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Atoms, Molecules, and Ions

Z Ch 2

"According to convention there is a sweet and a bitter, a hot and a cold, and according to convention there is a color. In truth there are **atoms** and a void."
Democritus, 5th century B.C.

"... there must be some point beyond which we cannot go in the division of matter. The existence of these ultimate particles of matter can scarcely be doubted, though they are probably much too small ever to be exhibited by microscopic improvements. I have chosen the word atom to signify those ultimate particles ... [which for] all homogeneous bodies are perfectly alike in weight, figure, etc. In other words, every particle of hydrogen is like every other particle of hydrogen ...."
John Dalton, 1808

Atomic Theory of Matter (Dalton)

Conservation of Mass

Laws of
- Definite Proportions
- Multiple Proportions

Avogadro's Hypothesis

Building Blocks of the Atom

Periodicity

Nomenclature (Elements, Ions, Cmps) – **KNOW**

Prelabs: 1) ALL prelab assignments submitted **before** lab begins 2) remainder of prelab a) ONLINE - submitted before lab begins or b) IN-PERSON - checked by TA before experiment begins
ALL Lab Reports: ONE PDF which contains the entire prelab (even if a component previously submitted)

FRIDAY
"W" OWL homework due

TA OFFICE HOURS
posted on Blackboard next week

ALL emails: class, include TA

REVIEW FROM MONDAY

Prefixes

every third power of 10

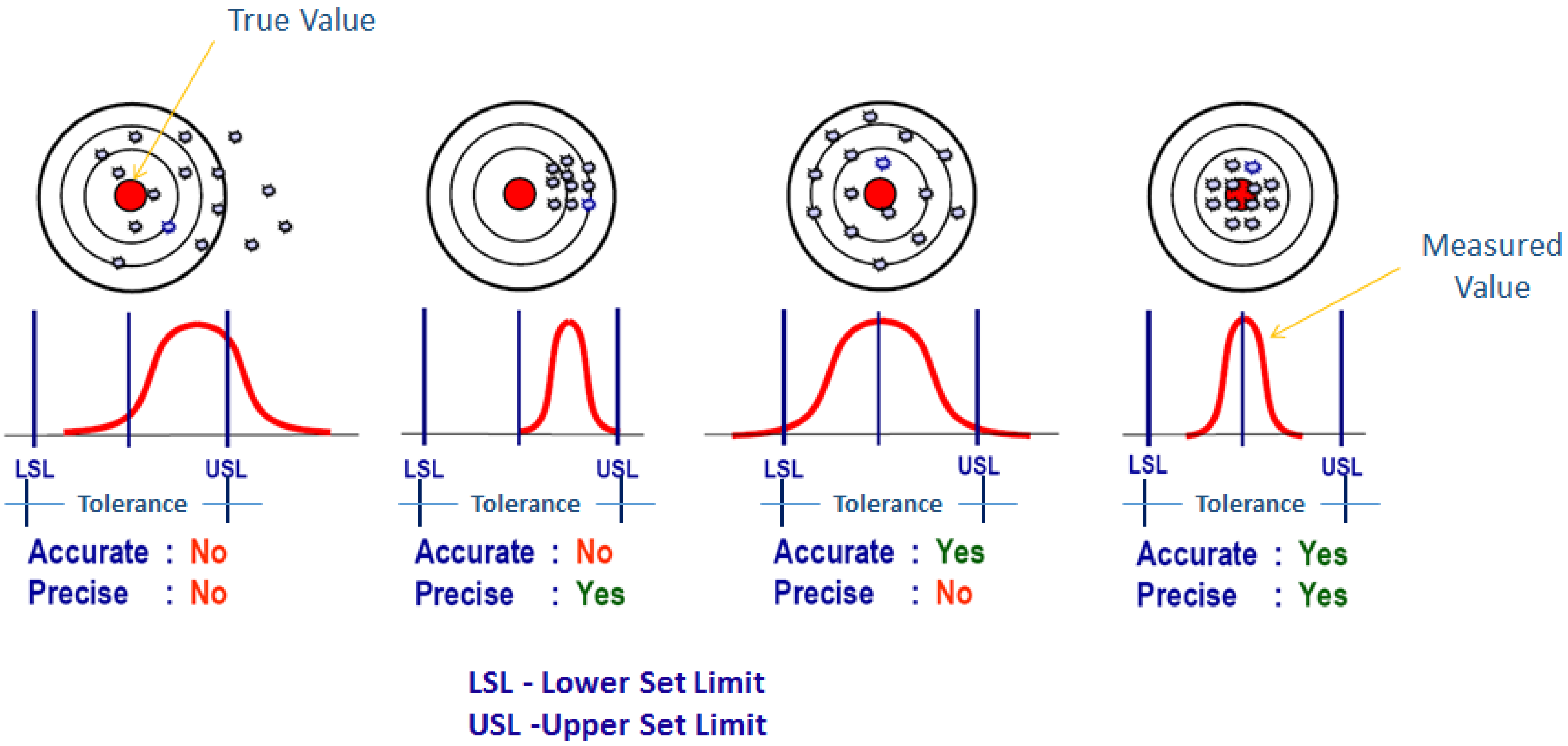
Table 1-3 Prefixes

Prefix	Symbol	Factor	Prefix	Symbol	Factor
yotta	Y	10^{24}	deci	d	10^{-1}
zetta	Z	10^{21}	centi	c	10^{-2}
exa	E	10^{18}	milli	m	10^{-3}
peta	P	10^{15}	micro	μ	10^{-6}
tera	T	10^{12}	nano	n	10^{-9}
giga	G	10^{9}	pico	p	10^{-12}
mega	M	10^{6}	femto	f	10^{-15}
kilo	k	10^{3}	atto	a	10^{-18}
hecto	h	10^{2}	zepto	z	10^{-21}
deca	da	10^{1}	yocto	y	10^{-24}

