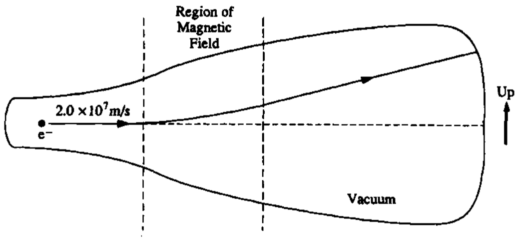
Electromagnetic Radiation: In the previous review sheet we discussed the electromagnetic spectrum.

Maxwell: Derived a famous series of four equations that could completely describe electromagnetic effects. His equations, which were a compilation of the work of many other famous scientists, showed the existence and predicted the speed of these waves. However, you won't need the equations now. You can enjoy this chapter of physics in college.

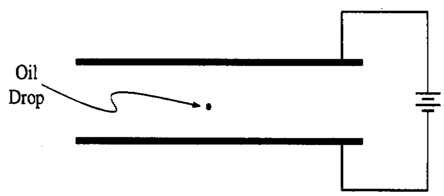
Atomic Theory

Thompson: Designed the Cathode Ray Tube (CRT), the basis for TV and computer monitors. In the partially evacuated tube he had two electrical terminals, thus creating an electric field. When a potential difference was created between the electrodes (plates) he witnessed an eerie beam that came from the negative (cathode) plate and went to the positive plate. He surmised the existence of negative particles that must have come from inside the atom. So the atom was no longer recognized as the smallest entity in the universe. These particles were called electrons.



Cross Section of Cathode Ray Tube

Milikan Oil Drop: He charged oil drops with these negative particles. He then sprayed the oil drops between two charged plates. He could adjust the potential difference between the plates until the oil drops were suspended in mid air. This means that the force up = the force down. So the electric force up = the gravity force down. $Eq = mg$ so $\boxed{q = \frac{mg}{E}}$ By finding the mass of the oil drop and noting the strength of the electric field he could calculate the excess charge on the oil drop. He performed the experiment many times. He noted that the charge was always a multiple of 1.6×10^{-19} C and he never found a value smaller than this. So he concluded that this is the charge on the electron. After all charge comes in quanta, or whole number quantities. There are no half electrons.



Rutherford: Fired alpha particles at gold foil. Around the foil he placed a screen sensitive to alpha particles. He thought the heavy and fast alpha particle would fire right through the foil. While most did, he did note that many rebounded from the foil. He likened this to shooting a cannon at tissue paper and having the shell bounce back. He postulated that the atom was mainly empty space, but that there was a small dense nucleus comprised of positive particles (protons) located at the center. The empty space would account for most alpha particles passing through. The positive nucleus would explain how the positive alpha particles were bounced back. He did calculations based on the various trajectories of the alpha particles, and he was able to predict the relatively small size of the nucleus. His model of the atom was similar to the solar system (planetary model) with the nucleus (sun) at the center and the electrons (planets) orbiting at a great distance.

Einstein: Postulated that light has a particle nature, and travels in packets of energy known as photons.

Planck: Found the energy of a photon. $\boxed{E = hf}$. The energy of a photon is Planck's constant (***h***) x frequency.

Emission Spectrum: It was noted that when gaseous elements were placed in a tube at near vacuum and a potential difference was placed at the ends of the tube (Thompson CRT) different colors were seen. When shot through a diffraction grating the colors showed up as discrete lines with dark areas in between. Formulas were worked out for Hydrogen, the simplest element and the placement of the lines fit a mathematical pattern.

Bohr: He predicted that the atom was similar to Rutherford's model, but Bohr added the concept of energy levels. The fact that atoms only emitted certain frequencies of light implied that the electrons could only occupy certain discrete energy levels. And these electrons could never be in between these energy levels. When photons strike an atom, the electrons (normally in the ground state) of the atom absorb the energy. These electrons (excited) now have higher energy and thus move to higher energy levels within the atom. When the electrons returned to the ground state photons are emitted since the electrons loose energy. But the electrons may drop to a variety of levels on the way back to the ground state. This explains the many colored lines in the emission spectrum and the calculations matched those of the emission spectrum. The ***Bohr Model of the atom*** is outdated & incomplete, but it is still used to visualize the atom.

Debroglie: Felt that since light can act as both a particle (photon) and a wave, perhaps electrons (a particle) can have a wave property as well. He calculated the wavelengths of electrons $\boxed{\lambda = h/p}$ and found that theoretically an electron in the lowest energy level has one electron wavelength in a ***standing matter wave***. An electron in the second energy level completes two wavelengths, etc. This resulted in the ***Wave Mechanical Model of the Atom***. So the electrons were not jumping from energy levels as Bohr had surmised, rather they were changing wavelength when bombarded by photons.

