THE WORLD OF CHEMISTRY

Program #10

SIGNALS FROM WITHIN

Producer Robert Kaper

Air Script: October 31, 1988

PRODUCED BY

EDUCATIONAL FILM CENTER
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THE UNIVERSITY OF MARYLAND

THE WORLD OF CHEMISTRY

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Annenberg/CPB Project Logo and Music

Funder Credits

MONTAGE: Suntan lotion, insects, drugs, vegetables, graphics, models, computer images

NARRATOR (MUSIC under):
Suntan lotion, insect sex lures, illegal drugs, chlorophyll and its continuing miracle of food creation, all molecules have their own unique arrangements. They're far too small for us to see directly. Yet it's possible to make molecules send out signals revealing their own internal structure. We can then determine what atoms the molecules are made of, and how those atoms are arranged, by deciphering these signals from within.

SUPER: SIGNALS FROM WITHIN

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH in laboratory

ROALD HOFFMANN (SYNC):
The very first question that a chemist asks is, what is it? This may be a sample of moon dust brought back at great expense from the surface of the moon. It might be an impure narcotic off the street, or the extract from the glands of a hundred Gypsy moths. What I want to know is, what are the atoms in these substances, how those atoms are connected up, and what is the shape of the molecule that results. How do we determine the structure of a molecule? Well, we can take a mixture that's impure, because most molecules are impure. We can separate the components. We can purify them. We can put them into the solution. But then what? These molecules, these marvelous little entities, are too small to be seen with any microscope I ask, speak to me, what are you? Remarkably, they can speak. Molecules can respond to a probe at the molecular level, at their level. That probe is light, or better said, electromagnetic radiation. They interact with that probe. They modify it in a way that depends on their own structure and motions. Here is a molecule in solution. Let's turn off the lights and turn on the laser beam, and what we see is light of a certain color coming out from the laser into the sample, and then coming out, after passing through the sample, of a different color. (cont.)

ROALD HOFFMANN cont:
These imprints of a molecule on electromagnetic radiation, interpreted by us, are the signals from within which tell us what it is that we have.

MONTAGE: Chemists in spectroscopy lab, graphs, sun streaks, jewelry, nature, sunbathers on beach, military night vision scopes, radio tower, x-ray machine, microwave, satellite dish, rainbow

NARRATOR (MUSIC and NAT SOUND under):
Probing matter with electromagnetic radiation is the basis of the analytical technique known as spectroscopy. Any substance can be examined spectroscopically, and many different forms of radiation can be used to analyze it. The key principle underlying spectroscopy is the interaction of the radiation with the material being analyzed. In order to understand the interaction, you have to know something about electromagnetic radiation. Electromagnetic radiation interacts with matter all around us. Visible light interacts with chlorophyll to provide the energy needed for photosynthesis. Radiation that we can't see, ultraviolet, makes skin tan or burn. Infrared radiation lets night vision scopes see objects that otherwise would be invisible. (cont.)

NARRATOR cont:
Radio waves interact with tuning circuits to produce sound. X-rays kill malignant cells. And microwaves cook food. Electromagnetic radiation makes up a spectrum ranging from high frequencies to low frequencies. The higher the frequency, the more energy the radiation delivers.

GRAPHIC: The visible light spectrum and the electro-magnetic spectrum

NARRATOR:
The spectrum of visible light ranges from violet, with the highest frequency, to red with the lowest. So violet packs more energy than red. But visible light makes up only a narrow part of the complete electromagnetic spectrum. Gamma rays have the highest frequency and, therefore, the most energy. X-ray radiation is next, then ultraviolet, visible light, infrared, microwave, and radio.

Shots of people at the pool and on the beach, Coppertone on assembly line

NARRATOR (NAT SOUND under):
How do these different forms of energy interact with matter? One well-known interaction is ultraviolet radiation's effect on skin. Ultraviolet radiation can cause sunburn and skin cancer. (cont.)

NARRATOR cont:
So we have evolved a radiation-absorbing molecule called melanin to protect our skin. Skin exposed to ultraviolet produces more melanin, that is, it tans. Melanin is not the only molecule that absorbs ultraviolet radiation. Chemists have developed artificial molecules for use in suntan lotion. The Schering-Plough Corporation makes Coppertone, and they're continually trying to design more effective molecules to absorb ultraviolet radiation.

Suntan lotion testing

DR. ROBERT SAYRE (VO):
It is a fascinating area of research. What we do with sunscreens is remove the radiation that produces sunburn, skin aging, and skin cancer, and we do this with specific chemicals in these products.

Shot of Dr. Robert Sayre

NARRATOR (NAT SOUND under):
Schering-Plough photobiologist, Dr. Robert Sayre.

INTERVIEW: Dr. Robert Sayre, photobiologist, Schering-Plough

SUPER: Robert Sayre

DR. ROBERT SAYRE (SYNC):
We try to select molecules that have the electronic structure that can absorb the radiation, that, that they will settle, they will settle on the surface of your skin, and basically protect you by absorbing the incoming radiation before it can penetrate into the skin.

Suntan lotion testing, chemist working in lab with spectroscope, people on beach

NARRATOR (NAT SOUND under):
Plough tests its products extensively to see how long they stay on in the water, and how well they absorb ultraviolet radiation. The most accurate way to measure ultraviolet absorption is with spectroscopy. A carefully measured amount of sunscreen is first smeared onto a rectangular block made of protein. The protein chemically simulates human skin, and the thin layer represents a typical application of sunscreen on it. The material is then placed in a spectroscope. The device sends ultraviolet radiation through the sunscreen layer and measures how much of it is absorbed by the molecules.
(cont.)

NARRATOR cont:
With this information, Plough scientists can predict how effective those molecules will be in protecting skin. They verify those predictions by exposing human volunteers to simulated solar radiation. The exposure time it took to produce a sunburn is then compared to the time it takes to burn unprotected skin. This comparison lets them calculate the Sunburn Protection Factor, or SPF. An SPF of 2 lets half of the ultraviolet rays through. And SPF of 4 lets only one-fourth come through, and so on.

Sunburn commercial

ACTRESS 1
As the number gets higher the more the damaging rays are being filtered out. Oh no.

ACTRESS 2
What?

ACTRESS #2
A two!

Shots of people sailing

NARRATOR (NAT SOUND under):
But why do melanin and sunscreen molecules absorb ultraviolet rays? The reason is that any molecule absorbs radiation when it's raised from one energy level to the next, and a molecule's energy levels result from its internal motions.

GRAPHIC: The motion and energy of molecules

NARRATOR (MUSIC under):
The most obvious form of molecular motion is movement in space from one location to another. So moving molecules possess kinetic energy. But molecules are also involved in internal motions. They rotate, like this two-atom hydrogen chloride molecule. So molecules also possess rotational energy. Another state of energy is vibration. The bonds that hold atoms together are like springs, and molecules vibrate as their bonds stretch and contract. Molecules also possess additional energy from their electrons, which exist at specific energy levels. The larger and more complicated a molecule is, the more energy states it has. Even a relatively simple water molecule possesses energy from bending, stretching, and rotation. All these energies from the different modes of internal motion are discrete, that is, they're at specific levels. Don Showalter.

