Lecture 04 2/1/09
Atoms, Molecules, and Matter
Mark Croft

Mark:

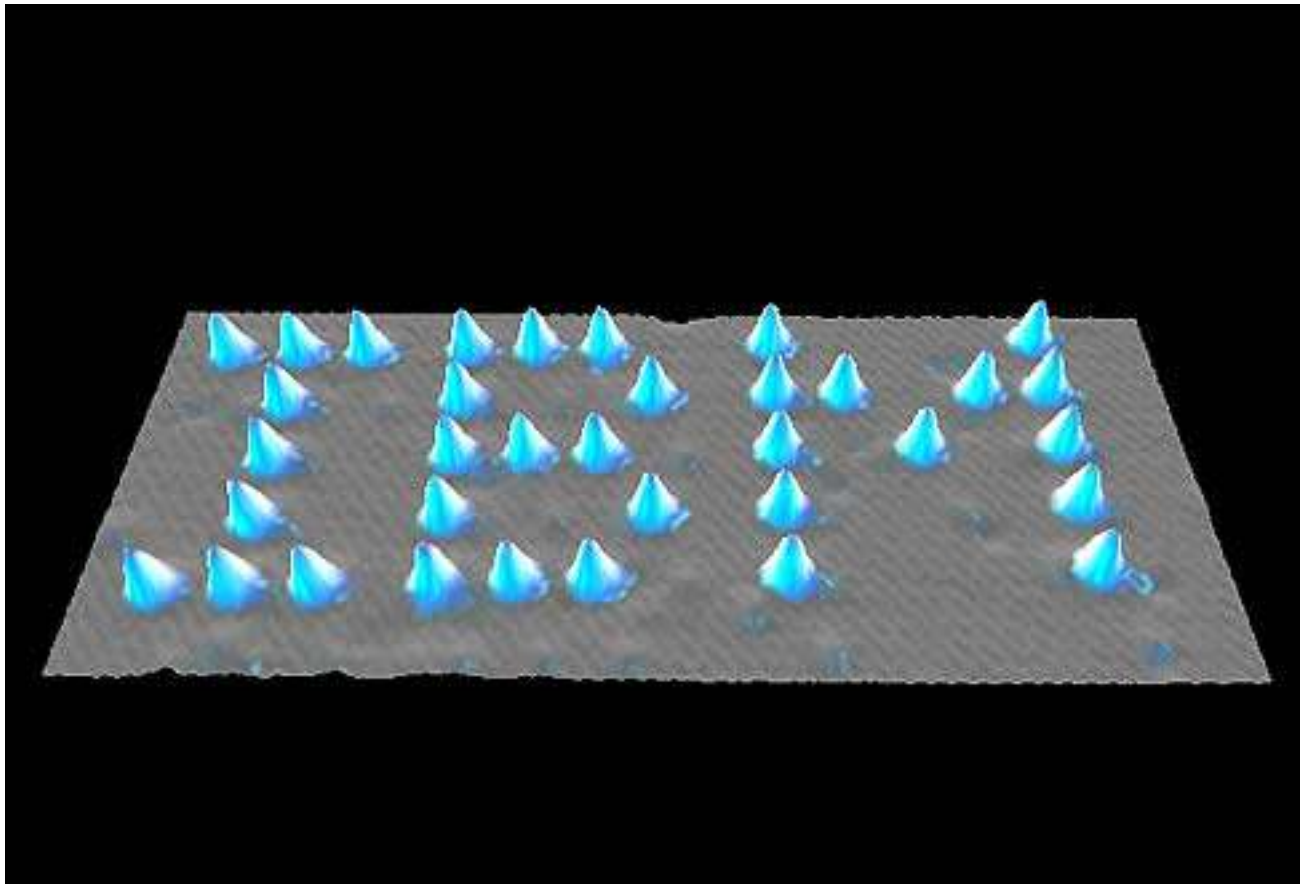
- Several slides intended for you, like this one, are flagged as “hidden” so that they should not show as part of the presentation.
- Of course, feel free to modify, expand, or rearrange the slides as much as you like.
- Note the suggested use of an Applet at one point in the lecture. Of course it’s up to you if you want to do this, but I find it’s fun.
- I’ll leave it to you to figure out how to work the demos into the presentation.

Demos Paul used last year

4
Monday
02/02/09

- Universe and Atoms-
(1) Crystal Models
(2) NaCl Model
(3) Marbles in a Box
(4) Brownian Motion simulation
(5) Marbles in a square jar

Chapter 2
Atoms: The Nature of Things



Units of Chapter 2

The Greek Atom: The Smallest Pieces

Atoms and Molecules

The Atom's Explanatory Power: The Odor of Violets

Metric Distances and Powers of 10

The Incredible Smallness of Atoms

Atomic Materialism: Atoms and Empty Space

Three Atomic Models: Greek, Planetary, and Quantum

Chemistry and Life: What Did Atoms Ever Do for You?

2.1 The Greek Atom: The Smallest Pieces

Democritus reasoned that there must be a smallest, indivisible bit of each type of matter. He called these bits atoms.

Atomic theory of matter: All matter is made of tiny particles, too small to be seen.

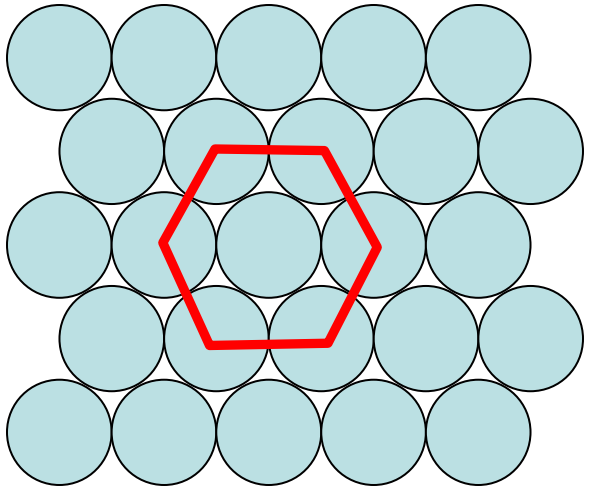
Nature of ancient debate

Atomic theory was one of several popular topics for debate; truth was to be decided by the quality of the rhetoric, rather than by any serious experiment.

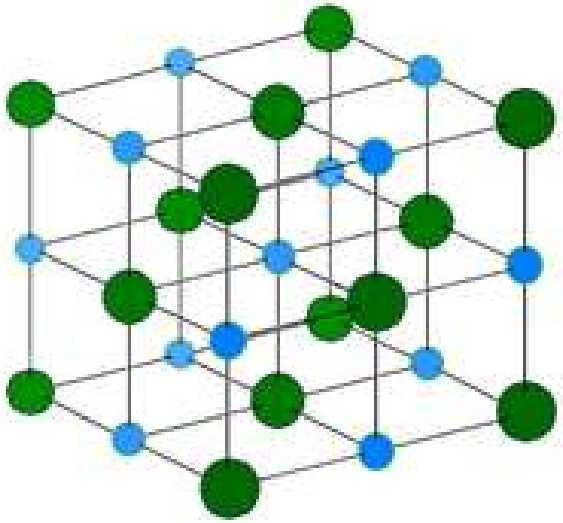
> Atoms must be made of imperishable stuff into which everything can be resolved in the end, so that there may be a stock of matter for building the world anew. The atoms, therefore, are absolutely solid and unalloyed. In no other way could they have survived throughout infinite time to keep the world in being.

Evidence for atomic theory?

(ask students …)



Descartes attributed the beautiful symmetry of snowflakes to the existence of spherical water molecules

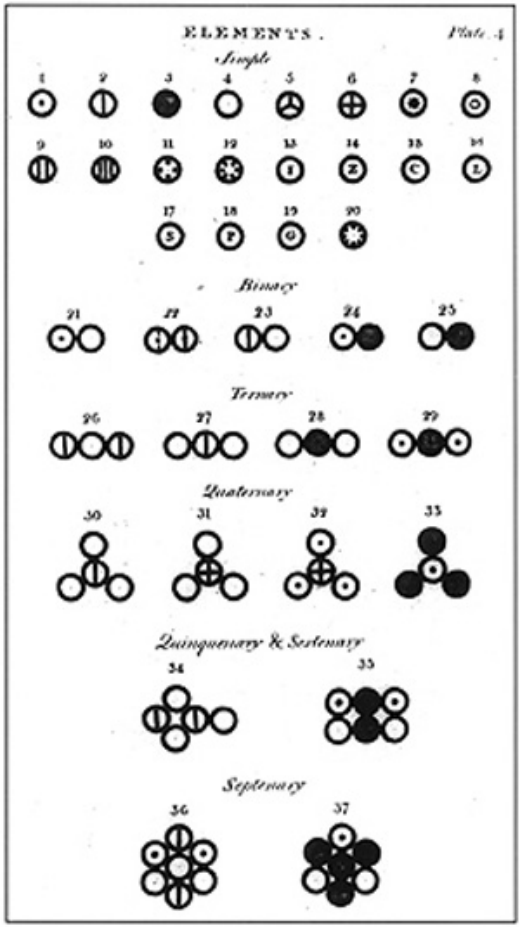


Salt crystals (cubic in shape)

Evidence from Chemstry: Dalton

Five main points of Dalton's atomic theory

- The atoms of a given element are different from those of any other element; the atoms of different elements can be distinguished from one another by their respective relative atomic weights.
- All atoms of a given element are identical.
- Atoms of one element can combine with atoms of other elements to form chemical compounds; a given compound always has the same relative numbers of types of atoms.
- Atoms cannot be created, divided into smaller particles, nor destroyed in the chemical process; a chemical reaction simply changes the way atoms are grouped together.
- Elements are made of tiny particles called atoms.



Most convincing was Dalton's table for nitrogen oxides

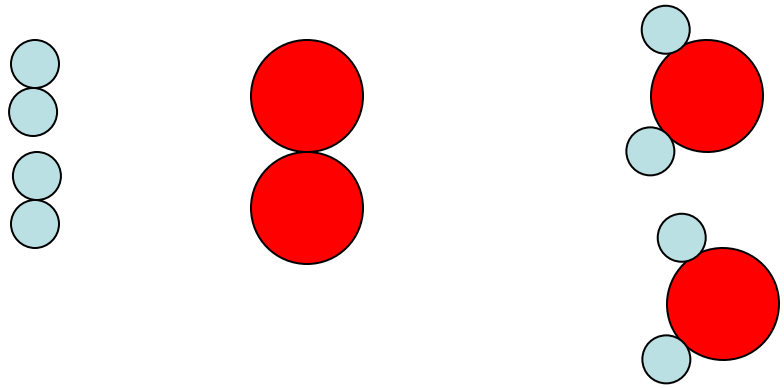
Current name	Formula	Mass ratio*
Nitrous oxide	N_2O	57
Nitric oxide	NO	2 x 57 = 114
Nitrous anhydride	N_2O_3	3 x 57 = 171
Nitrogen dioxide	NO_2	4 x 57 = 228
Nitric anhydride	N_2O_3	5 x 57 = 285
Nitrogen peroxide	NO_3	6 x 57 = 342

* Grams of oxygen for each 100 grams of nitrogen

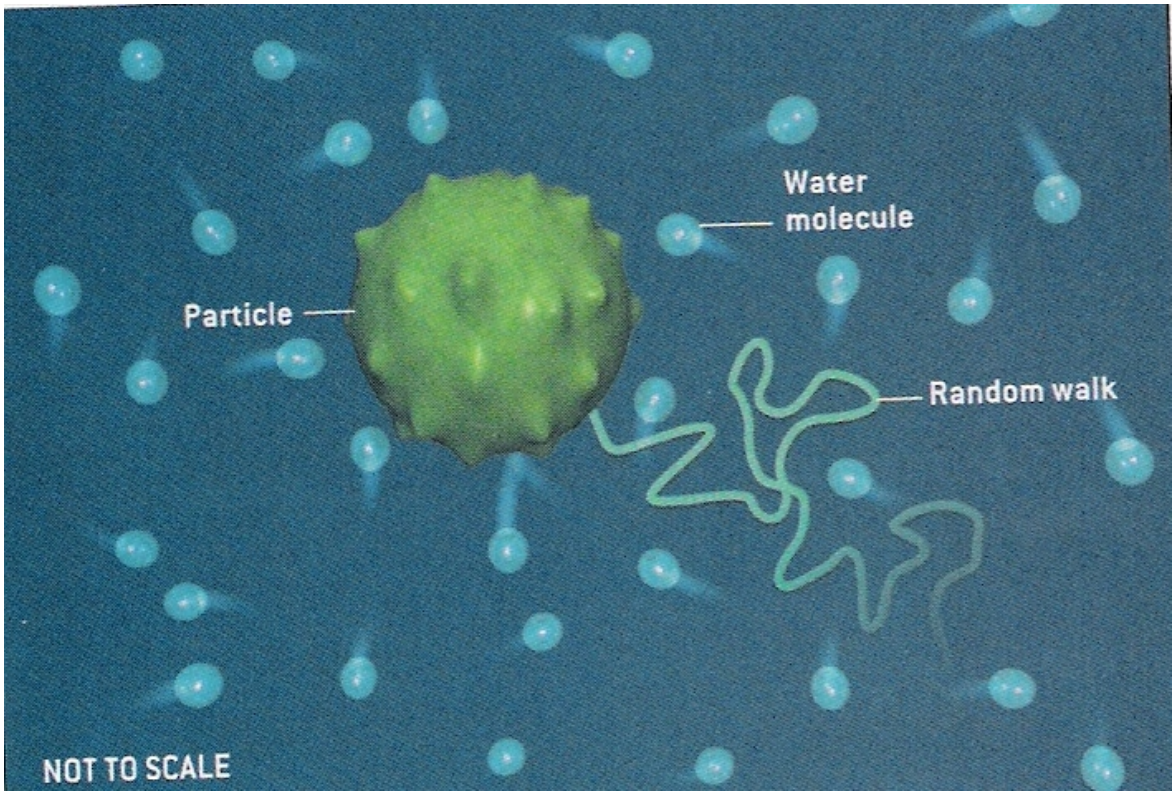
Chemical Reactions

Number of atoms "conserved" (stay the same) they just rearrange who they partner (bond) with

$$2\ H_2 + O_2 \Rightarrow 2\ H_2O + \text{ENERGY}$$



Another piece of evidence for the atomic theory is Brownian motion – the erratic motion of a tiny particle in water as it is buffeted by the water molecules.



