Nuclear Science Basics

Prerequisite Material for the TAMU ANS Nuclear Science Merit Badge Program

Howdy

- Thank you for choosing to be a part of our merit badge program.
- This slideshow is to teach you or review for you the basics of chemistry, radiation, and some basic terms.
- There will be a slide with information, and then a slide with graphics to help explain the concepts.
- You should go through this presentation by yourself, only seeking outside help if you really need assistance.
- If you do need further assistance, you can E-mail us at this address:

  nuclearbsa@gmail.com

Our Universe

- Everything in the universe is made of matter.
- Examples:
  – You
  – Trees
  – Automobiles
  – The sky
  – The computer you are staring at now

- At its smallest level, matter is composed of atoms.

Atoms

- Atoms are the basic building blocks of all matter. An entire section of science, Chemistry, is devoted to studying in detail how atoms interact with each other.
- Atoms can interact by moving past each other, such as in water, forming a liquid, gas, or mixture.
- Ex.
  - Dirt
  - Soapy water
  - Natural gas
- They can also interact by forming new bonds with each other. When this happens it is called a chemical reaction.
- Ex.
  - Fire burning
  - Mentos and coke

Interactions

Typical chemist---------

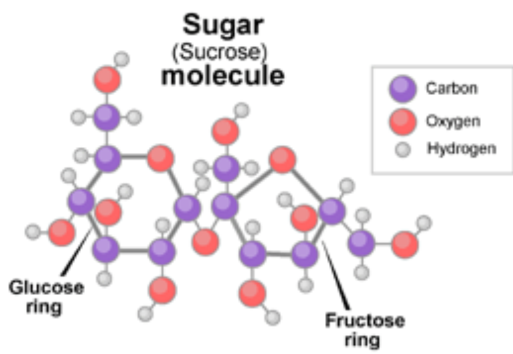
Strip mining demolition charge-------

------Play-doh being smashed together

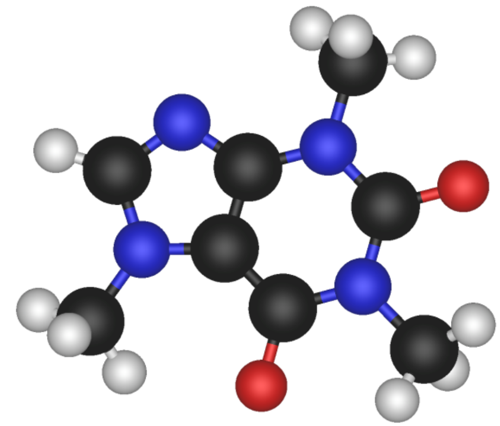
Mentos and coke geyser-----

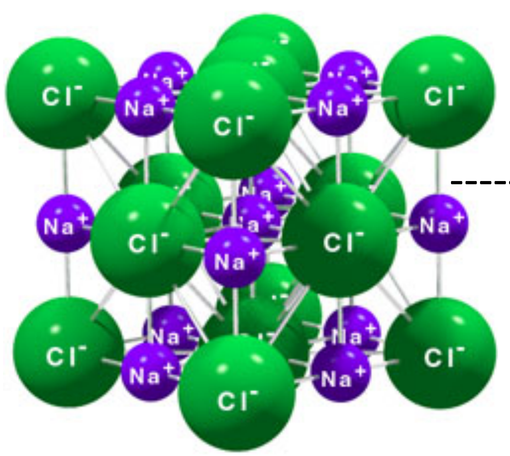
----a dirt mixture

Arrangements of Atoms



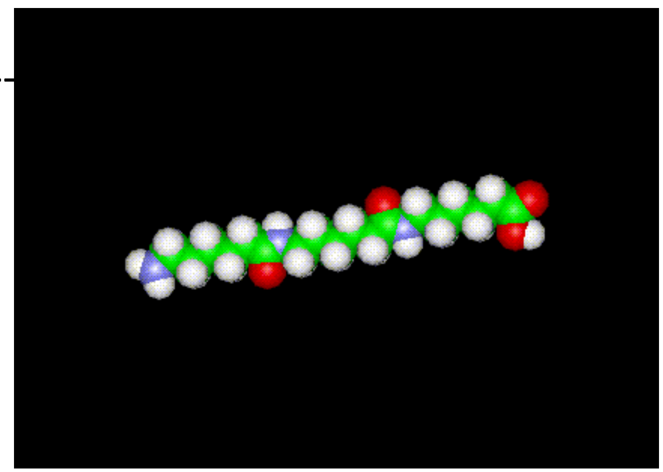
Caffeine--------





--------table salt

Nylon------



Parts of the Atom

- An atom is very small, way too small to be seen without aid from microscopes. So small in fact that there are over 10^{27} atoms in your body. Expanded out, that number is 1000000000000000000000000000 atoms!
- An atom is made up of three parts:
  - Protons
  - Neutrons
  - Electrons
- Protons and neutrons are both the same size and very large when compared to the electron (over 1000 times bigger)
- The protons and neutrons are lumped together to form one unit called the nucleus
- The electrons orbit the nucleus in specific patterns called orbitals

Parts of the Atom

- Protons are positively charged. (+)
- Electrons are negatively charged. (-)
- Neutrons have no charge.

- The charges on the proton and electron are equal in strength, even though the proton is much bigger than the electron.

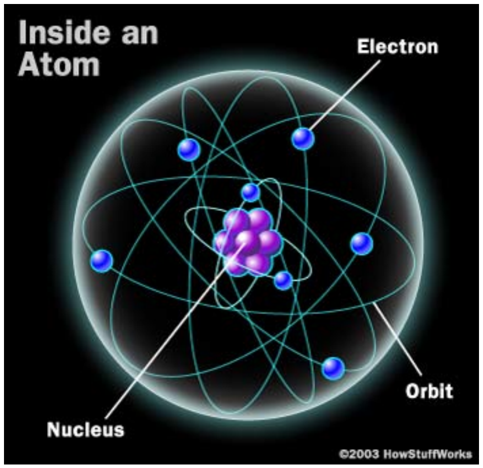
- A neutron carries no charge on it, but supplies "glue" to hold the nucleus together.

