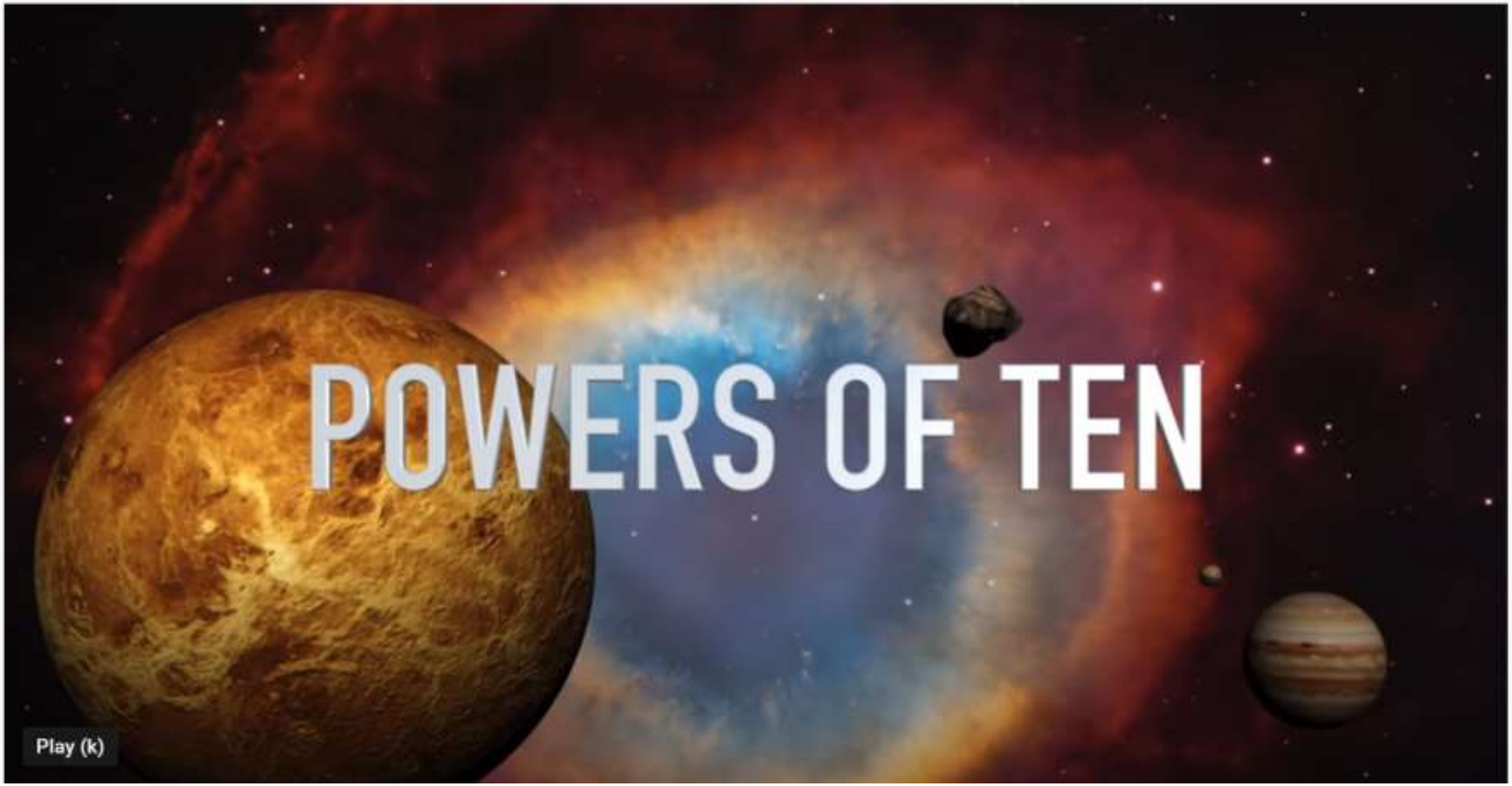
Powers of 10 video



Clicker Question

Which statement is **FALSE**?

A. 1×10^{-4} is greater than 1×10^{-5}.
B. A Gigawatt is 1,000,000 Watts.
C. A microgram is 10^{-9} kg.
D. A centimeter is 10 millimeters.
E. A millipede is a kind of arthropod.

Clicker Question

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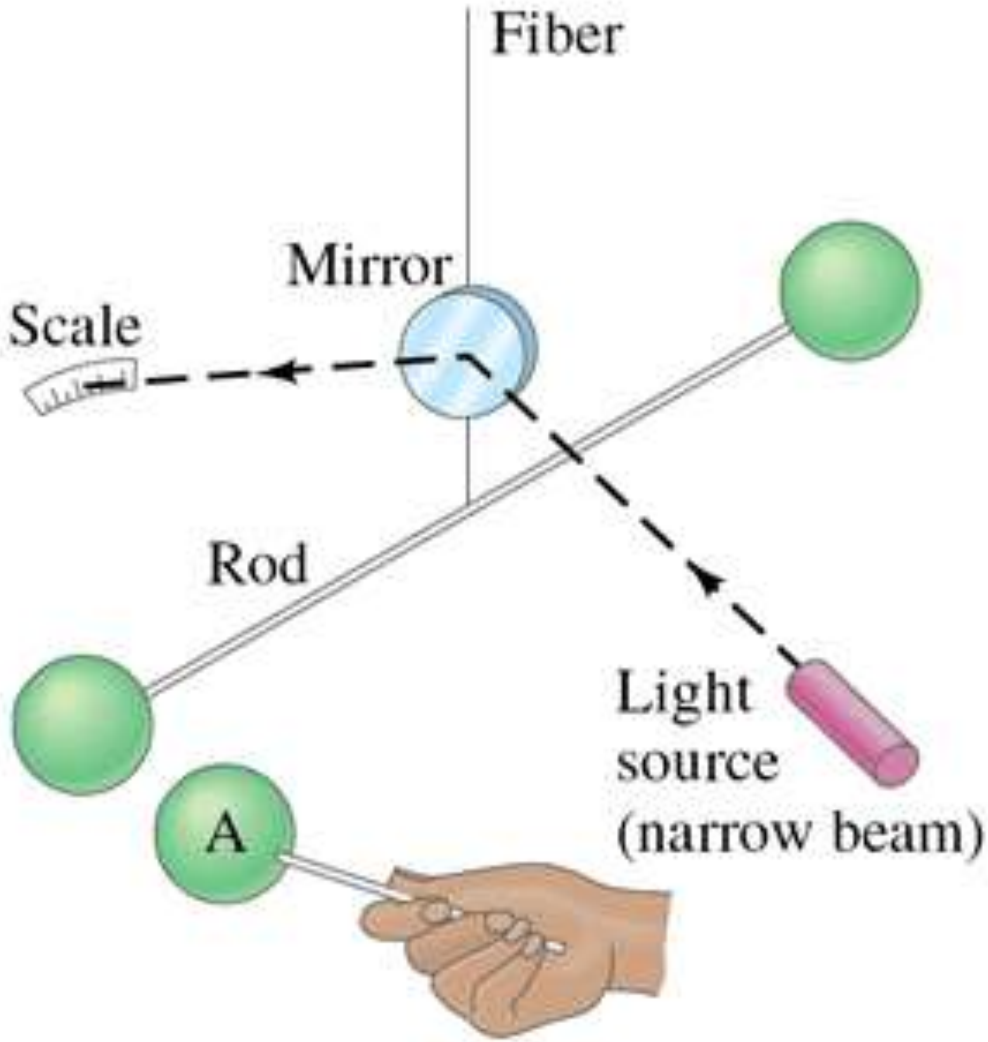
Cavendish Experiment: Direct measurement of *G*



Henry Cavendish
1797

Clicker Question

Which is ***false*** about the Cavendish experiment?

