Shedding Light on Atoms
Episode 1:
The Dawn of Modern Chemistry

The Shedding Light on Atoms series gives students the perfect introduction to the world of atoms. Using amazing demonstrations and animations we take students on a journey of discovery to explain not just what we know about atoms, but also how we know what we know about atoms!
In Episode 1, The Dawn of Modern Chemistry, we briefly examine what the ancient Greeks thought about what everything was made of and then explain the basics of atoms. We take a look at the discovery of carbon dioxide and oxygen in the mid-1700s and explore some of the properties of these gases, including oxygen's vital role in fire.

Contents:

Part A: Introduction: Atoms are far too small to be seen directly, even with the most powerful of optical microscopes. So how we know that they exist? That's what we're going to answer in this series.

Part B: Ancient and Medieval Ideas About Matter: The ancient Greek four-element theory (of Fire, Wind, Earth and Water), Democritus's atomic theory, the alchemists and their work…

Part C: Atoms and Elements: A brief introduction to what we now know about atoms, elements (substances made up of only one type of atom), and compounds (substances made of two or more different types of atoms which have bonded together). Knowing a little bit about atoms from the outset helps give students a better understanding of the various chemical reactions which led to the discovery of atoms.

Part D: The Discovery of Carbon Dioxide (CO_2): In the 1750's, carbon dioxide was discovered, showing for the first time that air was made of more than one type of gas.

Part E: The Discovery of Oxygen: Oxygen is essential for life and fuels won't burn without it.

The images shown below are screen grabs from the program and the text is more or less the program's script. Visit www.liacoseducationalmedia.com to see an excerpt and to download the student worksheet.

Part A: Introduction

What is everything made of? It's a question that people have been asking for thousands of years, from the days of the ancient Greeks right up to more modern times.

We now know that everything on Earth is made of atoms. Atoms are the tiny, tiny building blocks that make up the millions of substances that are all around us, from water, to salt, to sand, to the proteins that make up our skin and every other part of our bodies.

Atoms are so small, that it's impossible to see them directly, even with the most powerful of optical microscopes. So how do we know they exist? To answer that question, we need of course to look into the history of their discovery.

In this series of programs, we're going to look at how atoms were discovered starting with the discovery of the many types of gases that make up our atmosphere. We'll examine the famous periodic table of the elements and then show you how it was discovered that atoms themselves are made up of even smaller particles called protons, neutrons and electrons. Finally, we'll delve into the discovery of atomic bonds, that is the bonds that make atoms stick together to produce different substances. Along the way, we'll also mix in a lot of modern chemistry as well.

It's chemistry, it's history, it's human ingenuity. And where better to begin our voyage of discovery than with the time-honoured philosophers of ancient Greece.

Part B. Ancient and Medieval Ideas About Matter

The many philosophers of ancient Greece loved discussing ideas about the world and about nature and they spent a lot of their time trying to explain why things are the way they are.

One of the theories about matter, was that everything is composed of four so-called "elements": Fire, Wind, Earth and Water.

An element is a substance that can't be broken down into anything simpler, because it's not itself made up of anything else.

It was believed that these four elements combined in varying amounts and in different ways to produce all of the other substances that we see around us.

It was also believed that these four elements could be divided up into smaller and smaller bits forever because matter was continuous.

In about 400BC however, one of the philosophers, a man called Democritus, came up with a new theory. He believed that if you break a substance down into smaller and smaller bits, you'll eventually get down to single, incredibly tiny, particles. Each particle can't be broken down into anything smaller he said, so he called the particles "atoms". Atom is the Greek word for indivisible.

Now the ancient Greek philosophers didn't perform experiments like modern scientists do; they simply tried to explain everything using logic and their everyday observations.

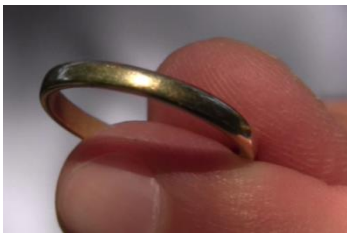
One of Democritus's arguments was based on the growth of a tree. He knew that a tree would grow, die at some point, and then decay.

When a new tree grew from a seed, it had the same kinds of chemicals in it as the original tree.
It follows then, that even though the original tree decays, the stuff that had made it up must have been made of tiny building blocks that would never decay and which were indestructible and which could therefore be recycled over and over.
The idea that tiny indestructible atoms can separate and then join back together again to create something new seemed to explain what was going on.

In this respect, Democritus was correct. Some of the atoms that make up our bodies right now, used to be part of dinosaur bodies millions of years ago.

