John Dalton (1766-1844)

British chemist and physicist.

Father of meteorology, recorded over 200,000 observations of the atmosphere

First scientific description of color blindness, now called "Daltonism."

Studied mixed gases and the expansion of gases under heat.

Dalton's Law is still used to describe partial pressures of gases.

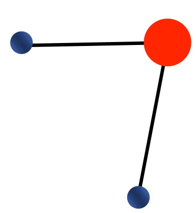
A scientifically grounded atomic theory of matter.

1) chemical elements are made of atoms
2) the atoms of an element are identical in their masses
3) atoms of different elements have different masses
4) atoms only combine in small, whole number ratios such as 1:1, 1:2, 2:3 and so on.

A fifth idea implicit In Dalton's theory

- Atoms can be neither created nor destroyed.
- An element's atoms do not change into other element's atoms by chemical reactions.
- For example, nitrogen and oxygen atoms stay as themselves even when combined.

Law of Definite Proportions



$$\frac{2.0 \text{ g H}}{16.0 \text{ g O}}$$

Law of Multiple Proportions

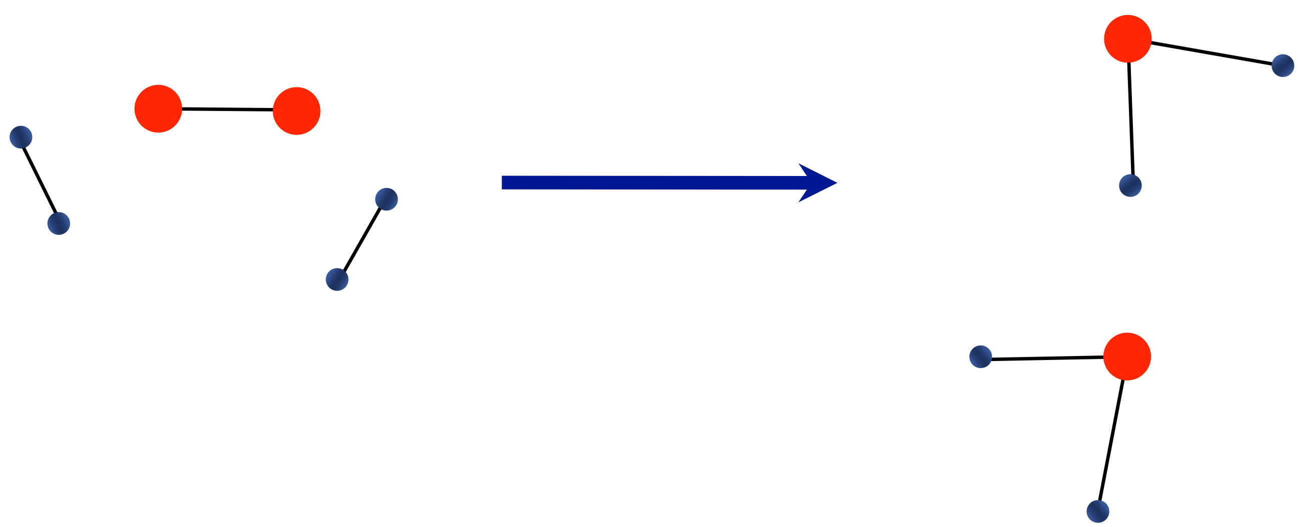
Dalton discovered this law while studying some of the oxides of nitrogen.

The law, in modern terminology, is:

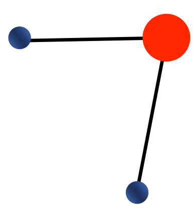
Atoms of the same element can unite in more than one ratio with another element to form more than one compound.

NO, N_2O, NO_2, N_2O_5

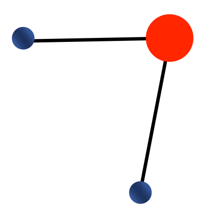
Law of Conservation of Mass



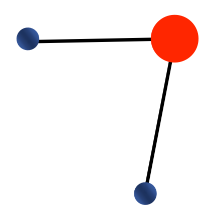
Law of Constant Composition



sample 1

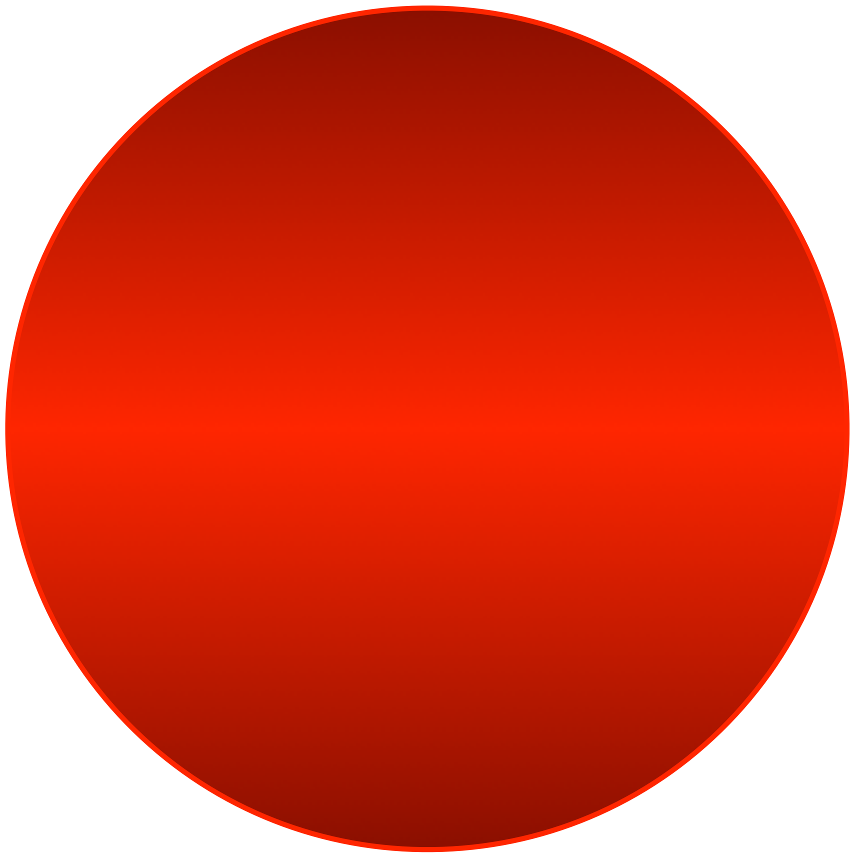


sample 2



sample 3

Dalton’s Atom



1807 – billiard ball model

Atoms: are they billiard balls?

What did later experimentation lead researchers to conclude?

Charge

In nature we find some things carry an electric charge.

There are 2 types, we call them + or -.

Drag your feet on a carpet then touch something metal – what happens?

What is observed is that

opposite charges attract

like charges repel

J. J. Thomson – the electron

Thomson studied electrical discharges in partially evacuated tubes called **cathode-ray tubes**.

From 1898-1903 Thomson found that when a high voltage was applied to the tube, a "ray" he called a **cathode ray** was produced.

The cathode ray turns out to be electrons.

The electrons came from somewhere!

The experiments tell us that atoms have a negatively charged part called electrons.

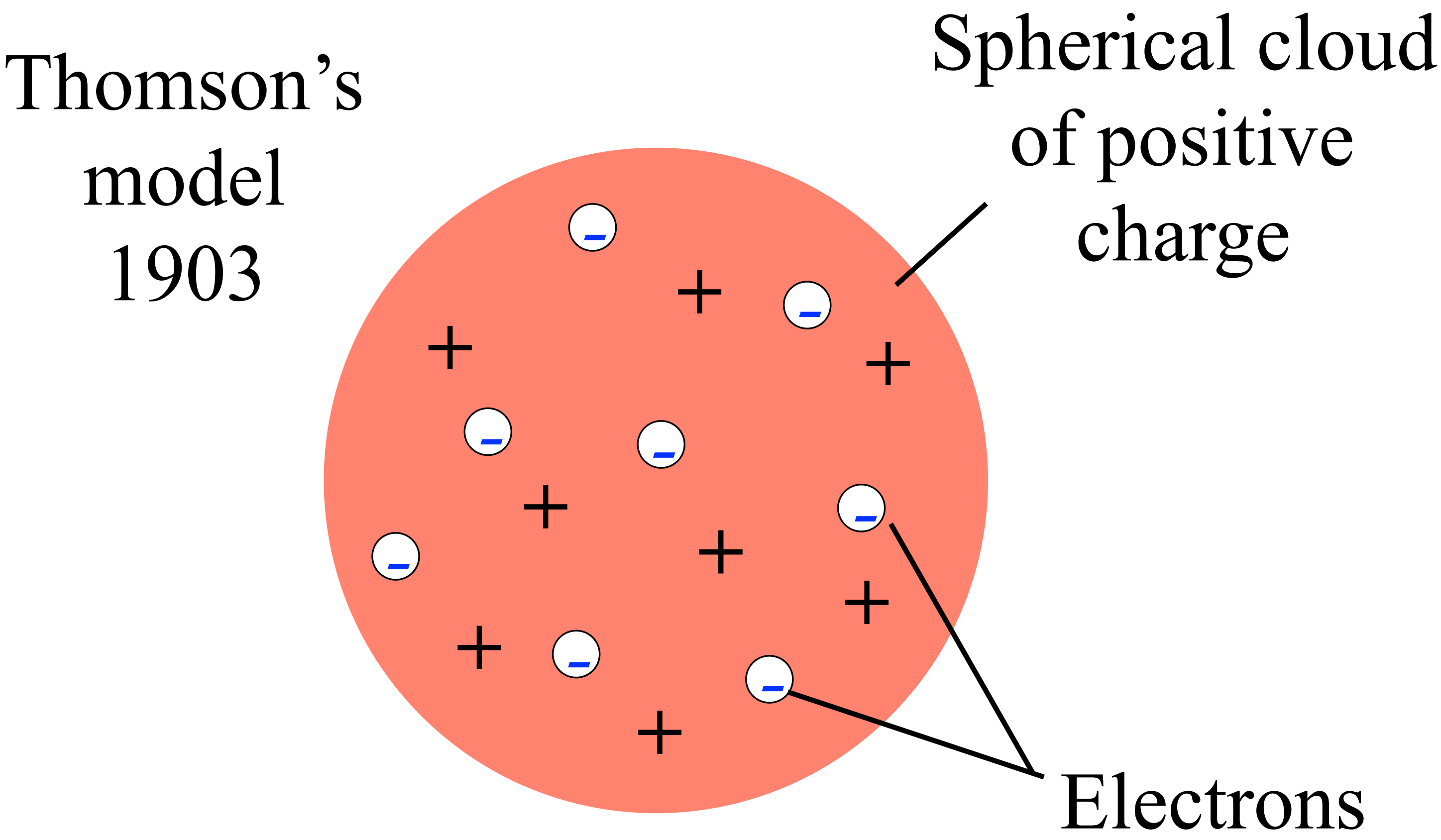
Other information

Atoms appear to be neutral.

What can we deduce from this information?

Atoms must also have an equal number of positively charged particles - **protons**.

Plum pudding model of the atom



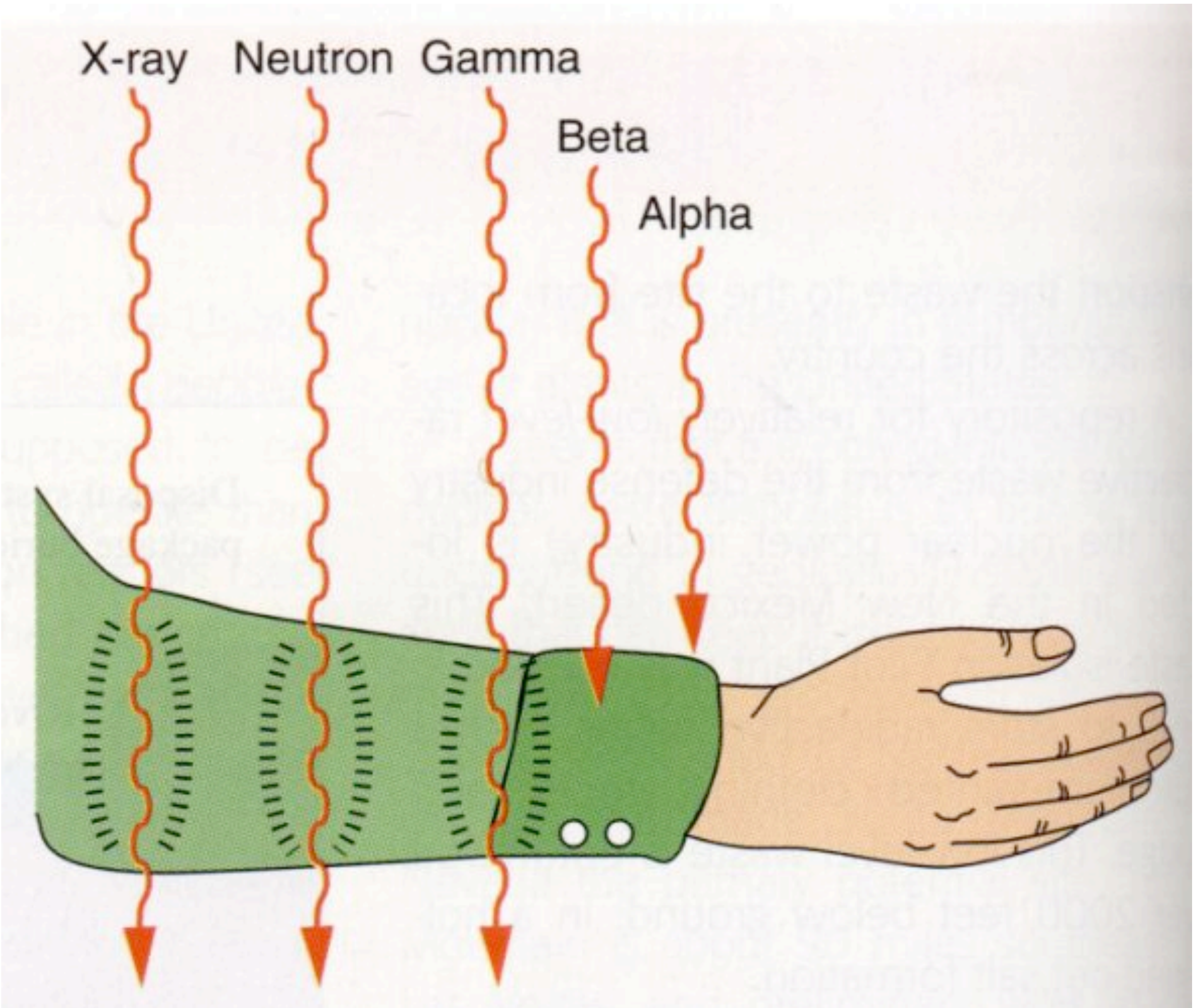
What else is going on?

