Atoms-Molecules-Ions

Dr. Ron Rusay

Atoms, Compounds, and the Periodic Table

Modern History of the Atom

- *1909: Millikan determines charge and mass of e-*
- *1913-19: Rutherford & Bohr's atom; The proton.*
  http://www.yrbe.edu.on.ca/~mdhs/science/chemistry/ch2_2.htm
- *1927: Waves & Particles, Quantum Mechanics*
  http://www.nmsi.ac.uk/on-line/electron/section3/1927.html
- *1932: James Chadwick "discovers" the neutron*
  http://www.nmsi.ac.uk/on-line/electron/section3/1932a.html

CHEMISTRY of the Atom

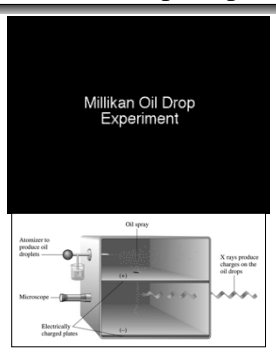
Ernest Rutherford (1871-1937)

Modern History of the Atom

1897: J.J. Thomson "discovers" the electron:
http://www.nmsi.ac.uk/on-line/electron/section2/

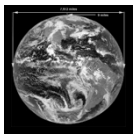
Photo © The Nobel Foundation
http://pl.nobel.se/laureates/physics-1906-1-bio.html

Milliken Oil Drop Experiment



How does an atom relate to nanotechnology?

Consider Powers of 10 (10^x)
http://www.eamesoffice.com/powers_of_ten/powers_of_ten.html
http://www.powersof10.com/



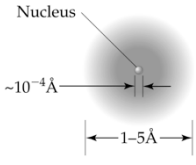
Earth = 12,760,000 meters wide
(12.76 x 10^6), 12.76 million meters (megameters)

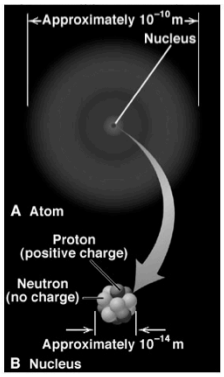
Plant Cell = 0.00001276
meters wide (12.76 x 10^{-6})
(12.76 millionths of a meter)
(12,760 nanometers!)

Nano scale is regarded as < 1,000 nanometers ~1/50 the diameter of a human hair (anything less than a micron (10^{-6} m). Chemists typically think in views and images of < 1 nanometer (eg. bond lengths and atomic sizes).

General Features of the Atom

Anders Jöns Ångström
(1814-1874)
1 Å = 10 picometers = 0.1 nanometers = 10^{-4} microns = 10^{-8} centimeters





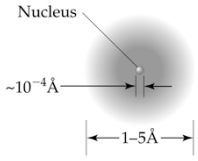
~ 0.1 nm

Nucleus = 1/10,000 of the atom

- *1 nm = 10 Å*
- *An atom vs. a nucleus ~10,000 x larger*

Can we "see" and manipulate atoms using a microscope?

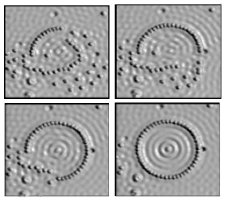
Yes, using atomic force microscopy (AFM) and a variety of instruments such as Scanning Transmission Electron Microscopes.



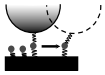
- *1 nm = 10 Å*
- *An atom vs. a nucleus ~10,000 x larger*

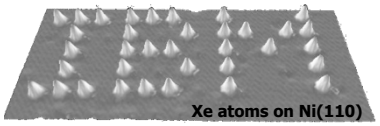
TEAM 0.5:
LBL's Latest (2008)
***T**ransmission*
***E**lectron*
***A**berration-corrected*
***M**icroscope*
Resolution:
+/- 0.5 Å

Atomic/molecular structures atom-by-atom



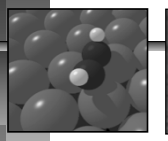
Building of a quantum "corral" with Fe atoms on Cu