Parts of the Atom

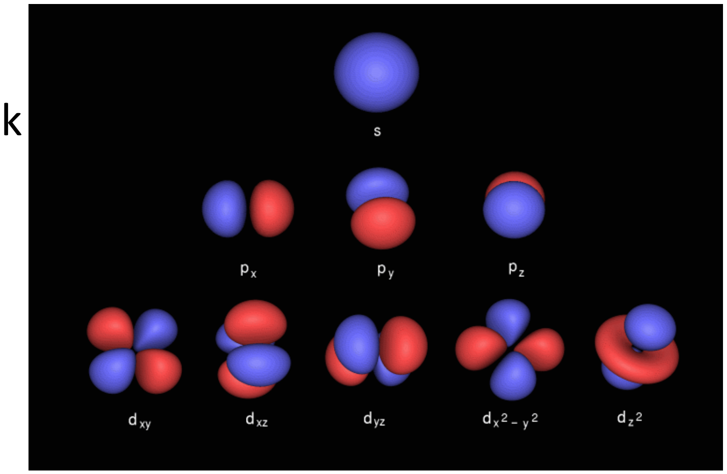
A neutron is “neutral” and carries no charge.

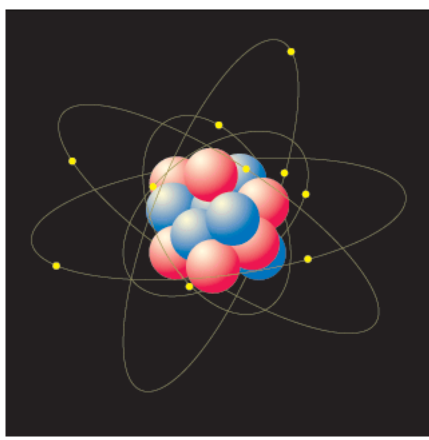
The positive charge on the proton is equal strength to the charge of the electron, even though the proton is bigger.

Atom Structure



What electron orbitals really look like----------





Notice size difference of electrons vs. protons and neutrons, in real life this is even greater!!

Periodic Table

- The periodic table shows all of the types of atoms.
- These elements (a type of atom, eg. Carbon) combine together in different ways to form the molecules of the compounds we see all around us.
- For instance, one Oxygen atom (O) and two hydrogen atoms (H) make up the compound most commonly known as water. This can be written as H_20

Periodic Table

- This is a table of all the elements that can be formed by humans and nature:

Periodic Table of the Elements

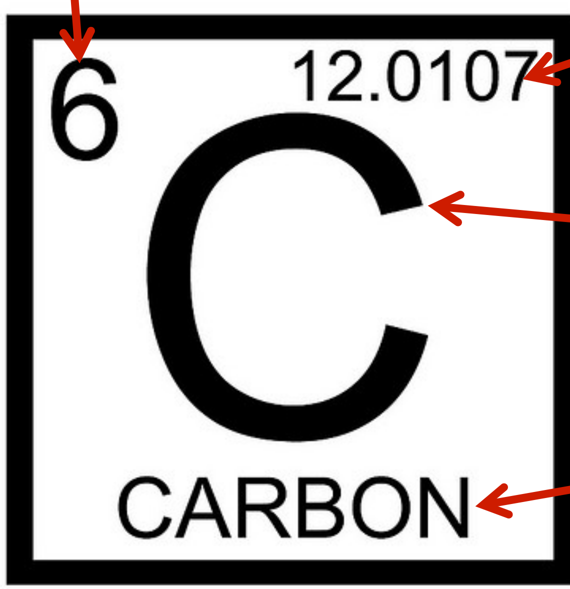
1 **H** 1.008																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.20	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.0	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.8	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.7	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.2
55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.1	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** 223.0	88 **Ra** 226.0	89 **Ac** 227.0	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (262)	108 **Hs** (265)	109 **Mt** (266)	110 **Ds** (281)	111 **Rg** (272)	112 **Uub** (285)	113 **Uut** (284)	114 **Uuq** (289)	115 **Uup** (288)	116 **Uuh** (292)		

58 **Ce** 140.1	59 **Pr** 141.0	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 153.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
90 **Th** 232.4	91 **Pa** 231.4	92 **U** 238.0	93 **Np** (237)	94 **Pu** (240)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (248)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (257)	102 **No** (259)	103 **Lr** (262)

A Typical Element from the Periodic Table

The Atomic number corresponds to number of protons and determines element.

The Atomic mass corresponds to number of protons and neutrons. (this element has 12 protons and neutrons, round to find this number)