A. In the Cavendish experiment, it helps to use masses of large density as this allows the distance between masses to be reduced.
B. The Cavendish experiment helps us determine the mass of the Earth, if we know the Earth's radius and the acceleration of gravity.
C. The Cavendish experiment, performed on the surface of Mars, can tell us what Newton's gravitational constant is.
D. The Cavendish experiment, performed on a spacecraft falling into a black hole, would yield the same value for the gravitational constant as when performed on Earth.
E. If the Cavendish experiment were conducted on the moon, the gravitational acceleration of the moving masses would be about 1/6 of that measured on Earth.

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Clicker Question

Which statement about supernova explosions is ***<u>false</u>***?

A. Supernovae can be so bright that they can be seen with the naked eye.
B. Supernova explosions happen when very massive stars run out of nuclear fuel.
C. Supernova explosions leave behind neutron stars or black holes.
D. Supernovae were first detected when telescopes were invented.
E. Supernova explosions can be observed in far-away galaxies.

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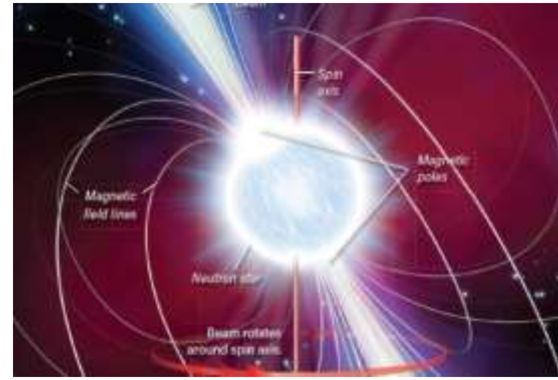
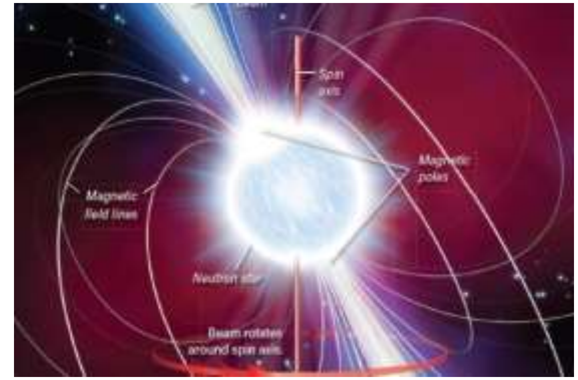
Clicker Question



Which statement about neutron stars is true?

A. Neutron stars tend to spin many times per second.
B. Neutron stars emit intense neutron radiation.
C. Neutron stars are created when black holes merge.
D. Neutron stars are much bigger in diameter than the sun.
E. Stars much less massive than the sun end up as neutron stars.

Clicker Question



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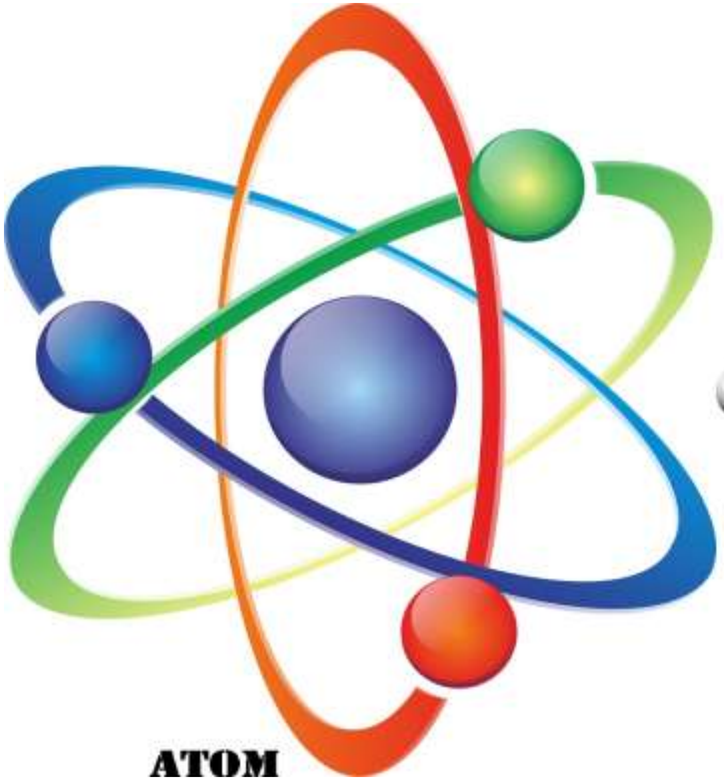
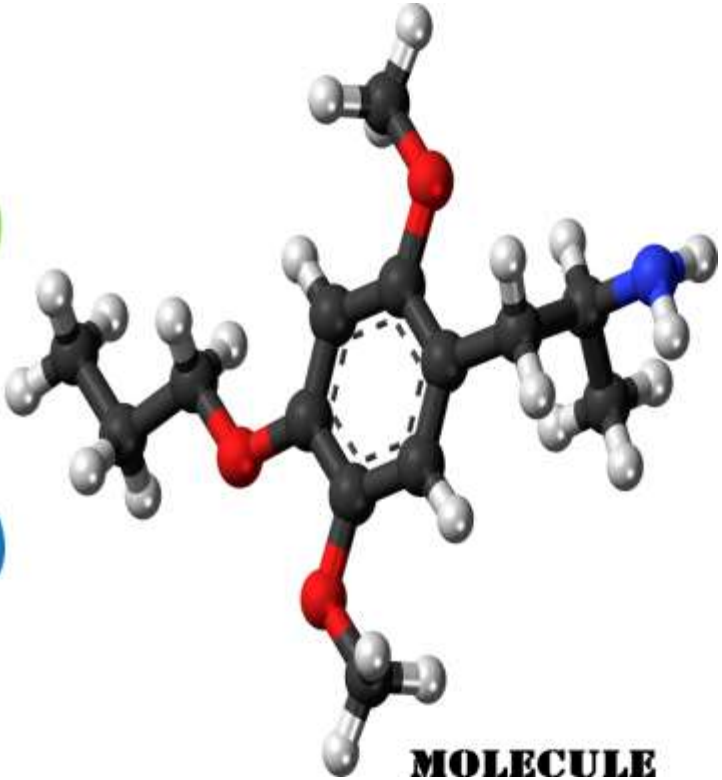
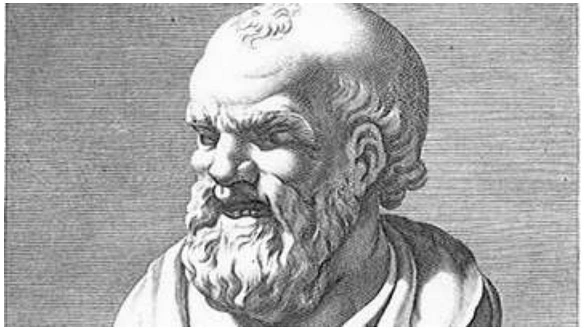
Atoms and Molecules

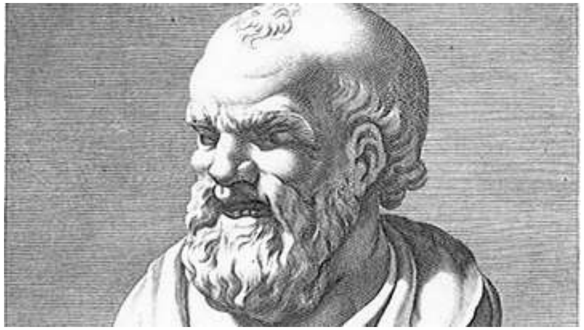




Greek philosopher Democritus pondered:



- Suppose you divide a piece of matter in half, then again, then again, …
- Then either:
  - You can do this indefinitely (“matter is continuous”)
  - Or, you arrive at a smallest indivisible piece of matter (“atom”).
- Democritus argued in favor of the atomic theory of matter:
- All matter is made of tiny, indivisible particles, too small to be seen.



