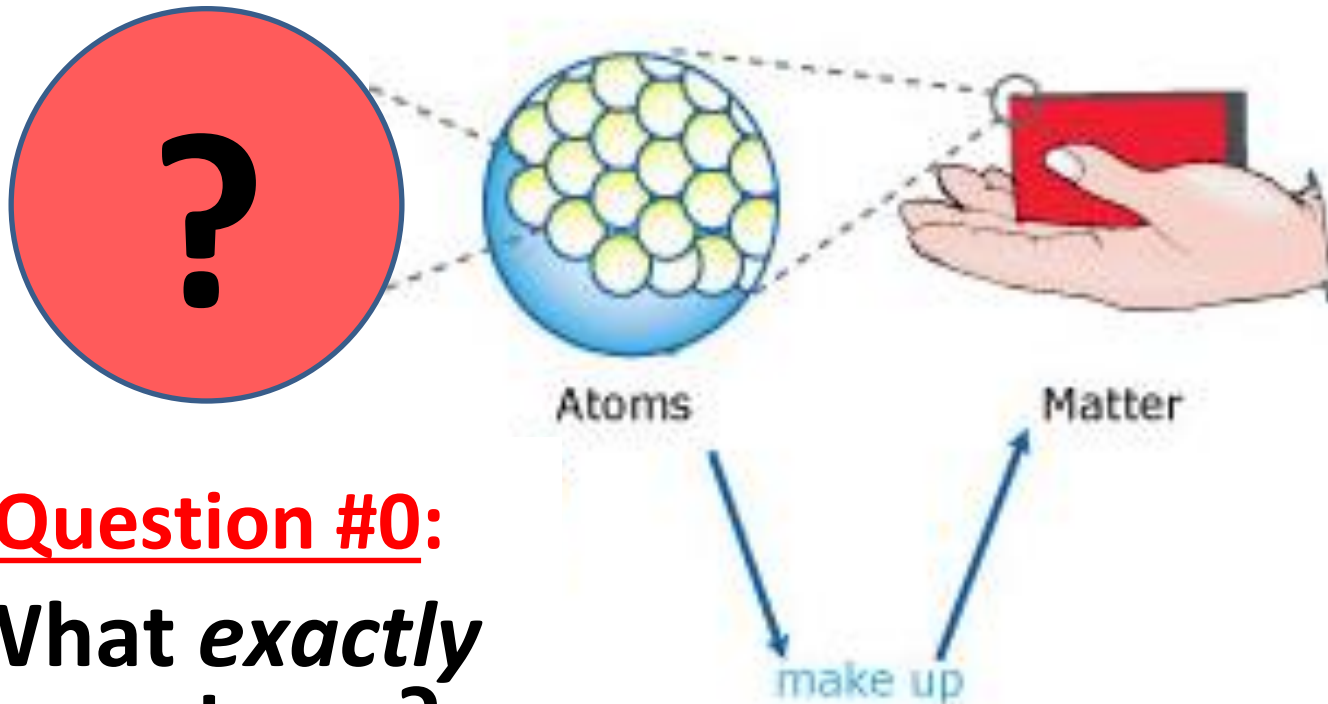


# Structure of Matter



Question #0:

What *exactly*  
are atoms?

Are they all the same?

If not, what  
makes them  
different?

# Atomic Theory Development

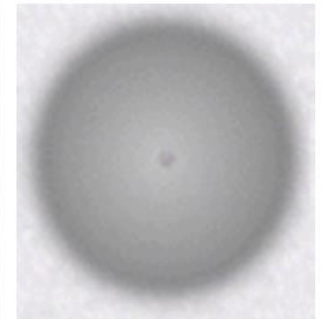
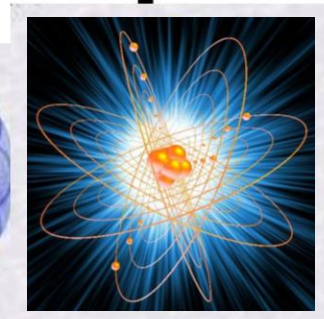
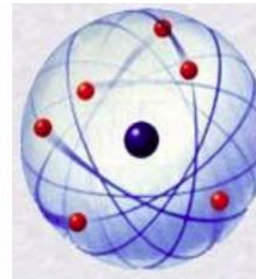
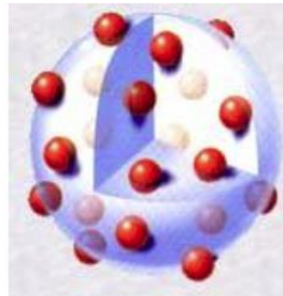
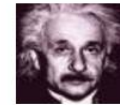
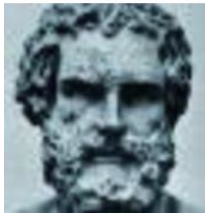
Democritus 460 BC  
and Dalton 1803 AD