usually ends in __a

usually ends in __o

Precision, Accuracy, and Experimental Error



accuracy – deviation from true value (systematic error)
precision – agreement of replicate measurements (random error)
standard deviation, $s = \sqrt{\sum_i [(x_i - \langle x \rangle)^2]/(n-1)}$

REVIEW FROM MONDAY

Calculating a Standard Deviation

EX 1. A student makes the following six independent measurements of pressure, *P*, in torr

762.2, 761.8, 762.0, 761.5, 762.2, and 760.0

Calculate the average value of *P* and its standard deviation. (NOTE: useful for lab reports!)

$$\langle P \rangle = (762.2 + 761.8 + 762.0 + 761.5 + 766.2 + 760.0)/6 = 761.6166 \Rightarrow 761.6$$

mean to report

standard deviation

$$s = \sqrt{\sum_i [(x_i - \langle x \rangle)^2]/(n-1)} = \sqrt{[(762.2 - 761.6166)^2 + \ldots]/5}$$

$$= \{ [(0.583)^2 + (0.183)^2 + (0.383)^2 + (0.116)^2 + (0.583)^2 + (1.616)^2] / 5 \}^{1/2}$$

$$= \sqrt{3.488/5} = 0.835 \Rightarrow 0.84$$

standard deviation to report

$$= 761.6 \pm 0.84 \text{ torr}$$ (**Harris 761.6 ± 0.8**)

result to report

Harris p. 54 The *Real* Rule for Significant Figures:

first digit of uncertainty = last digit of answer

Pre-Atomic Theory of Matter

concept: infinite indivisibility of matter

ancient Greek, Indian, Chinese philosophy – matter composed of four "elements": air, earth, fire, water

Heraclitus (535-475 BC; Greek philosopher in Asia Minor) everything in a state of flux, becoming, element fire; Parmenides (515-450 BC, Greek philosopher in southern Italy) change is impossible, being

Leucippus (480-420 BC; Greek philosopher) and his student Democritus (460-371 BC; mathematician, astronomer, physicist; traveled to India, Babylon, Persia, Egypt, Ethiopia?) – postulated existence of atoms – tiny particles always in motion, interacted by collision; all change due to motion of atoms

