See if you can demonstrate the whole fusion process to a classmate.

Fission Model

1. Begin by making a model of a Uranium-235 nucleus. You will need 92 protons and 143 neutrons. Compare the size of this nucleus to the size of the nuclei used in the fusion process. Only very large atoms are able to undergo fission.
2. Take an additional neutron and allow it to be absorbed by the U-235 nucleus. Now the nucleus will split apart. The result of this fission is Krypton-92 and Barium-141and 3 neutrons and lots of energy. Split your U-235 into a nucleus with 36 protons and 56 neutrons to form the Kr-92 and a nucleus with 56 protons and 85 neutrons to form the Ba-141. You should have 3 neutrons left. In a nuclear reaction, the remaining 3 neutrons would trigger 3 more fission events, setting off a chain reaction.

Extensions

1. A poster can be made to illustrate the fusion process modeled in this activity.
2. A poster can be made to illustrate the fission process modeled in this activity.
3. Research nuclear reactors and their use of the fission process.
4. Research some of the scientists who developed using nuclear fission.

Assessment:

1. Write out a step by step explanation of the process of fission.

2. Write out a step by step explanation of the process of fusion.

3. What are the products of the fission of U-235?

4. Where does fusion naturally occur?

5. Where does the energy that is released come from in a nuclear reaction?

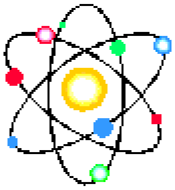
6. How does the Law of Conservation of Matter and Energy apply to nuclear reactions?

Nuclear Chemistry

Activity #2 - Conceptual Fission/Fusion Activity:

Questions:
Motivation for Learning
What is the difference between fission and fusion?

Objectives



Students will
- visualize the process of nuclear fusion;
- visualize the process of nuclear fission.

Teacher Notes:
Background Information
Nuclear fusion is the combining of light elements into heavier ones. Nuclear fission is the splitting of a heavy element into smaller, lighter elements. In both of these processes energy can be released. This demonstration with soap bubbles is limited as a model for fission or fusion because it illustrates only the overall concept. The elements that are missing from the soap bubble model are the neutrons and the energy released during fission, and the protons and energy released during fusion. A nuclear source of energy in nature is the sun. Stars fuse hydrogen atoms into helium atoms and in this process of fusion release energy in the form of electromagnetic radiation.

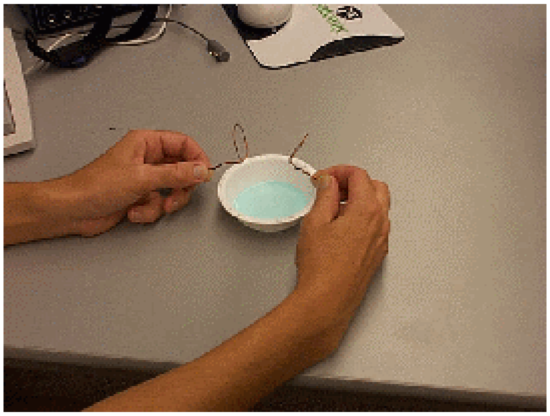
Student Activity
Materials

- 2 mL dish detergent (Joy or Dawn work well)
- 5 mL glycerin
- 6 mL water
- 10 mL Graduated cylinder
- Small plastic tray (approximate capacity of 100 mL, approximately 8 cm in diameter)
- 2 pieces of wire (able to be easily bent), 25 cm in length
- Wood splint

Source:
http://galileo.phys.virginia.edu/education/outreach/8thgradesol/FissionFusion.htm

Procedure

1. Use the graduated cylinder to carefully measure 2 mL dish detergent, 5 mL glycerin, and 6 mL water into the tray. Use the wood splint to stir the liquid until it is of a uniform consistency.
2. Make two bubble wands from the wire pieces. Take each piece of wire and form a 3-4 cm circle at the center of the length, twist the two ends together to form the handle (see diagram).
3. Hold one wire frame in each hand. Dip the two circular wire frames in the solution.
4. Gently blow through each wire frame to create a bubble with a diameter a little larger than the frame, and catch the bubble on the frame.
5. Bring the frames and the bubbles together. Let the bubbles press against each other until they form one large bubble. This illustrates the fusion process.
6. Stretch the bubble by pulling the two frames farther apart until the bubble separates into two bubbles, one in each frame. This demonstrates the fission process. When this is done a little faster a small bubble may be released, illustrating the released neutron.



Assessment

1. What is the name of the nuclear reaction where small elements combine to make larger elements?

2. What is the name of the nuclear reaction where a large element splits into smaller elements?

Nuclear Chemistry

Activity #3 - Personal Exposure to Radiation

Motivation for Learning

List the answers as given by students to the following questions on the board or a transparency:

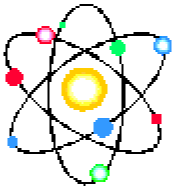
How many useful uses of radiation can you name? (x-rays, food irradiation to eliminate bacteria, smoke alarms, oil discovery, radio waves, TV waves, microwaves, light, etc.).

Can radiation exposure be totally avoided? (no, there is radiation coming from outer space and from material all around us. Our radiation exposure is higher when we fly in airplanes.)

What are some unusual sources of radiation? (smoke alarms, concrete walls, microwaves, TVs)

When is radiation exposure a risk worth taking? (for health reasons: x-rays for teeth and tuberculosis, food irradiation)

Objectives



Students will

- differentiate between naturally occurring and manmade radiation;
- identify different sources of radiation;
- compare amounts of radiation exposure from a variety of common sources;
- identify the three forms of basic radiation protection: time, distance, and shielding.

Teacher Notes:

Background Information

Every day we are exposed to radiation. Radiation is the process of emitting energy in the form of particles or waves. Some forms of radiation are more energetic (and therefore more potentially harmful) than others. The only difference between different waves of the electromagnetic spectrum is the frequency (or amount of energy) of each wave. X-rays are much more energetic than radio waves. Exposure to energetic waves like x-rays should be limited. However, people permit x-ray radiation exposure in order to locate a broken bone or identify medical problems. Some forms of radiation exposure are unavoidable, such as cosmic radiation from outer space.

The basic unit for measuring radiation received is the rad (roentgen absorbed dose). One rad equals the absorption of 100 ergs (erg--a small but measurable amount of energy) in every gram of tissue exposed to radiation. To show biological risk, rads are converted to rems. The rem (roentgen equivalent man) is adjusted to take into account the type of radiation absorbed and the likelihood of damage from the different types of radiation. Exposures are normally in fractions of a rem, so the commonly used unit of exposure is the millirem (mrem). 1 rem =

1000 millirem. Most scientists estimate that the average person in the United States receives a dose of about 360 millirem of radiation per year.
See the two sites given in the Extensions for considerable additional information about nuclear radiation, reactors, radioactive waste, etc. They have lesson plans for teachers.