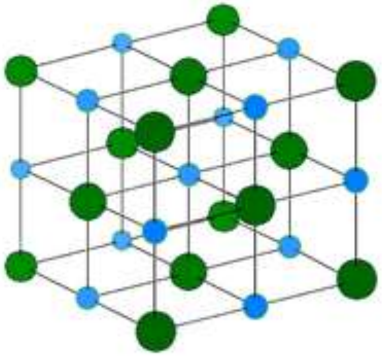
How did Democritus know about atoms?

- He didn’t. He just liked the idea.
- Atomic theory was a popular topic for debate for the ancients.
- Truth was to be decided by the quality of the rhetoric, rather than by actual evidence.

What evidence do we have for atomic theory?

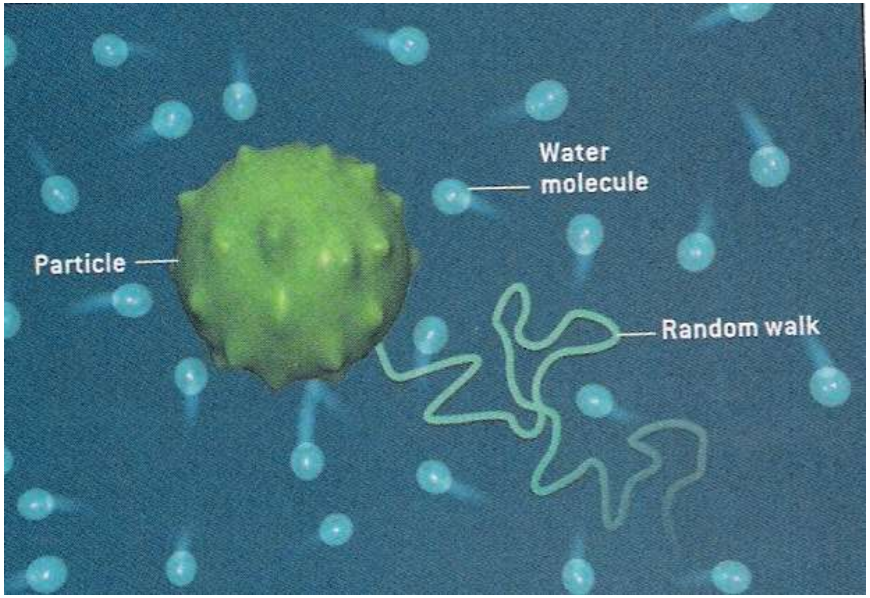
Descartes attributed the beautiful symmetry of snowflakes to the existence of water molecules that arrange themselves in hexagonal arrays.

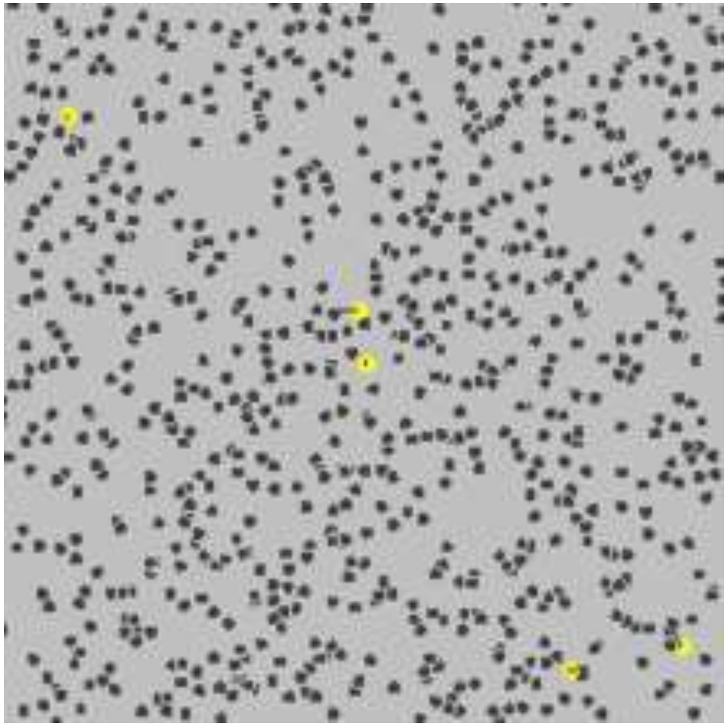
Salt crystals (cubic in shape)



Another piece of evidence for the atomic theory is Brownian motion:

The erratic motion of tiny particles in water as they are bounced around by the water molecules.

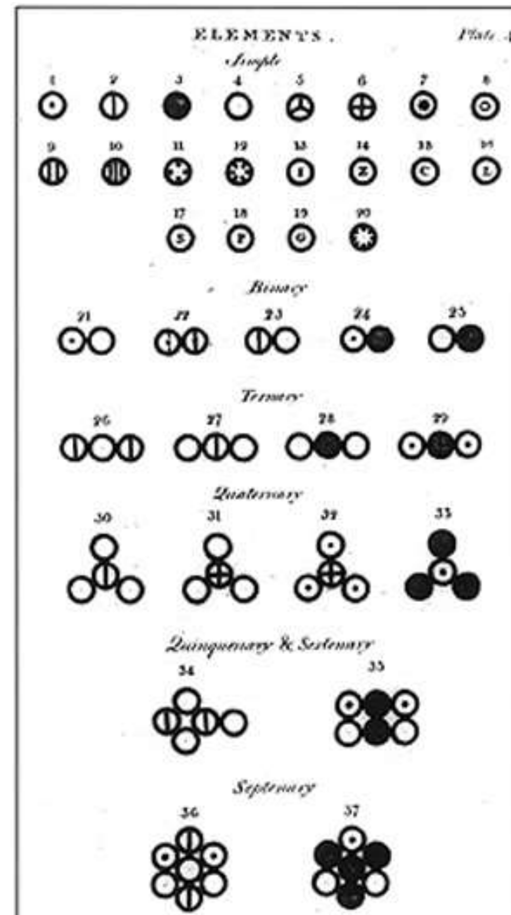




Evidence from Chemistry: Dalton

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_5	5 x 57 = 285
Nitrogen peroxide	NO_3	6 x 57 = 342

* Grams of oxygen for each 100 grams of nitrogen

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* Grams of oxygen for each 100 grams of nitrogen

Size of atoms?

- Can Dalton's measurements of ratios tell us how big atoms are?
- For example, how many atoms in a gram of oxygen?