Researchers were discovering/inventing all kinds of new ~~toys~~ tools.

1895 Wilhem Röntgen discovers X-rays

Henri Becquerel discovers γ-rays

Marie Curie discovers radioactivity - a source of X- and γ-rays

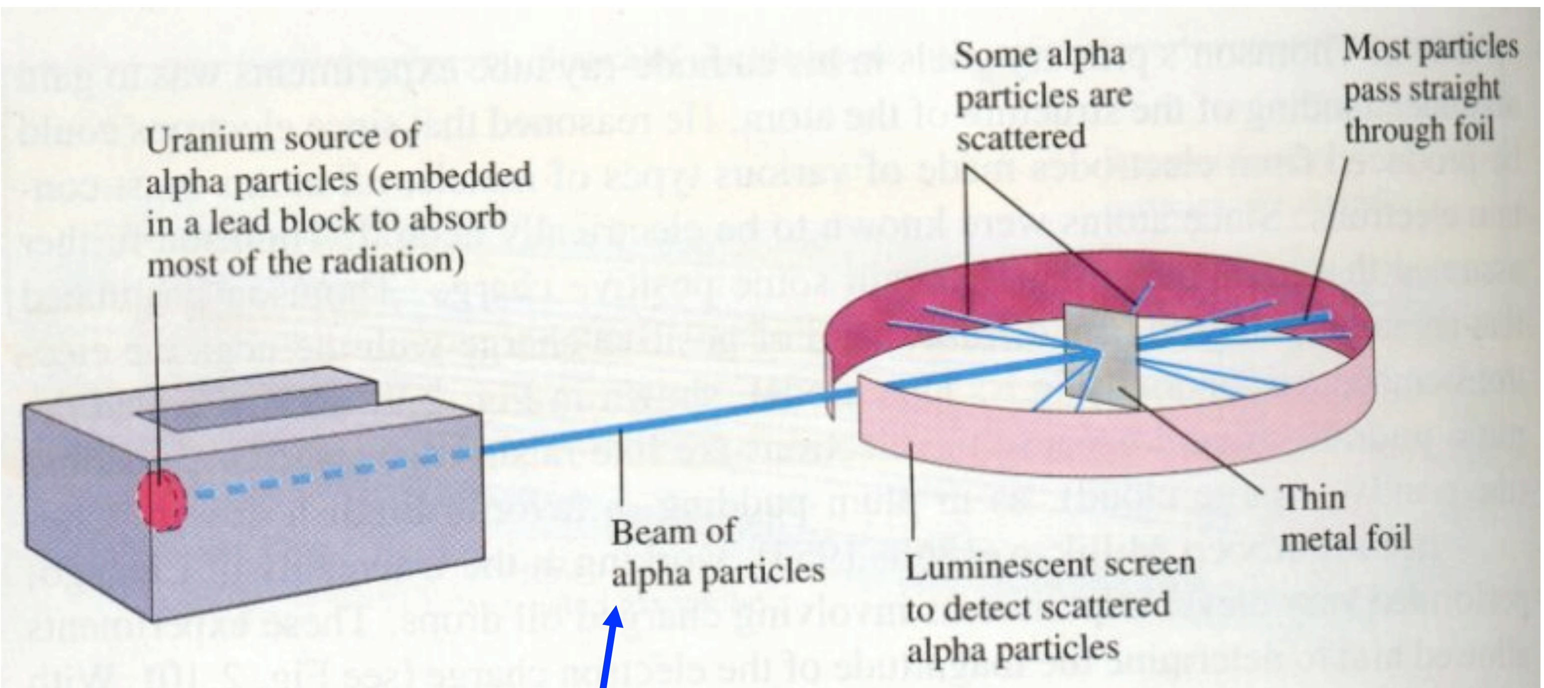

X-ray
Neutron
Gamma
Beta
Alpha


Michael
Columbia

Ernest Rutherford

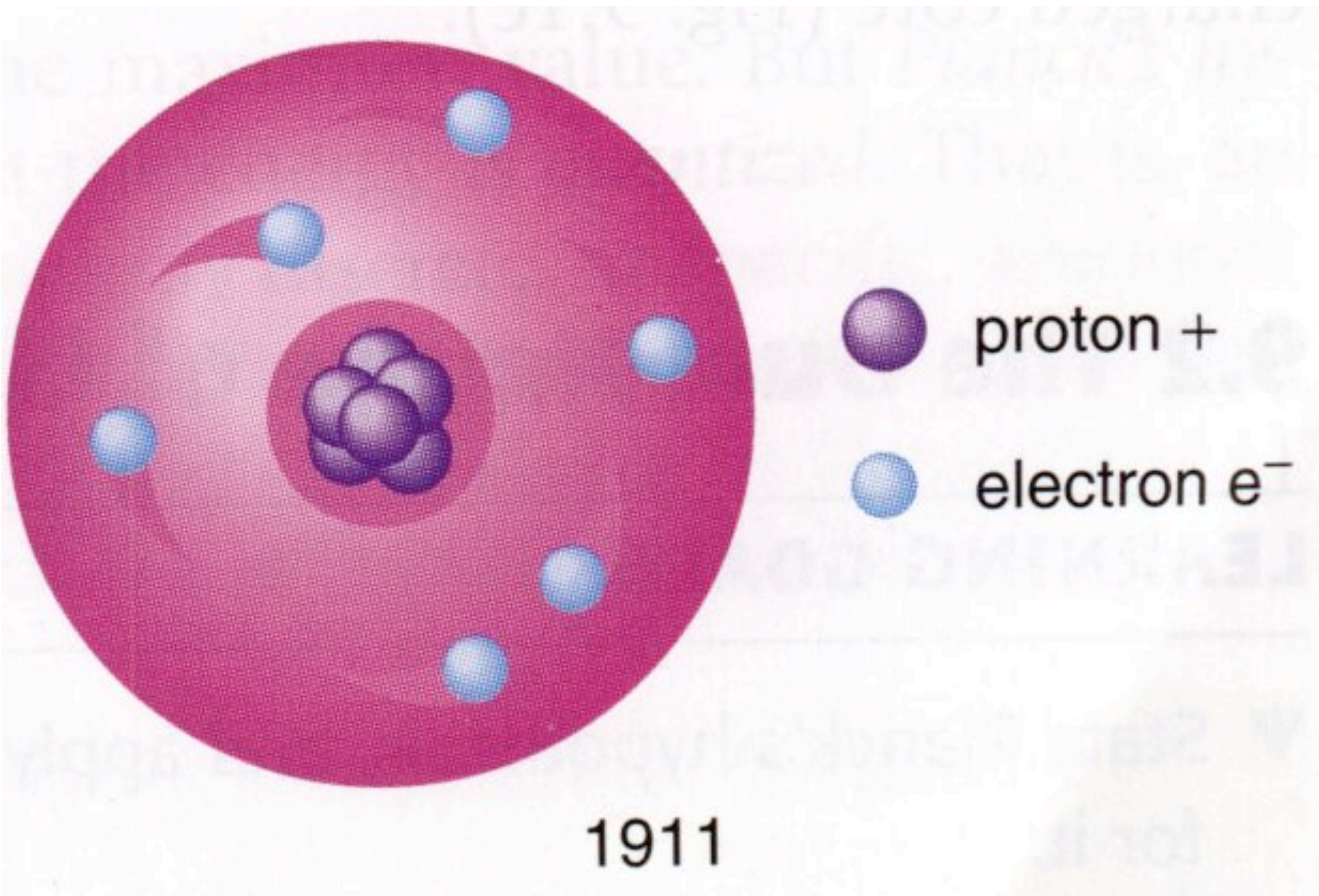
Using the new tools, Rutherford finds that the positive charge of an atom is concentrated at the center and the negative charges are spread around.

Rutherford Scattering Experiment



+ charge

Rutherford's model

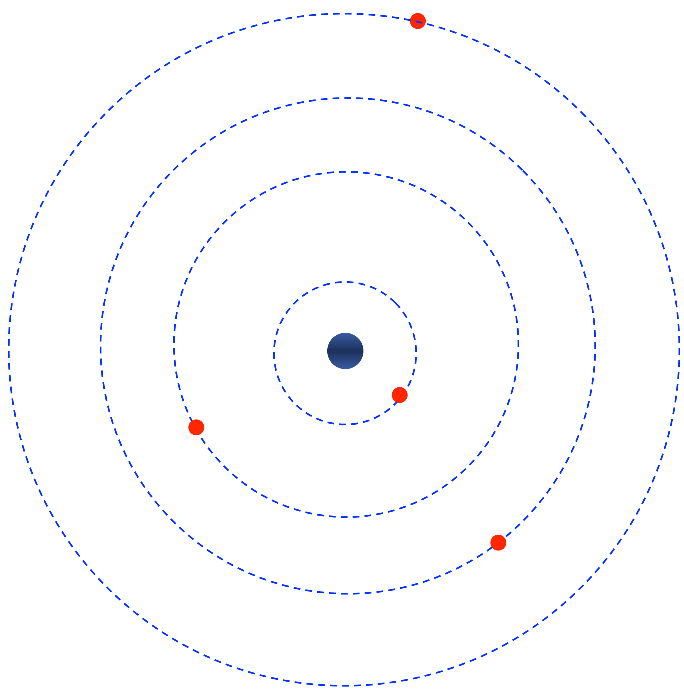


Bohr's planetary model of the atom

Evidence starts mounting that the energy structure of the atom is not like anything that can be explained by current physics.

It appears that the energy states of atoms are fixed. To explain this Niels Bohr proposes a planetary model of the atom.

Bohr's planetary model of the atom



1926 – Quantum Mechanics

Bohr's model could not explain all the observations about atoms.

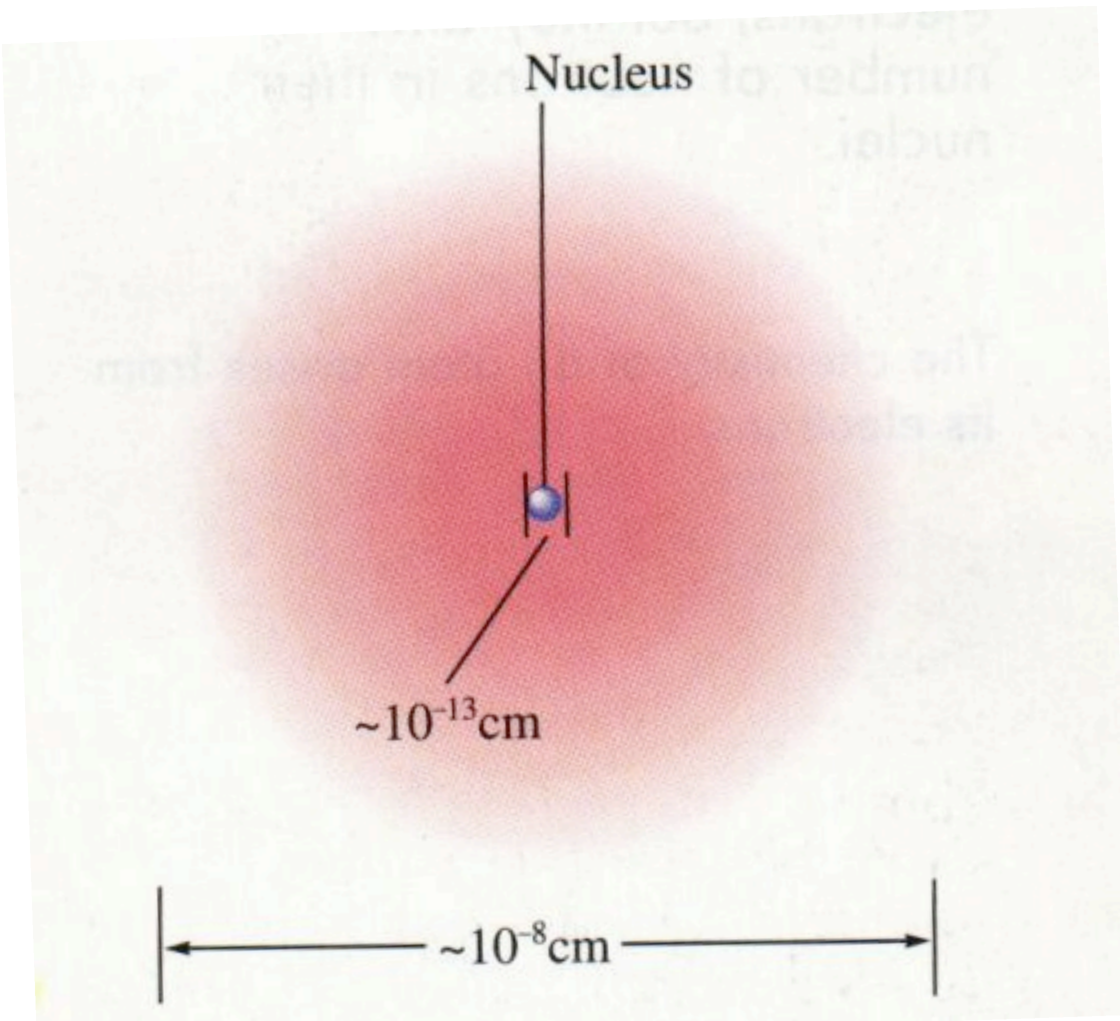
From 1923-1927 a new theory was being developed.