Epicurus (341–270 BC, Greek philosopher) refined Democritus theory, he and Pythagoreans atomists

6th century BC – Hindu Kanada – cannot infinitely divide matter, Jainas (3rd century AD) were atomists

Socrates → Plato → **Aristotle** (384-322 BC, Greek philosopher, physicist, biologist) – knowledge proceeds from observation, only four elements, atoms rejected as implausible since could not be perceived by the senses; Stoics, Cicero, Seneca, **St. Augustine** (354-430 AD) **opposed atomism**

Lucretius (99-55 BC; Roman poet, philosopher) explained numerous natural processes by **atoms**, even **negating necessity of a supreme being** – branded an **atheist,** atomism condemned.

Venerable Bede (762-735 AD) was an atomist

medieval Arabic speaking world the intellectual tradition of kalam supported atomism; Rhazes - Abu Bakr al-Razi (841-926; Persian physician, philosopher, astronomer, alchemist)

“Modern” Pre-Atomic Theory

in 12th century works of **Aristotle** rediscovered, brought back concept of an atom, controversy heightened in 14th century; Epicureanism contradicted orthodox Christian teachings, it was a “heresy”

Pierre Gassendi (1592-1655) got around the objection by stating that atoms were created by God

Rene Descartes (1596-1650), Issac Newton (1642-1727), Robert Boyle (1627-1691) defended atomism; generally accepted by end of 17th century.

1775 – Lavoisier (combustion of Hg) => **law of conservation of mass**

1799 – Proust (amount of O in Fe oxide) => **law of definite proportions:** “In a given chemical compound the proportions by mass of the elements that comprise it are fixed ...”

1803 – Dalton **law of multiple proportions** (“When two elements form a series of compounds the masses of one element that combine with a fixed mass of the other element are in the ratio of small integers to each other.”)

Dalton used atomic theory to explain via an empirical process of experimentation and analysis – flaw did not realize that some elements were composed of more than one atom and that simplest combination was not always 1 atom of each element

Law of Multiple Proportions

When two elements form a series of compounds the masses of one element that combine with a fixed mass of the other element are in the ratio of small integers to each other

EX 3. Chlorine (Cl) and oxygen form four different binary compounds. Analysis gives the following results
a) Show that the law of multiple proportions holds for these compounds.

cmpd	mass O combined with 1.0000 g Cl
A	0.22564 g
B	0.90255
C	1.3539
D	1.5795

B/A = 0.90255/0.22564 = 3.9999... = 4
C/A = 1.3539/0.22564 = 5.9998... = 6
D/A = 1.5795/0.22564 = 7.0000... = 7

b) If the formula of compound A is a multiple of Cl_2O, then determine the formulas of the other compounds.

Note: B/A = $\boldsymbol{(m_O/m_{Cl})_B\ /\ (m_O/m_{Cl})_A = (m_O \div M_o/m_{Cl} \div M_{Cl})_B\ /\ (m_O \div M_o/m_{Cl} \div M_{Cl})_A = (n_O/n_{Cl})_B\ /\ (n_O/n_{Cl})_A}$

