Oakland Schools Chemistry Resource Unit

Atomic Theory & Structure

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Atomic Theory and Structure

Content Statements:

C4.8 *Atomic Structure*

Electrons, protons, and neutrons are parts of the atom and have measurable properties, including mass and, in the case of protons and electrons, charge. The nuclei of atoms are composed of protons and neutrons. A kind of force that is only evident at nuclear distances holds the particles of the nucleus together against the electrical repulsion between the protons.

C4.10 *Neutral Atoms, Ions, and Isotopes*

A neutral atom of any element will contain the same number of protons and electrons. Ions are charged particles with an unequal number of protons and electrons. Isotopes are atoms of the same element with different numbers of neutrons and essentially the same chemical and physical properties.

C4.10x *Average Atomic Mass*

The atomic mass listed on the periodic table is an average mass for all the different isotopes that exist, taking into account the percent and mass of each different isotope.

Content Expectations:

C4.8A - Identify the location, relative mass, and charge for electrons, protons, and neutrons.

C4.8B - Describe the atom as mostly empty space with an extremely small, dense nucleus consisting of the protons and neutrons and an electron cloud surrounding the nucleus.

C4.8C - Recognize that protons repel each other and that a strong force needs to be present to keep the nucleus intact.

C4.8D - Give the number of electrons and protons present if the fluoride ion has a -1 charge.

C4.10A - List the number of protons, neutrons, and electrons for any given ion or isotope.

C4.10B - Recognize that an element always contains the same number of protons.

C4.10c - Calculate the average atomic mass of an element given the percent abundance and the mass of the individual isotopes.

C4.10d - Predict which isotope will have the greatest abundance given the possible isotopes for an element and the average atomic mass in the periodic table.

C4.10e - Write the symbol for an isotope, $^{A}X_{Z}$, where Z is the atomic number, A is the mass number, and X is the symbol for the element.

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Instructional Background Information

Parts of the atoms

Electrons are the negatively charged particles of atoms. Together, all of the electrons of an atom create a negative charge that balances the positive charge of the protons in the atomic nucleus. Electrons are extremely small compared to all of the other parts of the atom. The mass of an electron is almost 1,000 times smaller than the mass of a proton.
Electrons are found in clouds that surround the nucleus of an atom. Because electrons move so quickly, it is impossible to see where they are at a specific moment in time. After years of experimentation, scientists discovered specific areas where electrons are likely to be found. These shells change depending on how many electrons an element has. The higher the atomic number, the more shells and electrons an atom will have.

Atomic number is the number of protons in the nucleus

Mass number is the mass of an individual atom. Mass number is the number of protons plus the number of neutrons.

Atomic mass is the "weight" or mass of a single atom.

Atomic mass units (amu) are "invented" measurement units of the atomic mass.

Examples of Atomic Mass Units (amu)

1. Proton: 1.673×10^{-24} g ${}_{1}p^{1}$ = 1 amu
2. Neutron: 1.675×10^{-24} g ${}_{0}n^{1}$ = 1 amu
3. Electron: 9.11×10^{-28} g ${}_{-1}e^{0}$ mass is negligible

Atomic weight is the decimal number on the periodic table. This is the weighted average of the atomic masses of different isotopes which takes into account their abundance.

A neutron is an uncharged (electrically neutral) subatomic particle with mass 1,839 times that of the electron. Neutrons are stable when bound in an atomic nucleus, whilst having a mean lifetime of approximately 1000 seconds as a free particle. The neutron and the proton form nearly the entire mass of atomic nuclei, so they are both called nucleons.

Isotopes are atoms of the same element that have different numbers of neutrons.

Weighted average is an average in which each quantity to be averaged is assigned a weight. These weightings determine the relative importance of each quantity on the average. Weightings are the equivalent of having that many like items with the same value involved in the average.

Ions

An atom or group of atoms that carries a positive or negative electric charge as a result of having lost or gained one or more electrons.

Predicting ion charges

Source:
General Chemistry Online
http://hyperphysics.phy-astr.gsu.edu/hbase/forces/funfor.html

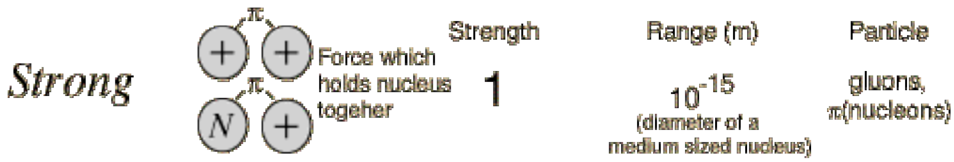
- Metal ion charges:
- Metals lose electrons to get the same number of electrons as the nearest noble gas.
  - This rule works only if predicted charge is +3 or less. If the charge is greater than +3, more than one common cation usually exists in this case.
- Nonmetal ion charges:
  Nonmetals gain electrons to get the same number of electrons as the nearest noble gas.
  - This rule works only if predicted charge is -3 or less.
    Nonmetals that break this rule usually form covalent, not ionic, compounds.
- when the rules don't help, get charges from a formula for a compound of the ion

Forces within an atom

Source:
HyperPhysics
http://hyperphysics.phy-astr.gsu.edu/hbase/forces/funfor.html

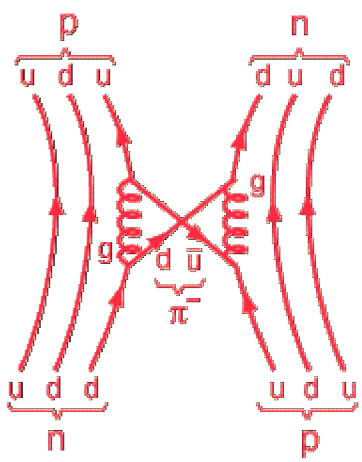
The Strong Nuclear Force (also referred to as the strong force) is one of the four basic forces in nature (the others being gravity, the electromagnetic force, and the weak nuclear force). As its name implies, it is the strongest of the four. However, it also has the shortest range, meaning that particles must be extremely close before its effects are felt. Its main job is to hold together the subatomic particles of the nucleus (protons, which carry a positive charge, and neutrons, which carry no charge. These particles are collectively called nucleons). As most people learn in their science education, like charges repel (+ +, or - -), and unlike charges attract (+ -).

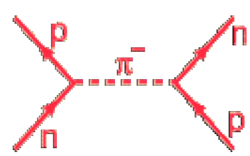
The Strong Force



A force which can hold a nucleus together against the enormous forces of repulsion of the protons is strong indeed. However, it is not an inverse square force like the electromagnetic force and it has a very short range. Yukawa modeled the strong force as an exchange force in which the exchange particles are pions and other heavier particles. The range of a particle exchange force is limited by the uncertainty principle. It is the strongest of the four fundamental forces

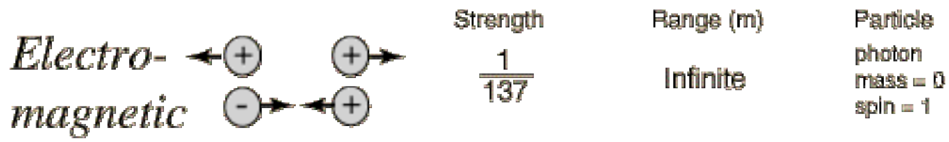
Since the protons and neutrons which make up the nucleus are themselves considered to be made up of quarks, and the quarks are considered to be held together by the color force, the strong force between nucleons may be considered to be a residual color force. In the standard model, therefore, the basic exchange particle is the gluon which mediates the forces between quarks. Since the individual gluons and quarks are contained within the proton or neutron, the masses attributed to them cannot be used in the range relationship to predict the range of the force. When something is viewed as emerging from a proton or neutron, then it must be at least a quark-antiquark pair, so it is then plausible that the pion as the lightest meson should serve as a predictor of the maximum range of the strong force between nucleons.



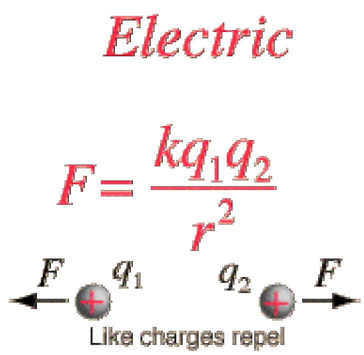


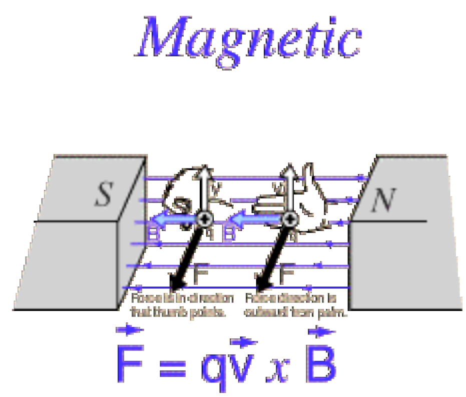
The sketch is an attempt to show one of many forms the gluon interaction between nucleons could take, this one involving up-antiup pair production and annihilation and producing a π^- bridging the nucleons.

