Atomic Theory

1. Handout: Condensed Unit Notes
2. Black Box Model
3. Early Theories - 400 B.C.
    1. Common Greek theory was that all matter consisted of four "elements" - earth, air, fire, and water.
    2. Democretus (460-360 BC)
        1. A philosopher/scientist who theorized that all matter was made of indivisible particles (atoms).
        2. His theory was based on logical reasoning, not empirical data. Philosophers/scientists of this time period did not think doing experiments was necessary. They thought you could reach the truth by pure logical reasoning. It's interesting to note how right he may have been.
    3. Alchemy, the process of changing base metals to gold, was the chief form of experimentation from this time period until the the late 1600's.
4. Robert Boyle (1622 - 1691)
    1. He defined the term element - a substance that cannot be broken down into more simpler substances.
    2. He also did some pioneering work in the area of gas pressures, but we will talk about that later.
5. Antoine Lavoisier (1743 - 1797)
    1. He is considered to be the pioneer of modern chemistry.
    2. He used the scientific method and did careful and controlled experiments.
    3. Because of his methods he was able to determine correctly what was happening during the combustion of metals. Stemming from this work and other experiments, he is credited with developing evidence for the Law of Conservation of Mass in 1777.

4. The Law of Conservation of Mass states that during chemical reactions matter is neither created or destroyed. The mass of the reactants should be equivalent to the mass of the products.
    1. Lab: Does Mass Change During Chemical Reactions?
    2. Homework: Does Mass Change During Chemical Reactions Lab Questions.

6. Joseph Proust (1754 - 1826)
    1. He first published his Law of Definite Proportions (or Law of Constant Composition) in 1794.
    2. This law states that a compound is composed of exact proportions of elements by mass regardless of how the compound was created. For example, to make water there is a specific ratio of grams of hydrogen to grams of oxygen regardless of where your sample of water was found. All water has this particular proportion.
    3. For example, if one sample of water breaks down into 2 grams of hydrogen and 16 grams of water, then twice the amount of water would contain 4 grams of hydrogen and 32 grams of water. The proportion of hydrogen to oxygen is "definite" or fixed.
    1. Demo: The Big Bunsen Burner
    2. Lab: Adjusting the Bunsen Burner
    3. Lab: Making water the right way. Put loudest pop ratio on the board when done.
    4. Handout: Good Graphing.
    5. Homework: Making Water the Right Way Lab Questions

7. John Dalton (1768 - 1828)
    1. Combined the following ideas to form his atomic theory
        1. elements cannot be broken down into simpler substances
        2. conservation of mass
        3. law of constant composition or definite proportions

        2. Dalton's Atomic Theory - 1808
            1. All elements are composed of atoms (indivisible particles)
            2. All atoms of the same element are identical - in particular they have the same mass.
            3. The atoms of one kind of element are different from the atoms of all other elements - in particular the atoms of one element have a different mass than those of other elements.
            4. Atoms are indestructible and retain their identity in chemical reactions.
            5. Compounds are formed by joining atoms in specific whole number ratios.
        3. Black box model of the atom. Even after 2000 years of the atomic concept the structure of the atom was unknown. At this point in history it was still thought to be the smallest unit of matter.
    1. Handout: Dalton's Atomic Theory
    2. Homework: Put the five components of Dalton's atomic theory into your own words.
8. William Crookes (1832 - 1919)
        1. Invented the Crookes tube in early 1870s.
        2. He noticed that as you removed gas from a tube, a glow would appear if you place a high voltage across it.
        3. He noticed that a shadow would form if something was placed in the tube, so he believed some new kind of light was being produced.
        4. He called these rays - cathode rays.
    1. Demo: Crude Crookes tube
    2. Demo: Actual Crookes tube
9. Plum Pudding Model
    1. J.J. Thompson (1856-1940)
        1. One set of experiments involved working with Crookes tubes and cathode rays.
        2. He discovered that the rays were not like ordinary light. They could be deflected by electric or magnetic fields. He determined that these rays must be made of many small particles.