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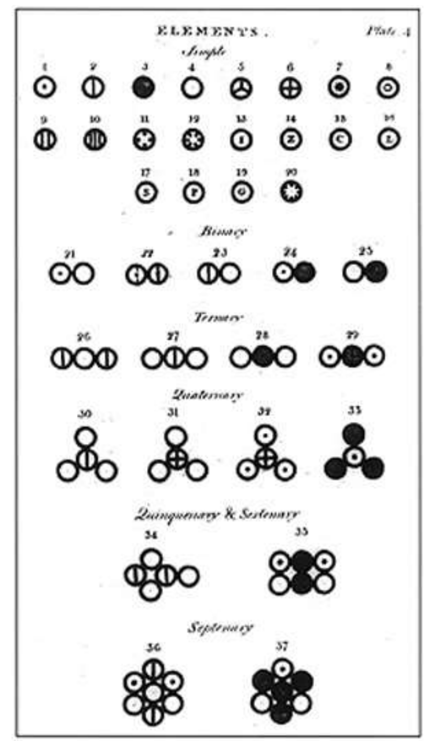
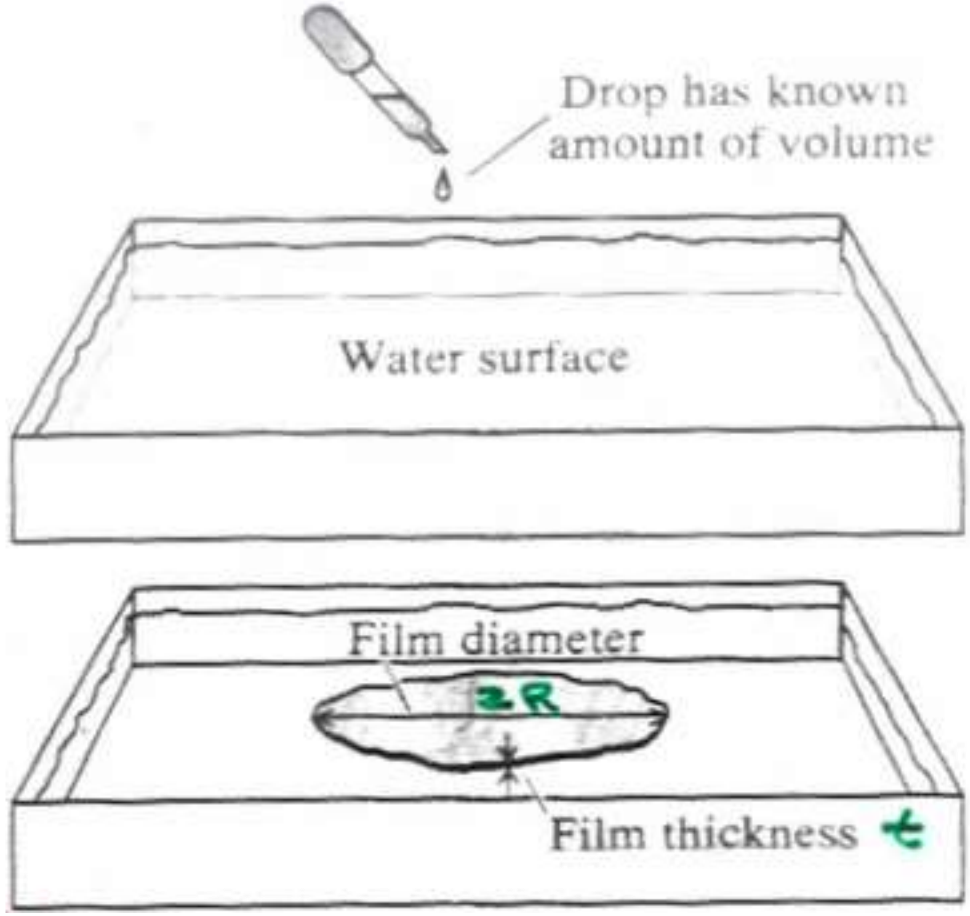


Size of atoms/molecules

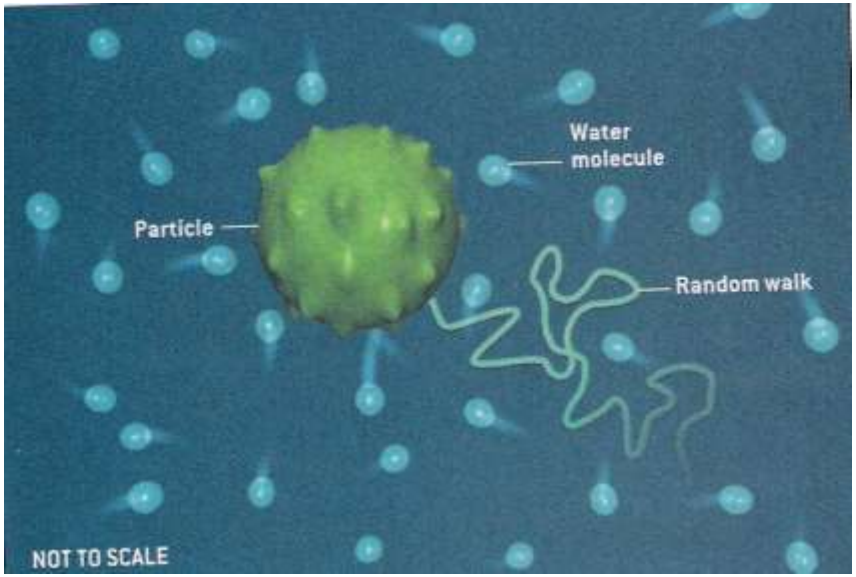
The English physicist Lord Rayleigh (John William Strutt, 1842 – 1919) came up with an ingenious and simple method estimate the size of oil molecules:

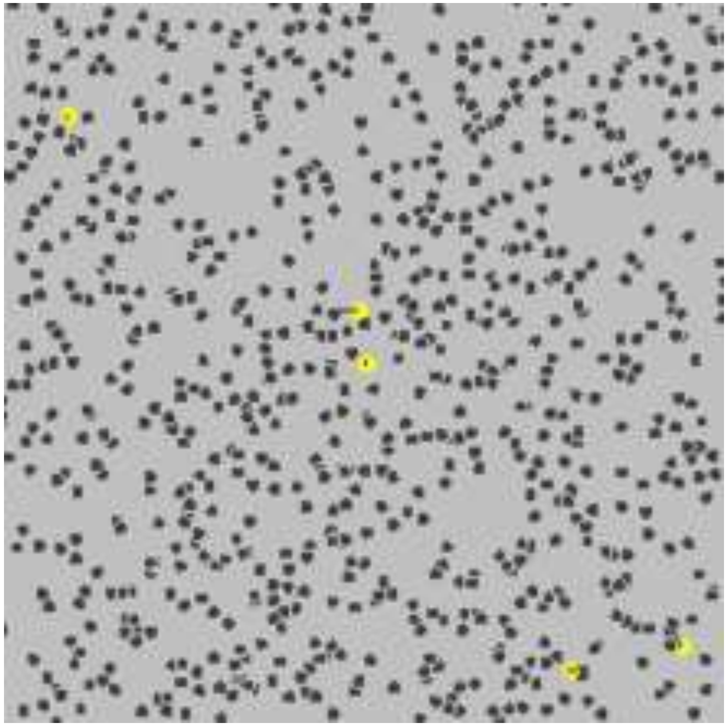
- Drop of oil onto water.
- Oil spreads to form a very thin layer.
- Spreading stops when the oil film is one molecule in thickness.
- From know volume of drop, determined thickness to be 10^{-9} m.
- Concluded atoms must be even smaller than this.



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

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

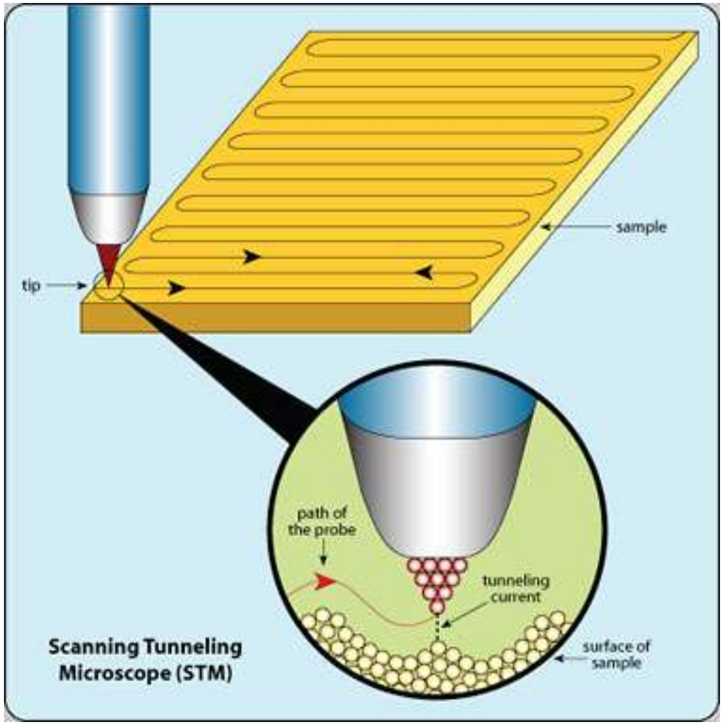




Video

Scanning Tunneling Microscope (STM)