The Electromagnetic Force



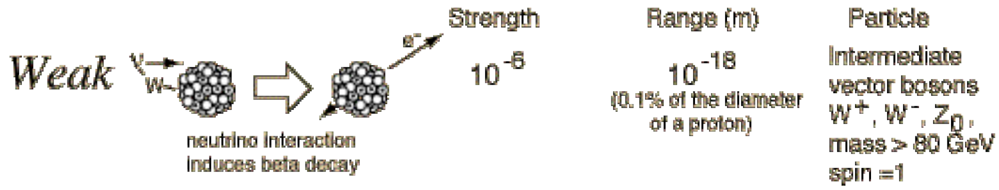
One of the four fundamental forces, the electromagnetic force manifests itself through the forces between charges (Coulomb's Law) and the magnetic force, both of which are summarized in the Lorentz force law. Fundamentally, both magnetic and electric forces are manifestations of an exchange force involving the exchange of photons. The quantum approach to the electromagnetic force is called quantum electrodynamics or QED. The electromagnetic force is a force of infinite range which obeys the inverse square law, and is of the same form as the gravity force.





The electromagnetic force holds atoms and molecules together. In fact, the forces of electric attraction and repulsion of electric charges are so dominant over the other three fundamental forces that they can be considered to be negligible as determiners of atomic and molecular structure. Even magnetic effects are usually apparent only at high resolutions, and as small corrections.

The Weak Force



One of the four fundamental forces, the weak interaction involves the exchange of the intermediate vector bosons, the W and the Z. Since the mass of these particles is on the order of 80 GeV, the uncertainty principle dictates a range of about 10^{-18} meters which is about 0.1% of the diameter of a proton.

The weak interaction changes one flavor of quark into another. It is crucial to the structure of the universe in that

1. The sun would not burn without it since the weak interaction causes the transmutation p -> n so that deuterium can form and deuterium fusion can take place.
2. It is necessary for the buildup of heavy nuclei.

The role of the weak force in the transmutation of quarks makes it the interaction involved in many decays of nuclear particles which require a change of a quark from one flavor to another. It was in radioactive decay such as beta decay that the existence of the weak interaction was first revealed. The weak interaction is the only process in which a quark can change to another quark, or a lepton to another lepton - the so-called "flavor changes".

The discovery of the W and Z particles in 1983 was hailed as a confirmation of the theories which connect the weak force to the electromagnetic force in electroweak unification.

The weak interaction acts between both quarks and leptons, whereas the strong force does not act between leptons. "Leptons have no color, so they do not participate in the strong interactions; neutrinos have no charge, so they experience no electromagnetic forces; but all of them join in the weak interactions."(Griffiths)

Henry Moseley (1887-1915) made many important contributions to science, including demonstrating that atomic numbers were not arbitrary but had a physical basis that could be measured. This breakthrough (Moseley's Law) would enable the elements in the periodic table to be put in their correct order and the existence of as-yet-unknown elements to be accurately predicted. His work ... provided one of the first experimental tests of quantum theory. Many believe that, had he lived, Moseley would have been awarded the Nobel Prize.

Bohr's theory that electrons existed in set orbits around the nucleus was the key to the periodic repetition of properties of the elements. The shells in which electrons orbit have different quantum numbers and hold only certain numbers of electrons -- the first shell holds no more than 2, the second shell up to 8, the third 10, the fourth 14. Atoms with less than the maximum number in their outer shells are less stable than those with "full" outer shells. Elements that have the same number of electrons in their outermost shells appear in the same column in the periodic table of elements and tend to have similar chemical properties.

Historical Summary

Source: Moodle Online Learning (Craig Riesen @ Clarenceville High School)
http://www.clarenceville.k12.mi.us/

Democritus (400 BC)

1. Matter consists of discrete, individual particles
2. Democritus held a very general theory with no experimental evidence
3. Democritus' ideas were rejected by Plato & Aristotle (*fathers of philosophy and ancient "scientific thinking"*)… and therefore, forgotten

Gassendi (1650 AD)

1. Italy
2. Supported by Newton in his view of a particle nature of matter

Dalton's Theory (1806 AD)

- Dalton explained several of the contemporary laws of chemistry which evolved into part of the modern Atomic The

1. An element is composed of extremely small particles called "atoms." All atoms of a given element show the same chemical properties.
    a. The oxygen atom has a diameter of 10^{-8} cm and a mass of 10^{-23} g.
    b. All oxygen atoms behave chemically the same.
2. Atoms of different elements have different properties.
    a. Metals, non-metals, metalloids, inert gases
    b. Isolated hydrogen is explosive; Helium is basically unreactive.

3. In the course of an ordinary chemical reaction, no atom of one element disappears or is changed into an atom of another element.
    a. "Mingling" → hydrogen and oxygen can react together to form water, which is a new molecule, but hydrogen remains hydrogen and oxygen remains oxygen.
    b. No new element is formed from ordinary chemical reactions.
4. Compound substances are formed when atoms of more than one element combine.
    a. In a given pure compound, the relative numbers of atoms of the elements present will be definite and constant (expressed as whole numbers integers)
    b. Water is composed of 2 Hydrogen atoms and 1 Oxygen atom [H_20].
    c. Ammonia is composed of 1 Nitrogen atom and 3 Hydrogen atoms [NH_3].

Components of the Atom

A. Review of Electrical Charge

- What causes matter to be different and diversified?
- Why do different kinds of matter behave differently?

1. Positive and negative charges exist
2. Neutral objects possess equal amounts of positive and negative charges → neutrons are neutral, but not like neutral objects
3. Transfer of charge → **FRICTION**
    - *mainly comes through the movement of the negative charge*
    a. Negatively charged objects → the object gains (-)
    b. Positively charged objects → the object loses (-)
    c. **Conduction** (*charge by contact*)
        1) rubber rod (ebony) with wool or fur → *negative charge*
            a) rubber attracts electrons, wool/fur gives off electrons
            b) The neutral electroscope picks up electrons from the rubber rod and spreads the aluminum leaves

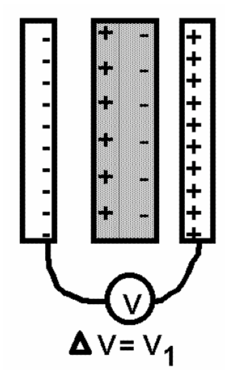
2) glass rod with silk → *positive charge*

a) glass loses electrons, silk gains electrons

b) The neutral electroscope loses electrons to the glass rod and spreads the aluminum leaves

d. **Induction** (*charge by proximity*) → *electrical polarization*

1) Rubber rod (ebony) with wool or fur → *positive charge*



a) Rubber rod is negatively charged from the wool/fur

b) Electrons in the neutral electroscope are repelled deeper and protons are attracted to surface

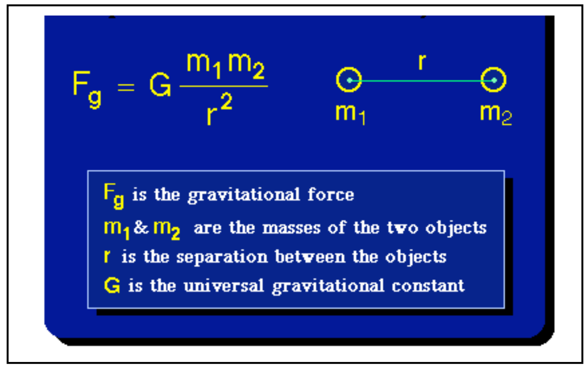
2) Glass rod with silk → *negative charge*

a) Glass rod is positively charged from the silk

b) Electrons are attracted to the surface of the neutral electroscope while protons are repelled deeper

4. Electrostatic Forces causes attraction or repulsion between charges
   a. Like charges repel each other (-) to (-) OR (+) to (+)
   b. Unlike charges attract each other (-) to (+)
5. Conservation of Charge
   a) Charge is not created nor destroyed, but only transferred
   b) Chemists use the concept of "Oxidation State" to identify the charge of atoms and showing the conservation of charge
6. Electrical Energy
   a) Electrostatic forces of attraction and repulsion are closely associated with energy, which can do electrical work.
   b) When electrostatic forces of repulsion push two like charges apart, electrical energy is needed and work is done.
   c) When electrostatic forces of attraction pull two unlike charges together, electrical energy is needed and work is done.
7. Coulomb's Law
   a) The amount of electric force that charged objects exert on each other depends on the **amount of charge** on the objects and the **distance** between the objects

$$F = k\frac{q_a q_b}{r^2}$$

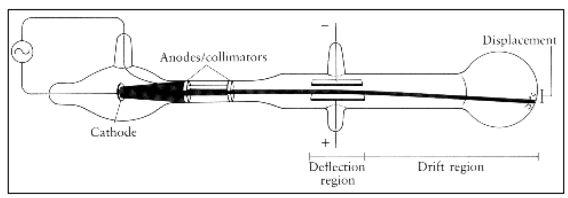


b) $F \sim 1/d^2$ … the closer the charges, the greater the electrostatic force (attraction or repulsion)

