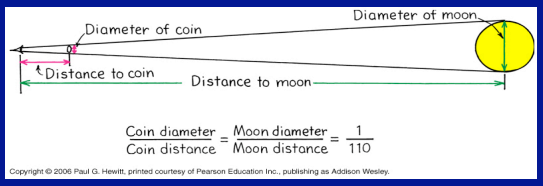
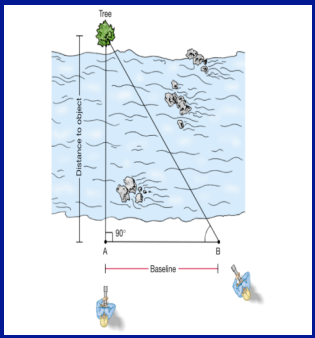
Determining the Distance to the Moon



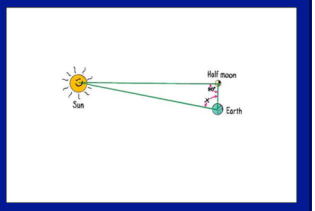
Triangulation - Using Geometry to Measure Distances

- Know:
  - Angle at A
  - Angle at B
  - Length of Baseline
- Calculate:
  - Distance to object



The Earth-Sun Distance

- At any time exactly half of the moon's surface is lit by the sun.
- During a quarter moon we only see ½ of this half.
- Knowing Earth-Moon distance and measuring angle `X' we can find Earth-Sun distance.
  - Wait for a quarter moon and use triangulation



Clicker Question:

Which of the following is the largest?

A: size of the Moon

B: size of the Earth

C: size of the Sun

D: distance from the Moon to the Earth

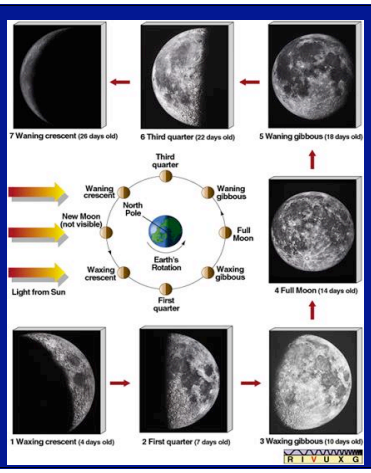
Why don't we get eclipses every month?

A: The moon has lots of holes in it.

B: The moon moves too far away to block the sunlight.

C: The orbit of the moon is tilted.

D: We do get them every month but don't notice.

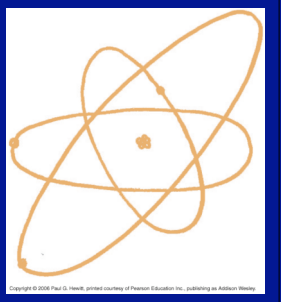


The Nature of Matter

- You can break a rock into smaller pebbles, break the pebbles into sand, crush the sand into powder, etc.
- Is there a limit to this process or can any material be divided into smaller and smaller pieces, with the smaller pieces retaining all of the same characteristics of the original?

Molecules and Atoms

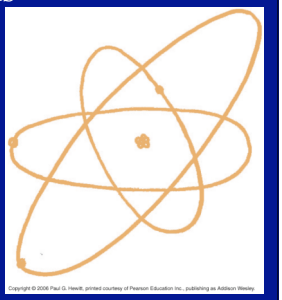
- Molecule
  - Retain all chemical properties of original substance
- Atoms - The building blocks of all matter
  - Smallest unit that retains properties of a given element
- What are the components of an atom?



Which component of an atom is the smallest?