Matrix Mechanics – Werner Heisenberg

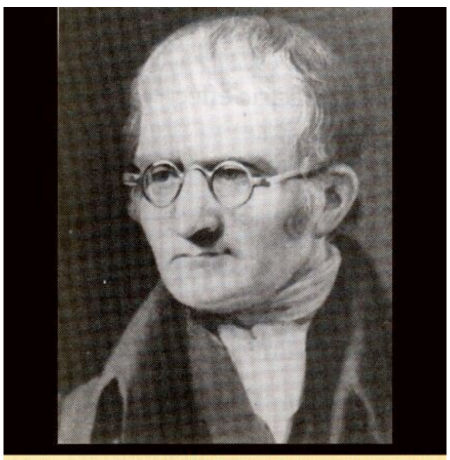
Wave Mechanics – Erwin Schrodinger

$$H\Psi = E\Psi$$

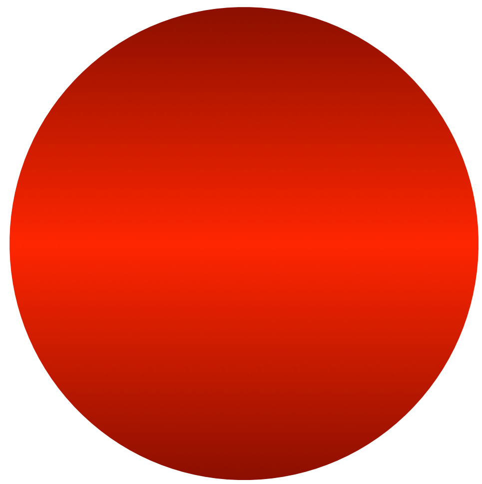
Modern view

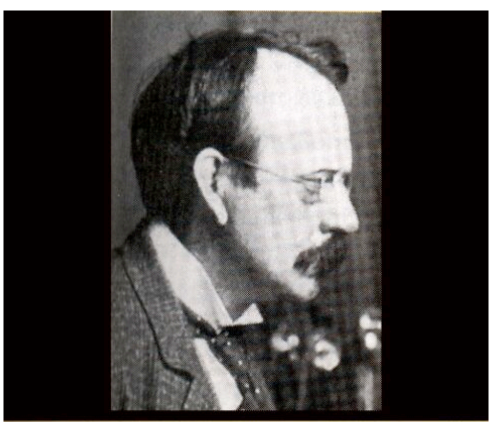


The Atom 1807-1926

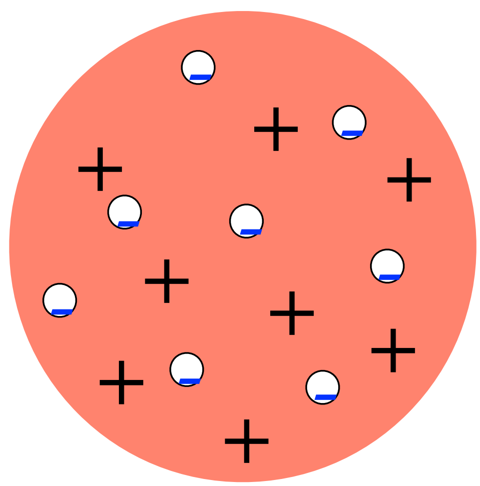


Dalton, 1807 **(billiard ball model)**

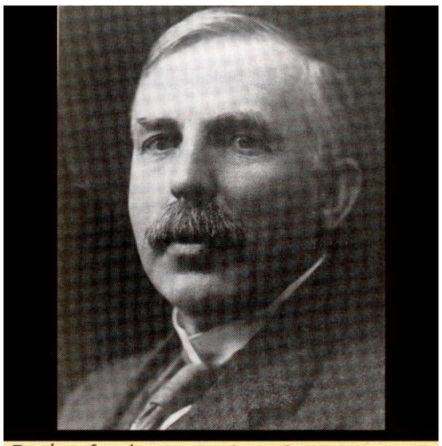




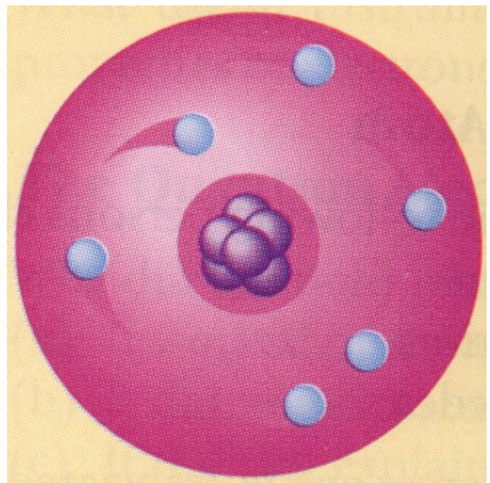
Thomson, 1903
(plum pudding model

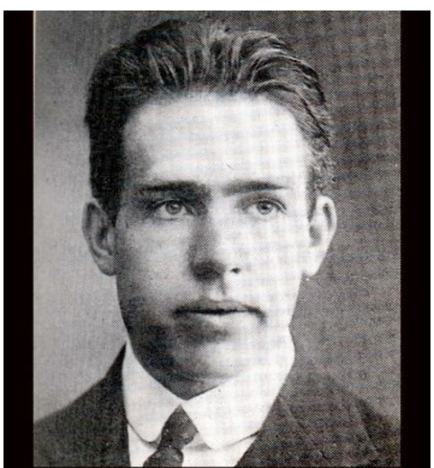


The Atom 1807-1926

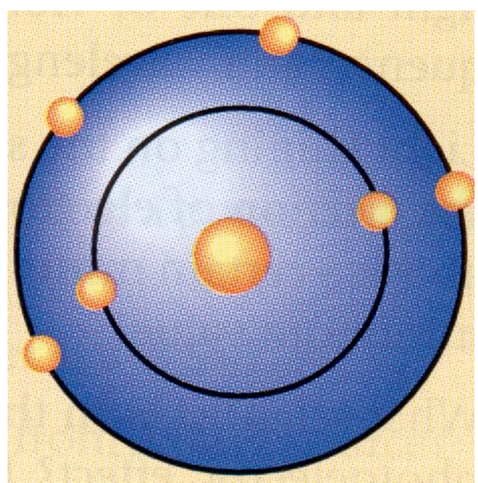


Rutherford, 1911 **(nuclear model)**

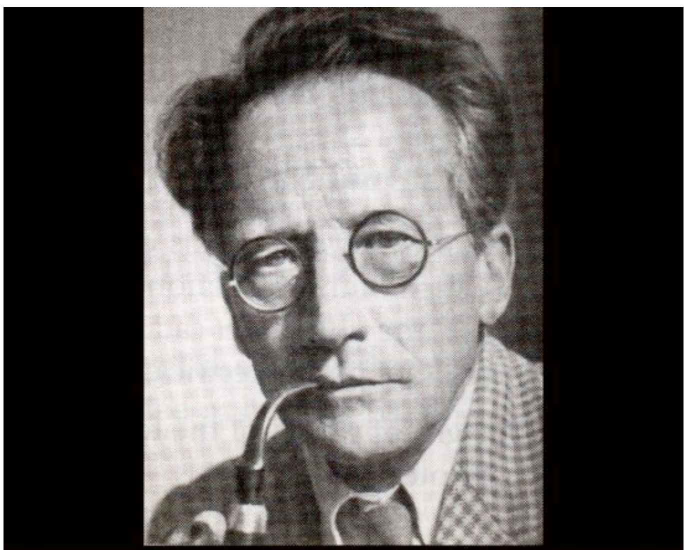




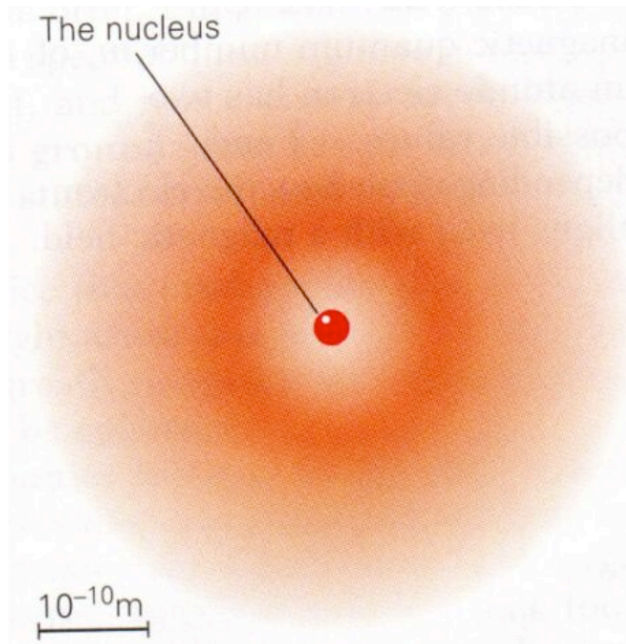
Bohr, 1913 **(planetary model)**



The Atom 1807-1926



Schrödinger, 1926 **(electron cloud model)**

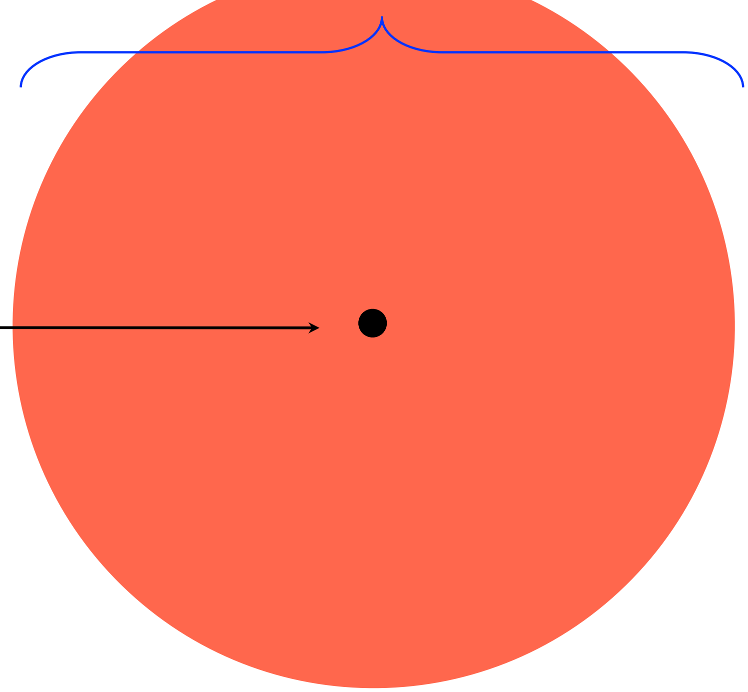


Atoms - What we know.

How small is the nucleus

City of Lowell as the electron cloud.

Just over 4 miles across.



Nucleus 1.3”

something
about the size
of a tennis ball

Everything is 99.999999% empty space.

This classroom → solid part is a sphere with ~ 0.0014 inch radius: half the thickness of a human hair.

“Nothing exists except atoms and empty space, everything else is opinion” - Democritus

Dr. Feynman, what is the most important finding of modern science?

“The world is made of atoms.”

The Building Blocks

Proton

mass=1.672 621 58(13) $\times 10^{-27}$ kg

charge of +1

Electron

mass=9.109 381 88(72)$\times 10^{-31}$ kg

charge of -1

Neutrons

mass=1.674 927 16(13) $\times 10^{-27}$ kg

charge of 0 neutral

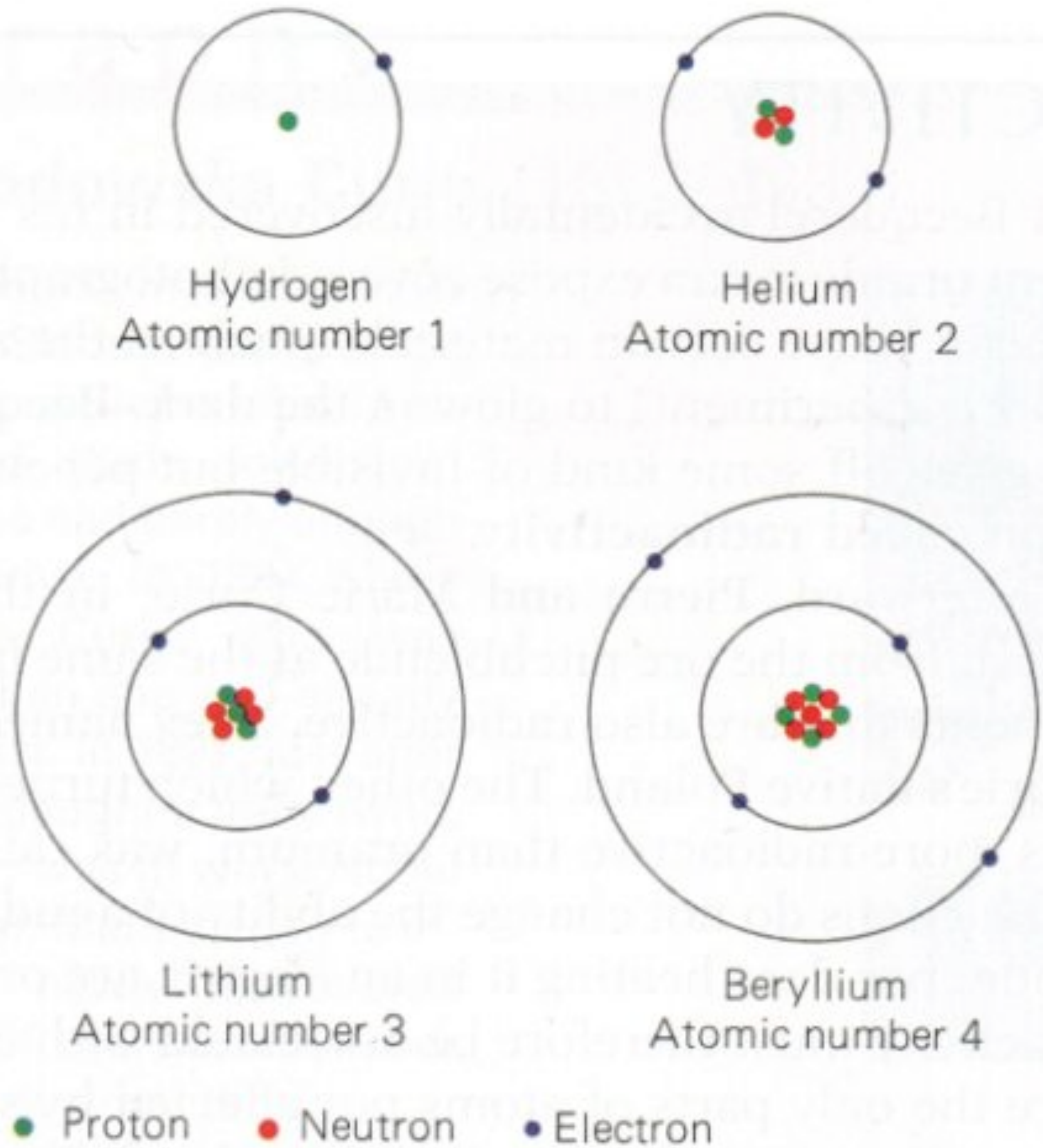
The Structure of an Atom

Usually, at the surface of the earth, the number of electrons (M) equals the number of protons (Z) , $M=Z$. The atom is neutral.

