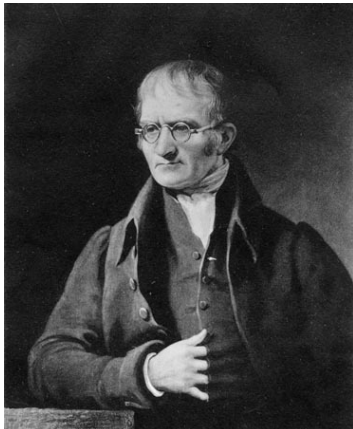


Atomic Structure before Bohr



Dalton's exceptional gift for recognizing and interpreting patterns in experimental data lead him from a problem in meteorology to the idea of atoms as fundamental constituents of matter. He realized the vital theoretical connection between atomic weights and weight relations in chemical reactions. He was the first to associate the ancient idea of atoms with stoichiometry.

Dalton's Atomic Theory rests on the following postulates.

1. **All matter consists of tiny particles.** The existence of atoms was first suggested more than 2000 years before Dalton's birth. Atoms remained pure speculation through most of this time, although Newton used arguments based on atoms to explain the gas laws in 1687. (Newton's speculations about atoms in the *Principia* were carefully copied by hand into Dalton's notebooks.)
2. **Atoms are indestructible and unchangeable.** Atoms of an element cannot be created, destroyed, broken into smaller parts or transformed into atoms of another element. Dalton based this hypothesis on the law of conservation of mass and on centuries of experimental evidence. With the discovery of subatomic particles after Dalton's time, it became apparent that atoms could be broken into smaller parts. The discovery of nuclear processes showed that it was even possible to transform atoms from one element into atoms of another. But we don't consider processes that affect the nucleus to be chemical processes. The postulate is still useful in explaining the law of conservation of mass in chemistry. A slightly more restrictive wording is "Atoms cannot be created, destroyed, or transformed into other atoms in a chemical change".
3. **All atoms of the same element are identical. Elements are characterized by the mass of their atoms.** All atoms of the same element have identical weights, Dalton asserted. Atoms of different elements have different weights. With the discovery of isotopes, however, the postulate was amended to read, "Elements are characterized by their atomic number".
4. **Atoms combine in new ways during a chemical change. When elements react, their atoms combine in simple, whole-number ratios.** This postulate suggested a practical strategy for determining relative atomic weights from elemental percentages in compounds. Experimental atomic weights could then be used to explain the fixed mass percentages of elements in all compounds of those elements!

This effectively explained both the law of definite proportions and the law of multiple proportions. Some of the details of Dalton's original atomic theory are

now known to be incorrect. But the core concepts of the theory (that chemical reactions can be explained by the union and separation of atoms, and that these atoms have characteristic properties) are foundations of modern physical science.

- **J. J. Thomson's cathode ray experiment**



"cathode rays" pass from negative electrode towards positive electrode in an evacuated tube

hypothesis: cathode rays are streams of **electrons***

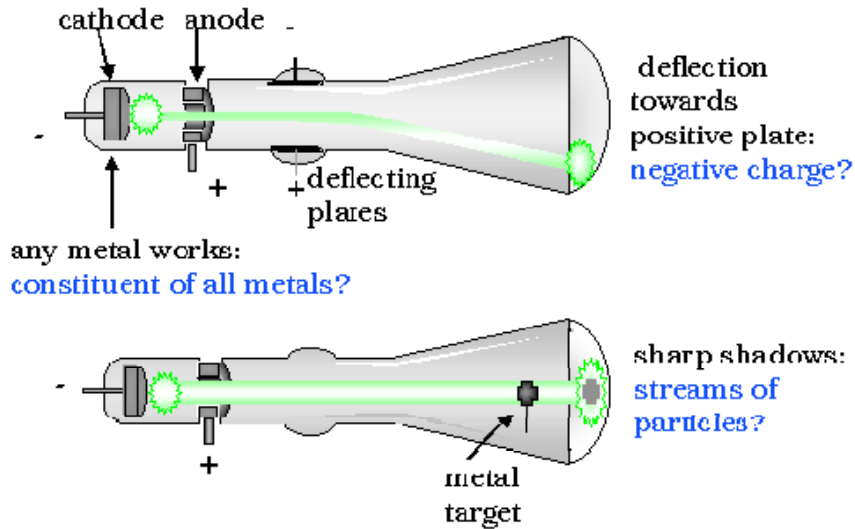
calculated mass to charge ratio for electrons by observing bending of cathode rays in electric and magnetic fields

proposed the plum pudding model of the atom

Table: Hypothetical properties of the electron. How J. J. Thomson used properties of cathode rays to hypothesize properties of the electron.