- This same principle works with electricity or magnetism
- All electromagnetic waves exhibit this same principle (*includes radio, microwave, infrared, visible, ultraviolet, x rays and gamma rays*)
- Parallels Newton's Law of Gravitation

B. Electron $_{-1}e^0$

1. Electrons were produced in "Cathode Ray Tubes" when studying electrical current in gases at very low pressures.
   a. CRT is made up of a beam of fast moving electrons
   b. The electron beam is deflected in an electric or a magnetic field, showing that the "cathode rays" (electrons) were negatively charged



2. A "mass to charge" ratio was determined (m/e) for an electron
   a) Calculates to the same for any gas used in the CRT … implying that the e- is a fundamental particle common to all atoms
   b) m/e = 5.69×10^{-9} gram/coulomb
   c) e/m = 1.76×10^{8} coulomb/gram
   d) 1 coulomb = 1 amp/sec
      - 1 mole of e- = 96,500 coulombs of charge

3. The charge of the electron (Robert Milliken, 1909)
   a) Milliken Oil drop experiment
      1) Milliken changed the charge on the oil drop and determined how much the drop moved.
      2) e- = 1.60×10^{-19} coulombs
   b) Mass of the electron (9.11×10^{-28} g)
      Mass = (1.60×10^{-19} coulomb) x (5.69×10^{-9} g/coulomb)
      1) Approximately 1/2000th the mass of hydrogen atom
      2) Atoms contain 1 e- to over 100 e-

Cathode rays and electrons

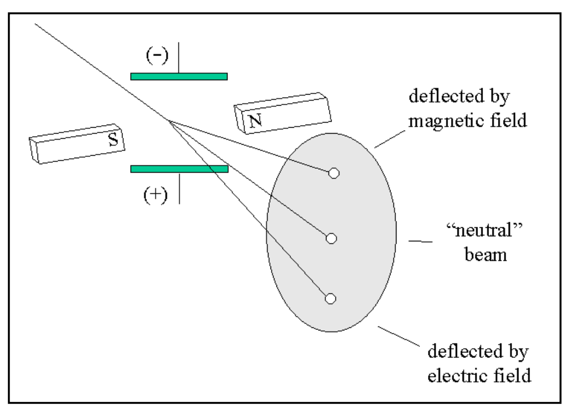
Electrical discharge through partially evacuated tubes produced radiation. This radiation originated from the *negative* electrode, known as the cathode (thus, these rays were termed cathode rays).

- The "rays" traveled towards, or were attracted to the positive electrode (anode)
- Not directly visible but could be detected by their ability to cause other materials to glow, or fluoresce
- Traveled in a straight line
- Their path could be "bent" by the influence of magnetic or electrical fields
- A metal plate in the path of the "cathode rays" acquired a negative charge
- The "cathode rays" produced by cathodes of different materials appeared to have the same properties

These observations indicated that the cathode ray radiation was composed of *negatively* charged particles (now known as electrons).

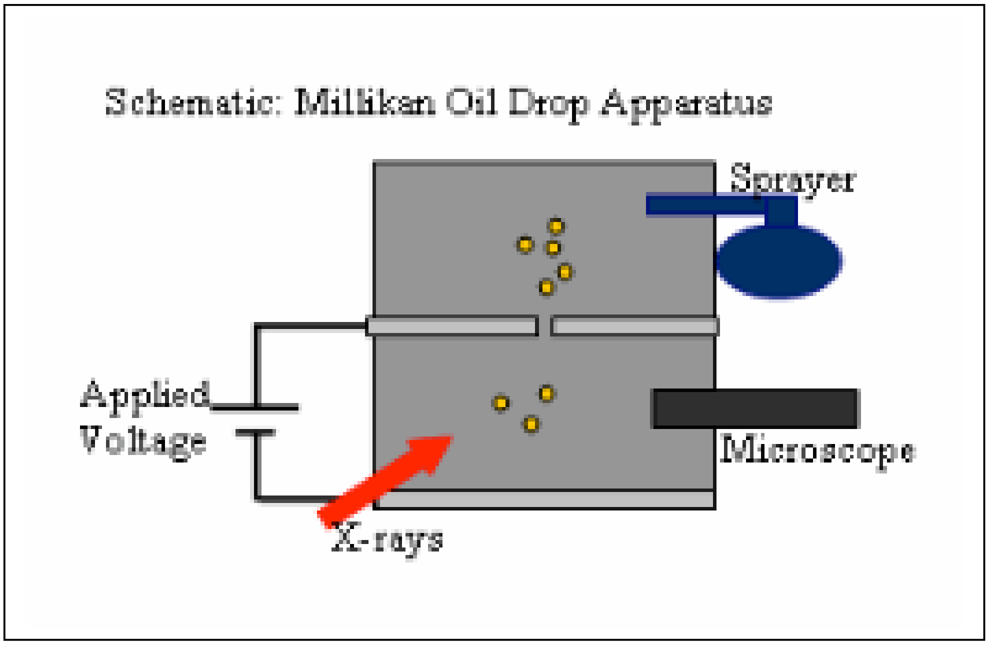
J.J. Thompson (1897) measured the charge to mass ratio for a stream of electrons (using a cathode ray tube apparatus) at 1.76×10^8 coulombs/gram.

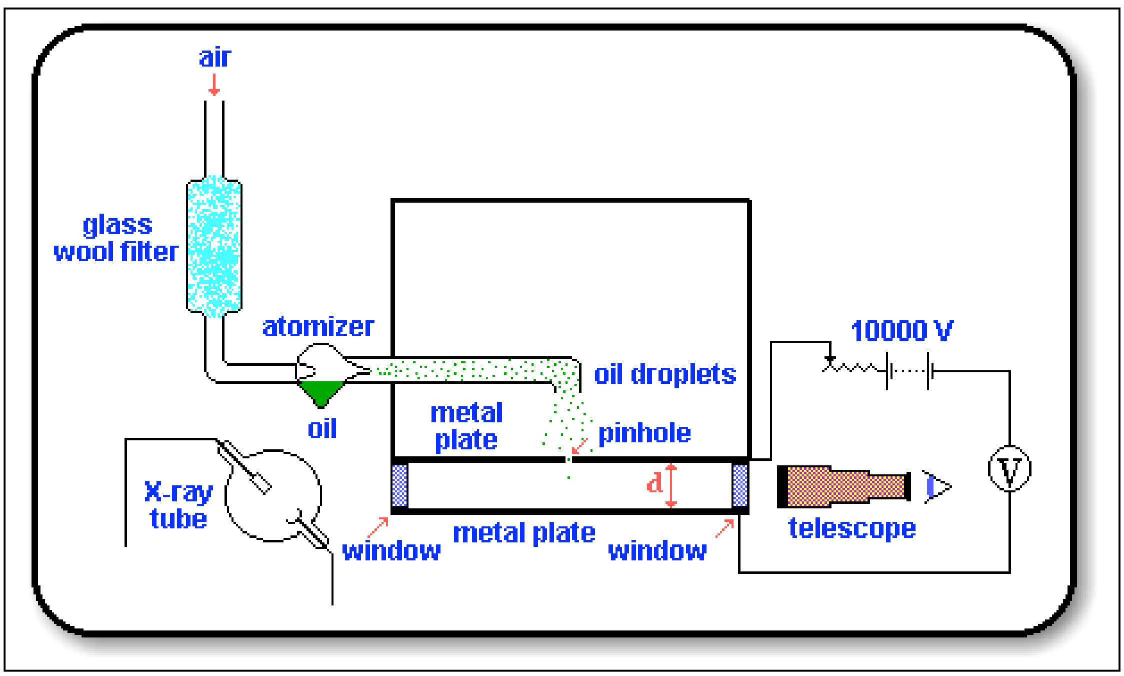
- Charged particle stream can be deflected by both an electric charge and by a magnetic field
- An electric field can be used to compensate for the magnetic deflection - the resulting beam thus behaves as if it were neutral
- The required current needed to "neutralize" the magnetic field indicates the charge of the beam



- The loss of mass of the cathode indicated the "mass" of the stream of electrons