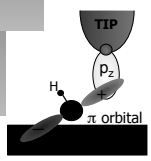
STM images courtesy of Don Eigler, IBM, San Jose

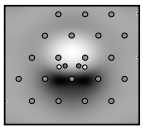
Imaging: acetylene on Pd(111) at 28 K



Molecular Image
Tip cruising altitude ~700 pm
Δz = 20 pm

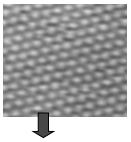
Why don't we see the Pd atoms?
Because the tip needs to be very close to image the Pd atoms and would knock the molecule away





Calculated image
(Philippe Sautet)

Surface atomic profile
Tip cruising altitude ~500 pm
Δz = 2 pm

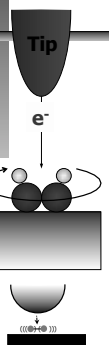


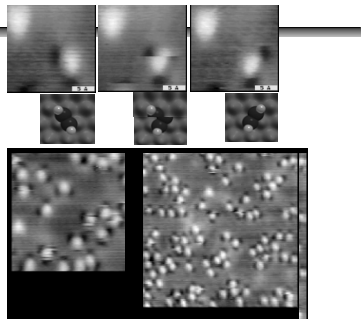
If the tip was made as big as an airplane, it would be flying at 1 cm from the surface and waving up an down by 1 micrometer

The STM image is a map of the pi-orbital of distorted acetylene

M. Salmeron (LBL)

Excitation of frustrated rotational modes in acetylene molecules on Pd(111) at T = 30 K





M. Salmeron (LBL)

CHEMISTRY of the Atom

FUNDAMENTAL PARTICLES:

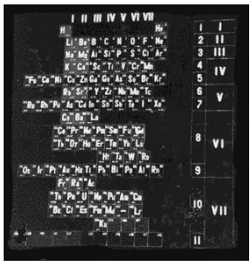
	Mass	Charge	Symbol
Nucleus:			
ð *PROTON*	*1 amu*	*+1*	*H+, H, p*
	• *1.67 x 10 $^{-27}$ kg*		
ð *NEUTRON*	*1 amu*	*0*	*n*
	• *1.67 x 10 $^{-27}$ kg*		
ð *ELECTRON*	*very small*	*-1*	*e $^{-}$*
	• *≈ 2000 x smaller than a proton or neutron*		

The particle is said to "hold" or "bond" atoms together in molecules.

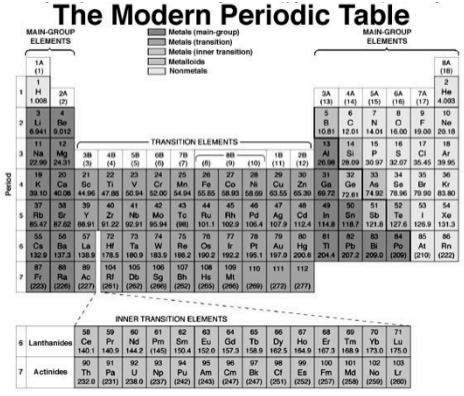
Periodic Table

- ***Mendeleev's Table 1868-1871***

Mural at St.Petersburg University, Russia

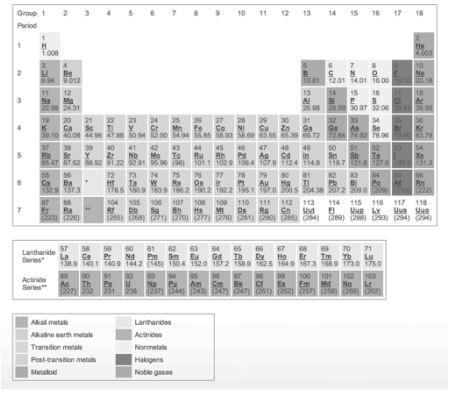


The Modern Periodic Table



Periodic Table

Los Alamos National Lab



QUESTION

The element found in the 6A family (or group 16) and period four can be toxic, a micronutrient, and found in compounds in dandruff shampoos. What is the symbol for that element?