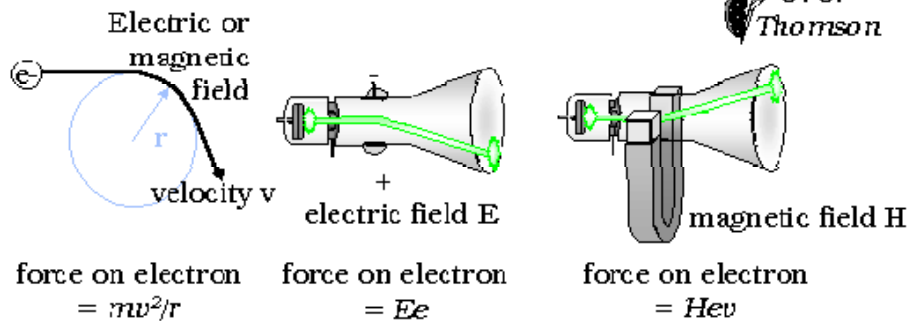
observations	hypothesis
ray properties are independent of the cathode material	... cathode ray stuff is a component of all materials
cathode rays bend near magnets	... magnets bend the paths of moving charged particles; maybe cathode rays are streams of moving charged particles
rays bend towards a positively charged plate. rays impart a negative charge to objects they strike.	... cathode rays are streams of negative charges
Cathode rays don't bend around small obstacles, cast sharp shadows, can turn paddlewheels placed in their path, and travel in straight lines	... cathode rays behave like streams of particles

Probing Atomic Structure: Cathode Rays

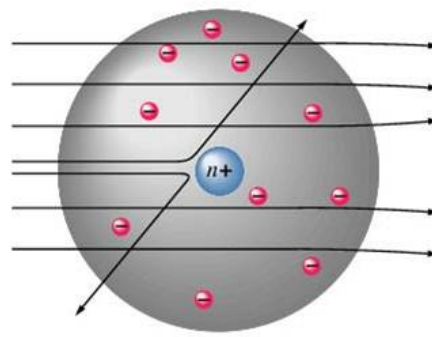
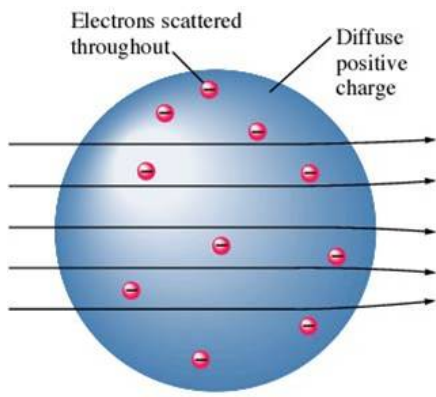
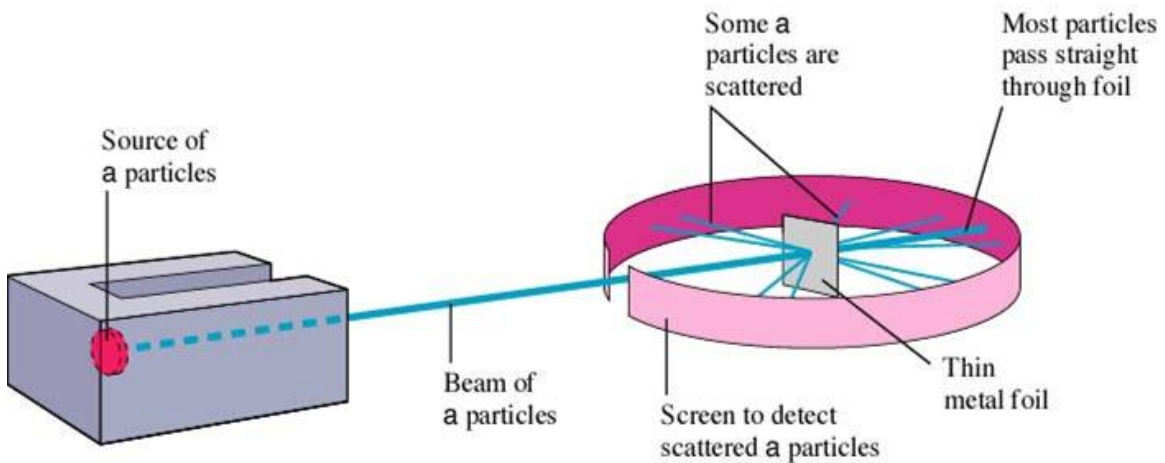
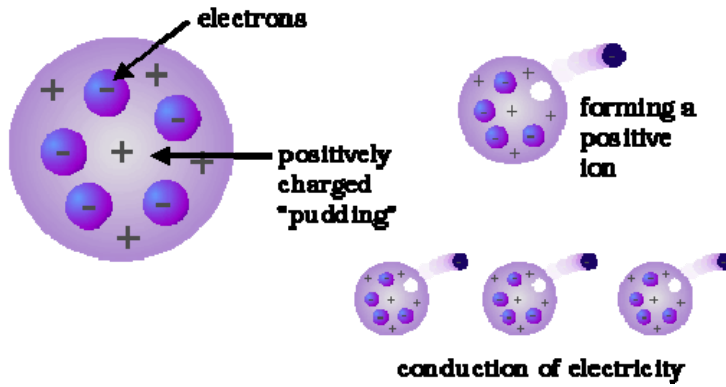