Unfortunately, Democritus didn't have any proof that his theory was correct and it didn't catch on at the time and the 4-element theory remained the most popular theory right up to the 1700s, even though that too didn't have any evidence to support it.

In fact, during all this time, many people thought that if they could somehow combine the four elements in exactly the right way they could create gold!

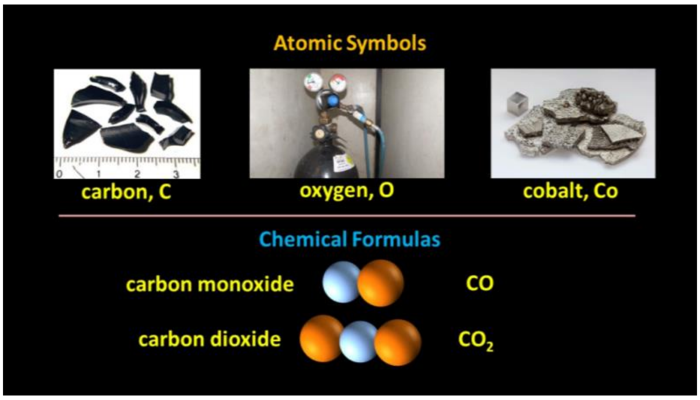


People who tried to purify various chemicals and then create new ones were called alchemists.
They never managed to achieve their objective of producing gold, because the four-element theory is completely wrong, but many of them did invent and develop a lot of tools for mixing, grinding and purifying the chemicals they worked with.

Part C: Atoms and Elements

Now let's pause our history lesson for a moment to look at some modern chemistry. An element is now defined as something that is made up of only one type of atom, and we now know that there are about 92 different types of naturally occurring atoms on Earth.
Pure platinum for example, is made up entirely of platinum atoms so it's an element. Pure zinc is made up entirely of zinc atoms so it's an element too. And since sulphur is an element too, it's made up entirely of sulphur atoms. (Sulphur and sulfur are UK/US spelling variations, much like colour/color, aluminium/aluminum and many other examples.)
Different types of atoms chemically react in different ways and have different weights and sizes.
The diameter of copper atoms for example is about 280picometres, that is 280 millionth millionths of a metre.
A row of 180 million copper atoms laid end to end is only 5cm long.
The elements, and the atoms that make them up, have each been given an "atomic symbol".

A carbon atom for example has the atomic symbol capital "C", a calcium atom, the atomic symbol capital "C" lower case "a", and a Lithium atom, capital "L" lower case "i".
All atoms are represented either by a single capital letter or a capital letter combined with a lower case letter.
Some of the symbols reflect the element's Latin name: Pb for example comes from the Latin word Plumbum. Plumbum is where we get our word plumber from. Lead pipes were sometimes used by the ancient Romans to carry water.
The so-called Periodic Table of the Elements lists all the elements along with their symbols.



So, while the atomic symbol for Carbon is capital C is and capital O is the atomic symbol for oxygen, Capital C lower-case o, Co, is the atomic symbol for Cobalt, a type of metal.
If a substance is made of two or more atoms that have joined together, it's represented by a chemical formula.
Carbon monoxide is an invisible poisonous gas made up of 1 carbon atom attached to 1 oxygen atom. Its chemical formula is capital C capital O.
Whenever you see a capital in a chemical formula, you know it represents a different atom.
Carbon dioxide is made of one carbon atom bonded to two oxygen atoms, so its chemical formula is CO_2.
Substances made of two or more different kinds of atoms joined together are called compounds. We'll learn about the different ways that atoms stick together later on.

The most well-known chemical formula, that of water, H_2O, tells us that water is made of 2 hydrogen atoms bonded to 1 oxygen atom.
On Earth there are untold trillions of these tiny H_2O units, called molecules, floating around each other in the oceans and forming a part of every living thing. The numbers in a chemical formula are always written as subscripts half way below the line, never as superscripts.

Of course most things are mixtures of elements and compounds. A cake for example is a mixture of things like flour, sugar, water and eggs. Flour and eggs are themselves mixtures of lots of different proteins and carbohydrates.
In a mixture, the substances are all next to each other, but are not bonded to each other like the atoms in a compound are.
Soft drinks are mixtures of water, sugar, flavours and carbon dioxide.