then A = $x(Cl_2O)$ => $(n_O/n_{Cl})_A = ½$

so B/A = 4 => Cl_2O_4 ClO_2 Cl_3O_6

B/A = 6 => Cl_2O_6 ClO_3 Cl_3O_9

B/A = 7 => Cl_2O_7

law of multiple proportions is based on mole ratios

Atomic Theory

1803 – Dalton's Atomic Theory

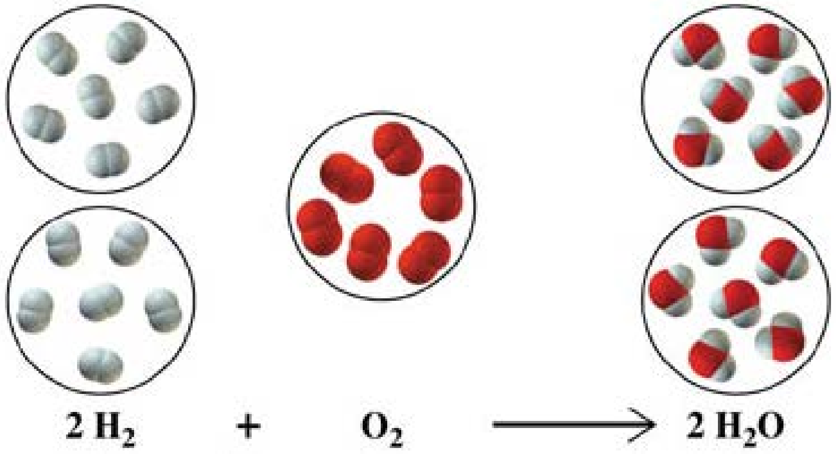
all matter consists of individual atoms
atoms are indestructible
all atoms of the same element are identical
different elements have different kinds of atoms
compounds formed from elements combining in small whole-number ratios

1808 - Guy-Lussac: gases (same *T, P)* combine in simple whole number ratios

1811 - **Avogadro's Hypothesis** - equal *V* (gas; same *T*, *P)* contain equal number of particles

$PV = nRT \Rightarrow \quad n = PV/RT$

Avogadro's law corrected Dalton's flaw and showed that many gases exist as diatomics

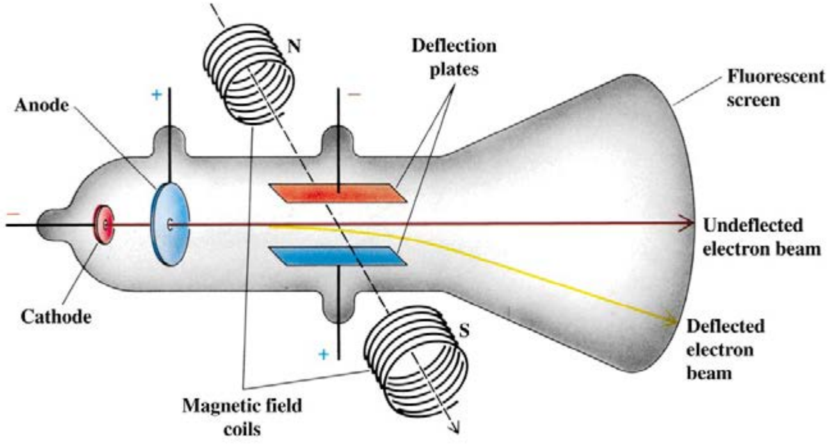


1860 - Cannizzaro: experiments convinced world that Avogadro was correct

Building Blocks of Atoms electrons, protons, neutrons (electrons and **quarks**!)

FIG I. 1897 – Thomson: charge/mass of e⁻

(Plum Pudding Model, e^- + cloud of charge)



deflects up

etic field (N → S) ↑

ic field (– → +) ↓

deflects down

FIG II. 1909 – Mulikan: charge (oil drop exp)