If atoms exist, how big are they?

Can Dalton’s theory tell us?

Some of the best proof that individual atoms existed was shown in the 1800's. The "fingerprint" or "DNA" like evidence was seen in glorious detail in the light they gave off or absorbed. i.e. their optical spectra

Note the reasons for these spectacularly unique atomic spectral fingerprints was a total mystery until quantum mechanics explained it in the 20^{th} century. Never the less the Rogues gallery of fingerprints was so clear that He was discovered this way in the Corona of the sun before the atom was found on earth.

Black Body Radiation

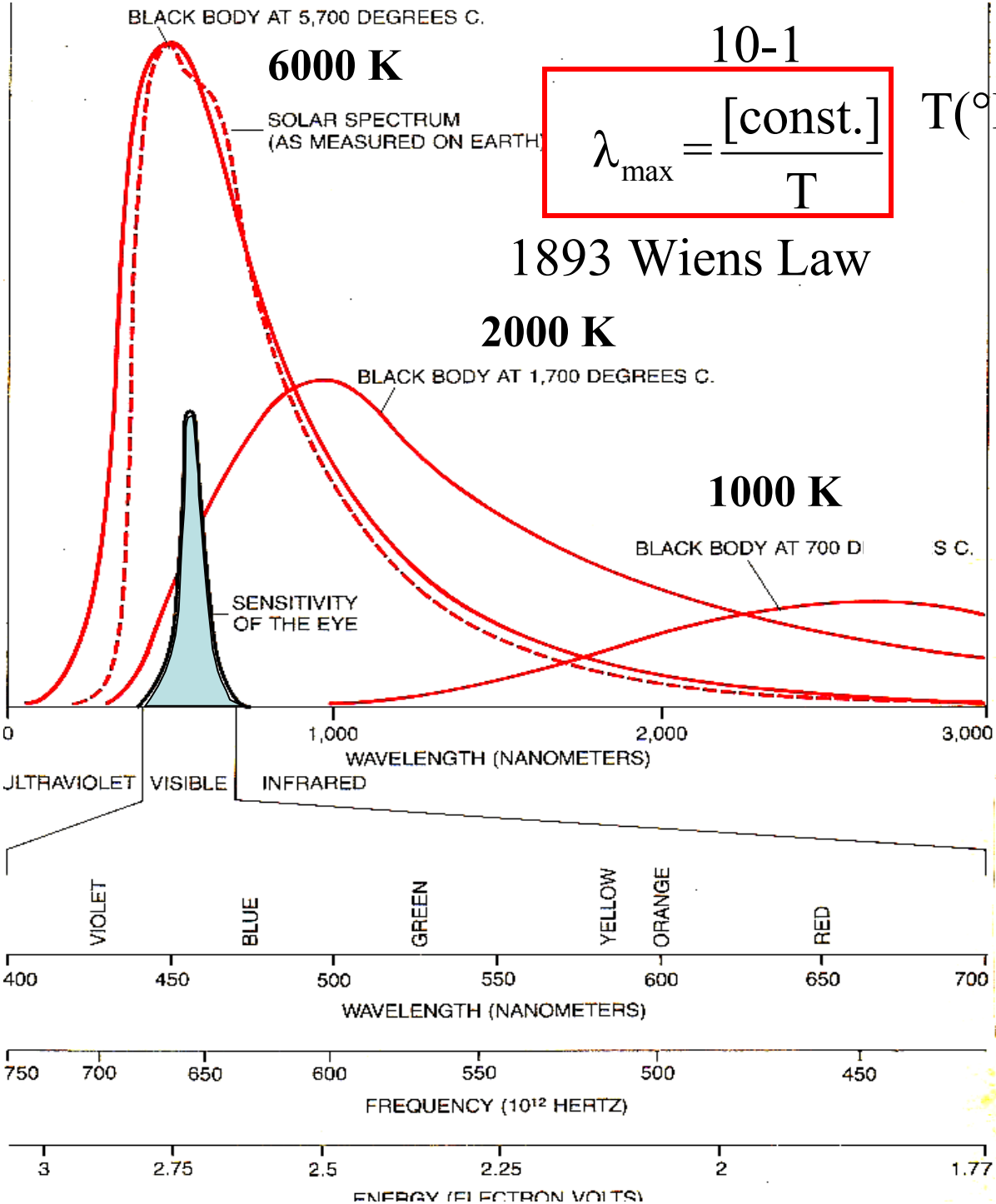
10-1

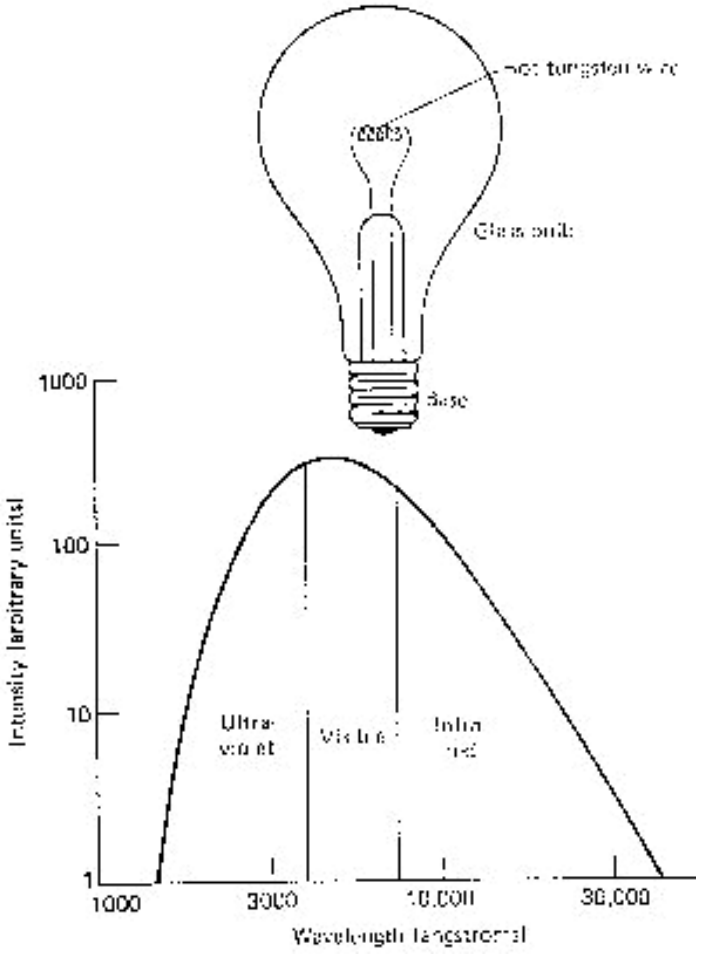
$$\lambda_{max} = \frac{[\text{const.}]}{T} \qquad T(^{\circ}K)$$

1893 Wiens Law

Stefan Boltzman Law

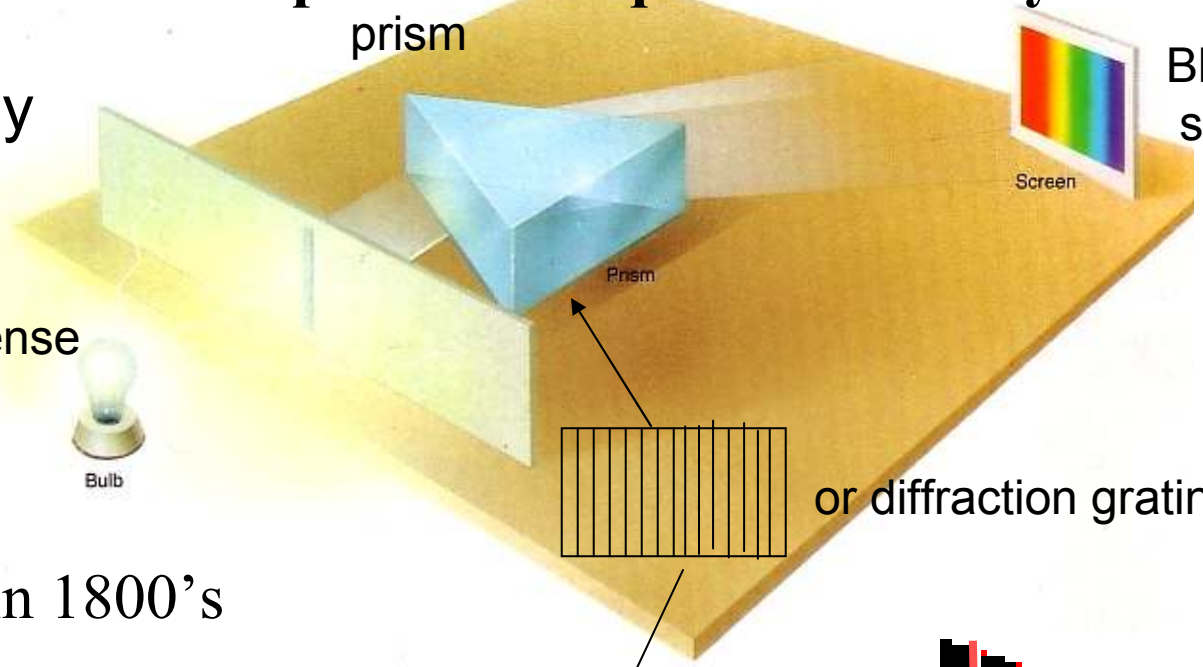
$$\frac{E_{radiated}}{\text{surf. area}} = \sigma T^4$$



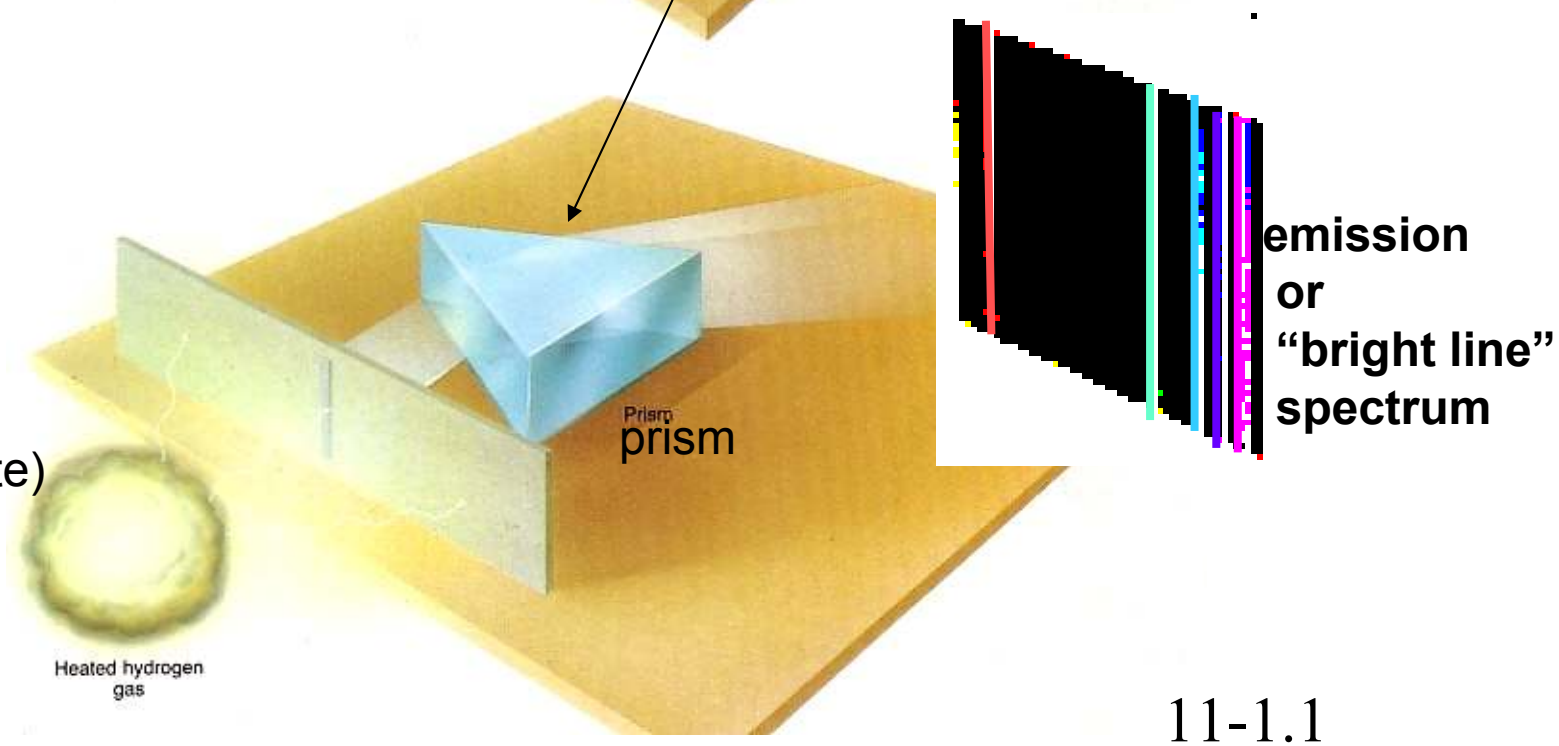


Experimental backdrop to atomic quantum theory development

Spectroscopy (emission)