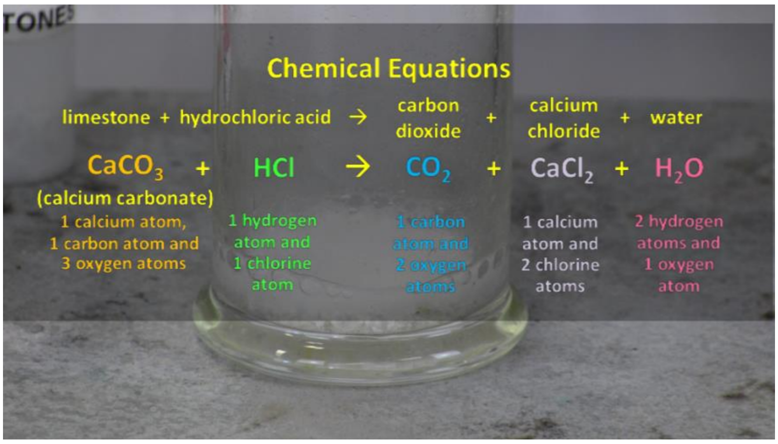
Mixtures of metals, like bronze, which is a mixture of copper and tin, are called alloys. Bronze is actually harder than either pure copper or pure tin. Brass, is a mixture, or an alloy of copper and zinc.
Steel is basically a mixture of more than 98% iron and less than 2% carbon. This mixture is harder and stronger than iron is on its own.
Now the alchemists of the middle ages didn't know anything about atoms or compounds. They were operating under the ancient and mistaken theory that there were only 4 elements.

It wasn't until the 1700s that scientists really started making progress, and actually began performing carefully controlled experiments to test their theories. They then realized that the idea that everything was made of combinations of Fire, Wind, Earth, and Water, just couldn't explain what was happening in the chemical reactions they were observing.

Part D: The Discovery of Carbon Dioxide (CO_2)

The idea that "air" is an element, that is a basic building block of matter which can’t be broken down into anything simpler, started falling apart when scientists realized that there are many different types of gases that make up the air. In the 1750s, Scottish scientist Joseph Black started experimenting with the gas that is produced when limestone chemically reacts with acids.
If I pour some crushed limestone into this gas jar and then add some hydrochloric acid, a chemical reaction occurs between the two substances and a gas is produced.

But is this gas the same as the air we breathe?
We can find out with a simple test.
An icy-pole stick on fire will quite happily burn away in the air, but as soon as I put it into the gas being produced in this chemical reaction, the flame is extinguished.
Joseph Black called this gas "fixed air", but we now call it carbon dioxide.
Black found that carbon dioxide is a natural but very small part of our atmosphere, and we now know it makes up about 0.04% of it.
In modern chemistry, we use chemical equations to show which substances reacted and which new substances are produced.
The chemical equation for the reaction that we’re looking at is
limestone + hydrochloric acid → (produces) carbon dioxide + calcium chloride (which we can’t actually see because it’s dissolving into the acid as soon as it’s forming) + water
This is called a word equation.
The things that chemically react are called the reactants, and the things that are produced are called the products.
Since we now know about atoms and we know the chemical formulas of these substances, we can also write a symbol equation.



$CaCO_3 + HCl \rightarrow CO_2 + CaCl_2 + H_2O$
$CaCO_3$ (the technical name for limestone is calcium carbonate which is made of 1 calcium atom, 1 carbon atom and 3 oxygen atoms all bonded together, (well not just 5 atoms in total of course but millions of repeating units) + HCl (hydrochloric acid is made of 1 hydrogen atom and 1 chlorine atom) produces CO_2 (carbon dioxide is made of 1 carbon atom and 2 oxygen atoms bonded together) + $CaCl_2$ (calcium chloride is made of 1 calcium atom and 2 chlorine atoms bonded together) + $H_2$0 (water is made up of 2 hydrogen atoms bonded to one oxygen atom).

Carbon dioxide is also produced when pure carbon powder burns.
The equation for the reaction is carbon + oxygen → carbon dioxide.
$C + O_2 \rightarrow CO_2$
C (the modern symbol for carbon) + O_2 (oxygen atoms in the air always come in pairs) produces CO_2 (one carbon atom and two oxygen atoms bonded together)
Carbon is the substance that makes up most of the charcoal and soot in a fireplace; most of the wood burns away, but small amounts of unburnt carbon are left behind.

