The World is Made of Legos

Chemistry 1010

Review

Let's begin by reviewing what we learned about chemistry:

What is chemistry?

the study of MATTER and the CHANGES it undergoes

the study of all of the STUFF in the universe and what can HAPPEN to the stuff

What are some examples of things that we can study with chemistry?

Introduction

In today's lecture, we will begin our study of matter, the stuff the universe is made of.

I. Atoms, Elements, Compounds, and Chemical Reactions

First, we'll look at four fundamental ideas: atoms, elements, compounds, and chemical reactions.

II. How Small Are Atoms?

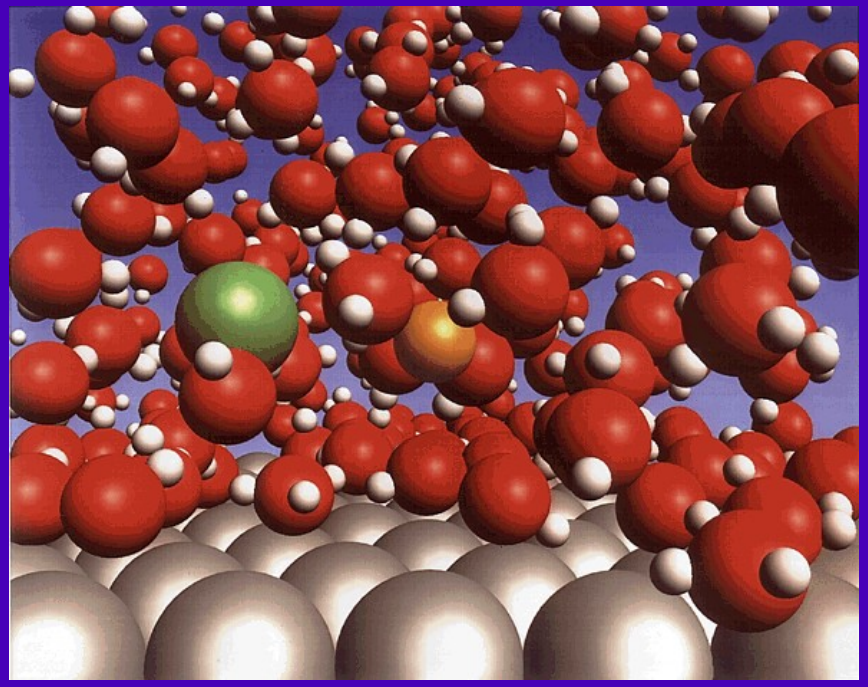
Second, we will talk about how small atoms are, and give some examples that help to illustrate this. We'll also look at some images of actual atoms, and talk about how to count them.

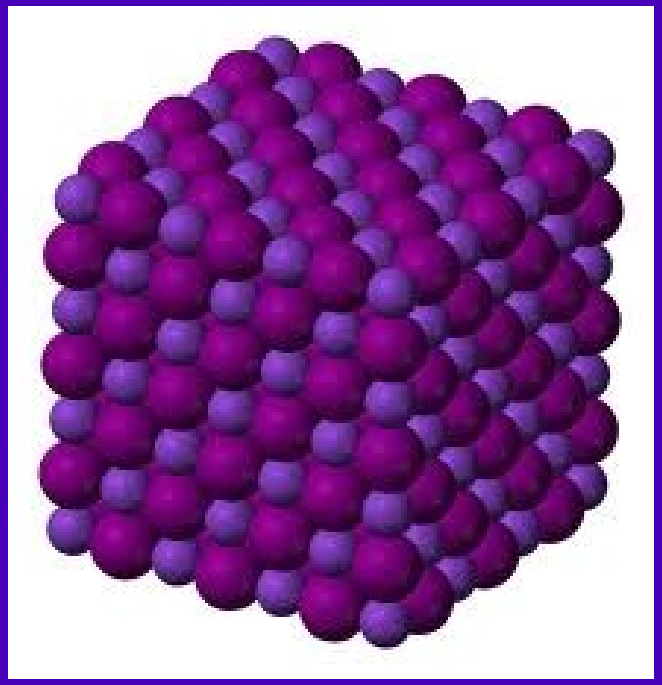
III. What are Atoms Made Of?

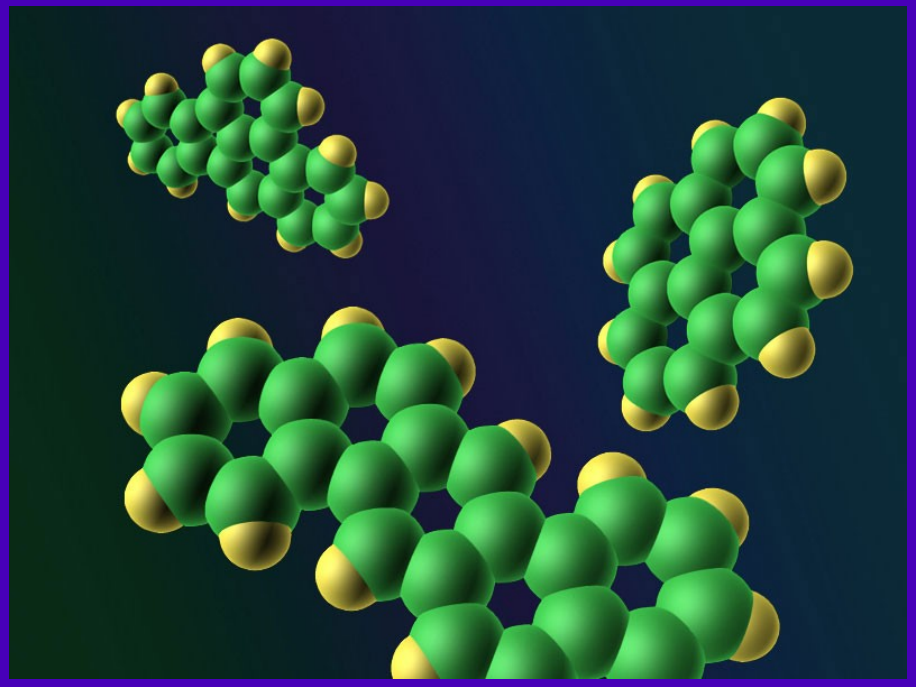
Finally, we'll introduce the elementary particles, which is what atoms are made of. We'll discuss how they are arranged in an atom, and how they determine an atom's charge and mass.

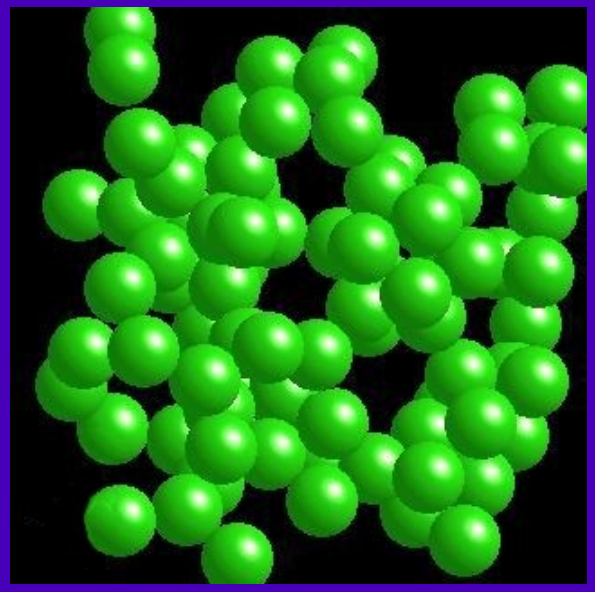
I. Atoms, Elements, Compounds, and Chemical Reactions

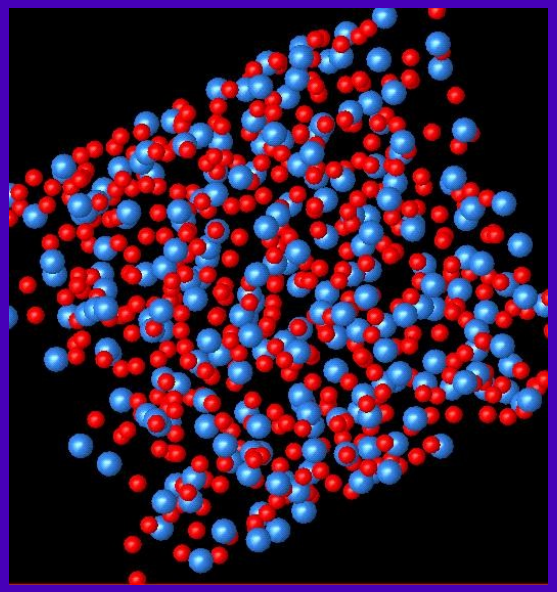
If you could look at matter really close up, what would it look like?