DS in lab

DON SHOWALTER (SYNC):
Each molecule has only specific sets of energy states, vibrational, rotational, and electronic. Now, in order to get signals from within the molecule, we need to excite it from one allowed energy state to another. Now, that's not quite as simple as it seems. We need to add an exact amount of energy. Now, can we illustrate this idea with, as an example, from our microscopic world. Well, there are a few examples that occur only if we add a specific package of energy, no more, no less. This is an ordinary laboratory beaker. If you hit it, it vibrates with a certain frequency. Now, can we add a specific amount of energy, a package of energy, to this beaker to cause it to vibrate so much that it will break? Let's see.

NARRATOR:
This demonstration uses a sound wave analogy to show that energy must be at the right frequency before it can interact with matter. The only frequency the beaker will absorb is the frequency of the tone it makes when it's hit.

DON SHOWALTER (SYNC):
This is an oscillator amplifier. It produces sound waves. The sound will deliver energy to the beaker. We can also follow the waves and see the waves on the oscilloscope. (cont.)

DON SHOWALTER cont:
The greater the number of waves, the greater the frequency. Now, we want to start with a frequency lower than that of the beaker. Now, let's turn up the volume and see if we can break the beaker. Now, the peaks are getting higher, but their number is still the same. That is, the frequency hasn't changed, it's just got a lot louder. This particular frequency is too low to break the beaker. Let's try a frequency higher than that of the beaker. Still nothing. Now let's try the right frequency, the frequency that matches the beaker's, and we'll turn up the volume full blast, and let's see what happens. The energy directed through the beaker had to be at the right frequency in order for the beaker to vibrate enough to finally shatter. Lower or higher frequencies, even though they were very intense, wouldn't work.

NARRATOR:
On the molecular level, the picture is more complex than the sound wave analogy. Molecules may absorb several different radiation frequencies, depending on their energy levels, and each frequency must provide the exact package of energy needed to lift a molecule from one energy level to the next.

GRAPHIC: Electromagnetic radiation and the change in molecular energy levels

NARRATOR (MUSIC under):
For example, a vibrating hydrogen chloride molecule exists at a specific energy level. A specific package of energy is required to make it vibrate at the next higher energy level. Electromagnetic radiation at the right frequency will be absorbed by the molecule. It carries just the right package of energy needed to make the molecule vibrate at the next higher energy level. Radiation with a frequency that's too low doesn't carry a large enough package of energy. It can't make the molecule vibrate at the next higher energy level. So it passes through the molecule without being absorbed. And radiation with a frequency that's too high carries too large a package of energy. It's not absorbed either. Its energy is not the specific amount needed to make the molecule vibrate at the next higher level. Don Showalter.

DS in lab

DON SHOWALTER (SYNC):
Here's a simple spectroscope that works in the visible light region. It has a light source, two focusing lenses, a slit for narrowing down the light beam, a stage for putting a sample on, and a prism.
(cont.)

DON SHOWALTER cont:
And the prism will break up the light into the colors of the spectrum and project it on the screen. Let's first see what the spectrum looks like without a sample in there. I'm gonna turn off the room lights and turn on the spectroscope. The colors we see are the ones we're all familiar with: violet, blue, green, yellow, orange, and red. Now, what would happen if we put a sample in there? The sample that we're going to examine is chlorophyll. I've mixed some grass with alcohol and chopped it up in a blender. The alcohol extracted the chlorophyll from the grass. And look what happens when the light passes through the chlorophyll sample? A band of light is removed. The chlorophyll molecules have absorbed certain frequencies of the visible light. This absorbed energy has lifted some of the electrons in the chlorophyll molecules to a higher energy level. The energy of the absorbed band of light matches exactly the energy difference between the ground state of those electrons and the higher level to which they have been excited.

GRAPHIC: Generalized spectroscope appartus diagram

NARRATOR (MUSIC under):
All spectroscopic instruments have the same basic components, a source of electromagnetic radiation, a container for the sample, and an analyzer detector. The type of radiation used depends on the information we want to get. The sample, whether a solid, liquid, or gas, modifies the radiation passing through it, and the energies emerging from the sample are analyzed and recorded. A graph is produced showing what frequencies have been transmitted and what frequencies have been absorbed.

Shots of illegal drugs, DEA spectroscopy lab

NARRATOR (NAT SOUND under):
The graph serves as a fingerprint of the substance being analyzed. Drug analysis is one area where spectroscopic fingerprints come in very handy. The many different illegal drugs in circulation require sensitive and precise analyses to identify them. So spectroscopy has become a major weapon in the arsenal of the Federal Drug Enforcement Administration. DEA chemists use infrared spectroscopy, along with other techniques, to analyze drug samples. The first step is to separate the drug from its cutting agent. (cont.)

NARRATOR cont:
The purified drug is pressed into a transparent disc or pellet. The pellet goes into a sample holder, which is placed in the spectrometer.

INTERVIEW: Dr. Ted Kramm, chemist, Drug Enforcement Agency

DR. TED KRAMM (SYNC):
Okay. We're now gonna put the pellet in the spectrometer and do our infrared analysis. We will get a spectrum which will be an unique fingerprint pattern for this particular substance.

DEA spectroscopy lab

NARRATOR (NAT SOUND under):
DEA uses a computerized spectrometer. The computer's memory contains a library of infrared spectra of known drugs. The unknown sample is compared with the information in memory for identification. An infrared spectrum dips down at the frequencies that are absorbed. The location of these dips, or bands, tells what chemical structures are present.

INTERVIEW: Dr. Ted Kramm cont.

DR. TED KRAMM (SYNC):
And then we go to our search button, and we will search our library to see if we have something that will match this spectrum. (cont.)

DR. TED KRAMM cont:
And the search indicates that our compound is most likely cocaine hydrochloride. Now I'd like to show you the difference between the hydrochloride, which is the water-soluble form, and cocaine base, which is also known as free base or crack. Okay. Now, here you can see this this is the hydrochloride. You can see the hydrochloride area right over here, which is absent in the cocaine free base. And the rest of the molecule more or less is similar.

DEA spectroscopy lab, drug arrests

NARRATOR (MUSIC and NAT SOUND under):
But what happens when DEA comes across new drugs, ones the computer doesn't have in its library? That was the case when a deadly new drug called China White entered the marketplace. The drug was so powerful that only a tiny amount was needed. And conventional lab tests couldn't detect the minute quantities present in confiscated samples. It was DEA's infrared spectrometers, along with other techniques, that finally broke the drug's chemical code. Dr. Ted Kramm.

INTERVIEW: Dr. Ted Kramm cont.

DR. TED KRAMM (SYNC):
We found several significant features in the spectrum which helped towards the eventual identification of this compound as alpha-methyl. Now, here's the structure as we had eventually determined, using an assortment of techniques.

DEA spectroscopy lab, drug arrest

NARRATOR (NAT SOUND under):
With the molecule finally deciphered, DEA chemists were able to develop a test that could be used to identify the drug in the field. Armed with the field test, agents were finally able to arrest the manufacturer as he delivered eight pounds of the drug to a buyer. The test needed to prove him guilty wouldn't have been possible without the DEA chemists and infrared spectroscopy.

