# THE WORLD OF CHEMISTRY

Program #7

THE PERIODIC TABLE

Producer Doug Bolin

Air Script: October 31, 1988

PRODUCED BY

EDUCATIONAL FILM CENTER
and
THE UNIVERSITY OF MARYLAND

# THE WORLD OF CHEMISTRY

Program #7: The Periodic Table
Producer Doug Bolin
Air Script: October 31, 1988

Annenberg/CPB Project Logo and Music

Funder Credits

RH in front of periodic table

ROALD HOFFMANN (SYNC):
I'd like to show you the most important piece of equipment that you're likely to encounter in a chemical laboratory. How much do you think it'll cost? Was it invented in the United States and made in Japan? Are you ready? Let's see. Here it is. This is it. Not a superconducting supercollider, is it? Not a piece of equipment that's worth a hundred million dollars. Just a piece of paper, a chart, an idea, a tool for the mind. This was invented by Mendeleev, a Russian, 120 years ago. It's called the periodic table, and it's worth more to chemists than all of the pieces of equipment in our laboratories.

SUPER: THE PERIODIC TABLE

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

MONTAGE: Sunset shots, close up of experiments, diamond, heating, boiling, lightbulb, close ups of various elements

NARRATOR (MUSIC and NAT SOUND under):
What are the properties of the substances in the world around us? There are two types of properties. Chemical properties refer to the elements' ability to combine with other elements and form compounds. Physical properties include density, hardness, melting point, boiling point, and conductivity. Each element is different from every other element in its chemical and physical properties. This uniqueness can be traced to the atomic structure of the element. But some groups of elements also share common properties that vary systematically and predictably. These common properties are the basis of the modern periodic table.

GRAPHIC: The periodic table: symbols for the elements

NARRATOR (MUSIC under):
There are 109 elements in it. 88 occur naturally. The other 21 are man-made or artificial elements. For centuries, Latin was the common language of science, so many elements have Latin names. (cont.)

NARRATOR cont:
For instance, iron was ferrum, so its abbreviation became "Fe". Gold was Aurum, Latin for "shining dog," so it became "Au". Madame Curie discovered an element and named it after her native Poland, "polonium." And more recently discovered elements have been named after famous people, such as Einsteinium, named for Albert Einstein, and Nobelium, named for the man who established the Nobel prize, Alfred Nobel. Besides a symbol for the element's name, in this case helium, each box also contains some important numbers. Notice the number below the He symbol. This is the atomic mass of the element, the total mass of the protons and neutrons.

GRAPHIC: Isotope definition

NARRATOR (MUSIC under):
All helium nuclei contain two protons. However, the number of neutrons may vary. For example, there's a rare form of helium which has only one neutron in the nucleus. The two varieties of the same element are called isotopes.

GRAPHIC: The periodic table: atomic mass and number

NARRATOR (MUSIC under):
The atomic mass of an element is the weighted average of the masses of the isotopes in the naturally occurring element. The number over the symbol in each box is the atomic number of the element, the number of protons in each nucleus.

DS in lab

DON SHOWALTER (SYNC):
An atomic number is what determines an element's position in the table. The elements in the table are arranged in order of ascending atomic numbers, as you go from left to right. Here we have hydrogen number 1, way over here, helium number 2, then lithium 3, beryllium 4, boron 5, and so on across to neon 10, back to sodium 11, and magnesium 12, and so on, left to right. Now there's another facet to the table. Because of the way it's laid out, each element is a member of a group that goes up and down the table, and a period that goes across the table. For example, potassium, it is a member of this group, and it is a member of this period.

GRAPHIC: The periodic table: periods

NARRATOR (MUSIC under):
There are seven horizontal periods, running from left to right. Each one has been assigned a number, which is placed at the left of the period. Fourteen of the elements in periods 6 and 7 are pulled out of their place and laid out below. If they were placed in the table, it would look like this. So it makes it much easier to arrange the table if they are at the bottom.

DS in lab

DON SHOWALTER (SYNC):
There are also 18 vertical columns, called groups or families. Each group is designated by a number and a letter, which is placed at the top of the column.

GRAPHIC: The periodic table: groups

NARRATOR (MUSIC under):
Elements within a family all have similar properties. To demonstrate this, let's look at one family on the far right of the periodic table, the noble gases.

DS in gymnasium

SUPERS: He, Ne, Ar, Kr, Xe

DON SHOWALTER (SYNC):
These balloons contain the first five noble gases. We have helium, neon, argon, krypton, and xenon. (cont.)

DON SHOWALTER cont:
Now, we're missing radon because it's radioactive. We're all familiar with helium. It's used in balloons and blimps. The rest are used to fill various light bulbs and lamps. But what are some of the properties that they have in common? Well, they're odorless, and they're colorless, and they're all quite unreactive. And as you go down in the family, each one gets heavier than the previous one. Let me show you what I mean. This is helium. Here it goes. This is neon. It's somewhat lighter than air. There it goes. Now, argon and krypton are both heavier than air, and xenon is the heaviest of the ones we've seen. It's the proverbial lead balloon.

GRAPHIC: The periodic table

NARRATOR (MUSIC under):
You can begin to see the different types of information that can be derived from the periodic table. But how do chemists use the table in their work?

MONTAGE: Shots of glass making, glassware

NARRATOR (MUSIC and NAT SOUND under):
Glass making is one example. At one time in the ancient world, glass was so rare that it was prized more highly than jewels or gold. (cont.)

NARRATOR cont:
But as we mastered the techniques of glass working, glass became a commonplace necessity. The types of glass multiplied tremendously. So that today glass comes in many forms and colors. Artists use it to create new and intriguing constructions. Craftsmen mold it by hand into the elegant forms of Steuben crystal. And factories manufacture glass for countless everyday uses. Basically, different types of glass are made by mixing silicon dioxide, sand, with different metal oxides, then melting them together. The choice of the oxides, which determines the characteristics of the glass, is guided by the periodic table. Dr. Gerry Fine is a glass chemist at the Corning Glass Works in Corning, New York.

INTERVIEW: Dr. Gerry Fine, glass chemist, Corning Glass Works, Corning, New York

SUPER: Gerry Fine

DR. GERRY FINE (SYNC):
I cannot imagine working without the periodic table, because scientists are interested in looking for systematic relationships between different substances and between different elements. (cont.)

DR. GERRY FINE cont:
The periodic table is a simple way of looking up and finding systematic relationships between different elements that we can understand at a very simple level.

Shots of glass making, periodic table graphic

NARRATOR (MUSIC and NAT SOUND under):
In the glass research center at Corning, thousands of samples are poured each year as new types of glass are developed and perfected. One group of elements frequently used to make glass is on the far left of the periodic table, the alkali metals. By mixing in different alkali metals, glass with different characteristics can be produced. So understanding their variations in behavior is important to glass makers, and, indeed, to all chemists.

DS in lab

DON SHOWALTER (SYNC):
We call this family the alkali metals. They make up Group 1 in the periodic table. The first element is lithium, and then there's sodium, and potassium. Down here is rubidium, and this one is cesium. And do you notice anything that they all have in common? You probably see that they're all stored in very unusual ways. (cont.)

DON SHOWALTER cont:
The reason we do this is because they're all highly reactive. I have here three containers of just water. I'm gonna take a piece of this lithium and put it into the water. And watch what happens, how it starts to fizz a little bit. The fizzing now is the reaction of lithium with the water to produce hydrogen gas. Let's try the sodium. I'll get a small piece of that, not too big, because we don't want the reaction to be too violent. Oh, that reacts much faster, doesn't it? See the sodium bouncing around there, again fizzing, giving off that hydrogen gas. Okay. Let's try potassium, the most reactive of the three. I'll get a small piece of that and put it into the water. Wow! That really reacted violently. Did you see the immediate reaction of the potassium? Again, it's formed that hydrogen gas and the hydrogen gas was ignited.