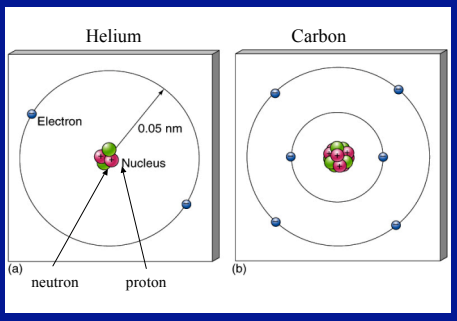
Atoms

- Building blocks of all matter
  - Smallest unit that retains properties of a given element
- What are the components of an atom?
  - Nucleus: Very dense core
    - Protons (Positive charge)
    - Neutrons (Electrically neutral)
  - Shells of orbiting electrons
    - Negatively charged



Which component of an atom is the smallest?

Example Elements



Atoms have equal positive and negative charge.
Isotopes: Carbon-12: 6 protons and 6 neutrons in the nucleus
Carbon-14: 6 protons and 8 neutrons in the nucleus

Properties of Atoms

- Incredibly Small
  - Atom : Apple : Earth
    - # of atoms in apple = # of apples needed to "fill" Earth
- Incredibly Numerous
  - How many atoms are there in a thimble filled with water?

Properties of Atoms

- Incredibly Small
  - Atom : Apple : Earth
    - # of atoms in apple = # of apples needed to "fill" Earth
- Incredibly Numerous
  - There are more stars in the universe than grains of sand on all of Earth's beaches and deserts. But there are more atoms in a thimble full of water (10^{23}) than there are stars in the observable universe!
- Perpetually Moving and Diffusing
  - Dye in a glass of water or perfume in a room
- Ageless
  - Most atoms in your body almost as old as the universe itself!

- What are the chances that in your next breath you will inhale some of the atoms exhaled by Julius Caesar in his dying breath?

- What are the chances that in your next breath you will inhale some of the atoms exhaled by Julius Caesar in his dying breath?
  - Not only are we made up of the same types of atoms, the same atoms go into making each of us up at different times!
  - Almost every light atom in our bodies has existed in innumerable forms since the beginning of time, while the heavier elements were formed by stars that exploded long ago!

It takes a few years for your breath to spread uniformly through the atmosphere. So, everyone on Earth is inhaling atoms that used to be part of you with every breath.

Clicker Question:

Ionized Helium consists of two neutrons and:

A: two protons in the nucleus and 1 orbiting electron

B: two protons in the nucleus and 2 orbiting electrons

C: one proton in the nucleus and 1 orbiting electron

D: one proton in the nucleus and 2 orbiting electrons

E: two protons in the nucleus and 3 orbiting electrons

Clicker Question:

Which of the following is largest:

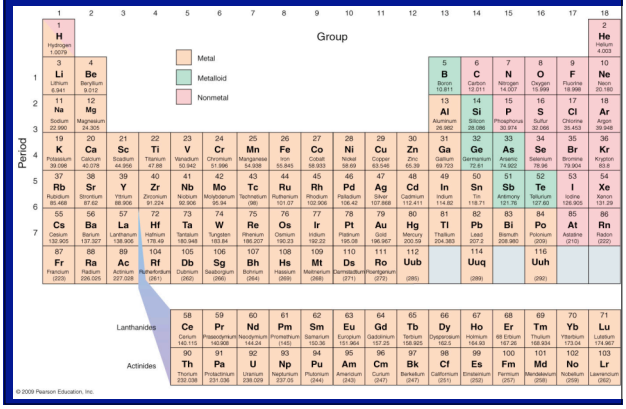
A: number of people in this room

B: number of people alive today

C: number of stars in the observable universe

D: number of atoms in a glass of water

Periodic Table of the Elements



Death of a High-Mass Star

$M > 8\ M_{Sun}$

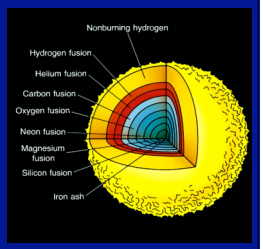
Iron core

Iron fusion doesn't produce energy (actually requires energy) => core collapses in < 1 sec.