Milliken Oil Drop Experiment





C. Atomic Nucleus

1. Rutherford (1911):

   a. Used radioactive source from lead and produced alpha particles to bombard a gold foil… a zinc sulfide screen was used to observe the effects … figure 2.3

   b. Most alpha particles went through foil undeflected or small deflection (an atom is mostly empty space)

   c. Some alpha particles were deflected at a larger angles as seen on the screen (the mass of the atom is concentrated in a "core" or "nucleus" with a small volume compared to the whole atom)

   d. A few alpha particles were deflected back at acute angles (nucleus has a positive charge… repelled alpha particles (helium nucleus)

   e. The gold foil as well as the many other elements Rutherford used were not attracted or repelled by the charged bodies fired at them (atoms appear to be neutral therefore, the # e- = # +p)

   f. The deflection varied depending on the source of metal used [large deflections are caused by atoms with larger nuclei (more protons)]

   g. Nuclear dimensions: 10^{-8} cm diameter (.5 angstroms)

      1) If nucleus is the size of the golf ball, the electron is the size of a tennis ball 0.7 miles away (1.07 km)

      2) Diameter of the Uranium atom = 2.5 * 10^{-8} cm… it would take 76,000,000 atoms aligned side by side to span one penny.

   h. New Atomic Model

      1) Dalton: indivisible particle

      2) Thompson: + and – interspersed

      3) Rutherford: dense nucleus, which contains protons with e- orbits

98% went through the gold foil undeflected

<2% were deflected as they passed through the gold foil

~0.1% rebounded back from the gold foil

Thompson on left
Rutherford on right

2. Protons $_1p^1$ $_1H^1$

   a. "protons" were discovered in the cathode ray tube using hydrogen gas rather than vacuum

   b. Protons were originally called "canal rays" in the CRT, electrons were called "cathode rays"

      1) Metal disc with holes at cathode away from the anode

      2) Responded opposite to the "cathode rays" indicating an opposite charge

   c. "Canal rays" are particles (JJ Thompson)

      1) Possess the same amount of charge as e-, but opposite sign

      2) Called the "proton"

      3) The mass of a proton is 1837 times the mass of e- (the mass of the proton was almost the same as the mass of the most common form of hydrogen atom)

3. Neutrons $_0n^1$ (Chadwick, 1932)

   a. Used Rutherford's findings that the mass of the nucleus was about twice the mass of that atom's protons

      1) e.g. Na 11 protons, atomic mass ~ 23

      2) Rutherford suggested the name "neutrons" and thought they were an electron – proton pair

   b. Chadwick bombarded Beryllium with alpha particles and found a new particle was released

      1) No charge (*did not deflect under electric or magnetic field influence*)

      2) Essentially the same mass as the proton

      3) Highly penetrable particle (*could penetrate 10-20 cm into lead*)

4. Atomic Number (Moseley 1910)
    a. Moseley worked with X-rays
        1) Used different metals as anodes ... Wavelengths of emitted X-rays (*emitted from + anode with high voltage – cathode*) were characteristic of the metal used for the anode
        2) Wavelength depended on the number of protons in the metal, and was constant for a given element
    b. The number of the protons and neutrons in an atom's nucleus is a fundamental property of the corresponding element.
    c. Isotopes: atoms of the same element having different numbers of neutrons
        1) Nucleons → particles which make up the nucleus [p, n]; a nuclide is a particular nucleus containing a definite number of nucleons

            e.g. protium $_1H^1$, deuterium $_1H^2$, tritium $_1H^3$
        2) Atomic Number [Z-number] "*Zahl*" → *German*
            a) Number of protons in an atom's nucleus
            b) Symbolized at lower left of element e.g. $_ZH$
        3) Mass Number (A)
            a) Protons + neutrons (*sum of the nucleons*)
            b) Symbolized at upper left of element ^AH

Terms & Concepts

Atom	Mass Number	Bohr Model
Electron	Atomic Mass	Charges
Proton	Atomic Mass Units (amu)	Anion
Neutron	Atomic Weight	Cation
Coulomb's Law	Weighted Average	Isotope
Ion	Strong Nuclear Force	Nucleus
Electromagnetic Force	Nucleon	Weak Force
Atomic Number	Dalton's Atomic Theory	

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Atomic Structure and Theory
Activity #1 - Bohr Model Activity

Adapted from: Keiffer, B. (1995). Atom Illumination. Science Teacher, 62:1, pp. 29-31.

Objectives

Students will

- construct Bohr models of atoms;
- interpret data from the periodic table;
- use atomic number and atomic mass to determine structure of atoms.

Driving Question

How can we make a model of an atom? Atoms are much too small to be seen, but experiments on the behavior of atoms have allowed us to understand that an atom is made up of protons and neutrons in the nucleus and electrons in various orbitals around the nucleus. Because the atom is so small and the electrons move so quickly, it is difficult to know exactly how an atom looks. However, we can develop models to help us understand them better.

Background Information

This activity is written using the old toys called "Light Brites" that consist of plastic pegboards in front of a light bulb. Colored plastic bulbs are inserted into the peg holes to make a lighted picture of sorts. Those actual "Light Brites" may not be available in all classrooms; some schools have made a commitment to teach science with toys when possible and may have several of the toys available. Other objects could be substituted for the light bright such as "Chinese Checker" marbles and boards or even pieces of paper to represent the atomic components. The main idea is to provide students an opportunity to produce a two dimensional model of the Bohr atom in the class where teacher feedback is readily available.

The model fails to illustrate the modern atomic model that places electrons in specific orbitals in a three-dimensional space-filling model. However, it illustrates that electrons occupy areas of varying distance from the central nucleus.

Student Activity

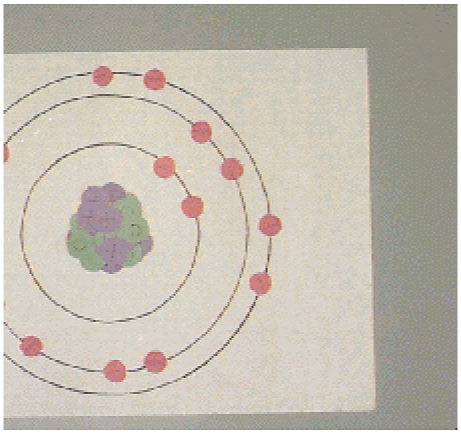
To print out the Student Copy only, click here.

Materials

- Light Brites (one per group of 4 students)
- Bulbs for Light Brites (100 bulbs per group preferably of only 3 colors if possible)
- Student activity sheets
- Periodic Tables
- Balance

Procedure

1. Tell the students they will work in groups to make models of four common elements. Explain that the model has several shortcomings (outlined in the "Background" section for this lab).
2. Divide students into groups of four. Throughout the exercise, each student will be assigned a specific job. The students will rotate through each of the four jobs for each atom to offer everyone an opportunity to perform all responsibilities. The jobs include:
    - *Researcher-locates the assigned atom on the periodic table and ascertains the atomic number, atomic mass.*
    - *Calculator-Calculates the number of protons, neutrons, and electrons in the atom.*
    - *Designer-Decides on the position and arrangement of the parts of the atom to be constructed.*
    - *Builder-Places the bulbs in the designated positions on the Light Brite.*
3. Assign the class four different atoms to construct (hydrogen, oxygen, carbon, and sodium, for example).
4. One student from each group retrieves the Light Brite and 100 bulbs, in a sealed sandwich bag, from the teacher. (Massing the bulbs before the activity and after will help ensure all are returned.)
5. Each group constructs the first atom assigned by the teacher on the Light Brite. The bulbs for the protons and neutrons should be grouped as a nucleus at the center of the Light Brite board. The bulbs representing electrons should be distributed around the nucleus according to the accepted valence arrangement. When a group completes construction of an atom, it should request that the teacher inspect the work. Once the teacher approves the model, each student should sketch the arrangement on the "Data Sheet".
6. For each of the subsequent atoms, the students within the group will rotate so everyone fulfills each responsibility.



wo-dimensional model of a
ısing 1 inch paper circles to
otons (blue), neutrons (green),
s (red).

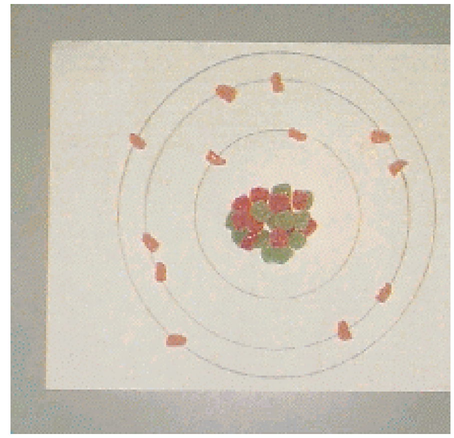
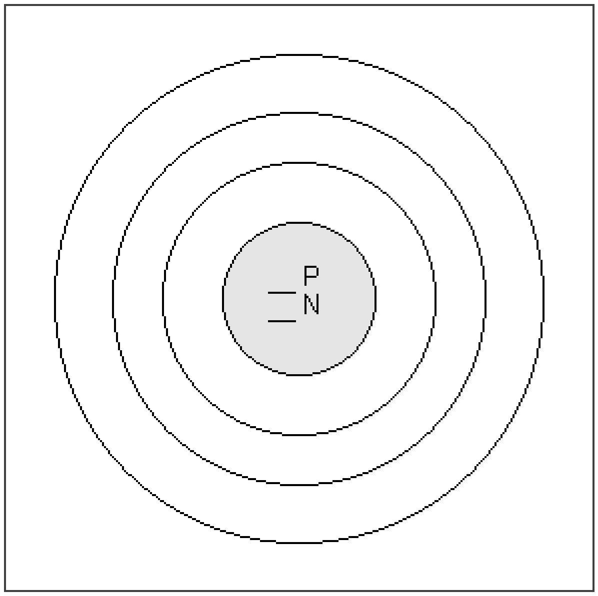


Figure 2: Atomic model of a ma
atom using gumdrops to repres
(green), neutrons (red), and el
(orange).