Shots of USDA lab work, cotton plants, computer models

NARRATOR (MUSIC under):
Infrared spectroscopy's ability to identify known molecules and decipher the structure of new ones makes it useful in many other fields. Scientists at the U.S. Department of Agriculture use it extensively in their research on natural defenses against insects, as a substitute for pesticides. (cont.)

NARRATOR cont:
Infrared spectrometers help them unravel the structures of complex natural molecules to learn how they're put together. Once the structure is fully understood, they try to make synthetic copies of it in the laboratory so it can be mass produced. One important research area is the sex attractants used by female insects to entice males. The sex lures are called pheromones. They offer a safe, nontoxic way to lure insects into traps and avoid the use of pesticides. Dr. Meyer Schwartz makes synthetic insect pheromones in his laboratory.

INTERVIEW: Dr. Meyer Schwartz

SUPER: Meyer Schwartz

DR. MEYER SCHWARTZ (VO/SYNC):
What I am doing here is converting an alcohol to a bromide, which is going to be the starting material for one of our syntheses of a insect sex pheromones. This requires purification, distillation, and verifying the structure by infrared spectroscopy and other means.

Dr. Schwartz working in lab

NARRATOR (NAT SOUND under):
An important part of Dr. Schwartz's work is confirming that he has made an exact copy of the natural chemical.
(cont.)

NARRATOR cont:
He uses infrared spectroscopy to verify the structure of the molecules he's tried to duplicate in the lab. The spectrometer sends a range of infrared frequencies through the sample, and the spectrum on the screen reveals important characteristics of the molecule's structure.

INTERVIEW: Dr. Meyer Schwartz cont.

DR. MEYER SCHWARTZ (SYNC):
The ones that are more important at this point are the one here that represents a carbon to oxygen double bond, in combination with this particular band, it represents a acetate ester which, indeed, we were making before.

USDA wind tunnel

NARRATOR (MUSIC and NAT SOUND under):
Once an accurate copy is made, it's tried out to see if it works. A miniature wind tunnel lets Agriculture Department scientists see just how tantalizing their creation is. The feremone is placed at one end of the tunnel, and a love-struck male Gypsy moth flies against the wind to get it. It's bad enough that he's going to all this trouble for a synthetic chemical, but the Agriculture Department scientists have another dirty trick up their sleeve. (cont.)

NARRATOR cont:
They can control the speed of a striped conveyor belt on the wind tunnel floor. The distracted moth sees the belt moving by and thinks he's flying full tilt toward a female. By carefully adjusting the belt speed, the researchers can stop the moth's forward progress. The speed required to stop the moth gives them a good measure of how strong a sex lure their feremone is. When he finally reaches the end, all he finds are synthetic pheromones in a cold steel cage. Another triumph for chemical ingenuity and spectroscopic analysis.

SUPER: SIGNALS FROM WITHIN

MONTAGE: Lab demonstration shots, spectrums, program graphics, spectroscopy lab, computer analysis

NARRATOR (MUSIC under):
To review: Electromagnetic radiation interacts with matter. Visible light is only a small part of the full spectrum of electromagnetic radiation. The complete spectrum ranges from gamma rays, through X-rays, ultraviolet, visible light, infrared, microwave, and radio. Molecules absorb radiation when they are moved from one energy level to a higher one. The discrete energy levels of a molecule are the result of its internal motions. (cont.)

NARRATOR cont:
Spectroscopy is an analytical method that makes use of molecular absorption. A beam of radiation is sent through a sample, and a spectrum shows which frequencies have been absorbed and which ones have passed through. The peaks and valleys of the spectrum provide clues to the sample's molecular structure. Spectroscopy is used to identify substances by matching their spectral fingerprints with known spectra and to decipher the structure of previously unknown molecules. Whatever the use, all spectroscopic analysis is based on the same principle, that molecules can produce their own signals from within.

RH in laboratory

ROALD HOFFMANN (SYNC):
What we've seen in this program is spectroscopy mostly used in a fingerprint mode. We have an unknown, and we take a spectrum. That's those peaks, bumps, and valleys in its interaction with electromagnetic radiation, and then we compare that spectrum with the spectra of several known molecules and look for matches. Often the situation is not like that: the molecule that's made in the laboratory was never there before, or it's been isolated from a biological organism for the first time. (cont.)

ROALD HOFFMANN cont:
Still we can use spectroscopy to get a structure. From one spectroscopic technique we get that there is a CH bond and a CO bond. From another technique, we find that this hydrogen is attached to a carbon that has an oxygen, but there are other hydrogens which are attached to carbons that don't have an oxygen. Slowly we piece together the structure of the molecule. There is something interesting about this in that none of these measurements, by itself, proves the entire structure of the molecule. What we get are clues, a partial revelation. What it takes is a chemical detective, the mind of an inquiring, puzzle-solving, man or woman, to piece together from these clues the intricate structure of something like the Gypsy moth feremone.

Credits, Closing Montage, Closing Music

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THE WORLD OF CHEMISTRY

Program #11

THE MOLE

Producers Linda Moulton Howe
and Stephen Redhead

Air Script: October 31, 1988

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THE WORLD OF CHEMISTRY

Program #11: The Mole
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MONTAGE: Babies in Africa, IV bag, children in hospitals, making IV solutions

NARRATOR (MUSIC and NAT SOUND under):
Human lives can depend on the exact science of chemistry. From the familiar IV bag, salts and sugar pass into the bloodstream. They act at a molecular level so the body's cells can function again. How can we produce, on a factory scale, substances that work so accurately at a molecular level? How can we mix just the right amounts for the molecular world we cannot even see? To do this, in laboratory and in industry, chemists use a concept called the mole.

SUPER: THE MOLE

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH in office sitting
at a desk

ROALD HOFFMANN (SYNC):
At the heart of chemistry is synthesis, the making of molecules. At the beginning of any chemical reaction, there are reactants; at the end, there come out products. Now, a caricature of a way of making molecules is to take the reactants, mix them together, beat on them with heat, or light, or some other source of energy, and then, in an explosion, a flash of light and smoke, the product materializes. That's the way it goes in comic books, but that's not the way that any chemical company is going to make a cent of profit. Into any modern chemical process there goes planning, whether it is into the making of ammonia, or of aspirin, or of a beautiful molecule shaped like a tube, for which no use has as yet been found. Into any of these, there goes careful planning. Precise amounts of reactants have to be weighed out. Too little and the reaction might not go. Too much, and there is going to be something left over, waste. How does a chemist know precisely how much is right?

Microscopic shots, chemist working in lab

NARRATOR (NAT SOUND under):
Today, chemists know how much is right because they can count the fundamental particles of matter, atoms and molecules. It is now possible to connect the macroscopic world that we can see with the invisible molecular world. In short, chemists have learned how to count molecules by weighing macroscopic amounts.

Chemist working in antique laboratory

NARRATOR (MUSIC and NAT SOUND under):
Two hundred years ago, scientists weren't even sure what atoms and molecules were, let alone being able to count them. For Berzelius, an outstanding analytical chemist of the 19th Century, a major problem was obtaining accurate atomic masses. One needed to know how much of each element combined, the combining masses, and the correct formula for the compound. Berzelius was one of the pioneers in this effort.