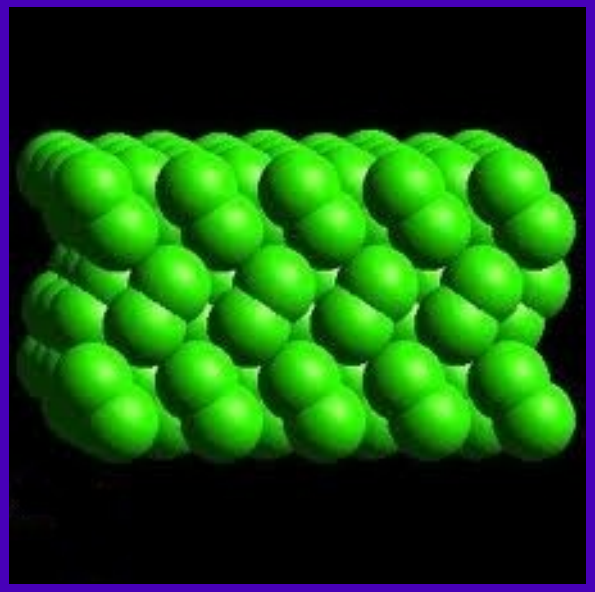


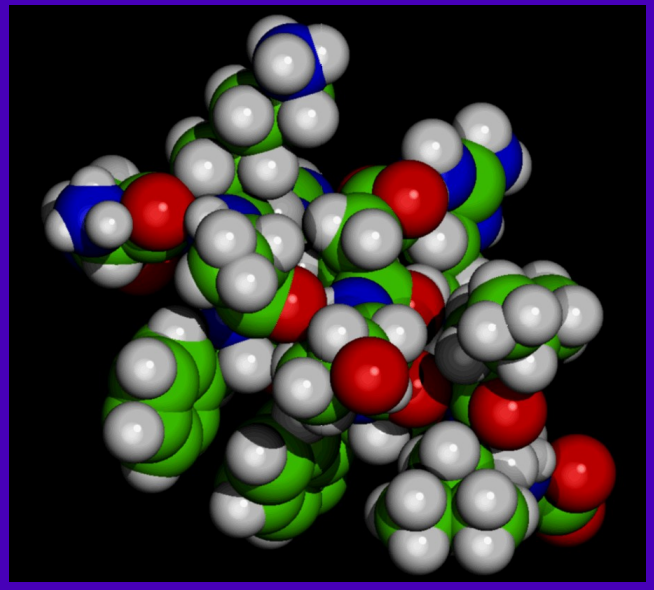


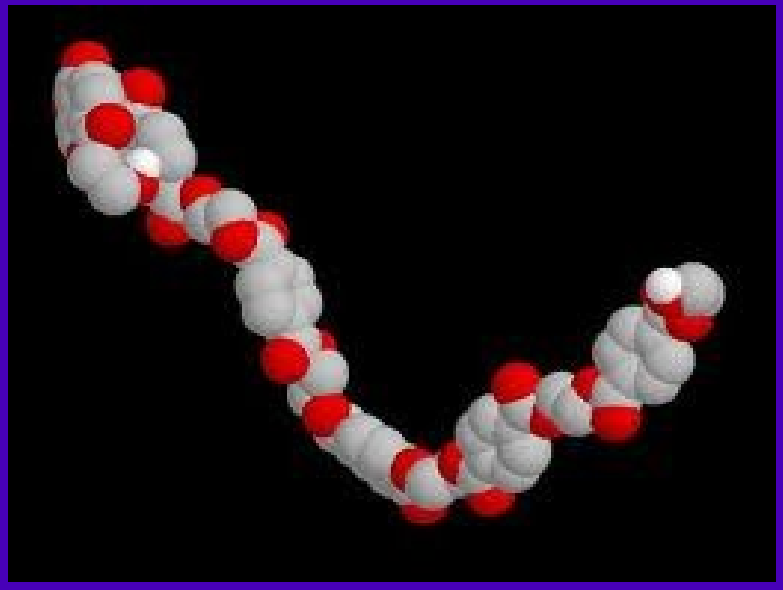


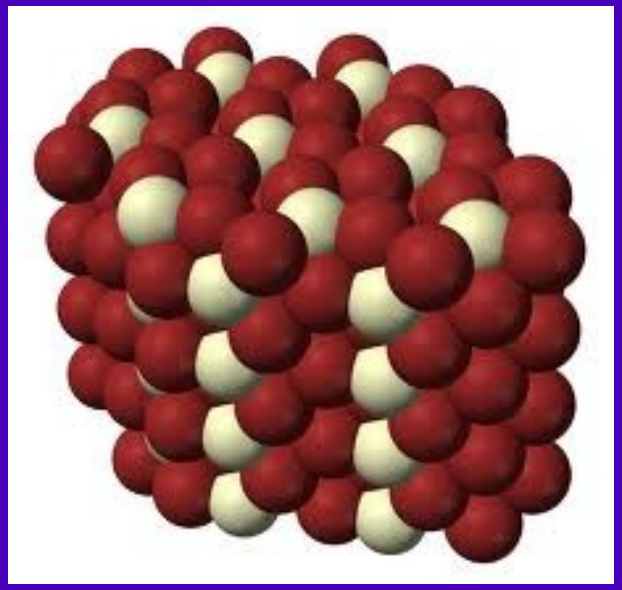


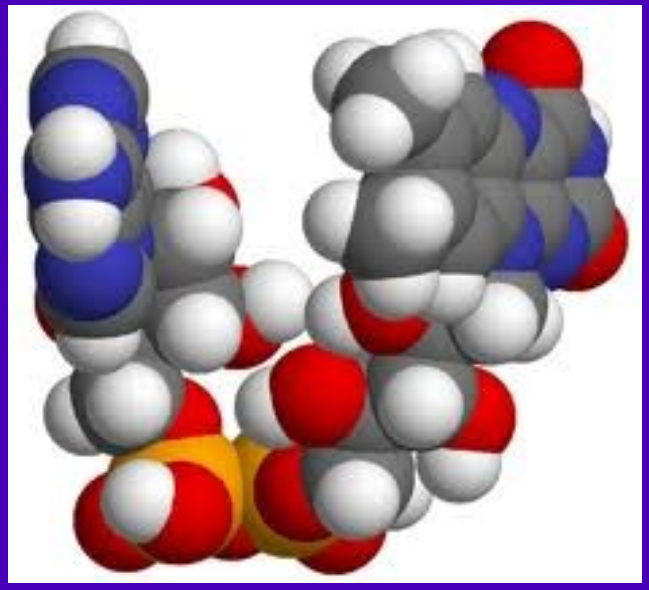


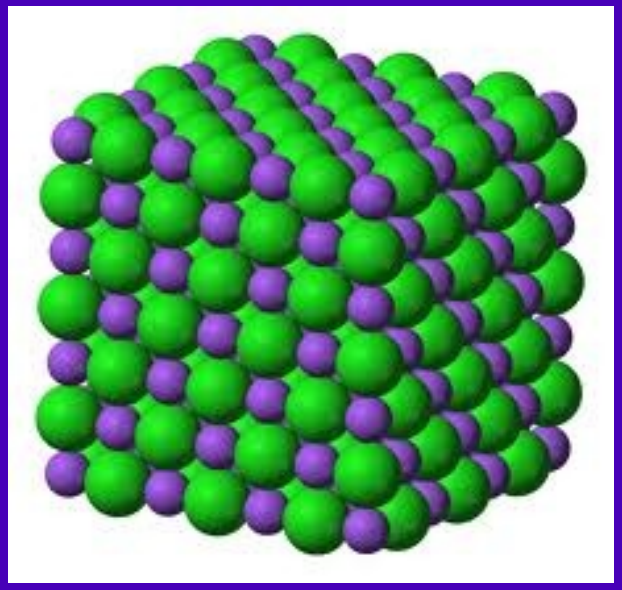


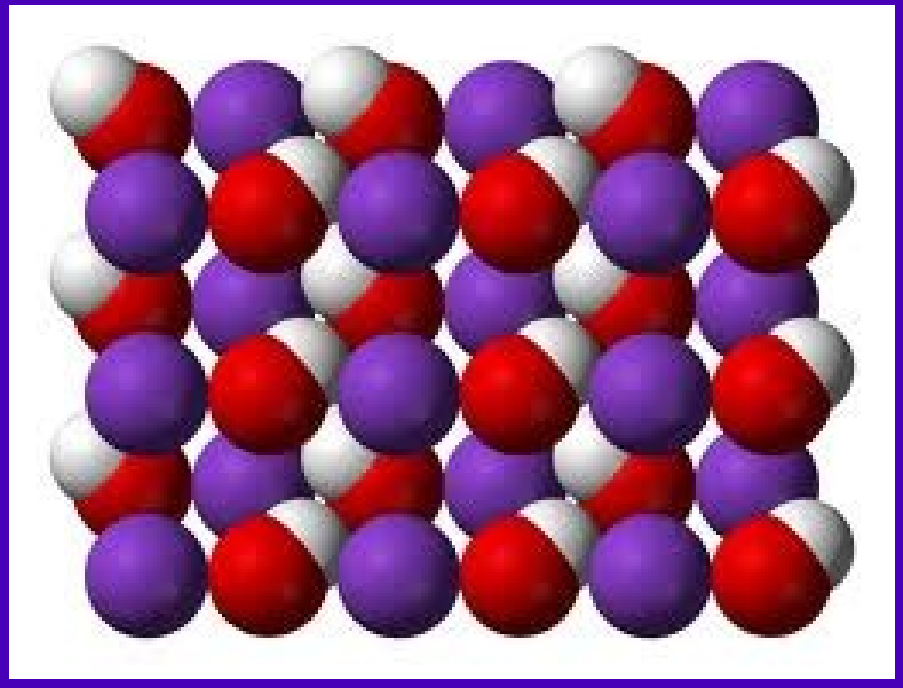


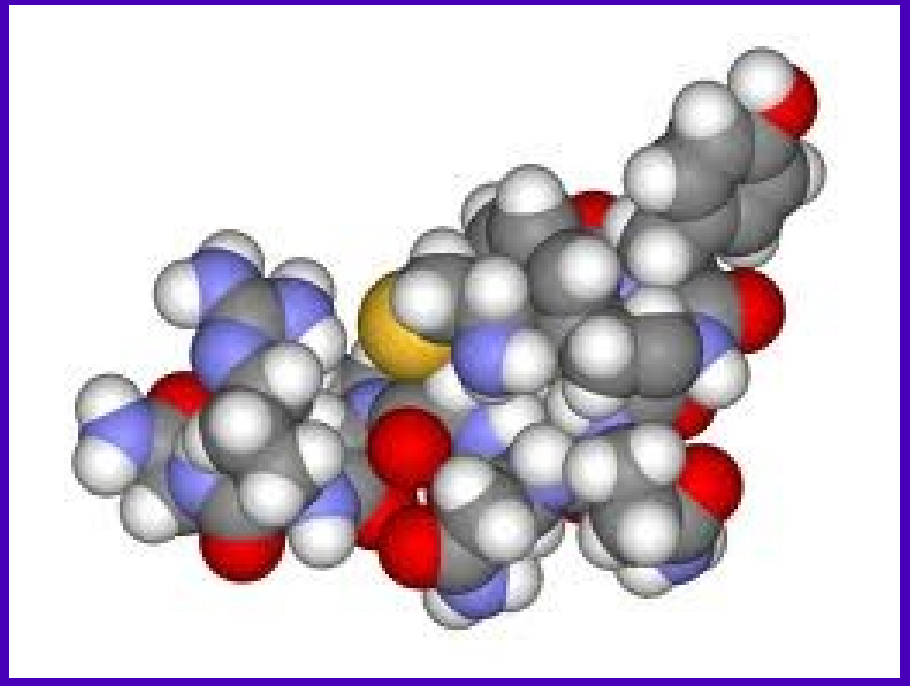




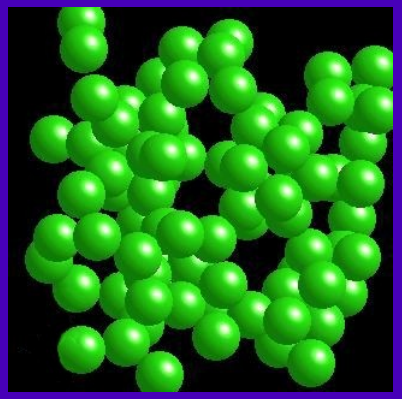








Atoms



The first thing you probably noticed is that matter is made of lots of little round balls.