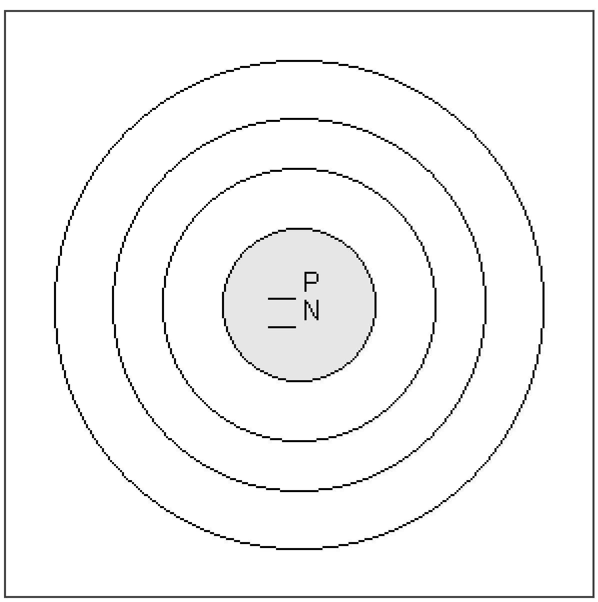
Data Sheet

To print out the Data Sheet only, click here.

Atom #1 ________________



Atom #3 ________________



Extensions

1. Students pick an element to research using web and library sources.
2. Students produce a power point presentation on their element.
3. Students post their element presentation to a class web page as part of a "Cyber Periodic Table."

Students with Special Needs

This activity is accessible to most students; though if a student is unable to manipulate small objects comfortably, the students within the groups may not be able to rotate through all jobs assigned.

Click here for further information on laboratories with students with special needs.

Assessment

1. Students draw arrangements of other atoms independently.
2. Students independently make a two dimensional model of an atom to be assessed by the teacher for accuracy.

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Atomic Structure and Theory

Activity #2 - Atomic Structure Simulation with worksheet

Find the PhET Simulator site on your computer.

http://phet.colorado.edu/new/simulations/sims.php?sim=Models_of_the_Hydrogen_Atom

1. Open the "**Models of the Hydrogen Atom**" simulation. Click on "Prediction" in the upper left corner of the simulation. The simulation should be on "Billiard Ball." Otherwise click on that button.
2. Click the "O" just above the "light control" box. Allow the "light beam" to pass for about 10 seconds and click again, observing what happens to the center particle and the light particles.
   a. RECORD your observations:
   b. Who stated that all matter is made up of indivisible particles?
3. Return to the Hydrogen Atom simulation and click on "Plum Pudding" prediction mode. Allow the "light beam" to pass for about 10 seconds, observing what happens to the center particle and the light particles and then stop the light beam.
   a. RECORD your observation of the "blue sphere" within the red blob:
   b. Do the light particles "bounce" off the blob as the billiard balls in the previous simulation? What happens instead?
   c. ____________________ (scientist) made the inference that atoms could be separated into a negative part and a positive part. He made the inference that _________ rays were made of _____________ charges, and therefore that the negative charges could be removed from the bulk of the atoms. He then developed a model of the atom in which little electrons were stuck in big positive goo called the ______ _________ model. He just assumed the positive charge was one big mass.

4. Click on: Rutherford Scattering simulation [*PHET, Chemistry, Rutherford Scattering*]. Turn the "gun" on for 10 seconds and observe the pattern of particles in relation to the central mass.
   a. RECORD your observation of how the moving particles behave near the central mass:
   b. This simulation gives a microscopic picture of Rutherford's famous experiment in which he shot ___________ particles at a thin foil of _______. Change the number of protons to "20" at the right side of the screen. Turn the gun on again and record your observations:
   c. Slide the "number of protons" bar to the right little by little and observe the "particles" as they approach the central mass. Record how the deflection of the particles changes as one adds more protons:
   d. Based on Rutherford's finding, what inference did he make about the distribution of positive charge in the atom (*where is it concentrated*)?
   e. Just for comparison, click on the "Plum Pudding Atom" simulation (next to Rutherford's simulation) and see how this compares to what Rutherford ACTUALLY found:
5. Return to the Models of the Hydrogen Atom simulation. Click on "Prediction" and "Classical Solar System" mode. Rutherford developed a "solar system" model of the atom based on a positive nucleus and a negative electron orbiting that nucleus. Run the simulation several times and explain why Rutherford was NOT correct:
6. Bohr made a simple observation that atoms are stable and do not collapse in on themselves. Click on the "Bohr" simulation. Draw a sketch of the atom that Bohr developed.
   a. In the upper right corner of the simulation, click on "Show electron energy diagram." What does "**n**" refer to in the Bohr simulation? How many are present?
   b. As "**n**" gets larger, do the **orbits** get closer together or farther apart? Why?
   c. As "**n**" gets larger, do the **energy levels** get closer together or farther apart? Why?
   d. Turn the gun on and allow it to run for about a minute. Observe closely what happens to the blue "electron" in the simulation as light particles strike it. Where does it go when struck? Observe the diagram to the right of the simulator (*electron energy levels*) as well.
   e. When an electron changes energy levels (*when struck by the light*), we say the atom is in the _____________ state. A stable atom (*before getting excited*) is in the _________ state.
7. Click on the "deBroglie" simulator and observe for 30 seconds.

8. Click on the “Schrodinger” simulator. Change the speed at the bottom of the screen to “fast” and observe this simulation for one minute. Click on pause as a pattern develops and then play it again. Observe the electron energy level diagram to the right as well.

Note to teacher: For activities and ideas using simulations Models of the Hydrogen Atom and Rutherford Scattering open the following link

http://phet.colorado.edu/teacher_ideas/view-contribution.php?contribution_id=162&referrer=/teacher_ideas/browse.php

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Atomic Structure and Theory

Activity #3 - Introduction to Isotopes

Materials:

9 Plastic Easter Eggs (of the same mass)
Skittles or colored M & Ms
Triple Beam Balance
Periodic table

Procedure:

1. Before class, place 5 skittles of the same color (i.e. red) in TWO of the plastic eggs. Add 5 skittles of another color (i.e. green) to one of those eggs. Add 6 green skittles to the other egg.
2. Before class, place 10 skittles of the same color (i.e. yellow) in TWO plastic eggs. Add 10 skittles of another color (i.e. blue) to one of those eggs. Add 12 blue skittles to the other egg.
3. Before class, place 1 skittles of the same color (i.e. yellow) in THREE plastic eggs. Add 0 skittles of another color to one of those eggs. Add 1 blue skittle to the other egg. Add 2 blue skittles to the third egg.
4. Before class, place 15 skittles of the same color (i.e. green) in TWO plastic eggs. Add 15 skittles of another color (i.e. red) to one of those eggs. Add 16 red skittles to the other egg.
5. Have students find the mass of each plastic egg according to nine stations.
6. Students should then organize their data and determine what kinds of elements they have.
7. Open the plastic eggs and have students re-trace all the nine stations again, observing the actual items within each egg.

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Atomic Structure and Theory

Activity #4 - Isotope Activity - Penny Isotopes

Not all pennies are alike! In 1982 the price of copper had increased so much that the penny was containing a quantity of copper worth more than 1 cent! This would not do at all. Therefore the government decided to change the make up of the penny. As a result the pennies after 1982 have a different mass than the pennies made before 1982.

Purpose:
In this lab you will use pennies to represent isotopes of a new element, Coinium to use the average atomic mass of a sample of the element to determine the percent of each isotope present in the sample.

Procedure:

1. Obtain 10 pennies dated before 1982. Weigh the ten pennies in a group. Determine the average mass of a pre 1982 penny. Record this information in the data table.
2. Repeat the above procedure with pennies dated after 1982 (post 1982 pennies).
3. Obtain a sealed film container with an unknown combination of pre and post 1982 pennies.
4. The mass of the film container without the pennies is recorded on the container. Record the container letter and mass in the data table.
5. Determine the mass of the film container with the pennies in it. Record this in the data table.
6. Use the information you have just recorded to determine the mass of the pennies in the film container alone. (Remember **NEVER OPEN THE FILM CONTAINER DURING THIS LAB**, do not open the container)
7. Assuming that there are 10 pennies in the container, determine the average mass of a penny in the container. Record this in the data table.
8. Use your algebra to determine the number of pre and post 1982 pennies in the container.