In outer space the energetic rays of stars generally ionize atoms, the number of electrons is less that the number of protons, $M<Z$

Atoms are labeled by
the number of protons

We call this the atomic number of the atom.


Hydrogen
Atomic number 1
Helium
Atomic number 2
Lithium
Atomic number 3
Beryllium
Atomic number 4
Proton
Neutron
Electron

Mass of atoms

The total mass of an atom is called the **atomic mass number**.

This number is the sum of the masses of all the atom’s components (electrons, protons, and neutrons) minus a small amount of mass that was converted to energy when the components came together to form the atom.

Mass of an atom

Proton

mass=1.672 621 58(13) x10^{-27} kg

Neutrons

mass=1.674 927 16(13) x10^{-27} kg

Electron

mass=9.109 381 88(72)x10^{-31} kg

Mostly from protons and neutrons.

Isotopes of atoms

Many atoms exist with different numbers of neutrons.

- # protons the same (so it's the same atom and same physical properties)
- # electrons the same (so it is electrically neutral and the same chemical properties)
- Chemical properties mostly due to electronic structure of the atom.

Questions about isotopes

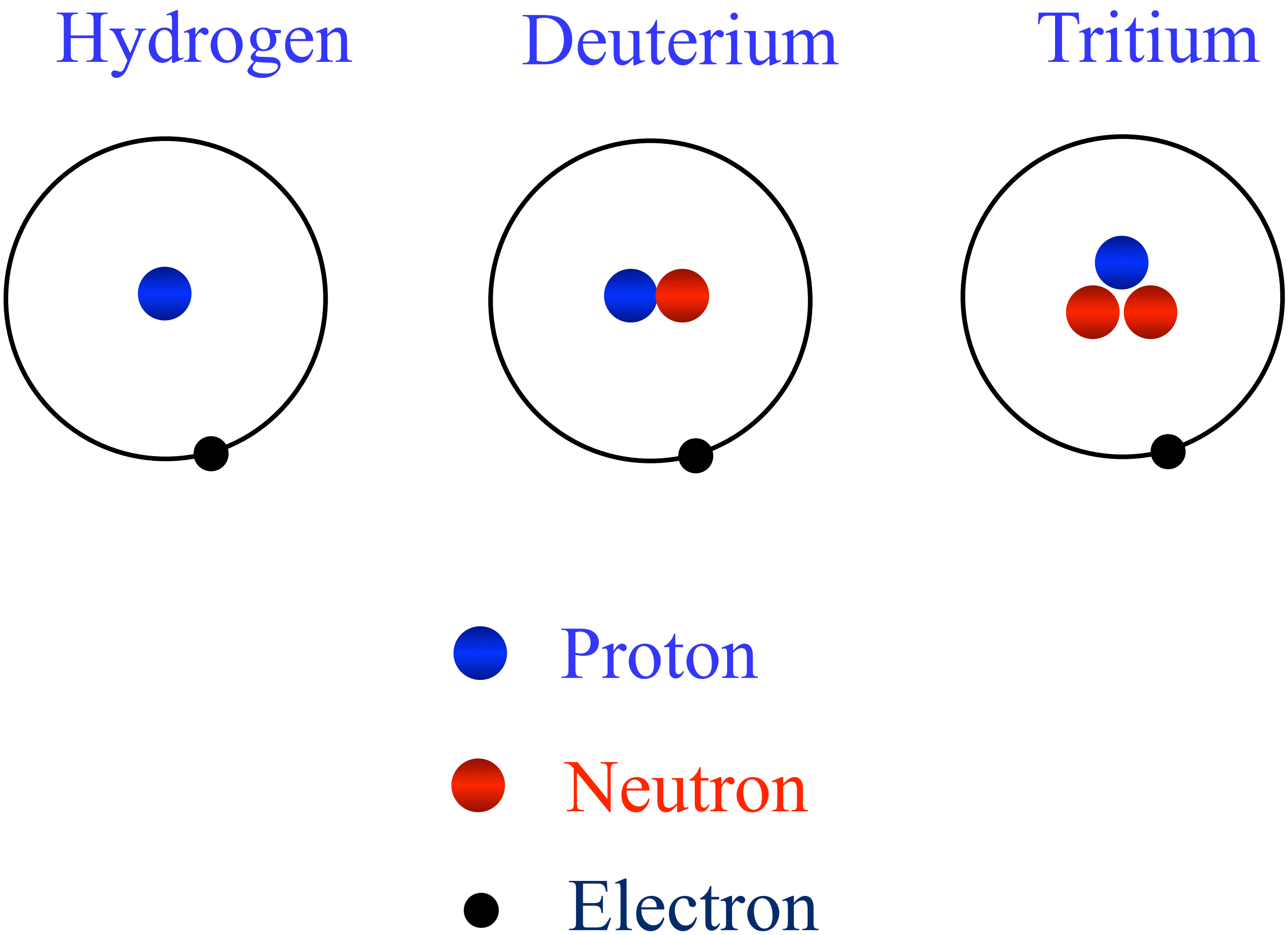
What isotopes are there?
How much of each can exist?
Do they last for ever?

Isotopes of atoms

^{1}H - Hydrogen atom with 1 proton and 1 electron - hydrogen

^{2}H - Hydrogen atom with 1 proton, 1 neutron and 1 electron - deuterium

^{3}H - Hydrogen atom with 1 proton, 2 neutrons and 1 electron – tritium 12.26 year half-life


Hydrogen
Deuterium
Tritium
Proton
Neutron
Electron

Isotopes of atoms

atom	#p	#n	#e	½ life
^{10}C	6	4	6	19.45 µs
^{11}C	6	5	6	20.3 min
^{12}C	6	6	6	stable
^{13}C	6	7	6	stable
^{14}C	6	8	6	5730 year
^{15}C	6	9	6	2.4 s
^{16}C	6	10	6	0.74 s

Isotopes of atoms

atom	#p	#n	#e	½ life
^{13}O	8	5	8	0.0087 s
^{14}O	8	6	8	71.0 s
^{15}O	8	7	8	124 s
^{16}O	8	8	8	stable
^{17}O	8	9	8	stable
^{18}O	8	10	8	stable
^{19}O	8	11	8	29 s
^{20}O	8	12	8	14 s

Questions about isotopes

What isotopes are there?
How much of each can exist?
Do they last for ever?

How much of each can exist?

It will depend on where in the universe you are looking.

Gives clues to evolution of atoms and the chemistry going on.

Isotope ratio can be used to study the evolution of atmospheres.

Here we consider the surface of the Earth.

Abundance of Isotopes

Relative natural abundance – the percentage that the particular isotope occurs in a natural sample.

^{1}H -- 99.985

^{2}H -- 0.015

Note only the stable isotopes are listed.

Abundance of Isotopes

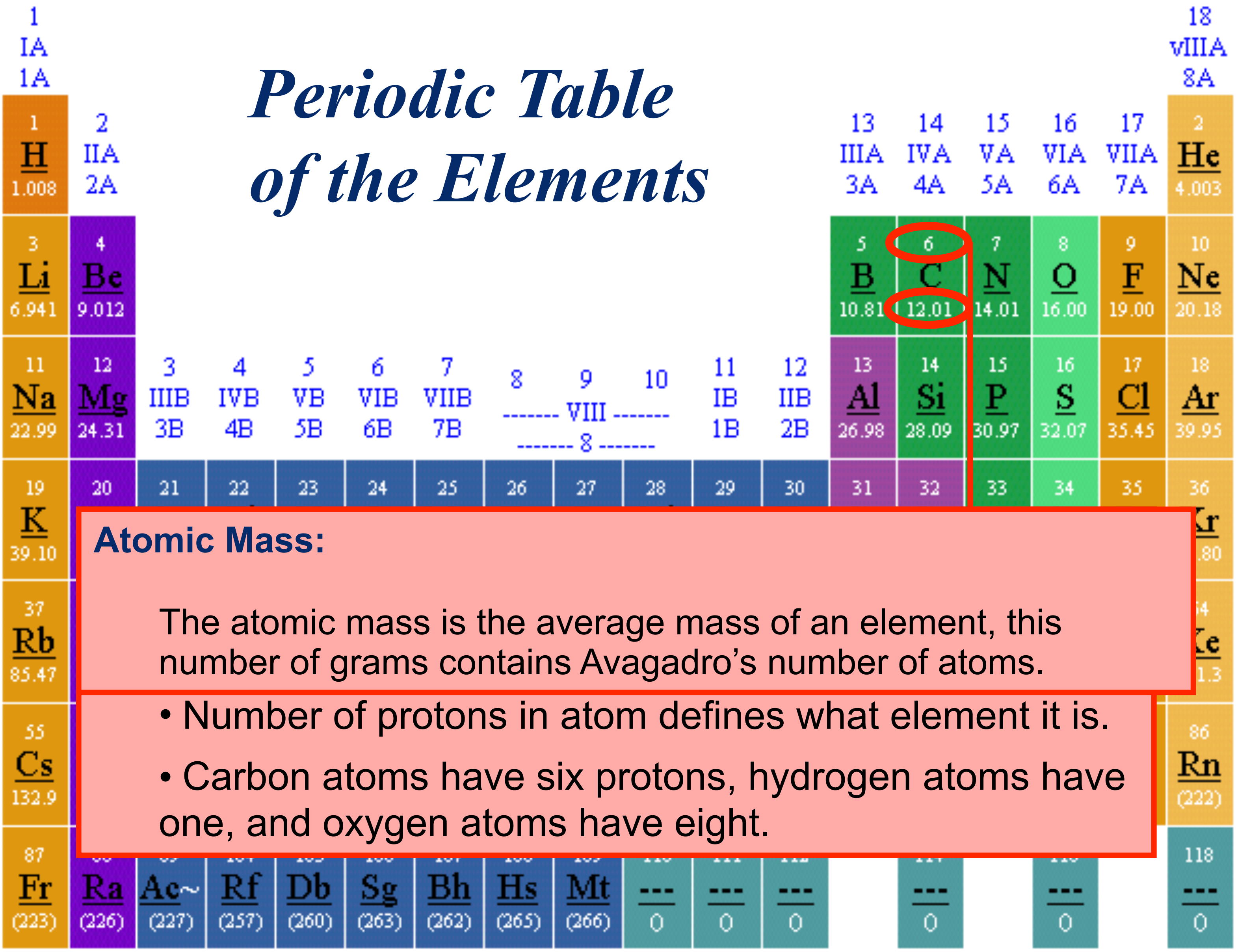
^{12}C -- 98.889 %

^{13}C -- 1.111 %

^{16}O -- 98. 7628 %

^{17}O -- 0.0372 %

^{18}O -- 0.200045 %



Atomic Mass:

The atomic mass is the average mass of an element, this number of grams contains Avagadro's number of atoms.

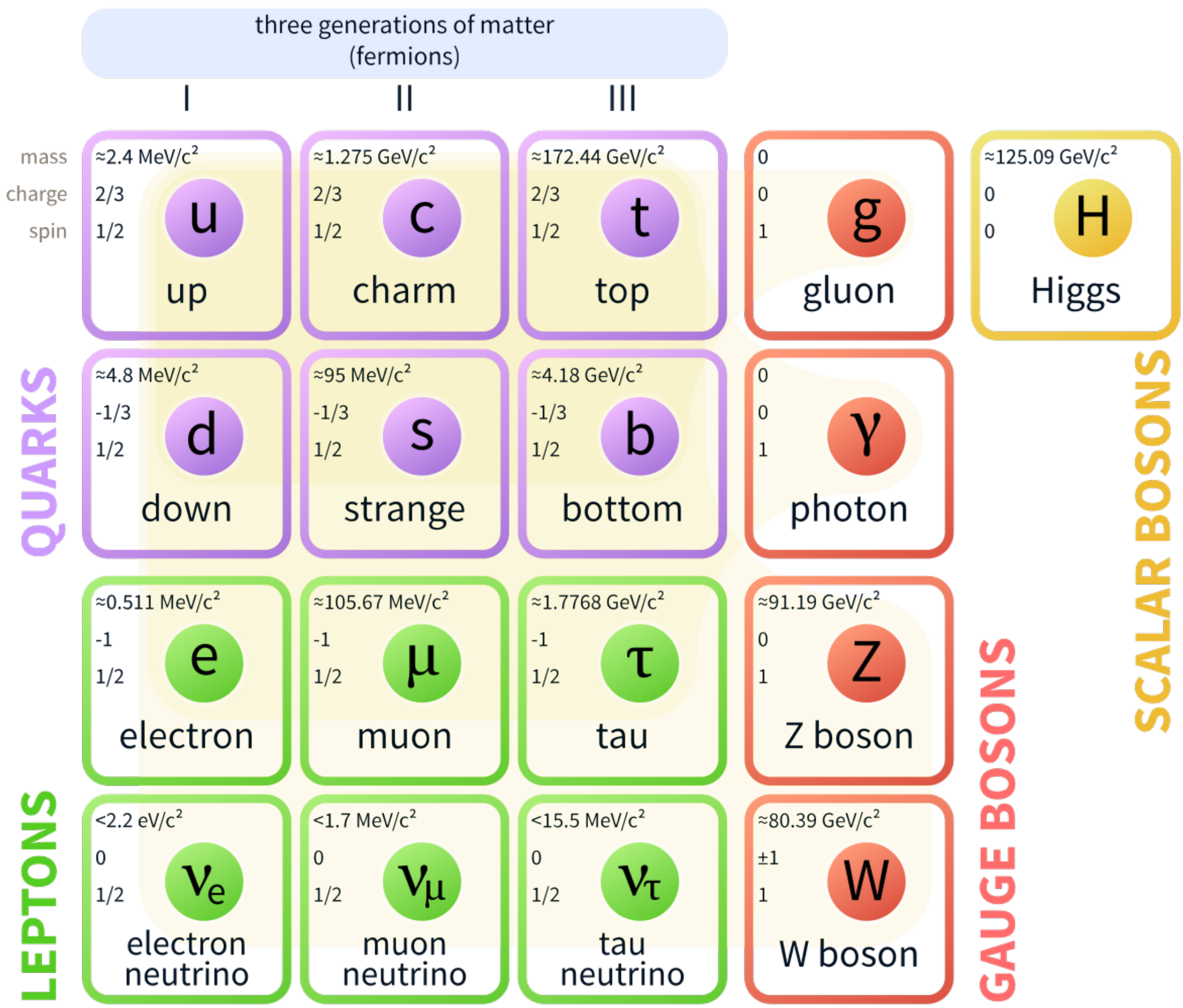
- Number of protons in atom defines what element it is.
- Carbon atoms have six protons, hydrogen atoms have one, and oxygen atoms have eight.