Student Activity

Materials

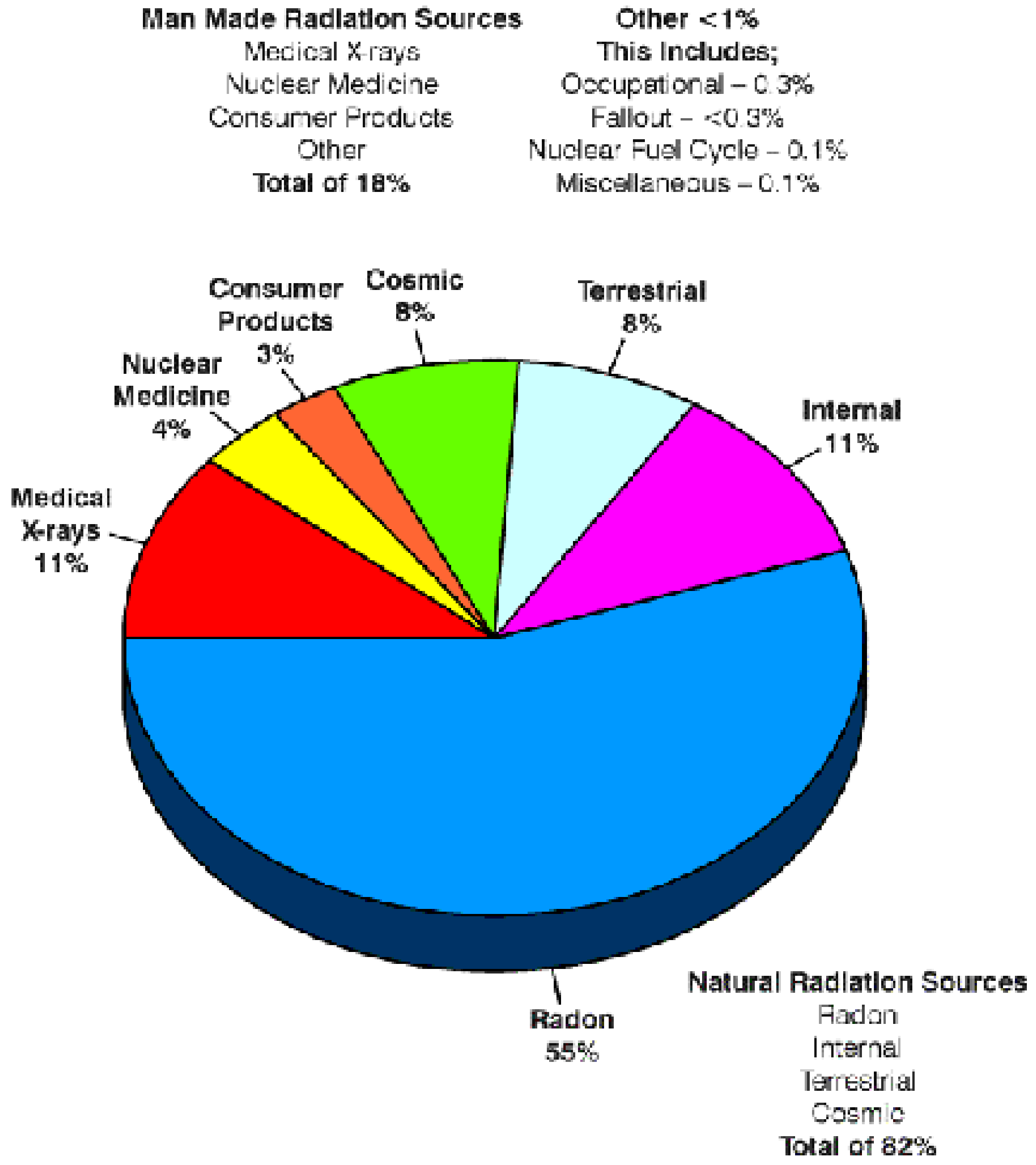
- Ionizing Radiation Exposure to the Public Chart
- Student Activity Sheet: Average Personal Radiation Dose

Source:
http://galileo.phys.virginia.edu/outreach/8thgradesol/RadiationExposureFrm.htm
http://www.nrc.gov/

Procedure

1. Have students list 3 sources of radiation that they think have the most potential danger.
2. Explain that naturally occurring radiation has always been present. Show the chart that lists types of naturally occurring radiation.
3. Describe sources of manmade radiation.
4. Explain the units for radiation exposure: rem and millirem.
5. Have each student fill in their own activity sheet.
6. Allow students to compare sources of radiation that they thought were most dangerous to the chart of radiation exposure doses. How does nuclear energy risk compare to other forms of exposure?

Ionizing Radiation Exposure to the Public



The above chart is taken from the National Council on Radiation Protection and Measurements (NCRP) Report No. 93, "Ionizing Radiation Exposure of the Population of the United States," 1987.

This chart shows that natural sources of radiation account for about 82% of all public exposure while man made sources account for the remaining 18%.

Activity Sheet

Average Personal Radiation Dose
Every day each of us is exposed to radiation: ultraviolet light from the sun, x-rays, warmth from other people, and a vast spectrum of electromagnetic waves. Some of these are very high energy and potentially dangerous. Exposure to these should be limited. Some radiation exposure is unavoidable, such as the cosmic radiation from space. Some radiation is permitted for medical or health benefits. Use the information below to calculate your exposure to radiation for the past calendar year. This is only an estimated value.

Type of Radiation	**Amount of Radiation in mrem**
From Space	
Cosmic radiation at sea level - 26	26
For your elevation (in feet) add:	
1000 feet add 2	
2000 feet add 5	
3000 feet add 9	
4000 feet add 15	
From the Ground	16
(for the Atlantic Gulf Coastal Plain)	
From Food, Water and Air	24
From Building Materials	
If you live in a wooden structure - 5	
If you live in a brick structure -7	
From Jet Plane Travel	
For each 2500 miles add 1	
From Nuclear Fuel Plants	
Average dose is .1 mrem if there are one or more plants in your state.	
Virginia has two nuclear plants.	
From Radioactive Waste Disposal	
Average US dose is 1.0	

From Medical Diagnosis	
x-rays: chest - 6	
pelvis and hips - 65	
arms, hands, legs, feet - 1	
skull, head, neck - 20	
mammogram - 400	
From Cigarette Smoke	
If you are exposed to cigarette smoke on a regular basis add 100-500	
(Add 500 if you are exposed every day for 8 hours or more)	
If you smoke one pack of cigarettes or more a day add 1500	
TOTAL	

Extensions

The United States Nuclear Regulatory Commission has a teacher lesson site that can be downloaded. It contains the figure that we have in this site.

http://www.nrc.gov/

Assessment

1. Each student should complete a Personal Radiation Dose worksheet.
2. Students can report out on their personal radiation worksheets in front of the class.