These little balls are called atoms.

All of the matter in the universe is made of atoms:

water

cookies

rocks

flowers

stars

quilts

tigers

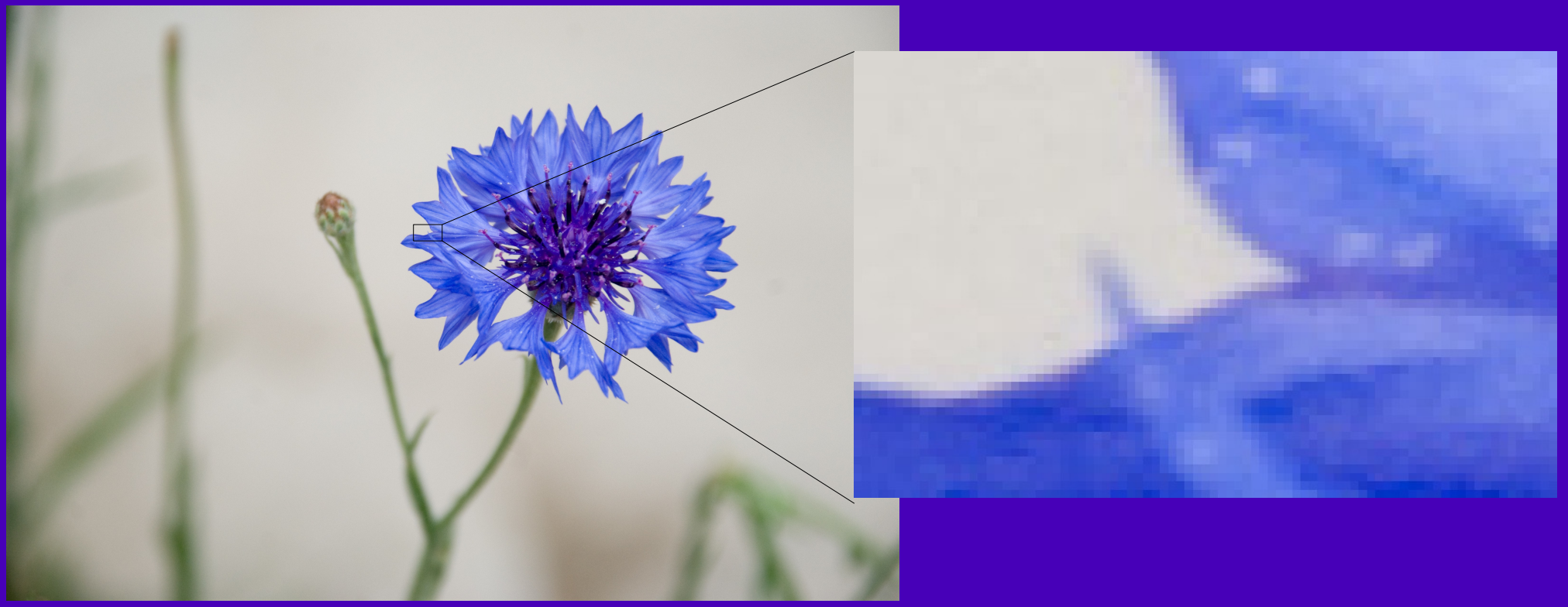
canoes

What else?

It's a little like looking at a sand dune...

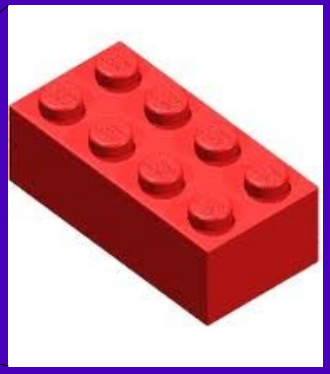
from a distance, it looks smooth, but if you get up close, you can see that it is actually made of tiny particles.

It's also like a picture stored in a computer...



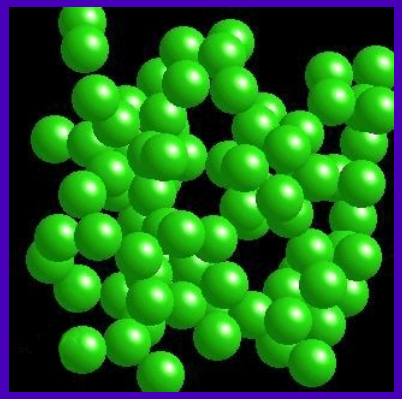
from a distance, it looks continuous, but if you blow it up, you can see the individual pixels that it is made from.

It's also like building things out of Legos...



You can take small, individual pieces and put them together to make something bigger.

Have you have heard of the idea that all matter is made of atoms before?

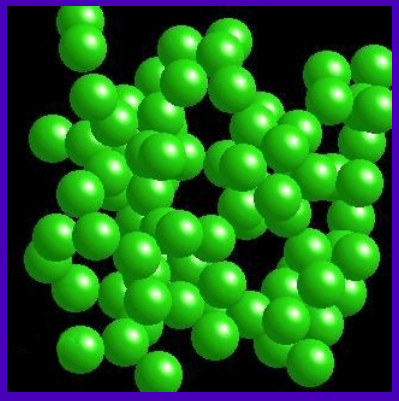


Here's the odd thing – nothing in our ordinary experience tells us this.

With a sand dune, you can see the sand grains if you look closely.

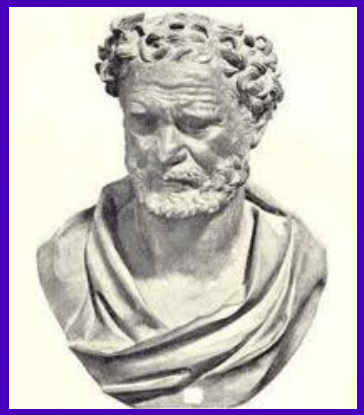
With a digital image, you can blow it up and see the pixels.

With a Lego structure, you can easily see the blocks.



But there is no way to see the atoms, even with a microscope, because they are too small.

Where does the word “atom” come from?



The idea of atoms is actually pretty old – it was suggested by some Greek philosophers, Democritus and Leucippus, around 400 BC, and also appeared in Indian and Islamic philosophy.

Democritus coined the term “atomos”, which means “uncuttable.”

The philosophers had some good arguments for their ideas, but no actual evidence.

When was the first atomic theory published?

The idea of atoms didn't really catch on until **1805** when **John Dalton** published the first modern atomic theory with experimental evidence to back up his claims.

Dalton was a school teacher in England who taught himself chemistry in his spare time.

Rather than reading a textbook, he waded through pages and pages of experiments performed by chemists throughout Great Britain and Europe.

By reading and thinking about these experiments, he realized that the results could only be explained if matter were made of tiny, separate particles.

This idea answered many questions that scientists had, and made it possible for our understanding of matter to really take off.

How long did it take until the idea of atoms was commonly accepted?

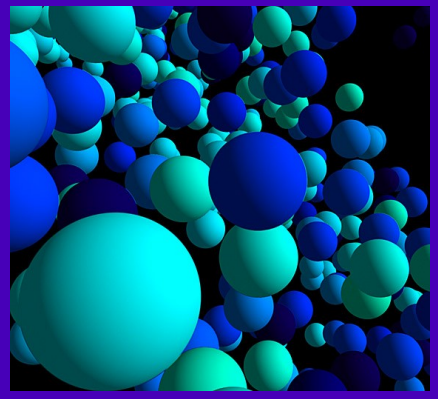
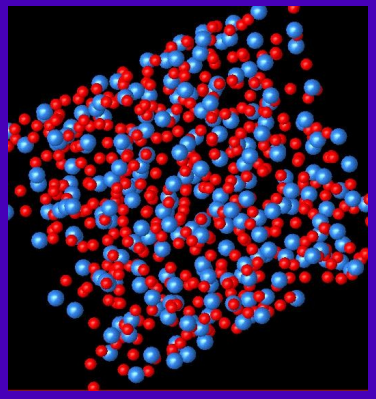
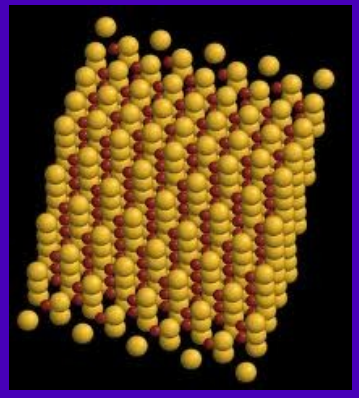
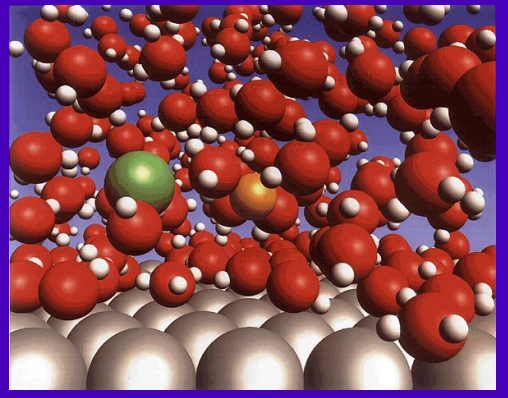
Even after Dalton published his atomic theory, there were some doubts among scientists about the actual existence of atoms.

This lasted until around 1900, when we began to unravel what atoms themselves are made of.

Now the evidence is so overwhelming that we no longer refer to the idea of atoms as a theory.

Elements

Another thing you probably noticed is that the little round balls that make up matter are not all alike – they are different colors and sizes.

Different kinds of atoms are called elements.

Do you think atoms are actually different colors?