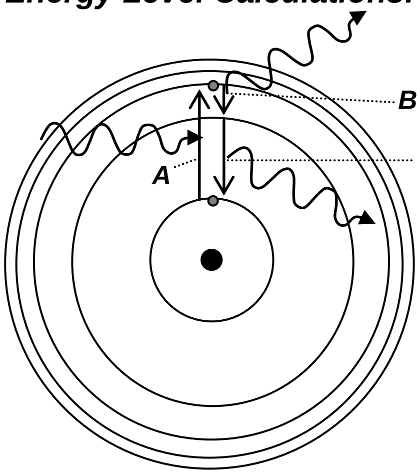
Heisenberg: Postulated that you can never know both the location and the momentum of an electron simultaneously. His ***Uncertainty Principle*** states that you cannot find an electron or predict what it will do, since if you shoot photons at electrons to see what their doing the photons interact with the electrons changing their location and / or their speed.

Schrodinger: Performed the calculations to narrow down the possible locations that electrons may be found in an atom. These statistical shells that electrons occupy are the basis of the current ***Electron Shell Model of the Atom***.

Einstein: Found the mass energy equivalence $\boxed{\Delta E = (\Delta m)c^2}$. Even though a photon is really mass-less energy it does have a mass equivalence. So if its energy can be converted to a mass value, then the photon can be given a mathematical momentum. So Planck's equation is updated. $\boxed{E = hf = pc}$

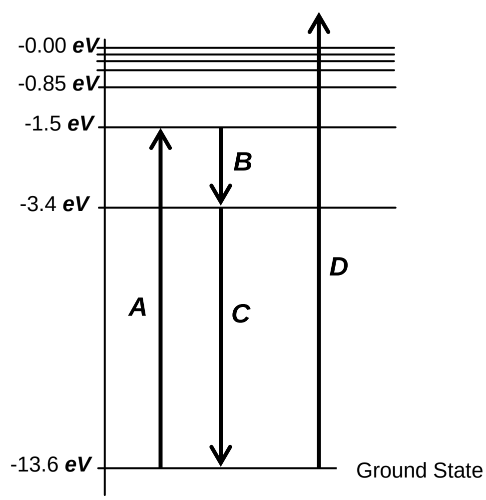
Energy Level Calculations:

Bohr's model has been updated, but the energy levels still hold mathematically.



If a photon of the right frequency and energy were to strike the lone electron in hydrogen while it is in the ground state, the electron would then acquire all of the photons energy. The ***photon is absorbed by the atom***. The energy of the photon determines how much energy the electron receives and thus determines the energy level that the electron is boosted to. Perhaps the electron would receive enough energy to be excited to the 3rd energy level as shown in process ***A***. This excited electron would be unstable and would eventually return to the ground state, but not necessarily in one leap. It could conceivably drop all the way back releasing a photon of the same frequency and energy as the one that struck the electron boosting it out of the ground state. Or it might drop to the 2nd energy level first (***B***), and then finally drop back to the 1st energy level (***C***). This two-step return will result in two photons that have different frequencies, and these photons are also different from the photon that hit the electron initially. ***Photons are emitted from the atom***. Here are some of the energy levels of a hydrogen atom. The atom is small, so energy is measured in electron volts.

Drawing a circular atom is tedious. The following covers the same scenario as detailed above, but includes the mathematical steps and an additional step ***D***. Remember this is only one scenario, there are many energy levels.



A: ***Absorption*** of a photon. The hydrogen atom is bombarded with light of frequency, 4.14x10^{-15} Hz.

$$E = hf = \left(4.14\times10^{-15}eV\cdot s\right)\left(2.92\times10^{15}Hz\right) = 12.1eV$$

As a result an electron in the ground state, -13.6 *eV* is boosted to the second energy level, -1.5 *eV*. In this case it drops to the first energy level and then drops back to the ground state. Lot's of possibilities exist.

B: ***Emission*** of a photon. The electron falls to the first energy level, a drop of 1.9 *eV*. This corresponds to a frequency of,

$$f = E/h = (1.9eV)\big/\left(4.14\times10^{-15}eV\cdot s\right) = 4.59\times10^{14}Hz$$

A photon of light is emitted from the atom with this frequency. This ***generates a distinct band of light on the emission spectrum***.