Nuclear Chemistry

Activity #4 - Alpha Particle Lab

Question:

What is an alpha particle and how are they emitted?

Objective:

The purpose of this experiment is to find the range of alpha particles and determine if the inverse square law applies.

Teacher/student notes:

Introduction

An alpha particle is a nucleus of a helium-4 atom. It has two protons and two neutrons with an atomic mass of 4. The new nucleus that results from alpha decay will have a mass and charge different from those of the parent nucleus. A nucleus which undergoes alpha decay transforms into a new element. This process is called transmutation.

The atomic number changes from 106 to 104. Measurements show that the sum of the masses of the daughter nucleus and the alpha particle is less than the mass of the parent isotope. Recalling Einstein's formula $E=mc^2$, this loss of mass is converted into energy. This form of energy is a positively charged particle moving at high speed. It is easily stopped by paper or your hand.

In this experiment the distances are 0.5 cm, 1.0 cm, 1.5 cm, and 2.0 cm. Data point one equals 0.5 cm. Thus data point two equals 1.0 cm and so on.

Materials:

- Geiger counter
- rail tracker
- Po-210 (alpha source)
- stop watch/beeper
- counting paper or hand counter

Sources:

C:\Documents and Settings\osmtech4\Desktop\Experiment #2 Alpha Please Leave Home.htm

Real world Connection: Radiation is everywhere and it is a natural process.

Procedure:

1. Place alpha radiation source into hole on wooden block of rail tracker.
2. Set digital Geiger counter to one minute intervals and turn power on. Allow the instrument to warm up for a few minutes.
3. Record background activity.
4. Place the instrument on the slider, 0.5 cm from the source.
5. Record counts per minute (cpm) in Table 2.1 for each trial and calculate the average.
6. Move Geiger counter and slider to 1.0 cm from source. Repeat step 5.
7. Move Geiger counter to 1.5 cm and repeat step 5.
8. Move Geiger counter to 2.0 cm and again repeat step 5.
9. Calculate the uncertainty *. Record the calculation in column 8 of Table 2.1. The number following the plus or minus will indicate the error of the measurement.

*Formula for the uncertainty of the number of counts

Uncertainty (counts / time) =

Data

Distance (cm)	Data Points	r^2	Trial 1	Trial 2	Trial 3	Average (cpm)	Uncertainty (cpm)	($1/r^2$) average count of first data point
0.5	1	1						
1.0	2	4						
1.5	3	9						
2.0	4	16						

1. Graph the activity readings (cpm) vs. distance.
2. Graph the activity readings (cpm) vs. $1/r^2$.

Assessment:

Questions

1. At what distance did the alpha radiation count equal that of the background count?
2. What is the charge of the alpha particle? How do you know this?
3. List several reasons why the alpha particle does not travel more than several centimeters.

Going Further

1. What is the mass of an alpha particle compared to an electron?
2. Using "Chart of Nuclides," what distinguishes the daughter isotopes and the particles emitted from each other?

Nuclear Chemistry

Activity # 5 - The Radioactive Decay of "Pennium"

Question:

What is the half-life of the fictitious radioisotope "pennium"?

Objectives:

To understand the concept of isotopes and radioactive decay.

Sources:

Adapted from Glencoe's *Chemistry: Concepts and Applications*

Materials:

100 pennies per group
Plastic cups
1 box per group

Procedure

1. Count 100 pennies. Put them back into the plastic cup.
2. Pour the pennies into the box.
3. Cover the box and shake up and down 20 times while timing this decay process. Record your time in seconds. Assume each decay process takes this same amount of time, so keep adding on this number of seconds to the last time in the table.
4. Uncover the box. Remove all the pennies that are tails up. They represent atoms that have under gone radioactive decay.
5. Count the heads up pennies as you put them back into the plastic cup. These are the undecayed atoms. Record your data in the data table.
6. Repeat steps 4-5 until you have no pennies left.

Data

Time (seconds)	Number of Undecayed Atoms (heads up pennies)
0	100

Graph your data. Place the time on the X-axis and the number of undecayed atoms on the Y-axis. Be sure to label the X and Y-axis. Give your graph a title. Use the entire graph.

Assessment:
Analyze and Conclude

1. Define half-life.

2. What is the half-life of pennium in your experiment?

3. Explain how you arrived at the number in question 2.

Apply and Assess

1. a. Does exactly the same fraction of pennium atoms decay during each half-life?

   b. What does this suggest about half-life?

2. Why are such variations not likely to be obvious when actual atoms are involved?

Nuclear Chemistry
Activity #6 - Candy Half Life

Questions:

Motivation for Learning

How fast does a radioactive isotope decay? How long will it take for a sample to completely transmutate (change) into a new element?

Objectives

Students will

- define the terms isotope and radioactive isotope;
- understand the concept of half-life;
- use the following skills: observing and recording data (observations), inferring from observations, graphing.

Teacher Notes:
Background Information

Most elements have atoms that come in two or more forms called isotopes. Isotopes are atoms of the same element, but with different atomic masses. This occurs because different isotopes have different numbers of neutrons. For example, hydrogen has three isotopes that are listed in the table below.

	Isotope:		
	Hydrogen	**Deuterium**	**Tritium**
Atomic Number	1	1	1
Atomic Mass	1	2	3
# Protons	1	1	1
# Neutrons	0	1	2

Some isotopes are unstable or radioactive. For instance, in the example above, tritium is an unstable isotope of hydrogen. Radioactive isotopes slowly decompose by discarding part of the nucleus. This nuclear decomposing process is called nuclear decay. The length of time required for half of the isotope to decay is the substance's **half-life**. Each radioactive isotope takes its own particular amount of time to decay. However, when the amount of remaining isotope is plotted against time, the resulting curve for every radioisotope has the same general appearance.

Teacher Preparation

1. Purchase a box of resealable plastic bags.
2. Purchase large bags of candy that have one side labeled (Plain M&Ms and Skittles work well).
3. M&Ms and Skittles will work as is, but you could also buy those M&Ms that are sold around a certain major winter holiday - the one closest to New Year's. These M&Ms come in only two colors (red and green) which could signify atoms of different elements. The idea here is to get more than one variety of flat candy that is labeled on one side.
4. This lab requires that the students have some knowledge of atomic structure.