Atomic theory and chemistry

$$CH_4 + 2\ O_2 \rightarrow 2\ H_2O + CO_2$$

Conservation of mass
Law of definite proportions

Standard Model of Elementary Particles



Origin of mass

Ordinary matter is made from atoms. The mass of atoms is overwhelmingly concentrated in their nuclei. Electrons provide less than a part in two thousand of the mass!
Nuclei are assembled from protons and neutrons.

Protons and neutrons are made from quarks and gluons.

So most of the mass of matter can be traced, ultimately, back to quarks and gluons.

Frank Wilczek, MIT

Origin of mass

When a collision between a high-energy electron and a high-energy positron occurs, we often observe that many particles emerge from the event.

The total mass of these particles can be thousands of times the mass of the original electron and positron. Thus mass has been created, physically, from energy.

Frank Wilczek, MIT

Quantum Chromodynamics

Quantum Chromodynamics (QCD) is the modern theory of the strong interaction — understanding what protons and neutrons are and how they interact.

Frank Wilczek, MIT

Origin of mass

QCD Lite is cooked up from massless gluons, massless u and d quarks, and nothing else. If we use this idealization as the basis for our calculation to calculate how the particles come together to make a proton, they get the proton mass low by about 10%.

So we find that 90% of the proton (and neutron) mass, and therefore 90% of the mass of ordinary matter, emerges from an idealized theory whose ingredients are entirely massless.

Frank Wilczek, MIT

Origin of mass

Full-Bodied QCD differs from QCD Lite in two ways. First, it contains four additional flavors of quarks. These are not in the proton, but they do have some effect as virtual particles. Second, it allows for non-zero masses of the u and d quarks. The realistic value of these masses is small (a few percent of the proton mass). Each of these corrections changes the predicted mass of the proton by about 5%, as we pass from QCD Lite to Full-Bodied QCD, yielding the correct mass of protons and neutrons.

Origin of mass
The Higgs boson

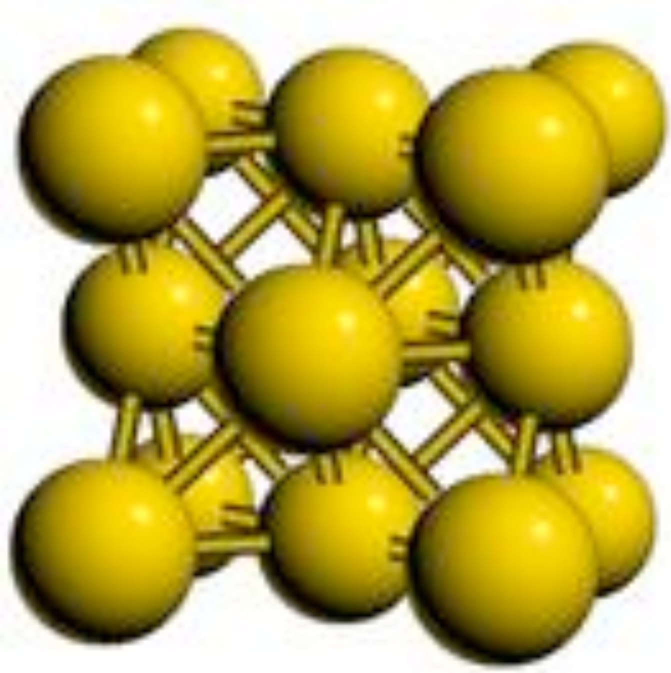
While the mass of the nucleons (and, by extension, most of the visible universe) is caused by the energy stored up in the force field of the strong nuclear force, the mass of the quarks themselves comes from a different source. It is thought the mass of the quarks and the leptons is caused by the Higgs boson.
"thought to be caused" merely means that this is the most popular theoretical proposal.
In fact, we don't really know why the quarks and leptons have the masses that they do.

Origin of mass
String theory

String theory started out as a theory to explain particles, such as hadrons, as the different higher vibrational modes of a string. In most current formulations of string theory, the matter observed in our universe comes from the lowest-energy vibrations of strings and branes.

The mass of these fundamental particles comes from the ways that these string and branes are wrapped in the extra dimensions that are compactified within the theory, in ways that are rather messy and detailed.

Solids



Atoms are tightly packed in a structure of a particular symmetry. In general higher density than liquids or gases.

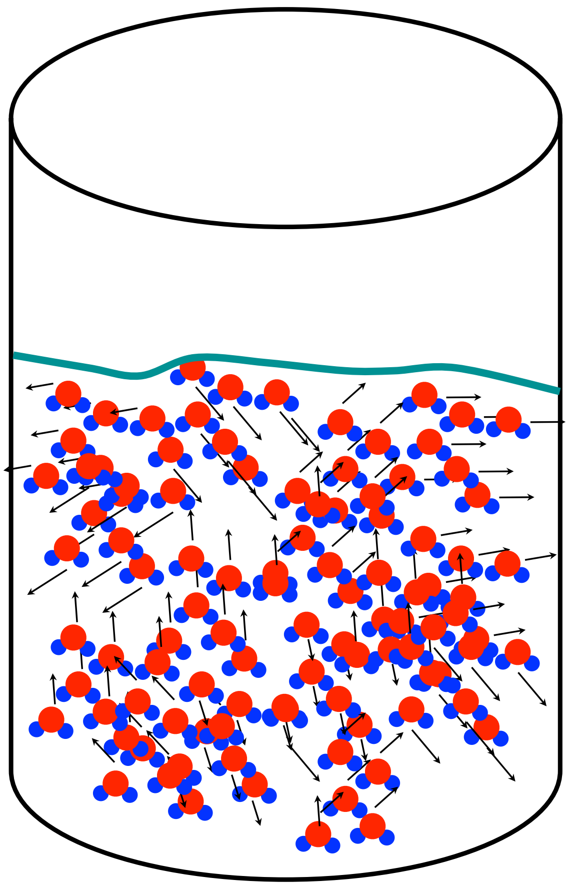
SOLID

A state of matter in which the matter is not compressible nor does it flow.

Not compressible

Does not flow

Liquids



Molecules are less tightly packed than in a solid, overall movement of the molecules. In general higher density than gases.

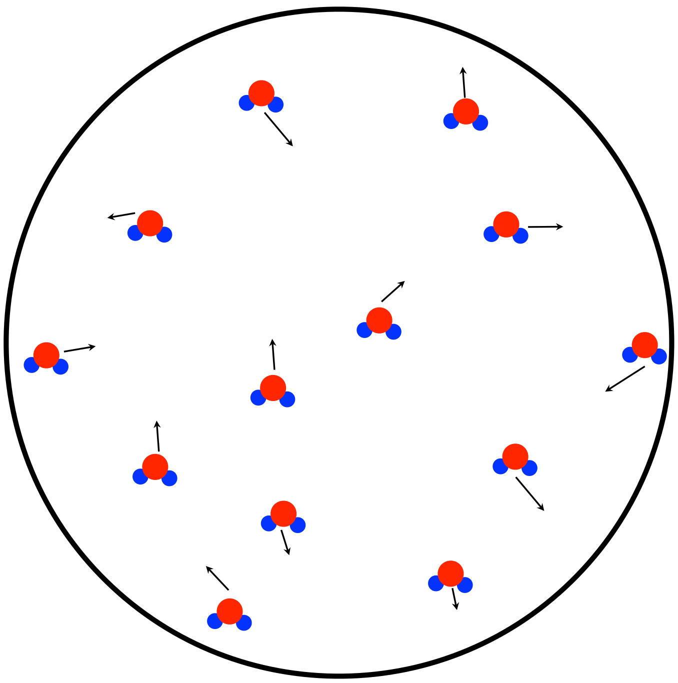
LIQUID

A state of matter in which the matter is not compressible but can flow.

Not compressible

Can flow

Gases



Molecules are moving swiftly, separated by large average distances. Mostly free space.

GAS

A state of matter in which the matter is compressible and can flow.

Compressible
Can flow

Glasses

These are in between solids and liquids.

Closer to solids but they do “flow” over long periods of time.

Not compressible

Flow over decades

What determines the phase of a material?

First we should ask what keeps the material held together?

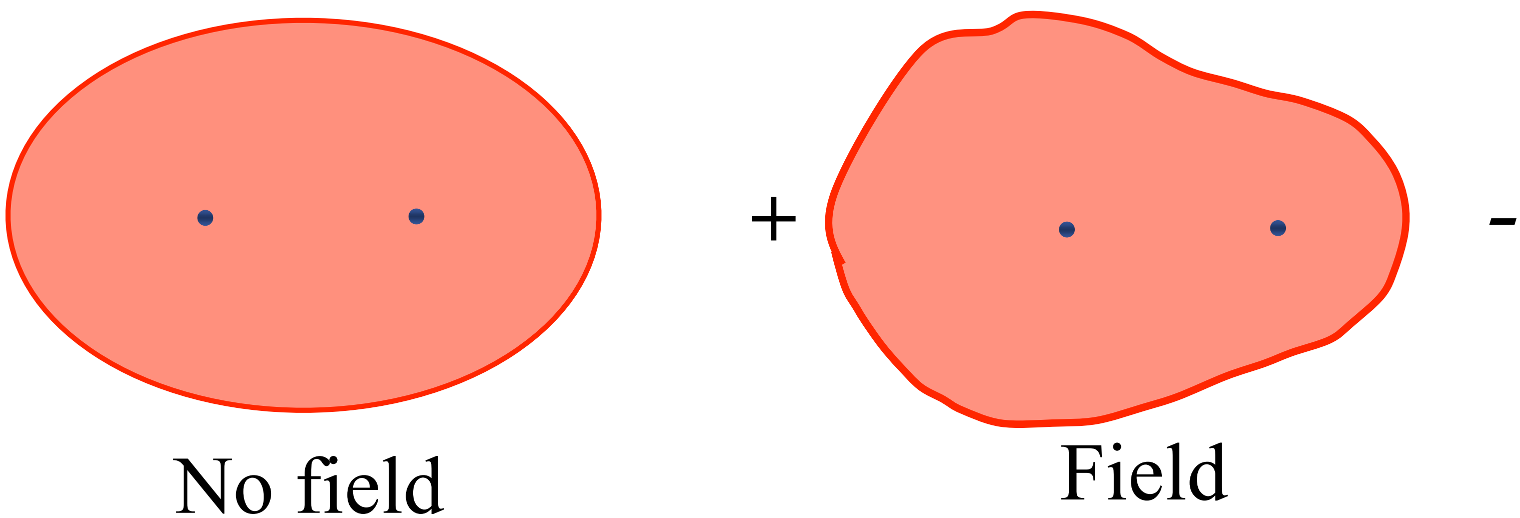
It is ***intermolecular forces*** between the molecules that keep the material together. These are forces of attraction (and repulsion) between molecules.

Forces and symmetry of the molecule

The forces are based on electrostatic interaction.

Since molecules at the surface of earth are generally neutral, there must be a way to get an overall imbalance in charge.

Electron cloud model of the molecule



Polarizability - the ease with which the charge distribution in a molecule can be distorted by an external field.