Shots of alkali metals, glass strength test

NARRATOR (MUSIC under):
So the alkaline metals all have similar chemical properties, but they also vary systematically. As you go from the top to the bottom of the column, the atoms of each element become larger. Chemists can use this characteristic to increase the strength of their glass.

GRAPHIC: The periodic table (size chart)

NARRATOR (MUSIC under):
The size of an atom increases as we go down any column. In the alkali metal group, the atomic size increases from lithium, to sodium, to potassium, and so on. But as we move across a period, starting with an alkali metal, the size of the atom gets smaller and smaller until we get to a new period. Here we see a jump in atomic size in the next alkali metal, and again a decrease along the period. This pattern repeats itself throughout the table and is called periodicity.

INTERVIEW: Dr. Gerry Fine cont.

DR. GERRY FINE (SYNC):
Everyone is aware that glass tends to be a brittle material. If you've ever thrown a baseball through a window, you know that the glass breaks quite readily. However, there are ways of taking that simple window glass, which is made of sodium, calcium, and silicon, and treating the glass to make it strong. One way that we do that is by use of the periodic table. If we take that glass that contains sodium and substitute potassium in the surface for the sodium, or substitute an element that behaves basically in the same way, but is slightly larger, we can enhance the strength of that glass and make strong glass.

Glass strength demonstration

NARRATOR (NAT SOUND under):
The results of this process are quite easy to demonstrate. If a steel ball bearing is dropped from one foot onto glass made with the alkali metal, sodium, watch what happens. The sodium-based glass shatters completely. Now watch what happens if the same ball bearing is dropped on a piece of glass where potassium has been substituted for sodium. This time the ball will be dropped from 20 feet.

INTERVIEW: Dr. Gerry Fine cont.

DR. GERRY FINE (SYNC):
The way we do that is by taking the glass, which contains sodium, and dipping it in a bath containing molten potassium. What happens is the molten potassium substitutes for the sodium in the glass on the surface of the glass. Because, from the periodic table, we can tell that potassium is larger than sodium, the potassium atom literally stuffs the surface of that glass.

GRAPHIC: The periodic table, archival photographs of Dmitri Mendeleev

NARRATOR (MUSIC under):
The predictive ability of the period table was first demonstrated by a Russian chemist, Dmitri Mendeleev. (cont.)

NARRATOR cont:
One hundred years ago, he developed the predecessor of our modern table. Mendeleev's table included all the elements then known and was consistent with their varying properties. For three undiscovered elements, he left blank spaces, predicting that they did exist and that their properties would be consistent with their position in the table. For his time, it was an amazing hypothesis. One position that he left blank was this one, for gallium. Based on the properties of the two neighboring elements, aluminum and indium, Mendeleev was able to predict some of the properties of gallium. He was also able to predict two other elements, germanium and scandium. When the elements were discovered and their properties measured, Mendeleev's predictions were found to be remarkably accurate.

Archival photographs of Glenn Seaborg

NARRATOR (MUSIC under):
In this century, another chemist, an American, rearranged the structure of the table based on the properties of elements that he, himself, had discovered. His name is Glenn Seaborg.

GRAPHIC: The periodic table

NARRATOR (MUSIC under):
In 1944, the periodic table didn't look like it does today. The periods and groups were laid out differently.

INTERVIEW: Dr. Glenn Seaborg

SUPER: Glenn Seaborg

DR. GLENN SEABORG (SYNC):
Back in the days of Mendeleev, and actually extending into the 1930s, the heaviest elements, thorium, protactinium, and uranium, were put into the periodic table up in the body of the periodic table under hafnium and tantalum and tungsten, and it was my idea, in 1944, while I was working on the -- at the metallurgical laboratory in Chicago on the Manhattan atomic bomb project, that these might be misplaced, and that they might be the first three members of the actinide series. And then I boldly, and against the advice of some of my eminent inorganic chemist friends, plucked those out of the body of the periodic table and put them in the row below, and then continued that with 93, 94, and so forth, up to 103.

Archival photographs of Glenn Seaborg

NARRATOR:
The idea to rearrange the table occurred to Seaborg late one Friday afternoon. He was drafting a classified report for a seminar the following Monday. And he decided to include this idea in his report.

INTERVIEW: Dr. Glenn Seaborg cont.

DR. GLENN SEABORG (SYNC):
I presented this at that Monday seminar and, you know, it went over like a lead balloon, you know, the idea that one would be brash enough to change the periodic table after all these years, in this fashion, when, you know, everybody felt that thorium, protactinium and uranium should be in those sancrosanct [sic] positions up in the body of the periodic table under hafnium, tantalum, and tungsten.

Archival photographs of Glenn Seaborg

NARRATOR:
His discoveries of the new elements remained classified until after World War II. When he was able to publish, he incorporated his new arrangement of the periodic table.

INTERVIEW: Dr. Glenn Seaborg cont.

DR. GLENN SEABORG (SYNC):
I showed this periodic table to some of my friends, the most eminent inorganic chemists in the world, and told them that I planned to publish it, and they said, "Don't do it, Glenn. It's wrong. It will ruin your scientific reputation." Well, I'm fond of saying that I had an advantage, I didn't have any scientific reputation at that time, so I went ahead and published it.

Archival photographs of Glenn Seaborg, Nobel Prize

NARRATOR:
Seaborg's new arrangement enabled him to predict the properties of still more elements. His ideas were later verified when the elements were produced artificially. Seaborg was awarded the Nobel prize in chemistry in 1951.

GRAPHIC: The periodic table

NARRATOR (MUSIC under):
His rearrangement is our modern periodic table. And what ultimately determines the position of an element in this modern table is the way the electrons are arranged in the energy levels of the atom.

Image of atom

GRAPHIC: Energy level diagrams for elements

NARRATOR (MUSIC under):
As we move through the table and the number of electrons in an atom increases, the energy level diagrams contain more and more levels and sublevels. Both the number and types of electron clouds increase in complexity. For example, this is the energy level diagram for hydrogens, one electron in an s-cloud called the 1s. Lithium's three electrons are diagrammed like this, two electrons in the 1s-cloud. Each cloud can contain two electrons. Then the third electron is in another cloud, an s-cloud at the second level. Let's move forward to sodium and look at an energy diagram for its 11 electrons. Its first two electrons are in the cloud at the 1s level. Its next two electrons are in an s-cloud at the second level. This is actually only the first of two sublevels at the second level. So it's called the 2s sublevel. The next 6 electrons of sodium are in the other sublevel, called the 2p sublevel. Notice the number of clouds in the 2p sublevel. There are three p-shaped clouds in it. Each of these clouds contains two electrons. Where does sodium's 11th electron go? As we move higher on this energy diagram, we encounter the first sublevel of level 3, the 3s. It has only one s orbital in it. Sodium's 11th electron goes here. (cont.)

NARRATOR cont:
When chemists diagram energy levels of electrons within an atom, they replace the figures of the clouds or orbitals with blank lines. Arrows are used to indicate the presence of electrons in each orbital. This is the diagram for sodium's 11 electrons. Sodium is the second alkali metal. Note that it has only one electron in its outer orbital, the 3s. This is the diagram for lithium, the first alkali metal. Look at its highest energy level. Once again, it is only half-filled with only one electron in the 2s sublevel. The similarities in properties of lithium and sodium, and, indeed, all the alkali metals, are due to the similarities in their outer electron structure. The outer electrons in any atom are called its valence electrons. The noble gases are another example of a similarity in outer electron structure. They have a filled s or p sublevel, a very stable arrangement. Next to them is an important group called the halogens. They are all missing an electron from an almost-filled sublevel, which makes them very reactive. Now, as the number of electrons in an atom increases, what are the rules these electrons follow in filling different sublevels and orbitals? To find out,

DS on school playing field

NARRATOR:
Don Showalter went to St. Albans School on the grounds of the National Cathedral in Washington, D.C.