3. By studying how they were deflected he determined that these particles were negatively charged.
4. It didn't matter what gas the tube was initially filled with or what metal the electrodes were made of. He always got the same cathode rays/particles. Because of this he determined that these tiny particles must be part of all matter.
5. In 1897 he discovered the first subatomic particle, a component of all atoms, the electron.
6. He realized that if there ware negative parts to atoms, then there must be positive parts as well to balance it, because most matter is neutral.
7. Listen to a recording of J.J. Thompson talking about the atom.
   This recording was made on 18 October 1934, when Thompson was 78 years old and was found at the London Science Museum website exhibit on electrons.
8. Lord Kelvin (1824 - 1907) proposed a new model of the atom based on the work done by J.J. Thompson. It was said that he thought of this idea while eating dessert. He called the new model of the atom the Plum Pudding model. The negative electrons were the plums sprinkled throughout a positive pudding. The electrons were considered to be hard particles and the positive charge a soft haze of electrical charge.

10. Hard nucleus model
    1. Radioactivity
        1. Henri Becquerel (1852 - 1908)
            1. Discovered nuclear radiation in 1896.
            2. While storing some uranium compounds in a desk drawer with photographic paper, he noticed that when developed, the photo paper had an image of the compound. This was particularly extraordinary because the photographic paper was sealed. Somehow the compound "exposed" the photo paper through its protective covering.

2. Marie Curie (1867-1934)
    1. Shortly after this discovery Marie Curie began experiments with uranium to determine the nature of this "radioactivity", a term coined by her. Her husband also turned his research toward the understanding of radiation. In 1903, Marie and Pierre Curie and Henri Becquerel received the Nobel prize for their work in radioactivity.
    2. These experiments laid the groundwork for a new era of physics and chemistry. Eventually this would lead to the discovery of the neutron.

1. <u>Homework:</u> Read the article by Marie Curie on the state of radioactive study in 1904 and answer the questions at the end of the article.

2. Ernest Rutherford (1871 - 1937)
    1. Discovered the proton in 1910, giving us a new model of the atom which has small, hard, positively charged protons in a nucleus. He and other scientists weren't sure where the electrons fit into this structure so they are depicted above as just floating around somewhere outside the nucleus.
    2. Remember, before this time we were working with the Plum Pudding model of the atom. Which involved hard electrons floating in a mush of positive charge.
    3. Rutherford decided to test this model by setting up what is now known as the Gold Foil Experiment. This involved bombarding a very thin sheet of gold foil with positively charged alpha particles. Given the Plum Pudding model, Rutherford expected all of the alpha particles to blast their way through the haze of positive charge that was theorized in that model of the atom. What Rutherford found was that almost every alpha particle did go straight through the foil. However, a few particles were deflected to the side and 1 of every 20,000 was deflected back. Click here to see a recreation of the Gold Foil Experiment.
    4. From this experiment Rutherford determined the following.
        1. There is a nucleus. Why?

2. The nucleus is very small. Why?

3. The nucleus is very dense. Why?

4. The nucleus is positively charged. Why?

5. So we have a new model of the atom with protons in a very small (1/10,000 the size of the total atom), dense, nucleus, and electrons doing something somewhere, perhaps orbiting, perhaps not.

11. Bohr Model of the atom
    1. Niels Bohr (1885 - 1962)
        1. One of the possible models proposed by Rutheford after completion of his gold foil experiment stated that electrons orbit the nucleus like planets orbit the sun. However, there were problems with this idea. For reasons beyond the scope of this course, electrons would emit energy as they rotated around the nucleus, eventually spiraling into the nucleus.
        2. Bohr proposed that electrons are orbiting, but that they can only orbit at specific predefined distances from the nucleus. Electrons could exist in one orbit or another, but nowhere in-between.

