Slide 1

Of Atoms, Molecules & Ions I Sing

The Foundations of Chemistry

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Atomic Structure

We defined chemistry as the study of the physical and chemical properties of materials.

The study of material properties does not require an understanding of underlying atomic and molecular structure – but it can be helpful.

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What things matter?

“Things” that have mass and take up space are called “matter”.

“Thingness”, the property of being a material, is determined by the presence of mass and occupation of space.

It is these two properties that define an object as being a material entity (as opposed to a spiritual entity, an abstract concept, or a non-entity).

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Construction of Matter

Matter itself consists of many different types of objects.

Atoms are "physically indivisible" matter.

Molecules are collections of atoms that are joined together.

Mixtures are collections of different molecules that are intertwined with each other.

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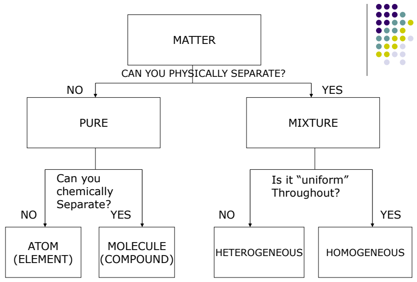

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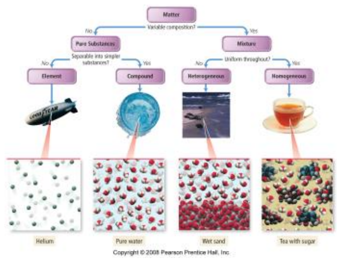

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The Atomic Theory of Matter

At its lowest level, matter is made up of atoms. The current theory is most directly traceable to John Dalton in the early 1800s.

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Conservation of Mass

It all starts with Lavoisier who showed that **mass is conserved**: he burned things in sealed containers and found that the total mass of the container was the same before and after the burning.

This showed that in a chemical reaction, the materials might change form, but the total mass remains the same.

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Law of Definite Proportions

Joseph Proust made a series of mixtures of different elements and discovered that the ratio of the masses that reacted was always the same.

For example if mixing hydrogen and oxygen to get water, he found that if you started with 16.0 g of oxygen, you needed 2.0 g of hydrogen but if you started with 8.0 g of oxygen, you only needed 1.0 g of hydrogen. Always an 8:1 oxygen:hydrogen mass ratio!

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Law of Multiple Proportions

John Dalton extended the definite proportions to "multiple proportions": when 2 atoms (A and B) form different possible compounds, the mass of B combining with 1 g of A is always a whole number.

In other words, 1 g of hydrogen will react with 8 g oxygen to make water (8:1 ratio) 1 g of hydrogen will react with 16 g oxygen to make hydrogen peroxide (16:1 ratio)

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Question

Gasoline burns in the presence of oxygen to form carbon dioxide and water. If 21 kg of gasoline requires 84 kg of oxygen to completely combust, what mass of carbon dioxide and water would be created?

A. 63 kg
B. 42 kg
C. 84 kg
D. 105 kg
E. 21 kg

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Question

Gasoline burns in the presence of oxygen to form carbon dioxide and water. 21 kg of gasoline requires 84 kg of oxygen to completely combust. If my gas tank has 30 kg of gas, how much oxygen would I need to completely burn it?

A. 105 kg
B. 120 kg
C. 51 kg
D. 7.5 kg
E. 21 kg

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Putting it all together:

Combining Lavoisier's observation (conservation of mass) with Proust's (definite proportions) and Dalton's (multiple proportions) created Dalton's Theory of Atomic Structure…

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Dalton's Atomic Theory

- Each element is composed of atoms – which are incredibly small.
- All atoms of a given element are identical to one another in mass and other properties, and different from all other atoms.
- That atoms were indivisible, and were not created or destroyed in chemical reactions.
- When atoms of different elements form compounds, the ratio of one type of atom to another is fixed.

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Refining the model

Dalton's model is useful for explaining how atoms form molecules.

We now know that atoms are divisible, but not by normal chemical means.

At extremely high energies (nuclear reactor), it is possible to split atoms into constituent particles.

