THE WORLD OF CHEMISTRY

Program #19

METALS

Producer John Ketcham

Air Script: October 31, 1988

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NARRATOR cont:
Metal machines make metal products, products that we wrap in metal, ship in metal, and use every day. Even food comes sealed in metal. We use metals to generate electricity, and then we transmit it across the country in metal wires. We make crowns with them, and coins with them. Of course, it's not surprising we've found so many ways to employ metals.

GRAPHIC: Periodic table

NARRATOR (MUSIC under):
About three-quarters of all known chemical elements are metals. The most abundant in the earth's crust are iron, aluminum, as well as calcium, sodium, potassium, and magnesium.

MONTAGE: Forging steel, Egyptian painting, engine, furnace, wires, factory shots

NARRATOR (MUSIC and NAT SOUND under):
There seems to have been a direct relationship between the metals we used, how we used them, and civilization. Human progress was even marked in terms of stone, bronze, and iron. As our needs become more sophisticated and our abilities to produce metals and alloys become more advanced, our uses of metals become more specialized and diverse. But what is it about metals that makes them so useful? (cont.)

(Air Script)

NARRATOR cont:
They conduct heat and electricity, and they're malleable and ductile. They can be pounded and drawn into many shapes. These are physical properties. What chemical properties do they have? Most metals are oxidized, and, in the process they give up electrons. But some metals are more reactive than others, some oxidize more readily.

DS in chemistry classroom

DON SHOWALTER (SYNC):
I feel extravagant today. Let's try to burn a piece of platinum metal. So I'll light this burner, and here's my piece of platinum wire. I'll put it into the flame, and watch what happens. Well, you see that it's conducting the heat very well. In fact, it's getting red hot. But it's not oxidizing. Let me show you. I'll bring it outside and we let it cool. Again, the heat is conducted away from the metal very easily, and you see it's right back to normal. Thank goodness, huh? That's a lot of platinum. Now, we know other metals, though, oxidize readily. For instance, on this rusty old screw that I have here, we formed iron oxide. Iron oxidizes. Aluminum, you might not know, oxidizes even more readily than iron. So, in the process of competition for oxygen, which would win, iron or aluminum, in that process? (cont.)

(Air Script)

DON SHOWALTER cont:
Well I have a little experiment that I want to show you that will exhibit that. Inside this clay flower pot I have a mixture of aluminum powder and rust, iron oxide, and I have this magnesium strip here as a wick to initiate the reaction. Now, when we do initiate that, what we will see is that the aluminum will reduce the iron in the rust to form molten iron, and you will see a stream of molten iron come out of the bottom of that clay flower pot and be caught down in this system down in here. Now, there's a tremendous amount of heat given off there, so I'm just going to put on my face shield and get out of here, huh?

NARRATOR:
The difference in reactivity between the aluminum and the iron is accounted for by the difference in the electronic structure of the atoms.

DON SHOWALTER (SYNC):
Wow! That was quite a reaction, huh? Did you see that molten iron coming flowing out of there? Well, let me see if I can fish out some of the iron out of there. I've got this magnet. This is a thermite process that you just saw. That is used in welding, underwater welding, and railroaders use that for welding rails together. Oop! There's the nugget. Look at that. (cont.)

EQUATION

DON SHOWALTER cont:
Now, what you have seen is that aluminum has reduced iron oxide, rust, to iron metal.

DS at desk

DON SHOWALTER (SYNC):
To help us understand why metals have their characteristic properties, we're gonna have to look at their molecular make-up. Let's imagine now that these balls are metal atoms. I've got two different colors now so that you can see them. Metals certainly have all the same color. How would we stack them? Well, we would put the balls into the notches provided now by that lower layer. And this is, type of stacking is what we call the close-packed sort of structure, all the balls fitting into the notches of the lower layer. Now, this type of structuring is what allows metals to act as they do.

GRAPHIC: Atomic packing in metals

NARRATOR (MUSIC under):
Metals are crystalline solids. In most cases, they have a fairly simple symmetrical structure of close-packed atoms. Notice here the second layer is formed by atoms resting in the depressions between the atoms of the first layer. In this case, the third layer is stacked exactly above the first. (cont.)