gas in chamber ionized, e^-'s produced adhere to droplets

- **gravity ↓**
- **electric field (– → +) ↑**

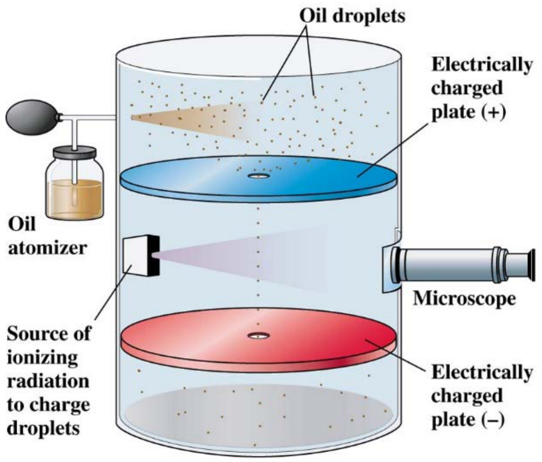


FIG III. 1909 – Geiger/Marsden (α off Au) $^{4}_{2}He^{2+}$

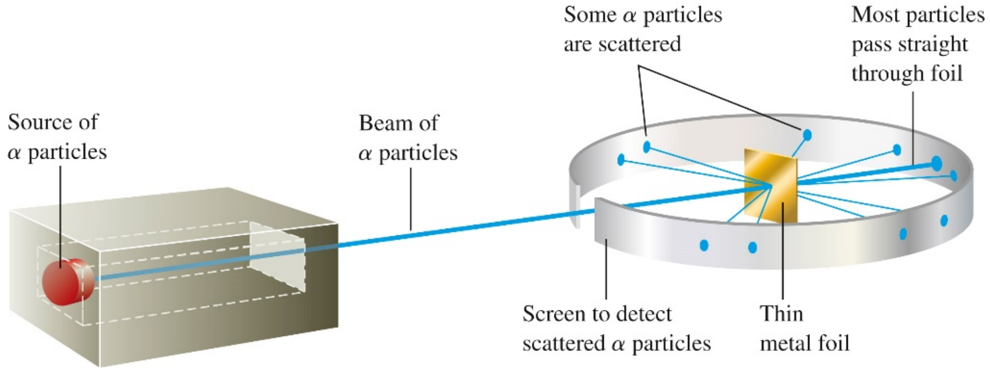
(**nuclear model** – V, e^-; m small + nucleus)

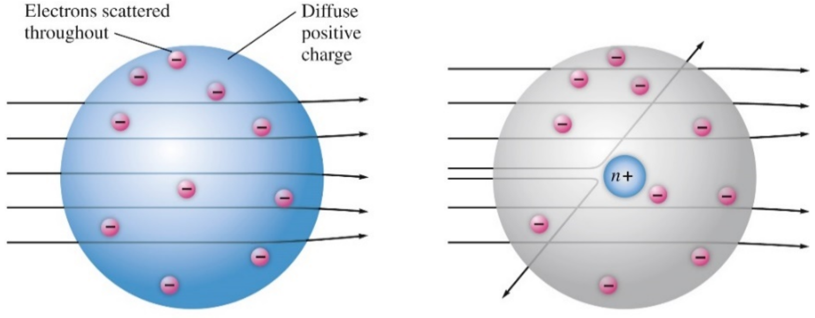
1898 – Rutherford discovered α, β (1908 Nobel)

1911 – explanation, nucleus (mass, + charge)

1919 – discovers proton

1932 – Chadwick discovers neutron

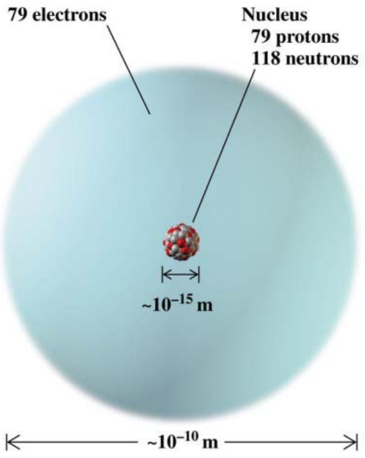




(a) Thomson (b) Rutherford

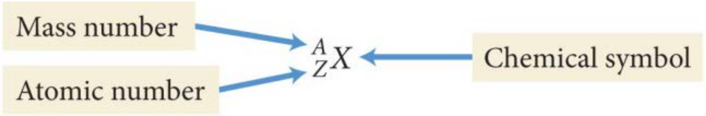
Basics of the Atom

small, dense world – example of an atom of gold
diameter of a nucleus, 10^{-15} m
diameter of an atom, 10^{-10} m
density of 2.3×10^{14} g cm^{-3}