Atomic symbol

Name

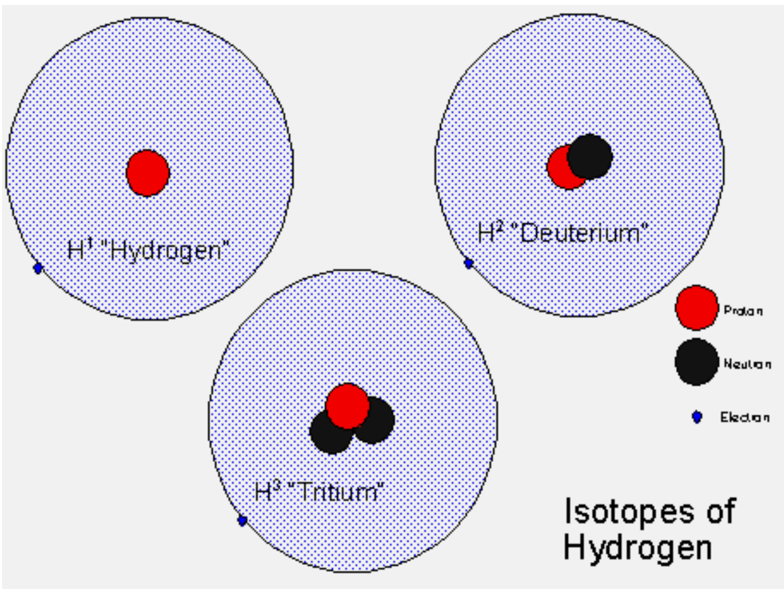
Isotopes

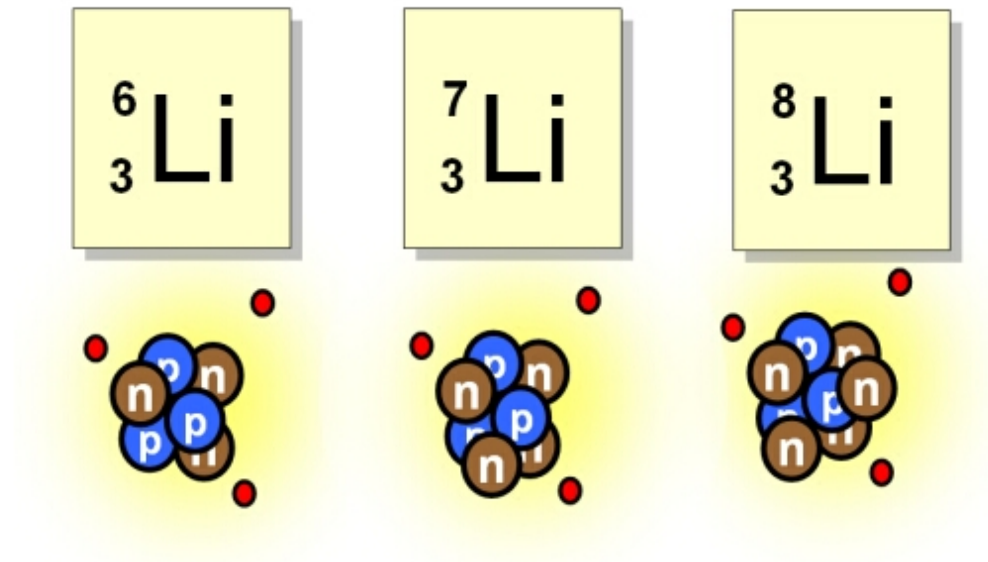
- An element can have **different numbers of neutrons**, while keeping the same number of protons. When this happens it is called an isotope.

- Different isotopes have different nuclear properties, but have the same chemical properties as the regular element. The mass number lets you calculate how many neutrons an atom has

- Example: ^{235}U and ^{238}U
  - They are still the same element, however ^{235}U has 143 neutrons while ^{238}U has 146 neutrons

Isotopes





Hydrogen and lithium isotopes.

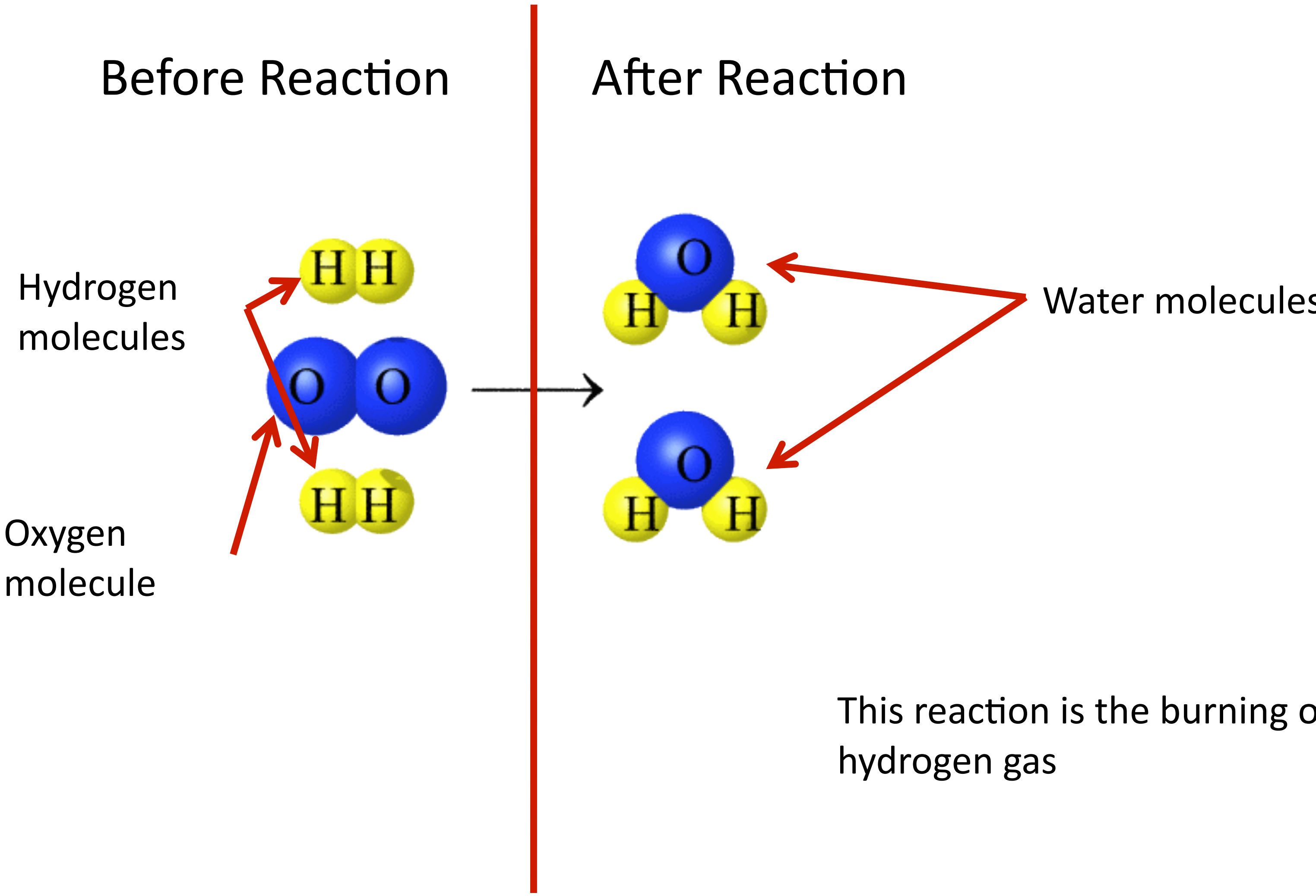
Notice the number of protons does not change, but the number of neutrons does. The isotopes will react chemically the same but their nuclear properties are different.