Periodic table graphic, balloon blowing up

NARRATOR (MUSIC and NAT SOUND under):
Nowadays, even a beginning chemistry student can calculate a formula, using analytical data and the atomic masses found in the periodic chart. How has this come about? The initial breakthrough came from the study of gases.

GRAPHICS: Volumes and numbers of molecules in a gas reaction

NARRATOR (MUSIC and NAT SOUND under):
Here is a gas reaction like one they did then. One volume of hydrogen gas is released into a clear balloon, then one volume of chlorine into another balloon. The valve is opened so the two gases mix together. When a light is shined on them, there's a chemical reaction to form two volumes of a new compound, hydrogen chloride. Note one volume plus one volume produced two volumes. As you know, chemists learned that all gases react in small, whole-number ratios. What principle lay behind this gas law, stated in 1808? What is happening at the molecular level? The Italian scientist, Amadeo Avogadro, pondered these questions. (cont.)

NARRATOR cont:
In 1811, he proposed that equal volumes of different gases, at the same temperature and pressure, contain equal numbers of molecules. Now we understand Avogadro's insight. We know why gases react with each other in simple ratios. A molecule of chlorine gas is made of two atoms, and a molecule of hydrogen gas is also made of two atoms. When the gases combine, one volume to one volume, two volumes of the hydrogen chloride molecule are produced. In gases, there is a simple relationship between numbers of particles and volume. Therefore, if we measure the mass of equal volumes of different gases, at the same temperature and pressure, we can easily calculate the relative masses of the molecules, since there are an equal number of molecules in each case.

MONTAGE: Hot air balloon, slow motion drop of water, crystals

NARRATOR (MUSIC and NAT SOUND under):
So, in gases, the determination of relative masses is quite straightforward, but determining the relative atomic masses of solids and liquids requires more ingenious methods. Let's take a closer look at the problem of the relative masses of solids and the notion of counting by weighing. Don Showalter.

DS in lab

DON SHOWALTER (SYNC):
We have in front of us here a balance that chemists use to weigh chemicals. The weight will be read out here in grams. However, rather than just weighing chemicals, let's way something we all like. Let's weigh some money. I have a quarter. One quarter weighs 5.7 grams. Let's weigh one penny. The penny weighs 2.5 grams. If we wanted to determine the relative weight of the two coins, we would divide the weight of the quarter by the weight of the penny. If we do that, you see that we come up with a value that shows that the quarter is about twice as heavy as the penny. Now let's weigh this pile of 20 quarters. It weighs 111.9 grams. Now let's weigh this pile of 20 pennies, the same number of pennies. The weight is 51.0 grams. We would want to determine the relative weight of the piles of quarters to pennies, we would do that in the exact same fashion as we did with the single coins. And you see that that ratio comes out the same. The same principle of relative weights that we've done with the pennies and quarters applies also to the molecular world, even though we can't see molecules or atoms. I can't pick up an atom or a molecule and put it on that balance, but I can pick up a huge number of atoms or molecules and weigh them. (cont.)

DON SHOWALTER cont:
Now, here is something we can see and weigh. It's the element carbon. It's this black powder in here. Let's see how much this carbon weighs. I'll put a dish on there to protect the balance, cancel out the weight of the dish, and we weigh the amount of carbon. It's 12.0 grams, an important weight to remember. If we wanted to compare the weight of another element with the weight or carbon, we would have to have exactly the same number of atoms of that element as there is in this 12 grams of carbon, just as we did with the quarters and pennies. We had to have an equal number of quarters and pennies to compare the relative weights. What is the number of atoms of carbon in that material, 12 grams of carbon? That number is what the chemists call a mole. A mole is the chemist's unit of measure, just as the dozen is the baker's. The mole isn't a single molecule or a single atom it's a huge number of atoms or molecules, and it's always the same number, just like the dozen is always 12. But the mole is much larger than the dozen. It's 6.02 times 10 to the 23rd. That's what we call Avogadro's number. How big is Avogadro's number?

GRAPHIC: Avogadro's number analogy

NARRATOR (MUSIC under): A molecule is so small we can't even see it, but if it were the size of a single grain of sand, one mole of sand would cover a city the size of Los Angeles 600 meters deep.

Chemist working with scale, computer room

NARRATOR (MUSIC and NAT SOUND under):
So, the mole is a unit of measurement. It's a number, an inconceivably large number. It is determined experimentally and not by counting. Can you imagine that a computer, counting 10 million atoms a second, would take 2 billion years to count out one mole? The mole allows chemists to count molecules and atoms by weighing the mass of vast numbers of these particles.

Copper wire, water in beaker, red balloon

NARRATOR (MUSIC and NAT SOUND under):
This is a mole of copper. This is a mole of water. And this is a mole of hydrogen gas. All have different masses, but each contains exactly the same number of particles, trillions and trillions of them, but exactly the same number, Avogadro's number, one mole.

GRAPHIC: The mass of a mole of elements and compounds

NARRATOR (MUSIC under):
The mass of a mole of any element is equal to the element's atomic mass expressed in grams. These are the relative atomic masses of the elements in the periodic table, based on assigning carbon a mass of 12 units. Let's use the periodic table for some examples. Here's copper. Its relative atomic mass is 63.5. A mole of copper weighs 63.5 grams. Let's see another element. Here's magnesium. Its relative atomic mass is 24.305. A mole of magnesium weighs 24.305 grams. The same principle applies to compounds. Here's a water molecule, H2O. The relative atomic mass of oxygen is 15.999. The relative atomic mass of hydrogen is 1.008. If we add these atomic masses together, one mole of water will weigh 18.015 grams.

DS in lab

DON SHOWALTER (SYNC):
And so we see how we can go from the number of particles to the number of moles, and then to the weight of a substance. Now we have some real, live moles. Each of these substances is a mole -- sugar, water, carbon, copper, and hydrogen. They all have different weights, but they all are made up of Avogadro's number of particles.

Computer graphic, crystals

NARRATOR (MUSIC and NAT SOUND under):
The mole, then, is the crucial link between the invisible molecular world and the chemical elements and compounds that we can see and measure.

GRAPHIC (EQUATIONS)

NARRATOR:
Through an understanding of the mole, the chemical equations used to describe reactions represent an extremely informative kind of chemical shorthand. This equation tells us the number of molecules that react and the number of molecules formed, the number of moles that react and the number of moles formed. And using the relative atomic masses, the weights of the reactants, and the products. With the mole, chemistry has become an exact and quantitative science.

Exterior: Baxter Travenol labs, working in labs, mixing IV bags, IV in use in hospital

NARRATOR (NAT SOUND under):
The largest manufacturer of intravenous fluids in the world is Baxter Travenol, Incorporated. As in other chemical plants across the country, chemistry is carried out here on an enormous scale. (cont.)

NARRATOR cont:
IV solutions are prepared by pouring bags of chemicals, in this case the sugar, dextrose, and salt, into a huge mixing tank containing distilled water. There is little room for error. The cells in our body depend on precise molar quantities of molecules and ions to function correctly. The wrong balance can destroy those cells. So, each batch of IV solution has to meet exact medical specifications. Chemist Johnny Long.