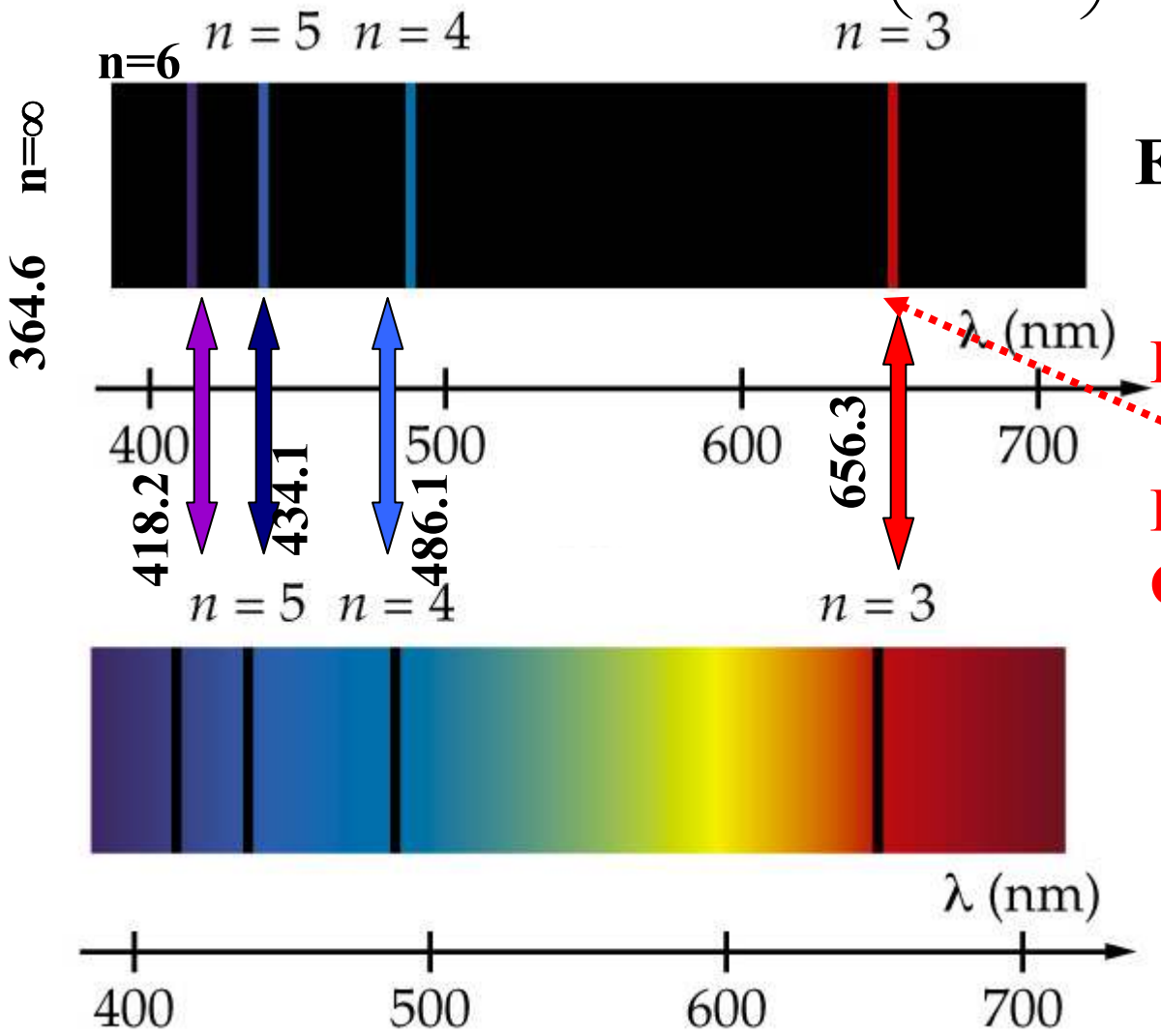


Developed in 1800's



H atom absorbs and emits specific wavelengths (energies) of light

1885 Balmer: visible light $\lambda=(364.56)\left(\frac{n^2}{n^2-2^2}\right)$: $n=3,4,5,6,\ldots,\infty$



Emission spectrum

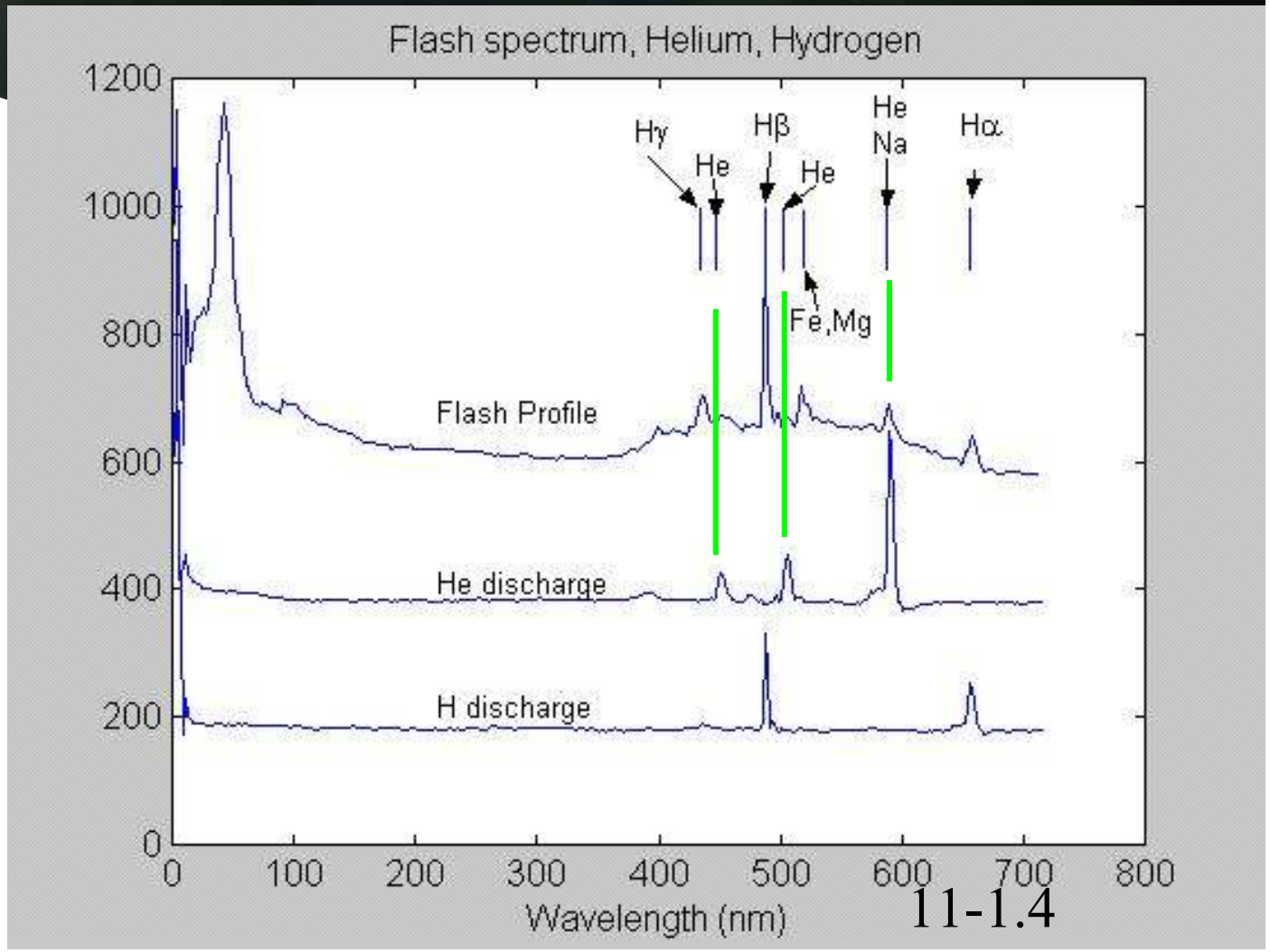
Red Balmer

Line in Orion Nenula

Absorption spectrum

He discovered in solar flash spectrum at solar eclipse ~ 1850 long before identified on Earth

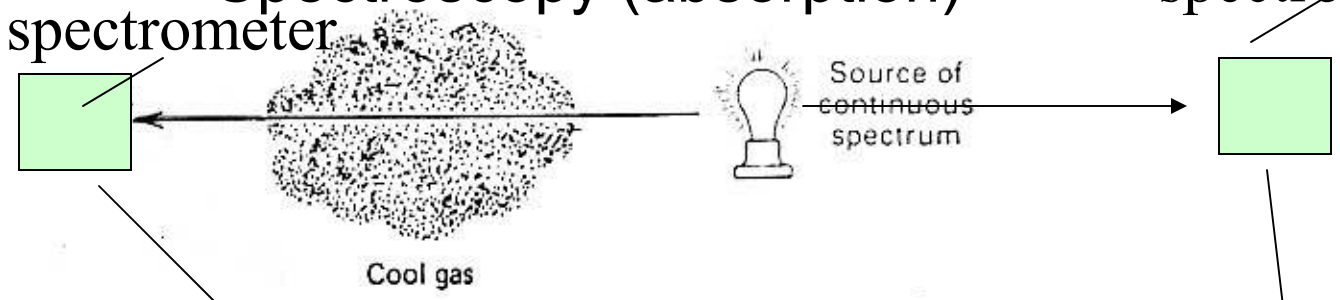
Other unique atomic spectra fingerprints



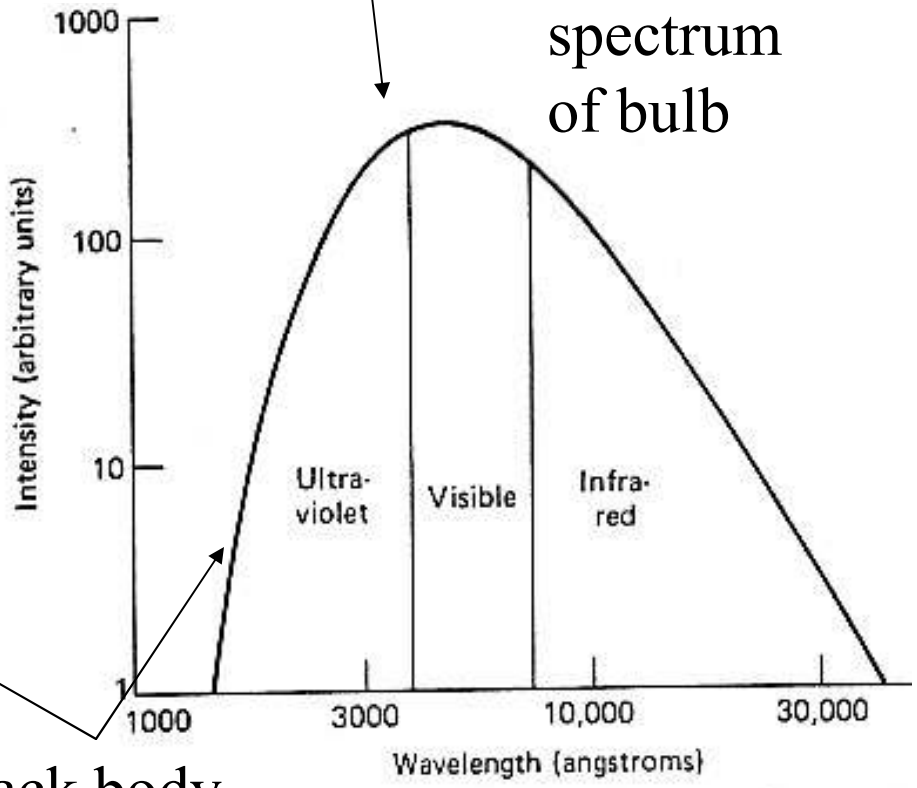
Spectroscopy (absorption)