Let x = the number of pre 1982 pennies, then

10-x = the number of post 1982 pennies.

Write and solve an algebraic equation that shows the total mass of the pennies in the canister will be equal to the average mass of each type of penny times the number of pennies. Check this equation with your teacher before proceeding.

Data Table:

Mass of 10 pre 1982 pennies

Average mass a of pre 1982 penny

Mass of 10 post 1982 pennies

Average mass of a post 1982 penny

Film canister Letter

Mass of film canister and pennies

Mass of empty film canister (from top)

Mass of pennies in the film canister

Average mass of a penny in the film canister

Number of pre 1982 pennies

Number of post 1982 pennies

Show all calculations here:

Questions:

1. Explain how the two types of pennies are similar to isotopes of the same element.

2. Why did you weigh ten pennies at a time instead of only weighing one individual penny to determine the mass of the pre and post 1982 penny?

3. New element Z has two isotopes Z-71 is 26.6% abundant and Z-73 is 73.4% abundant. Determine the average mass of element Z. Show all work!

4. New element Q has three isotopes Q-12 is 62.10% abundant, Q-13 is 2.43% abundant, and Q-14 is 35.47% abundant. Determine the average mass of element Q. Show all work!

5. A new element was discovered on planet X. The element exists as two different isotopes, E-21 and E-23. Which isotope is more abundant if the average mass is 21.7 g? Explain.

6. Identify two things that you learned from this lab.

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Atomic Structure and Theory
Activity #5 - Atoms and Isotopes

Purpose

Atoms and isotopes are identified by the numbers of protons, electrons, and neutrons that they contain. The number of protons, electrons, and neutrons in atoms determines the chemical properties of the elements. Knowledge of the number of protons and electrons in an atom will help you understand how atoms combine to form molecules.

Learning Objectives

- Identify the composition of atoms in terms of protons, neutrons, and electrons.
- Use atomic symbols to represent different atoms and isotopes.

Success Criteria

- Quickly identify atomic symbols, atomic numbers, mass numbers, and number of electrons for elements.

Resources

Olmsted and Williams (*Chemistry*, Wiley, 2002) pp. 38-58.

New Concepts

proton, electron, neutron, atom, atomic nucleus, isotope, element, atomic symbol, atomic number, mass number

Vocabulary

composition, electrical charge, subscript, superscript

Definitions

In your own words, write definitions of the terms in the New Concepts and *Vocabulary* sections.

Model: Two Isotopes of Sodium:

The diagrams below show representations of sodium isotopes. Note that the diameter of an atom is about 10,000 times larger than the diameter of the atomic nucleus so the relative sizes of the atom and the nucleus are not accurately depicted in these diagrams.

Atomic Symbol Notation

Mass Number

$^{A}X_{Z}$ **Atomic Symbol**

Atomic Number

Isotope 1

Nucleus (11 protons, 12 neutrons)

$^{23}Na_{11}$ **11 electrons**

Isotope 2

Nucleus (11 protons, 13 neutrons)

$^{24}Na_{11}$ **11 electrons**

Key Questions

1. What do the two sodium isotopes in the model have in common and how do they differ?
2. How is the mass number, A, determined?
3. What information is provided by the atomic number, Z?
4. What is the relationship between the number of protons and the number of electrons in an atom?
5. Because of the relationship between the number of protons and number of electrons in an atom, what is the electrical charge of an atom?
6. Where are the electrons, protons, and neutrons located in an atom?
7. Where is most of the mass located in an atom?
8. What do all sodium isotopes have in common that distinguishes them from atoms and isotopes of other elements?

Exercises

1. (a) Write the atomic symbols for two isotopes of carbon, one with mass number 12, the other with mass number 13.

(b) Sketch pictures, similar to those in the model, of these two carbon isotopes.

2. Construct a model for an atom in which the relative sizes of the nucleus and the atom are represented accurately.

3. Fill in the missing information in the following table.

Name	Symbol	Atomic Number Z	Mass Number A	Number of Neutrons	Number of Electrons
oxygen	$^{16}O_8$	8	16	8	8
		7		7	
	^{34}S				
beryllium			9		
		12	24		
		12	25		
			238		92

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Atomic Structure and Theory
Activity #6 - Bean City USA Lab

Source:

Flynn Foundation Workshop

Bean City USA- Nuclear chemist, performing basic research on dirty silverware and plates in local restaurants today, discovered what is believed to be an element number 118. The researchers have named this element beanium. It is derived from the small vegetables which grow on climbing leguminous plants. It was this type of food residue that dishwashers could not remove from plates or silverware that led to the research and ultimately the discovery.

Further research of the new element will be conducted in more suitable surroundings, namely the chemistry classes at Walled Lake Central High School. Your teacher has volunteered your class to participate in this news-breaking research.

Your first task in this possible Nobel Prize winning endeavor will be to determine how many isotopes of this element exist. Isotopes are atoms of an element which behave chemically the same, but have different physical properties. One variable property among isotopes is their atomic weight. After finding how many isotopes comprise the element, your second task will be to determine the atomic weight of each isotope and lastly to calculate the average atomic weight of beanium.

One unique property of beanium should make these experiments particularly easy – beanium atoms are very large. Therefore, sorting the isotopes of this element should be accomplished with very little difficulty. Good Luck in your research!

Procedure:

1. Obtain your isotopic sample of beanium and count and record the total number of atoms in your sample.
2. Sort the beanium atoms into groups of different isotopes.
3. Find and record the total mass of each isotope of beanium and record this mass on the data sheet.
4. Count and record the total number of each isotope that you have in your sample.
5. Calculate and record the average mass of each of the three beanium isotopes.
6. Determine the % abundance of each isotope by using the formula below and then record this information in the data table below.

$$\% \text{ abundance} = \frac{\text{\#of atoms of one isotope}}{\text{total \# of atoms in your sample}} \times 100$$

7. Determine the average atomic mass for beanium by using the % abundance of each isotope and that isotope’s respective atomic weight. This formula is the same one used to determine the average atomic weight of all elements.

Data

Total number of atoms in your isotope sample - __________

TYPE - Description	NUMBER OF BEAN ISOTOPES	TOTAL MASS OF THE BEAN ISOTOPE

Isotope average mass =total mass of the isotope/number of isotope beans

Type #1 –

Type #2 –

Type #3 –

Percent abundance = number isotope beans/ total number of beans x 100

Type #1 –

Type #2 –

Type #3 –

Average atomic mass of beanium - _________

Ave. Atomic Mass = (%isotope/100 x average mass of isotope) + (%isotope/100 x average mass of isotope) + (%isotope/100 x average mass of isotope).

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Atomic Structure and Theory
Activity #7 - Composition of the Atom

Source: Smile Program Chemistry
http://www.iit.edu/~smile/ch9217.html

Objectives:

1. This lesson is for High School.

2. The students will become familiar with the following vocabulary:

atom	proton	neutron	electron	hadron
nucleus	quark	lepton	probability	wave
charge	mass	muon	pion	strong force
weak force	vector boson	gluon	graviton	Higg's boson

3. The students will be able to construct a model of the atom for any element. A performance assessment will be made of this task.

Materials Needed:

Class

beaker	water	ethyl alcohol
small pointed stick	food coloring (optional)	motor oil
periodic table of the elements		

Group of four

gumdrops	toothpicks	calculator
sheet of paper filled with circles		

Individuals

gumdrops	toothpicks	calculator
wave line		

Strategy:

Define the words: proton, electron, neutron, and nucleus. Pass out copies of the periodic table of the elements and put one enlarged element on the board or the overhead. Review the recognition of the atomic number and atomic mass and how one would use them to determine the number of protons, neutrons, and electrons in the rest atom.

Have the class discuss perceptions of normal behavior of positively and negatively charged particles. To demonstrate the effect of the strong force in the nucleus: Fill a beaker half full of water. Float a layer of ethyl alcohol on the top of the water. Add one or two drops of motor oil. It will remain suspended between the water and the alcohol. (If you wish this to appear to be magic, add the alcohol to the water out of the students' sight. If you want the students to be aware of the two different layers, add a small amount of food coloring to the water before adding the alcohol.) Poke at the oil bubble with the stick and notice how it resists splitting. Relate this to the strong force in the atom.

Pass out one sheet filled with circles to each group of four students. Have each student in the group drop a pen or pencil, point down, from waist height 25 times. The students will count the total number of marks that have landed inside any of the circles. Using the ratio:

$$\frac{\textbf{area of all of the circles}}{\text{area of the sheet of paper}} = \frac{\textbf{dots inside any circle}}{\text{100 dots}}$$

Find the area of all of the circles. Divide this number by the total number of circles to find the area of one circle.