C: ***Emission*** of a photon. Next the electron falls back to the ground state, a drop of 10.2 eV. This corresponds to a frequency of,

$$f = E/h = (10.2eV)\big/\left(4.14\times10^{-15}eV\cdot s\right) = 2.46\times10^{15}Hz$$

A photon of light is emitted and this ***generates a distinct band of light on the emission spectrum***.

D: ***Ionization***. If a photon strikes a hydrogen atom electron in the ground state with more than 13.6 *eV* the electron receives enough energy to leave the atom entirely. The hydrogen atom lacking its electron becomes an ion. Therefore, this energy is referred to as the ***ionization energy***. (Also called the ***work function***. See below.)

Photoelectric Effect:

Young's Double Slit Diffraction experiment provided evidence that light exhibited wave properties. The photoelectric effect provided evidence of lights particle behavior. If light is shined on certain photoelectric materials a current can be induced. This requires the light to have enough energy to knock electrons out of the atoms, so a current can flow. This is the basis of solar energy. This process requires a certain minimum energy, known as the work function ϕ. So if a photon $\boxed{E = hf}$ strikes a photoelectric material some of its energy is required to move the electron completely out of the atom. This is the energy needed to ionize the atom. The kinetic energy given the electrons is the energy left over after the ionizing energy, work function, is subtracted from the photons energy. $\boxed{K_{max} = hf - \phi}$

Nuclear Physics

Nucleons: ***Proton*** Positive charge $+e = 1.6 \times 10^{-19}\ C$ $m_p = 1.6726 \times 10^{-27}\ kg$

Neutrons Neutral charge $q = 0$ $m_n = 1.6749 \times 10^{-27}\ kg$

???? Mass difference between a proton & a neutron ($1.6749 \times 10^{-27} - 1.6726 \times 10^{-27} = 2.3 \times 10^{-30}$)

It is almost the mass of an electron. A neutron is made of a proton and an electron that have fused. This explains why the neutrons are neutral. As for the mass not quite adding up, see $E = mc^2$.

Atomic Mass Number (A) = # Nucleons
Atomic Number (Z) = # Protons $^{A}_{Z}X$ $^{12}_{6}C$ or just ^{12}C
Neutron Number ($N = A\text{-}Z$) = # Neutrons

Isotopes: Same # of Protons, different # of Neutrons $^{12}_{6}C$ $^{13}_{6}C$ $^{14}_{6}C$

Unified Atomic Mass (u)

C-12 = $12.00000\ u$ $1.00000\ u = 1.66054 \times 10^{-27}\ kg$
$E = mc^2$ $100000\ u = 931.5\ MeV$

Binding Energy: Total mass of a stable nucleus is less than the component protons and neutrons

He: $4.002602\ u$ Added separately: $4.032980\ u$

When ***He*** is formed some mass turns into energy: $\Delta E = \Delta m\, c^2$, ***Mass Defect*** = Δm = 28.30 *MeV*

Total Binding Energy: Mass difference, amount of energy required in order to break the nucleus apart.

Average Binding Energy per Nucleon: Divide Total binding energy by the number of nucleons

Highest for Iron: Requires the most energy to split this nucleus, most stable
Hydrogen: Used in fusion, Energy drops from ***Fe*** to ***H***. Binding energy released: Powers stars
Uranium: Used in fission, Energy drops from ***Fe*** to ***U***. Binding energy released: Nuclear power & bombs

Strong Nuclear Force: Force holding nucleons together

Radioactivity: Disintegration / decay of unstable nucleus. Certain isotopes are unstable and emit rays (radiation).

- The ***Electric Force*** acts over entire nucleus. It results from the repulsion of all the protons. Neutron are not involved in the electric force.
- The ***Strong Force*** is a short-range force. It holds the individual nucleons together. Both neutrons and protons attract due to this force.
- So adding more neutrons can help hold the nucleus together, since they do not contribute to the repulsive electric force. There is however an ideal amount of neutrons, not too many and not too few that each nucleus needs in order to be stable. If this number is out of balance the nucleus can deteriorate spontaneously.
- The larger the nucleus the greater the electric force. The distances become too large for the strong force to hold the nucleons together. The balance of force favors electric force.
- ***Transmutation:*** Occasionally parts of the nucleus are repelled out with great force and speed. When part of the nucleus is ejected the ***Parent nucleus*** changes into a ***Daughter nucleus***

Alpha (α) ***Decay:*** Results when an α ***Particle***, ***He*** nucleus $\boxed{^{4}_{2}He}$ is spontaneously ejected from the nucleus. The nucleons comprising the alpha particle are strongly bonded to each other and they eject as a single packet.