A. Sb
B. As
C. Se
D. Te

Chemical Symbols & Historical Names

The Symbols for the Elements That Are Based on the Original Names

Current Name	Original Name	Symbol
Antimony	Stibium	Sb
Copper	Cuprum	Cu
Iron	Ferrum	Fe
Lead	Plumbum	Pb
Mercury	Hydrargyrum	Hg
Potassium	Kalium	K
Silver	Argentum	Ag
Sodium	Natrium	Na
Tin	Stannum	Sn
Tungsten	Wolfram	W

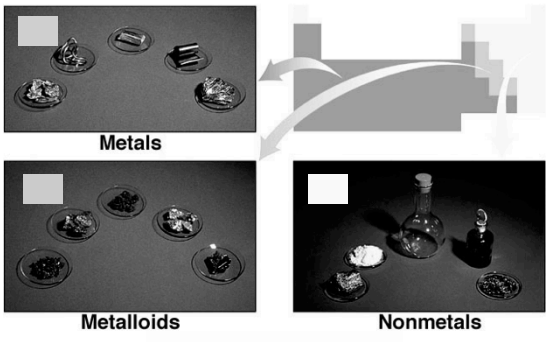
What is the symbol for gold and what was its original name?

QUESTION

Which of the following names and symbols are incorrectly paired?

A. Phosphorus, Ph
B. Palladium, Pd
C. Platinum, Pt
D. Lead, Pb
E. Potassium, K

Metals, Metalloids, and Nonmetals



QUESTION

Of the following which would not be considered a metalloid?

A. Ge
B. Sb
C. Te
D. Se
E. As

Periodic Table

- *Elements are classified by:*
  - ***properties & atomic number***
  - ***metals, non-metals, metalloids***
- *Groups or Families (vertical)*
  - ***1A = alkali metals***
  - ***2A = alkaline earth metals***
  - ***6A (16) = chalcogens***
  - ***7A (17) = halogens***
  - ***8A (18) = noble gases***
- *Periods (horizontal)* ***numbers 1-7***

QUESTION

Select the correct statement relative to the modern periodic table.

A) Tin is a transition element.

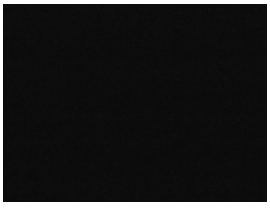
B) Lead is a nonmetal.

C) Antimony is a metalloid.

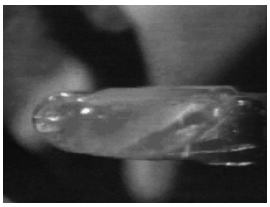
D) Elements are arranged in order of increasing atomic mass.

E) Sulfur is a halogen.

Group 1 and Group 2 Metals

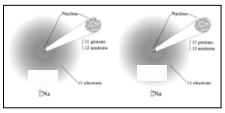


Using the Periodic Table



Atoms, Molecules & Ions

- *Atoms (neutral electrostatic charge: # protons = # electrons)*
  - *# Protons = Atomic Number*
  - *Atomic Mass = # Protons + # of Neutrons*
  - *Isotope: same atomic number but different atomic mass (different # of neutrons)*



QUESTION

Which among the following represent a set of isotopes? Atomic nuclei containing:

a. 20 protons and 20 neutrons.
b. 21 protons and 19 neutrons.
c. 22 neutrons and 18 protons.
d. 20 protons and 22 neutrons.
e. 21 protons and 20 neutrons.

A. a, b, c
B. c, d
C. a, e
D. a, d and b, e
E. No isotopes are indicated.

Atoms, Molecules & Ions

- *Isotopes vary in their relative natural abundance.*
- *Periodic Table's atomic mass is a weighted average of all isotopic masses*
- *The mass of sodium, Na, element #11 is listed as 22.99 amu. Which isotope is naturally present in the larger amount: the isotope with 12 neutrons or with 13 neutrons? (There is a small percentage of the isotope with 11 neutrons.)*

QUESTION

Two stable isotopes of an element have isotopic masses of 10.0129 amu and 11.0093 amu. The atomic mass is 10.81. Which isotope is more abundant?