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Finding an Electron…

J.J. Thomson was playing with cathode ray tubes (precursor to your glass tubed television).

He discovered a stream of particles were actually moving from the cathode (negatively charged plate) to the anode (positively charged plate)

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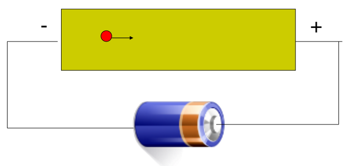

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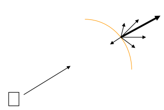
Rutherford found the rest

He fired alpha particles (charged Helium atoms) at a gold foil. What he found surprised him – most went straight through, a few deflected, but some bounced straight back!



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Rutherford's conclusion

Most of a gold foil (and other matter by extension) is made up of empty space, but there are some really hard little parts in between)

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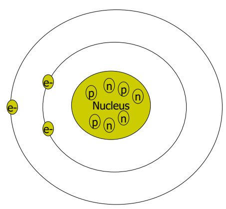
The Bohr Model



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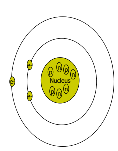
The Bohr Model

The Bohr Model was "planetary":

- The nucleus (like the sun) lay at the center of the atom.
- Electrons (like planets) were orbiting in circular orbits around the nucleus.
- Most of the mass was the result o the protons and neutrons. Electrons are light (about 1/2000th of a proton)
- Electrons are negatively charged while protons are postively charged (equal in magnitude to each other).



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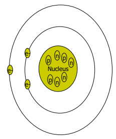
The Bohr Model

We know now that the Bohr model isn't completely accurate. Is there anything surprising about it?

-What keeps the protons from flying apart?

-What keeps the electrons from collapsing inward?



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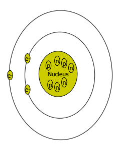
The Bohr Model

Electrostatic forces aren't the only forces in nature.

There exists a "strong force" and a "weak force" that counter the electrostatic forces at very short distances.

Despite its shortcomings, the Bohr Model remains instructive.



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The Bohr Model

Key Points:

1. The mass is a result of the total # of protons and neutrons.
2. The charge is a result of the net number of protons – electrons
3. The number of protons determines the identity of the atom
4. The electrons are responsible for the chemistry of the atom

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Mass Number

The **mass number** is the total number of neutrons and protons.

The mass number is related to the atomic mass of an atom, but it isn't directly connected.

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Atomic Mass

Atomic mass has units of "atomic mass units" (amu). An "amu" is an arbitrary unit of mass, it is relative to carbon-12 having a mass of 12 amu.

Typically, the atomic mass is a little less than the mass number (for relativistic reasons). So a mass number of 24 will usually have an atomic mass of 23.99 amu.

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Atomic Number

The **atomic number** is the number of protons the atom possesses.

All atoms of a particular type MUST have the same number of protons. It is the proton number that determines the identity of the atom. Carbon is atomic number 6 because all carbon atoms have 6 protons. If you find an atom by the side of the road and it has 6 protons, then you know it MUST be carbon.

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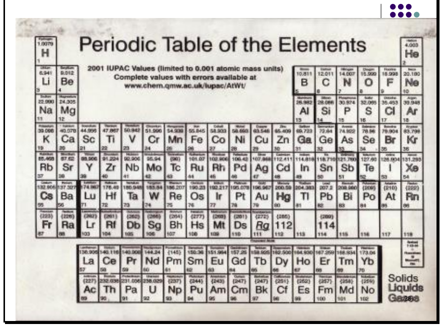

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Isotopes

All carbon atoms must have 6 protons, but they can have different numbers of neutrons. Adding neutrons will change the mass number.

An **isotope** is a type of atom with a particular mass number. An atom, like carbon, can have multiple isotopes.

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Isotopes of Carbon

All carbon has 6 protons.

But carbon has 3 different isotopes: one with 6 neutrons, one with 7 neutrons, and one with 8 neutrons.