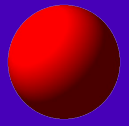
no – we just use color to show which atoms are which

Then how are atoms different from each other?

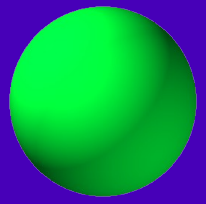
different sizes, different masses, other properties

What are some examples of elements?

hydrogen 

oxygen 

sodium 

chlorine 

How many elements are there?

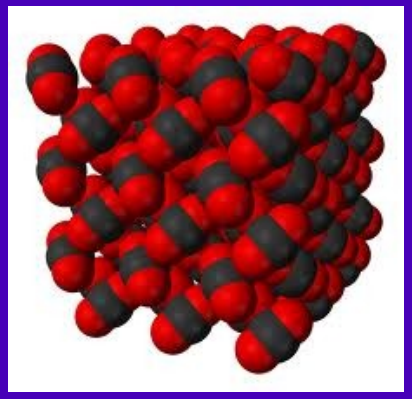
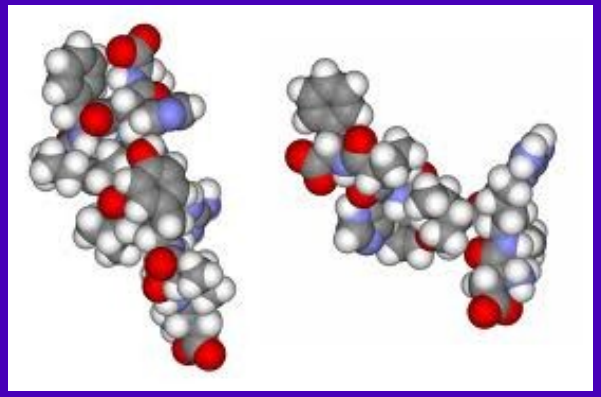
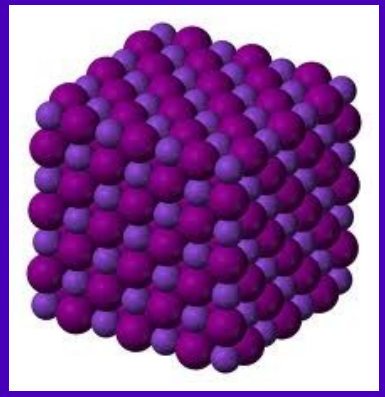
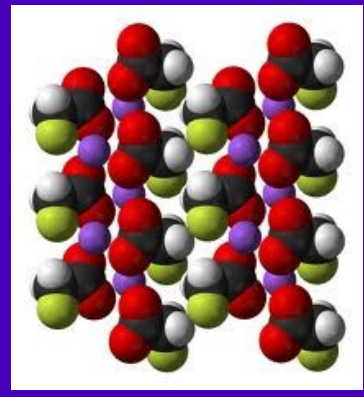
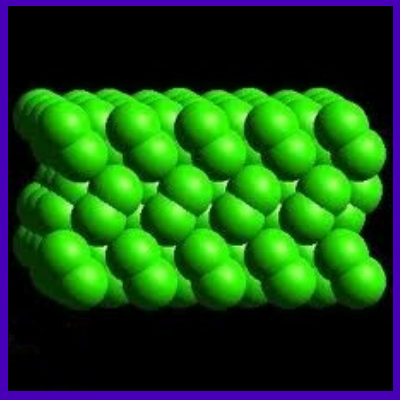
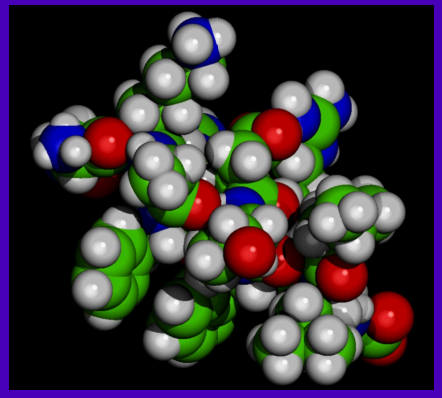
total number of known elements: 118

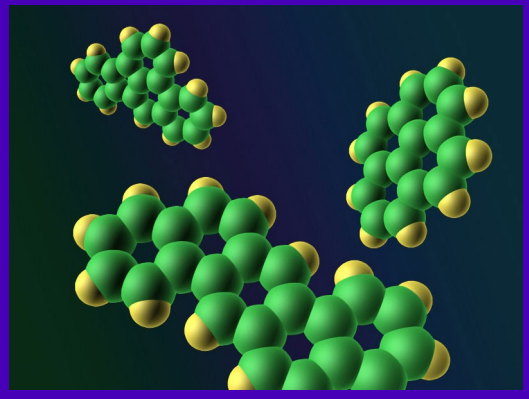
elements that have been found in nature: 90

elements that have been made artificially: 28 (and counting)

Compounds

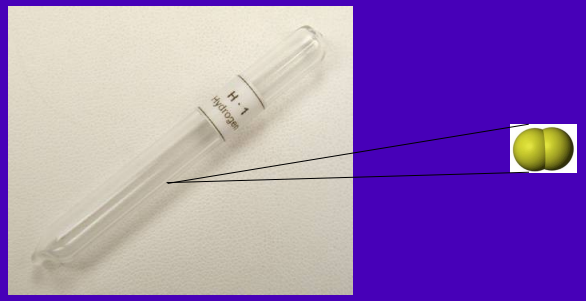
You may also noticed that some of the atoms are stuck together in groups.

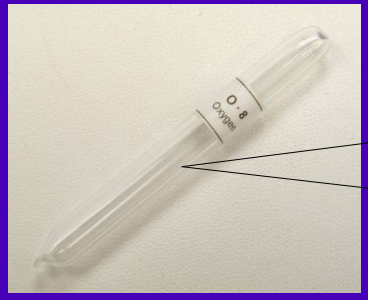


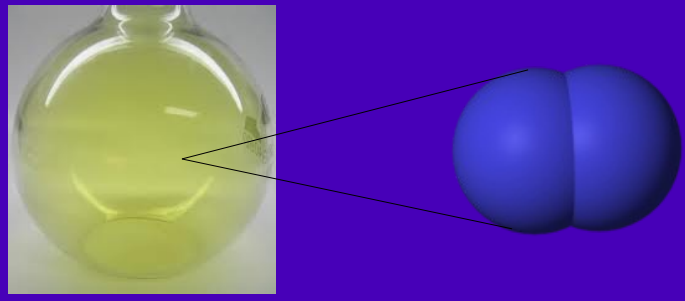
Atoms have the ability to connect to each other through chemical bonds.

For example, when only **hydrogen** atoms are present, they hook up to form pairs. These are called **diatomic molecules**.

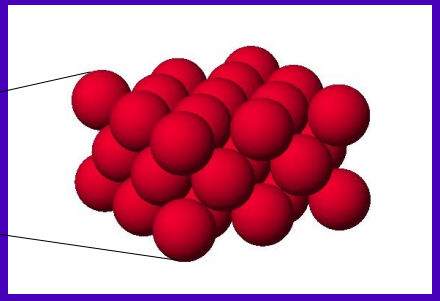


Oxygen and **chlorine** atoms do the same thing.





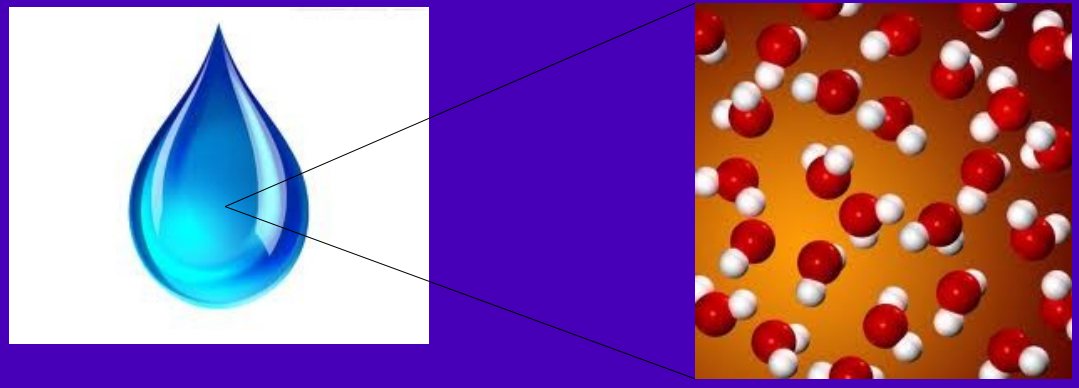
Sodium atoms, however, do not. They remain as individual atoms lined up in rows unless some other element is present.



(More on why in a later lecture...)

When two or more atoms of different elements are joined together in a specific ratio, this is called a **compound**.

water: **1 atom of oxygen, 2 atoms of hydrogen**



How is water different from oxygen and hydrogen?

gas

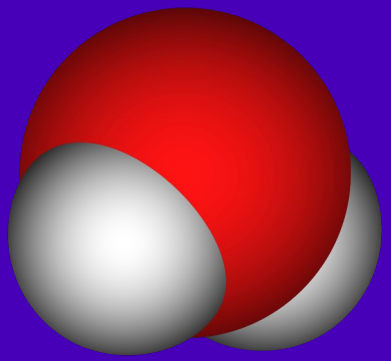
gas

liquid

When atoms are combined in compounds, their properties are different from when they were separate.

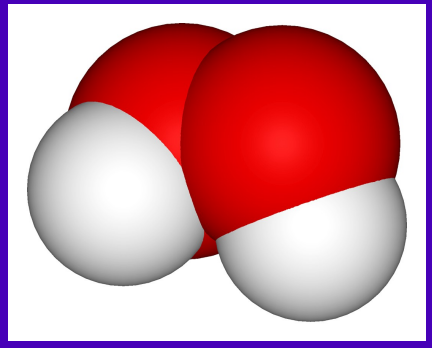
What if the ratio were different?