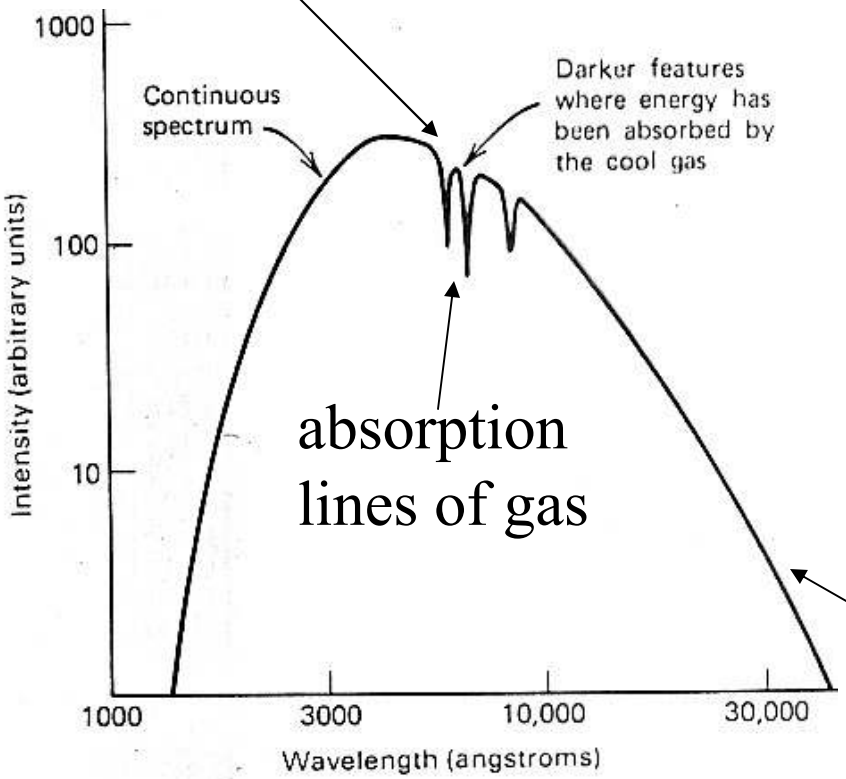
spectrometer

spectrometer



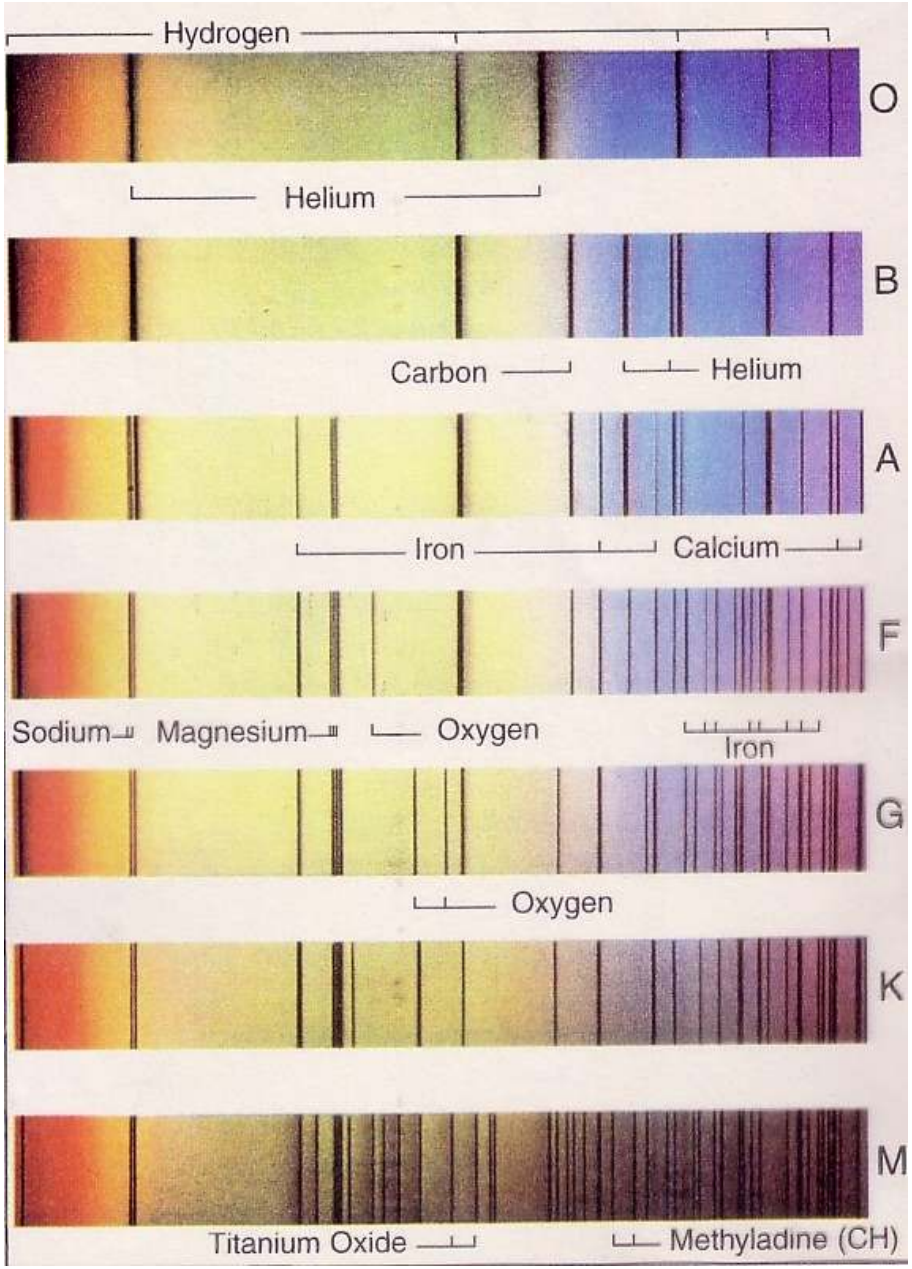
black body spectrum of bulb



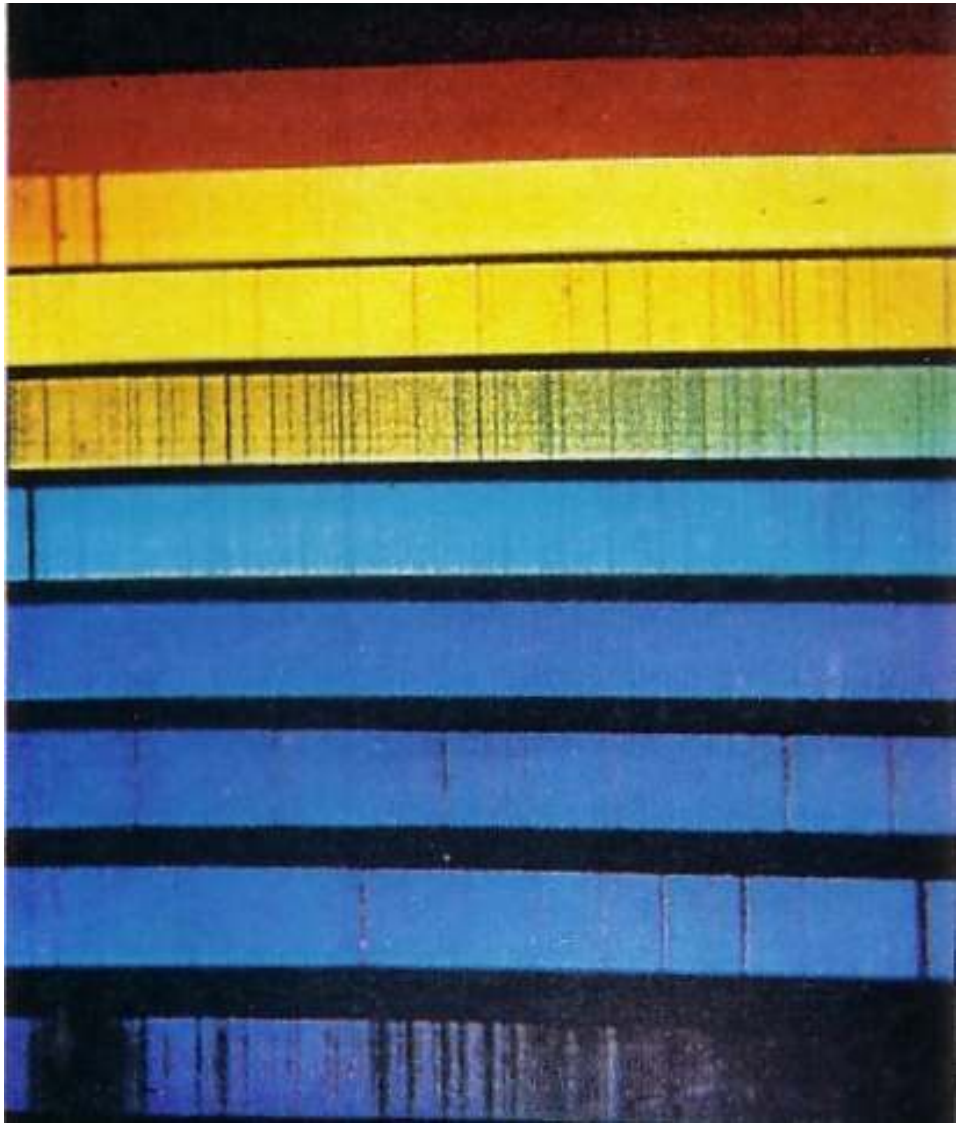


absorption lines of gas

black body spectrum of bulb



absorption lines in spectra of stars
with different surface temperatures (mass)



absorption lines in Sun's spectrum

11-1.6

table 2.1

Metric distances

Name of unit	Distance	Conversion to American units
Kilometer (km)	$1000\ \text{m} = 10^3\ \text{m}$	$1\ \text{km} = 0.62\ \text{mi}, 1\ \text{mi} = 1.6\ \text{km}$
Meter (m)		$1\ \text{m} = 3.3\ \text{ft} = 39\ \text{in.}, 1\ \text{ft} = 0.30\ \text{m}$
Centimeter (cm)	$0.01\ \text{m} = 10^{-2}\ \text{m}$	$1\ \text{cm} = 0.39\ \text{in.}, 1\ \text{in.} = 2.5\ \text{cm}$
Millimeter (mm)	$0.001\ \text{m} = 10^{-3}\ \text{m}$	
Micrometer (μm)	$0.000\ 001\ \text{m} = 10^{-6}\ \text{m}$	

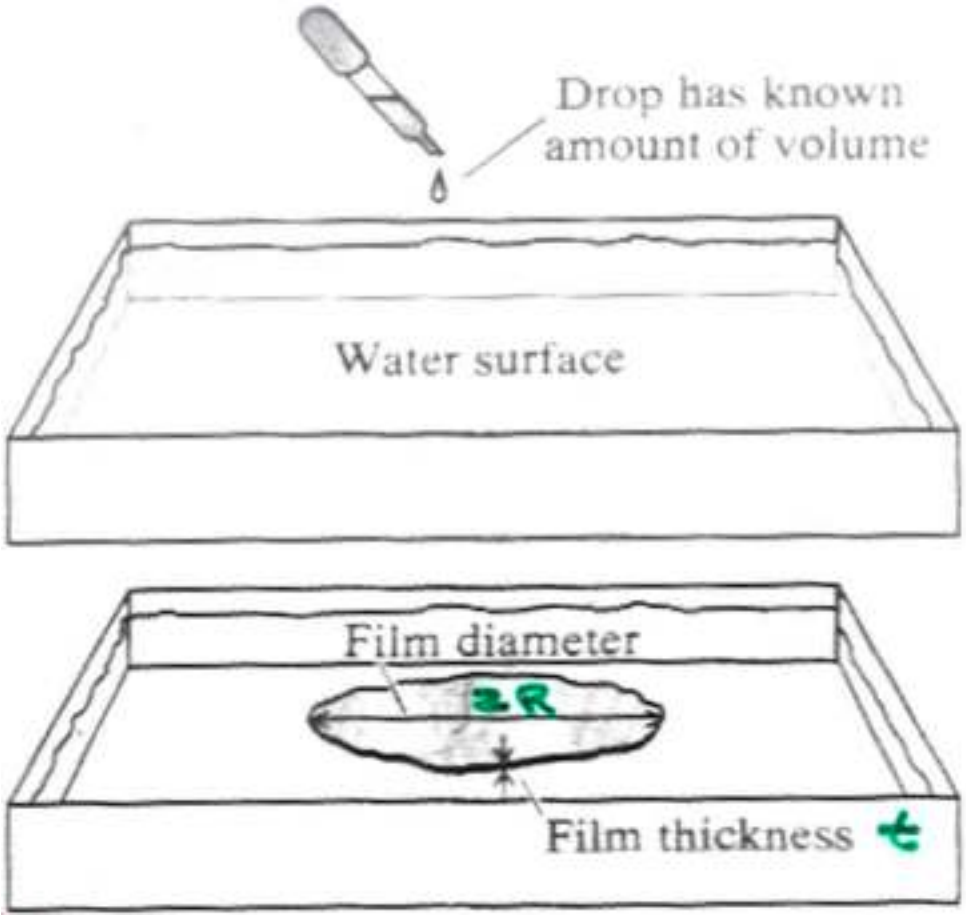
The power of 10 involved is indicated by the exponent; it tells you how many 10s to multiply.

Example: 10^5 = 10x10x10x10x10.

Small numbers are indicated by negative exponents; this means you divide by 10s rather than multiplying.

Example: $10^{-5} = 1/10^5 = 1/(10\text{x}10\text{x}10\text{x}10\text{x}10)$.