Some examples of intermolecular forces

London forces

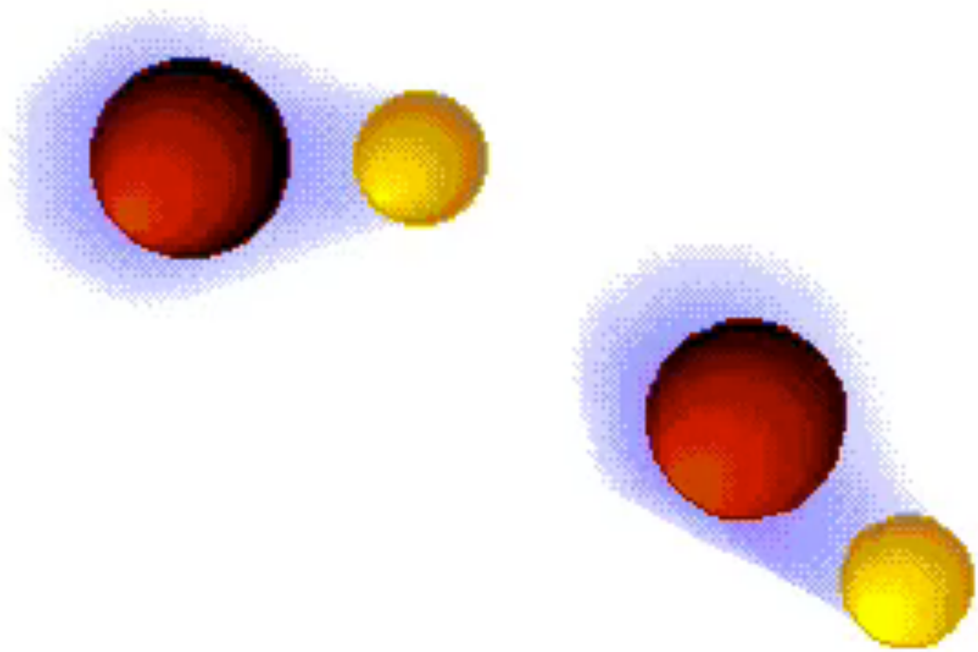
Dipole-dipole forces

Hydrogen-bonding

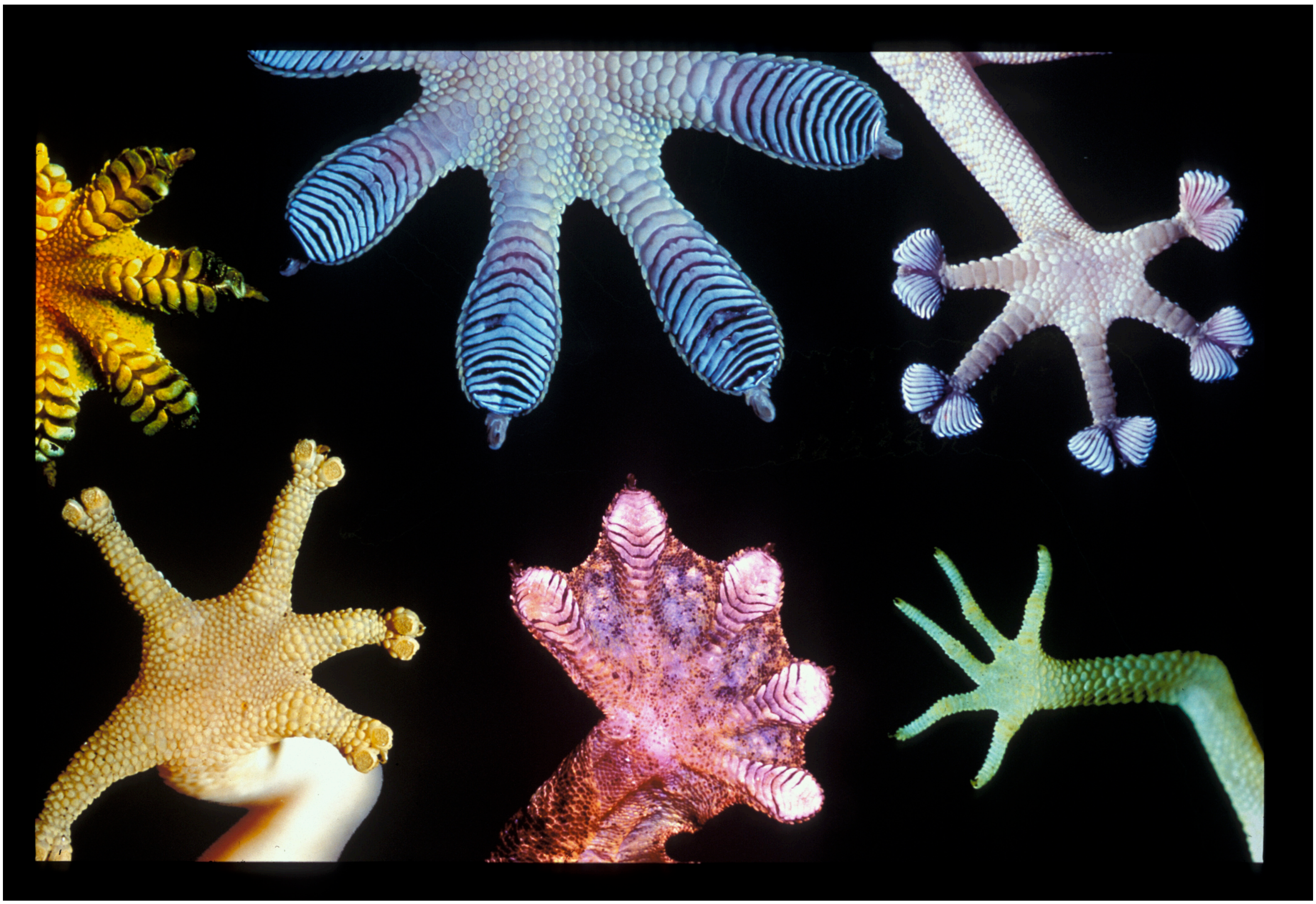
Hydrogen bonding

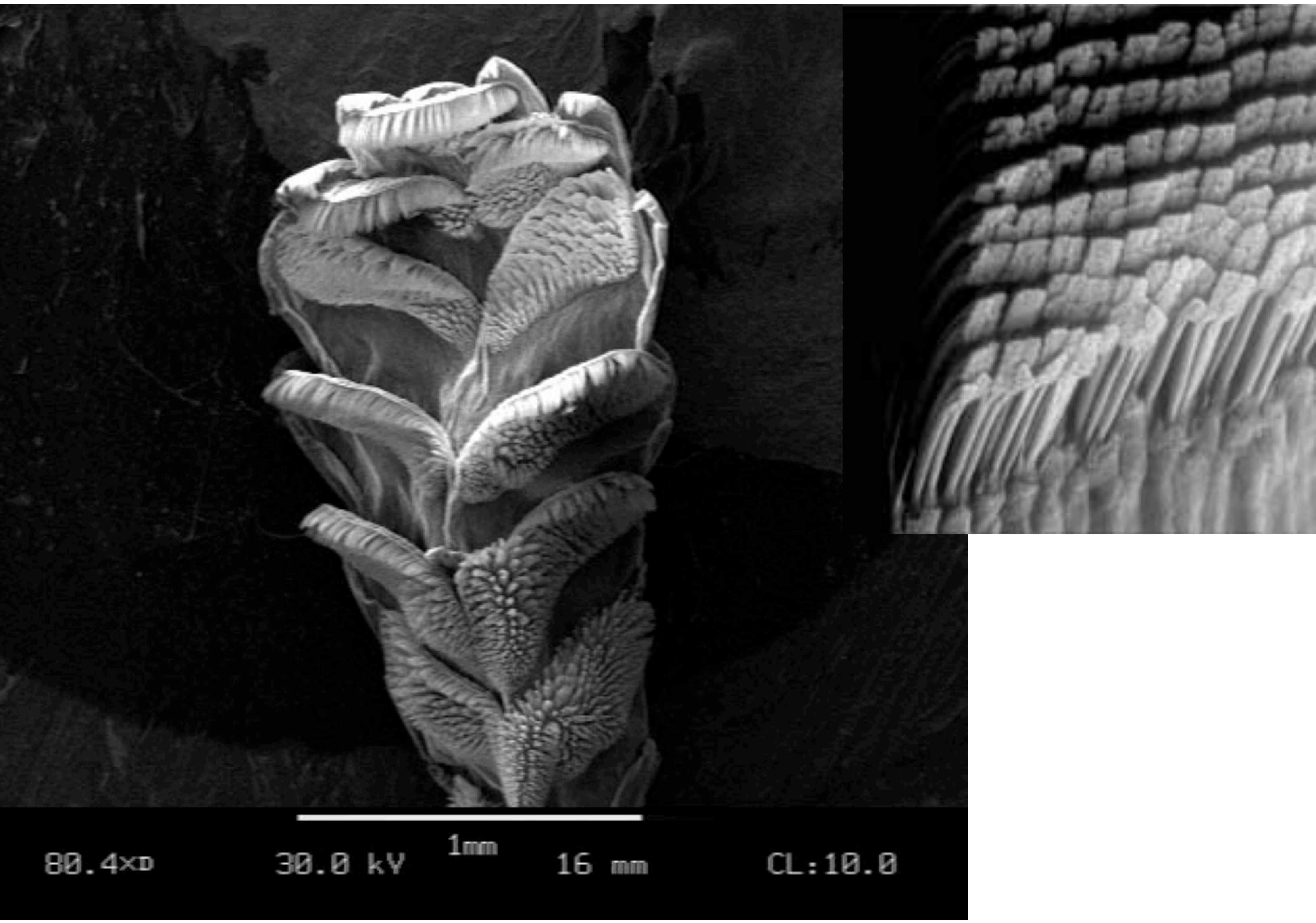
Hydrogen bonding - these occur between polar covalent molecules that possess a hydrogen bonded to an extremely electronegative element, specifically - N, O, and F.

About one tenth the strength of a covalent bond.



http://cost.georgiasouthern.edu/chemistry/general/molecule/forces.htm




1mm
80.4×D
30.0 kV
16 mm
CL:10.0

SPIDERS ARE FOUND TO USE GECKOS' MECHANISM FOR HANGING AROUND

from The Los Angeles Times 27 April, 2004

Spiders, it turns out, are very much like geckos — at least in the way in which they cling to walls and ceilings. In both cases, the creature's extraordinary gripping ability has been found to be produced by Van der Waals' forces generated by literally thousands of microscopic hairs on each of their feet. The discovery provides a remarkable example of evolution providing identical answers to the same problem in widely divergent species. Researchers pondered for years how the gecko, which is substantially heavier than a spider, was able to scamper across ceilings so easily. In 2000, biologist Robert J. Full of UC Berkeley showed that the clinging ability was produced by minute hairs, or setae, on the animal's feet. Each gecko toe contains more than 100,000 tiny hairs, and each of those hairs is split at the end into hundreds of even tinier tips. http://snipurl.com/5zjo

The Quantum World

In the latter half of the nineteenth century, physicists were busy putting the finishing touches on the theory of gravity (Mechanics), thermodynamics, and the wave theory of light.

The late 1800s

The Industrial Revolution had occurred ~ 100 years before

Power, new devices, instrumentation,…

Old measurements were repeated with much higher accuracy

New measurements were being done

New measurements tested old theories

Problems in the new measurements

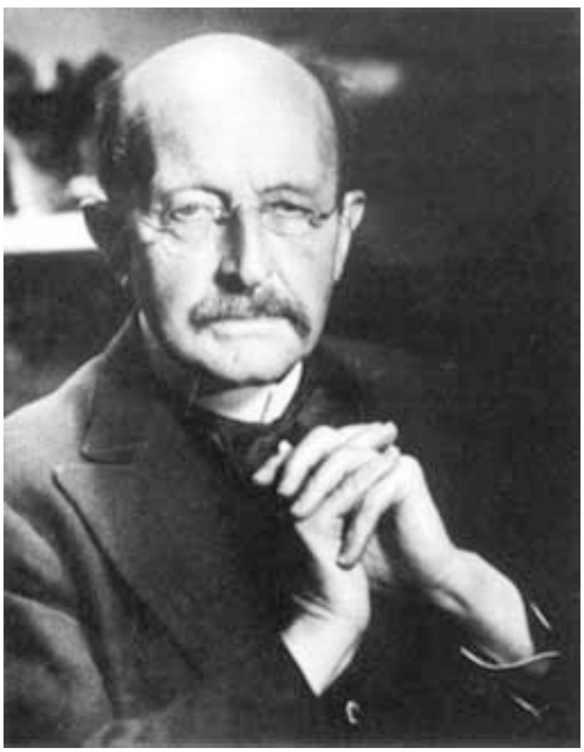
Physics of the time could not explain all of the observations.

Blackbody radiation

Photoelectric effect

Structure of atoms and molecules

Max Planck – 1858-1947



From an academic family

University of Munich in 1880

1885 appointed to a chair in Kiel

chair of theoretical physics at the University of Berlin in 1889

Planck's formula

In 1900 Planck derived a formula that matched the measured curve exactly.

His derivation was based on the blackbody having energy states that are *quantized*.

$$E = n h \nu$$

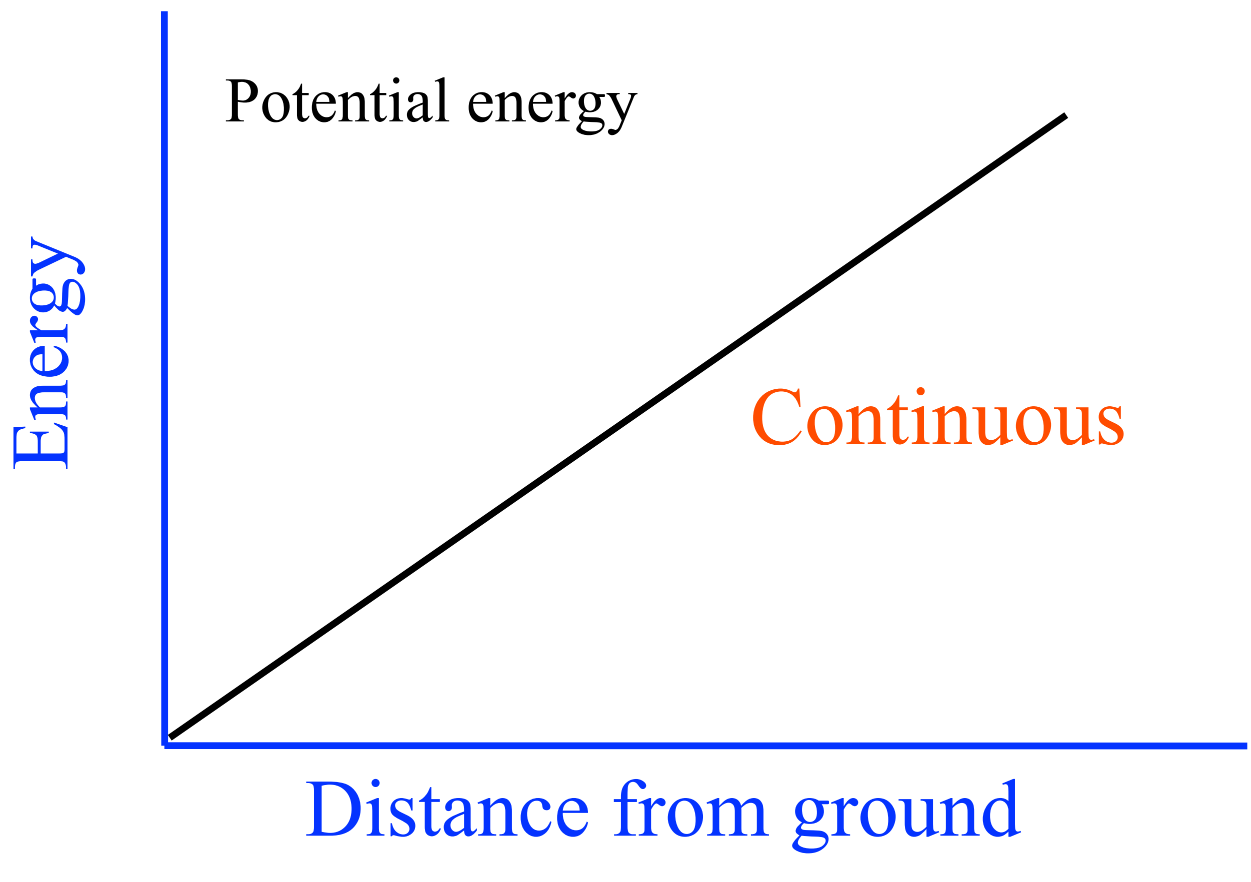
$$n = 1, 2, 3, \ldots$$

So what is the problem?