DON SHOWALTER (SYNC):
We're out here today to show you how the electrons fill up the various energy levels that you just saw on that diagram. And to help us out, we have these 11 baseball players.

TEAM
Right, coach!

DON SHOWALTER (SYNC):
These baseball players are now gonna represent electrons, and we're gonna have an electron practice. They're gonna practice the rules that chemists use to fill the various energy levels. Now, here's the ground rules. These bleachers represent the various energy levels, the lowest one being the 1s, colored blue.

SUPER: 1s

TEAM
1s!

DON SHOWALTER (SYNC):
The next energy level is the 2s. It's colored green.

SUPER: 1s, 2s

TEAM
2s!

DON SHOWALTER (SYNC):
Alright! Now, the 2p has three sublevels, and it's colored red.

SUPER: 1s, 2s, 2p

TEAM
2p with three sublevels!

DON SHOWALTER (SYNC):
Good. And we've got the highest energy level is the 3s, and it's colored yellow.

SUPER: 1s, 2s, 2p, 3s

TEAM
3s!

DON SHOWALTER (SYNC):
Alright. Now, there are three basic rules that we have to follow. Rule No. 1: Electrons fill lowest energy level first.

TEAM
Electrons fill the lowest energy level first!

SUPER: Electrons fill the lowest energy level first.

DON SHOWALTER (SYNC):
Okay. Here's Rule No. 2: No more than two electrons in any one orbital.

TEAM
No more than two electrons in one orbital!

SUPER: No more than two electrons in one orbital.

DON SHOWALTER (SYNC):
Beautiful. Here's Rule No. 3: If you have more than one orbital in a sublevel,

TEAM
If we have more than one orbital in a sublevel,

SUPER: If we have more than one orbital in a sublevel,

DON SHOWALTER (SYNC):
one electron in each orbital before you double up.

TEAM
one electron in each orbital before you double up.

SUPER: one electron in each orbital before you double up.

DON SHOWALTER (SYNC):
Great. Have you got it?

TEAM
Yes coach!

DON SHOWALTER (SYNC):
All right. Let's get energized. The first element is hydrogen. Go!

NARRATOR:
Hydrogen has one electron, so it goes in the lowest energy level available, the 1s.

DON SHOWALTER (SYNC):
Now we're gonna skip to nitrogen. Go!

NARRATOR:
Nitrogen has 7 electrons. The first four fill up the 1s and the 2s. But what about the next three? One goes in each of the three 2p orbitals.

DON SHOWALTER (SYNC):
Now we'll skip ahead to sodium. Are you ready, team?

TEAM
Yes coach!

DON SHOWALTER (SYNC):
Go!

NARRATOR:
Sodium has 11 electrons. The first 4 go into the 1s and the 2s. The next three go into each of the 2p orbitals. Then numbers 8, 9, and 10 go in. Finally, the 11th electron goes into the 3s sublevel.

DON SHOWALTER (SYNC):
And that's the way the electrons fill the energy levels. Right, team?

TEAM
Right coach!

Shots of x-ray fluorescence

NARRATOR (NAT SOUND under):
Scientists at the Smithsonian Museum have applied a technique that uses information about the energy levels of different atoms to study works of art. This technique analyzes the elements in different pigments and is called x-ray fluorescence. Dr. Jackie Olin is a chemist at the Smithsonian.

INTERVIEW: Dr. Jackie Olin, chemist, Smithsonian Institution

SUPER: Jacqueline Olin

DR. JACKIE OLIN (SYNC):
If, for example, you were to know an artist's work so very, very well that you knew that that particular artist never used a particular pigment in all the paintings that have been studied, and there's a painting in question, one might analyze a painting to determine whether or not that pigment, a pigment that is not characteristic of that artist, is present.

Still photograph of painting

NARRATOR (NAT SOUND under):
X-ray fluorescence involves bombarding the atoms in the painting with x-rays, causing them to eject an electron. To see exactly how this happens, let's return to the electron team.

"Electron Team"

NARRATOR (NAT SOUND under):
Here are the electrons in their energy levels for the element sodium. As an x-ray enters the atom, it knocks out an electron in the lowest orbital, the 1s. When this happens, some of the electrons in higher energy levels fall to lower energy levels, filling the gaps. As the electrons cascade down to lower energy levels, they give off an x-ray pattern that is characteristic of each element.

Instruments analyzing x-rays

NARRATOR (NAT SOUND under):
Instruments analyze these x-rays and identify what element is present.

INTERVIEW: Dr. Jackie Olin cont.

DR. JACKIE OLIN (SYNC/VO):
It's very nice to be able to quickly and easily find out what some of the elements are that are in the painting, because we have looked at the painting in terms of the colors we see, and we'll be interested to know that blue is a copper-containing blue or a cobalt-containing blue, and that can be done readily by using x-ray fluorescence to identify the elements present in that area. (cont.)

Analyzing artwork

JACKIE OLIN cont:
So it's a nice technique for nondestructively and quickly identifying some of the elements present in the painting.

SUPER: THE PERIODIC TABLE

MONTAGE: Periodic table graphic, elements, program demonstrations

NARRATOR (MUSIC under):
To review: The elements in the periodic table are arranged in serial order according to their atomic number. The rows are called periods, and the columns are called groups. The size of the atoms increases as we go down in a group and decreases as we go across any period. This is an example of a periodic property. Elements in any group have similar arrangements of electrons in their energy levels. Therefore, they have similar chemical properties.

RH in front of periodic table

ROALD HOFFMANN (SYNC):
You can see right away that a given electronic configuration implies similar properties. For instance, the alkali metals, with their 1 electron in the s subshell, they all readily give up that electron, and no more than one electron.
(cont.)

ROALD HOFFMANN cont:
And all of the halogens, on the other side of the periodic table, with their missing electron and a p subshell, readily accept such an electron. One might ask, why do we concentrate on the outermost electrons and not all the other ones. It's because the outermost electrons are at highest energy, the furthest away from the nucleus. In them is chemistry.

Credits, Closing Montage, Closing Music



The World of Chemistry Logo

A Production of
UNIVERSITY OF MARYLAND
AND
EDUCATIONAL FILM CENTER

The Annenberg/CPB Project Logo

Funder Credits

1-800-LEARNER

PBS Logo

# THE WORLD OF CHEMISTRY

Program #8

CHEMICAL BONDS

Producer John Ketcham

Air Script: October 31, 1988

PRODUCED BY

EDUCATIONAL FILM CENTER
and
THE UNIVERSITY OF MARYLAND

# THE WORLD OF CHEMISTRY

Program #8: Chemical Bonds
Producer John Ketcham
Air Script: October 31, 1988

Annenberg/CPB Project Logo and Music

Funder Credits

MONTAGE: Shots of the natural world, explosion

NARRATOR (MUSIC and NAT SOUND under):
Our world is filled with a vast variety of different things: plants, animals, the sea and air, rocks and minerals, yet everything is made of atoms so small they're invisible. Combinations of atoms form these larger varied objects. Energy is certainly involved in bonding atoms, but how? If there is an interatomic glue holding our world together, what's the nature of that glue? Intriguing and important questions, because nearly all the substances around us, and within us, are held together by chemical bonds.