A) There is insufficient information to answer the question.

B) There are equal amounts of each isotope.

C) The isotope with a mass of 10.0129 amu is more abundant.

D) The isotope with a mass of 11.0093 amu is more abundant.

Atoms, Molecules & Ions

- *Atomic Mass of Carbon:*

Exact Mass	% Occurence
12.00000	*98.98*
13.00335	*1.011*
14.00	*negligible*

- *What is the "weighted" atomic mass?*

QUESTION

The two major isotopes of bromine are ^{79}Br and ^{81}Br. Assume that the masses of the ^{79}Br and ^{81}Br isotopes are 79.00 and 81.00 amu, respectively. The weighted average atomic mass of bromine is 79.90 amu.

What are the relative % abundances of each isotope?

	% Abundance of ^{79}Br	***% Abundance of ^{81}Br***
A.	***79.0%***	***21.0%***
B.	***19.0%***	***81.0%***
C.	***35.1%***	***64.9%***
D.	***55.0%***	***45.0%***

Atoms, Molecules and Ions

- *Atomic Number = 6 (atom's identity)*
- *Carbon*
- *Atomic Mass = 13 (isotope 13)*
- *6 protons; # neutrons = 13 - 6*
- *neutral atom has 6 electrons*

$^{13}_{6}C$

QUESTION

The average mass of a carbon atom is 12.011. Assuming you were able to pick up only one carbon unit, the chances that you would randomly get one with a mass of 12.011 is

A. 0%.
B. 0.011%.
C. about 12%.
D. 12.011%.
E. greater than 50%.

Atomic Symbols

Mass number → ^{39}K ← Element Symbol

Atomic number → $_{19}$

Also written as → ^{39}K

Atoms, Molecules and Ions

- *Atomic Number = 12 (atom's identity)*
- *Atomic Mass = 24*
- *12 protons; # neutrons = 24 - 12*
- *neutral atom has 12 electrons*
- *Ion contains 10 electrons: symbol?*

Atoms, Molecules and Ions

- *Atomic Number = 17 (atom's identity)*
- *Atomic Mass = ?*
- *# protons = ? ; # neutrons = ?*
- *neutral atom has ? electrons*
- *Ion contains 18 electrons: symbol?*

Ions

- *Cation: A positive ion*
  - *Mg^{2+}, NH_4^+*
- *Anion: A negative ion*
  - *Cl^-, SO_4^{2-}*
- *Ionic Bonding: Force of attraction between oppositely charged ions.*

QUESTION

Calcium plays several critical roles in the functioning of human cells. However, this form of calcium is the ion made with 20 protons and 18 electrons. Therefore the ion would be…

A. positive and called an anion.
B. positive and called a cation.
C. negative and called an anion.
D. negative and called a cation.

QUESTION

Of the following, which would NOT qualify as an isotope of ^{35}Cl?

A. ^{36}Cl
B. $^{35}Cl^-$
C. $^{37}Cl^-$
D. ^{37}Cl

Worksheet: Atoms I
(Lab Manual)

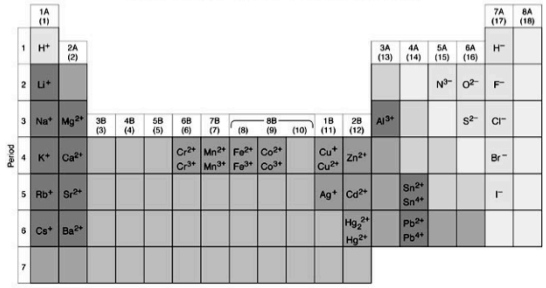
Nuclear Symbol	Number of Protons	Number of Neutrons	Number of Electrons	Atomic Number (Z)	Mass Number (A)
$^{12}_{6}C$	6	6	6	6	12
$^{14}_{7}N$			7		
	7	8	7		
			18	20	40
$^{17}O^{2-}$				8	
^{56}Fe			26		
$^{19}F^-$				9	

QUESTION

Which of these species has the highest number of electrons?