Chemical Reactions

- As said before, atoms interact with one another. They form larger structures called molecules, crystals, and compounds.

- When these larger structures interact, they can occasionally form new compounds. When the change occurs it is called a **chemical reaction.**

Chemical Reactions



This reaction is the burning of hydrogen gas

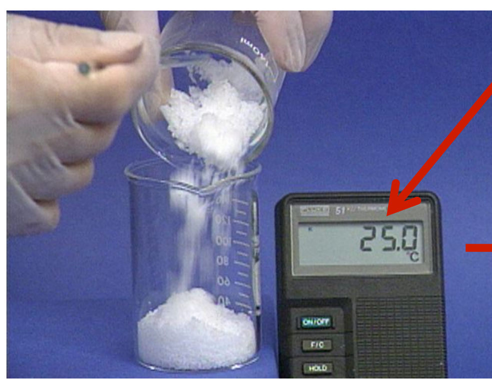
Chemical Reactions

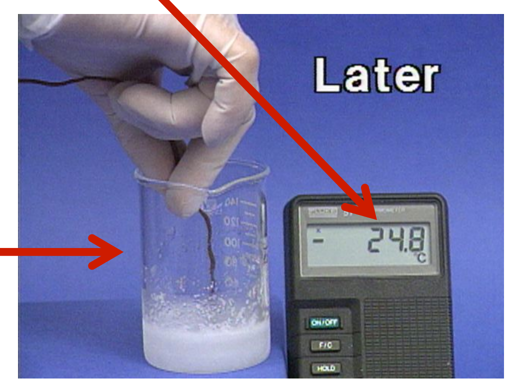
- Chemical reactions are important to us since they can cause a change in forms of energy quite readily.
- Think of the gas in your car. Energy is stored in the gasoline molecules and when it is burned in your engine, chemical energy is converted into mechanical energy to make the car run.
- It can also go the other way. Think of ICYHOT. The cooling sensation you get is from a chemical reaction sucking the heat energy out of the surrounding air, and your sore muscle.

Chemical Reactions

This reaction we all know. By burning the logs energy is released into area, warming the air and your wet socks.

As you can see this reaction is sucking energy into the substance, lowering the temperature. Not by a whole lot, but typically these reactions are hard to make happen.





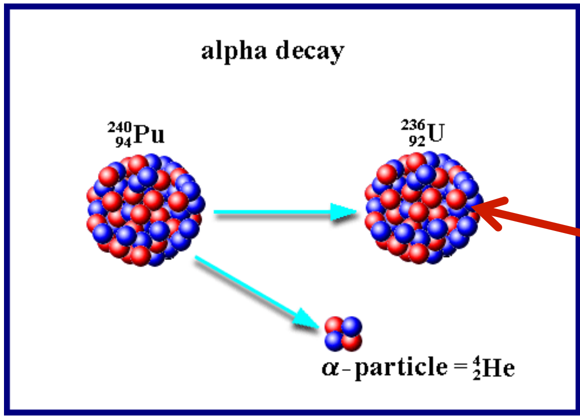
Why Nuclear Science is Different

- While chemistry concerns the interactions between **atoms**, nuclear science concerns the interactions between **parts of atoms**.

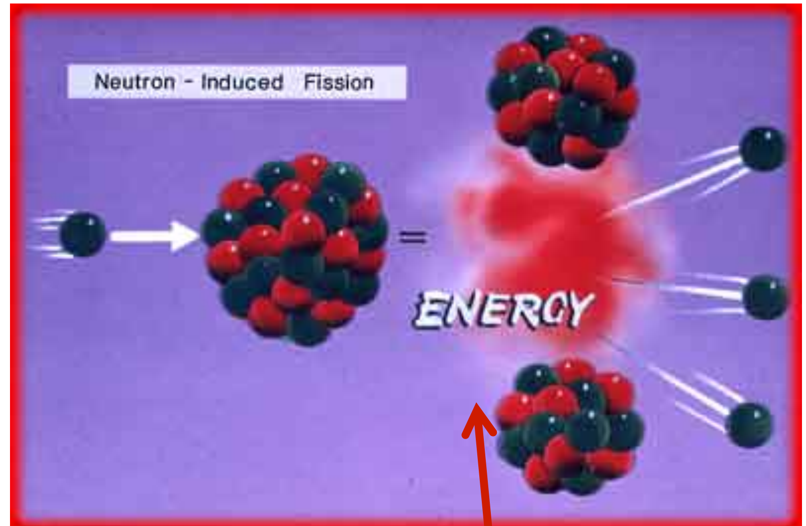
- This is very exciting!