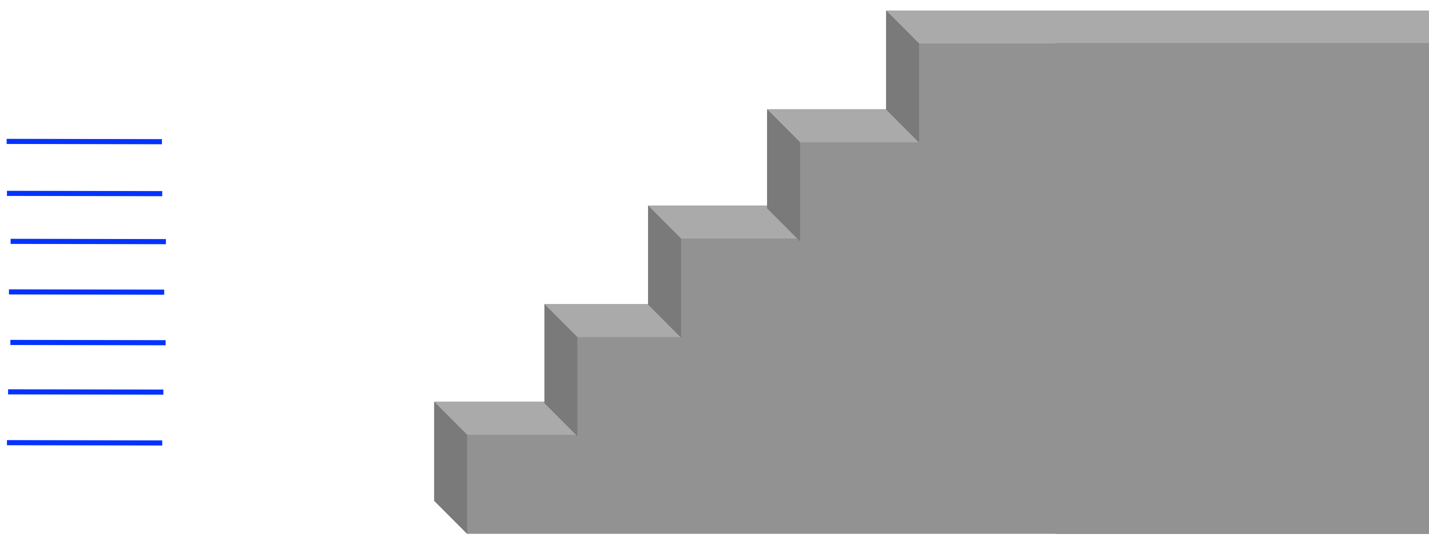
Up until that time, energy in physics (now called classical physics) was not quantized but continuous.

This was a revolutionary change.

Energy in classical physics



Planck's proposed energy



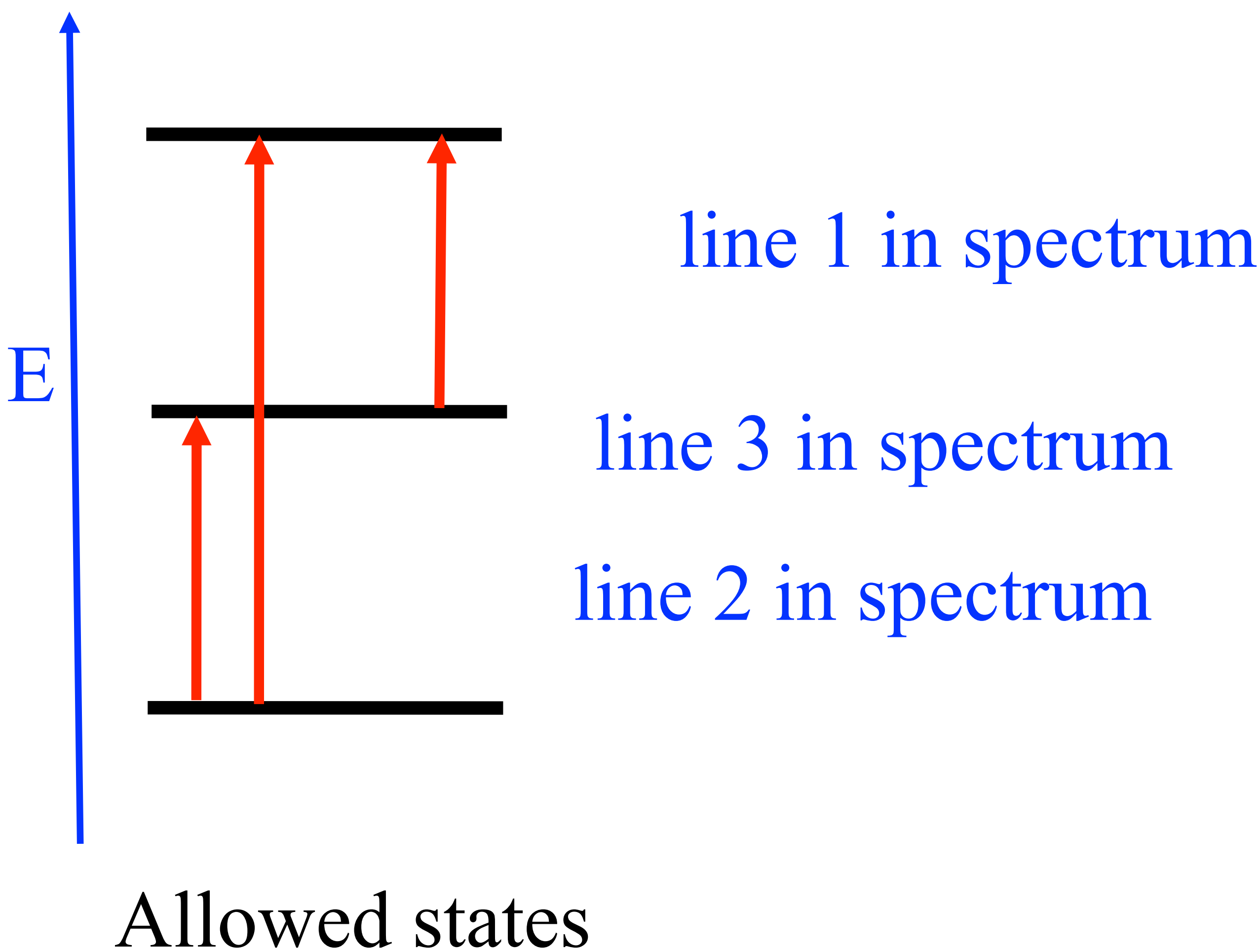
quantized

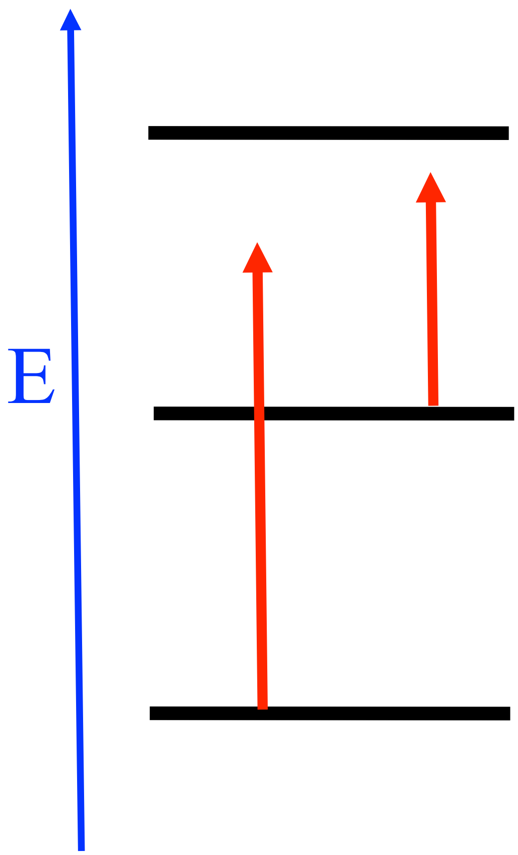
Spectra of atoms and molecules

Atoms and molecules interact with electromagnetic radiation.

Energy of the radiation at certain frequencies can be absorbed when it hits the atom or molecule

Energy is conserved so it has to go somewhere


E
line 1 in spectrum
line 3 in spectrum
line 2 in spectrum
Allowed states



Allowed states

line 1 not observed

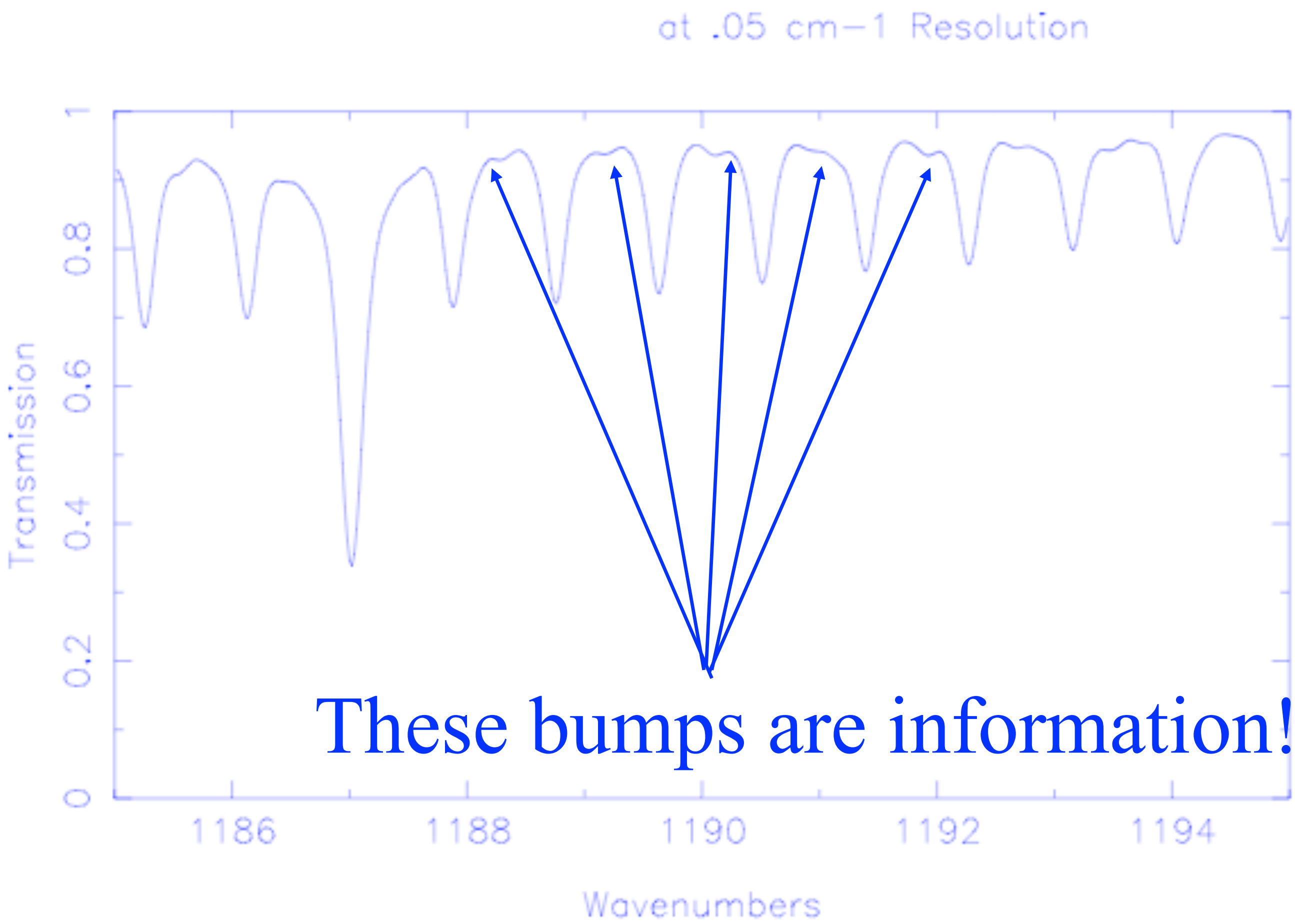
hν of the photon must be very close to the energy of separation of the levels for a transition to occur.

Visible region – electronic spectra

Infrared – molecular vibration and rotation

Microwave – molecular rotation

What do we see?



at .05 cm−1 Resolution
Transmission
0
0.2
0.4
0.6
0.8
1
1186
1188
1190
1192
1194
Wavenumbers
These bumps are information!

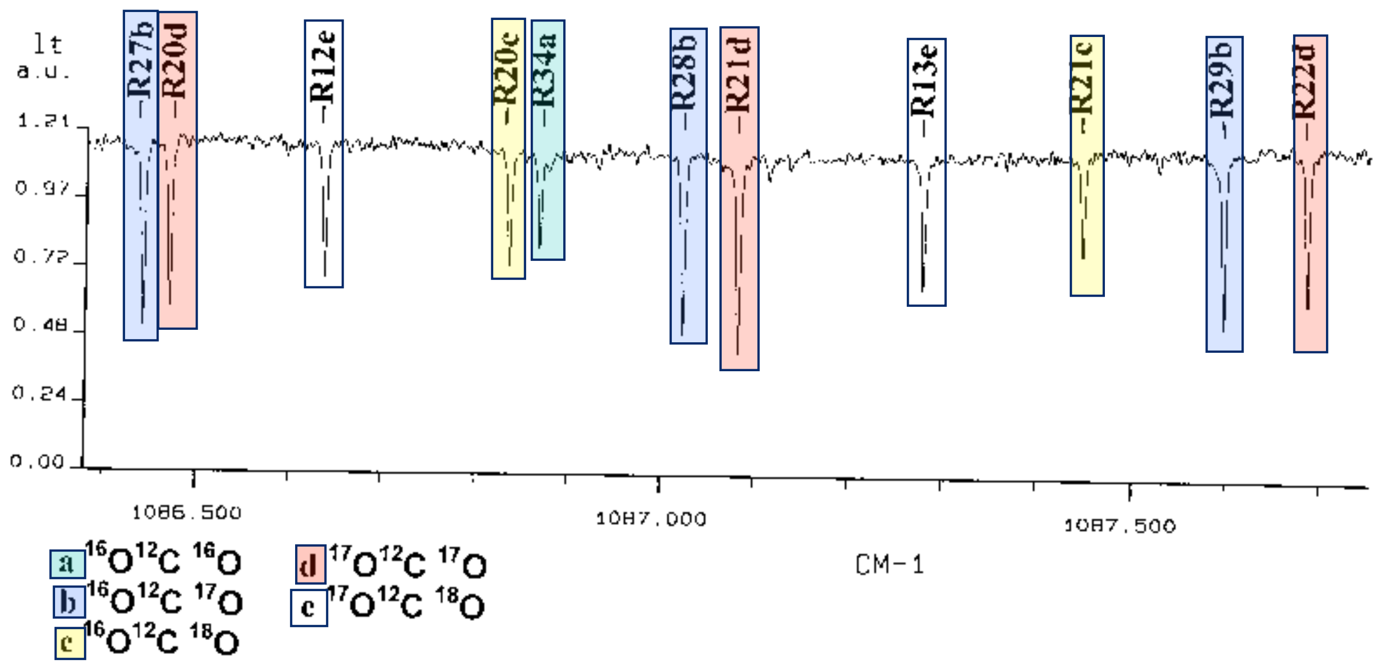
Spectra - “fingerprint” of a molecule

How good is it?