Materials

- 100 candy pieces (The amount of pieces of candy can be adjusted based on the size of the lab group. Give each lab group a distinct kind of candy.)
- Resealable bag
- Stop watch or visible clock that displays seconds
- Graph paper

Sources:
http://galileo.phys.virginia.edu/outreach/8thgradesol/CandyHalfLifeFrm.htm

Student Activity
Procedure

1. Place atoms (candy pieces) in the bag.
2. Seal the bag and gently shake for the specific amount of time that corresponds to the half-life of your candy.
   Half-life of M&Mium (M&Ms) is 1 minute.
   Half-life of Skittlium (Skittles) is 2 minutes.
3. Gently pour out candy.
4. Count the number of pieces with the print side up. These atoms have "decayed."
5. Return only the pieces with the print side down to the bag. Reseal the bag.
6. Record the time. (For M&Ms it would be 10 seconds on the first trial. On the second trial it would be 20 seconds (10 + 10). On the third trial it would be 30 seconds (10 + 10 + 10) and so on).
7. Consume the "decayed" atoms.
8. Gently shake the sealed bag again for the prescribed amount of time.
9. Continue shaking, counting, and consuming until all the atoms have decayed.
10. Graph the number of undecayed atoms vs. time.

Half-Life	Total Time	# of Undecayed Atoms	# of Decayed Atoms
0	0		0
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Using a whole sheet of graph paper and the data above, make a graph with time on the x-axis and number of atoms on the y-axis.

Extensions

Repeat the experiment starting with 50 atoms and 75 pieces of candy. Compare the resulting graphs. (The graphs can be plotted on the same paper used for the first graph.

Assessment

(Please write complete sentences):

1. Define half-life in your own words.
1. In the experiment, what was the half-life of the isotope M&Mium? Skittlium?

3. At the end of 2 half-lives, what fraction of the atoms had not decayed?

4. Describe the shape of the curve from the graph of your data?

5. As a class, compare and contrast the graphs made by the different lab groups.

Answers to Assessment

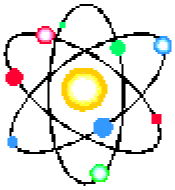
1. Half-life is the length of time required for one half of the isotope to decay.
2. The half-life of M&Mium in this activity was 10 seconds. The half-life of Skittlium in this activity was 20 seconds.
3. At the end of two half-lives 1/4 of the original sample remained; 3/4 of the sample had decayed into a new element.
4. The graph is a decreasing logarithmic curve.
5. The graphs will be almost the same.

Nuclear Chemistry
Activity #7 - Protection from Radiation

Questions:
Motivation for Learning

What are nuclear reaction products? Are all forms of radiation equal? What types of protection exist for exposure to radiation? Ask the students some of these questions and try to obtain a response. What do they know about radiation? Most of them will think it is bad. Some of them may know that radiation is used to treat some forms of cancer, and from that standpoint, is considered good.

Objectives



Students will

- define alpha particles, beta particles, gamma waves;
- compare penetrating ability of alpha particles, beta particles, gamma waves;
- identify various types of protective shielding for radiation;
- identify hazards presented by radiation

Teacher Notes:
Background Information

Radiation is energy being emitted in the form of particles or waves. Radiation is emitted from atoms and nuclei that are changing their energy states. Most radiation is naturally occurring; some radiation is manmade. In general, the following kinds of radiation are monitored for purposes of radiation protection: alpha particles, beta particles, gamma rays, x-rays and neutrons.

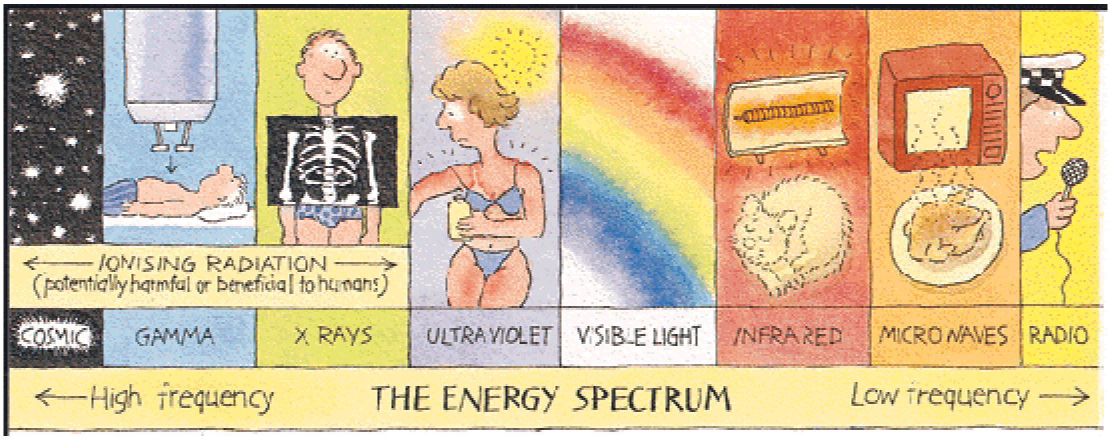
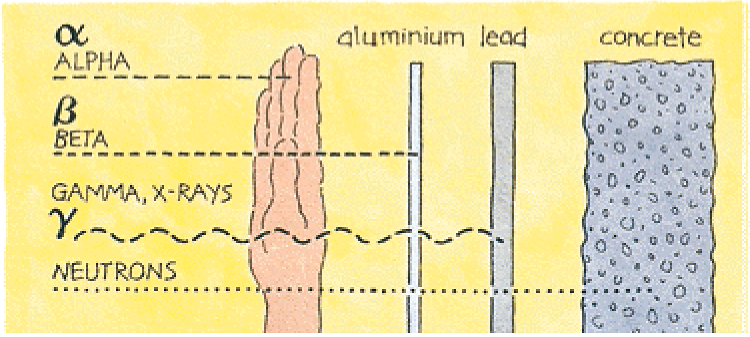


Illustration used by permission of the Uranium Information Centre, Melbourne, Australia

An alpha particle (a) consists of two protons and two neutrons (a helium nucleus). It has a relatively large mass and a positive charge. Alpha particles are easily shielded by a piece of paper or human skin. Therefore, health effects of alpha exposure occur only when the particles are inhaled, ingested, or enter the body through a cut in the skin. More serious would be a material that is radioactive (alpha emitter) that is ingested into the body. The alpha particles emitted inside the body, for example in bone marrow, can be exceedingly dangerous.

Beta particles (b) are fast electrons produced following nuclear decay of certain radioactive materials. The amount of energy (speed) that a beta particle contains determines its penetrating capacity. Six millimeters of aluminum are needed to stop most b particles.