SUPER: CHEMICAL BONDS

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH in laboratory

ROALD HOFFMANN (SYNC):
Everything is made of atoms, but the building blocks of this world are groups of atoms, big or small in number, connected up to each other. So, in this flask of water there are 10 to the 24th or so water molecules, every one of them H2O, in every one an oxygen connected up to two hydrogens. In this salt, there is a vast ordered array of sodium and chloride ions. We've got to figure out what it is that holds atoms together, in salt or in water. The key to chemical bonding is this marvelous periodic table of the elements, and a knowledge of the electron configurations of the atoms; in particular, those of the noble gases, like helium or neon. The noble gases are chemically inert. Why? Because they have a filled s and p electron cloud. Now, with very few exceptions, there are no compounds of the noble gases, but everything else in the periodic table, arsenic, copper, indium, nitrogen, sulfur, nickel, these do form compounds. They do so by trying to achieve the stable electron configuration of the noble gases. There are at least two ways to do that.

MONTAGE: Shots of fluorescent lights using different noble gases, rain, lightning, algae

NARRATOR (MUSIC and NAT SOUND under):
The elements in compounds are held together primarily by ionic or covalent bonds, and the basic rules governing how these bonds form are, first, atoms lose, gain, or share electrons to complete their valence shells; and second, electrons tend to exist in pairs. Only the six noble gases do not readily combine with other elements, because their valence shells are already full. Making and breaking these chemical bonds is chemical change, and when chemical change occurs, energy is involved. It might take a lightning bolt, or something as complicated as algae, to break a chemical bond.

Close up of chemical reaction

NARRATOR (MUSIC and NAT SOUND under):
What exactly are these bonds, and how do they form? Electrostatic attraction of oppositely charged particles, ions, forms one type of bond, called ionic bonding.

SUPER: IONIC BONDING

How do ions form? Let's look at an alkali metal, sodium.

GRAPHIC: Valence electrons and ionic bonding

NARRATOR (MUSIC UNDER):
A sodium atom has one valence electron. Its energy level diagram looks like this. Very little energy is required to lose that electron. The outer shell is now full. A positive sodium ion has been formed, smaller than the atom. On the other side of the table, a chlorine atom has seven valence electrons. Energy is given off when it gains an electron, filling its valence shell, forming a negative chloride ion. When sodium and chlorine are brought together, one gives off an electron, the other accepts an electron. They react, producing an ionic crystalline solid, salt. Energy is involved, as demonstrator Don Showalter explains.

DS in lab

DON SHOWALTER (SYNC):
Now, what would happen if we would mix together sodium that wants to lose an electron, with chlorine that wants to acquire an electron. Let's see. In this beaker is chlorine gas. See the green color that's in there. That's quite a poisonous gas. What I want to do is to heat a piece of sodium metal. So I'm gonna put a piece into this glass spoon. (cont.)

DON SHOWALTER cont:
I'm gonna melt it a little bit, get it in the bottom there, get it nice and molten, and put it inside here, and let's see what happens. That's quite a reaction, huh? A lot of light. It gets more and more intense. There's a white powder that's forming in there. And certainly the reaction is giving off a lot of energy. Now, once it calms down, let's see what it formed. There's a white crystalline material that has formed on the side of the beaker. That's sodium chloride, regular table salt. What we have done is to take two elements that are quite dangerous, and combined them into a substance that is essential for life.

GRAPHIC: Ionic structure of sodium chloride crystal

NARRATOR (MUSIC under):
Sodium chloride, table salt, is a member of a huge family of salts, all crystalline solids. The electrostatic forces between the oppositely charged ions holds them together in the crystal. The electrical charge is evenly distributed over each ion. So ions of opposite charges are attracted from all directions. In sodium chloride, each chloride ion is surrounded by, and holds, six sodium ions. Each sodium ion is surrounded by, and holds, six chloride ions. This results in a rigid ordered pattern of alternating positive and negative ions. NaCl is the formula of sodium chloride. (cont.)

NARRATOR cont:
It implies there is one ion of sodium for each chloride ion. That one-to-one ratio of the ions exists throughout the cubic crystal. Dr. Jeffrey Post, a crystallographer for the Smithsonian Institution, studies mineral crystals, like salt.

INTERVIEW: Dr. Jeffrey Post, crystallographer, Smithsonian Institution

SUPER: Jeffrey Post

DR. JEFFREY POST (SYNC):
If you were to take a magnifying glass and look at these salt crystals from your salt shaker on your dinner table at home, you'd see that each of those little crystals looks exactly like this crystal, which is on a much smaller scale. And we've taken some crystals and looked at them on an electron microscope, and even at that scale, magnified hundreds of thousands of times, the crystal shapes are exactly the same, the same cubic shape. That's an inherent property of the structure.

GRAPHIC

NARRATOR (MUSIC under):
The lattice structure formed by the ions gives sodium chloride, and other salts, distinct properties unique to ionic compounds.

DS in lab

DON SHOWALTER (SYNC):
I have two crucibles. Both of them contain white crystalline solids. They look very much the same. However, one of them is ionically bonded. If the way substances are bonded together give them different properties, we ought to be able to test that. One way to do that is to see if they conduct electricity. We can do that by this sort of setup in here: light bulb, and electrode system. Let turn on the electricity -- and nothing happens. Well, sure, nothing's gonna happen, the circuit's open. Let me show you what happens if I close it with this screwdriver. The light comes on. How about this one? All right. Well, instead of using that screwdriver, what if we would lower the electrodes into the substances, test the conductivity that way? I'll lower them in there, and look what happens? Nothing. The light bulbs do not light up. Well, if one of them is ionically bonded, maybe because in the solid the ions aren't free to move around, what if we could help it by melting it? Oh, I hear something happening. Oh look. It's getting a little brown. I see some liquid coming around there. I've got all liquid, and this does not conduct electricity. So, in the molten form, this is a nonconductor, non-electrolyte. (cont.)

DON SHOWALTER cont:
Let's see what's happening over at the other crucible. I'm heating this one, and I have to heat it really hot, it looks like, in order for anything to happen. Oop! Here we go. Here we go! The light bulb is lighting. The bulb is lit. It must mean, now, that as we melt this substance it conducts electricity. So what we see is that this substance in this crucible is an electrolyte. The substance over here is a non-electrolyte, doesn't conduct electricity. Let's do one more test. I have two beakers here, each with a pair of electrodes in them. The electrodes are nice and clean. I'm gonna put in there some distilled water, pure water. Water into this one, and water into this one. Okay. Now, let me turn on the electricity with these switches, and let's see what happens. Nothing. Pure water does not conduct electricity. Now, into this beaker let's put some of this white solid, number one. Oh, and look what happened? The light comes on. When solid number one dissolves in water, it conducts electricity. It is an electrolyte. Let's try white solid number two. It looks pretty much the same. Put in there. Nothing happened. A little more. Nothing. Solid number two does not conduct electricity. It is a non-electrolyte. Now, what do you think these two solids are? (cont.)

DON SHOWALTER cont:
Well, solid number one was ordinary table salt, sodium chloride, and solid number two is ordinary sugar.

MONTAGE: Third World scenes

NARRATOR (MUSIC and NAT SOUND under):
Salt and human history are closely linked. Ancient people understood its value to life itself. Salt was once as valuable as gold. Good people are still the salt of the earth.

MONTAGE: Salt mine equipment, salt ponds, salt wells

NARRATOR (NAT SOUND under):
Today we produce nearly 40 million tons of sodium chloride a year, with half of it coming from caverns like this one, deep beneath the Louisiana Delta. The rest of our supply comes from huge evaporating ponds, or from salt wells. Very little of this salt actually reaches the table. Simple salt is needed by the chemical industry. Chlorine, sodium hydroxide, or lye, and sodium carbonate are all made from sodium chloride.

MONTAGE: Cows and farm workers

NARRATOR (NAT SOUND under):
And salt is needed by most living things. Cows seek salt instinctively. Whole herds can be moved by simply moving the salt lick. In mammals, salts are practically all dissolved into solutions of ions in bodily fluids. The concentration of the proper ions must be maintained, because that concentration actually affects the cell membranes.