Thomson  
1897

Rutherford  
1912

Bohr  
1913

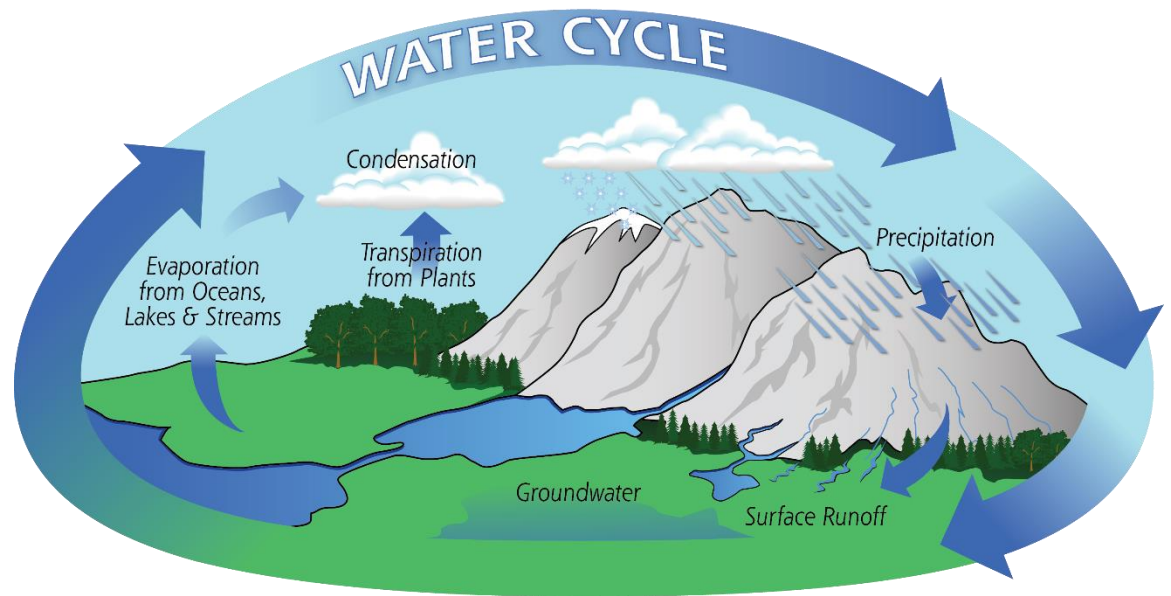
Modern  
Quantum  
Cloud Model  
post 1930



Born **as early as 400 BC**, it took more than 2000 years before Science was ready to accept the idea of atomic structure of matter...and another 150 years to develop a good model!

# What is a Model?

In Science, a model is a physical, mathematical, or conceptual (abstract) representation of a real phenomenon that is difficult to observe directly – that is, a *convenient substitute*.

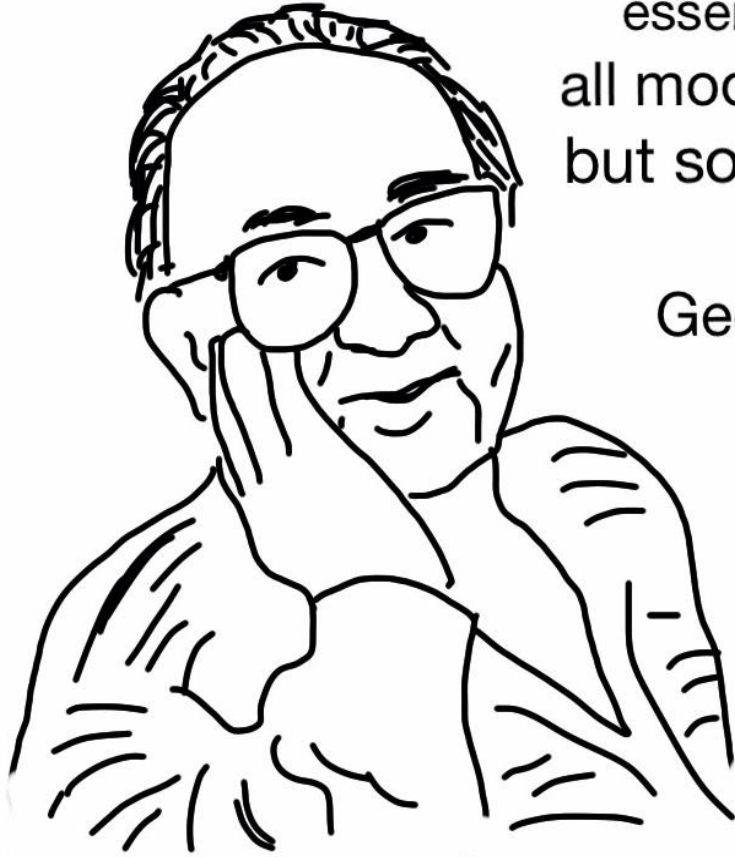


Scientific **models** are used in a variety of scientific disciplines to explain and predict the behavior of real objects or systems.