2 atoms of hydrogen
1 atom of oxygen



water

2 atoms of hydrogen
2 atoms of oxygen



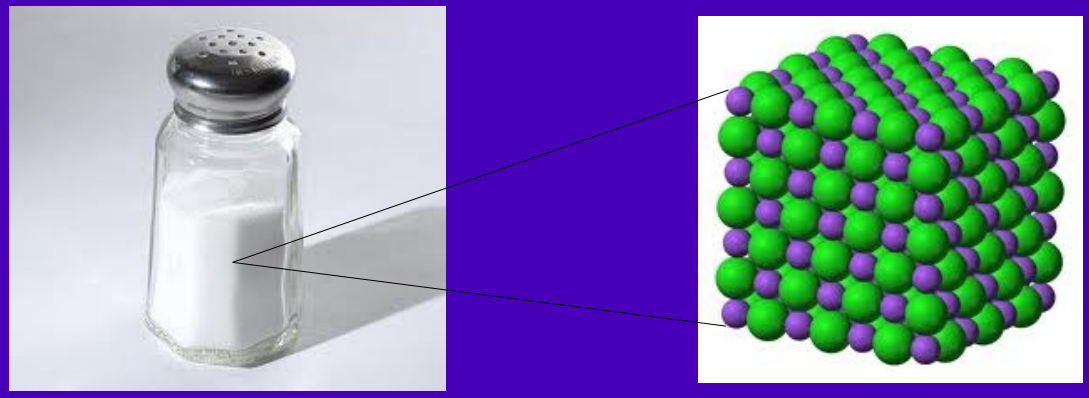
hydrogen peroxide

A different ratio of elements gives a different substance!

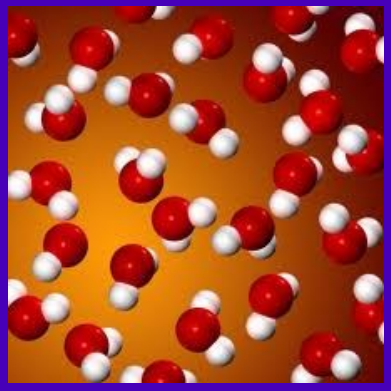
Do you think there could be a compound with 2 hydrogen atoms and 1.5 oxygen atoms?

nope – they have to be whole numbers
this was important to Dalton's atomic theory

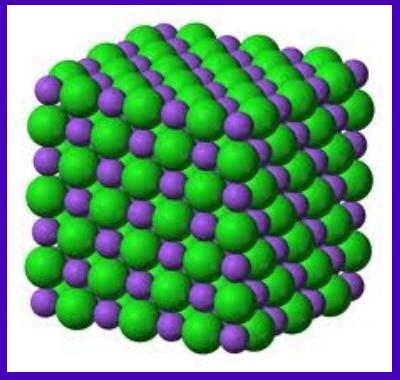
table salt: 1:1 sodium and chlorine



How are water and table salt different?



separate molecules



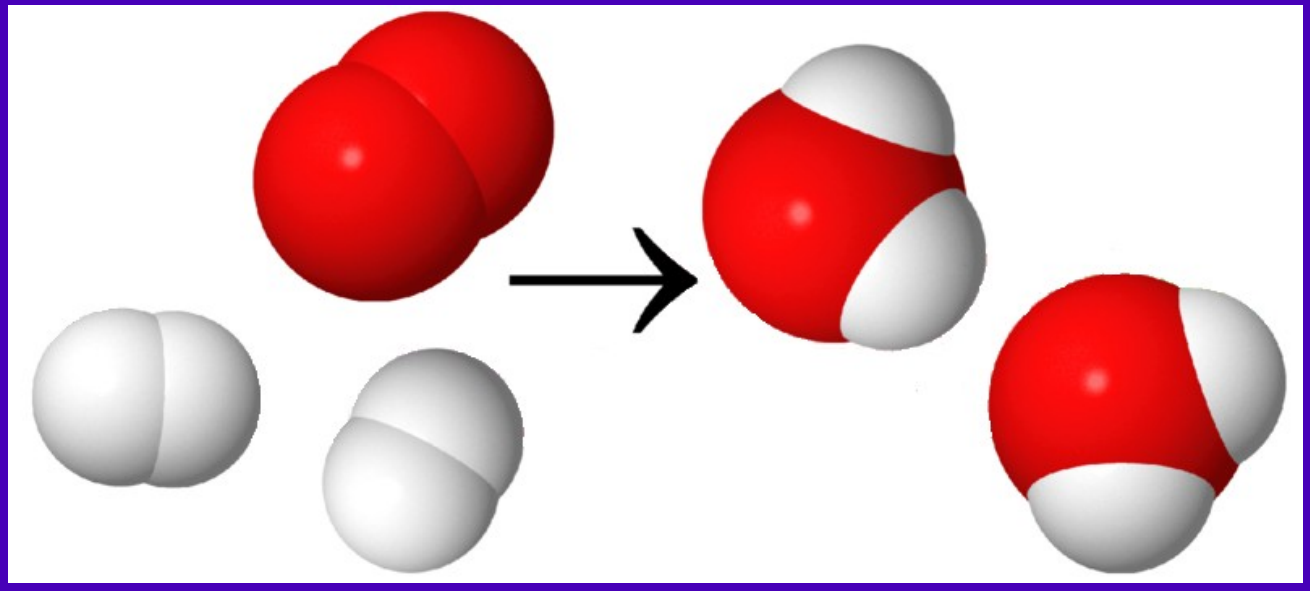
all atoms connected

We'll learn why these compounds are different in a later lecture.

Chemical Reactions

Since the images of atoms are not in motion, you can't see from the pictures what kinds of things they can do.

Here is an example of a chemical reaction. What's happening?



two hydrogen molecules + one oxygen molecule → two water molecules

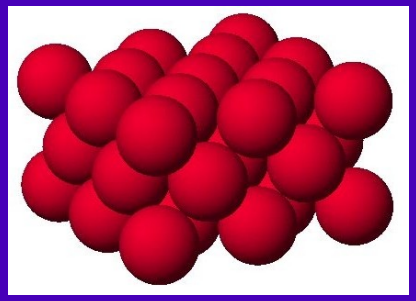
A chemical reaction = changing the connections between atoms!

What would the reaction of hydrogen and oxygen look like?

When hydrogen is burned, it is combined with oxygen from the surrounding air.

This is also the reaction that powers the Space Shuttle launch – the huge orange tank contains two separate tanks that hold oxygen and hydrogen which have been compressed to form liquids. When these are released and ignited, the resulting force carries the shuttle into orbit.

Here is another example. What is happening here?



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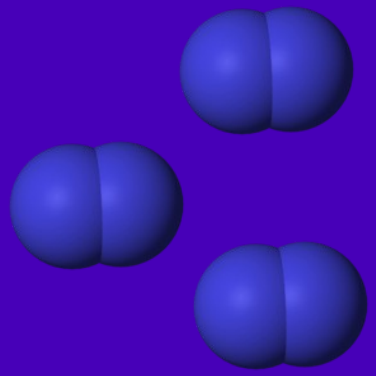
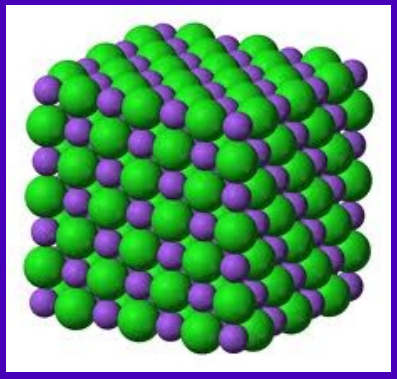




sodium atoms

chlorine molecules

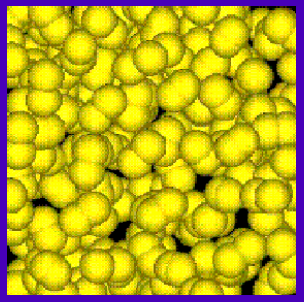
sodium chloride

This is a very energetic and dangerous reaction! Sodium metal is highly reactive, and chlorine gas is both reactive and poisonous.

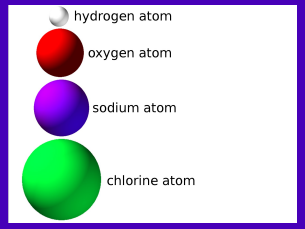
Amazingly, the result of the reaction is not very dangerous or poisonous (unless you are a slug or a person with high blood pressure...).

Putting it all together

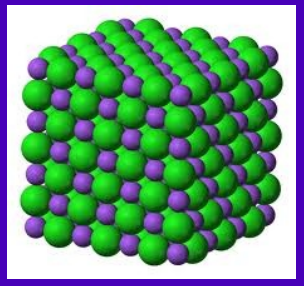
So far we've talked about 4 key terms:



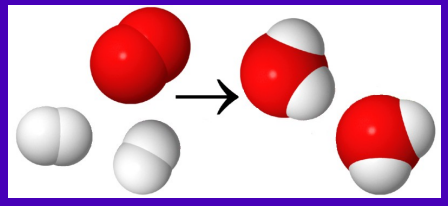
atoms: the building blocks of matter



elements: different types of atoms



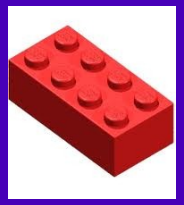
compounds: atoms joined together



chemical reactions: rearranging of connections between atoms

To review the ideas of atoms, elements, compounds, and chemical reactions, let's return to the comparison with Legos.

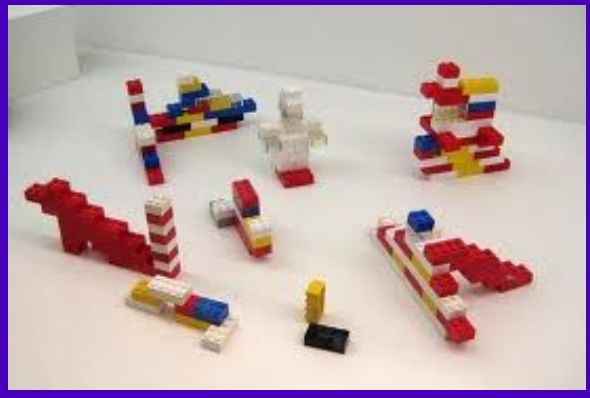
If an atom were a lego piece...



what would be the elements?

each type of Lego piece
only 6 colors and certain shapes

what would be the compounds?



Lego structures
they can only be joined in certain ways
you can make thousands of structures
with a few types of pieces

what would a chemical reaction be?

taking a structure apart and putting it back together again

Consider the following printed text. What would be the best comparison to...