Discovery of the Electron

- ❖ measurement of mass-to-charge ratio (m/e) for electrons



Thomson's Plum Pudding Atom



(a)

(b)

Discovery of the Nucleus

- Radioactivity
 - heavy elements are radioactive
 - electric field resolves radiation into 3 components: alpha, beta, and gamma

Table: hypothetical description of alpha particles based on properties of alpha radiation

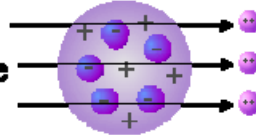
observation	hypothesis
alpha rays don't diffract	... alpha radiation is a stream of particles
alpha rays deflect towards a negatively charged plate and away from a positively charged plate	... alpha particles have a positive charge
alpha rays are deflected only slightly by an electric field; a cathode ray passing through the same field is deflected strongly	... alpha particles either have much lower charge or much greater mass than electrons

- scattering experiment
 - hypothesis: If the plum pudding model of the atom is correct, atoms have no concentration of mass or charge (atoms are 'soft' targets)
 - experiment to test hypothesis:
 - fire massive alpha particles at the atoms in thin metal foil
 - alpha particles should pass like bullets straight through soft plum pudding atoms
 - observation: a few alpha particles ricocheted!
 - new hypotheses:
 - all of the positive charge and nearly all of the mass of the atom is concentrated in a tiny, incredibly dense 'nucleus', about 10^{-14} m in diameter
 - electrons roam empty space about 10^{-10} m across, around the nucleus

The Nuclear Atom

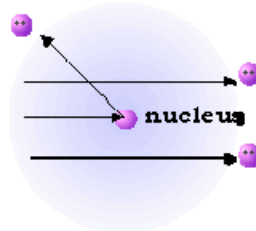
+ Thomson's Atom

- diffuse mass and charge



+ Rutherford's Atom

- concentrated mass and positive charge at the **nucleus**
- electrons roam empty space around the nucleus



- Composition of the Nucleus
 - nuclei are composed of "nucleons": protons and neutrons
 - atomic mass units
 - 1 amu (aka 1 dalton) = exactly 1/12 the mass of a carbon-12 nucleus
 - 1 dalton = 1.67×10^{-24} g

Table: Subatomic particles important in chemistry.

particle	symbol	charge	mass, kg	mass, daltons
electron	e ⁻	-1	9.10953×10^{-31}	0.000548
proton	p ⁺	+1	1.67265×10^{-27}	1.007276
neutron	n	0	1.67495×10^{-27}	1.008665

Structure of the Nucleus

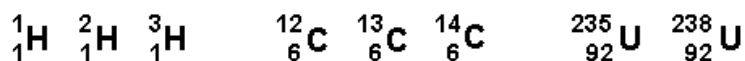
✦ nuclei are composed of "nucleons": **protons** and **neutrons**

	Symbol	Charge	Mass, kg	Mass, amu
electron	e^-	-1	9.10953×10^{-31}	0.000548
proton	p^+	+1	1.67265×10^{-27}	1.007276
neutron	n	0	1.67495×10^{-27}	1.008665