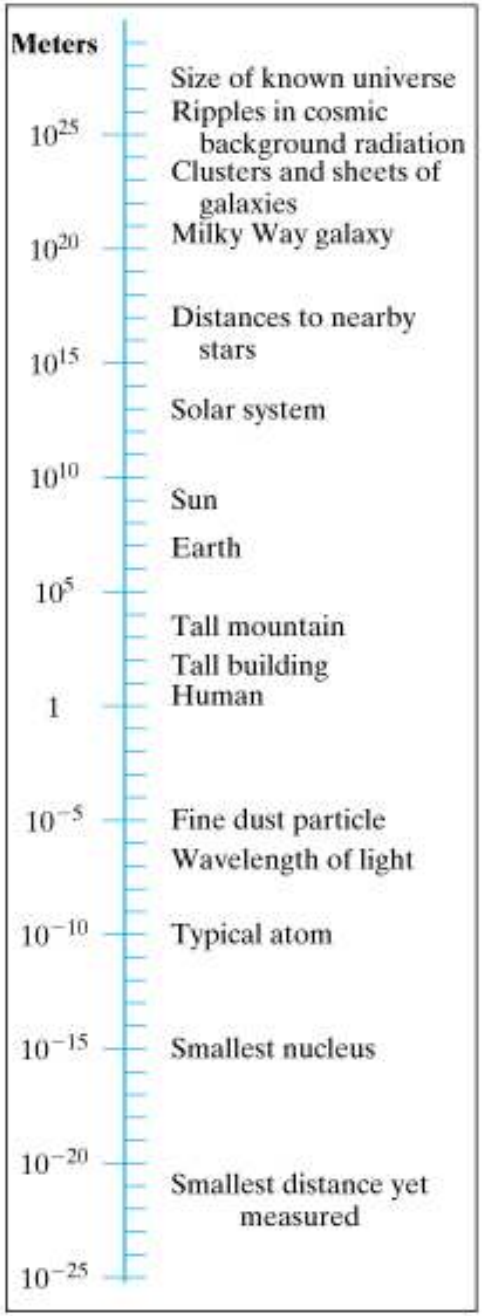
Incredible smallness of atoms



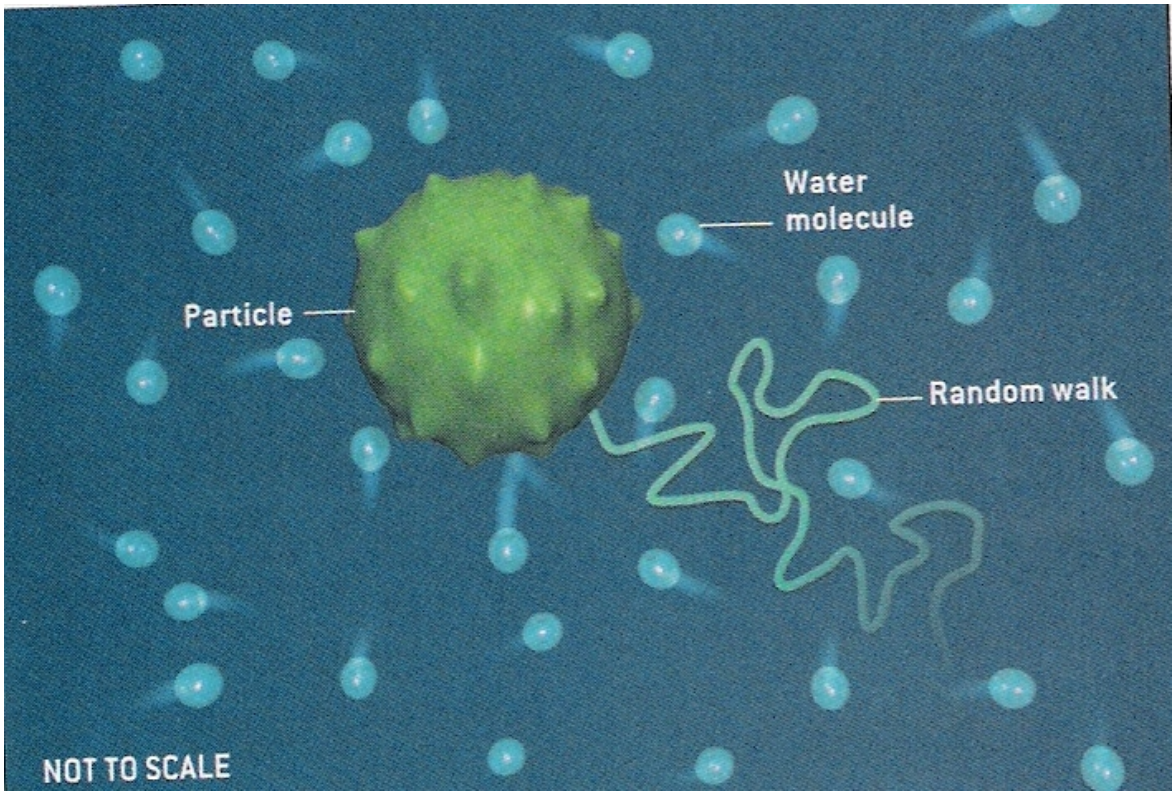
Size of atom is about 10^{-10} meters, i.e., 0.0000000001 meters

The Incredible Smallness of Atoms

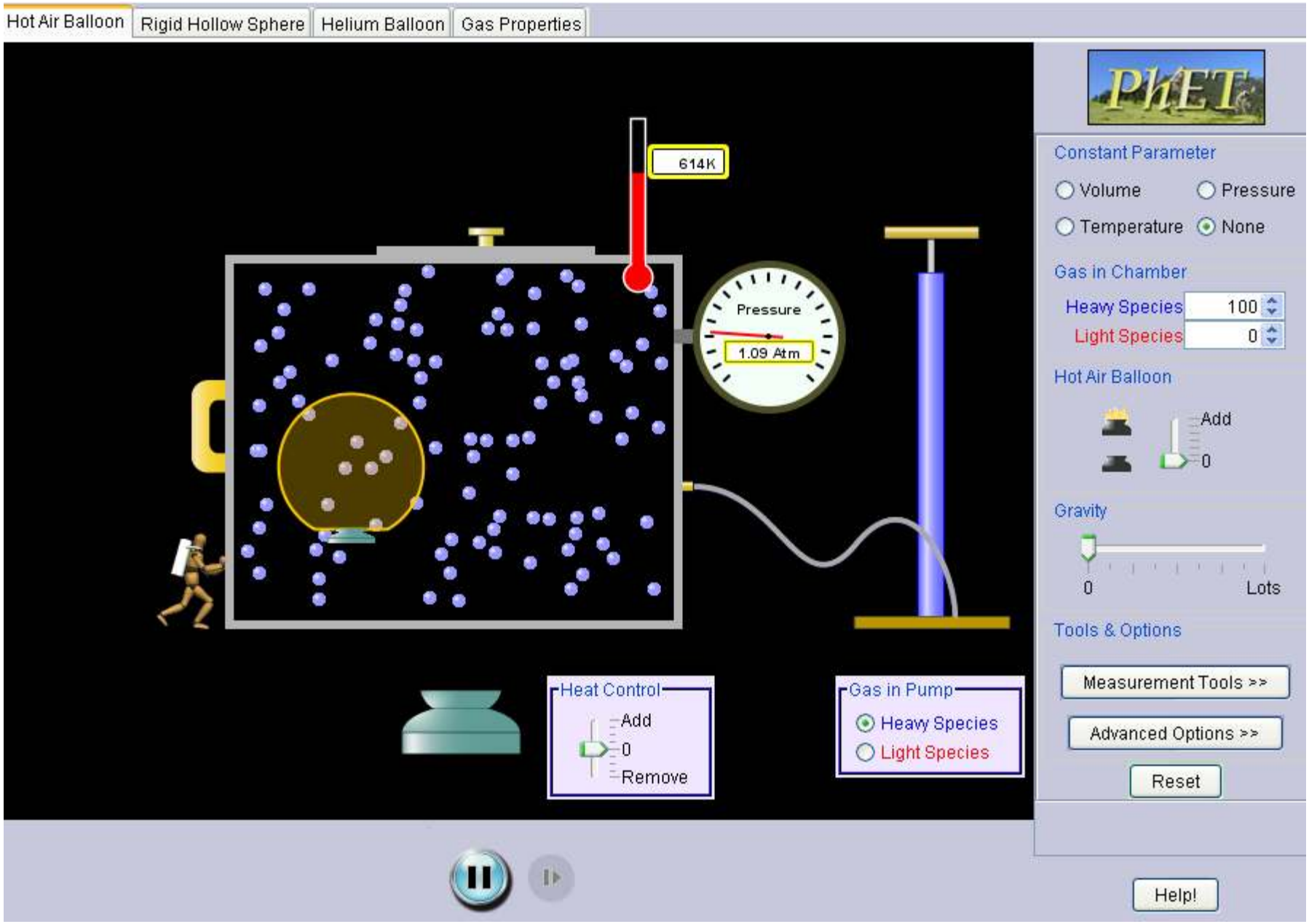
This graph shows the vast array of sizes in the universe. It would be impossible to draw without using powers of 10.



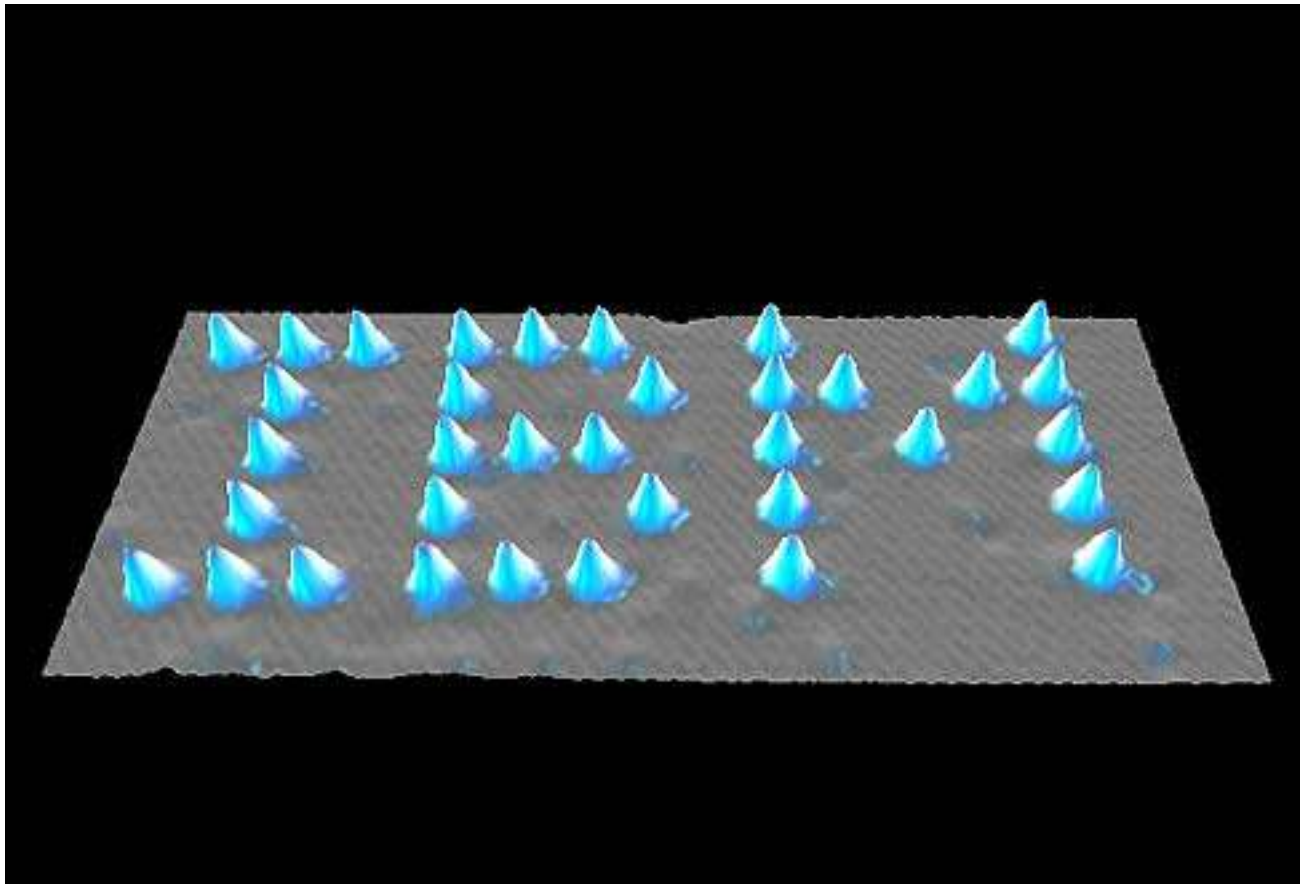
In 1905, Einstein made an estimate based on an atomic theory of Brownian motion and got about the same answer.



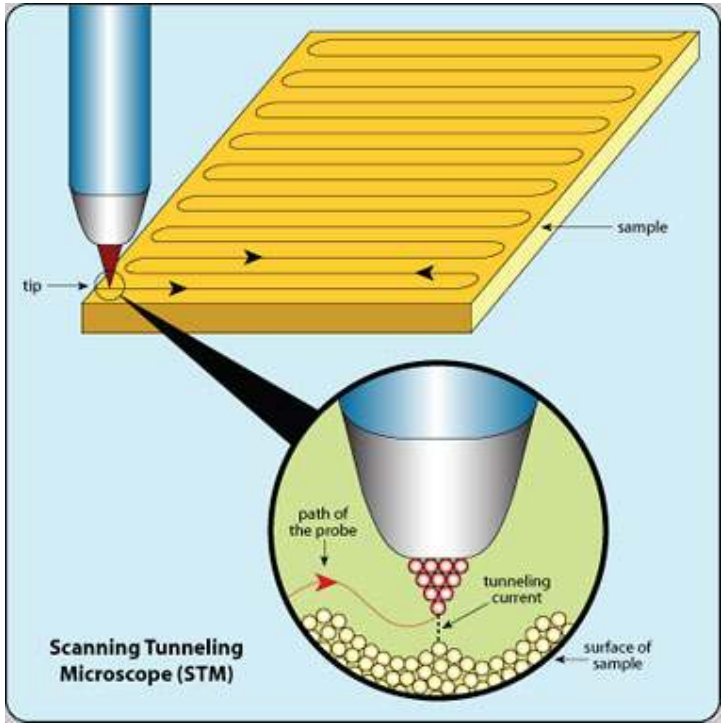
This simulation shows a Brownian like motion.