INTERVIEW: Johnny Long, chemist, Baxter Travenol

JOHNNY LONG (SYNC/VO):
We have many codes registered with the Food and Drug Administration. The one we're mixing today is a salt and sugar combination batch which contains 4.5 grams of sodium chloride, or salt, per liter of distilled water, and 50 grams of dextrose, or sugar, per liter of distilled water. These weights are added to a known volume of distilled water in our mixing tanks.

Chemists mixing, testing and analyzing IV solution

NARRATOR (NAT SOUND under):
Quality control is vital. Before the IV bags are filled, a sample of the solution is withdrawn and analyzed to make sure the correct amounts of sugar and salt are present. This is where the mole comes in. (cont.)

NARRATOR cont:
Here the chemist is analyzing the amount of sodium chloride in the sample. The procedure involves titrating a sample of IV solution with a standard solution containing one-tenth of a mole of silver nitrate per liter.

GRAPHIC (EQUATIONS)

NARRATOR:
Let's look at the equation for this reaction. We see that one mole of silver nitrate reacts with one mole of sodium chloride to produce a white precipitate of silver chloride and soluble sodium nitrate.

Chemist working in lab, calculating moles, filling IV bags

NARRATOR (NAT SOUND under):
Using a burette, which makes precise measurements of volume possible, silver nitrate is added until all the sodium chloride has reacted, as shown by the color change in the indicator. The chemist then reads off the volume of silver nitrate added, from which she can calculate the number of moles used, which equals the number of moles of sodium chloride present in the sample. This number can then be expressed in grams of sodium chloride per liter of IV solution. (cont.)

NARRATOR cont:
A comparison with the specifications tells the analyst whether or not the IV solution is within acceptable limits. If so, the tank solution is released to fill the IV bags.

INTERVIEW: Johnny Long cont.

JOHNNY LONG (SYNC):
This is one of our IV bags. As you can see, our label for this particular code states that each 100 milliliters contains 5 grams of dextrose and 450 milligrams of sodium chloride.

Chemists mixing IV solution

NARRATOR (NAT SOUND under):
That label translates back to the mixing process and the careful analysis.

Weighing on scale, solution spinning

NARRATOR (MUSIC and NAT SOUND under)
Counting by weighing. The mole is ubiquitous in chemistry. It gives us a window through which we can glimpse the molecular changes that accompany chemical reactions.

DS in lab

DON SHOWALTER (SYNC):
Remember that original question, how much of which? Well, to see what that means, let's perform a chemical reaction. In these three flasks I have equal amounts of hydrogen chloride dissolved in water. Each one contain a tenth of a mole of hydrogen chloride. Each of the balloons have differing amounts of magnesium. This balloon has a tenth of a mole of magnesium. This one has half as much, and this one has a quarter as much. I will empty the magnesium into the hydrogen chloride, form magnesium chloride and generate hydrogen gas. That will blow the balloon up. Which one of the balloons do you think will inflate the most, the one with the most magnesium in it? Well, let's try it and see. We'll introduce the magnesium into the hydrogen chloride. You see now that hydrogen is being given off. The balloon is inflating. Let's start the other ones, too. Again you see hydrogen gas giving off. Magnesium chloride is formed inside the flask, but it is soluble in the water, so we really don't see it very much. Let's try this one. Now remember, this one had a small amount of magnesium in it. This one had the most, .1 moles. This one had half as much, and this one had one quarter as much magnesium. The reaction is completed. (cont.)

DON SHOWALTER cont:
These balloons are very much the same size. This one's only half the size. We can explain the difference here, because this had half as much magnesium as this one. But why are these two balloons the same size?

EQUATIONS over still lab shots

NARRATOR (NAT SOUND under):
The answer lies in the chemical equation for this reaction. For every one mole of magnesium we need two moles of hydrogen chloride to complete the reaction. Here are the results of our experiment. The green balloon had equal mole amounts of magnesium and hydrogen chloride. The hydrogen chloride was used up. But a lot of magnesium was left over. In the flask with the yellow balloon, the ratio was twice as much hydrogen chloride as magnesium, which is the 2-to-1 ratio we needed for the most efficient reaction. In the flask with the blue balloon, there was too little magnesium to consume all the hydrogen chloride. The result: less hydrogen gas and less inflation. When molecules or atoms combine during a chemical reaction, they do so in simple molar ratios. (cont.)

NARRATOR cont:
In the magnesium-hydrogen-chloride reaction, this combining ratio is 1-to-2, exactly the amounts present in the amounts present in the reaction with the yellow balloon. The additional magnesium in the green balloon does not change the amount of hydrogen gas produced. Without a corresponding increase in the amount of hydrogen chloride, the additional magnesium remains unreacted.

Chemist working in lab

NARRATOR (NAT SOUND under):
Chemists must use the correct number of moles of reactants in a reaction in order to get the desired amount of product. Sometimes the molar ratio also determines the kind of product. If you use an inappropriate molar ratio of reactants, you end up with a different product.

MONTAGE: Epoxy resins, construction worker on roof, auto plant, tin cans on assembly line, fighter jets, computer circuit board

NARRATOR (MUSIC and NAT SOUND under):
Take epoxy resins. We use them in our homes as adhesives. Due to their unique combination of properties, toughness, excellent strength and adhesion, and resistance to other chemicals, (cont.)

NARRATOR cont:
they are widely used as coating and structural materials. Food and beverage cans are coated with epoxy before the contents are added, so as to protect them from the metal. Fighter jets are held together with epoxies. Even computer circuit boards are made using epoxy. But their properties depend on their molecular structure, and this, in turn, relies on combining the correct amounts of other chemicals.

Interior shots at Dow Chemical, lab shots

NARRATOR (MUSIC and NAT SOUND under):
Here at Dow Chemical, in Freeport, Texas, an important class of epoxies used as coatings is made by reacting liquid epoxy resin of low molecular mass with bisphenol-A, an advancing agent. The object is to have the two combine to form large epoxy molecules, each with a very high molecular mass, in a process called polymerization. The higher the molecular mass of this epoxy, the more desirable its properties. The relative amounts of each reactant are crucial to this process. John Massingill is a research and development chemist at the plant.

INTERVIEW: John Massingill, research and development chemist, Dow Chemical, Freeport, Texas

SUPER: John Massingill

JOHN MASSINGILL (SYNC):
In order to build a maximum toughness into our final coatings, we combine liquid epoxy resin and bisphenol-A in equal numbers of molecules, and this is where the mole concept comes into our practical world of chemistry at an industry.

Lab shots

NARRATOR:
Massingill uses the mole to convert numbers of molecules into mass.

INTERVIEW: John Massingill cont.

JOHN MASSINGILL (SYNC):
From the mole concept, we know that using the molecular weight in grams of each of the combined materials, we can get equal molar quantities. So, in terms of the liquid epoxy resin, the molecular weight is 343. So we use 343 grams of the liquid resin. With the bisphenol-A the molecular weight is 228 grams. So the combining ratio is 228 grams to 343 grams. When those are reacted in those ratios, we will get a very high molecular weight.