Binning & Rohrer
Nobel Prize in Physics: 1986



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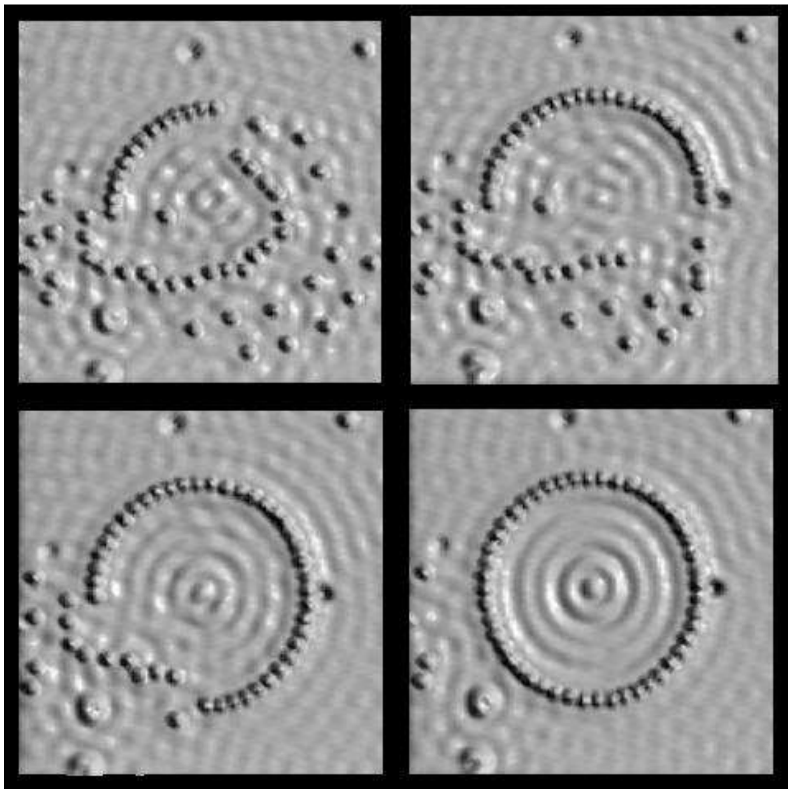
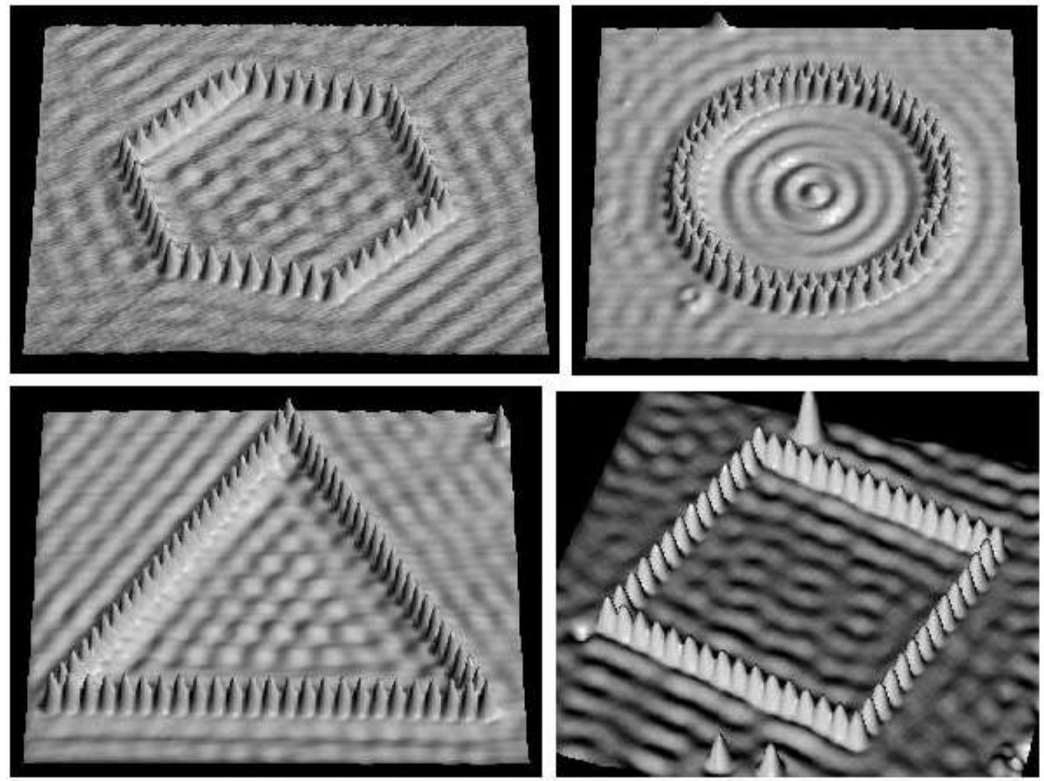
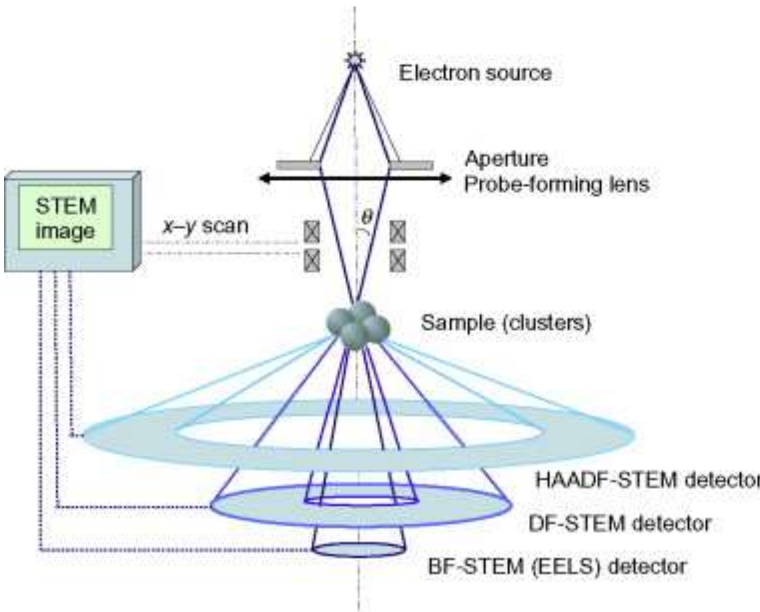
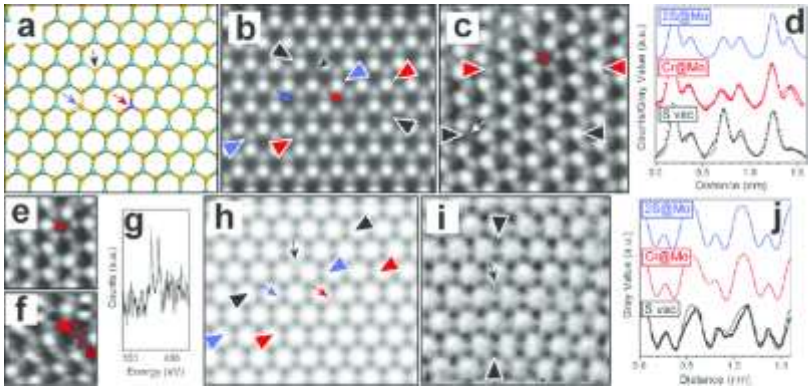
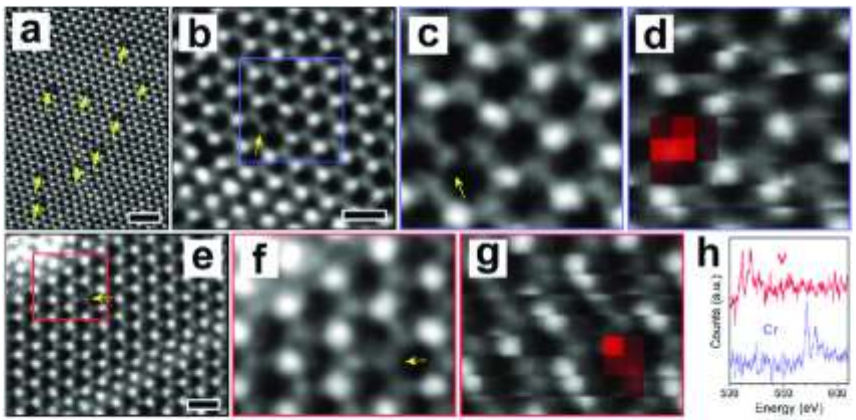