Carbon Dioxide

Isotopically enriched sample ^{17}O

$^{16}O^{12}C^{16}O$	m = 44 g/mol
$^{16}O^{12}C^{17}O$	m = 45 g/mol
$^{16}O^{12}C^{18}O$	m = 46 g/mol
$^{17}O^{12}C^{17}O$	m = 46 g/mol
$^{17}O^{12}C^{18}O$	m = 47 g/mol

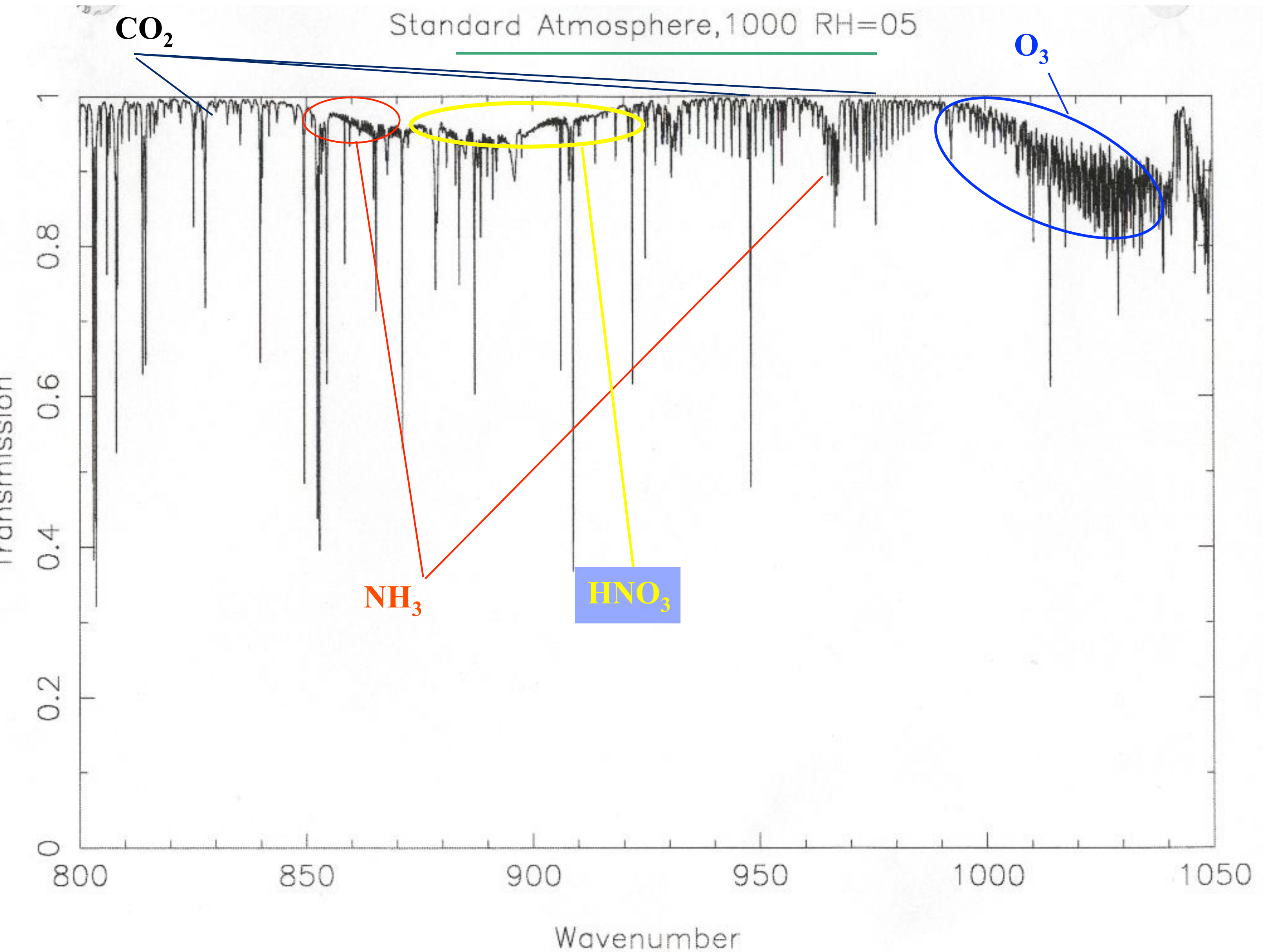


It
a.u.
1.21
0.97
0.72
0.48
0.24
0.00
R27b
R20d
R12e
R20c
R34a
R28b
R21d
R13e
R21c
R29b
R22d
1086.500
1087.000
1087.500
CM-1
a 16O12C 16O
b 16O12C 17O
c 16O12C 18O
d 17O12C 17O
e 17O12C 18O

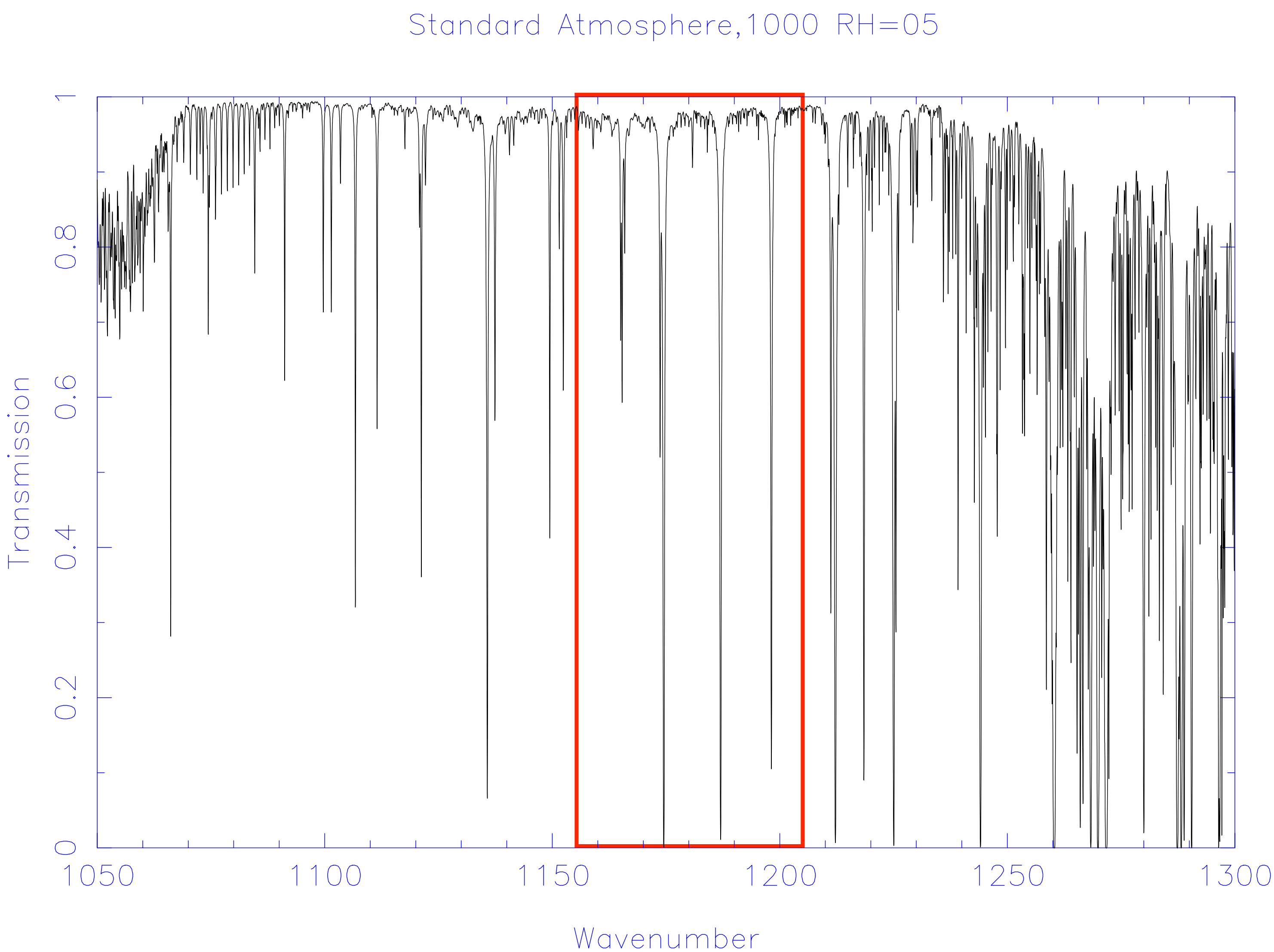
What does this allow us to do?

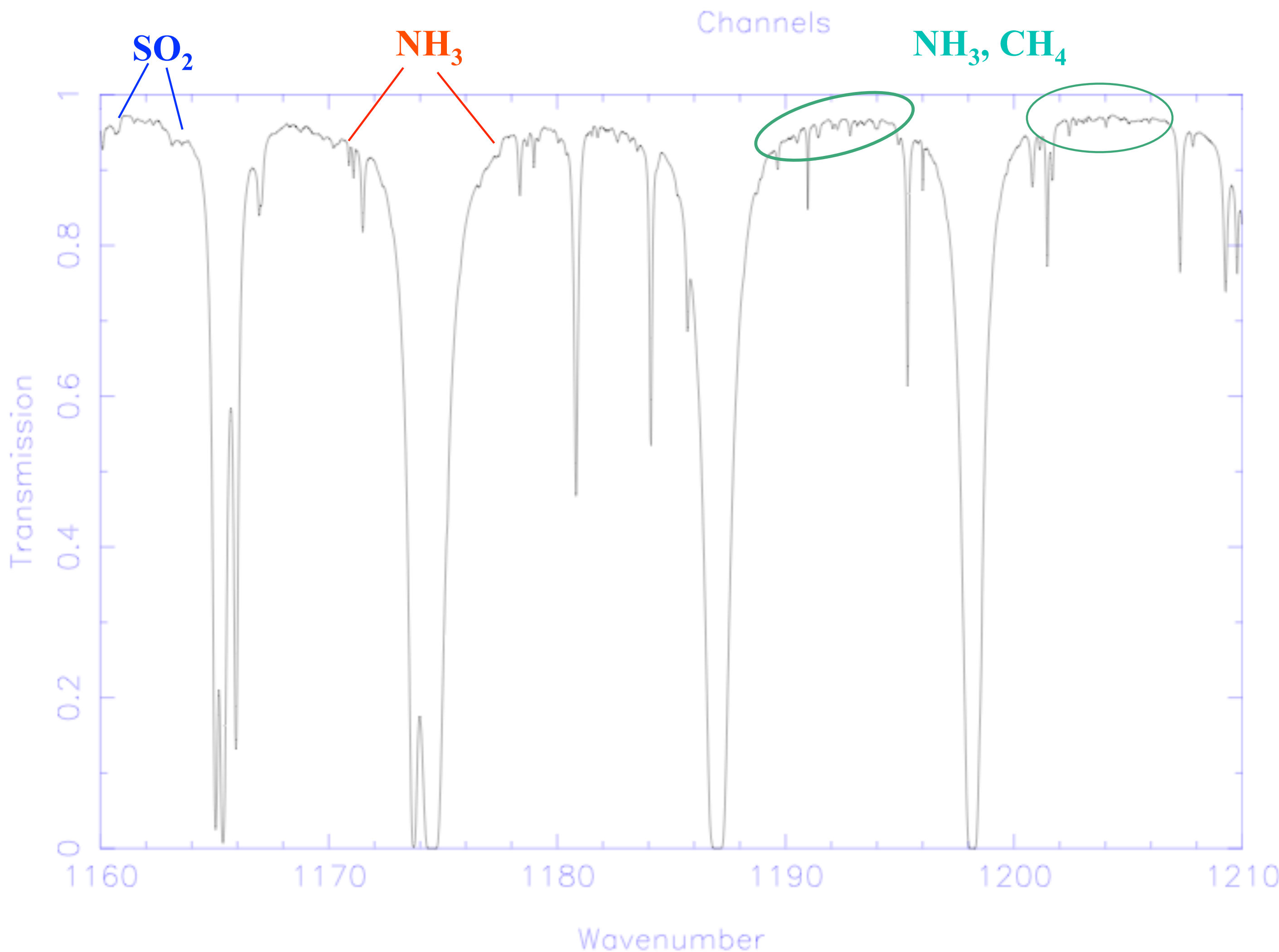
Record spectra from distant places, analyze the signal to determine the constituents by their “fingerprints”

Called -- *Remote Sensing*



Standard Atmosphere,1000 RH=05
CO2
O3
NH3
HNO3
Transmission
0
0.2
0.4
0.6
0.8
1
800
850
900
950
1000
1050
Wavenumber


Standard Atmosphere,1000 RH=05
Transmission
Wavenumber
0
0.2
0.4
0.6
0.8
1
1050
1100
1150
1200
1250
1300


Channels
SO2
NH3
NH3, CH4
1
0.8
0.6
0.4
0.2
0
Transmission
1160
1170
1180
1190
1200
1210
Wavenumber

Composition of Venus' Atmosphere

Species	% volume
carbon dioxide	97
water vapor	1×10^{-1}
carbon monoxide	5×10^{-3}
hydrogen chloride	6×10^{-5}
hydrogen fluoride	5×10^{-6}

Composition of Earth's Atmosphere

Species	% volume	Species	% volume
nitrogen	78.084	krypton	1.14×10^{-4}
oxygen	20.946	[illegible]gen	5×10^{-5}
argon	0.934	N_2O	3×10^{-5}
CO_2	0.0345	CO	10^{-5}
neon	1.82×10^{-3}	xenon	8.7×10^{-5}
helium	5.24×10^{-4}	ozone	up to 10^{-5}
methane	1.5×10^{-4}	water vapor	up to 1

99.964%

Composition of Mars' Atmosphere

Species	% volume	Species	% volume
CO_2	95.32	water vapor	0.03
nitrogen	2.7	neon	2.5 ppm
argon	1.6	krypton	0.3 ppm
oxygen	0.13	xenon	0.08 ppm
CO	0.07	ozone	0.03 ppm

Composition of Titan's Atmosphere

Species	% volume	Species	% volume
nitrogen	~ 94	methylacetylene	3 $\times 10^{-8}$
helium	6	HCN	2 $\times 10^{-7}$
methane	10^{-2}	cyanoacetylene	10^{-8} - 10^{-7}
ethane	2 $\times 10^{-5}$	cyanogen	10^{-8} - 10^{-7}
acetylene	3 $\times 10^{-6}$	carbon dioxide	10^{-10}
propane	2 $\times 10^{-5}$	carbon monoxide	?
diacetylene	10^{-8} - 10^{-7}		