6 p + 6 n = mass number 12
6 p + 7 n = mass number 13
6 p + 8 n = mass number 14

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Specifying isotopes

6 p + 6 n = mass number 12
6 p + 7 n = mass number 13
6 p + 8 n = mass number 14

These 3 isotopes are called carbon-12, carbon-13 and carbon-14.

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Shorthand notation for isotopes

^{12}C
^{13}C
^{14}C

Specifying the atom using its atomic symbol along with the mass number as a superscript gives a concise symbol for each of the isotopes.

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Shorthand notation for isotopes

$^{12}_{6}C$
$^{13}_{6}C$
$^{14}_{6}C$

While it is somewhat redundant, the atomic number is sometimes also included as a subscript.

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Ions

An **ion** is an atom (or compound) that has an unequal number of protons and electrons. A **cation** is a positively charged ion (more protons than electrons) and an **anion** is a negatively charged ion (more electrons than protons).

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Ion Notation

$^{12}_{6}C$
$^{13}_{6}C^{+1}$
$^{14}_{6}C^{+2}$

The charge is indicated as a superscript on the atomic symbol. If the isotopes aren't relevant, you can just use the symbol and the charge:

C
C^{+1}
C^{+2}

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The Periodic Table is Your Friend

Knowing your way around the periodic table is the key to being a chemist. It contains a great deal of information.

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Clicker Question #1

Consider the following atom: $^{139}_{56}Ba^{2+}$

The indicated atom has:

A. 56 neutrons, 56 protons, 56 electrons
B. 56 protons, 83 neutrons, 58 electrons
C. 56 protons, 56 neutrons, 54 electrons
D. 56 neutrons, 83 protons, 56 electrons
E. 56 protons, 83 neutrons, 54 electrons

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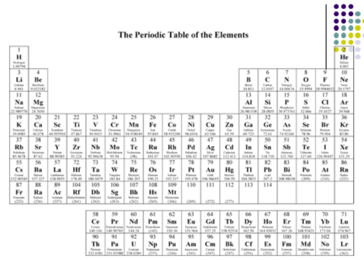

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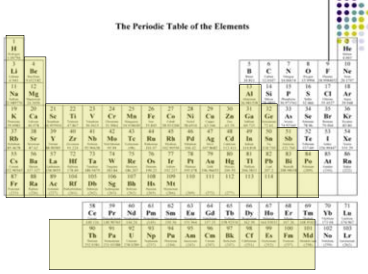
Metals vs. Non-metals



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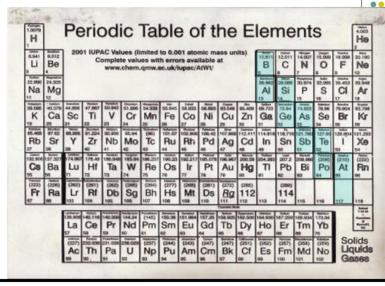
Metalloids or Semi-metals



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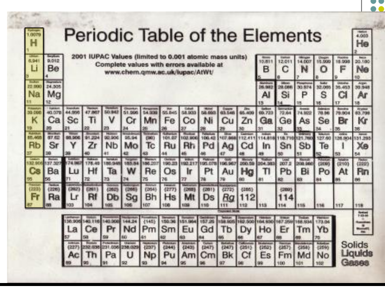
Alkali Metals



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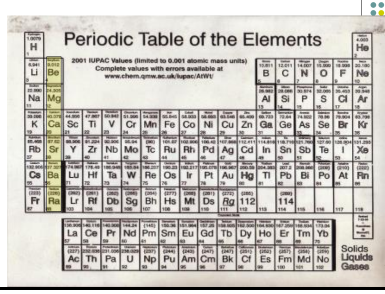
Alkali Earth Metals



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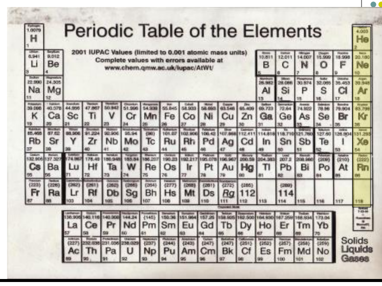
Noble Gases