$T \sim 10^{10}$ K, radiation disrupts nuclei,

p + e => n + neutrino

Collapses until neutrons come into contact. Rebounds outward, violent shock ejects rest of star => A Core-collapse or Type II Supernova

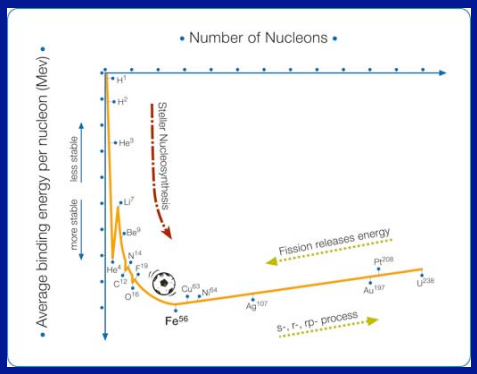


Ejection speeds 1000's to 10,000's of km/sec!

Remnant is a "neutron star" or "black hole".

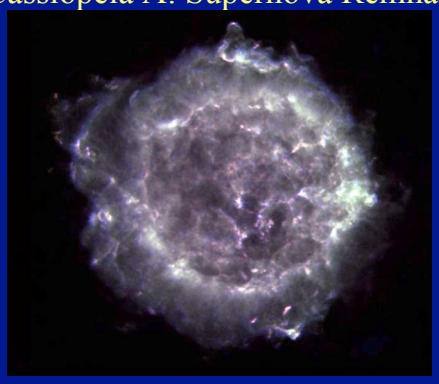
Such supernovae occur roughly every 50 years in Milky Way.

Binding Energy per nucleon



Example Supernova: 1998bw

Cassiopeia A: Supernova Remnant



Making the Elements

Universe initially all H (p's and e's). Some He made soon after Big Bang before stars, galaxies formed. All the rest made in stars, and returned to ISM by supernovae.

Solar System formed from such "enriched" gas 4.6 billion years ago. As Milky Way ages, the abundances of elements compared to H in gas and new stars are increasing due to fusion and supernovae.

Elements up to iron (^{56}Fe, 26 p + 30 n in nucleus) produced by steady fusion (less abundant elements we didn't discuss, like Cl, Na, made in reactions that aren't important energy makers).

Heavier elements (such as lead, gold, copper, silver, etc.) by "neutron capture" in core, even heavier ones (uranium, plutonium, etc.) in supernova itself.

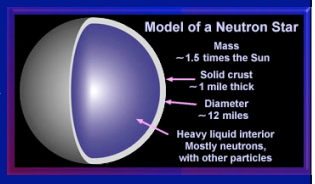
Atomic Structure

- Atoms are electrically neutral
  - Have same number of protons and electrons
  - How does the electrical force behave?

Atomic Structure

- How does the electric force behave?
  - Opposite charges attract and like charges repel
- Almost all of the mass of an atom is concentrated in the nucleus
  - Nucleus is incredibly dense
  - Atoms are mainly empty space
  - If pressure is great enough, can pack nuclei together
    - Neutron star: Thimble-full of material would weigh 100 million tons on Earth

Neutron Stars



Leftover core from Type II supernova - a tightly packed ball of neutrons.

Diameter: 20 km only!

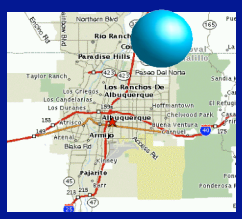
Mass: 1.4 - 3 M_{Sun}

Density: 10^{14} g / cm^3 !

Surface gravity: 10^{12} higher
Escape velocity: 0.6c

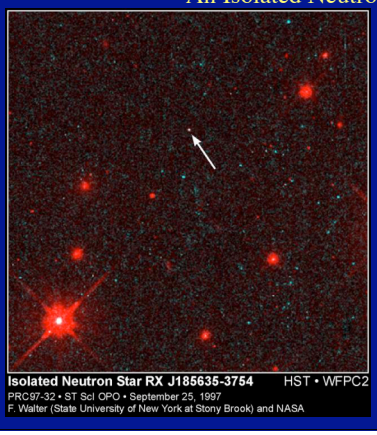
Rotation rate: few to many times per second!!!