NARRATOR cont:
When a large number of metal atoms come together, forming a crystal, an interesting phenomenon occurs. When a valence electron from one atom feels the force field of the neighboring atoms, it leaves the original atom, briefly attaching to the other. It then moves to another, and yet another. We say these electrons are de-localized. They are free to wander throughout the entire metal crystal. We can picture the metal structure as a close-packed arrangement of positive metal ions immersed in a sea of negative electrons.

GRAPHIC: Electrical conductivity in metals

NARRATOR (MUSIC under):
When we apply an external electrical field, the de-localized electrons begin to drift from the negative to the positive side of the field. This is how they carry electrical current through the metal. It's this freedom of the electrons to move that also enables metals to conduct heat and reflect light.

MONTAGE: metals in many forms

NARRATOR (NAT SOUND under):
But why are metals malleable and ductile? The answer there, too, is found in the metal's structure. (cont.)

NARRATOR cont:
Because the electrons are free to move, the metal ions can slip over one another, as if riding on a cushion of electrons. This slippage is facilitated by the presence of imperfections in the arrangement of the atoms.

MONTAGE: Rock blasting, open pit mining, smelting plant

NARRATOR (NAT SOUND under):
(SFX: Blast) But how, exactly, do we get metals from the earth? And what has to be done so we can put them to use? Iron is one of the world's most well-known and useful metals. The most common way of obtaining iron from the earth is open-pit mining, like this in Australia. If it is commercially feasible to extract the metal from the mineral mixture, we call that mixture an ore. Most iron ores are oxides. But occasionally iron is found as a sulfide mixed with other rocks. When a low-grade ore is mined, it must be physically separated from the other rocks and dirt. Only then is it ready to be shipped to a smelting plant where the metal will be extracted from its ore. Different metals come from different ores. But heat alone may not be enough to obtain metals from their ores. What else needs to be done?

DS in lab

DON SHOWALTER (SYNC):
We're going to have to add a reducing agent, and a common one that is used in this type of process is hydrogen gas. So I'm gonna put some of the iron oxide, the hematite, in this boat -- this is a little combustion boat -- and put it in there, and I want to do another experiment while we're doing this one to see if it will work. I'm gonna take some aluminum oxide and put it into this other boat here, in here, get enough of that powder in there. And what we'll do then is put these boats inside this combustion tube. All right, here is the hematite. Put the hematite in there, push it down the tube a little bit, hopefully not turning it over. There we go. Okay. And this is the aluminum oxide. We'll put it in there. What we're gonna do now is pass hydrogen gas over there and see if it's possible now to get the metal from the oxide. We'll see what happens. Close it up, and then I'll put some hydrogen gas from this source over here, run it through here and pass it over the metals. We'll turn that on. And now what we need to do, now we've got hydrogen passing over there, we need to heat this. Now, this probably will take some time, so I'm gonna heat it. (cont.)

EQUATION

DON SHOWALTER cont:
Well, we've heated it for quite awhile, passing hydrogen over there all the time. Let's see what happened, and I hope that -- yeah, it's cool, cool enough to handle. Let me take the cork out and see if I can grab those little boats out of there. The first one now that I'm gonna grab is aluminum oxide. It doesn't look much different than what it did originally. And in the second one now is the hematite. Let's see what it looks like. I'll grab a hold of it. Oh, it looks quite different. Let's look at that one. So what we can do, we can pass a bar magnet, I have a small bar magnet here, over that hematite, and if it did indeed reduce the iron, we should see some of that iron. Look at that! The iron was picked up right by the magnet.

Blast furnace

NARRATOR (MUSIC and NAT SOUND under):
Iron is most commonly produced in a blast furnace like this. The furnaces are huge, 30 meters tall and 10 meters wide at the base.

GRAPHIC: Animated diagram of blast furnace

NARRATOR (MUSIC under):
Iron ore, coke, and limestone, calcium carbonate, are loaded into the top of the furnace. Then hot air, about 600 degrees Celsius, is forced through. As the carbon in the coke burns, the temperature rises even higher. Carbon monoxide, produced by the burning coke, moves up within the furnace, and both it and the carbon react with the iron oxides, reducing them to metallic iron.