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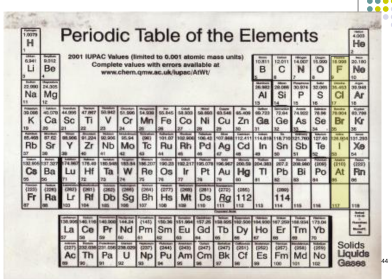
Halogens



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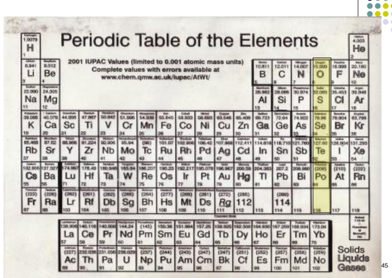
Chalcogenides



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Mass Number vs. Atomic Weight

If carbon has a mass number of 12, 13 or 14 (depending on the isotope), why is the atomic mass in the periodic table 12.011?

It is a **weighted average** of all of the isotopes.

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What's a weighted average?

It's like calculating your GPA:

Principles of Chemistry – A – 4 credits
Chemistry Lab – C – 1 credit

The average grade is a B or 3.0.
The weighted average is 3.6 – the class counts for much more than the lab.

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Neon

Neon has 3 different isotopes

^{20}Ne – mass = 19.9924 amu
^{21}Ne – mass = 20.9938 amu
^{22}Ne – mass = 21.9914 amu

But they aren't equally common.

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Natural Abundance

All isotopes occur with a certain "natural abundance" – the % of a sample of that element that has that isotope mass.

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Neon – natural abundances

^{20}Ne – mass = 19.9924 amu – 90.48% NA
^{21}Ne – mass = 20.9938 amu – 0.27% NA
^{22}Ne – mass = 21.9914 amu – 9.25% NA

The natural abundances are significantly different for the different isotopes and this must be accounted for in the "average atomic mass" of a sample of neon.

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Neon – atomic mass

^{20}Ne – mass = 19.9924 amu – 90.48% NA
^{21}Ne – mass = 20.9938 amu – 0.27% NA
^{22}Ne – mass = 21.9914 amu – 9.25% NA

19.9924 * 0.9048 + 20.9938 * 0.0027 + 21.9914 * 0.0925 = 20.180 amu

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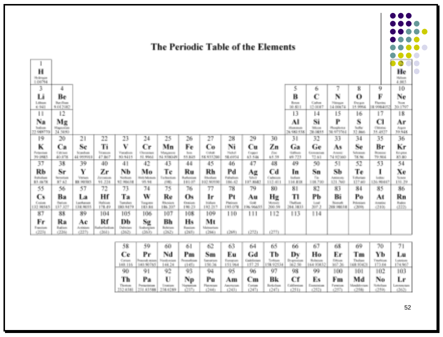

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Neon – alternate calculation

^{20}Ne – mass = 19.9924 amu – 90.48% NA
^{21}Ne – mass = 20.9938 amu – 0.27% NA
^{22}Ne – mass = 21.9914 amu – 9.25% NA

$$\frac{(19.9924 * 90.48 + 20.9938 * 0.27 + 21.9914 * 9.25)}{100}$$

= 20.180 amu

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Molecules from atoms

Molecules are made by combining 2 or more atoms. It makes no difference whether they are the same atom or different atoms.

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Diatomic molecules

Some of the elements actually exist in nature ONLY as diatomic molecules (di-atomic = two atoms).

For example H_2, O_2, N_2, F_2, Br_2, Cl_2, I_2

These are considered to be the natural form of these elements.

Halogens, HON!

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Diatomic molecules

You can form a myriad of diatomic molecules from different atoms joined together.

MgO, FeO, CO, NO, HCl are examples

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Molecular Mass

A molecule has a molecular mass just like an atom has an atomic mass.

Both are frequently called “molar mass” and have units of g/mol (which is why they are called “molar mass” which is the mass, in g, of a mole of substance)

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Molar Mass

To determine the molar mass of a molecule, you simply add together the atomic masses of the atoms that make it up.