Shots in lab, shots of epoxy and titration

NARRATOR (NAT SOUND under):
During the production of this epoxy, samples are taken and analyzed by the quality control lab to make sure the product has a sufficiently high molecular mass. This analysis involves titration. Once again, the mole comes into play, allowing the analyst to equate numbers of moles with mass. Too much of either reactants results in an unacceptable product. Only by combining equal numbers of moles of the liquid epoxy and bisphenol-A is a solid epoxy resin with the correct properties produced.

INTERVIEW: John Massingill cont.

JOHN MASSINGILL (SYNC):
So using the mole concept, we're able to, in the laboratory, in the real world of chemistry, to measure out numbers of molecules that we need for our chemical reactions.

MONTAGE: Factory, work in lab

NARRATOR (MUSIC and NAT SOUND under):
No matter what the scale, the mole helps us understand chemical change. It points to the essential arithmetic that accompanies all chemical reactions. It tells us how much we have and how much we need.

SUPER: THE MOLE

MONTAGE: Chemical reactions, lab demonstrations, lab work, program graphics, microscopic shots

NARRATOR (MUSIC under):
To review, modern chemistry is a quantitative science. During chemical reactions molecules, atoms, and ions, those unimaginably tiny entities, combine in exact whole-number ratios. Chemists have found a way of counting these particles, not individually, but by weighing huge numbers of them. The counting unit is the mole, Avogadro's number, 6.02 times 10 to the 23rd. Whether a gas, liquid, or solid, element or compound, one mole contains that enormous number of particles. The mass of one mole of any element is equal to the element's atomic mass expressed in grams. One mole of a compound has a mass equal to that compound's molecular mass. The mole allows chemists to move between the invisible molecular world and the macroscopic world, whether in medicine or in industry, in the lab, or in full-scale production.

RH in laboratory

ROALD HOFFMANN (SYNC):
The mole: a simple idea, many practical uses. Imagine you're a farmer; you've cut down an acre of corn and in that corn are 6 kilograms of phosphorous needed by the plant essential to us. So you know you have to replace that phosphorous in the soil before you plant. You go to the store and you see a fertilizer called super-phosphate. You read Calcium 3, Phosphorous 2, Hydrogen 14, Sulphur 2, Oxygen 21. How much of it should you buy? A pound? A ton? The simple arithmetic of the mole tells us how much. Or imagine you're a chemist -- I'm a chemist. Someone tells me to make some titanium disulfide, TiS2. Do I take a gram of titanium and two grams of sulphur? No. I take a mole of titanium and two moles of sulphur. Were I to take some other proportions for instance three moles of sulphur, I'd get a different compound, titanium-trisulfide. What's important about this is not that an expert, a chemist, can figure it out, it's that others can -- you can -- think about that.

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<u>THE WORLD OF CHEMISTRY</u>

Program #12

WATER

Producer Robert Kaper

Air Script: October 31, 1988

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THE WORLD OF CHEMISTRY

Program #12: Water
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MONTAGE: Water, bathing, forests, ocean liner, earth, waves, water in a glass, ice cubes, waterfall

NARRATOR (MUSIC and NAT SOUND under):
The chemical we're most familiar with is the strangest substance on earth. It forms solutions that can dissolve solid rock, yet it's gentle enough to saturate the tissues of every living thing. Its molecular mass is less than most of the gases in air, yet it's normally a liquid dense enough to float a tanker. It's extremely rare on every other planet in the solar system, yet it's one of the commonest compounds on earth. It's water, and it's the strangest chemical of all.

SUPER: WATER

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

MONTAGE: Streams and rivers, irrigation, flowers, stalactite & stalagmite formation, rain, plants, fish, drinking water, dam, fountain, factory

NARRATOR (MUSIC and NAT SOUND under):
There's so much water around us, we take its unusual characteristics for granted. In fact, water's oddest trait is the one that's most familiar. It's a liquid at normal temperatures. The presence of a large amount of liquid water has had a profound effect on Planet Earth. Constantly circulating masses of water moderate extremes of temperature and make the planet livable. In plants, water reacts with carbon dioxide to form glucose, the source of energy for all life. Water dissolves so many things it's called the universal solvent. Plants are 95 percent water, fish 80 percent, and humans 65 percent, so all living things need a continuous supply. Because of water's unique characteristics, we put it to plenty of other uses. In fact, we use it far more than any other substance on earth. The annual consumption in the U.S. for all purposes is 2 million gallons per person. Eighty percent of the world's water is used in agriculture. In industry, we use it to transfer heat and as a chemical reactant and solvent.

MONTAGE: Dead fish, polluted water, sludge, chemist in lab, fishing, microscopic shot

NARRATOR (MUSIC and NAT SOUND under):
But remarkable properties can create difficulties. Because it's a liquid, water can pick up large amounts of contaminating particles, and since it's a good solvent, it can dissolve potentially harmful chemicals. As the earth's population grows, we add more and more contaminants, from industry, human waste, and sediment runoff. A major challenge facing the world of chemistry is to find better ways to clean up the water that we use, and more efficient ways to use the water that we have. To do that, we must first understand the chemistry behind the odd behavior of this unusual substance.

RH in park

ROALD HOFFMANN (SYNC):
My friends know that I'm the kind of guy who always carries around molecules in this back pack. You never know when they might come in handy. Here, for instance, is a nitrogen molecule, one component of the atmosphere. It's got a molecular mass of 28 grams per mole. Now, here is an oxygen molecule, the more important component to us of the atmosphere. (cont.)

ROALD HOFFMANN cont:
It has a molecular mass of 32 grams per mole. Let's see what else I've got. Carbon dioxide, the molecule we exhale. It's a bit heavier, but still a light gas, with a molecular mass of 44 grams per mole. But here is a molecule which has a molecular mass of only 18 grams per mole. It's water. It's lighter than any of these other molecules which are gases, and yet, as you know, it's not a gas, it's a liquid. What is it that makes water so special? It can't be just the atoms in it, oxygen and hydrogen, because we have other molecules which contain those atoms and which don't have the properties of water. It must be the special combination of the atoms with each other, their arrangement in space, the disposition of the electrons in them, which gives this molecule, this molecule that is so important to us, its special properties.

GRAPHIC: The bonding of H2O in different states

NARRATOR (MUSIC under):
Water molecules are polar. Oxygen has a much stronger attraction for electrons than hydrogen does. So the electrons in each bond spend more time near the oxygen atom than they do near the hydrogen atoms. The oxygen atom, with two pairs of unbonded electrons, carries a partial negative charge. (cont.)

NARRATOR cont:
The two hydrogen atoms carry a partial positive charge. Each positive charge is concentrated in a tiny exposed hydrogen nucleus. When a positive hydrogen nucleus of one molecule comes near the negative pole of another molecule, they're attracted to each other. This attraction forms a hydrogen bond. Hydrogen bonds between molecules are not as strong as the covalent bonds that hold molecules together. But it takes far more energy to break apart molecules held by hydrogen bonds than to separate other molecules of similar size and mass. Below zero-degree Celsius, hydrogen bonds lock water molecules together into solid ice. As the temperature rises to zero, molecular motion increases and some of the hydrogen bonds are broken. Groups of molecules slide over each other and the solid form becomes a liquid. It remains a liquid over a wide temperature range. At 100 degrees Celsius, molecular motion becomes so rapid that the hydrogen bonds are broken completely, the molecules fly off and become a gas.