Gamma rays (g), an electromagnetic wave, are similar in form to visible light and radio waves. However, gamma waves are very energetic and have a far shorter wavelength. Gamma rays are produced from radioactive decay, in nuclear reactions, and in fission. Gamma rays are dangerous because they have great penetrating ability. Several millimeters of lead are needed to stop g rays.



Various types of shielding for different nuclear particles

Illustration used by permission of the Uranium Information Centre, Melbourne, Australia

Radiation is measured in two units - rads and rems. A rad stands for "radiation absorbed dose" and measures the amount of energy that is actually absorbed per unit mass. A rem stands for "roentgen equivalent man" and is a unit that measures the absorbed dose in human tissue and relates it to the effective damage done to your tissue. It is significant because not all radiation has the same biological effect. The radioactivity of a source is usually measured in how many rads or rems you would receive per hour; a Geiger counter normally measures radiation in millirems per hour (mr/hr).

X-rays have the same characteristics as gamma ways, but they are produced differently. In 1895, Wilhelm Roentgen observed that when high-speed electrons hit metals, the electrons stopped and released an electromagnetic wave. He named this energy wave an **x ray**.

Neutrons are released during the nuclear fission process and during certain nuclear reactions. Neutrons trigger the nuclear chain reaction. Neutrons do not carry an electrical charge. However, when the neutrons hit the nucleus of hydrogen (a constituent of water molecules in cells), ionizations that can lead to damage can occur.

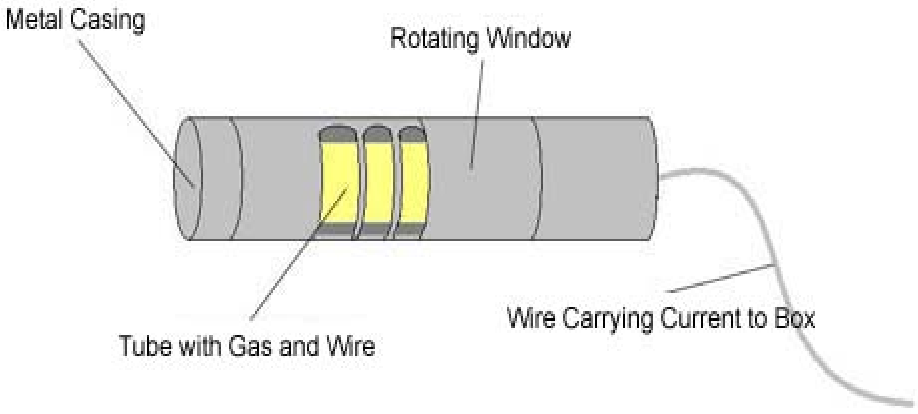
There are three basic forms of protection from radiation: time, distance and shielding. The amount of time spent near a source of radiation affects the amount of exposure received. The farther the distance from the radiation source, the less the amount of exposure will be. A shield (specific to the type of radiation) can limit the exposure to radiation.

When dealing with radiation, it is important for scientists to know where it exists, and how much is present. A Geiger counter is an instrument that does just this - it detects when radiation is present, and tells us how much is present by electronically counting the number of radioactive particles that interact with the counter. It is useful because it can measure very low levels of radioactivity.

To know how it works, you must first be familiar with the construction of a common Geiger counter. The counter uses a metal tube usually containing a wire at the center with high voltage and a gas that is ionized by particles passing through it. The ionized particles are collected as a current, and the electronics inside the box amplifies the pulse to where it can be recorded.

Geiger counters are more useful for detecting beta particles and gammas. Most counters cannot detect alpha particles. Remember that alpha particles are easily shielded. For this reason, the Geiger counter tube has to be made with a special window, or else the window itself will block the alpha particles and they won't be detected. Secondly, the counter must be held steady for several seconds at the same distance in order for us to obtain a good reading. Moving the counter around will change the number of particles that enter the tube; so make sure that you hold the tube the same distance from each object that you are trying to measure, or else your results will not be accurate. A third disadvantage of a Geiger counter is that it cannot measure very high amounts of radiation; in fact, the machine can be damaged if you expose it to an extremely high radiation, but that is unlikely in our case.

Geiger Counter Tube



An excellent Geiger counter to use in student experiments is the CD V-700, because thousands of them were made in the 50s and 60s for civil defense. The American Nuclear Society gives each teacher a Geiger counter who takes their workshop. Another similar instrument is called a Survey Meter. A survey meter is similar to a Geiger counter, except that it is used to measure very high levels of radiation. However, a survey meter cannot measure very low levels of radiation, so it is not very useful in classroom experiments.

Student Activity
Materials

- Geiger counter
- Radioactive sources such as:
  - Gas lantern mantle
  - Fiesta ware pottery (orange glaze)
  - Luminescent clock face
  - Smoke detector
  - Commercially available radioactive source from science supplier
- Shielding materials such as:
  - Paper
  - Aluminum foil
  - Brick
  - Jar of water
  - Piece of wood
  - Sheet of lead

Source:
http://galileo.phys.virginia.edu/outreach/8thgradesol/RadiationProtectionFrm.htm

Procedure

1. Set up the Geiger counter according to the unit's instructions; be sure it is calibrated.
2. Test each source item by placing the item 5 cm away from the Geiger counter probe. Keep the probe steady for 15 seconds, and find the average reading on the meter. The needle will shift around some, so choose a value in the middle of its oscillations. Record your findings in the data table.
3. Select the three source items with the highest readings. One at a time, place the source far enough away from the Geiger counter probe so that you will be able to fit the thickest piece of shielding in between the probe and the source. Test each of the shielding materials by placing them between the source and the counter. Follow the same procedure as in step 2 when taking the reading. Remember to keep the probe at the same distance for each measurement. Record your findings in the data table along with the thickness of each type of shielding that you use.
4. Answer the questions on the worksheet after you have recorded your findings.

Data Table

Source	**Without Shielding**	**Paper**	**Aluminum**	**Brick**	**Jar of Water**	**Wood**	**Lead**
Gas lantern mantel							
Fiesta ware pottery							
Luminescent clock face							
Smoke detector							

Questions

1. Which item had the highest reading?

2. Which item had the lowest reading?

3. Do you think the density of the shield was important? Why?

4. Do you think the thickness of the shield was important? Why?

Extensions

1. Do experiments for different thickness of the same absorbing material.
2. Do the experiment for various distances from the source. Make a graph and describe the result.

Assessment

1. Each student should complete a data table and the questions on the worksheet.
2. If you were designing a building to protect the occupants from alpha particles, what type of shielding would you need to consider?
3. If you were designing a building (or a room) to protect the workers from beta particles, what type of shielding would you include in your project?
4. Why do x-ray technicians stand behind a lead barrier when they take an x-ray of someone?