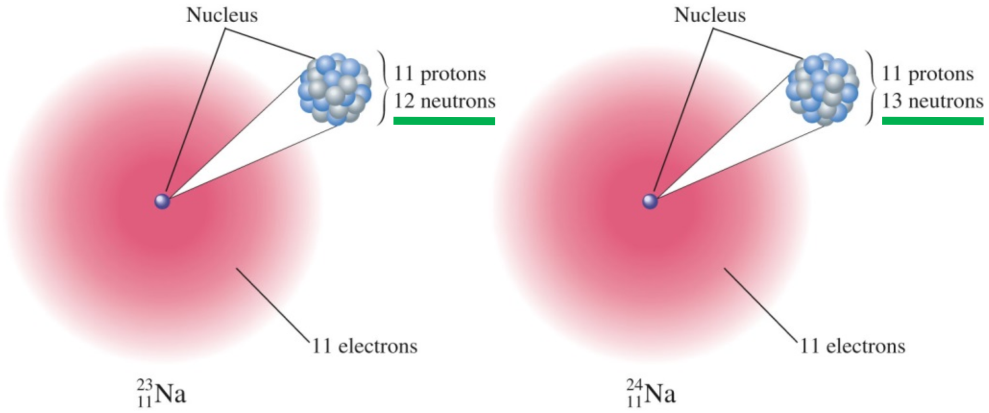


particle	charge	atomic mass units (amu)
electron	-1	0.000548579911
proton	+1	1.0072764669
neutron	0	1.0086649158

designation



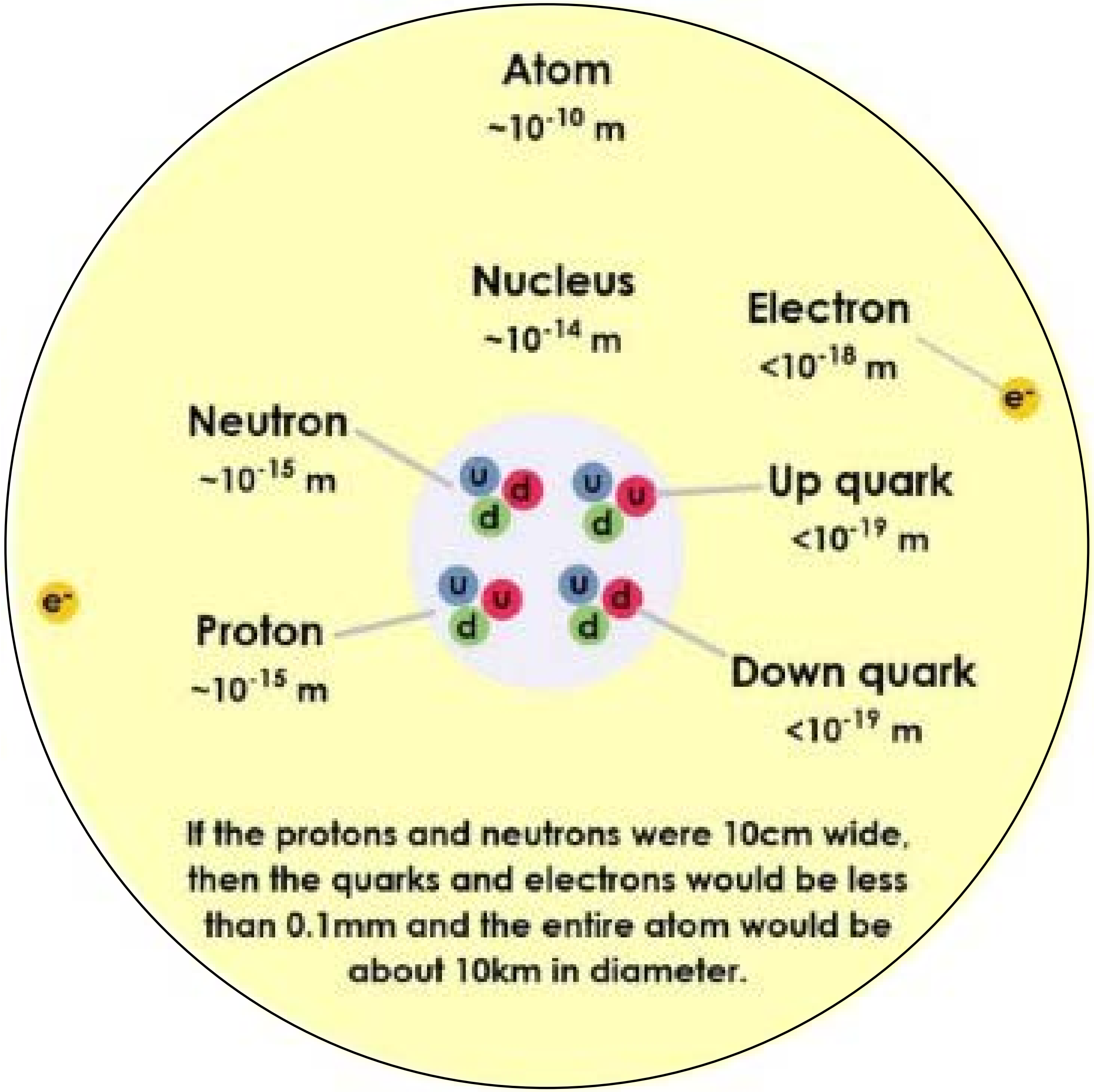
Z = atomic number (number of protons)
A = mass number (sum of the numbers of protons and neutrons) – there can be isotopes