MONTAGE: Salt trucks, archival footage of brushing teeth, salt under microscope

EQUATION

NARRATOR (NAT SOUND under):
Other common salts are calcium chloride, which is spread on streets to melt ice. And stannous fluoride, the salt of tin and fluorine, which is used in toothpaste. These different salts might have different crystalline structures. The ion ratios and sizes may be different.

INTERVIEW: Dr. Jeffrey Post cont.

DR. JEFFREY POST (SYNC):
This is a calcite crystal, and the edges come together at an angle, they're not perfectly squared off like they were in the salt or in the halite. And so this is a property of the basic structure of calcium carbonate. (cont.)

DR. JEFFREY POST cont:
The calcium ions and the carbonate ions stack together, and they repeat in three dimensions millions of times to build up a crystal, but, because of the different shape and the different charges of the carbonate molecules and the calcium ions, these stack together energetically in a different manner. And so the result is a crystal shape that looks quite different from that of the halite.

MONTAGE: Shots of salt and salt containers

MUSIC

RH in restaurant

ROALD HOFFMANN (SYNC):
This table salt is our most commonly known ionic compound. But ionic bonding is not the only way that atoms can combine. Most substances around us are molecules held together in another way. Take this salad oil, or vinegar, or any molecule in my body, the atoms in these molecules are held together in a different way, by covalent bonding.

MONTAGE: Shots of diamond, water, gases, hot air balloon

NARRATOR (MUSIC and NAT SOUND under):
Covalent bonding is the most common type of chemical bonding that holds atoms together in molecules. Molecules are electrically neutral combinations of different atoms. Unlike ionic substances, which are solids, molecular substances can be solids, liquids, or gases. To understand covalent bonding, let's begin with the simplest element, hydrogen.

SUPER: Covalent Bonding

GRAPHIC: Covalent bonding

NARRATOR (MUSIC under):
Imagine two hydrogen atoms, each with one proton in the nucleus and one electron. Both atoms have the same energy and their valence shells are not complete. As they move towards one another, the electron clouds begin to overlap. They start sharing electrons. A molecule is forming. When the clouds overlap, the electrons are paired together, shared. The valence shells are complete and a covalent bond has been formed.

MONTAGE: Shots of the sun

NARRATOR:
On the sun, at high temperatures, hydrogen can exist as separate atoms. But at far lower temperatures, here on earth, hydrogen exists as molecules, which have lower energy than the two single atoms. Here that's the preferred natural state.

GRAPHIC: Bonding and energy

NARRATOR (MUSIC under):
So, as the two atoms move together and the electron clouds begin to overlap, forming the molecule H2, the energy within this two-atom system decreases. Whenever a covalent bond is formed, energy is released. Where does the energy go? It's released to the surroundings.

MONTAGE: Blasting

NARRATOR (SFX: bomb blasts):
If controlled, that energy can move mountains. In certain compounds, chemical bonds are weak and can be easily broken, freeing the atoms to reform into molecules with stronger bonds. When they do, an enormous amount of energy is released. Most conventional explosives contain nitrogen atoms weakly bonded to other atoms. Why nitrogen?

EQUATION

NARRATOR (NAT SOUND under):
Because, when nitrogen forms its molecule, N2, the atoms will share three pairs of electrons. The bond formed is one of the strongest known, and the energy released in the process makes nitrogen-based explosives unique, as Don Showalter will demonstrate.

DS in lab

DON SHOWALTER (SYNC):
Now, we've seen a little bit about nitrogen bonds, how two nitrogen atoms will combine to form a stable N2 molecule. Now, iodine, a member of the halogen family, will also form a stable diatomic molecule. Now, you would think that the electrons in the nitrogen atom would be easily shared with 3 iodines, and you're right. Now, this small brownish pile that you see in front of you is nitrogen triodide, nitrogen bonded to three iodine atoms. Nitrogen doesn't need much encouragement to go back to its elemental form, N2, and when it does that many times, the energy release is quite surprising. Let me show you. I'm gonna protect my ears by putting some cotton in them. And I'm gonna initiate this reaction by the touch of a feather. Let's watch. Wow! What a reaction. huh! (cont.)

EQUATION

DON SHOWALTER cont:
The nitrogen tri-iodide went to nitrogen, N2, and iodine, I2. You saw the purple iodine cloud that came out of there. Now, this strong tendency of nitrogen to form that N2 bond has many applications.

MONTAGE: Archival footage of blasting, tunnel building, modern blasting

NARRATOR (MUSIC and NAT SOUND under):
Explosives have impacted civilization in peace and in war. Tunnels, canals, excavations, and roadbeds were all made possible by these high-energy explosives. The trinitroglycerine of dynamite and TNT made mining more efficient, but the explosive of choice in today's blasting industry is a fertilizer.

Men preparing blasting holes

D. LINN COURSEN (VO):
The white stuff that's showing in there is a base load of ammonium nitrate and fuel oil.

NARRATOR (NAT SOUND under):
Ammonium nitrate, another nitrogen compound, is a fertilizer farmers use on their fields.

INTERVIEW: Linn Coursen, research fellow, ETI

D. LINN COURSEN (SYNC):
Now, these holes will go off in a time sequence.

NARRATOR (NAT SOUND under):
Lynn Coursen is a research fellow at ETI, the company supplying the explosives for today's shoot.

INTERVIEW: Linn Coursen cont.

SUPER: D. Linn Coursen

D. LINN COURSEN (SYNC):
What will happen is that the charges in front will begin moving the rock out of the way so that the charges in back will not have as much rock to move out.

Workers preparing blasting holes

NARRATOR (NAT SOUND under):
Each hole is filled with the ammonium nitrate-fuel oil mixture and a primer of TNT. In a fraction of a second, there will be millions of chemical bonds breaking and reforming to produce an explosion.

Blasting of wall

NARRATOR (NAT SOUND under):
Four and a half tons of ammonium nitrate were used in blasting away this rock cliff.

GRAPHIC

NARRATOR:
When any covalent bond forms, energy is released. The same amount of energy is needed in order to break that bond.

MONTAGE: Shots of clouds, water, birds, lightning, farm fields, farm machinery, roots of soybeans, greenhouse

NARRATOR (MUSIC and NAT SOUND under):
This is something nature does every day. There is nitrogen in all living things. Muscles, hair, and DNA all contain nitrogen bonded to other elements. But 80 percent of the atmosphere is nitrogen molecules held together by strong triple bond. How do living things get the form of nitrogen they need? Lightning helps. The electrical flash in the sky has enough energy to break apart nitrogen molecules, which then react with oxygen in the air, forming nitric acid. This natural acid dissolves in rain and falls to earth as a dilute solution. There it is absorbed and metabolized by plants. Some plants, though, convert molecular nitrogen in a different way. Soybeans and other legumes, like peas and peanuts, host a unique bacterium in their roots. It is this bacterium which converts the nitrogen molecule into a nitrogen compound, ammonia, which the plant can then use to make amino acids. (cont.)

NARRATOR cont:
Exactly how the bacterium works is the subject of vigorous research. From the U.S. Department of Agriculture, Don Keister.

INTERVIEW: Don Keister, U.S. Department of Agriculture

SUPER: Don Keister

DON KEISTER (SYNC):
This is one of the very unique enzymes in all of nature, because it is the only, it is the only solution that nature has come up with for biologically reducing nitrogen.

MONTAGE: Soybean, bacterium under microscope, farm fields, farm machinery

NARRATOR (NAT SOUND under):
The soybean and the bacterium have a symbiotic relationship. The plant houses and feeds the bacterium and, in turn, it receives the nitrogen it needs. But not all plants can host these nitrogen fixers. They have to rely on rain and manufactured fertilizers, like ammonium nitrate, and they're expensive. As the world's population grows, so does the demand for food, which depends on nitrogen fixation.

Shots of oil refineries

DON KEISTER (VO/SYNC):
We are currently using something like 300 million barrels of oil per year in this country alone to produce nitrogen fertilizers.