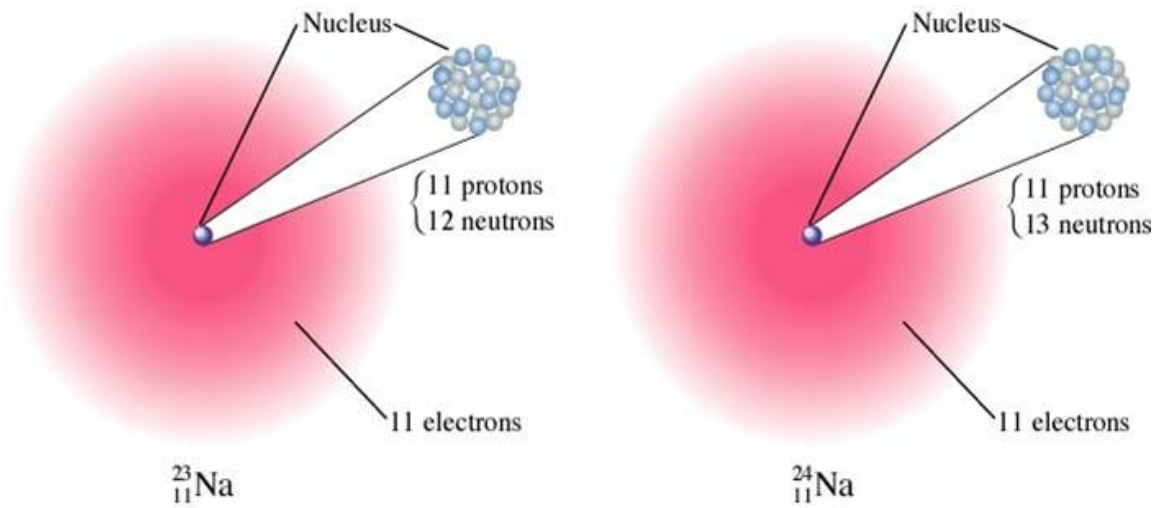
Isotopes

✦ **isotopes**: same Z, different M



✦ **isotopic abundance**: $\frac{\# \text{ atoms of isotope present}}{\# \text{ atoms of element present}}$

isotope	natural abundance	mass (amu)
carbon-12	98.89 %	12.000000
carbon-13	1.11 %	13.003354
average mass: 12.01_{11} amu		



Mass Number

$\overset{A}{Z}\text{E}$ ——— Symbol for the element

Atomic Number

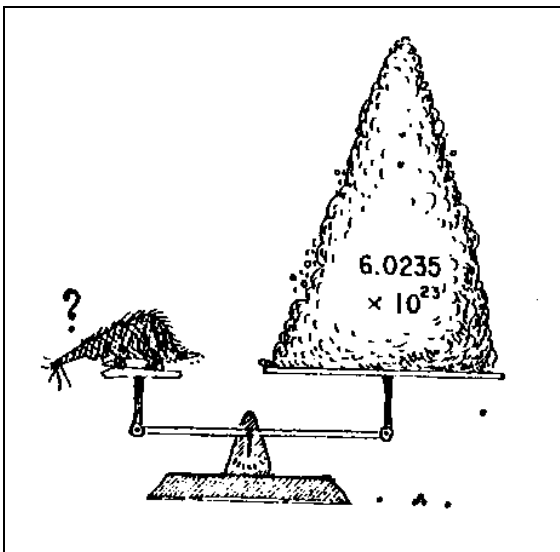
- ! **atomic number (Z)**--The number of p+ in an atom. All atoms of the *same* element have the *same number* of p+.
- ! **mass number (A)**--The sum of the number of neutrons and p+ for an atom. A different mass number *does not* mean a different element--just an isotope.

mass number—A $\overset{A}{Z}\text{X}$ ←element symbol
atomic number—Z

! **average atomic masses**—atoms have masses of whole numbers, HOWEVER samples of quadrillions of atoms have a few that are heavier or lighter [isotopes] due to different numbers of neutrons present

! **percent abundance**--percentage of atoms in a natural sample of the pure element represented by a particular isotope

$$\% \text{ abundance} = \left(\frac{\text{number of atoms of a given isotope}}{\text{total number of atoms of all the isotopes of that element}} \right) \times 100$$



THE MOLE

6.02×10^{23} atoms (particles) = the atomic mass in grams

6.02×10^{23} atoms (particles)= 1 mole

1 mole = the atomic mass in grams

The atomic mass is the weighted average of the relative mass of the isotopes of an element.

Relative mass is a comparative mass in the unit atomic mass units or amu. An atomic mass unit is defined as $1/12^{\text{th}}$ the mass of ^{12}C .

! **mole**—the number of C atoms in exactly 12.0 grams of ^{12}C ; also a number, 6.02×10^{23} just as the word “dozen” means 12 and “couple” means 2.

! **Avogadro’s number**— 6.02×10^{23} , the number of particles in a mole of anything

MOLAR MASS, MOLECULAR WEIGHT, AND FORMULA WEIGHT

! **molar mass, MM**--the mass in grams of Avogadro=s number of molecules; i.e. the mass of a mole!