MONTAGE: Lake, seals on ice, snow capped mountains, streams, windsurfer, fish, ocean, glaciers, floating ice, whales

NARRATOR (MUSIC and NAT SOUND under):
Water occurs as a gas at the same time it's found in both the liquid and solid states. That's fortunate for us, because if some of the water on earth didn't evaporate into a gas, it wouldn't rain or snow, and we depend on rain and snow to replenish the fresh water needed for drinking, agriculture, and industry. Although water's found nearly everywhere on earth, 97 percent of it is a salt solution. Less than one percent is fresh water we can use. Most fresh water is locked up in glaciers and Arctic ice caps. But ice does provide one benefit. It floats and insulates the water underneath from freezing. Ice floats because of another of water's unusual properties. The solid form is lighter than the liquid. If ice were heavier than liquid water, it would sink and stay frozen. Most of the water on earth would turn solid, with drastic consequences for all life.

DS in kitchen

DON SHOWALTER (SYNC):
Water is a constant part of our life. We're taking it in all day long. We take water to extract tea from tea leaves. And coffee. Coffee is extracted from coffee beans. And soft drinks and hard drinks, they're really just water solutions. Fruits and vegetables are just about all water. Let me show you. Take this orange and cut it, you can see the juice in there. Lots of water in fruits and vegetables in there for sure. And we use water for cleaning, and certainly for cooking. And now I want to show you something. Bring this glass in here, and take a cube and drop it in there. Wow! Now this is water. See the ice floating. Look what happened here. Have you ever seen solid sink to the bottom like that? It looks pretty bizarre, doesn't it?

Two glasses from lab demonstration

NARRATOR (NAT SOUND under):
The liquid on the left is an organic solvent. A frozen cube of it sinks because the solid form is denser than the liquid.

DS in kitchen

DON SHOWALTER (SYNC):
When substances cool, when they get colder, the molecules slow down, and they get closer together. They pull in closer together. So the solid is more dense than the liquid, and so the cube should sink in its own liquid. The water doesn't act this way. As it freezes, it becomes less dense, it expands. Let me show you some proof of that. A full bottle of water put in the freezer will break. Why? As water goes from the liquid to the solid, it expands. Now, this is the only substance I can think of that does this.

GRAPHIC: The structure of ice

NARRATOR (MUSIC under):
As water's temperature decreases, its molecules slow down and begin to form additional hydrogen bonds. As they lock together, the molecules orient themselves farther apart than they were in the liquid state. They form a six-sided open pattern, a solid. The solid -- ice -- is less dense than the liquid. So ice floats on liquid water.

MONTAGE: Shots of snowflakes, snow falling, snow making machines, skiers, chemists working in labs, microscopic shots of ice crystals forming

NARRATOR (MUSIC and NAT SOUND under):
Frozen water molecules form the most beautiful shapes, snowflakes. Snowflakes condense directly from water vapor in the air at below freezing temperatures. Making snowflakes is big business. Ski resorts around the world depend on snowmaking machines to keep the slopes covered when nature fails. Until recently, the temperature had to be below freezing to make artificial snow. But a technology has been developed to make snow at several degrees above freezing. It's called the Snomax process. A protein from bacteria helps to arrange water molecules into ice. Under the microscope, crystals take shape as the protein makes it easier for hydrogen bonds to lock the molecules together. On the ski slopes, freeze-dried bacteria are added to water that goes into snowmaking machines, and fluffy white crystals come out. Frozen water is relatively pure, even ice from frozen salt water. When water molecules link together to form ice crystals, they leave other substances behind.

MONTAGE: Rain, clouds over ocean, streams, flowing water

NARRATOR (MUSIC and NAT SOUND under):
Rain water is also relatively pure. When water molecules evaporate into a gas, they leave behind whatever was dissolved in them. But even raindrops contain dissolved gases absorbed from the air. They also pick up dust particles on their way down. And once they hit the ground, they pick up much more. Water acquires a lot of dissolved material: organic compounds from plants and animals, and inorganic minerals. These substances dissolve in water as individual molecules or ions. That is, they form solutions.

GRAPHIC: Water as a solvent

NARRATOR (MUSIC under):
Water's unique ability to dissolve many different substances is due to its polarity and its ability to form hydrogen bonds. We can represent water molecules in a more compact form to show how they dissolve sodium chloride. Ionic compounds, such as sodium chloride consist of alternating positive and negative ions. Water's relatively positive hydrogen atoms attach to the negative chloride ions and pull them out of the crystal. (cont.)

NARRATOR cont:
And the relatively negative oxygen atoms attach to the positive sodium ions and pull them out of the crystal. The forces of water's attraction are stronger than the forces holding the sodium chloride ions together. When all ions have been pulled out of the crystal, the salt is dissolved. It's in solution with water.

DS in kitchen

DON SHOWALTER (SYNC):
Now here I already have a solution, liquor. It's a solution of ethyl alcohol in water. It's 80 proof. That means 40 percent alcohol and 60 percent water. Now, how does alcohol dissolve in water?

GRAPHIC: Water as a solvent

NARRATOR (MUSIC under):
Water molecules are polar and form hydrogen bonds. Ethyl alcohol molecules are also polar, and they also form hydrogen bonds. When ethyl alcohol mixes with water, it dissolves. The opposing poles of alcohol and water are attracted to each other, and the water and alcohol molecules also form hydrogen bonds with each other.

DS in kitchen

DON SHOWALTER (SYNC):
Water is called the universal solvent because so many things dissolve in it. But there are some substances that do not dissolve in water. Look what happens here. If I pour water into this liquid, watch what happens. There's two layers, and no matter how much I shake it, they still don't mix. They'll separate back out to those same two layers that's in there. How come? Well, the water is composed of polar molecules, whereas the other liquid is composed of nonpolar molecules of relatively high molecular weight. And because these two liquids are not alike, they won't mix.

GRAPHIC: Liquids insoluble with water

NARRATOR (MUSIC under):
Water dissolves molecular substances that resemble it in size, polarity, and hydrogen bonding ability. Larger, nonpolar molecules that don't form hydrogen bonds are insoluble in water. An insoluble liquid mixed with water stays in a separate layer.

Chemist working
in lab

NARRATOR (NAT SOUND under):
Chemists have learned how to make such molecules soluble by adding ionic or polar portions to them. They can now make brand new water based products out of normally insoluble molecules. It's a technique used to modify natural polymers, long chains made of smaller molecules linked together. Dr. George Brode directs water-soluble polymer research for Union Carbide.

INTERVIEW: Dr. George Brode, director of water-soluble polymer research, Union Carbide

SUPER: George Brode

DR. GEORGE BRODE (SYNC):
We come in contact with the results of water-soluble polymers every day of our lives. For example, a latex paint that you use on your house, or to coat your walls, the stability of that depends on a water-soluble polymer. Personal care and medical products that are essential to us every day are based on water-soluble polymers.