INTERVIEW: Don Keister cont.

We, for instance, forget that we're going to need to double the food supply over the next 20 years. Where is that energy gonna come from? Where is the fertilizer gonna come from?

MONTAGE: Farm fields, fertilizer, greenhouse

NARRATOR (NAT SOUND under):
For feeding the world, there are two basic options: We can either produce more fertilizer at greater cost and some risk to the environment, or we can create new varieties of nitrogen-fixing plants. Both options are being pursued worldwide.

MONTAGE: Ocean, chemical reactions, graphics, salt crystals, lab demonstrations, blasting, wheat

SUPER: CHEMICAL BONDS

NARRATOR (MUSIC under)
To review, except for the noble gases like helium and neon, which have full valence shells, everything around us is chemically bonded. Ionic and covalent bonding are the two main ways which elements can bond. Ionic bonds form when atoms either give up or acquire electrons. In the process, they become positive or negative ions, which attract one another, producing salt crystals. Covalent bonds are formed when two or more atoms complete their valence shells by sharing electrons. As atoms form molecules, energy is released, so molecules have less energy than the initial atoms. To break molecules apart, back into their constituent atoms, energy must be put back into the system.

RH in office with models of molecules

ROALD HOFFMANN (SYNC):
My own research actually has to do with bonding in molecules. What I want to know is why a molecule has the structure that it does. Let me tell you a story, something I did a few years ago. (cont.)

ROALD HOFFMANN cont:
There is an important class of molecules called organometallics. They have an organic piece and a metal atom. One day a German group made a new one of these, tris(ethylene) nickel. It has in it ethylene and a nickel atom. Now, when they made it, they didn't know its shape, its structure, whether the ethylene was standing up, like soldiers, or if they should be lying down, the way they are in this model. Why does it matter? Well, the shape of a molecule is important in defining its properties. Molecules close to this one were active as catalysts in making polyethylene. But that's not the reason why I was interested in them. I just wanted to know their geometry. Together with my co-workers, and looking at the way that the electrons move in this molecule, we were able to predict that the ethylenes should be lying down, the way they are now. Within a very short period of time, a group in England confirmed this prediction on a related platinum-containing molecule. You can see that this is a problem in molecular architecture. Chemical bonds are connections between atoms, of a definite strength, a definite length. They make molecules out of atoms. But knowing the bonding in a molecule is not sufficient. (cont.)

ROALD HOFFMANN cont:
Molecules also have a characteristic shape, a structure, an architecture, which we will see in the next program.

Credits, Closing Montage, Closing Music



The World of Chemistry Logo

A Production of
UNIVERSITY OF MARYLAND
AND
EDUCATIONAL FILM CENTER

The Annenberg/CPB Project Logo

Funder Credits

1-800-LEARNER

PBS Logo

# THE WORLD OF CHEMISTRY

Program #9

MOLECULAR ARCHITECTURE

Producer John Ketcham

Air Script: October 31, 1988

PRODUCED BY

EDUCATIONAL FILM CENTER
and
THE UNIVERSITY OF MARYLAND

## THE WORLD OF CHEMISTRY

Program #9: Molecular Architecture
Producer John Ketcham
Air Script: October 31, 1988

Annenberg/CPB Project Logo and Music

Funder Credits

MONTAGE: City scenes, nature, glider, crystals, graphics

NARRATOR (MUSIC and NAT SOUND under):
All matter is made up of atoms, ions, and molecules, from our cities to the seas. Even the air is made of molecules. Just as we use particular building materials, nature uses only certain molecules while creating amazing variety. The natural world is highly selective when building its own molecular architecture.

SUPER: MOLECULAR ARCHITECTURE

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH at construction site

ROALD HOFFMANN (SYNC):
I know what's gone into the construction of that building, structural steel and wood, bricks and concrete. In fact, all the buildings around here are made of the same materials. Our achievement as human beings is to use the same simple building blocks to assemble an immense variety of structures that serve us. It's the same in chemistry. We've been given about a hundred building blocks. That's the atoms. They come in a variety from hydrogen to uranium. And, from these simple building blocks, nature has shaped the thousands and millions of molecules that are necessary to make life and the earth function, that make for the difference or the similarity between you and me. And then, also in the laboratory, we chemists, for good measure, add a million or so new molecules every year. We have learned the rules by which atoms are connected up to each other to form molecules. But it isn't only the way that the atoms are bonded to each other. It turns out it is the three-dimensional shape of molecules, their architecture, that governs chemistry.

MONTAGE: Shapes, flames, bubbles, graphics, sugar, graphite, diamonds, farm machinery, cotton, natural world

NARRATOR (MUSIC and NAT SOUND under):
All of the shapes surrounding us, whether synthetic or natural, and how they behave, whether they burst into flame or freeze, are determined by the bonds holding them together. And it is the nature of the atoms and how they form chemical bonds which determines how molecules are made. Substances can have the same number and same kinds of atoms and yet be different. Graphite and diamonds are both pure carbon, they're just bonded differently. Aspartame -- the molecule NutraSweet -- has a mirror-image molecule that tastes bitter. Only a variation in the molecular shape makes corn starch vastly different than the cellulose in cotton. How can this be? Molecules with the same numbers and kinds of atoms, but with different spatial arrangements, are called isomers. These different arrangements can result in significant differences in properties, which have an important impact on the natural world. To understand the implications of this, let's look at the atom common to all living things, carbon.

GRAPHIC: Carbon bonding

NARRATOR (MUSIC under):
This is an unbonded carbon atom. The valence electrons are arranged so that the bonds point to the corners of a tetrahedron. Four hydrogen atoms can bond with carbon, forming methane. Two tetrahedral carbon atoms can join together with a single bond, forming the molecule ethane. Longer molecules, built with single bonds, like ethane, will form long, straight chains. And because they can't accept any more hydrogen atoms, they're said to be saturated. Carbon can form double bonds, too, and when it does, the molecule will have a different shape. Notice because of the carbon-carbon double bond, this molecule, ethylene, has fewer hydrogen atoms than does ethane. More hydrogen could be placed there. So this molecule is said to be unsaturated.

Shots of deep fried foods, people eating, exterior: Johns Hopkins Hospital, Donna Sorensen with patient in hospital

NARRATOR (NAT SOUND under):
Saturated and unsaturated are terms we use to describe the fats and oils we eat, because edible fats and oils contain single and double bonds. The Johns Hopkins Hospital in Baltimore, Maryland. (cont.)

NARRATOR cont:
Donna Sorensen is a clinical dietician here. One of her patients, Mr. Agee, has been hospitalized because of high levels of cholesterol. He is abnormally sensitive to fats and oils in his diet.

Donna Sorensen with patient in hospital

DONNA SORENSEN (VO/SYNC):
Fish is excellent. Do you ever eat fatty fish? All of the foods that Americans tend to like, fast foods generally you will have some fatty acid. They range from margarine,

INTERVIEW: Donna Sorensen, clinical dietician, Johns Hopkins Hospital, Baltimore, Maryland

SUPER: Donna Sorensen

pastries made with shortening, cookies, french fries that are fried in these kinds of shortenings, any of the snack, fried snack foods are high. Even bread.

MONTAGE: Cooking with fats and oils, pastries, fast food, oils, shortening

NARRATOR (NAT SOUND under):
Most of us eat fats and oils every day. It's fat that makes meat taste good, and fat makes pastries tasty. And we need fat. We burn it for energy. Fats and oils are compounds of glycerine and fatty acids, and there's bad fat, saturated fat, and good fat, unsaturated fat. (cont.)

NARRATOR cont:
The differences between the two are those carbon bonds holding them together. Professor John Kinsella, a food chemist from Cornell University.