        3. He also proposed that electrons had very specific energies associated with each orbit. Electrons that were close to the nucleus had lower energies than ones orbiting at a distance. The energy of an electron was fixed or quantized into discrete values based upon its current orbit.
        4. Bohr proposed his quantum mechanical model of the atom in 1913.
2. Spectroscopy and Bohr's Model
    1. Electromagnetic Radiation (EMR)
        1. Electromagnetic Radiation is a type of energy that travels in waves.
        2. Types of EMR
            1. Radio waves
            2. Microwaves
            3. Infrared
            4. Visible light
            5. Ultra Violet
            6. X-Rays
            7. Gamma Rays
            8. Handout: Electromagnetic Waves
        3. To talk of a particular kind of energy we can discuss the energy, wavelength, or frequency of the wave.
            1. Wavelength is the distance from the peak of one wave to the peak of another.
            2. Frequency is the the number of waves per second that a stationary observer would count while the wave is passing by.
            3. Energy, frequency, and wavelength are all interrelated due to the fact that all EMR travels at the same speed. As wavelength decreases, frequency increases, and energy increases.

4. Nature of Light
    1. Light is just the range of electromagnetic radiation that had the correct wavelengths (or frequency or energy) to excite the molecules in cells at the back of our eyes. When these cells get excited they send electrical nerve impulses to our brain and we "see".
    2. Our eyes can combine multiple colors (wavelengths) of light to see one color. White light is the combination of all colors.
    3. Prisms and diffraction gratings can separate light which is a mixture into its component parts.
1. Demo: Look through Diffraction Gratings.
2. Demo: Why is the Sky blue

2. Production of EMR
    1. Light is produced when electrons loose energy when jumping from one energy level to a lower energy level. Energy, like mass, is conserved, so if an electron looses energy it must go somewhere. It goes into the production of a wave of electromagnetic radiation.
    2. Depending on how much energy is lost by the electron, an electromagnetic wave of varying energy (or wavelength or frequency) is produced. The amount of energy emitted is exactly equal to the difference between the two energy levels of the electrons.
    3. Electrons can only emit energy if they have absorbed some energy. There are several ways to excite electrons: heat, high voltage, and other EMR.
    4. Observations made by observing the EMR emitted when atoms are excited convinced Bohr that electrons must only be able to exist at specific energy levels and thus must only be able to orbit the nucleus at specific distances.
    5. See here an applet depicting Bohr's model of the atom and how electrons absorb and emit electromagnetic waves. This applet was created by folks at the Physics 2000 website produced by the University of Colorado at Boulder.

1. Handout: Electron Energy Levels and EMR production.

2. Demo: Diffraction gratings and high voltage emission tubes.
3. Homework: Electron Jumping Worksheet; Read Light Your Candy Article from the October '90 Edition of ChemMatters
4. Demo: MRI scans of my brain.

3. Emission and absorption spectroscopy
    1. Spectroscopy is the study of electromagnetic radiation that is either emitted or absorbed by substances.
    2. Emission spectroscopy is the study of EMR that is emitted from excited atoms.
    3. Absorption spectroscopy is the study of EMR that is absorbed by atoms, thus exciting them.
    4. See here an applet depicting the emission and absorption spectra for most of the elements. This applet was created by the Virtual Laboratory maintained at the University of Oregon.
    5. Scientists can use these spectra to determine the contents of various substances in the lab or in the stars. Spectroscopic analysis is also used in the art world to determine what kinds of pigments were used in a painting without destroying the original substance. The spectra is a kind of fingerprint for a substance. Each substance will emit or absorb a unique set of electromagnetic waves.
4. Lab: Flame tests
5. Homework: Read "Space 1998" article and underline each time were EMR is used in some sort of way to learn more about distant objects.

3. James Chadwick (1891-1974)
    1. Chadwick in collaboration with Rutheford realized that the atomic mass of most elements was about double the number of protons. For example, helium has an atomic mass of about 4 and only 2 protons. Electrons have minimal relative mass, so they postulated that a neutral particle may exist.