Two Isotopes of Sodium
differ in number of neutrons

leptons (*e.g.*, electrons) and quarks are the true elementary particles of matter
proton – 2u (+2/3) + 1d (-1/3)
neutron – 2d (-1/3) + 1u/(+2/3)

Structure of Helium Nucleus (^4_2He)

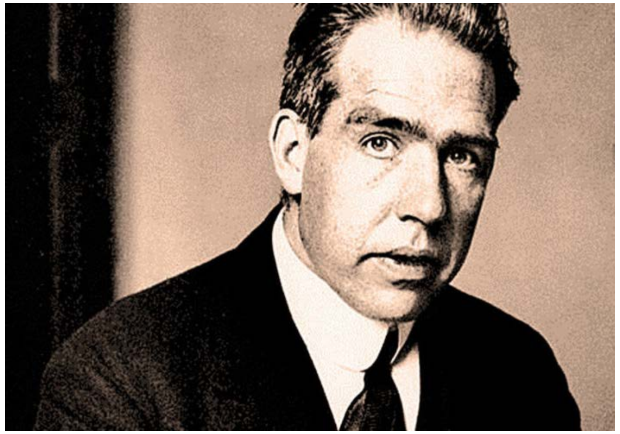


Periodicity and Nomenclature

“...I have tried to base a system on the magnitudes of the atomic weights of the elements. My first attempt in this respect was the following: I chose the smallest atomic weights and arranged them according to the sizes of their atomic weights. This showed that there existed a periodicity in the properties of these simple substances and that even according to their atomicity [valence] the **elements followed one another in the arithmetical sequence of their atomic weights.**“

Dimitri Ivanovich Mendeleyev (Mendeleev), 1869

1. Periodic Table Organization
2. Some Properties Observed in the Periodic Table
3. Nomenclature



EXTREMELY IMPORTANT FOR QUANTUM CHEMISTRY – CHEM 118

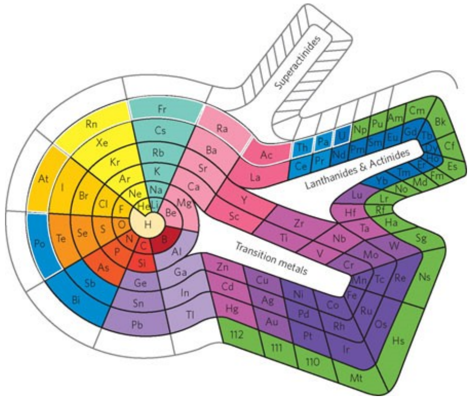
"The periodicity in the properties of the elements is connected with the continuing **build up and completion of the various electron groups that takes place with increasing atomic number**.“

Niels Henrik David Bohr, 1923

(Nobel Prize in Physics in 1922 "for his services in the investigation of the structure of atoms and of the radiation emanating from them".)