Nuclear Chemistry Activity #8

The Band of Stability

- *Students know* how to relate the position of an element in the periodic table to its atomic number and atomic mass.
- *Students know* protons and neutrons in the nucleus are held together by nuclear forces that overcome the electromagnetic repulsion between the protons.
- *Students know* some naturally occurring isotopes of elements are radioactive, as are isotopes formed in nuclear reactions.
- *Students know* the three most common forms of radioactive decay (alpha, beta, and gamma) and know how the nucleus changes in each type of decay.

Introduction

Radioactive decay changes the nature of an atom's nucleus, and it happens for a reason. Each element from hydrogen (atomic number 1) to lead (atomic number 82) has stable isotopes in which the tendency of protons to repel one another is overcome by attractive nuclear forces. These attractive nuclear forces require ideal distances between the protons. The neutrons help create these ideal distances. If there are too few neutrons, or too many neutrons, the nucleus becomes unstable.

If an atom has more than 82 protons in the nucleus, there is no arrangement of neutrons that can produce more attractive forces than repulsive forces. Therefore, all isotopes of elements beyond lead are radioactive. Their only route to stability is to first reduce the overall size of the nucleus by losing large particles called "alpha particles."

Example:

$$^{210}_{84}Po \;+\; \rightarrow {}^{206}_{82}Pb \;+\; {}^{4}_{2}He$$

Atoms that have fewer than 82 protons will undergo decay that alters the proton/neutron ratio. Neutrons may be converted to protons by losing a beta particle (essentially an electron).

Example:

$$^{1}_{0}n \;\rightarrow\; {}^{1}_{1}p \;+\; {}^{0}_{-1}\beta$$

Protons may be converted to electrons by positron emission. A positron is the anti-particle of the electron.

Example:

$$^{1}_{1}p \;\rightarrow\; {}^{1}_{0}n \;+\; {}^{0}_{+1}\beta$$

Protons may also be converted to neutrons through the process of electron capture.

Example:

$$^{1}_{1}p \;+\; {}^{0}_{-1}e \rightarrow {}^{1}_{0}n$$

Radioactive decay also often has associated with it the release of gamma radiation (γ). Gamma radiation is pure energy, of very short wavelength and very high energy. Since it does not have mass, it does not on its own change the nature of the nucleus. For this reason, it is often omitted from equations where is should appear. An example is the first equation on this sheet:

Example:

$$^{210}_{84}Po \;+\; \rightarrow {}^{206}_{82}Pb \;+\; {}^{4}_{2}He + {}^{0}_{0}\gamma$$

Part 1 – Create a "Band of Stability"

You will be graphing the proton and neutron numbers for some isotopes that are known to be stable.

1. Using an entire side of a piece of graph paper, draw a vertical "y" axis and label it "Neutrons." Draw a horizontal "x" axis and label it "Protons". (1 point each)
2. Scale the y-axis so that it goes from 0 to 150. (1 point)
3. Scale the x-axis so that it goes from 0 to 100. (1 point)
4. On a piece of binder paper, complete the following table (2 points):

Stable Isotope	***Atomic Number***	***Protons (X axis)***	***Neutrons (Y axis)***
Helium – 4			
Carbon – 12			
Silicon – 28			
Scandium – 45			
Iron – 56			
Silver – 109			
Xenon – 131			
Gadolinium – 160			
Tungsten – 184			
Lead – 206			

Note that this is only a small part of the list of stable isotopes. From hydrogen to lead, there are currently *243* isotopes identified as stable.

5. Plot the points that result from the table above, in the form (x,y), on your graph. (2 points)
6. Draw a bold curve through the points, creating as smooth a curve as possible. (1 point)

Part 2 – Unstable Isotopes

1. On a piece of binder paper, complete the following table (2 points):

Unstable Isotope	***Atomic Number***	***Protons (X axis)***	***Neutrons (Y axis)***
Carbon – 14			
Silicon – 32			
Iron – 52			
Xenon – 135			
Lead - 214			
Radium – 226			

Note that this is only a small part of the list of unstable isotopes. There are about *70 naturally occurring* isotopes identified as unstable, and MANY more that are the result of processes such as nuclear fission.

2. Plot the points that result from the table above, in the form (x,y), on your graph. Label each point with the identity of the isotope that it represents. (2 points)
3. On your binder paper:
   a) For each isotope in the table above, identify a type of decay that could begin to move the isotope toward the band of stability (1 point each)
   b) Write a nuclear decay equation for each isotope undergoing the type of decay that you have indicated. If you ask nicely, your instructor may help you with this ☺. (1 point each)
4. Your paper will be turned in with your name, date and period on top of the binder paper, and the graph paper attached to the back of it.

Name_________________________________ Per _____

Nuclear decay

Fill in the blanks to complete the following nuclear reactions. Use a periodic table.

1. $^{42}_{19}K \rightarrow {}^{0}_{-1}e +$ ____________
2. $^{239}_{\_\_}Pu \rightarrow {}^{4}_{2}He +$ ________
3. $^{235}_{92}U \rightarrow$ __________ $+ {}^{231}_{90}Th$
4. $^{1}_{1}H + {}^{3}_{1}H \rightarrow$ __________
5. $^{6}_{3}Li + {}^{1}_{0}n \rightarrow {}^{0}_{-1}e\ {}^{4}_{2}He +$ _________
6. $^{27}_{13}Al + {}^{4}_{2}He \rightarrow {}^{30}_{15}P +$ _________
7. $^{9}_{4}Be + {}^{1}_{1}H \rightarrow$ __________ $+ {}^{4}_{2}He$
8. $^{37}_{\_\_}K \rightarrow {}^{0}_{+1}e +$ __________
9. ________ $+ {}^{1}_{0}n \rightarrow {}^{142}_{56}Ba + {}^{91}_{36}Kr + 3\,{}^{1}_{0}n$
10. $^{238}_{92}U + {}^{4}_{2}He \rightarrow$ __________ $+ {}^{1}_{0}n$
11. $^{99}_{43}Tc \rightarrow$ _____ $+ {}^{0}_{-1}e$
12. $^{226}_{88}Ra \rightarrow {}^{4}_{2}He +$ _________
13. __________ $\rightarrow {}^{4}_{2}He + {}^{208}_{81}Tl$
14. $^{27}_{13}Al +$ _________ $\rightarrow {}^{24}_{11}Na + {}^{4}_{2}He$
15. $^{235}_{92}U + {}^{1}_{0}n \rightarrow 3\,{}^{1}_{0}n + {}^{139}_{56}Ba +$ _________
16. $^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{139}_{53}I + 2\,{}^{1}_{0}n +$ _________
17. $^{241}_{95}Am + {}^{4}_{2}He \rightarrow 2\,{}^{1}_{0}n +$ _________
18. $^{214}_{84}Po + 2\,{}^{4}_{2}He + 2\,{}^{0}_{-1}e \rightarrow$ __________