Magnetic field: 10^{12} x Earth's!



A neutron star over the Sandias?

An Isolated Neutron Star



T ~ 2 million K
Size ~ 30 km

- If atoms are mainly empty space, what keeps your hand from just passing right through your desk when you touch it?

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  - Electrical repulsion between the outer electrons in your hand and in the desk.
  - You have never really touched anything! The atoms in your hand get close enough so that you feel the electrical repulsion forces, but there is always a tiny gap of space between you and the object you are "touching".

The Elements

- What are some elements found in the periodic table?

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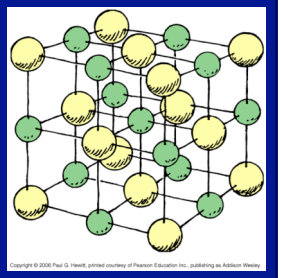
- So, what are the basic components of all elements?
  - Protons, Neutrons, and Electrons
- What differentiates one element from another and determines its properties?
  - The # of protons. All normal matter in the universe (algae, people, galaxies) is made of the same basic ingredients. Only the recipes differ.

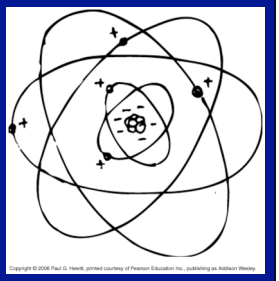
Compounds and Molecules

- Compound – Chemical material made up of more than one type of atom
  - Sodium (Na): Metal that reacts violently with water
  - Chlorine (Cl): Poisonous gas
  - NaCl = Table salt
- Molecule – Two or more atoms held together by the sharing of electrons
  - Can be same atom: O_2
  - Or different: H_2O



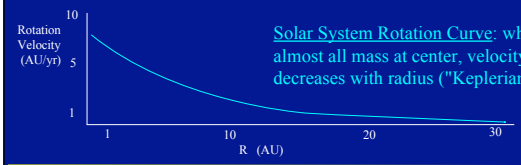
Antimatter

- Atoms with negative nuclei and positive electrons (or positrons)
  - All particles have an antiparticle with same mass and opposite charge
  - Regularly created in high-energy particle accelerators
  - Matter and Antimatter completely annihilate one another in a burst of radiation
  - Antihydrogen first constructed in 1995



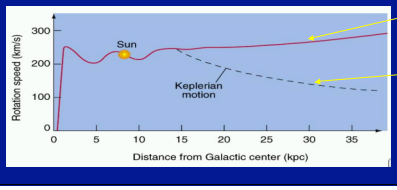
90% of Matter in Milky Way is Dark Matter

Gives off no detectable radiation. Evidence is from rotation curve:



Solar System Rotation Curve: when almost all mass at center, velocity decreases with radius ("Keplerian")

Milky Way Rotation Curve



observed curve

Curve if Milky Way ended where visible matter pretty much runs out.

Not enough radiating matter at large R to explain rotation curve => "dark" matter!

Dark matter must be about 90% of the mass!

Composition unknown. Probably mostly exotic particles that don't interact with ordinary matter at all (except gravity). Some may be brown dwarfs, dead white dwarfs …

Most likely it's a dark halo surrounding the Milky Way.

Mass of Milky Way

6×10^{11} solar masses within 40 kpc of center.

Clicker Question:

Most of the matter in the Universe is:

A: protons

B: some form of dark matter that we don't understand

C: electrons

D: hydrogen

Clicker Question:

Which of the following is another word for an anti-electron?

A: proton

B: neutron

C: positron

D: atom

Dark Matter

- Not enough observable matter to explain motions of galaxies
  - Ordinary mass: about 5% of mass-energy in universe
  - Dark matter: about 25%
  - Dark energy: about 70%
- "Powers of Ten" video