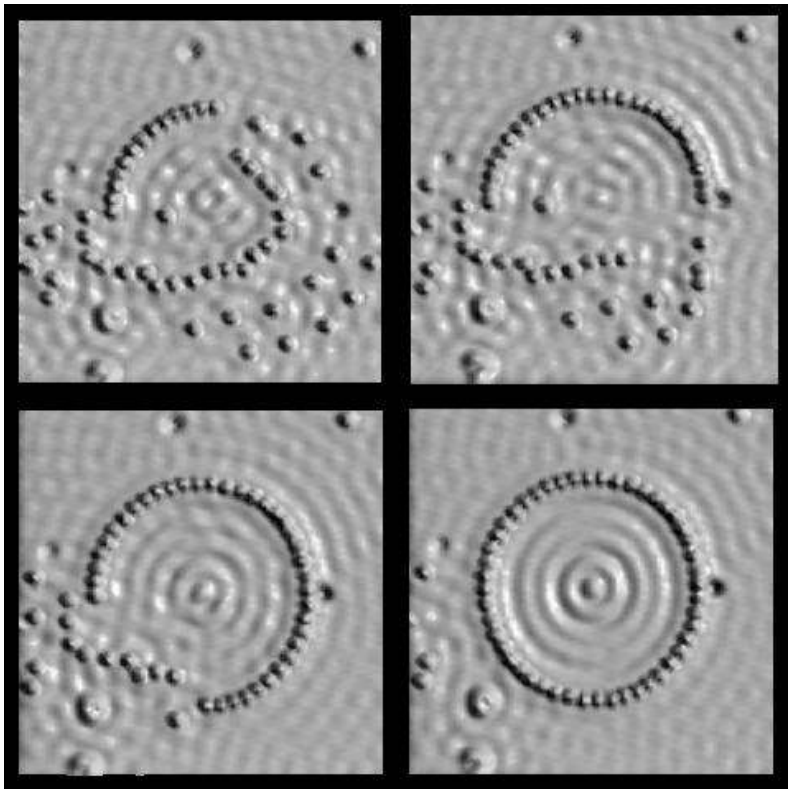


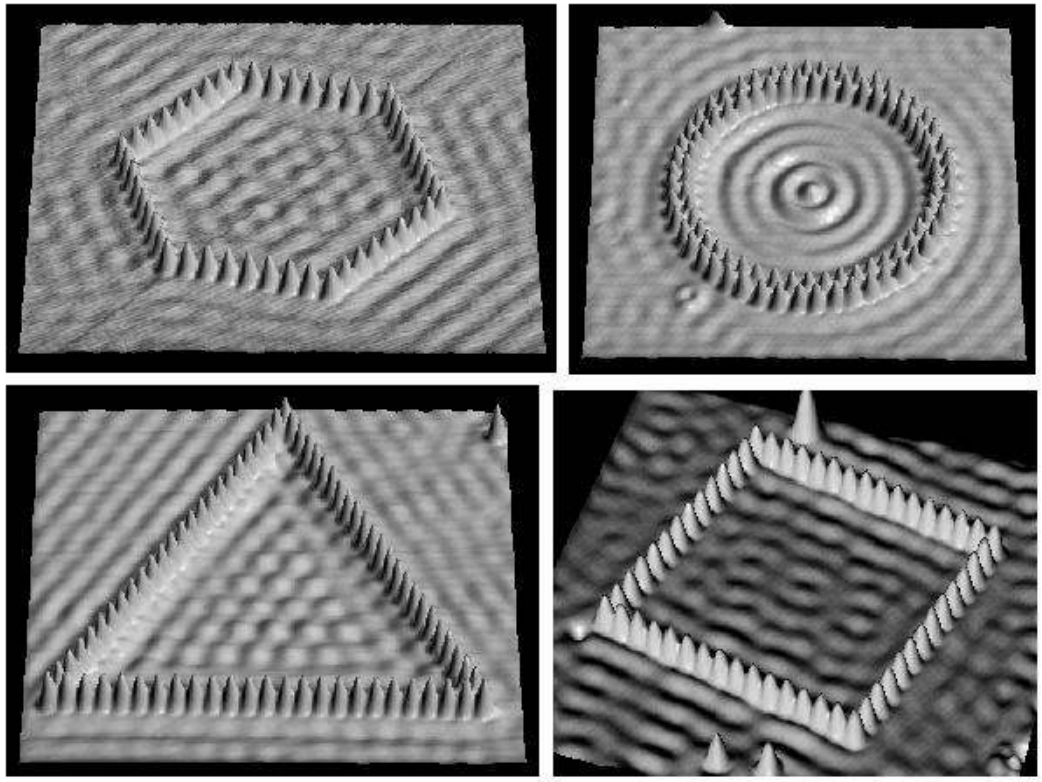
Today, we can “see” atoms!

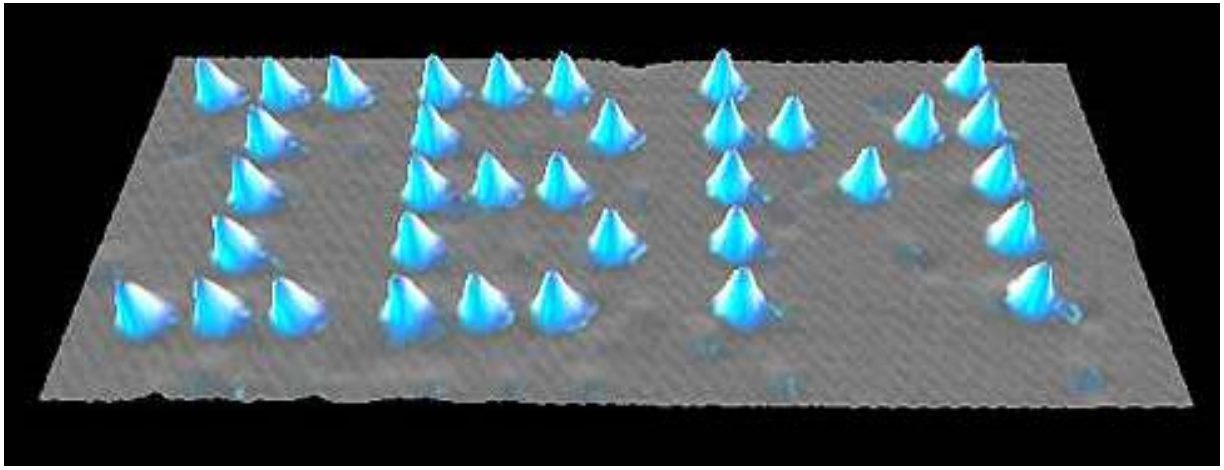


Scanning Tunneling Microscope (STM)



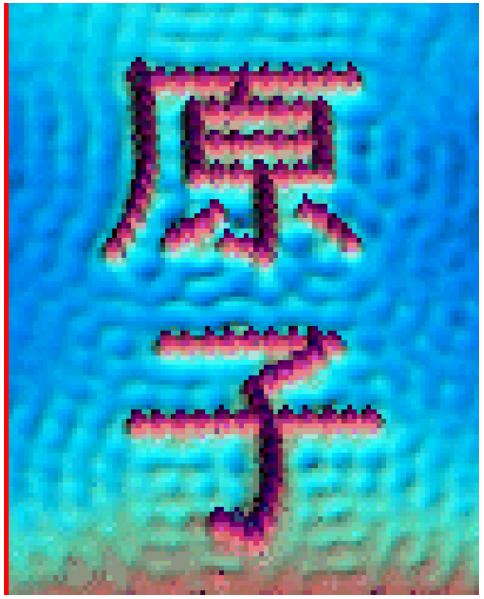




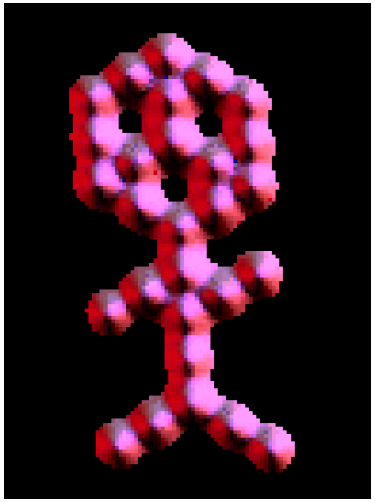


- Atoms can be arranged and imaged!

Iron atoms arranged on a copper (111) surface. These Kanji characters represent the word “atom”.



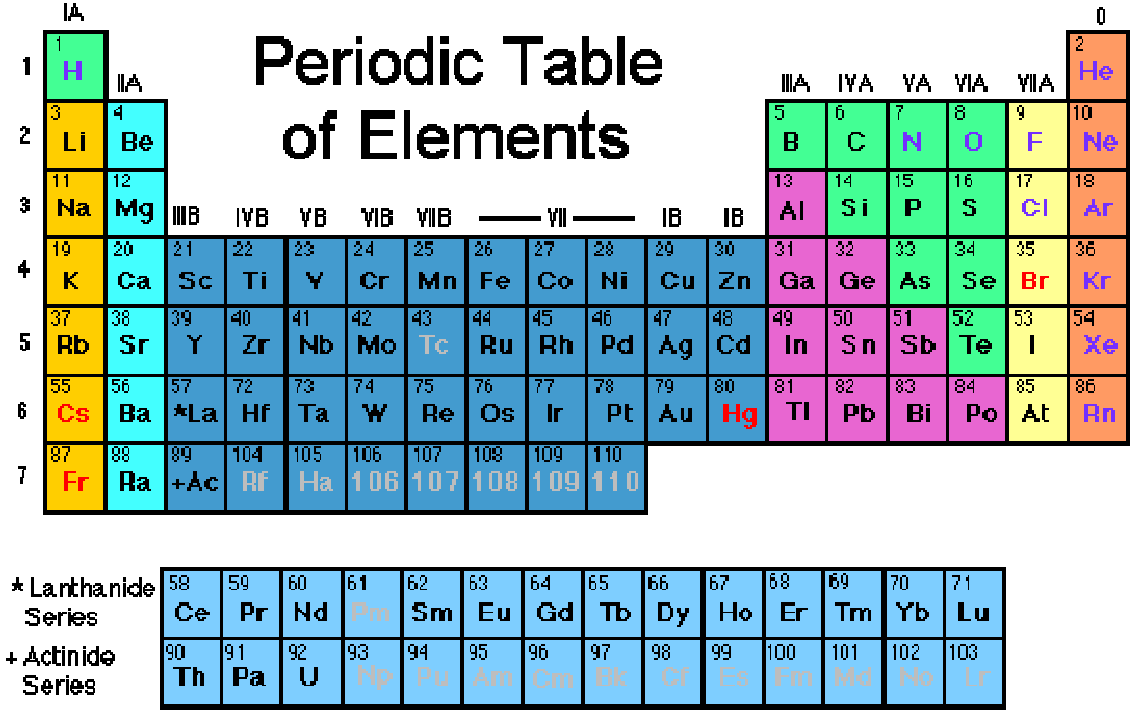
Crass commercial show-off-ism!
But impressive anyway…



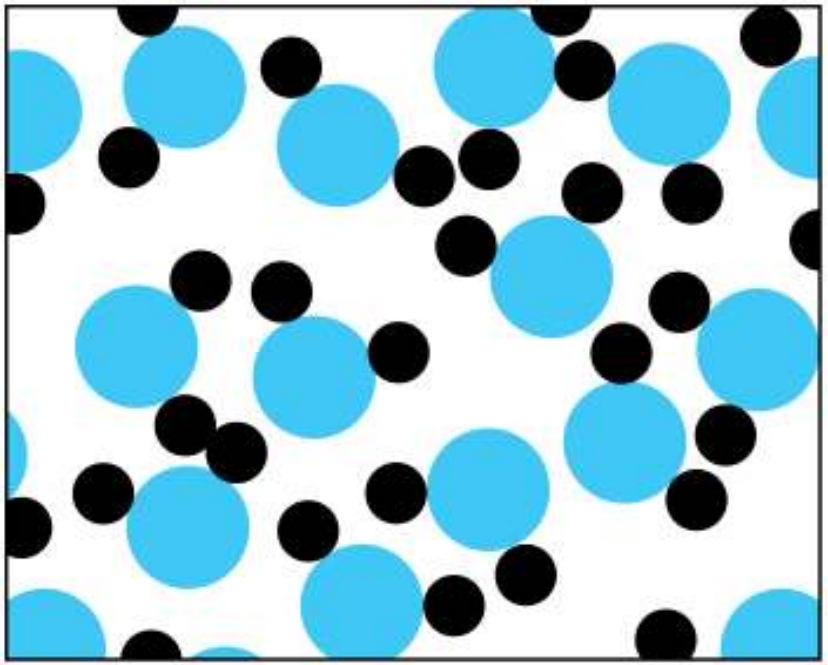
Carbon monoxide molecules arranged on a platinum (111) surface.

2.2 Atoms and Molecules

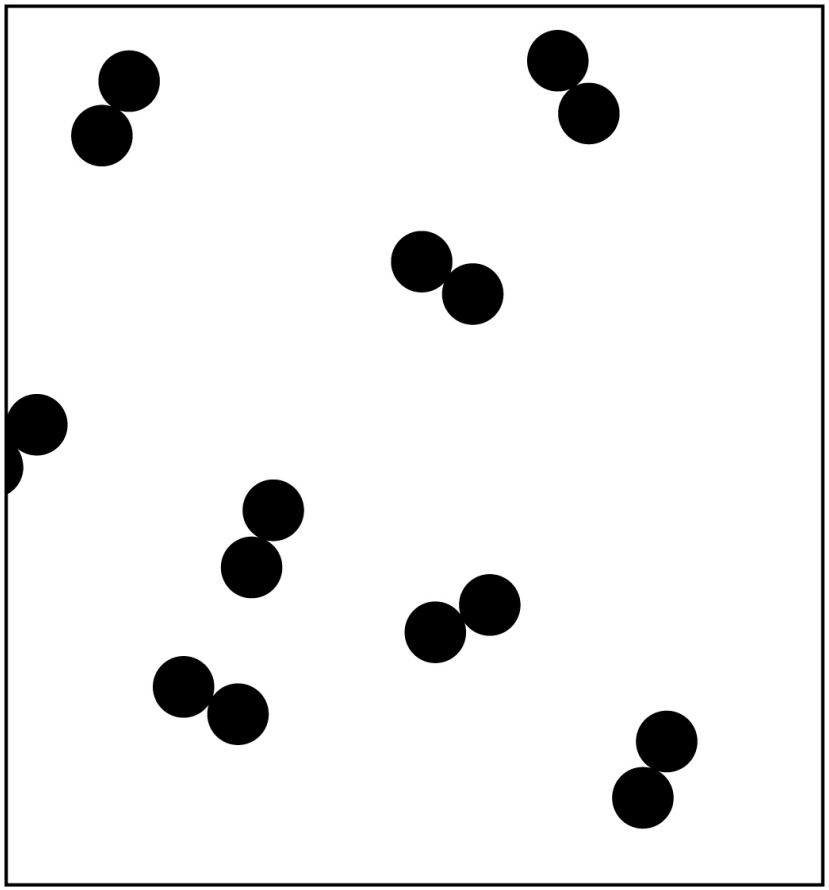
A total of fewer than 100 substances were found that could not be decomposed; these are called the chemical elements. Including elements that can only be made in the laboratory, there are 116 elements now known.