> Low pressue will dominate most of the Northeast, dumping the heaviest rain on Maine, northeastern New York, and northern sections of Vermont and New Hampshire. Scattered rain and thunderstorms are expected in portions of the Carolinas and southern Georgia. Scattered showers and storms will develop in the Florida Peninsula, with potential for heavy downpours, gusty winds, and frequent lightning.

an atom: letter

the elements: different letters of the alphabet
only 26 letters in English

a compound: words
only certain combinations make sense
thousands words can be made from only 26 letters

a chemical reaction: anagram – rearranging the letters of a word or phrase to make another one

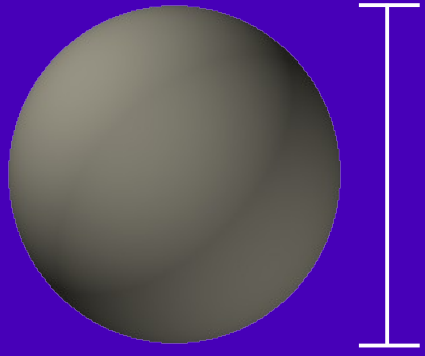
II. How small are atoms

Examples

Previously we mentioned that atoms are way too small to see, even with a microscope. So how small are they, really?

Here are some examples to help you get an idea of how small atoms really are.

1. One of the largest atoms is a uranium atom.



diameter = 350 picometers

= 3.5×10^{-10} m

= 0.00000000035 m

How many uranium atoms would fit in a millimeter?

100? 1,000? 10,000? 100,000? 1,000,000?

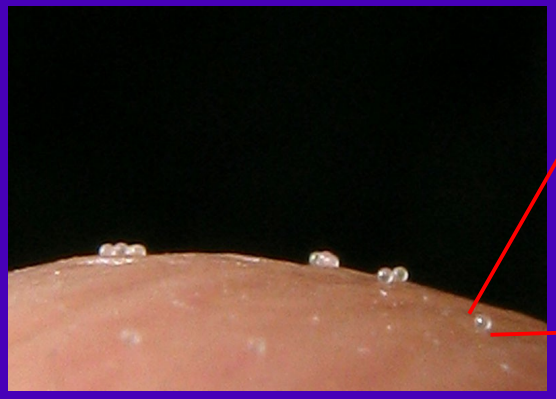
2,857,140

2. What is the smallest thing you can see?

The limit of human vision is about 200 microns, or 0.2 mm. The largest grains of pollen are about the size.







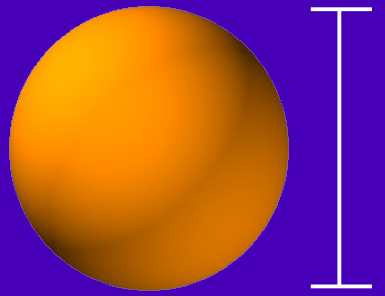
140 pm

Diamond is a substance made of pure carbon atoms. If you had a diamond the same size as this grain of pollen, how many carbon atoms would be in it?

a billion? a trillion? a quadrillion? a quintillion?

$739,000,000,000,000,000 = 7.39 \times 10^{17}$

3. Before 1982, pennies were made of pure copper.



If you turned all of the copper atoms in the penny into grains of sand, how much area would it cover?

29,377,400,000,000,000,000,000 copper atoms in a penny

Would that many grains of sand cover the floor of this room? **yes!**

Would it fill this entire room? **yes!**

Would it cover the Dixie State College main campus?

100 acres = 0.156 square miles = 0.405 km^2

yes!

Would it cover St. George?

65 square miles = 168 km^2

yes!

Would it cover the state of Utah?

84,899 square miles = 219,887 km^2

yes!

How deep?

41 feet

(a two story house is about 20 feet high)

Would it cover the state of California?

163,696 square miles = 423,970 km^2

yes!

How deep? 14 feet

Would it cover the United States?

3,794,101 square miles = 9,826,675 km^2

yes!

How deep? 7 inches

Could it cover the land surface of the earth?

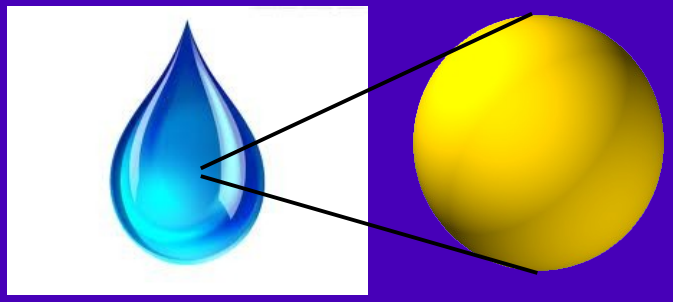
149,000,000 km2

yes!

How deep? 0.5 inches

That's how many atoms are in a penny!

4. There is some gold dissolved in sea water.



A single drop of water contains 6,022,000 atoms of gold.

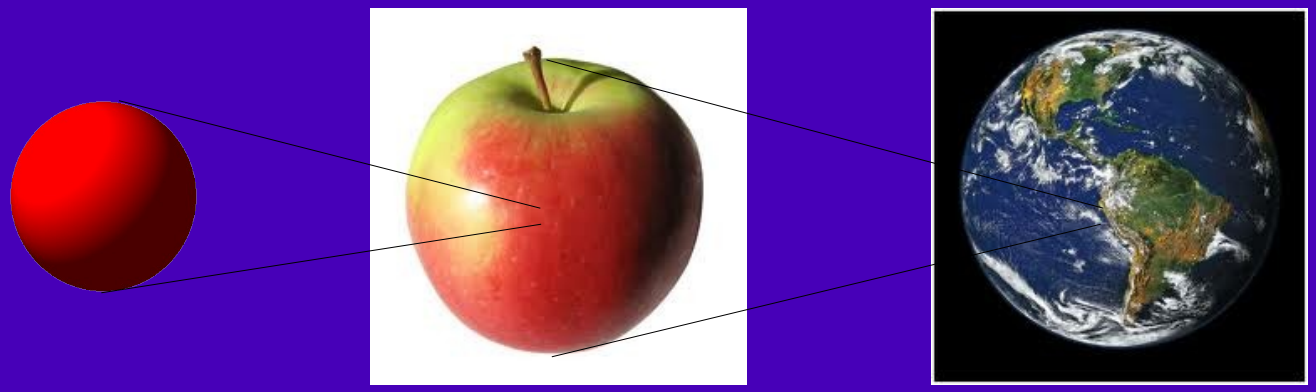
It is estimated that the world's oceans hold about 30,000 tons of gold (worth about $1.3 trillion).

How much ocean water would you need to get $1 worth of gold?

225,000,000 gallons!

That's 341 olympic swimming pools of water!

5. If you blew up an atom to the size of an apple, how big would an apple made of those atoms be?



the state of Utah?
the United States?
the moon?
the earth?
the solar system?

An atom is to an apple as an apple is to the earth!

Which of these examples do you like best?

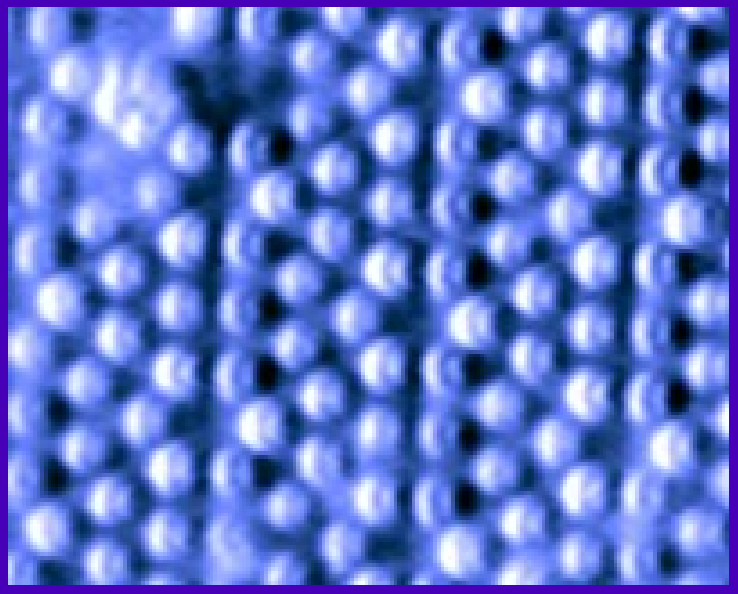
1. uranium atoms in a mm
2. carbon atoms in a barely visible diamond
3. atoms of copper in a penny
4. gold in the ocean
5. atoms the size of apples

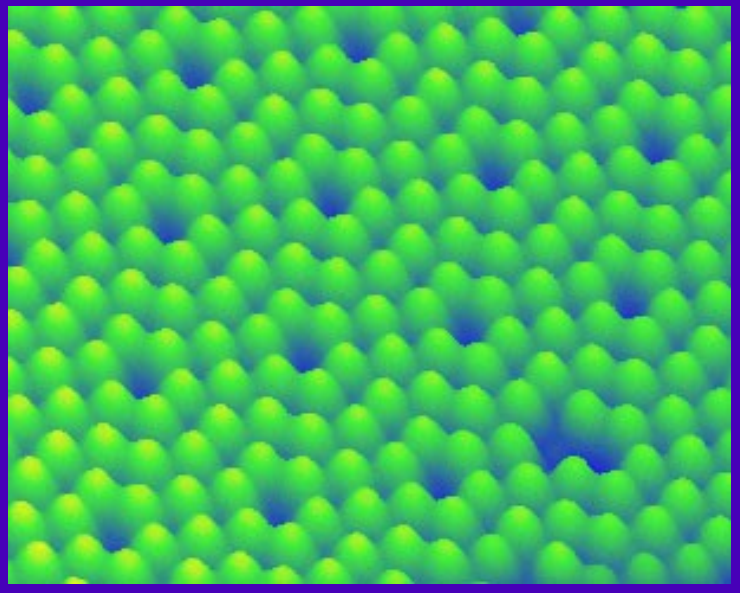
Images of Atoms

If atoms are so small that we can't see them with a microscope, is it still possible to get images of them?

Yes – using special instruments called scanning tunneling microscopes and atomic force microscopes.