A) $_{20}Ca$ ***B)*** $_{19}K^{+}$ ***C)*** $_{16}S^{2-}$ ***D)*** $_{15}P^{3-}$

Some Common Monatomic Ions of the Elements



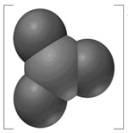
QUESTION

The ion $^{45}Sc^{3+}$ *has*

A) 24 electrons, 21 protons and 24 neutrons
B) 18 electrons, 21 protons and 24 neutrons
C) 24 electrons, 24 protons and 21 neutrons
D) 18 electrons, 24 protons and 21 neutrons

Polyatomic Ions

http://chemconnections.org/general/chem120/polyatomics.html



Carbonate ion CO_3^{2-}

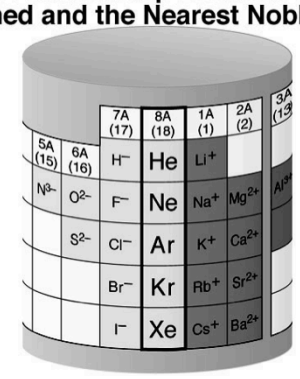
Common Polyatomic Ions

Ion	Name	Ion	Name
Hg_2^{2+}	Mercury(I)	NCS^-	Thiocyanate
NH_4^+	Ammonium	CO_3^{2-}	Carbonate
NO_2^-	Nitrite	HCO_3^-	Hydrogen carbonate (bicarbonate is a widely used common name)
NO_3^-	Nitrate		
SO_3^{2-}	Sulfite		
SO_4^{2-}	Sulfate	ClO^-	Hypochlorite
HSO_4^-	Hydrogen sulfate (bisulfate is a widely used common name)	ClO_2^-	Chlorite
		ClO_3^-	Chlorate
		ClO_4^-	Perchlorate
OH^-	Hydroxide	$C_2H_3O_2^-$	Acetate
CN^-	Cyanide	MnO_4^-	Permanganate
PO_4^{3-}	Phosphate	$Cr_2O_7^{2-}$	Dichromate
HPO_4^{2-}	Hydrogen phosphate	CrO_4^{2-}	Chromate
$H_2PO_4^-$	Dihydrogen phosphate	O_2^{2-}	Peroxide
		$C_2O_4^{2-}$	Oxalate

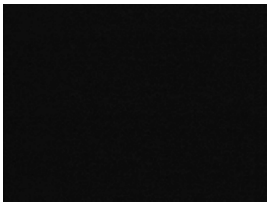
Molecules

- *Neutrally Charged*
- *Eg. Salt: NaCl -> 1 Na^+ and 1 Cl^-*
- *What is the proportion of ions for a compound formed from Mg ion and chlorine?*
- *Mg^{2+} and Cl^-*
- *1 Mg^{2+} combines with 2 Cl^-*

The Relationship Between Ions Formed and the Nearest Noble Gas



Ionic vs. Covalent



Ionic vs. Covalent

- *Metals generally combine with non- metals to form ionic compounds. Electrons are "lost" by the metal and "gained" by the non-metal following the octet rule.*
- *Non-metals generally combine with non -metals to form covalent compounds where electrons are "shared". Each pair of electrons ia a covalent bond. Eg. H_2O*
- *Polyatomic ions have both covalent and ionic properties. Eg. hydroxide, OH^-*

QUESTION

All of the following are true except:

A. Ions are formed by adding electrons to a neutral atom.
B. Ions are formed by changing the number of protons in an atom's nucleus.
C. Ions are formed by removing electrons from a neutral atom.
D. An ion has a positive or negative charge.
E. Metals tend to form positive ions.

Chemical Formulas

- *Molecular Formula:*
  Elements' Symbols = atoms
  Subscripts = relative numbers of atoms
- *How many atoms of each element are in the following componds?*

$MgCl_2$ CCl_4 $NaOH$ $(NH_4)_2CO_3$

$C_{20}H_{26}N_2O$ *(Ibogaine, not ionic)*

QUESTION

How many oxygen atoms are there in one formula unit of $Ca_3(PO_4)_2$?

A. 2
B. 4
C. 6
D. 8
E. None of these