Resources for Chemistry Teachers

Resource List

http://www.hschem.org/Resources/links.htm

lab safety article

http://www.cpsc.gov/CPSCPUB/PUBS/NIOSH2007107.pdf

Nuclear Chemistry

http://www.nclark.net/NuclearChem

Chemistry Resources Topics
http://www.chemtopics.com/unit11/unit11.htm

Chemistry: The Science In Context
http://www2.wwnorton.com/college/chemistry/gilbert/tutorials/ch2.htm

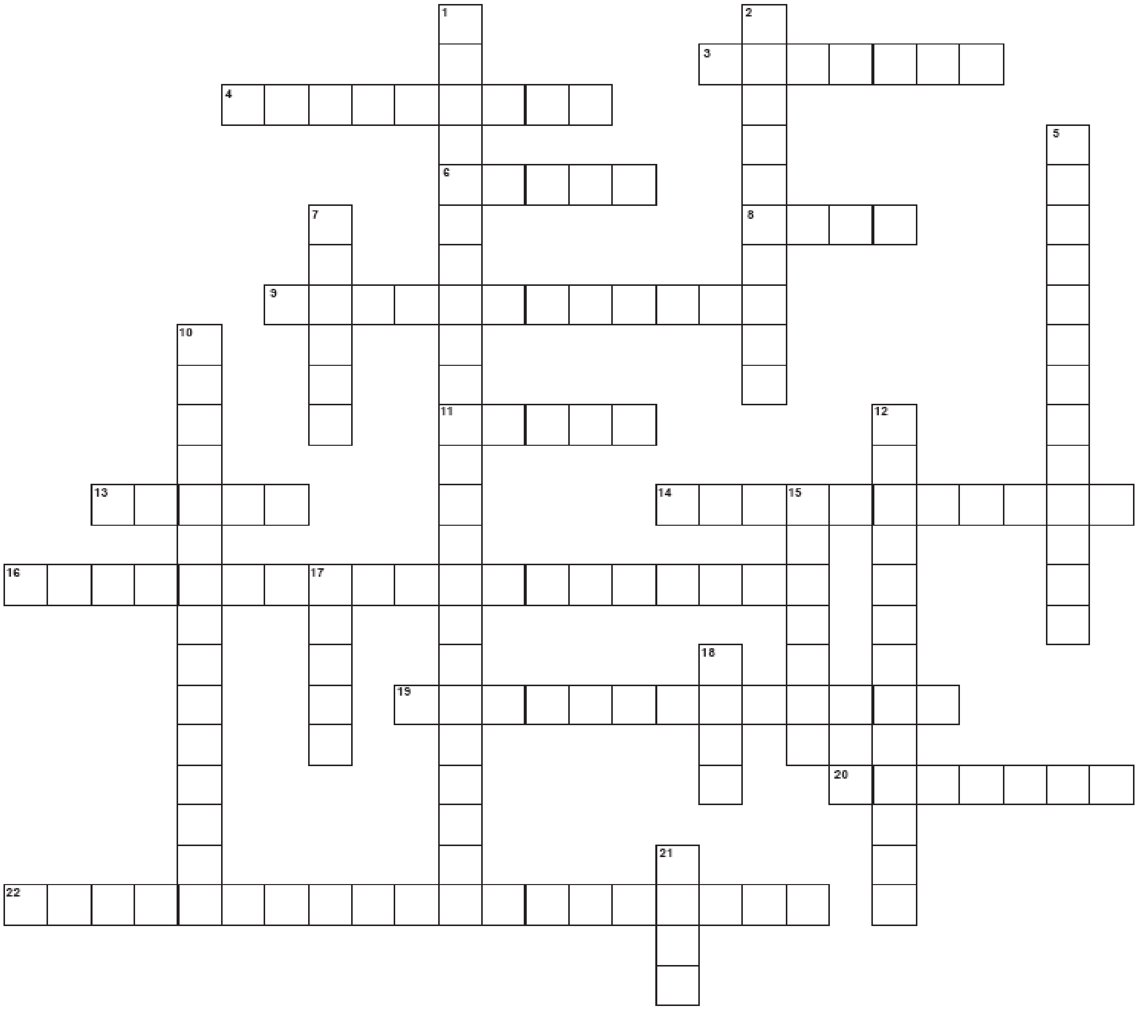
Cheap smoke detector and lantern mantle have radiation sources that can be used.

Uncontrolled and controlled nuclear reaction demonstration

Materials: matches, ring-stand, metal bar, clamp

Tape the open match packs in a line on the metal bar and clamp the metal bar to the ring-stand. Light the lowest match and watch the reaction propagate from the bottom up. This represents an uncontrolled nuclear reaction like a nuclear bomb. To represent a controlled nuclear reaction (like a nuclear power plant) interstice “blank matches” (matches with the head removed) between normal matches. This will allow you to control the reaction by controlling the rate of propagation. These “blank matches” represent control rods in a nuclear reactor. Be sure to do this demonstration in a fume hood or in a well-ventilated area as it produces copious amounts of smoke.