So, for MgO:

Molar Mass of MgO = Molar mass of Mg + Molar Mass of O

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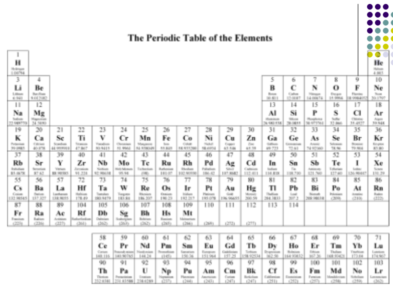

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A mole of Mg atoms has a mass of 24.31 g. How many moles of Mg atoms in 500 g?

1 mol of Mg atoms = 24.31 g
(from the Periodic Table)

$\frac{24.31\ g\ Mg}{1\ mol\ Mg}$ or $\frac{1\ mol\ Mg}{24.31\ g\ Mg}$

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Mass of MgO = 24.305 amu + 15.999 amu
Mass of MgO = 40.304 amu

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amu and moles

amu – “atomic mass unit” is arbitrary.

Before they could “weigh” atoms, there was no other way. They determined the mass relative to Carbon-12 and just left it at that.

Obviously, grams would be a better unit of mass than amu, since you could use a scale!

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Enter Avogadro’s number

Eventually, they were able to determine the absolute mass instead of the relative mass. Turns out that 1 amu = $1.66053873 \times 10^{-27}$ kg.

But that is an unsightly number and who ever uses a single atom!

Enter the “mole”

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A mole is just a "dozen"

Some things are measured in groups:

A dozen donuts (12)
A dozen eggs (12)
A ream of paper (500)
A gross of widgets (144)
…A mole of atoms.

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It's just convenience

A mole is just the number of atoms (molecules) required to turn an amu into a gram!!!

If ^{12}C has a mass of 12 amu, one MOLE of ^{12}C has a mass of 12 grams!

The better way to look at the mass in the periodic table is as g/mol rather than amu.

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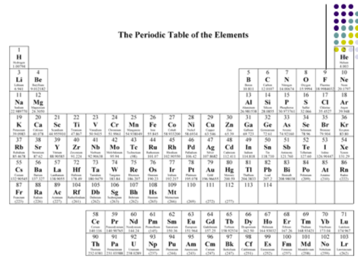

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$6.02214150x10^{23}$ anythings per mole

How many ^{12}C atoms in a mole of ^{12}C?

$6.02214150x10^{23}$

How many ping pong balls in a mole of ping pong balls?

$6.02214150x10^{23}$

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Avogadro's number

Just another conversion factor:

$\frac{6.022x10^{23} \text{ things}}{\text{mole}}$

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Clicker question

I have 182,000 pennies that I've collected. How many moles of pennies is that?

A. $1.096x10^{29}$
B. $6.022x10^{23}$
C. $3.0223x10^{-19}$
D. $6.022x10^{-23}$

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182,000 pennies * $\frac{1 \text{ mole}}{6.022\text{x}10^{23} \text{ pennies}}$ =

$3.022\text{x}10^{-19}$ moles of pennies

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Clicker question

The federal deficit year to date is $\$1.3\ \text{x}10^{12}$. How many moles of dollars is that?

A. $1.3\text{x}10^{-36}$
B. $7.8\text{x}10^{23}$
C. $4.6\text{x}10^{11}$
D. $7.8\text{x}10^{35}$
E. $2.2\text{x}10^{-12}$

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How many atoms are in 500.0 g of Mg?

A. $500.0\ g\ Mg \frac{1\ mol\ Mg}{6.022x10^{23} Mg\ atoms} = 8.3x10^{-22} Mg\ atoms$

B. $500.0\ g\ Mg \frac{6.022x10^{23} Mg\ atoms}{mol} = 3.011x10^{26} Mg\ atoms$

C. $500.0\ g\ Mg \frac{1\ mol}{24.305\ g\ Mg} = 20.57\ mol\ Mg$

D. $500.0\ g\ Mg \frac{1\ mol}{24.305\ g\ Mg} \frac{6.022x10^{23} atoms}{mol} = 1.24x10^{25}\ mol\ Mg$

E. Your mother is a critic