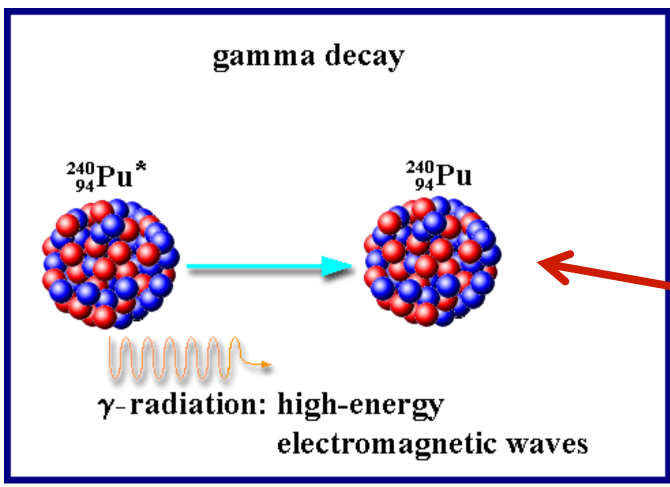
- **Nuclear reactions** can cause atoms to change elements, emit high energy waves, shoot off parts of their nucleus, and even explode.

Examples of Nuclear Reactions



You can see this atom threw off some of its nucleus. Since some protons left, it changed elements as well.



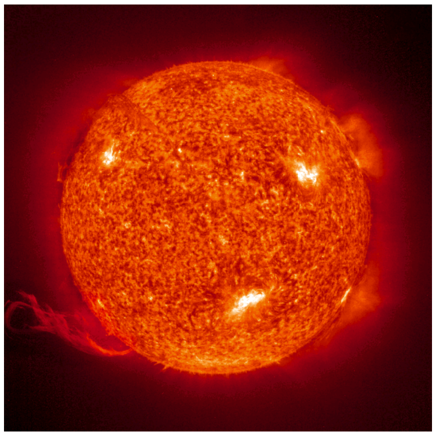


This atom was too energetic (the * next to its symbol stands for that) and so it lost energy by shooting off a very high energy wave

Even atoms can explode! An amazing discovery, this is how nuclear power plants produce their power.

Why Nuclear Science is Different

- While nuclear reactions are sometimes harder to see than chemical reactions, we still encounter them. Every time you go outside and feel the sun's warming rays you are feeling the product of a nuclear reaction. **Stars**, like our sun, produce their light and heat by **nuclear reactions**. There are other sources of radiation that we come in contact with every day, but we can't see the reactions. Here are some common naturally radioactive objects:
  - Bananas
  - Lantern mantles
  - Natural gas
  - Some smoke detectors



The sun is a giant fusion reactor, producing lots of energy to warm all of its planets

Bananas are great for you. They contain large amounts of potassium, which has a naturally radioactive isotope. (^{40}K)

Natural gas has radon in it, a naturally occurring, radioactive gas

Lantern mantles are produced with thorium, a radioactive heavy metal

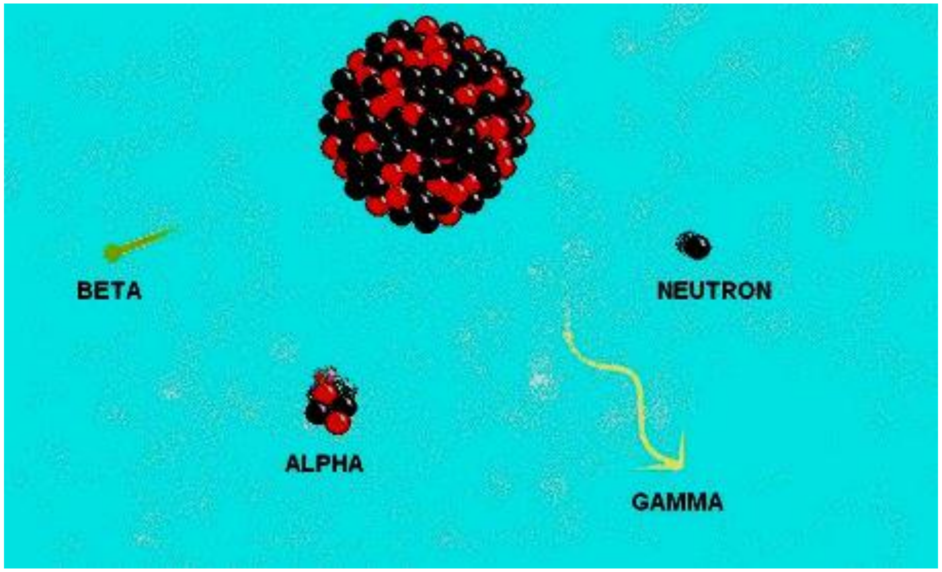
Nuclear Science

- When looking at changes in the nucleus of an atom you must consider that there are many things that can happen. We will review a few of these changes that are important to nuclear science.