2. Irene (Marie Curie's daughter) and Frederic Joliot-Curie were conducting many radiation experiments during this time. However, they were not searching for neutrons. Chadwick realized that some of their experiments might be used to find the elusive neutron, so he repeated their experiments with this goal in mind.
3. In 1932, he found definitive evidence for the existence of a neutral particle that had roughly the same mass as a proton. He discovered the neutron.

12. The Modern Atom (1950's - present)
    1. Many scientists contributed to our modern model of the atom.
    2. We no longer believe that electrons orbit the nucleus. In fact, in experiments done to identify the location of the electrons, we find that the best we can do is predict what probability one would have if looking for the electron in a particular location.
    3. There are defined regions where you are likely to find electrons. These three dimensional volumes are called orbitals. Depicted above is an atom with a nucleus containing protons, and neutrons, surrounded by an electron "cloud". This cloud represents the space around the nucleus where you are likely to find its electrons. The lighter the color the less likely you are to find the electron there. This cloud is the orbital. Click on the images below to get a sense of the structure of an atom.
    4. Orbitals have several shapes. Each shape is correlated with a particular energy level. This makes the model consistent with the spectroscopic data that show electrons can only exist in specific discrete energy levels. Click on the illustration to the right to see cartoon images of these orbitals.
    5. So, spectroscopy can be explained by the orbital shape. An electron of higher energy will most likely be found in an orbital that is different from the region that the electron will be found in when it is in a lower energy state. The electron cannot be in an in-between energy state or orbital.
    6. See an applet here that shows both the Bohr model of the atom and the Orbital model of the atoms as it absorbs and emits light.

1. Handout: Modern View of the Proton (Download this and open it in an image editing program to print.)

2. Demo: Atom in a Box Software
3. Computer Lab: Explore the modern atomic orbitals.
4. Video Clip: Seeing Atoms

13. Symbolic representation of atoms
    1. Atomic Symbols
        1. The subscript number is called the atomic number = number of protons.
        2. The superscript number is called the mass number = protons+neutrons

	Protons	Neutrons
${}^{14}_{6}C$	6	8
${}^{15}_{7}N$	Ans	Ans
${}^{1}_{1}H$	Ans	Ans

    2. The number of protons defines the element. All carbon atoms have 6 protons. All nitrogen atoms have 7 protons.
    3. Atoms of the same element can, however, have different masses. Each unique form of an element has a specific number of protons and neutrons.

	Protons	Neutrons
${}^{14}_{6}C$	6	8
${}^{13}_{6}C$	Ans	Ans
${}^{12}_{6}C$	Ans	Ans

4. Each form of carbon above would be called an isotope of carbon. Sometimes they are referred to as Carbon-14 or Carbon-12. All isotopes of carbon have the same number of protons, but their number of neutrons can differ.
5. Atomic mass is the weighted average of the isotopes of a particular element. For example ~99% of carbon is Carbon-12 and ~1% is Carbon-14. In any sample of carbon on earth you will generally find this ratio. When you use a sample of carbon it contains both isotopes, so you need a way of determining the average atomic mass. Calculate the average atomic mass based on the abundances of the isotopes listed above. It should match the atomic mass listed on the periodic table - 12.01.
6. Atoms of course are made of one other elementary particle - the electron. Neutral atoms would exactly balance positive and negative charge. Each proton carries a charge of +1 and each electron carries a charge of -1. Any atom that is not neutral is called an ion.

	Protons	Neutrons	Electrons
${}^{14}_{6}C$	6	8	Ans
${}^{14}_{7}N^{-2}$	Ans	Ans	Ans
${}^{14}_{7}N^{+3}$	Ans	Ans	Ans
${}^{16}_{8}O^{-2}$	Ans	Ans	Ans
${}^{7}_{3}Li^{+1}$	Ans	Ans	Ans

1. <u>Homework:</u> Atomic Practice Sheet

14. Handout: Review Sheet