Use the formula - area = πr^2 to find the radius and the diameter of one circle. Relate this to Rutherford's experiments to find the size of the nucleus. Explain that to be completely parallel there would be only one or two circles on the page, but that then you would need at least 500 to 1000 drops of the pencil to get an adequate sampling.

Discuss electron orbits, including energy levels, probability theory, and the formula for the maximum electrons in an orbit: $2n^2$. Have each group construct a model of a helium atom, using toothpicks and gumdrops. Color code the atom, using a different color for protons, neutrons, and electrons.

Introduce wave theory. Explain that each element has a unique wavelength associated with it. Then

Introduce modern physics by explaining that the word modern is extremely relative. Any music more recent than the nineteenth century composers Verdi and Wagner is considered modern. A turn-of-the-century Picasso painting is modern art. In physics, nothing older than yesterday is classified as modern. Twenty years ago scientists thought that an atom was composed of hadrons (protons, neutrons, and pions), and leptons (electrons, neutrinos, and muons). Ten years ago they were saying that hadrons were composed of quarks, of which there were three different types. At this point you might bring up the origin of the word quark. It was taken from the line "Three quarks for Muster Mark." from the James Joyce novel Finnegan's Wake. In German there are two translations of the word: the conventional "cottage pudding" and the colloquial "strange". By five years ago the scientists recognized six kinds of quarks. The up, charm, and truth (or top) each have a charge of +2/3. The down, strange, and beauty (or bottom) each have a charge of -1/3. In addition, quarks have the "colors" of red, blue, and green. Since quarks only exist in a high energy state, their mass is actually greater than the rest mass of the hadrons they compose. In addition to hadrons and leptons, atoms also contain vector bosons (the W and Z particles and gluons) which are associated with the strong force which binds the nucleus together, gravitons, and the Higg's boson.

Performance Assessment:

Using their copy of the periodic table of the elements, gumdrops, toothpicks, a model wave three wavelengths long, and a calculator, each student will construct a correct model of the magnesium atom.

Scoring Rubric:

BUILDING AN ATOM

Demonstrated Competence

6 - **Exemplary Response**
The numbers of protons, neutrons, and electrons are correct.
The number of electrons in each orbit is correct.
The circumference of each orbit is correct.
There is appropriate scientific justification for all of the above.

5 - **Correct Response**
The numbers of protons, neutrons, and electrons are correct.
The number of electrons in each orbit is correct.
The circumference of each orbit may not be correct.
There is no scientific justification for any of the above.

Satisfactory Response

4 - **Almost Correct Response**
The numbers of protons, neutrons, and electrons are correct.
The number of electrons in each orbit is not correct and/or there is no mathematical explanation for that number.
The circumference of each orbit is incorrect.

3 - **Partial Solution**
The numbers of the protons, neutrons, or electrons is incorrect.
The other two are correct.

Inadequate Response

2 - **Inadequate Solution**
The numbers for the protons, neutrons, or electrons is correct. The other two are incorrect.

1 - **Incorrect Response**
The numbers of protons, neutrons, and electrons are all incorrect.

0 - The student leaves a blank page or writes "I don't know".
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Atomic Structure and Theory
Activity #8 - Determining Atomic Mass

Source
www.siraze.net/chemistry

Pre-Lab Discussion

The atomic mass (or atomic weight) of an element is the average value of the masses of the isotopes in a natural sample of that element. Atomic masses of all the elements are based on the mass of an atom of carbon-12, which has been assigned the value of 12 atomic mass units. An atomic mass unit (represented by the symbol u) is denned as 1/12 the mass of a carbon-12 atom.

In their work, chemists do not deal with individual atoms or molecules. Rather, they deal with relatively large numbers of atoms and molecules. To make their calculations easier, chemists often use units of measure that are made up of large numbers of atoms or molecules. One such quantity is called the *gram atomic mass*, or *gram-atom*. A gram-atom is the mass in grams of 1 mole of atoms. A gram-atom of an element is, therefore, the mass of 6.02 x 1023 atoms of that element. The mass in grams of 1 gram-atom of an element is numerically equal to the atomic mass of that element. For example, 1 gram-atom of carbon-12 has a mass of 12 grams.

There are several methods for determining the gram atomic mass of an element. In this experiment, the gram atomic mass of silver will be calculated using a compound (silver oxide) of known composition (Ag2O).

Purpose

From measurements of a binary compound of known composition, determine the gram atomic mass of one of the elements in the compound when the atomic mass of the other element is known.

Equipment

Crucible,cover and crucible tongs
microspatula
ring stand, clay triangle, iron ring and burner
balance
safety goggles
lab apron or coat

Materials

silver oxide (Ag_2O)

Safety

Tie back long hair and secure loose clothing when working with an open flame. Do not touch the hot crucible or its cover with your fingers. Be sure to wear safety goggles and a lab apron or coat when working in the lab.

Procedure

1. Clean a crucible and cover. Place the crucible in the clay triangle as shown in the figure. Heat the crucible and cover in the hottest part of the burner flame for about 5 minutes. Be sure to tilt the cover as illustrated. Balance it carefully to avoid breakage. Put out the flame and allow the crucible and cover to cool.

2. Measure the mass of the crucible + cover. Record this mass as (a) in your data table.

3. Measure out exactly 1.75 g of dry silver oxide (Ag_2O). Add this compound to the crucible. With the cover on the crucible, measure the mass of the crucible and its contents. Record this mass as (b).

4. To remove oxygen gas from the silver oxide, tilt the cover as before and strongly heat the crucible, cover, and contents in the hottest part of the flame for 15 minutes. Allow the crucible to cool. Measure and record the mass of the crucible, cover, and contents (c).

5. If time permits, reheat strongly for 5 minutes. After cooling, again measure the mass of the crucible, cover, and contents to check for constancy of mass (d).

Observations and Data

a) Mass of crucible + cover	_______ g
b) Mass of crucible + cover + Ag_2O	_______ g
c) Mass of crucible + cover + Ag	_______ g
d) Mass after reheating	_______ g

Calculations

1. Find the mass of the Ag = c — a

=______ g

2. Find the mass of the O = b – c

=______ g

3. Find the number of g-atoms of O: g-atoms O:

$$\text{g-atoms O} = \frac{\text{mass of O in g}}{\text{16 g O / g-atom O}}$$

=______ g

4. Find the number of g-atoms of Ag:

$$\text{g-atoms Ag} = \frac{\text{2 g-atoms Ag}}{\text{1 g-atom O}} \times \text{no. of g-atoms O}$$

=______ g

5. Find g-atom mass of Ag:

$$\text{g-atomic mass Ag} = \frac{\text{mass of Ag in g}}{\text{no. of g-atoms of Ag}}$$

=______ g

Conclusion Questions

1. Write a balanced equation for the decomposition of Ag_2O by heating.

2. What are the most likely sources of error in this experiment?

3. Define a mole. What is the relationship between the mole and the gram-atom?

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Atomic Structure and Theory

Worksheet #1: Vocabulary

Since you have taken this course to learn chemistry, the important thing is that you learn chemistry. How you learn chemistry or who teaches it are an entirely different matter. Therefore, it is your turn to teach!!! You will be given a nuclear symbol of an isotope. You and your partners will need to provide the information requested on the following page. Please be aware that it is not enough just to provide the information, but you must understand your answers. Later in the activity you will be given a different nuclear symbol and asked to provide the same information for that symbol. Enjoy!

Oh! I almost forgot, you may utilize any of the resources in the classroom that you want, with the exception of me! Due to an unfortunate accident, I bumped my head, this morning and I have amnesia. So I will be unable to answer any questions, sorry.

Worksheet 1: Vocabulary Handout

symbol-

nucleons-

protons-

neutrons-

electrons-

atomic number-

mass number-

isotopes-

atomic mass-

ion-

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Atomic Structure and Theory
Worksheet #2 – Ion Calculations

Fill in the missing information in the following table.