# A Model is Never Perfect

essentially,  
all models are wrong,  
but some are useful

George E. P. Box



*(one of the most  
influential  
statisticians of  
the 20<sup>th</sup> century)*



Scientific models  
are **approximations**  
of the objects and  
systems that they  
represent!

Scientists are constantly working to **improve and refine** models.

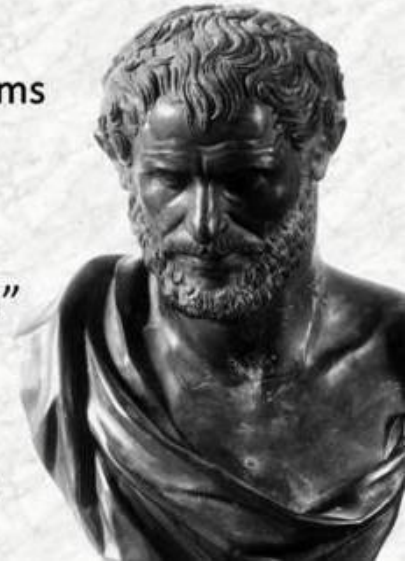
# Democritus

## ~400 BC

“atomos”=“not to be cut”

“Nothing exists except atoms  
and empty space;  
everything else is opinion”

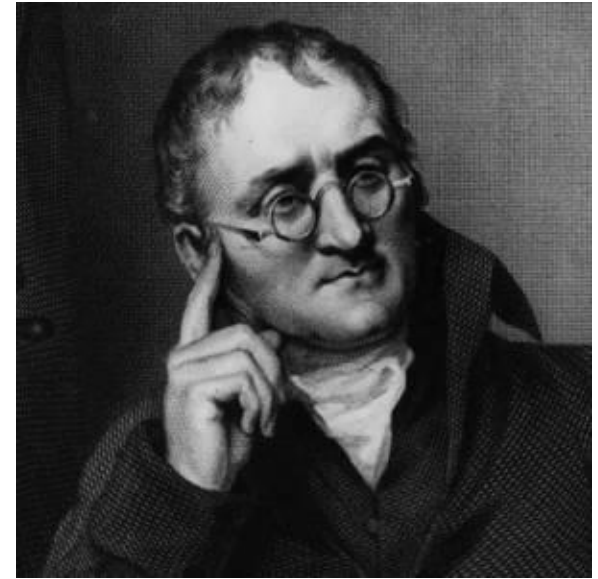
*Democritus*  
(ca. 460 BC – ca. 370 BC)



- Matter **could not** be divided into smaller and smaller pieces forever, eventually the **smallest possible piece** would be obtained.
- This piece, **atomos** (atom), would be **indivisible**.
- Between atoms, there would be **empty space**.
- To Democritus, atoms were **small, hard particles of different shapes and sizes** that were **all made of the same material**.
- Atoms were infinite in number, always moving and capable of joining together.

# John Dalton

## early 1800s



The **first truly scientific theory of the atom**: conclusions were reached by experimentation and examination of the results in an empirical fashion.

- All **elements** are composed of **atoms**.
- Atoms are indivisible and indestructible particles.
- Atom model: a billiard ball or a *marble*.

- H**  
**O**  
**W**  
**?**
- Atoms of the same element are exactly alike.
  - Atoms of different elements are different.
  - Compounds are formed by the joining of atoms of two or more elements.



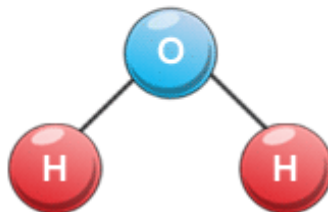
**Color?**  
**Size?**

**Mass?**

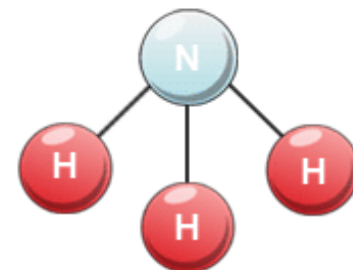
# How to find Atomic Weight?

- Assumption #1: atoms of a given chemical element are identical in size, **mass**, and all other properties.
- Assumption #2: chemical **compounds** are formed when atoms of different elements combine in simple whole-number ratios.