MONTAGE: Chemist working in lab, crabs, surgery, streams, children playing under waterfall, drinking water, cleaning with soap, factory shots, wastewater discharge, water treatment plants, chemical dumps

NARRATOR (NAT SOUND under): Dr. Brode has modified cellulose -- plant fiber -- so it will dissolve in water. The water-soluble cellulose is made into a gel that's used to open up clogged formations in oil wells. He's also figured out a way to take chitin, the polymer in crab shells, and make it dissolve in water. Potential uses for soluble chitin includes surgical sutures and blood anticoagulants. Water's solvent ability lets it dissolve a wide range of molecules, whether we want it to, or not. It can dissolve minerals, and pick up calcium, magnesium and iron ions. They're responsible for the hard water that tastes bad, reacts with soap to form an insoluble scum, and forms mineral deposits in pipes and hot water heaters. Water's dissolving ability makes it vital as an industrial material. Industry needs it as a solvent for a wide range of chemical reactions. Most of the water industry uses is discharged back into the environment, but before waste water can be returned to a river or lake, it first has to be cleaned. (cont.)

NARRATOR cont:
Treatment plants hold dirty water in settling tanks so large particles can sink to the bottom. Bacteria are then introduced to digest the remaining organic materials. Proper treatment removes enough contaminants so that the water can be safely returned to the environment. But not all waste water is properly treated, and undesirable substances still get into lakes and rivers, the main source of our drinking water. Further problems arise from leaking storage tanks and chemical dumps. Some of these substances are suspected carcinogens, which can cause cancer. So Senator David Durenberger has authored legislation to control carcinogenic contaminants that had been unregulated.

INTERVIEW: Senator David Durenberger, Minnesota

SUPER: Senator David Durenberger

SEN. DAVID DURENBERGER (SYNC):
This is a large group of chemicals whose presence in our water supply caused us deep concern. As our ability to diagnose, detect, becomes more refined, our knowledge and our understanding of the potential danger also expanded it.

Drinking fountain, water fountain

NARRATOR (NAT SOUND under):
The Federal Government has set limits on the levels of such chemicals, but critics argue that the limits are stricter than what's needed to protect our health. Geraldine Cox is a vice president of the Chemical Manufacturers Association.

INTERVIEW: Geraldine Cox, Vice President, Chemical Manufacturers Association

SUPER: Geraldine Cox

GERALDINE COX (SYNC):
I think just because the material is there doesn't mean it's harmful. I mean today I know that I ate carcinogens. I ate mushrooms with my omelet this morning. I had basil with the omelet. At lunch I had a hamburger. And all of those had known carcinogens. Am I afraid? No, I ate them.

Shots of water treatment plant: cleaning, testing, analyzing

NARRATOR (MUSIC and NAT SOUND under):
All chemicals are toxic at some level. The open question is what levels pose unacceptable health risks? Contaminants in drinking water are trapped with chemicals and filtered out by hard coal and sand. The last treatment step is disinfection to kill bacteria. (cont.)

NARRATOR cont:
That's usually done with chlorine, or, in some cases, with ozone gas bubbled through the water. Disinfection is the main reason most water-born diseases have been eliminated in this country. The water has been tested to make sure it meets government standards for cleanliness. But even the most modern treatments don't remove everything, and that's where the argument lies. Just how clean must our water be before it's considered safe? Modern analytical instruments can detect concentrations lower than one part of chemical in one billion parts of water. The limit for the chemical benzene, for example, is 5 parts per billion. Should we play it safe and set limits at these low concentrations or even lower, or could we set them higher without any additional danger?

INTERVIEW: Senator David Durenberger cont.

SEN. DAVID DURENBERGER (SYNC):
We have learned things repeatedly that tell us that our standards have been too lax. Lead, to me, is the best example, at least from my experience here over the last few years with lead. We used to tolerate some incredibly high amount of lead in water and in the air. (cont.)

SEN. DAVID DURENBERGER cont:
But today, we have banned lead from our gasoline. We are working on lead as one of the incredibly difficult problems in our drinking water system. And we've reduced -- we've increased the standards for lead very substantially on the basis of new knowledge.

INTERVIEW: Geraldine Cox cont.

GERALDINE COX (SYNC):
I think the criteria that we're using are the right ones. I think we need to be a little more realistic in setting the levels that we're dealing with. The goals for a carcinogen in drinking water are zero. But in some cases that may actually increase the risk of cancer. I'll give you an example, selenium. Selenium is a known carcinogen based on laboratory studies. If we -- but yet, if water doesn't have a certain amount of selenium, people drinking that water actually have a higher incidence of cancer. So at low levels it's an anti-carcinogen, at high levels it's a carcinogen.

INTERVIEW: Senator David Durenberger cont.

SEN. DAVID DURENBERGER (SYNC):
About everything we deal with in terms of the quality of drinking water has to do with chemists and chemistry. (cont.)

SEN. DAVID DURENBERGER cont:
Our wonderful chemists have created these problems for us; our wonderful chemists are hard at work in helping us detect and define these problems and they're also being asked to help us solve these problems.

INTERVIEW: Geraldine Cox cont.

GERALDINE COX (SYNC):
There have been contaminated wells. There have been hazardous waste sites contaminating material. And there have been releases of materials that shouldn't have gotten into the environment. That's all behind us. We are working very hard to clean up the environment, to reduce our emissions, to reduce the amount of contaminants. We have a responsibility to work, to protect the environment and the health of people around us. But so does everyone.

MONTAGE: Drinking from water fountain, chemist working in lab, wastewater, lake

NARRATOR:
Controversy about drinking water will continue. Hard choices will have to be made about acceptable levels of contamination, for new detection methods are bound to uncover more potentially toxic substances. Yet there is optimism. (cont.)

NARRATOR cont:
The quality of our water will improve because of a science that is responsible and creative and because of a public that is well-informed and active.

SUPER: WATER

MONTAGE: Shots of water in nature, in the home and in industry, program graphics

NARRATOR (MUSIC under):
To review: Water's unusual characteristics set it apart from all other substances. Based on its molecular mass, it should be a gas, yet it's a liquid at normal temperatures. Its solid form is less dense than the liquid. And it's able to dissolve a wide range of other substances, including the vital chemicals needed for life and those used in many industrial reactions. The water molecule have partial positive charges at one end and a partial negative charge at the other, so it can form hydrogen bonds with itself and with many other substances. Water's properties make it vulnerable to contamination from industry and human waste. These contaminants have to be removed from waste water before it's returned to the environment, and from drinking water before we put it into our bodies.

RH in park

ROALD HOFFMANN (SYNC):
Why water in the laboratories, in our bodies? Well, first of all, a liquid is best, better than a gas or a solid for transporting matter or running a chemical reaction. A gas is too dispersed, it's difficult to get anything transported with a gas. And a solid is rigid, it's difficult to mix liquids and gases with it. A liquid is just right. It's movable, deformable, and it's no wonder that there are slurries and solutions running down the pipelines of our factories, just as there are in our bodies, in arteries, in veins, in the intercellular space. Okay. So a liquid. But why water? Well, water is the universal solvent. It dissolves ionic solids, transporting through our body sodium, potassium, phosphate, and it also dissolves non-ionic molecules, sugars, alcohols, and acids. Water is also attuned to the temperature of the planet. It is a liquid under most normal conditions, a solid or gas at the extremes. Waters, teaming with life, covers 70 percent of this world. Perhaps we should have called this planet, not Earth, but Ocean.

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