Ion Name	Symbol	Atomic Number Z	Mass Number A	Number of Neutrons	Number of Electrons
Oxygen ion	O^{-2}	8	16	8	10
		7		7	
	Ca^{+2}			21	18
			9		
		12	24		
		12	25		
			238		92
	F^{-1}			10	
		13		14	13
Argon atom			40		
	P^{-3}		29		
Barium ion			135		

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Atomic Structure and Theory
Real World Applications

Source: Isotopes – Carbon Dating
http://science.howstuffworks.com/

How Carbon-14 Dating Works

by Marshall Brain

Browse the article *How Carbon-14 Dating Works*

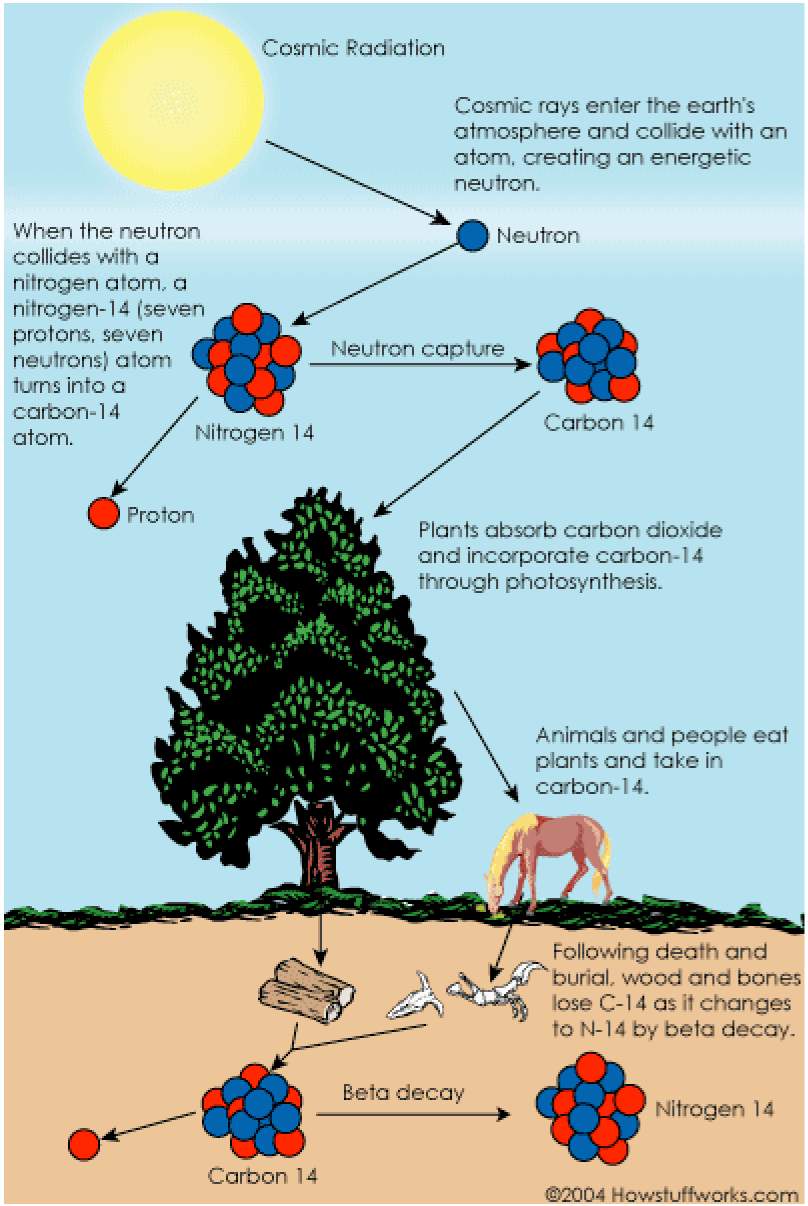
Introduction to How Carbon-14 Dating Works

You probably have seen or read news stories about fascinating ancient artifacts. At an archaeological dig, a piece of wooden tool is unearthed and the archaeologist finds it to be 5,000 years old. A child mummy is found high in the Andes and the archaeologist says the child lived more than 2,000 years ago. How do scientists know how old an object or human remains are? What methods do they use and how do these methods work? In this article, we will examine the methods by which scientists use radioactivity to determine the age of objects, most notably carbon-14 dating.

Carbon-14 dating is a way of determining the age of certain archeological artifacts of a biological origin up to about 50,000 years old. It is used in dating things such as bone, cloth, wood and plant fibers that were created in the relatively recent past by human activities.

How Carbon-14 is made

Cosmic rays enter the earth's atmosphere in large numbers every day. For example, every person is hit by about half a million cosmic rays every hour. It is not uncommon for a cosmic ray to collide with an atom in the atmosphere, creating a secondary cosmic ray in the form of an energetic neutron, and for these energetic neutrons to collide with nitrogen atoms. When the neutron collides, a nitrogen-14 (seven protons, seven neutrons) atom turns into a carbon-14 atom (six protons, eight neutrons) and a hydrogen atom (one proton, zero neutrons). Carbon-14 is radioactive, with a half-life of about 5,700 years.



For more information on cosmic rays and half-life, as well as the process of radioactive decay, see How Nuclear Radiation Works.

Carbon-14 in Living Things

The carbon-14 atoms that cosmic rays create combine with oxygen to form carbon dioxide, which plants absorb naturally and incorporate into plant fibers by photosynthesis. Animals and people eat plants and take in carbon-14 as well. The ratio of normal carbon (carbon-12) to carbon-14 in the air and in all living things at any given time is nearly constant. Maybe one in a trillion carbon atoms are carbon-14. The carbon-14 atoms are always decaying, but they are being replaced by new carbon-14 atoms at a constant rate. At this moment, your body has a certain percentage of carbon-14 atoms in it, and all living plants and animals have the same percentage.

Dating a Fossil

As soon as a living organism dies, it stops taking in new carbon. The ratio of carbon-12 to carbon-14 at the moment of death is the same as every other living thing, but the carbon-14 decays and is not replaced. The carbon-14 decays with its half-life of 5,700 years, while the amount of carbon-12 remains constant in the sample. By looking at the ratio of carbon-12 to carbon-14 in the sample and comparing it to the ratio in a living organism, it is possible to determine the age of a formerly living thing fairly precisely.

A formula to calculate how old a sample is by carbon-14 dating is:

$$t = [\ \ln (N_f/N_o) / (-0.693)\ ] \times t_{1/2}$$

where ln is the natural logarithm, N_f/N_o is the percent of carbon-14 in the sample compared to the amount in living tissue, and $t_{1/2}$ is the half-life of carbon-14 (5,700 years).

So, if you had a fossil that had 10 percent carbon-14 compared to a living sample, then that fossil would be:

$$t = [\ \ln (0.10) / (-0.693)\ ] \times 5{,}700 \text{ years}$$

$$t = [\ (-2.303) / (-0.693)\ ] \times 5{,}700 \text{ years}$$

$$t = [\ 3.323\ ] \times 5{,}700 \text{ years}$$

$$t = 18{,}940 \text{ years old}$$

Because the half-life of carbon-14 is 5,700 years, it is only reliable for dating objects up to about 60,000 years old. However, the principle of carbon-14 dating applies to other isotopes as well. Potassium-40 is another radioactive element naturally found in your body and has a half-life of 1.3 billion years. Other useful radioisotopes for radioactive dating include Uranium -235 (half-life = 704 million years), Uranium -238 (half-life = 4.5 billion years), Thorium-232 (half-life = 14 billion years) and Rubidium-87 (half-life = 49 billion years).

The use of various radioisotopes allows the dating of biological and geological samples with a high degree of accuracy. However, radioisotope dating may not work so well in the future. Anything that dies after the 1940s, when nuclear bombs, nuclear reactors and open-air nuclear tests started changing things, will be harder to date precisely.

For More Information

Related HowStuffWorks Articles

- How Nuclear Radiation Works
- How a Nuclear Power Plant Works
- How Nuclear Medicine Works
- How a Nuclear Bomb Works
- How Radon Works

More Great Links

- Layers of a Lake Refine Carbon Dating
- Answer Geek - Guess Its Age
- U.S. Geological Survey: Carbon-14 ages from East Maui volcano, Maui, Hawaii
- U.S. Geological Survey: Carbon-14 Technique
- NOVA: How Old Are the Pyramids?
- NIST Database of Isotopes in the Atmosphere: Measurements and Standards
- Radiocarbon introduction
- Carbon-14 Dating Calculator
- Carbon Dating
- A Science Odyssey: The Dating Game
- U.S. Geological Survey's Learning Web Activity: Time and Change
- U.S. Geological Survey's Publication "Geotime"

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Atomic Structure and Theory
Resources for Teachers

Websites

http://education.jlab.org/indexpages/teachers.php

http://www.wwnorton.com/college/chemistry/gilbert/home.htm

http://www.clarenceville.k12.mi.us

www.myteacherpages.com/webpages/TVERESH

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

http://www.isis.rl.ac.uk/aboutIsis/index.htm?content_area=/aboutIsis/whatisaNeutron.htm&side_nav=/aboutIsis/aboutisisSideNav.htm&

http://dwb4.unl.edu/

http://www.iit.edu/~smile/cheminde.html

Simulations

http://phet.colorado.edu/teacher_ideas/view-contribution.php?contribution_id=162&referrer=/teacher_ideas/browse.php

http://www.hazelwood.k12.mo.us/~grichert/sciweb/applets.html

Electromagnetic Spectrum

http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html

Fundamental Forces

http://hyperphysics.phy-astr.gsu.edu/hbase/forces/funfor.html

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