MONTAGE: Blast furnace, factory shots

NARRATOR (MUSIC and NAT SOUND under):
At these temperatures, iron melts and sinks to the bottom of the furnace.

EQUATION

Meanwhile, the limestone decomposes to form calcium oxide, lime, which then reacts with the silicates or sand that might have been in the ore.

EQUATION

The calcium silicate which forms floats to the surface. But in the case of aluminum oxide, this type of reduction simply doesn't work. Aluminum couldn't be obtained in the laboratory because hydrogen just isn't a strong enough reducing agent. Electrical energy -- a lot of it -- is needed. The process is called electrolytic reduction and is barely over 100 years old.

Archival photograph, aluminum plant shots, power plant

NARRATOR (MUSIC and NAT SOUND under):
Charles Martin Hall, an Oberlin College graduate, fresh out of school, invented the process in 1889. Prior to that, aluminum was so rare it was the metal of kings and queens.

EQUATION

Aluminum oxide is dissolved in a molten aluminum salt. The melt is then jolted with 130,000 amps of electrical current, reducing the aluminum oxide to metallic aluminum. The power requirements are enormous. One aluminum plant, in Frederick, Maryland, uses nearly a fifth of the total output of the nearby Potomac Edison Electric Company. Once aluminum has been purified, though, it takes only five percent of that initial energy to recycle it, making aluminum more economical.

RH in museum

ROALD HOFFMANN (SYNC):
We're in the National Building Museum in Washington. You can hear the sounds of renovation around me. That sculpture is actually a sheet metal exhibit, celebrating the wonderful properties of these materials which we use in our furnaces, in roofs, in duct work. (cont.)

ROALD HOFFMANN cont:
The sheet metals used in this exhibit include lead and tin-coated steel, zinc-coated steel that's called galvanized steel, copper, and brass. Now, copper, this beautiful shiny copper, is a reasonably pure metal, but the others are alloys, blends of two or more metals, or of a metal and a nonmetal. Since the beginnings of metallurgy, one of the first chemical technologies, it became clear that when one mixed two metals, that sometimes, not always, one obtained properties, melting points, strengths, that were superior to those of the components. The first such alloy, bronze, an alloy of copper and tin, was sufficiently important to have an age named after it. Soon after bronze came into use, people discovered another alloy, steel.

MONTAGE: Steel plant shots

NARRATOR (NAT SOUND under):
Steel, more than any other metal, it drives the economy of the modern world. Most commonly, steel is made by the basic oxygen process. A furnace is filled with pig iron, limestone, and scrap steel. First, the impurities are burned off with a blast of oxygen.
(cont.)

NARRATOR cont:
Then carefully measured amounts of carbon are added, producing the alloy, steel, which is harder than iron. But how does the addition of small amounts of carbon make iron stronger?

GRAPHIC: Atomic packing

NARRATOR (MUSIC under):
When you add small amounts of carbon to iron, as little as one part per thousand, the carbon atom, being smaller than the iron atom, fits into the interstitial spaces of the crystal. This small change in the structure of the iron crystal makes the slipping of iron ions more difficult. That's why steel is stronger than iron.

Steel plant shots

NARRATOR (NAT SOUND under):
This is Armco Steel in Baltimore. They make stainless steel here. Senior Metallurgist, Gerald Gelazela.

GERALD GELAZELA (VO/SYNC):
We make basic alloys, probably three or four dozen, but variations on those in which we put a little pinch of this, a little pinch of that, we can make two, three hundred varieties, more than Heinz Catsup. (cont.)

INTERVIEW: Gerald Gelazela, Senior Metallurgist, Armco Steel, Baltimore

SUPER: Gerald Gelazela

GERALD GELAZELA cont:
An alloy, basically some metal like base iron, to which you add some other chemical elements, like chromium, aluminum, nickel, copper, out of the periodic table. You may add a pinch of sulfur. That will give you machinability.

Steel plant shots

NARRATOR (NAT SOUND under):
This is 50 tons of molten iron. A pinch of chromium could be as much as half a ton, a pinch of boron could be as little as a few pounds.

INTERVIEW: Gerald Gelazela cont.