Radioactive Decay

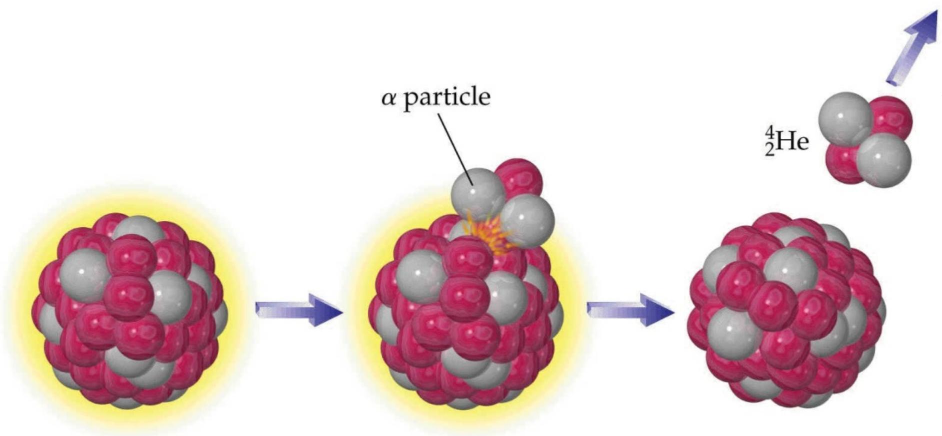
- The most common nuclear reaction is radioactive decay. That is when a nucleus has too much energy and expends this excess energy in either the form of a particle or wave.
- **Particle decay** releases part of the nucleus in the form of various sub-atomic particles.
- **Wave decay** does not release any material but releases energy in a form very similar to that of a light wave.

Radioactive Decay



This image shows the four most common types of decay. No atom will decay emitting all of these particles at once. But one atom could decay each of these ways emitting each particle one at a time. Out of all of these the gamma ray is the only one with out mass.

Radioactive Decay

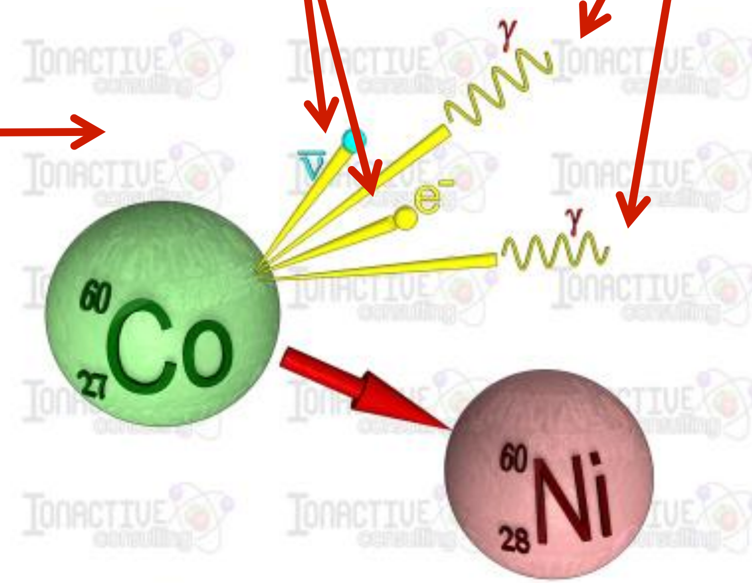


Particle decay

waves

Particles

This is a wave decay, but you can see particles are also coming off, this is very common



Notice in both of these decays the element changed. Most nuclear decays change the element. This makes an engineering challenge. Imagine every time you turned around your workbench was a different material.

Particle Decay

- There are several types of particles that can be released:
  - Alpha particles- a positively charged helium nucleus
  - Beta Particle- an electron formed in the nucleus of an atom
  - Neutron- a neutron that is expelled from the nucleus
  - Positron- a form of antimatter, same weight as an electron, but carries a positive charge
  - Neutrino- as close to nothing as you can get, of no real consequence to us as it doesn't interact with anything really

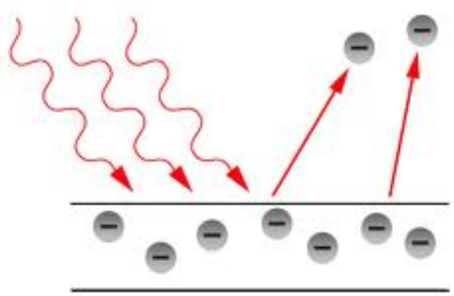
Particle Decay

- When these particles decay they are able to then interact independently with their surroundings and cause different things to happen.
- Examples:
  - An alpha particle will smash through whatever material is there (imagine a bowling ball through the pins) and will pick up electrons to become a helium atom
  - A neutron may be born in a reactor where it can cause a fission event (don't worry we'll get to fission soon enough)
  - A beta particle may get picked up by an atom and become an orbital electron
  - A positron will annihilate an electron producing pure energy