Scanning Transmission Electron Microscopy (STEM)



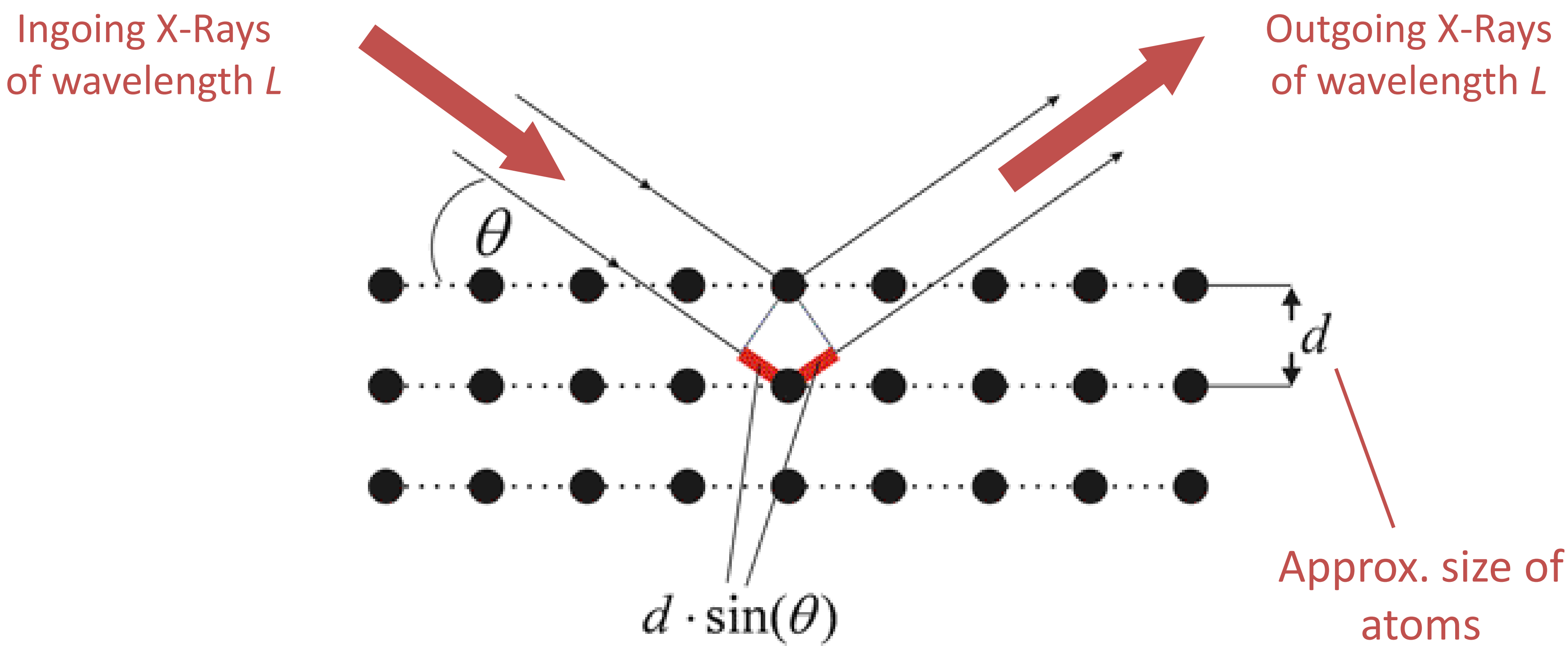




- Single Atom (Cr, V) Substitutional Dopants in Monolayer MoS_2
- Atomic Structure
- Identify atoms with EELS (spectroscopy)

X-Ray Diffraction

- Find location of atoms in crystals by scattering x-rays.
- Use known wavelength of x-rays to determine distance between atom layers.



$$L = 2\, d \sin(\theta)$$

Clicker Question

Which of the following does ***not*** give us an indication of the size of atoms?

A. Oil drop spreading on the surface of water.
B. Atomically resolved STM images.
C. Brownian motion.
D. X-ray diffraction of crystals.
E. Dalton's experiments on chemical combination ratios.

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A. Oil drop spreading on the surface of water.
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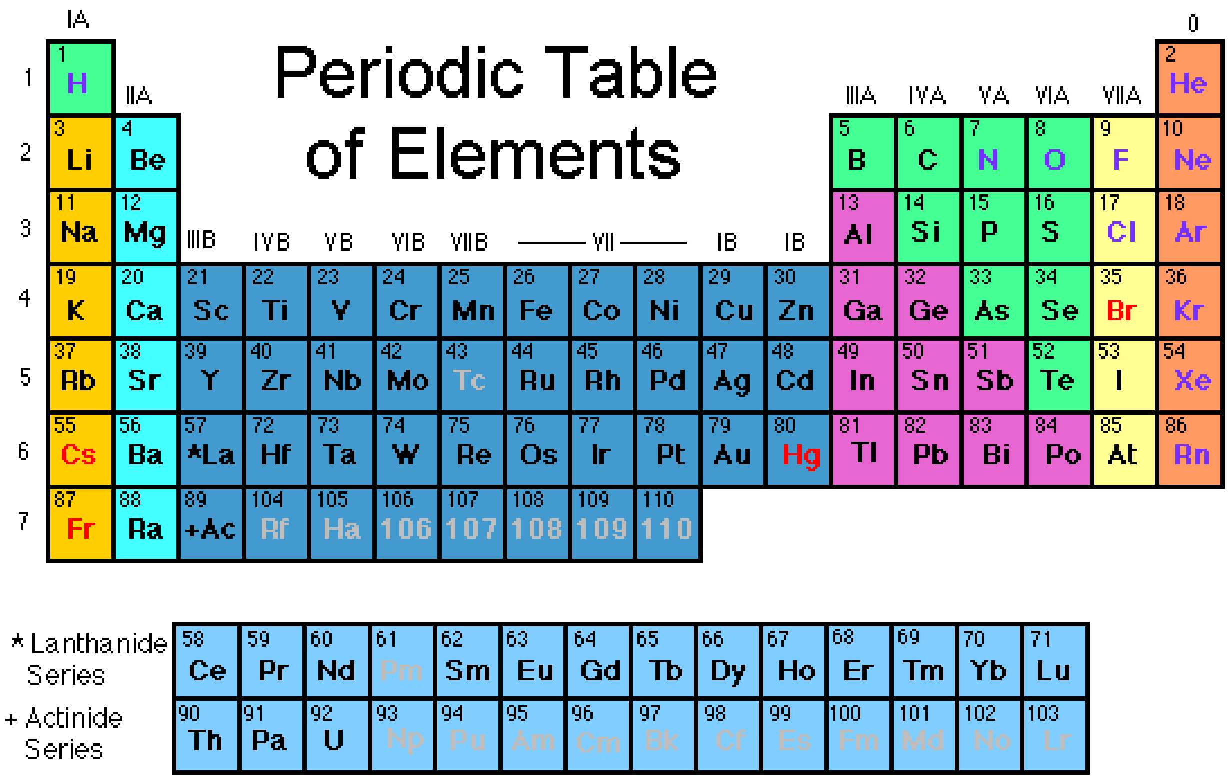
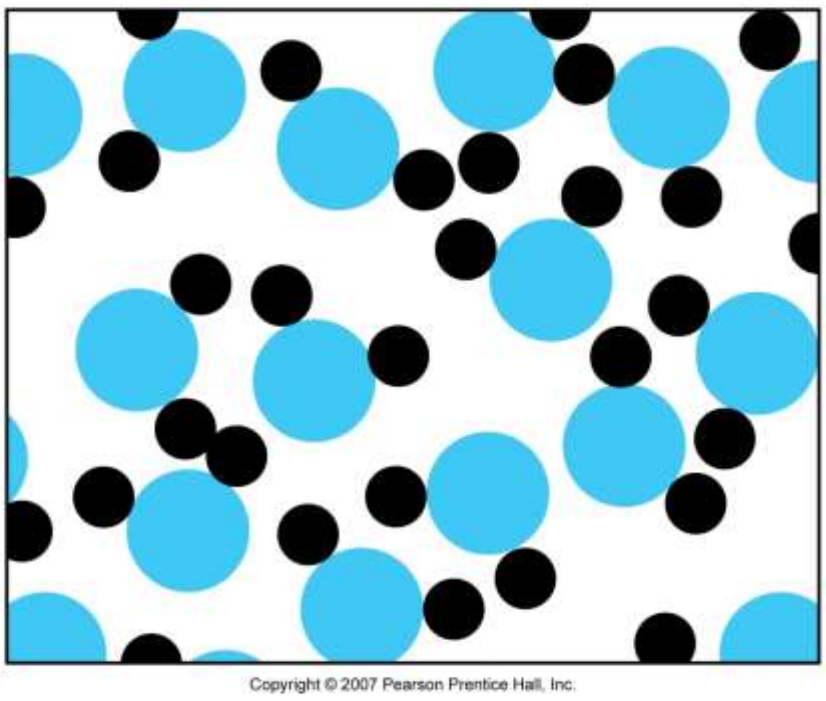
Atoms and Molecules