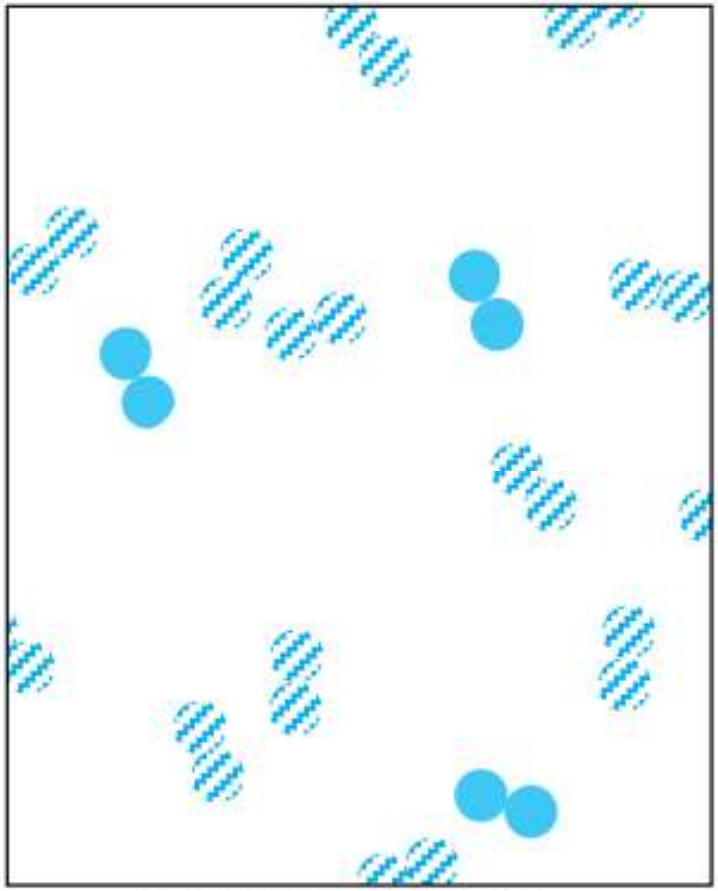


A substance made of more than one element is called a compound. One familiar example is water. Each water molecule contains one oxygen atom and two hydrogen atoms.

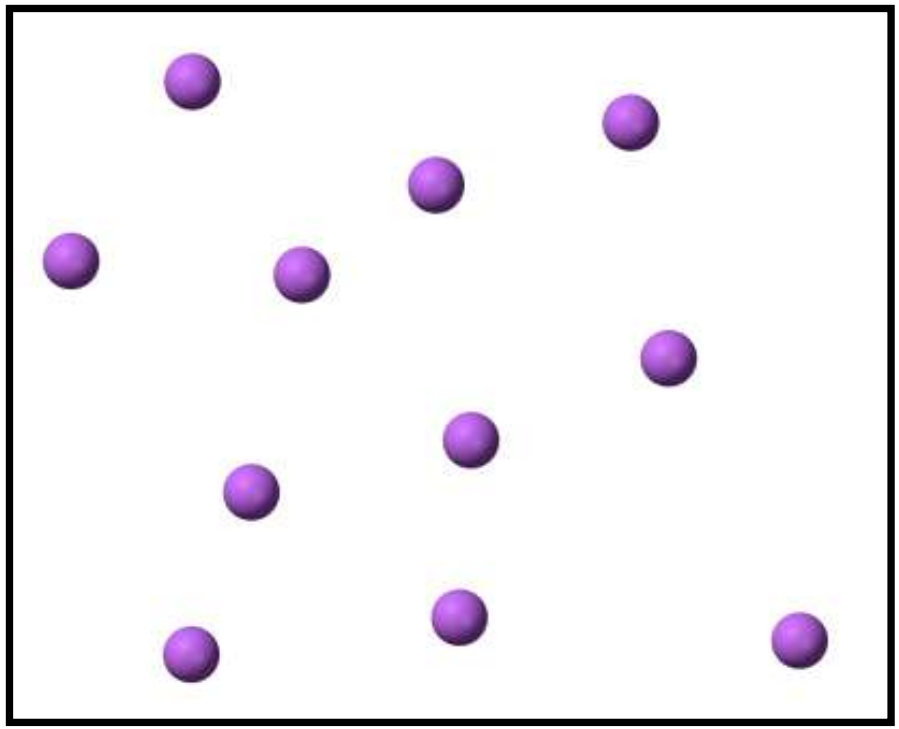


Some atoms, such as hydrogen, oxygen, and nitrogen, form two-atom molecules.

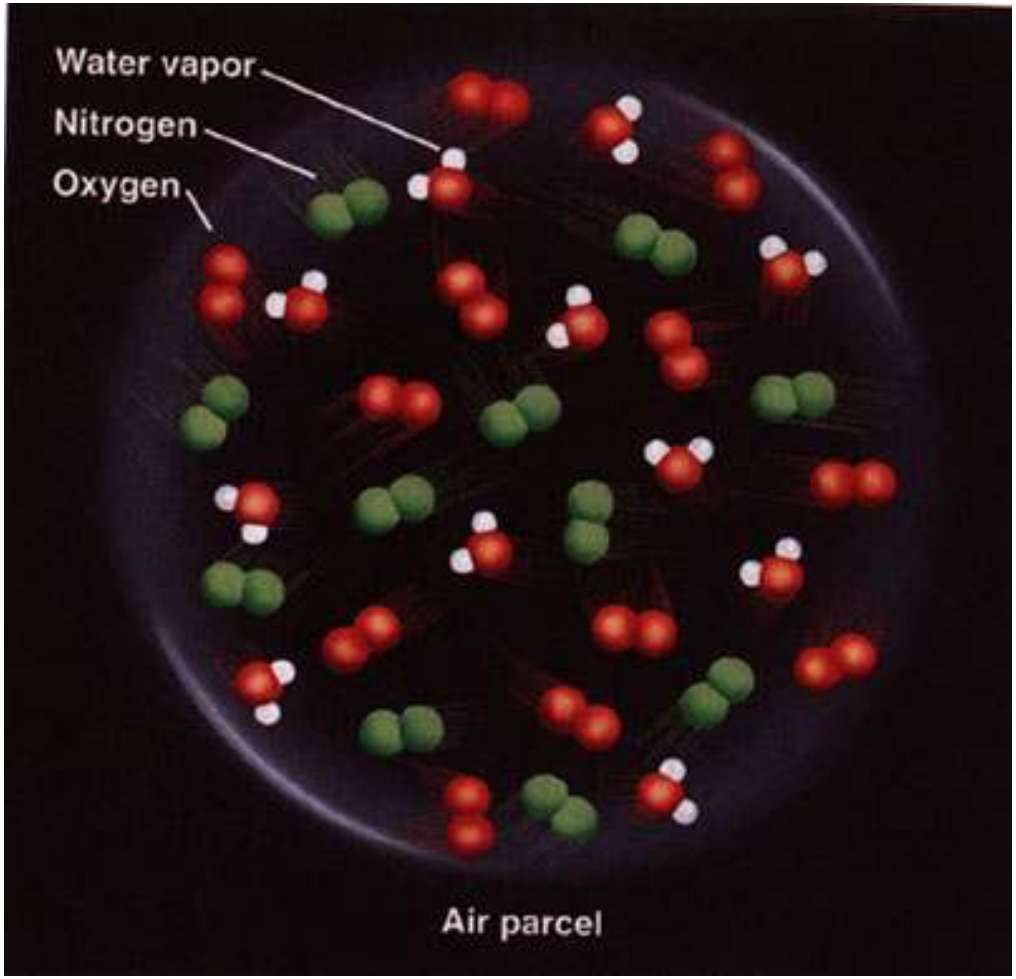




Others, such as helium, form single-atom molecules.



Air is about 80% nitrogen, 20% oxygen, and small amounts of water, argon, …



(relative populations are not realistic)

Compounds and elements are represented in abbreviated form. Every element has a one- or two-letter abbreviation, and the number of elements per molecule is given as a subscript.

Water: **H_2O**

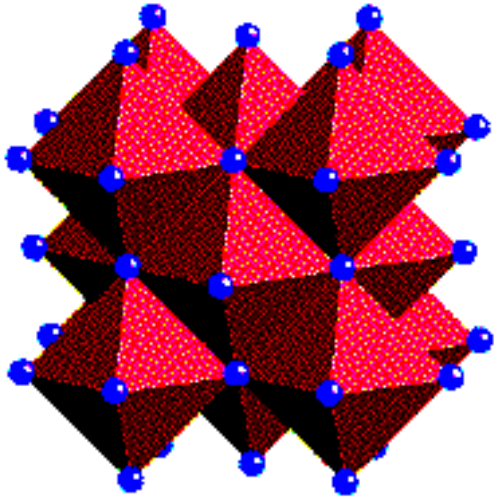
Salt: **NaCl**

Hydrogen gas: **H_2**

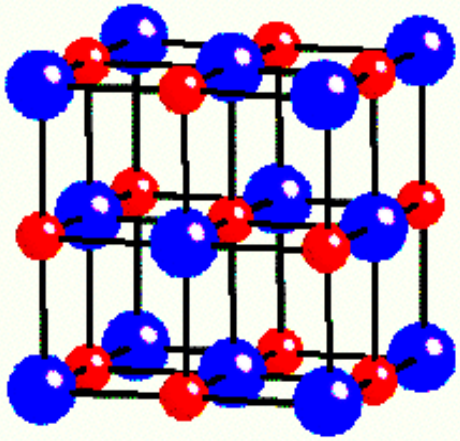
Sulfuric acid: **H_2SO_4**

Little Willie was a chemist. Little Willie is no more, for what he thought was H_2O was H_2SO_4.

STATES OF MATTER

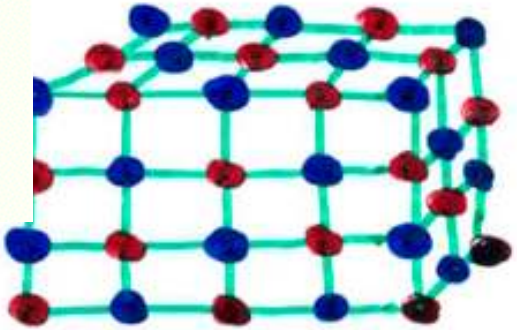


SOLID



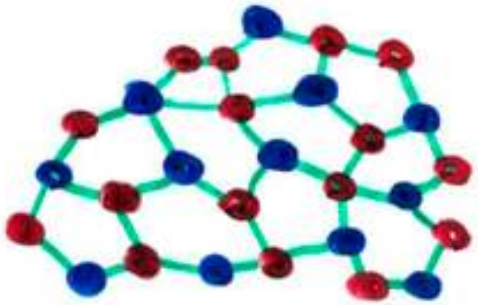
CRYSTALLINE

ATOMS ALIGNE
IN REGULAR LI
AND ARRAYS

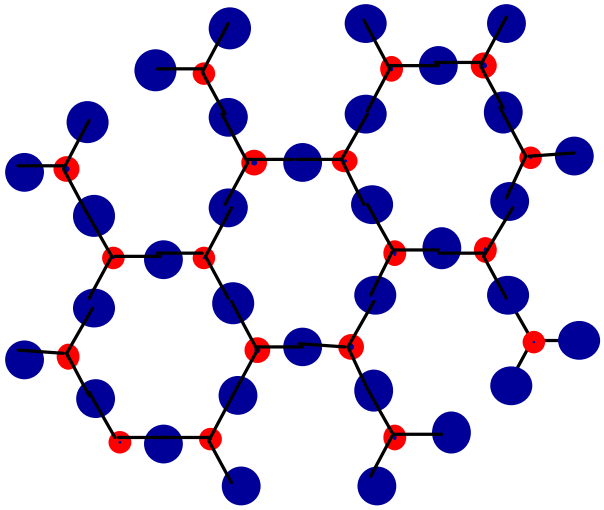


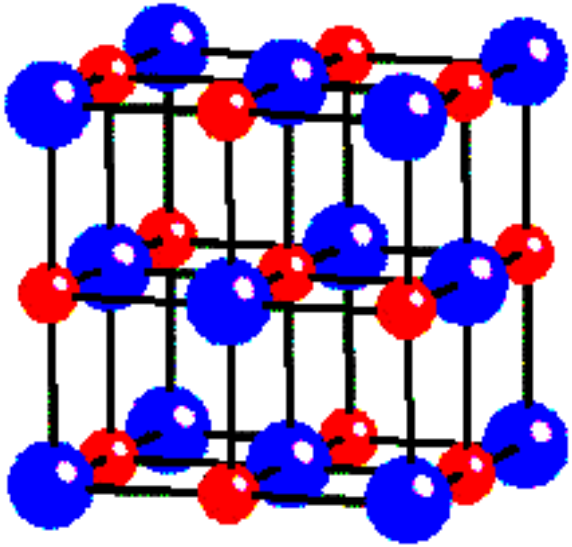
AMORPHOUS (GLASS)

ATOMS HAVE NO
LONG-RANGE ORDER



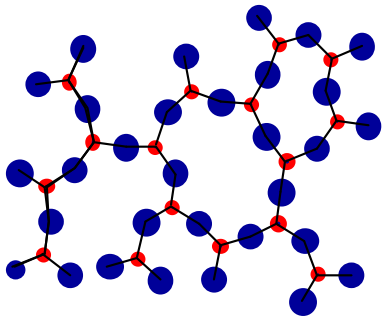
Rock Salt Structure





crystalline SiO_2

• Si • Oxygen



noncrystalline SiO_2

- atoms have no periodic packing
- occurs for: -complex structures
  -rapid cooling