! **empirical formula**--that ratio in the network for an ionic substance.

!

Calculating the Number of Moles and Mass

Examples:

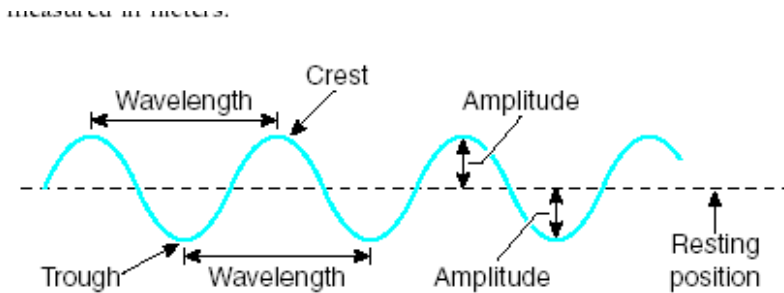
Cobalt (Co) is a metal that is added to steel to improve its resistance to corrosion. Calculate both the number of moles in a sample of cobalt containing 5.00×10^{20} atoms and the mass of the sample. How many atoms of carbon has a man given his fiancée if the engagement ring has a 0.500 carat diamond? There are 200.0 mg in a carat.

How many atoms of carbon has a man given his fiancée if the engagement ring has a 0.500 carat diamond? There are 200.0 mg in a carat.

How many protons are there in a 15 gram sample of neon?

Bohr's Model of the Atom

First a bit about waves:



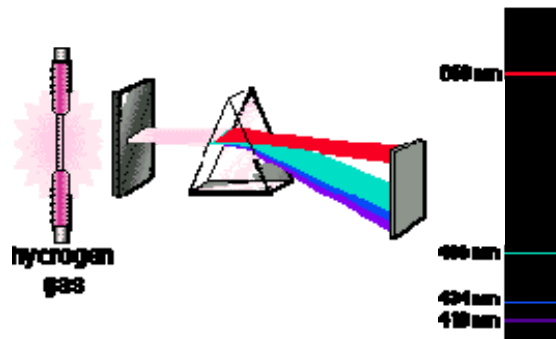
- Amplitude is the height of a wave from the resting position. . As the energy of a wave increases, amplitude increases.
- The frequency represents the number of waves that pass by a point every second. As the energy of a wave increases; frequency increases.
- Wavelength is the distance between two corresponding points on a wave. As the energy of a wave increases, wavelength decreases.

Emission Spectra

- experimental key to atomic structure: analyze light emitted by high temperature gaseous elements
 - experimental setup: spectroscopy



- atoms emit a characteristic set of discrete wavelengths- not a continuous spectrum!

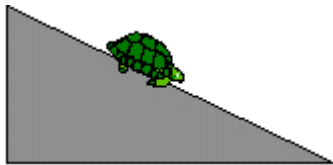


- atomic spectrum can be used as a "fingerprint" for an element

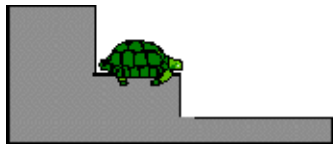
- hypothesis: if atoms emit only discrete wavelengths, maybe atoms can have only discrete energies

Bohr's Theory

- Electrons occupy orbits at discrete distances from the nucleus.
- Electrons in a non-energized atom occupy the lowest energy orbit (closest to nucleus this is called ground state).
- Electrons in energized atoms absorb just enough energy to move from a lower energy orbital to a higher energy orbit (further from nucleus) this is called excited state.
- Electrons do not remain in excited state and return to ground state releasing energy.
- an analogy

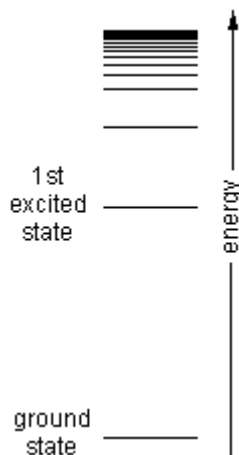


A turtle sitting on a ramp can have any height above the ground- and so, any potential energy



A turtle sitting on a staircase can take on only certain discrete energies

- energy is required to move the turtle up the steps (absorption)
- energy is released when the turtle moves down the steps (emission)
- only discrete amounts of energy are absorbed or released (energy is said to be **quantized**)
-
- energy staircase diagram for atomic hydrogen



- bottom step is called the **ground state**
- higher steps are called **excited states**

- summary: line spectra arise from transitions between discrete (**quantized**) energy states