INTERVIEW: Dr. John Kinsella, food chemist, Cornell University

SUPER: John Kinsella

DR. JOHN KINSELLA (SYNC):
These are two fatty acid molecules that occur abundantly in nature. As I can say, this is a typical saturated fatty acid, it's a straight linear molecule. Saturated means that all the valences of the component carbons are fully satisfied or saturated. The introduction of one double bond results in a bent or a curved molecule. This is the bent molecule. And this tends to be, have motion and tends to be liquid or fluid at normal temperatures.

GRAPHIC: Architecture from the carbon double-bond

NARRATOR (MUSIC under):
To see how the carbon double-bond determines the shape of the fatty acid molecules, let's look at the electron clouds of ethylene. Three of the bonding electron pairs around each of the carbon atoms are directed towards the corners of a triangle. (cont.)

NARRATOR cont:
The remaining bonding pair of electrons exist in two clouds, one above, and the other below the molecule. Rotation around the double bond is prevented, and when larger molecules, like fatty acids, have double bonds like this, they may be bent.

Shots of oils, margarine and shortening factories

NARRATOR (NAT SOUND under):
What starts out as soybean oil soon becomes margarine, or solid vegetable fat. Soybean oil is full of bent unsaturated molecules. It can be turned into margarine by adding hydrogen to it and then blending it with other oils and milk products. The more hydrogen, the more saturated the molecules, the more solid the fat. That's because the hydrogen opens the double bonds, forming new bonds and straightening the molecules.

DS in lab

DON SHOWALTER (SYNC):
This is vegetable oil, soybean oil. I would like to change the geometry of that molecule in there so it becomes a solid? Take the kink out. How can I do that? Hydrogenation. What I would do is put some of the oil into this flask, mix some palladium catalyst, the black material in there, and pass hydrogen gas through the mixture. (cont.)

DON SHOWALTER cont:
Let's do that. I'm gonna push the hydrogen bubbler down into the mixture. Alright. You see the hydrogen gas coming in there. Alright. Now, this reaction is gonna take quite a bit of time before we're gonna see any product. Hey look! It's turned solid. Now, how did that happen? Well, by adding hydrogen, we've converted the double bond to two single bonds, saturating the molecules. We've produced a new substance, fat. Now, if you would extract the catalyst out of there, you would get a substance that looks just like this. This is a vegetable fat, shortening.

Food in deep fry basket

NARRATOR (NAT SOUND under):
It's the straight saturated molecules which worry food chemists like Professor Kinsella.

INTERVIEW: Dr. John Kinsella cont.

DR. JOHN KINSELLA (SYNC):
It is better to eat more bent molecules than straight molecules. Generally the recommendations are that we reduce overall consumption of fat, and that we carefully control the amount of straight molecules, saturated fatty acids that we consume.

Cooking deep fried doughnuts

NARRATOR (NAT SOUND under):
According to Professor Kinsella and health officials, it's the straight saturated molecules that cause health problems.

INTERVIEW: Dr. John Kinsella cont.

DR. JOHN KINSELLA (SYNC):
One of the risk factors involved in heart disease is the amount and type of fat that a person consumes.

Cooking deep fried doughnuts and chicken, people eating fried chicken

NARRATOR (NAT SOUND under):
The shortening used in cooking donuts, french fries, and chicken is loaded with the straight saturated molecules. Shortening has its advantages: a longer shelf life, higher cooking temperatures. But as we eat more deep-fried food and exercise less, worries about our health mount. But there's more. Unsaturated molecules can also be straight.

GRAPHIC: Unsaturated fatty acid isomers

NARRATOR (MUSIC under):
There are two isomers, geometric isomers of the unsaturated fatty acids. The trans-isomer is straight, while the other, the cis-isomer, is the bent molecule.

Shots from margarine factory

NARRATOR (NAT SOUND under):
It's during the hydrogenation process that some of the cis-molecules, instead of adding hydrogen at the double bond, are converted into trans-isomers. These trans fatty acids are straight, and they help other saturated molecules stack together. In fact, they act just like a saturated molecule in fats, like margarine and shortening. That's why there's some concern over the impact of trans fatty acids on health, even though they are unsaturated.

Donna Sorensen with patient in hospital

DONNA SORENSEN (VO/SYNC):
I think the evidence is quite clear now that eating a lot of fat, and, in particular, saturated fat, is detrimental to our health.

INTERVIEW: Donna Sorensen cont.

We know that saturated fats raise cholesterol levels. There's now an hypothesis that transunsaturated fats may also raise cholesterol levels.

Family eating at dinner table

NARRATOR (NAT SOUND under):
While the impact of transfatty acids on our health is being debated, most everyone agrees we should eat less fat. But beyond these geometric isomers there are other isomers with more profound relationships with living things.

RH at mirror in health club

ROALD HOFFMANN (SYNC):
The same and not the same. That's the basic tension underlying relationships between human beings. And it's also the source of richness, variety and control in the molecular world. We've just talked about two molecules of a fat that have the same number of carbon and hydrogen atoms that are bonded in the same way, and yet they're somehow different. And the reason for the difference is one is straight and the other one is bent. That difference in shape translates into their chemical and biological properties. Molecules are exquisitely specific. Differences between them even more subtle than that between geometric isomers can be a matter of life or death. Even as subtle a difference as that between a left hand and a right hand, between a molecule and its mirror image.

MONTAGE: Sugar cane fields, microscopic cells, sugar cane in greenhouse

NARRATOR (MUSIC and NAT SOUND under):
Molecules produced by living things, like the sugar in the sugar cane, or proteins in cells, all have a definite shape. But sugars and amino acids, and other molecules, have isomers which are mirror images. They are built as the left hand is to the right hand, the same, but different.

GRAPHIC: Optical isomerism

NARRATOR (MUSIC under):
These two structures are mirror images of each other, and they can't be superimposed over one another. No matter how we turn them, the atoms of one will never exactly correspond to the atoms of the other. These are called chiral-molecules, chiralmeaning "hand" in Greek. If these two molecules have the same molecular formula, how can we tell them apart? Amazingly, chiral-molecules rotate the plane of polarized light, and so they are also called optical isomers.

DS in lab

DON SHOWALTER (SYNC):
These two disks are polarizing filters. The light source, back here, is a sodium vapor lamp. It emits light of a single wavelength. Now the polarizing disks act like a picket fence and filter out all the waves except those that can go through the spaces between the pickets. So the light that comes out is now plain polarized light. If I rotate this forward polarizing disk, I can reach a point where the light is blocked out by this forward disk. Now I'm going to put a flask that has distilled water in it in there. Do you notice any difference? Not much light coming through there, a little bit of scattered light. Now I'm gonna put a solution of sucrose, table sugar, in there. Oh, look at the difference there. Your light is coming through that forward disk now. So sugar molecules dissolved in the water have rotated the light waves so that now they come through the forward disk. Now, if I rotate this a little bit to the right, I can block that light out again, to show you how much it's rotated. That's what we mean when we say that table sugar is optically active. And so are most of the molecules we're made of.

Cells under microscope, computer graphic

NARRATOR (MUSIC under):
In living things, chiral-molecules exist in only one form or the other, but not both, either D or L. Sugars are D, for dextro, or right-handed, and amino acids are L, for levo, or left-handed. Historically, D and L referred to the direction polarized light was rotated. But if only one, and not both, occur naturally, how did the selection of one molecule over another begin? And what are the implications? Nobel Laureate, Christian Anfinsen.

INTERVIEW: Dr. Christian Anfinsen, Nobel Laureate

SUPER: Christian Anfinsen

DR. CHRISTIAN ANFINSEN (SYNC):
Now, how to start in the first place is anybody's guess. It's been assumed that some, some naturally occurring minerals, for example, might have been involved in binding one form and not the other form, and thereby building up the concentration of the form that we have now, so that when life started it was stuck with that form.