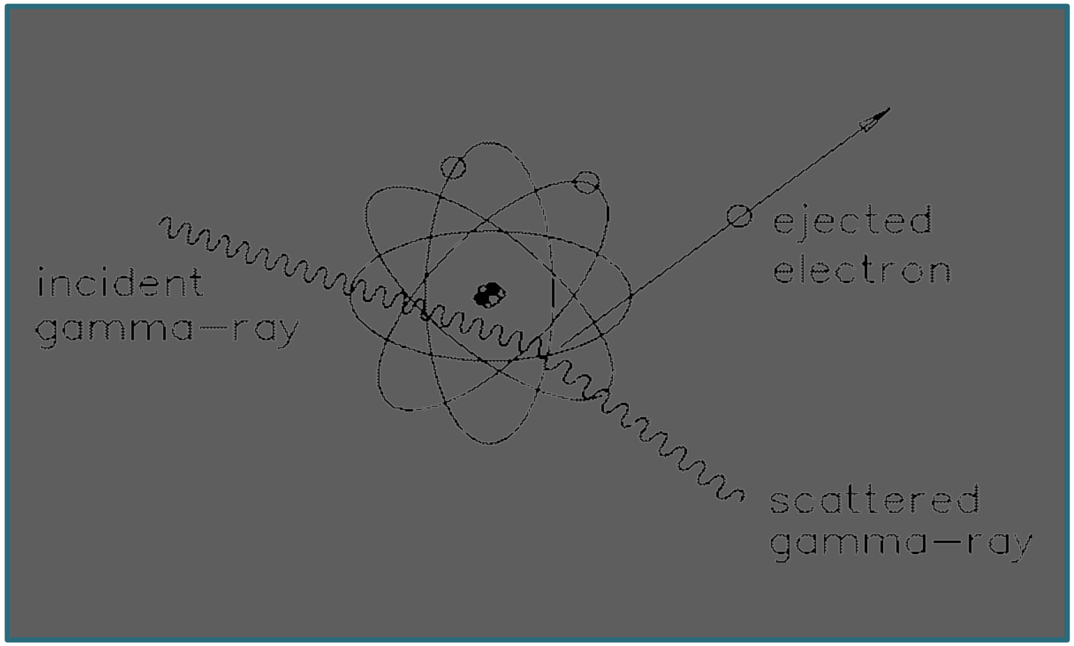
Wave Decay

- When a wave decay occurs the wave released will be a gamma ray. This is always the case. A gamma ray is defined as a wave that is emitted from the nucleus of an atom. This wave will be very high energy and will interact in one of three ways.
  - It will be absorbed by an electron, which then energized will be ejected from orbit at an amazing speed.
  - It can give only some of its energy to an electron, still knocking it out, however the ray will continue on.
  - The last interaction that commonly occurs is called pair production. It occurs when a high energy gamma ray interacts in the vicinity of a nucleus and is converted to a positron-electron pair.

Types of Gamma Ray Interactions



This is when a gamma ray is completely absorbed by an electron. This is known as the photoelectric effect and is what Einstein received his Nobel prize for.



This is a gamma partially giving its energy away to an electron. Known as Compton scattering this scattering can be used to determine how wide the atoms are spaced in a crystal.

Nuclear Fission

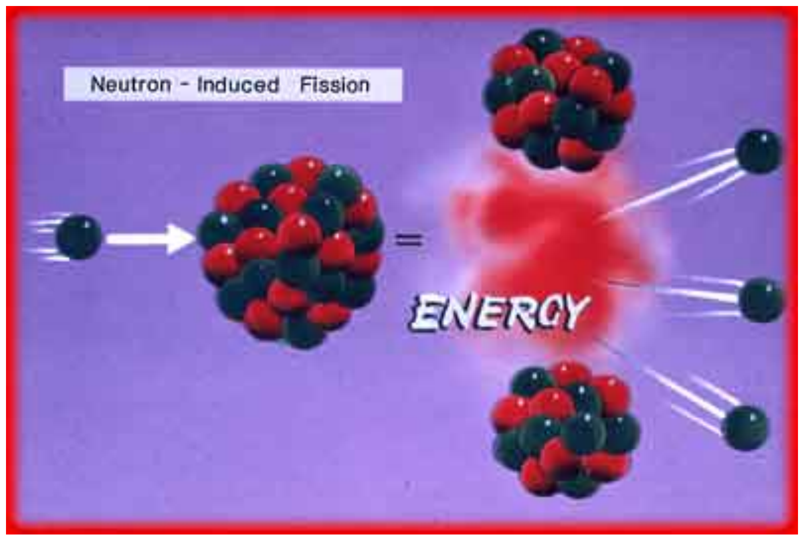
- Now that we have covered radioactive decay lets cover another important nuclear transformation, fission.

- Fission occurs when the nucleus of an atom splits in two.

- This is the process utilized to run nuclear reactors and produce power.

Nuclear Fission

The energy released in this reaction is what nuclear plants use to generate their power

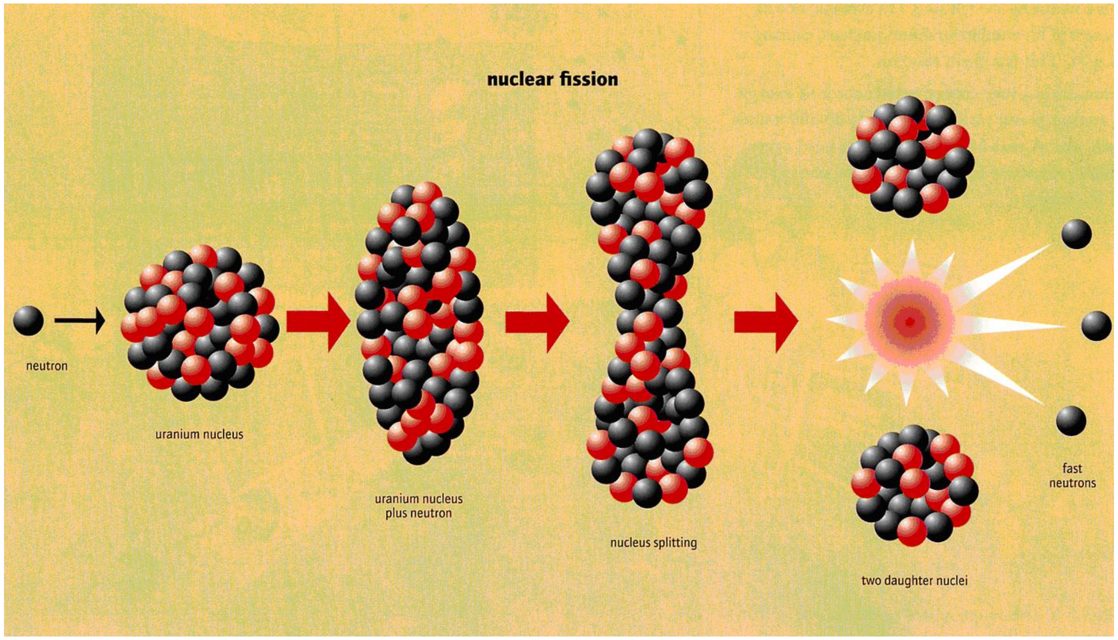


Nuclear Fission

- Fission can only occur with certain very large atoms, such as uranium. These atoms are unstable enough to be able to be split. Smaller atoms are too well kept together by the strong nuclear force to be split.
- The fission process is triggered when the nucleus of one of these certain atoms absorbs a neutron. When the nucleus absorbs this neutron it will become unstable, and then tear itself into two.
- When this happens, several things are emitted.

