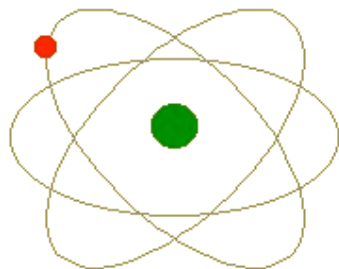


# Isotope Fundamentals

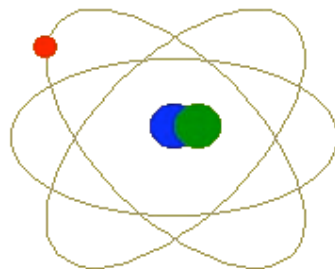
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- o A bit of history
- o Nuclear systematics
- o Nuclear stability and abundance
  - o The chart of the nuclides
- o The field of stable isotope geochemistry

Hydrogen (protium)



Deuterium



# Discovery of Isotopes

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- ~1800: compounds and elements had been distinguished; about 39 elements recognized, discoveries of new elements occurring rapidly
- J. Dalton: first atomic theory - all matter is made of atoms which cannot be further subdivided; all atoms of a given element are identical in all respects, including mass, but atoms of different elements have different masses
- 1870: ~65 elements recognized; Mendeleev organized available chemical knowledge into periodic table
- ~1900: periodic table complete up to U
- Problems: atomic weights of elements did not always increase with the atomic number, and therefore position on periodic table (e.g., Ar > K, Co > Ni, Te > I); samples of lead from different localities had different atomic weights (Richards); discovery of radiation and change in nuclear structure (Roentgen, Currie, Thompson, Becquerel);
- 1914: F. Soddy proposed a resolution to the problems by arguing that the place occupied by a particular element on the periodic table can accommodate more than one kind of atom. Soddy coined the term “isotopes”, Greek for “same place”. A standard definition is: Isotopes = Nuclides of a single element that have different atomic weights
- Confirmation of isotopes: Thompson (1913) used charge to mass ratio to show that neon comprises two different types of atoms with masses of 20 and 22. Aston constructed first mass spectrograph, and by 1919 had discovered 212 of the 287 naturally occurring isotopes

Today: more than 2500 nuclides known, yet together these constitute only about 110 different chemical elements

# A new model for the atom

Table 1.1 Important Nuclear Entities and Emanations

Particle	Symbol	Rest Mass (amu)	Charge
Proton	p	1.0072765	+1
Neutron	n	1.0086649	0
Electron	$\beta^-$	0.0005486	-1
Positron	$\beta^+$	0.0005486	+1
Gamma-ray	$\gamma$	0	0
Protium atom	$^1\text{H}$	1.007825	0
Deuterium atom	$^2\text{H}$ or D	2.014102	0
Alpha-particle	$^4\text{He}^{2+}$ or $\alpha$	4.001475	+2

After Walker et al., 1989.

Criss, 1996

Thompson  $\rightarrow$  electrons

Rutherford (1911)  $\rightarrow$  scattering experiment

$\alpha$ -particles (He atoms) shot at thin metal fo.  
atoms have small, positively charged nuclei:  
surrounded by electrons

Chadwick (1932) : discovery of neutrons

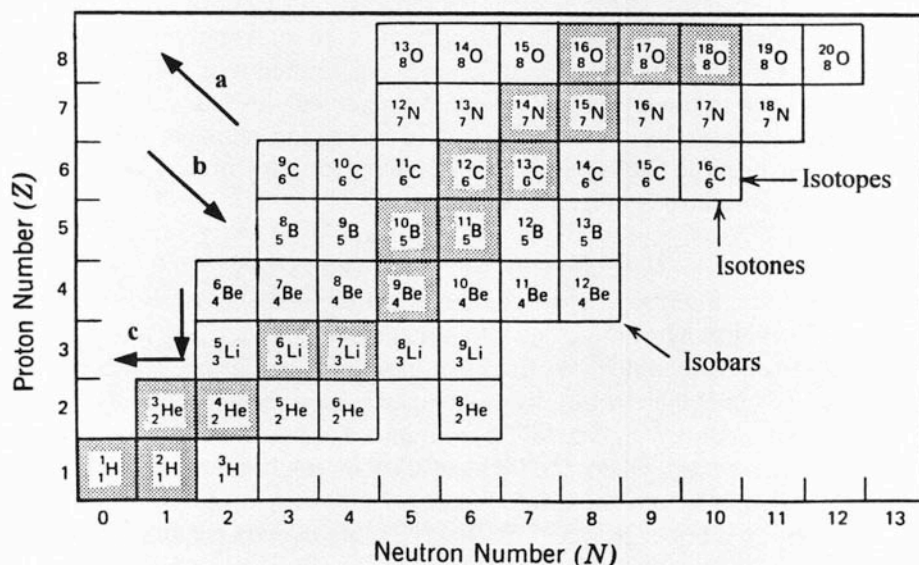
provided explanation for existence of isotopes  
atoms of different numbers of neutrons could  
have same nuclear charge, but different  
masses

led to modern understanding of atom model (Bohr, etc.)

$> 99.9\%$  of mass, and all positive charge,  
lies in nucleus

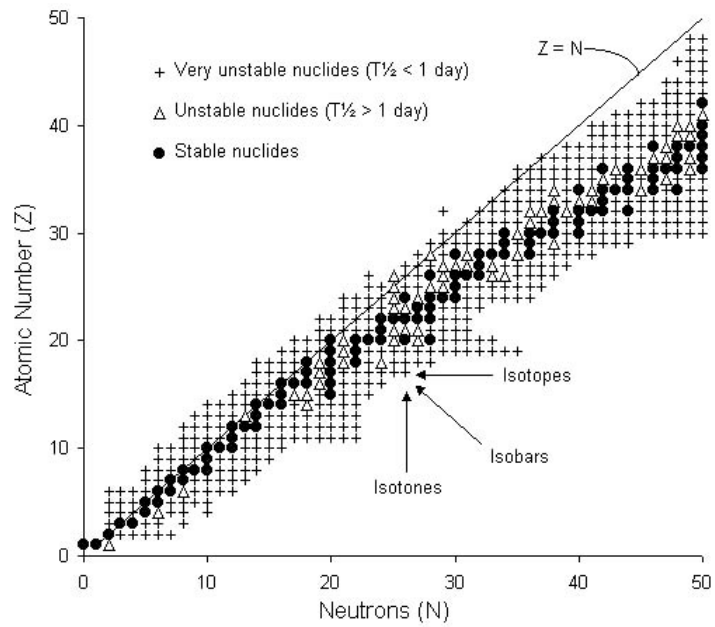
virtually all volume, and all negative charge, lies  
in electron shells

# Isotope Definitions



**Figure 2.1.** Partial chart of the elements. Each square represents a particular nuclide. The shaded squares are stable atoms and the unshaded squares are unstable or radioactive nuclides. Arrows at the left side of the diagram show the shifts in proton and neutron number caused by different decay mechanisms: beta decay (a), positron decay and beta capture (b), and alpha decay (c). Modified from Faure (1986).

# Chart of the Nuclides



# Urey - Stable Isotopes

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- 1931 - Harold Urey (U. Chicago) predicted on theoretical grounds that there should be a difference in the vapor pressure of hydrogen isotopes
- 1934 - Nobel prize for discovery of deuterium
- WWII - separation of  $^{235}\text{U}$  by gaseous diffusion
- 1950's - separation of oxygen isotopes in nature
- Urey's original work led to the field of stable isotope geochemistry

The Nobel Prize in Chemistry 1934  
"for his discovery of heavy hydrogen"