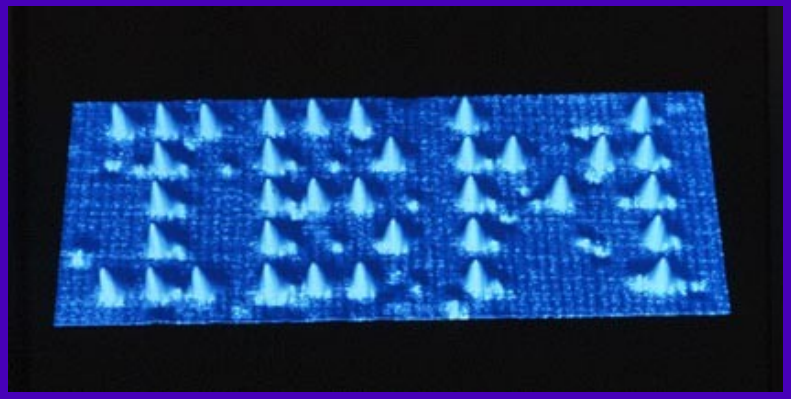
Instead of taking a picture with light, it shows us the shape of the atoms on a surface, rather like making a pencil rubbing.

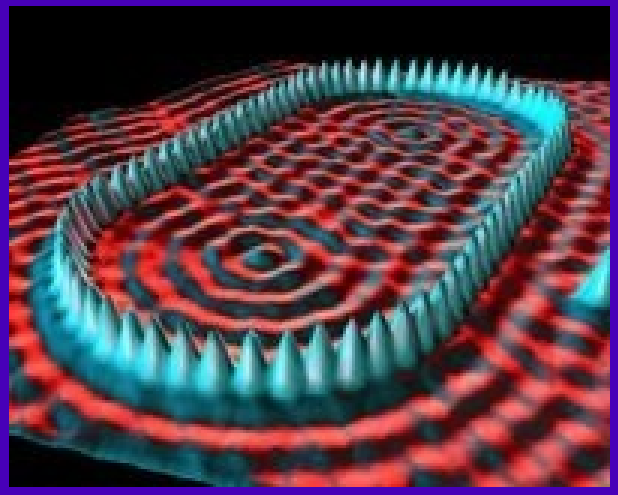


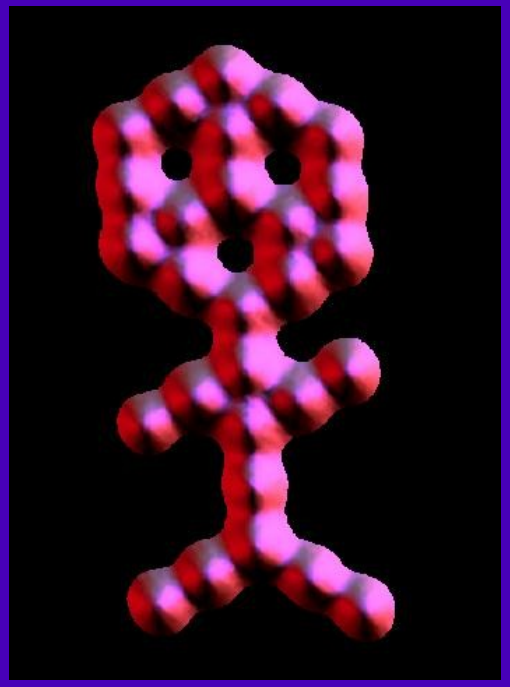


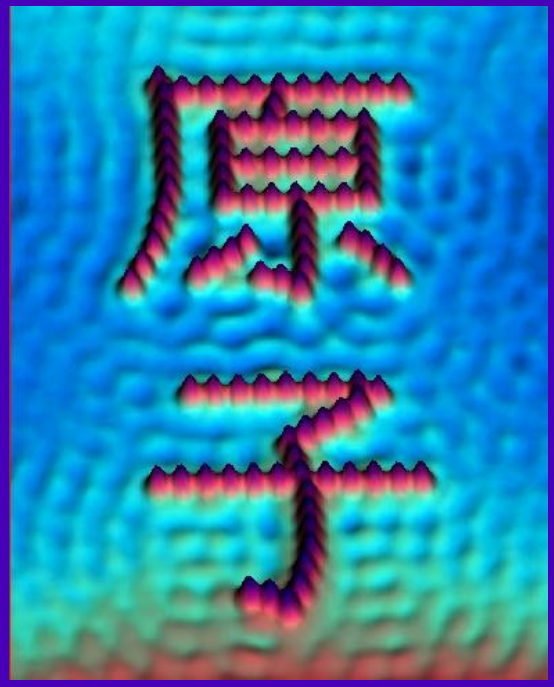
silicon atoms

We can even manipulate single atoms to create shapes on a surface.









Japanese characters for the word “atom”

IBM researchers made these images from 1990-1993.

Moles

Since atoms are so small, how can we count them or know how many there are?

We use a standard number of them.

An example of this that you might be more familiar with is a dozen.

a dozen eggs

a dozen roses

a dozen donuts

Every time you say "a dozen" you mean 12 of whatever it is.

With atoms, instead of a dozen, we use a **mole**.

mole of carbon mole of sulfur mole of copper

How many atoms do you think are in a mole?

$6.022 \times 10^{23} = 6{,}022{,}000{,}000{,}000{,}00{,}000{,}000{,}000$

This is also called **Avogadro's number.**

So when you say "a mole" of something you mean 6.022×10^{23} of that thing.

How did they pick this number?

a mole is actually defined as "as many atoms as there are in exactly 12.0 g of pure carbon"

If you had a balloon filled with one mole of hydrogen, and a balloon filled with one mole of oxygen, what would be the same about each? What would be different?

one mole of hydrogen **one mole of oxygen**

number of atoms? **the same**

mass? **different**

volume? **the same**

III. What are atoms made of?

Elementary particles

About 100 years after Dalton published his atomic theory, scientists discovered evidence that atoms are made up of even smaller particles.

name	symbol	charge	mass
protons	p^+	+1	1 dalton
neutrons	n^o	0	1 dalton
electrons	e^-	-1	0.00055 daltons

1 dalton = 1.66×10^{-27} kg

name	symbol	charge	mass
protons	p^+	+1	1 dalton
neutrons	n^o	0	1 dalton
electrons	e^-	-1	0.00055 daltons

How do protons, neutrons and electrons compare in size?

proton or neutron

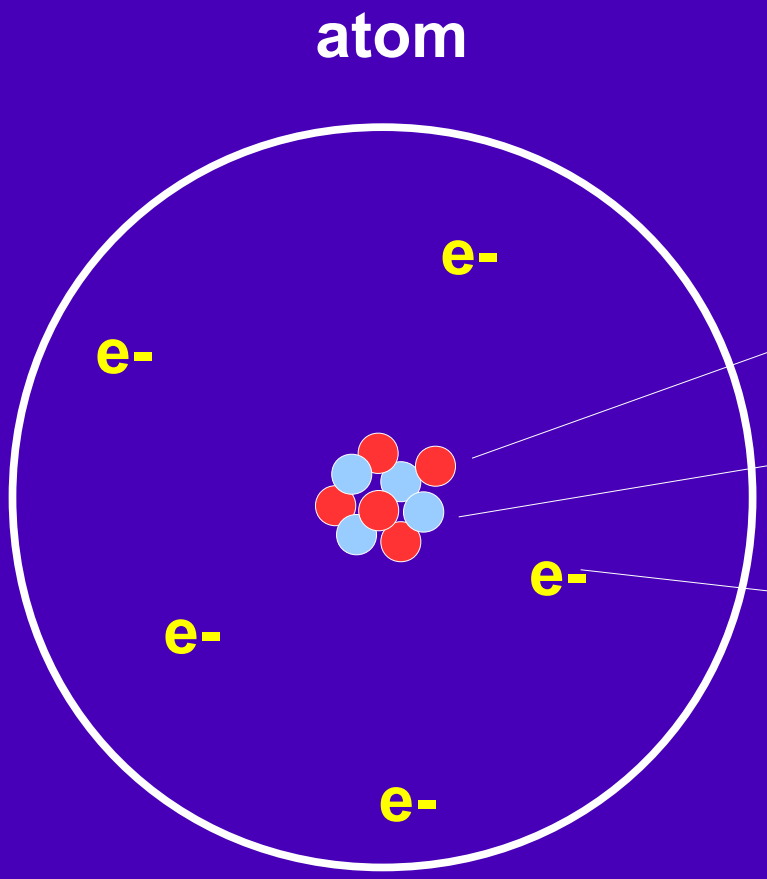
electron

How do the charges on the proton and electron compare?

exactly opposite

How atoms are put together

Draw a simple picture of an atom:

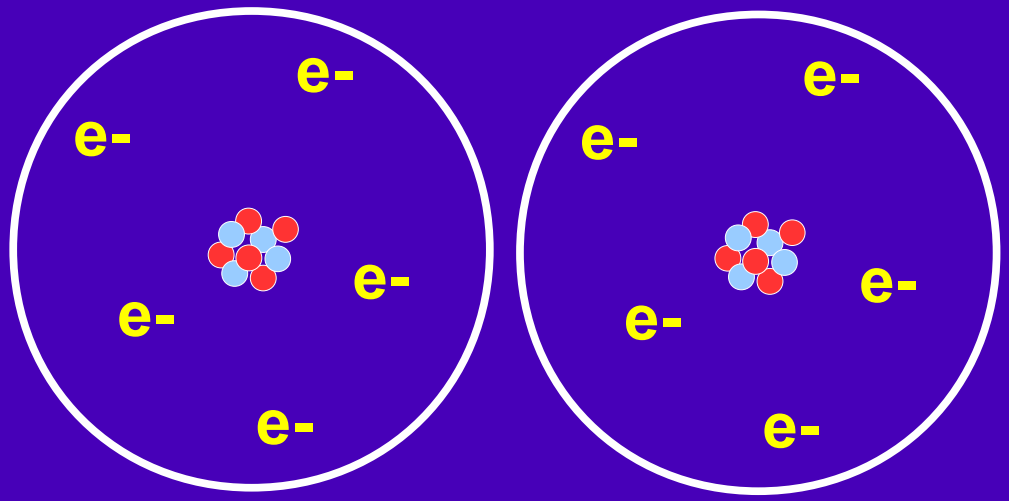


protons inside the nucleus

neutrons

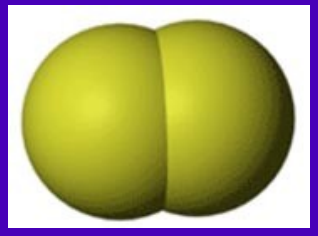
electrons outside the nucleus

If two atoms interact with each other to form a chemical bond, which elementary particles will be involved?