GERALD GELAZELA (SYNC):
I'm still accused of being a witch doctor, so to speak, with the little pinches of this and the little pinches of that. But we do know what we're doing.

Steel plant shots

NARRATOR (NAT SOUND under):
The alloy they're making here is called Nitronic-32. It's a special alloy that will be woven into wire mats and cast in concrete. (cont.)

NARRATOR cont:
The concrete slabs will then be used to line the banks of the Mississippi River to control erosion. Simple variations in composition can result in a variety of alloys. From car antennas to turbine blades, we use these alloys every day. As alloys enter the mainstream of American life, the elements needed to make them gain special importance. But the United States doesn't have the naturally rich deposits of some ores that other countries do.

GERALD GELAZELA (VO):
Nickel primarily comes from Canada. The chromium may come from Rhodesia, Africa somewhere, or the Soviet Union in some cases.

Steel plant shots, rocket launch

NARRATOR (NAT SOUND under):
What if, suddenly, we couldn't import the metals we need to make our alloys, the chromium, or the nickel? How could we design and then substitute other alloys to manufacture the products we need? Just how dependent on these metals are we? The engines that propel this missile and the fins that guide it are made of superalloys, alloys that can withstand extreme temperatures and stress. Most commonly, they are made of iron and nickel, or iron and cobalt. Dr. Lance Davis.

INTERVIEW: Dr. Lance Davis, Allied Signal Corporation

SUPER: Lance Davis, Allied Signal Corporation

DR. LANCE DAVIS (SYNC):
The source of cobalt is, is outside the United States, and, therefore, it is considered to be a strategic material, and you get exceptionally good properties in cobalt superalloys, but one would like to be able to produce the material as inexpensively as possible and not be susceptible to loss of supply due to changes in the political climate in another country.

Shots of jet airplanes

NARRATOR (NAT SOUND under):
But the uses of superalloys isn't limited to missiles and space exploration. This 80-ton airplane is about to land, and the wheels will have to support the weight and absorb the heat generated by the brakes. There are 3300 airplanes like this and each plane has an average of ten wheels. They cost over $8,000 each and they do wear out. Salt corrosion and stress are the two major concerns.

INTERVIEW: Dr. Lance Davis cont.

DR. LANCE DAVIS (SYNC):
The particular driving force and our own interest in aluminum has to do with various types of applications where corrosion resistance and high-temperature resistance could stand to be improved.

MONTAGE: Aluminum and aluminum research

NARRATOR (MUSIC and NAT SOUND under):
This is aluminum foil. Chemically and physically, it's very different from household foil. It's an alloy containing iron and silicon and other elements. In ordinary casting like this, the metal cools slowly and the other elements can combine, crystallizing together. Weak points would form and cracks could develop. But researchers here at Allied Signal Corporation found if they cooled the molten alloy quickly, up to a hundred degrees in a fraction of a second, the aluminum would solidify before the crystals could form. This created a new aluminum alloy. Its enhanced strength came from the iron and the good heat resistance came from the silicon.

INTERVIEW: Dr. Lance Davis cont.

DR. LANCE DAVIS (SYNC):
That really is the forte of the material scientist, is to try to control, to use changes in chemistry and processing to produce a material that has the unique properties that are required for a particular application. It all depends on the particular application that you have in mind and, and the properties that are required for that particular application. But there are many ideas and dreams that people have today which are ultimately limited by the availability of materials.

SUPER: METALS

MONTAGE: Skyscrapers, construction, auto plants, program graphics, working with metals and metal tools, mining, factory shots

NARRATOR (MUSIC under):
To review: Metals are used to form the framework of our cities, but there are many metals with many different uses, from jewelry to steel beams. Three-quarters of all known chemical elements are metals. The most abundant are iron and aluminum. Metals are malleable and ductile. They can be folded, pounded, and drawn into many shapes. And they conduct heat and electricity. (cont.)