$$^{226}_{88}Ra \to {}^{222}_{86}Rn + {}^{4}_{2}He$$

Beta (β) ***Decay:*** Results when there are too many neutrons compared to the ideal number required to maintain the electric / strong force balance. A neutron is a proton and an electron that have been fused together. So if there are too many neutrons one of them can split, forming a new proton (adding to atomic number) and a nuclear electron, known as a β ***particle*** $\boxed{^{0}_{-1}e}$. This particle has a very low mass and picks up all the energy of this transmutation. It is ejected at an extreme speed. Being smaller and faster than the alpha particle it has more penetrating power and is thus a more hazardous form of radiation. $^{14}_{6}C \to {}^{14}_{7}N + {}^{0}_{-1}e + \bar{v}$. One by product of this reaction is a positron (anti-electron). The existence of this anti-matter particle lead scientists to postulate the existence of a fourth fundamental force, the ***Weak Nuclear Force***. Don't worry about the positron on this exam.

Gamma Rays: Electrons around the nucleus can be found in excited states. It turns out that nucleons can exist in excited states as well. If a nucleon drops to a lower energy state a tremendous energy is released, since the energy differences in the nucleus are huge. This results in the emission of extremely high energy photons.

Law of Conservation of Nucleon Number: Total # of nucleons remains constant

Half Life: Length of time for half of the sample to decay. See worksheet that follows this section.

Nuclear Reactions: Nucleus is struck by a particle. Causes transmutation

Enrico Fermi: Neutrons most effective projectile particle. No charge, not repelled.

Fission

Hahn and Strassmann: Bombardment sometimes made smaller particles

Meitner and Frisch: Realized that Uranium split in two

Liquid drop model: Neutron added to nucleus increases energy. Increases motion of individual nucleons. Abnormal elongated shape. Short range Strong Force is weakened. Electric Repulsive Force dominates. 2 Fission Fragments result. Also some free neutrons are given off. Tremendous amount of energy released. Fission fragment plus neutron are substantially lower in energy than original U 235

Chain Reaction: 2 to 3 neutrons freed collide with other ^{235}U

Self Sustaining Chain Reaction: ***Nuclear Reactor***

Moderator: Need slow neutrons, with the right speed

Enriched Uranium: To increase probability of ^{235}U fission

Critical Mass: Mass of fuel large enough to compensate for lost neutrons

Multiplying Factor: 1 or more neutrons must go to next reaction.

Subcritical: Less than one neutron goes on

Supercritical

Control Rods: Cadmium or Boron. Absorb neutrons

Delayed Neutrons: Come from fission fragments

Core: Fuel plus moderator. 2 - 4 % ^{235}U

Problems

Thermal pollution: Disposal of radioactive fission fragments. Radioactive interaction with structural components. Accidental release of radioactivity into atmosphere. Leakage of radioactive waste. Life time of 30 yrs due to build up of radioactivity. Earthquakes. Limited supply of fissionable materials

Breeder Reactor: Some neutrons produced are absorbed by ^{238}U. ^{239}Pu is produced, and is fissionable. So the supply of fuel can increase 100 times. However, Plutonium is highly toxic and can readily be used in bombs, and it involves a graphite moderator, as was used in Chernobyl.

Fusion: Building up nuclei

Sum of energy of nucleus is less than sum of energy of its component parts

Elements may be result of fusion in stars

Proton Proton Cycle

$${}_1^1H + {}_1^1H \rightarrow {}_1^2H + e^+ + \nu \qquad \textbf{0.42 } \textbf{\textit{MeV}}$$

$${}_1^1H + {}_1^2H \rightarrow {}_2^3He + \gamma \qquad \textbf{5.49 } \textbf{\textit{MeV}}$$

$${}_2^3He + {}_2^3He \rightarrow {}_2^4He + {}_1^1H + {}_1^1H \qquad \textbf{12.86 } \textbf{\textit{MeV}}$$

$$4\,{}_1^1H \rightarrow {}_2^4He + 2e^+ + 2\nu + 2\gamma$$

Carbon Cycle: Similar method in hotter stars, can make heavier elements

Thermonuclear Device: Fusion Devices

- Stars are under tremendous gravity
- Creates tremendous pressure
- High pressure means high temperature
- High temperature means particles collide violently

On earth high temperatures and densities not easily achieved

Fission Bomb can ignite Fusion Bomb: Thermonuclear Device or H bomb

Plasma Need high density as well as temperature. Ordinary materials cannot contain plasma

Magnetic Confinement: Tokamak Reactor. **Break even point:** Output equals input

Inertial Confinement: Pellet of deuterium and tritium. Struck simultaneously by several lasers