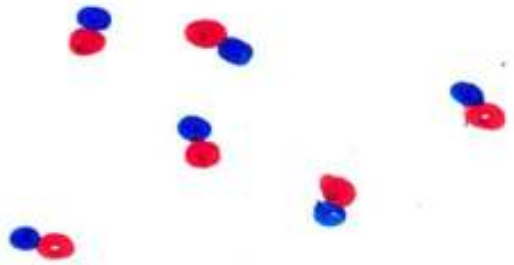
LIQUID

ATOMS ARE AT WELL DEFINED DENSITY OR AVERAGE SPACING, BUT CAN FLOW OVER ONE ANOTHER

($S = 0$)

GAS

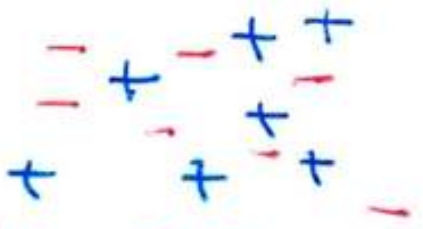
ATOMS MOVE FREELY AND RANDOMLY AND AVERAGE SPACING IS MUCH LARGER THAN ATOM SIZE (OR MOLECULE SIZE)



PLASMA

GAS OF ELECTRICALLY CHARGED PARTICLES

(OVERALL ELECTRICAL NEUTRALITY)



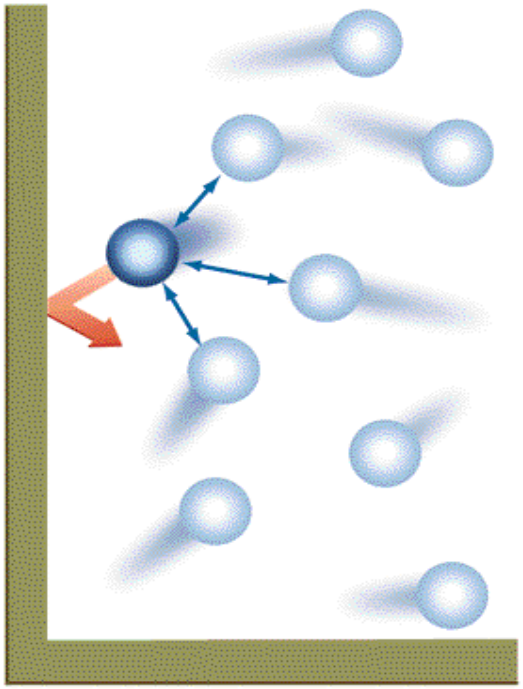
Vacuum: a complete absence of matter in any form

A vacuum created on earth is never perfect; it is called a partial vacuum, as there are still some gas molecules present.

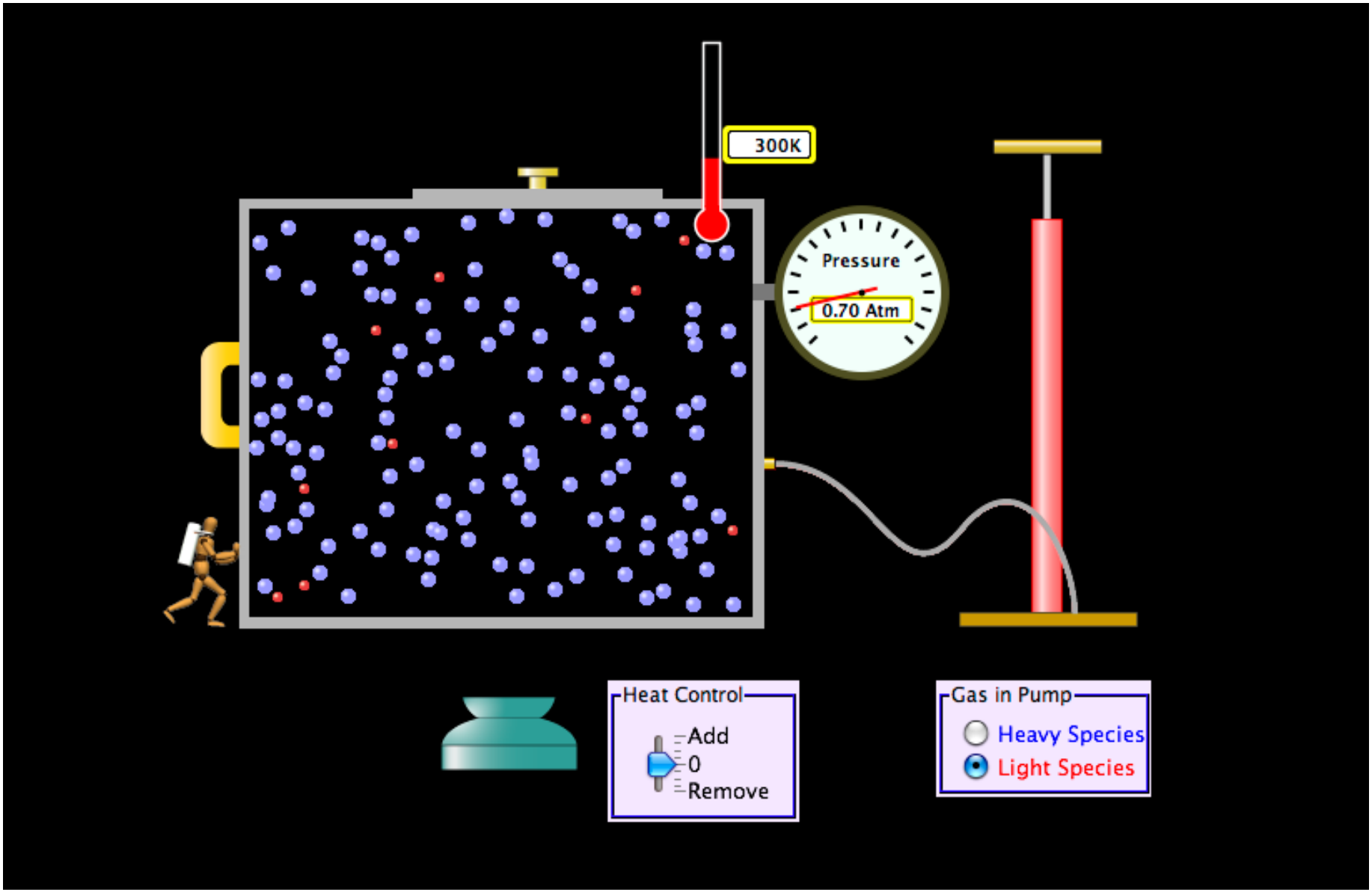
The **motion** of molecules, whether in a solid, liquid, or gas, is a measure of the ***temperature*** of the substance.

Energy of motion =*temperature*

As the molecules bounce off the walls of a container, they exert a ***pressure*** on them.

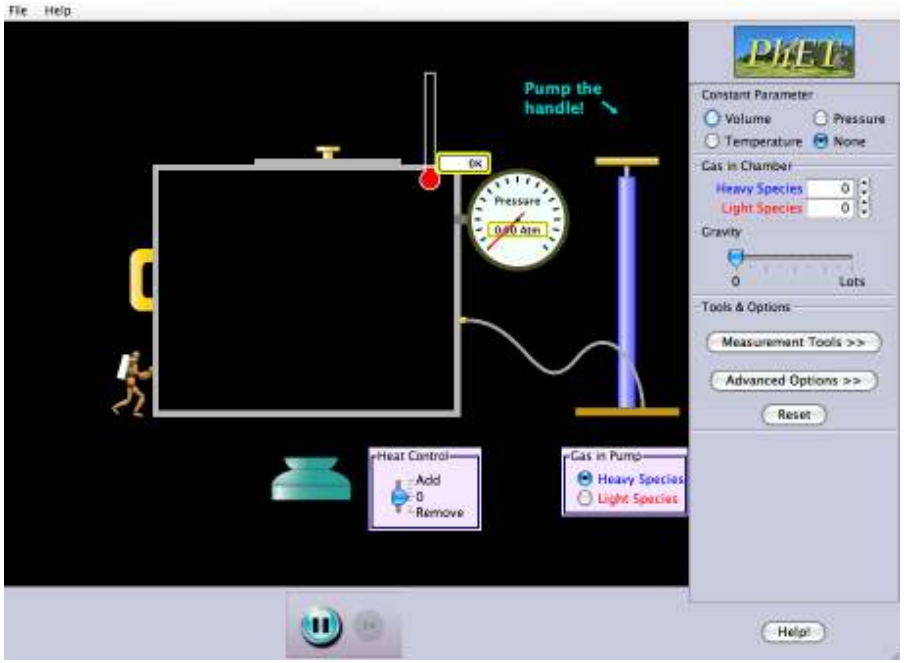


Show PhET demo:



Here I suggest to do “demo” using the applet:

http://phet.colorado.edu/simulations/sims.php?sim=Gas_Properties



The way I do this is to load the applet into my web browser and get it working ***before*** lecture starts. Then, when I want to show the applet, I get out of powerpoint, bring up the browser, and play with the applet…

2.7 Three Atomic Models: Greek, Planetary, and Quantum

The Greek atom was indivisible and unchangeable. This view persisted until the early 20th century, when it was discovered that the atom consists of a very tiny nucleus surrounded by relatively distant electrons.

I didn't get to the models of the atom- Mark

MODELS OF ATOMS

★GREEK MODEL (300 BC)

TINY, UNCHANGEABLE, IMPERISHABLE, SINGLE OBJECT

★ELECTRIC MODEL (19TH CENTURY)

ELECTRONS INSIDE WHICH CAN BE REMOVED LEAVING NET ELECTRICALLY CHARGED ION ⇒ ELECTRIC CONDUCTION CHEMISTRY

ALMOST ALL OF THE MATERIAL SUBSTANCE (THE MASS) RESIDES IN THE ION.

★NUCLEAR ATOM

ALMOST ALL OF THE MASS LIES IN A VERY TINY CENTER (THE NUCLEUS)

ELECTRONS ORBIT (AT GREAT DISTANCES) FROM NUCLEUS

ATOMS ARE ALMOST ALL EMPTY SPACE

★ ISOTOPES, NUCLEAR REACTIONS

THERE CAN BE DIFFERENT ATOMS (ISOTOPES) OF THE SAME CHEMICAL ELEMENT

NUCLEI CAN BREAK APART (FISSION), OR JOIN TOGETHER (FUSE)

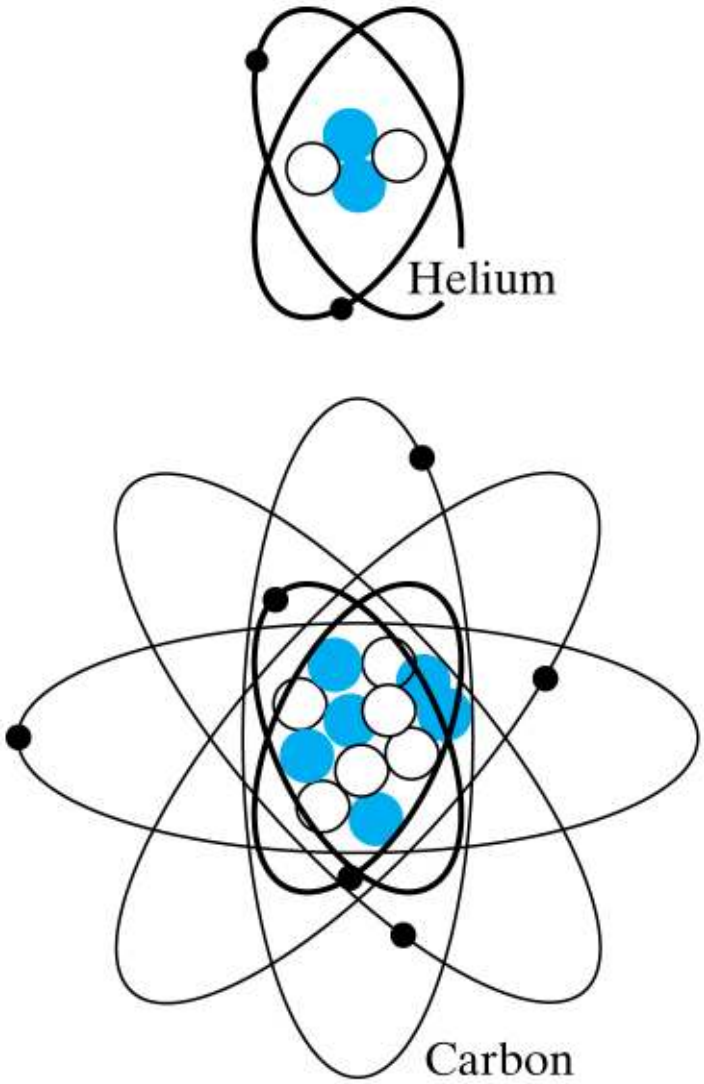
NEUTRONS, PROTONS

$_6C^{12}$

★ QUARKS – STRUCTURE OF NEUTRONS & PROTONS

The planetary atom was similar to a tiny solar system, with the nucleus at the center and the electrons in specific orbits.

The quantum atom is different in that nothing has a definite position.



Discussion: Materialism

Democritus:

"By convention sweet is sweet, bitter is bitter, hot is hot, cold is cold, and color is color. But in reality there are only atoms and empty space. That is, the objects of sense are supposed to be real, and it is customary to regard them as such, but in truth they are not. Only the atoms and empty space are real."

Reminders

- Pick up graded homework in front of lecture hall
  Read Chapter 3 for Monday
  Next homework due on Monday