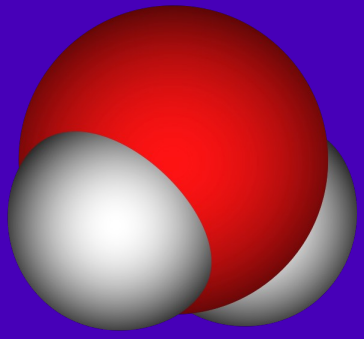


electrons – they're on the outside of the atom

What are some examples of this?



hydrogen molecules



water molecules

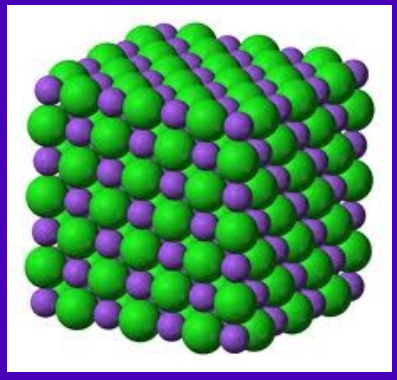
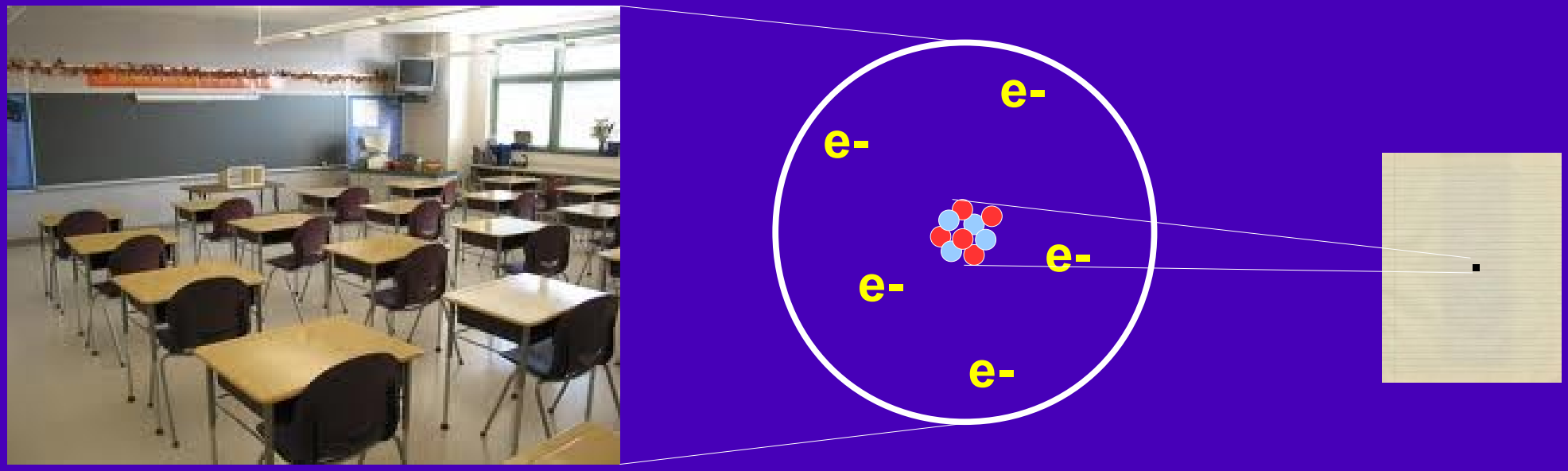


table salt

How big is the nucleus compared to the rest of the atom?



If you expanded an atom to the size of a large classroom, the nucleus would be the size of a period on a piece of paper in the middle of the room.

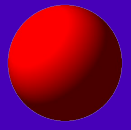
Properties of an atom

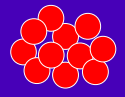
What makes a copper atom a copper atom, and not a gold atom?

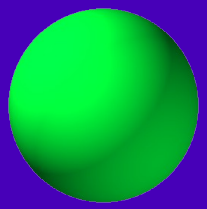
the number of protons

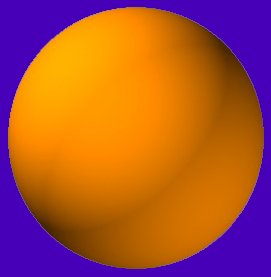
hydrogen atom  **1 proton** 

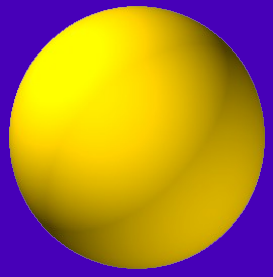
carbon atom  **6 protons** 

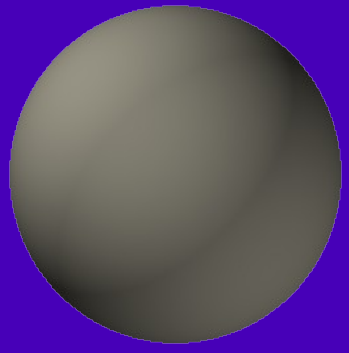
oxygen atom  **8 protons** 

sodium atom  **11 protons** 

chlorine atom  17 protons

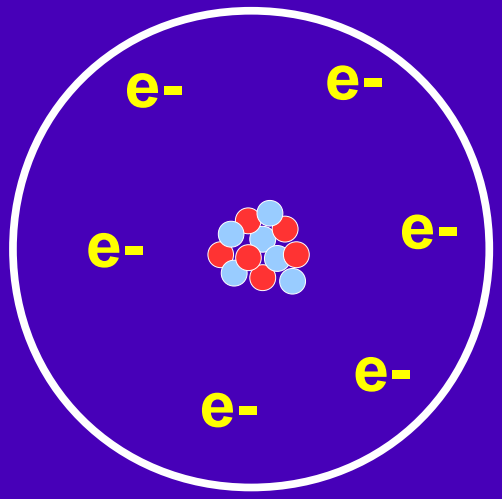
copper atom  29 protons

gold atom  79 protons

uranium atom  92 protons

The number of protons in an atom is called the **atomic number.**

A typical carbon atom has:



6 protons
6 neutrons
6 electrons

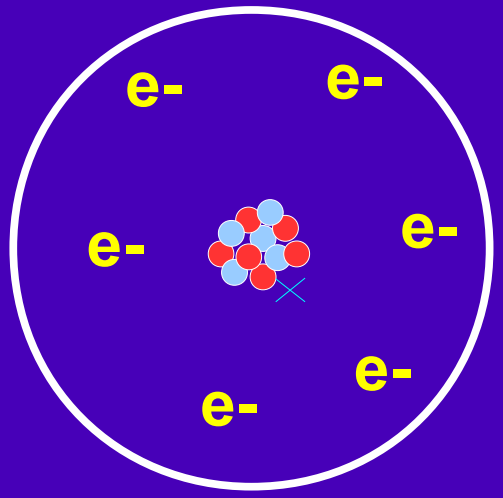
This gives it a mass of: 12 daltons

6 protons + 6 neutrons = 6 Da + 6 Da = 12 Da

and a charge of: 0

6 protons, 6 electrons = +6 + -6 = 0

What would happen if you removed a neutron from this atom?



6 protons
5 neutrons
6 electrons

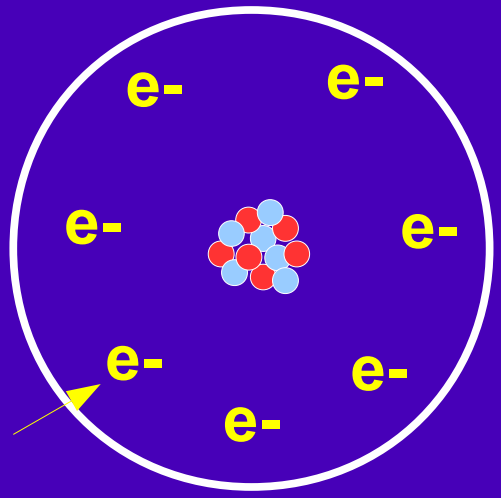
Is it still a carbon atom? yes – still has 6 protons

Does it still have a mass of 12 Da? no – now it is 11 Da

Does it still have a charge of 0? yes – 6 protons and 6 electrons

Two atoms that are the same element but have different masses are called isotopes.

What would happen if you added an electron to the original carbon atom?



6 protons
6 neutrons
7 electrons

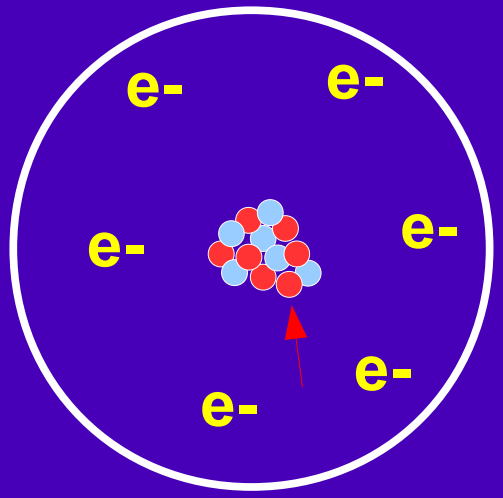
Is it still a carbon atom? yes – still has 6 protons

Does it still have a mass of 12 Da? yes

Does it still have a charge of 0? no – 6 protons and 7 electrons give it a charge of -1

Any atom with a charge is called an ion.

What would happen if you added a proton to the original carbon atom?



7 protons
6 neutrons
6 electrons

Is it still a carbon atom? no – now it is a nitrogen atom

Does it still have a mass of 12 Da? no – 7 protons + 6 neutrons gives a mass of 13 Da

Does it still have a charge of 0? no – 7 protons and 6 electrons give it a charge of +1

If you change the number of protons, you change the identity of the element!

Summing up:

Which elementary particle gives the atom its identity?

protons

Which elementary particles are involved in the mass?

protons and neutrons

Which elementary particles are involved in the charge?

protons and electrons

Which of these is easiest to change?

electrons – they're on the outside of the atom