Fission Process

The nucleus actually morphs like this after it absorbs a neutron. It forms a lot of ovals, but as soon as the dumbbell shape is formed, it tears itself in two, releasing energy and more neutrons

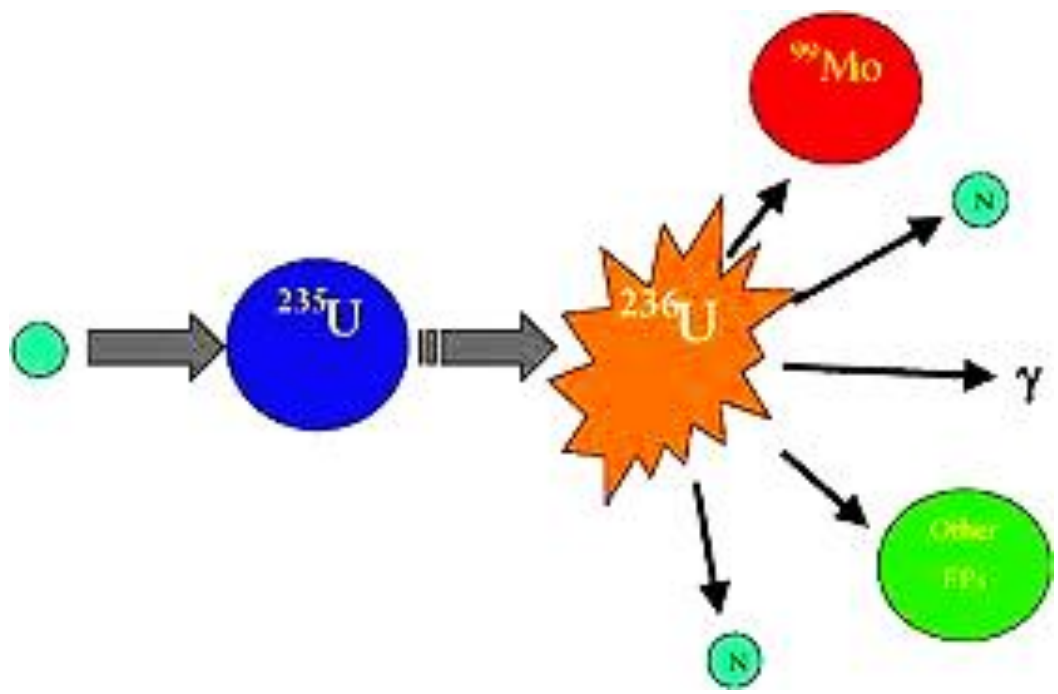


Fission Products

- The things emitted are called fission products. First there are two new atoms that are emitted, these are the two big chunks of nucleus that was torn apart. There are also extra neutrons that are released in this process.

Fission Product Examples

This is an example of two fission products that can form as the result of a neutron hitting a 235U nucleus. Notice that it is briefly 236U before it fissions, since it has another neutron. Other things than just neutrons and fission products come out. This process is quite destructive and random. In short, there is a chance that anything particle-wise can come out of a fission event.

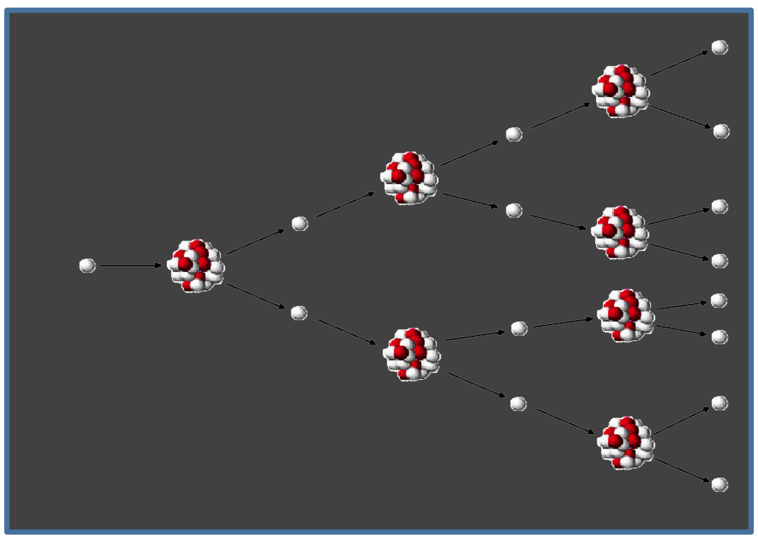


Chain Reaction

- So if a neutron is needed to fission a nucleus, and neutrons are emitted in a fission event. why don't we use the neutrons from the event to cause another fission?
- We do, this is called a chain reaction. Chain reactions are used in nuclear reactors to keep the fission events happening, this keeps the energy flowing and allows us to harness this for power production.

Chain Reaction

This is a basic illustration of a chain reaction. Using chain reactions we can keep the fuel "burning" in a reactor without having to provide neutrons ourselves. This reaction is "supercritical" meaning that it is growing in size. You can see each time there are more and more neutrons. In a power producing reactor, the number of neutrons is controlled so there is always the same number being absorbed and produced.



Thanks and Gig'em

- Thank you for taking the time to go through this course. While it is not required, doing extra research on your own before you come, online or in your science text book, is highly encouraged.
- If you are looking for information online here are some topics to look at:
  - Types of nuclear reactors
  - How nuclear science is used outside of power production
  - Fission
  - Consequences of radiation exposure
  - The history of nuclear power (Enrico Fermi, Albert Einstein)
  - Chart of the Nuclides
  - Pair production