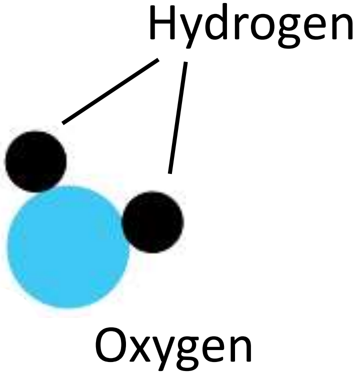
- A total of fewer than 100 substances were found that could not be decomposed.
- These are called the chemical elements.
- Including elements that can only be made in the laboratory, there are 118 elements known today.



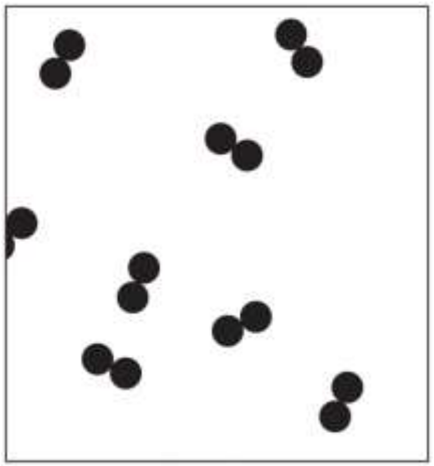
- A substance made of more than one element is called a compound.
- Water is a well-known example:



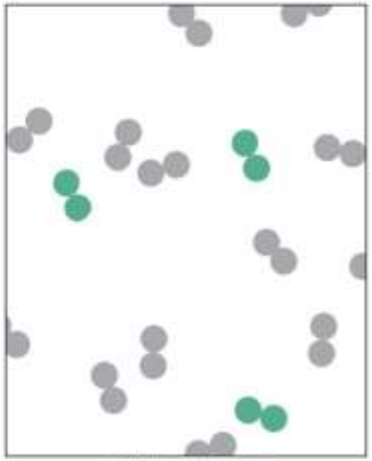
H_2O



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

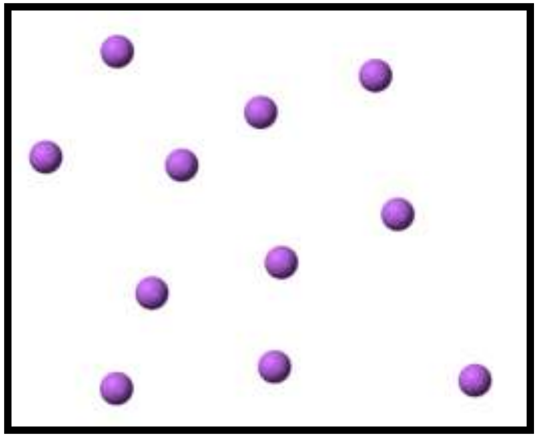


Hydrogen molecules



Air:
Nitrogen and
Oxygen Molecules

Others, such as helium, are single-atom gases.



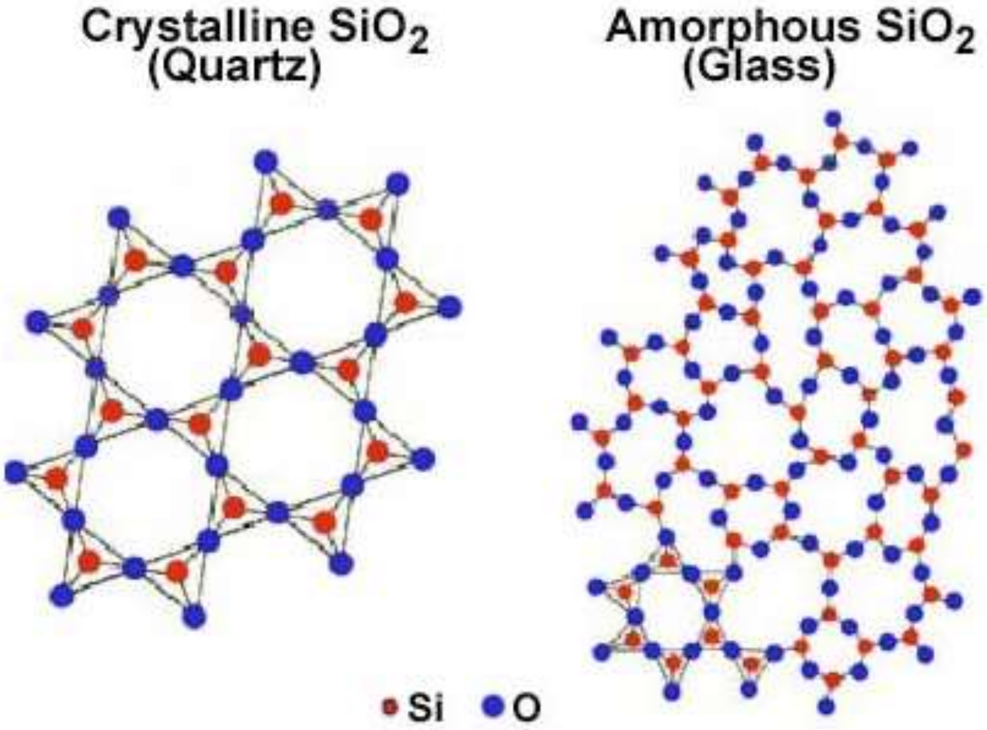
Compounds and elements are represented in abbreviated form. Every element has a one- or two-letter abbreviation, and the number of atoms of each element per molecule is given as a subscript:

Water:	H_2O
Salt:	$NaCl$
Hydrogen gas:	H_2

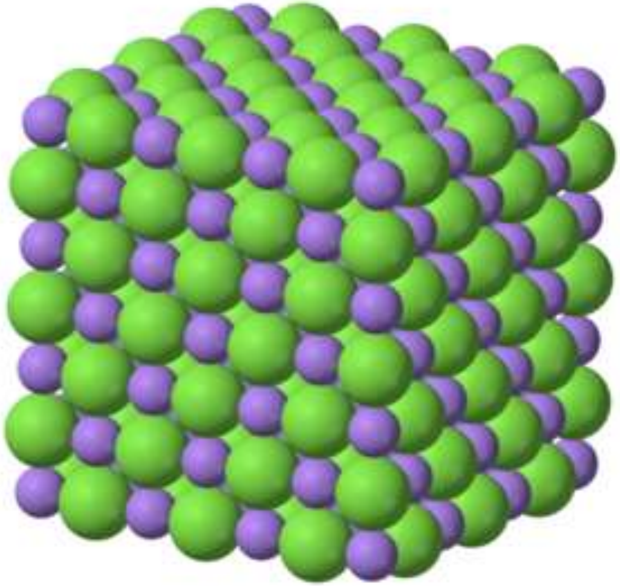
States of matter

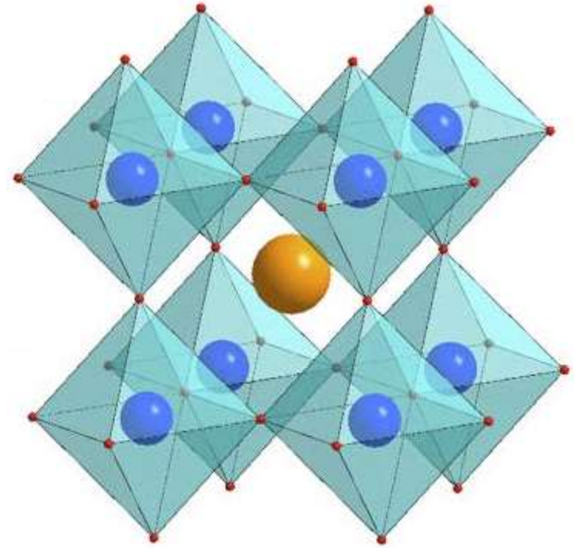
<u>Solids</u>

- Atoms are closely packed
- They vibrate around fixed locations
- The material is "rigid"
- Two variants:
  - Crystal
  - Amorphous



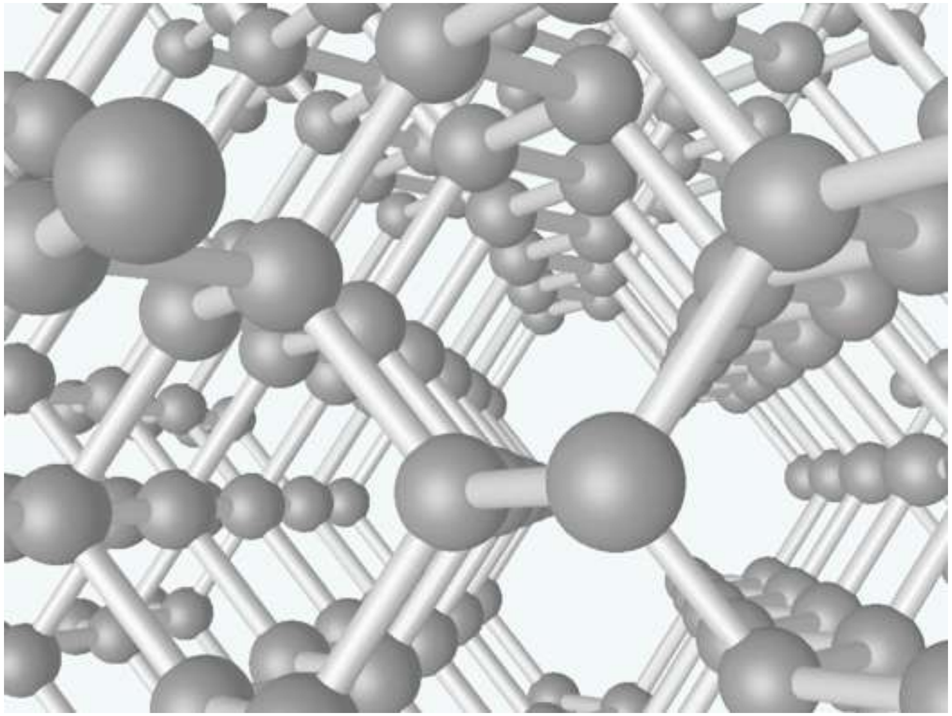
NaCl





Perovskite

($CaTiO_3$)



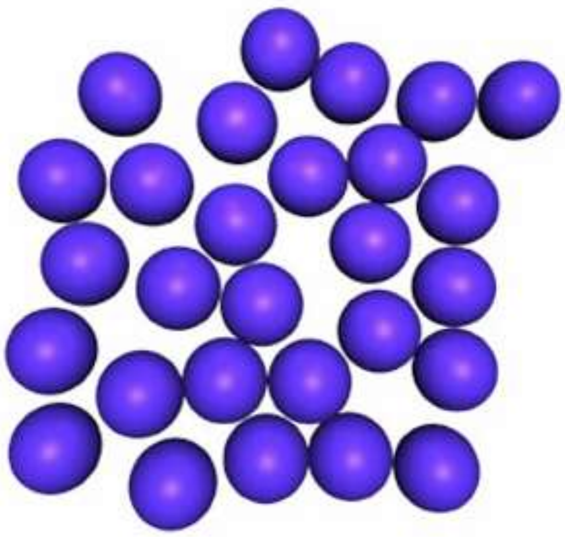
diamond

also: silicon

States of matter

<u>Liquid:</u>

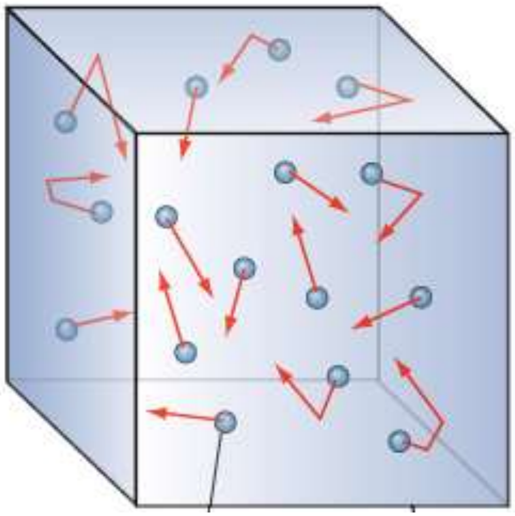
- Atoms are still closely packed.
- They move freely around one another.
- The material can “flow”.
- Volume is approximately fixed.



States of matter

Gas

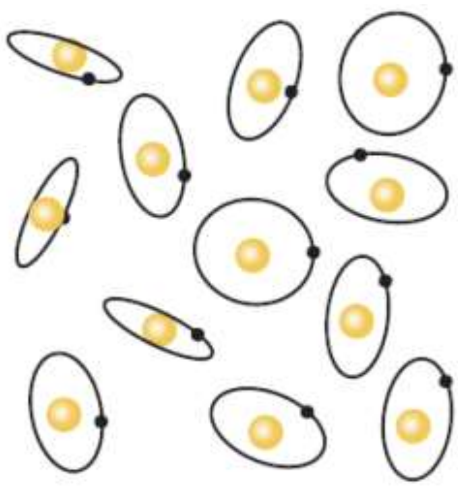
- Atoms or molecules are far apart.
- They move freely between collisions.
- Gas expands to fill available volume.



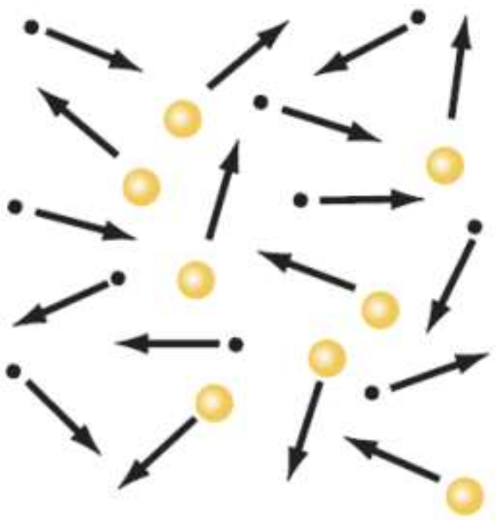
States of matter

Plasma

- Like a gas, but (+) ions and (-) electrons move separately



Gas



Plasma

Phase change simulation