NARRATOR cont:
These properties derive from the microstructure. At the micro level, metals are crystalline solids with a close-packed structure of atoms. Within the crystals, the valence electrons are de-localized and free to wander throughout the crystal. While all metals have many chemical and physical properties in common, they can be vastly different. So techniques for obtaining metals from their ores vary. Chemical reduction is used to obtain iron, and electrolytic reduction is needed to produce aluminum. Alloys are blends of metals and other elements which result in new materials with new properties and uses. Some countries don't have the ore deposits others do, so shortages or costs promote the development of new alloys.

RH in museum with chemical models

ROALD HOFFMANN (SYNC):
It's been a long road full of art, craft, and science, from copper and bronze to a new nickel-iron super-alloy, and there's more. So far we've talked only about the mechanical properties of metals and alloys, their strength, their malleability. But there is more about metals that makes them valuable to human beings. (cont.)

ROALD HOFFMANN cont:
There is their luster -- think of mirrors -- or magnetism, the unique features of iron as a magnet which made compasses and navigation possible, or, in our century, electrical conductivity. Copper is an extraordinarily good conductor of electricity when it's fashioned into wires. At the beginning of this century, people discovered a new phenomenon in some metals and alloys. These metals conducted electricity without resistance, essentially endlessly. But they did so only at very low temperatures, where it was not useful to make any devices from them. Something changed around 1986. First one material was made, then another one. These were high-temperature superconductors. Let me show you one of them. It has in it yttrium, a rare earth metal -- that's the blue balls -- barium, an alkaline earth metal -- that's the white balls -- our old friend, copper, and ubiquitous oxygen a real cross-section of the periodic table. This material is really a superconductor and at a high enough temperature that I think we will soon see wires and magnets fashioned from it. There are new metals and alloys with special properties, still waiting to be discovered.

Credits, Closing Montage, Closing Music

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THE WORLD OF CHEMISTRY

Program #20

ON THE SURFACE

Producer Robert Kaper

Air Script: October 31, 1988

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THE WORLD OF CHEMISTRY

Program #20: On the Surface
Producer Robert Kaper
Air Script: October 31, 1988

Annenberg/CPB Project Logo and Music

Funder Credits

MONTAGE: Surface tension, microscopic shots, washing machine, adhesive tape, catalysts

NARRATOR (MUSIC under):
Surfaces. Surprisingly, their chemistry is profound, not superficial at all. The surface of any substance is different from what's inside. That's why liquids have surface tension, detergents clean clothes, adhesives bond, and catalysts speed up reactions. All these behaviors have one thing in common, action on the surface.

SUPER: ON THE SURFACE

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH in lab with chemical models

ROALD HOFFMANN (SYNC):
Surfaces are special. Surfaces, or interfaces, are boundaries, first of all, between a solid and a liquid, a solid and a gas, or even between two liquids that don't mix with each other. The atoms at a surface are different from those in the interior or bulk of a solid. The reason that they're different is very simple, they've got fewer neighbors. There's nothing above them. Because the atoms at a surface are lacking some neighbors, their bonding capacity is still available. In fact, they will bind with any other molecule that comes near. They are reactive. And when a liquid or gas approaches a solid -- and that's typical situation in chemistry, that liquid can't feel the atoms in the bulk of the solid. All it sees is the surface.

MONTAGE: Computer chips, oil, race car, soap, adhesives, catalytic reaction

NARRATOR (MUSIC and NAT SOUND under):
Reactions take place on surfaces in all kinds of ways. Computer chip manufacturers depend on surface chemistry to bond the micro-thin layers that make up logic circuits. Oil and grease bind to metal surfaces and keep them from binding with each other.
(cont.)

NARRATOR cont:
Detergents bond with the surface of dirt to pull it into the wash water. Adhesives form bonds with the surfaces of solids and hold them firmly together. And molecules bonding with catalyst surfaces may react much faster than usual, and sometimes in entirely different ways. What is there about a surface that makes it so special? Series demonstrator, Don Showalter.

DS in lab

DON SHOWALTER (SYNC):
Here's a surface. It's the surface of water. It's different from the water inside, in the bulk. Why the difference? We all know that metal is much more dense than water. That's why it sinks. But what would happen if I carefully placed a piece of metal onto the surface? It's supported. It holds it up. There's a tension in the surface that supports the metal. Now, I could even put a bigger piece of metal on there. It supports that piece of metal, too. Here's another example of surface tension. Let me get some of this water, put a few drops onto this wax paper. Now, look how strong the surface tension is. I can drag these drops all across this paper without breaking them apart. Put them all together then. The water does not wet the wax paper. (cont.)