Bottles and aspirin on assembly line, chemist working in lab

NARRATOR (NAT SOUND under): Living things not only produced just one form of chiral-molecules, they can only use one form. Synthetic adrenaline, taken by asthma sufferers, must be the L form. D won't work. L-dopa is a medicine for Parkinson's Disease, not D-dopa. And only L synthetic morphine will alleviate pain.

INTERVIEW: Dr. Christian Anfinsen cont.

DR. CHRISTIAN ANFINSEN (SYNC): In nature, of course, we're stuck pretty much with one isomer. The world has been so evolved that, that living things, in general, are composed of one, one of the two possible mirror images of the basic compounds. The most important word would be "specific," meaning the whole problem in biology is specificity. And since everything that goes on in living cells is carried out by enzymes, it's important that the enzymes see only one form. As a matter of fact, if an enzyme works on one form, say the correct L form of an amino acid, it will be inhibited by the D. Things would stop dead if gluc -- all the glucose in the world suddenly became the wrong isomer.

DS in lab

DON SHOWALTER (SYNC):
A common property of living organisms is their ability to distinguish between D and L forms of optical isomers. Let me show you an example of that. I've got a setup here where I put distilled water into this flask. I put the L-glucose in this flask, and D-glucose into this flask. I also added an equal amount of yeast to each of the flasks. That's our living organism. Now, if the yeast reacts with the glucose, it will cause fermentation, which will then give off carbon dioxide, and the carbon dioxide will come through the tube and then into the water and you should see some bubbles. Let's check out and see what's happening. In the first one, distilled water, nothing's happening. That's what we thought. That's our control. Here is the L form of glucose. Look over here, no bubbles, no reaction, no fermentation. But look over here. Look at this flask. It certainly fermented. And look over here at the carbon dioxide being generated. So the yeast has reacted with the D form of glucose but not with the L form.

Desert cliffs, archaeological dig

NARRATOR (NAT SOUND under):
Amino acids, which are L, are used by all living things in metabolism. But when cells die, their proteins begin to decompose, breaking into amino acids. In the absence of life, some L-molecules can become D. Dr. Ed Hare of the Carnegie Institute.

INTERVIEW: Dr. Ed Hare, Carnegie Institute

SUPER: Edgar Hare

DR. ED HARE (SYNC):
However, when that process stops, when the living process stops and there are no longer building up materials, then nature tends to a mixture of D and L amino acids. So the downgraded part, when you're breaking down proteins, leads ultimately to a mixture of L and D amino acids. And this process is called racemization.

Chemists in lab, close ups of test tubes, graphing, meteorite study on top of Chilean mountain

NARRATOR (NAT SOUND under):
Racemization can be measured. L and D molecules both rotate polarized light, but in opposite directions. If the two are mixed together, they start to cancel each other out. (cont.)

NARRATOR cont:
So the degree of rotation of the polarized light depends upon the proportion of the L to D amino acids in any given sample. If the amounts are equal, there is no rotation at all. Because that proportion changes slowly through time, from the moment the cell dies, Dr. Hare believes, by measuring a sample's rotation of light, he can date fossils. As Dr. Hare perfected his technique of looking into the past, another tantalizing application emerged. In 1969, a meteorite fell to the earth in Chile. It wasn't made of iron and nickel, like most meteorites. This one had carbon in it.

INTERVIEW: Dr. Ed Hare cont.

DR. ED HARE (SYNC):
Carbon-containing objects from outer space. What does it mean? Does it mean there's life out in outer space and this represents a planet like Earth, that developed life and then blew up, or some -- hit into a, another object, and these meteorites are relics from this? That was one idea. Or do these represent a cumulation of interstellar matter producing organic matter?

Close ups of testing meteorite samples in lab

NARRATOR (NAT SOUND under):
Dr. Hare analyzed pieces of the meteorite's core. He discovered amino acids in one of the samples, but there was no rotation of polarized light. The sample was evenly mixed L and D.

INTERVIEW: Dr. Ed Hare cont.

DR. ED HARE (SYNC):
What did this mean? Did this mean that they were originally organic matter that had all L or D amino acids and they were racemized? That's one possible explanation. The other possible explanation is that we're seeing some of the early stages of pre biology, that is, the accumulation of amino acids by non-biological processes.

Close ups of testing meteorite samples in lab

NARRATOR (NAT SOUND under):
He looked further. The first core sample hadn't rotated the plane of polarized light. Another sample, taken from another place on the meteorite, did. The mystery deepened.

INTERVIEW: Dr. Ed Hare cont.

DR. ED HARE (SYNC):
Are we seeing essentially Earth's contamination superimposed on a racemic mixture of amino acids, or are we seeing a process in which we did have living organisms that were based on the same L-amino acid configuration that we know here on Earth that has racemized but not in all of its fractions. There are still some fractions that show a preponderance of L. More work needs to be done on this, and I'm not ready to say the jury's in.

SUPER: MOLECULAR ARCHITECTURE

MONTAGE: Program graphics, margarine factories, lab demonstrations, microscopic organisms

NARRATOR (MUSIC under):
To review: Molecular geometry depends on the number of electron pairs around the central atom and how these pairs are bonded. Molecules having the same kinds and numbers of atoms can have different shapes and properties. These are called isomers. The lack of rotation around the double bond is the reason for the existence of cis and trans isomers. These are geometric isomers. Certain molecules have a non-superimposable mirror image. (cont.)

NARRATOR cont:
These are optical isomers because they rotate the plane of polarized light. D and L optical isomers rotate the light in opposite directions. It's extraordinary that living organisms produce and use only one kind of optical isomer.

RH in vineyard

ROALD HOFFMANN (SYNC):
The connection between optical activity and molecular structure was made by a 26-year-old French chemist in 1848, but what a 26-year-old. Louis Pasteur went on to show that microorganisms cause disease and fermentation. He invented a vaccine for rabies and anthrax, and a process called pasteurization, that we still use to this day. He saved the wine and silk industries of France. But what he did in 1848, early on in his career, has something to do with the place where I'm at. This is Plains Cayuga Vineyards. And in wine, there come out occasionally crystals of a salt of an acid in wine, tartaric acid. Now, later on, in the winemaking process, there is another acid that comes up called racemic acid. It was known already in Pasteur's time that racemic acid and tartaric acid had the same chemical formula, C4H6O6. But whereas tartaric acid rotates the plane of polarized light the way many natural substances do, racemic acid does nothing to that light. Pasteur was intrigued by this. (cont.)

ROALD HOFFMANN cont:
He looked at crystals of racemic acid under a microscope. To his amazement, he saw that there were two mirror image crystal forms. He separated those tiny crystals painstakingly, with tweezers. He made solutions of them and measured their optical rotation, and he found that one of the crystal forms rotated the plane of polarized light exactly the same way tartaric acid did, and the other one did it in the opposite direction. So racemic acid turned out to be an equal mixture of two forms of one and the same molecule, which rotated light in opposite directions. This finding was tremendously important. It showed that the optical activity of molecules was something intrinsic to the molecules, that it had to be sought, that handedness, at the level of the molecule. As ingenious as he was, Pasteur did not come up with a molecular model for the source of the optical activity. It took a quarter of a century, two equally young chemists, a Dutchman, van't Hoff, a Frenchman, LaBelle, to suggest that optical activity is based on carbon being tetrahedral. And this was done forty years before anyone in the world ever saw a carbon atom. How do we find out the shapes of molecules, that carbon is tetrahedral? How do we interrogate molecules? Join us next for "Messages From Within."

Credits, Closing Montage, Closing Music



The World of Chemistry Logo

A Production of
UNIVERSITY OF MARYLAND
AND
EDUCATIONAL FILM CENTER

The Annenberg/CPB Project Logo

Funder Credits

1-800-LEARNER

PBS Logo