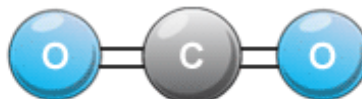
WATER



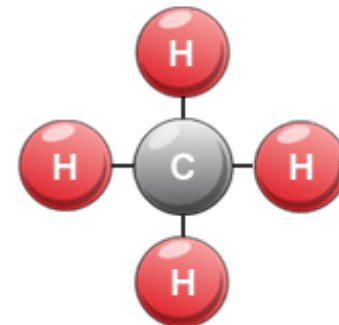
AMMONIA



CARBON  
DIOXIDE



METHANE



Atomic weights of elements can be determined by careful studies of chemical reactions!

## John Dalton

- 1803-1805: **first list** of **relative atomic weights** containing just **6 elements**, namely *hydrogen* (conventionally assumed to weigh 1), *oxygen*, *nitrogen*, *carbon*, *sulfur*, and *phosphorus*.

- 1808: expanded list of elements

ELEMENTS			
○	Hydrogen 1	⊕	Strontian 46
⊖	Nitrogen 5	⊗	Barytes 60
●	Carbon 5	⊙	Iron 50
○	Oxygen 7	⊕	Zinc 56
⊖	Phosphorus 9	⊗	Copper 56
⊕	Sulphur 13	⊙	Lead 90
⊖	Magnesia 20	⊕	Silver 190
⊕	Lime 24	⊗	Gold 190
⊖	Soda 28	⊙	Platina 190
⊕	Potash 42	⊗	Mercury 167

## Dmitri Mendeleev

- 1869: **periodic table** of **66 elements** ordered and grouped according to their atomic weight.

ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ.		
ОСНОВАННОЙ НА ВѢСЪ АТОМНОЕ ВѢСЪ И ХИМИЧЕСКОЕ СХОДСТВО.		
		Ti = 50    Zr = 90    ? = 180.
		V = 51    Nb = 94    Ta = 182.
		Cr = 52    Mo = 96    W = 186.
		Mn = 55    Rh = 104,4    Pt = 197,4
		Fe = 56    Ru = 104,4    Ir = 198.
		Ni = Co = 59    Pt = 106,8    Os = 199.
		Cu = 63,4    Ag = 108    Hg = 200.
H = 1		
Be = 9,4	Mg = 24	Zn = 65,2    Cd = 112
B = 11	Al = 27,4	? = 68    Ur = 116    Au = 197,7
C = 12	Si = 28	? = 70    Sn = 118
N = 14	P = 31	As = 75    Sb = 122    Bi = 210?
O = 16	S = 32	Se = 79,4    Te = 128?
F = 19	Cl = 35,5	Br = 80    I = 127
Li = 7	Na = 23	K = 39    Rb = 85,4    Cs = 133    Tl = 204.
		Ca = 40    Sr = 87,6    Ba = 137    Pb = 207.
		? = 45    Ce = 92
		?Er = 56    La = 94
		?Yt = 60    Di = 95
		?In = 75,6    Th = 118?

Д. Менделѣевъ



# Scientific Mysteries of 1870s

## LIGHTEST

1 <b>H</b> Hydrogen 1	Atomic # Symbol Name Atomic weight
3 <b>Li</b> Lithium 7	4 <b>Be</b> Beryllium 9
11 <b>Na</b> Sodium 23	12 <b>Mg</b> Magnesium 24

Elements are grouped and *ordered* according to their **atomic weight**...

## Fragment of the Periodic Table (showing elements known by 1869 when Mendeleev published his first version)

5 <b>B</b> Boron 11	6 <b>C</b> Carbon 12	7 <b>N</b> Nitrogen 14	8 <b>O</b> Oxygen 16	9 <b>F</b> Fluorine 19	10 <b>He</b> Helium 4.002602
13 <b>Al</b> Aluminium 27	14 <b>Si</b> Silicon 28	15 <b>P</b> Phosphorus 31	16 <b>S</b> Sulfur 32	17 <b>Cl</b> Chlorine 35	18 <b>Ar</b> Argon 39.948
31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.64	33 <b>As</b> Arsenic 75	34 <b>Se</b> Selenium 79	35 <b>Br</b> Bromine 80	36 <b>Kr</b> Krypton 83.795
49 <b>In</b> Indium 115	50 <b>Sn</b> Tin 118	51 <b>Sb</b> Antimony 122	52 <b>Te</b> Tellurium 128	53 <b>I</b> Iodine 127	54 <b>Xe</b> Xenon 131.293

UNKNOWN

...but not always!

**Puzzling question: what carries electricity?**