Carbon dioxide can also be produced by the chemical reaction between bi-carb soda, the white powder I'm spooning into the large beaker, and vinegar. The carbon dioxide gas being produced rises up and fills the beaker, snuffing out the flames one by one.
The chemical equation for the reaction is
sodium hydrogen carbonate (which is the technical name for bi-carb soda) + vinegar → carbon dioxide + sodium acetate + water
$NaHCO_3 + CH_3COOH \rightarrow CO_2 + CH_3COONa + H_20$

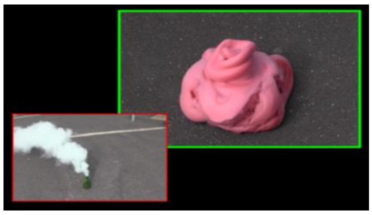
Part E: The Discovery of Oxygen

In the 1770s, another gas that makes up our atmosphere was discovered. We can create this gas by pouring hydrogen peroxide into a conical flask with a small amount of manganese dioxide powder in it.

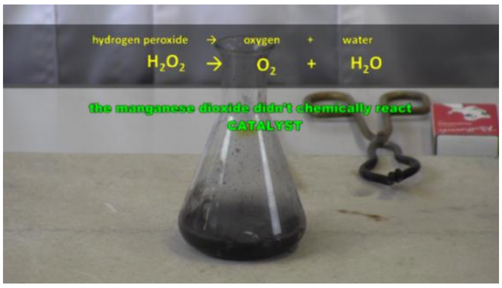
When these two chemicals come into contact, a gas is produced and the liquid froths up. This gas doesn't extinguish fire, but does the exact opposite: it makes the wood burn more vigorously, producing a hotter, brighter flame. It will also rekindle glowing embers.
In 1777, it was named "oxygen".
Two scientists independently discovered oxygen more or less at the same time: Sweden's Carl Scheele and England's Joseph Priestly.
It was French scientist Antoine Lavoisier though, who conducted extensive research into this new gas, who gave it the name oxygen.
Now they didn't use H_2O_2 to produce oxygen, they discovered it because of the way it chemically reacted with metals, but this reaction shows oxygen's effect on fire.
hydrogen peroxide → oxygen + water $H_2O_2 \rightarrow O_2 + H_2O$
$2H_2O_2 \rightarrow O_2 + 2H_2O$
The equation for the reaction is hydrogen peroxide produces oxygen gas + water. H_2O_2 produces O_2 + H_2O. Notice how the manganese dioxide, the black powder, isn't in the equation. This is because it didn't actually chemically react. H_2O_2 naturally decomposes to form O_2 and H_2O, but manganese dioxide speeds up the rate at which this happens, without itself actually changing at all! A chemical that speeds up a chemical reaction is called a catalyst.

This conical flask also contains manganese dioxide, and some food dye and detergent. When I pour in the hydrogen peroxide this time, the chemical reaction produces what's affectionately known as elephant's toothpaste.

The hydrogen peroxide I used in the lab was actually heavily watered down, but the hydrogen peroxide I used here was far more concentrated so the reaction lasted much longer, about two minutes or so and produced much more heat.



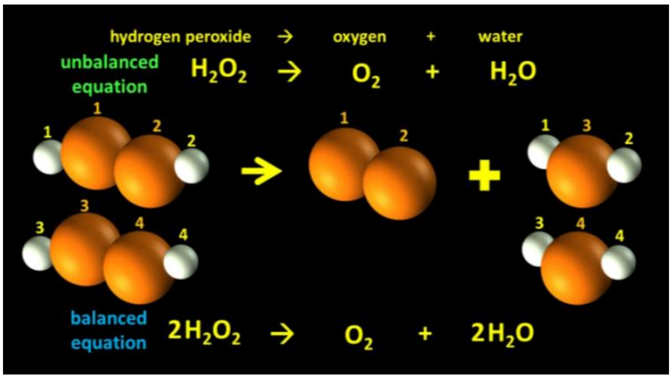
At the bottom left of screen, you can see what happens if I don't use detergent. No soap suds are produced and a hot fountain of steam and oxygen simply erupts out of the conical flask.



Now you may have noticed that there's a problem with this symbol equation. We can draw the H_2O_2 like this, showing the 2 oxygen atoms and the two hydrogen atoms that it's made of. We can also draw the oxygen gas produced and the water. We started with two hydrogen atoms on the left hand side of the equation and we ended up with 2 hydrogen atoms on the right hand side. But the two oxygen atoms that we started with, have become three oxygen atoms. Where did the third oxygen atom come from?

This equation is what's called an unbalanced equation. There's nothing wrong with an unbalanced chemical equation, since it tells us the chemical formulas of the reactants, well one reactant in this case, and of the products, but, since we've come this far, we might as well learn about what we call balancing equations.

The third oxygen atom in fact came from another H_2O_2.