The Periodic Table

Its Organization, and Chemistry (a beginning ...)



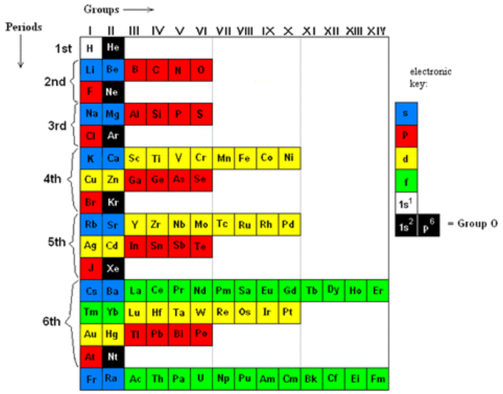
Spiral Periodic Table, Theodor Benfey, 1964

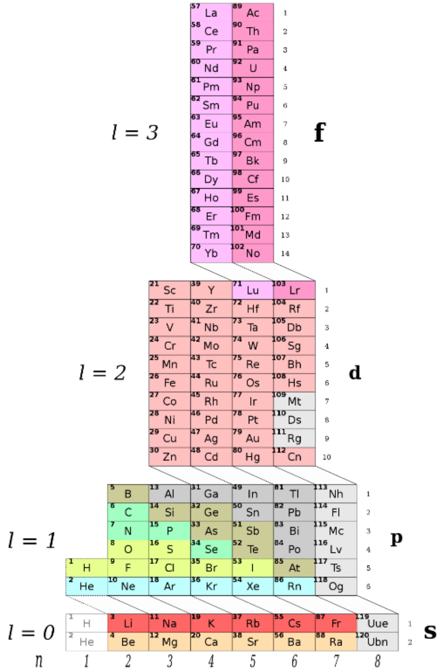
3D Periodic Table, Roy Alexander, 1965 (Chicago museum science exhibit designer)

1A (1)	2A (2)	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	(8)	8B (9)	(10)	1B (11)	2B (12)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1 H 1.008																	2 He 4.0026
3 Li 6.94	4 Be 9.0122											5 B 10.81	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.085	15 P 30.974	16 S 32.06	17 Cl 35.45	18 Ar 39.95
19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.85	27 Co 58.933	28 Ni 58.693	29 Cu 63.55	30 Zn 65.4	31 Ga 69.723	32 Ge 72.63	33 As 74.922	34 Se 78.97	35 Br 79.904	36 Kr 83.80
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.22	41 Nb 92.906	42 Mo 95.95	43 Tc (97/8)	44 Ru 101.1	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.6	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57 La 138.91	72 Hf 178.5	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (267)	105 Db (268)	106 Sg (269)	107 Bh (271)	108 Hs (277)	109 Mt (276/7)	110 Ds (281)	111 Rg (282)	112 Cn (285)	113 Nh (286)	114 Fl (289)	115 Mc (290)	116 Lv (293)	117 Ts (294)	118 Og (294)

Lanthanides	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.4	63 Eu 151.96	64 Gd 157.3	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97
Actinides	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

Marks Brothers' Periodic Table, 2010





ADOMAH Periodic Table, Valery Tsimmerman, 2006

Left Step Periodic Table, Charles Janet, 1929

The Periodic Table

Its Organization, and Chemistry (a beginning ...)

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Major Classification

- metals
- nonmetals
- metalloids (semimetals)

Periods/Groups

- main group
- transition
- lanthanides
- actinides

Main Group Elements

- alkali metals
- alkaline earth metals
- chalcogens
- halogens
- noble gases

Electronegativity

Acidic/Basic

- basic oxides (Na_2O)
- acidic oxides (SO_3)
- amphoteric (Al_2O_3)