ATOMIC CROSSWORD



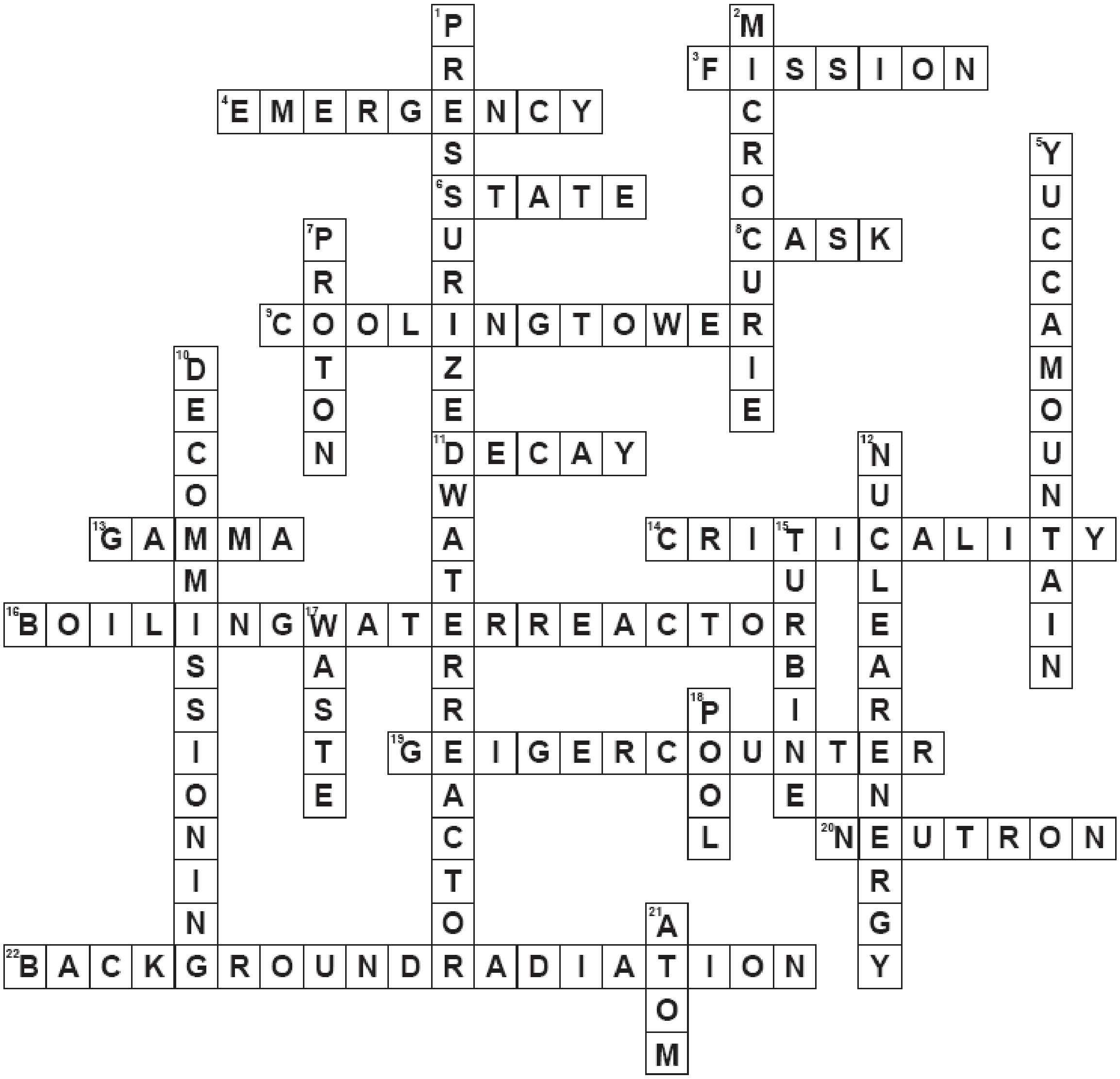
ACROSS

3. Splitting of atoms into smaller pieces
4. Owners of nuclear power plants must have ____ plans to practice how workers and residents handle this
6. The Low-Level Radioactive Waste Policy Act passed by the U.S. Congress in 1980 requires each ____ to provide for disposal of the low-level waste produced within its borders
8. Heavily shielded container used to store and/or ship radioactive materials
9. Removes excess heat from the reactor's circulating water system
11. The decrease in the amount of radioactive material with the passage of time
13. Penetrating rays that are best stopped or shielded by dense material
14. Reactor physics term describing the state when the number of neutrons released by fission is exactly balanced by the neutrons being absorbed by the fuel and poisons and escaping the reactor core
16. A reactor in which water, used as both coolant and moderator, is allowed to boil in the core
19. A radiation detection and measuring instrument
20. An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen
22. Comes from cosmic sources; naturally occurring radioactive materials, and global fallout as it exists in the environment from the testing of nuclear explosive devices

DOWN

1. Reactor that keeps water under pressure so that it heats, but does not boil
2. One millionth of a curie
5. Proposed high-level waste disposal site in Nevada
7. An elementary nuclear particle with a positive electric charge located in the nucleus of an atom
10. Shutting down a plant and reducing the level of radiation so that the land can be used for other purposes
12. Energy liberated by a nuclear reaction (fission or fusion) or by radioactive decay
15. A rotary engine made with a series of curved vanes on a rotating shaft, usually turned by water or steam
17. One of the main concerns about nuclear powerplants is what to do with the _____
18. Spent fuel that is stored inside a nuclear power plant goes in this
21. The smallest particle of an element that cannot be divided or broken up by chemical means

ATOMIC CROSSWORD



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http://www.lapeer.lib.mi.us/chemcom/Unit5/W5C5.html

Nuclear Energy Worksheet #1

1. Approximately when did scientists first cause fission?

2. Give two nuclear fission reactions:

3. Name the only naturally-occurring isotope that undergoes fission.

4. How does the amount of energy produced by fission compare to the energy released by ordinary chemical reactions?

5. In ordinary chemical and physical reactions changes, there is no overall change in the total ________; there also is no change in the total __________.

6. In nuclear reactions a lot of energy is released as the total _________ decreases.

7. If one gram of matter were completely converted into energy (according to Einstein's famous equation $E = mc^2$), the amount of energy would equal what?

8. Each time a nucleus undergoes fission, two or three ____________ are emitted.

9. Suppose you have some fissionable material. What would be true if you have a critical mass of it?

10. How many commercial nuclear power plants are producing electricity in the U.S.?

11. What percent of the U.S. electricity is generated in nuclear power plants?

12. In most nuclear power plants the <u>heat energy</u> released from fission is used to do what?

13. How often are fuel rods loaded into a nuclear reactor?

14. What percent of the uranium atoms in reactor fuel are fissionable U-235 atoms?

15. What percent of the uranium atoms in atom bombs are fissionable U-235 atoms?

16. The U in fuel rods is in what chemical compound?

17. What do control rods do to the neutrons that zoom around in a nuclear reactor?

http://www.lapeer.lib.mi.us/chemcom/Unit5/W5C6A.html

Nuclear Fusion Worksheet

1. Nuclear fusion involves the formation of a new, more _________ atom by forcing two less-_________ nuclei to combine.

2. The energy released from fusion can be enormous due to the conversion of __________ into __________.

3. In the sun, hydrogen begins to "fuse" when the temperature reaches WHAT?

4. What force causes the temperature of a star to get so high?

5. The energy released when 1 gram of H-1 fuses equals WHAT?

6. What is the ONLY use people have made of the energy of fusion?

7. A hydrogen bomb is called a ____________ device.

8. How long have scientists been trying to harness fusion to produce electricity?

9. What remains as the biggest problem with controlling fusion?

10. Is there any problem with scarcity of fuel for fusion?

11. WHAT would cause the containment wall (of a fusion reactor) to become radioactive?

12. Since the containment wall (and other parts of the reactor) can become radioactive, how does the expected <u>volume</u> of radioactive waste produced by fusion compare with the <u>volume</u> of waste produced by fission?

http://www.lapeer.lib.mi.us/chemcom/Unit5/W5C6A.html