When the reaction occurs, 2 H_2O_2s split apart to produce 1 pair of oxygen atoms and in fact 2 H_2Os. The balanced chemical equation can therefore be written as $2H_2O_2 \rightarrow O_2 + 2H_2O$

On the left hand side there are 4 H and 4 O atoms and on the right hand side there are 4 H and 4 O atoms as well. The equation is balanced.

But of course what really happens is that for every two trillion or some such number of H_2O_2 s we started with, one trillion O_2s and 2 trillion H_2Os are produced.

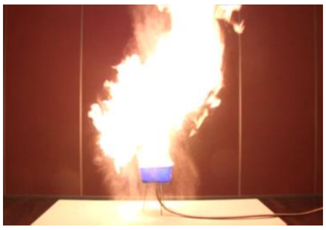
Balancing equations can sometimes be a little tricky, but with practise you can get the hang of it. Now let's get back to oxygen.

In the 1780s, Antoine Lavoisier showed that whenever anything burns, it's actually chemically reacting with the oxygen in the air.

To start a fire, you need three things:

1. a fuel, wood or paper for example,
2. a heat source that will make the fuel reach its ignition temperature, that is the temperature where it's hot enough to start burning. Often another fire is the heat source, but any heat source, will do. Electricity can make things hot enough to burn. And so can friction. The chemicals on a match head have a low ignition temperature, so even a little friction can make them hot enough to start burning. If you don't have modern conveniences, you can still start a fire, of course, but it's much more difficult, and
3. you need oxygen.

If your fire isn't that hot and you blow air onto it, there's more oxygen available, so the fire gets hotter.
However, you can blow out a match because the sudden puff of cold air onto the wood, cools the wood down and the fire goes out.
If you cover burning wood with sand, the oxygen in the air can no longer get to it, so the fire goes out. But, if your fire is at a campsite and you're about to leave, make sure that that any unburnt wood is actually cold to ensure that, if the wind picks up, the fire doesn't flare up again and cause a bush fire.
Water also stops oxygen getting to burning wood and so extinguishes the fire. Water has the added advantage of cooling the wood down: since a fuel will only ignite if it reaches a high enough temperature, wet wood, which stays relatively cool, doesn't burn.
It also works if I cover this flame with a bell jar. The wax needs oxygen to burn. Once the oxygen is used up, about 40 seconds later in this case, the fire goes out.
Earlier, we saw how carbon dioxide can put out a fire. This is because it fills the container and pushes out all the oxygen, so the fuel can't burn.
Many fire extinguishers have compressed carbon dioxide in them. The CO_2 sprays out onto the fuel and puts the fire out.



Now flour ordinarily won't burn, although it does char a little. However, if you puff it up and surround each tiny particle with oxygen, it'll burn very nicely… and very dangerously.
There was a lit candle inside the blue container that ignited the flour.
Sometimes especially when they're being filled or being emptied, silos can explode because the stuff inside them, wheat or flour for example can puff up and then catch fire. All it takes is a little spark from static electricity.
Here you can see the aftermath of a sugar refinery silo explosion in Port Wentworth, Georgia, United States in 2008. Many silos have carbon dioxide gas pumped into them, to reduce the risk of fire.
Now because oxygen is so common and because it chemically reacts with lots of different substances, its discovery in the late 1700s really helped to accelerate the study of chemistry and led to even more discoveries, discoveries we'll be looking at in our next program. See you then.

Credits:

Written, directed and presented by Spiro Liacos.

Photos of the elements © Heinrich Pniok. Used with permission. Visit http://pse-mendelejew.de/en/ to see originals.

3D anamation of the Rutherford atom.ogv by Damek (David Marin) is licenced under CC BY-SA 3.0. 

Aristoteles Louvre.jpg by Eric Gaba (User:Sting) is licensed under CC BY-SA 2.5. 

Socrates Louvre.jpg by Eric Gaba (User:Sting) is licensed under CC BY-SA 2.5. 

Plato Silanion Musei Capitolini MC1377.jpg by Marie-Lan Nguyen (user:Jastrow) is licensed under CC BY 2.5. 

Kapitolinischer Pythagoras.jpg by Galilea is licenced under CC BY-SA 3.0. 

Hippocrates pushkin02.jpg by Shakko is licenced under CC BY-SA 3.0. 

Friction fire - finding & using coal fungus (Daldinia concentrica) - first fire for year 2011 by freejutube is licensed under CC BY. 

Steelworks footage © Altos Hornos de Mexico. Used with permission.

Thanks to the National Archaeological Museum, Athens, Greece

Thanks to the Delphi Archaeological Museum, Delphi, Greece