DON SHOWALTER cont:
The forces of attraction between the individual water molecules are stronger than the forces of attraction between the water and the wax paper. Is there any way to reduce water surface tension to make it wet things better? Well, we can add a chemical that acts on surfaces, a surfactant, plain old detergent. It breaks down the surface tension, so it is no longer strong enough to support the metal, and it's no longer strong enough to hold the drop together. It collapses, and wets the wax paper.

GRAPHIC: Surface tension of water at the molecular level

NARRATOR (MUSIC under):
Water molecules inside the liquid pull together in all directions. Surface molecules are pulled only to the side and downward. The sideward and downward forces create a tension on the surface molecules. The water surface acts like an elastic skin. Surfactant molecules, added to water, line up at the air-water interface. Surfactants are long hydrocarbon chains with a polar or ionic end. The polar or ionic ends form bonds with water. The hydrocarbon portions stick up through the surface. They interrupt the hydrogen bonding between the water molecules and break down the elastic skin.

Shots of Shell Oil's Chemical Division

NARRATOR (NAT SOUND under):
Future lab technicians take heed. Here's your competition, a tireless robot arm testing surfactants around the clock for the Chemical Division of Shell Oil. The surfactants being tested are designed for laundry detergents. The chemical is added to a miniature washing machine, along with a little water, and cloth samples soiled with carefully measured amounts of dirt. A sample of the dirty wash water is taken for laboratory analysis to see how much dirt has been removed. Surfactants here are designed for everything from washing clothes to extracting petroleum from underground reservoirs. Dr. Herb Benson.

INTERVIEW: Dr. Herbert Benson, Chemical Division of Shell Oil

SUPER: Herbert Benson

DR. HERB BENSON (SYNC):
One of the uses of surfactants, developed some years back, was to enhance the recovery of oil from underground reservoirs. During normal recovery of oil, only about one-third, or 33 percent, of the oil is obtained.

Oil well shots

NARRATOR (NAT SOUND under):
But a water surfactant mixture pumped down a well reduces the surface tension between oil and water. The oil flows more freely so more can be pumped out, sometimes twice as much as without a surfactant.

INTERVIEW: Dr. Herbert Benson cont.

DR. HERB BENSON (SYNC):
It seemed to us that removing crude oil from porous rock was very similar to removing soil from fabrics.

Shell Oil lab shots, analyzing surfactants

NARRATOR:
So Dr. Benson's laboratory has taken an oil well surfactant and is modifying it to produce a new cold-water detergent. The surfactant collects around oily dirt in a thin layer that's thousands of times more concentrated than in the wash water. So it should be able to clean clothes much better than a conventional surfactant that's evenly distributed in the water.

GRAPHIC: Surfactant properties at the molecular level

NARRATOR (MUSIC under):
Oily dirt on a fabric can't be removed with just water. Water doesn't form bonds with nonpolar substances like oil, but the nonpolar ends of surfactant molecules form bonds with oil, and the polar ends with water. So they can pull oil away from cloth fibers and into the water.

MONTAGE: Adhesives and their uses

NARRATOR (MUSIC and NAT SOUND under):
The bonding action of adhesives depends on many of the same mechanisms that work with surfactants. Adhesives turn up in all kinds of places. Even in the human body. Surgeons sometimes hold incisions together with adhesive tape instead of sutures. And dentists bond caps to teeth with fast-setting glues. Adhesives also hold automobile parts together, glue wood veneers together to make plywood, and hold tape in place. Like surfactants, adhesive molecules have to form bonds with other molecules at interfaces, and they also have to be able to wet other surfaces. Dr. Al Pocius of the 3M Company.

INTERVIEW: Dr. Al Pocius,
3M Company

SUPER: Al Pocius

DR. AL POCIUS (SYNC):
What we have, when we are trying to make a roll of adhesive tape, is we want it to be in a situation where we can store it for many years and not have the tape roll just unfold on itself, or telescope, as we call it. And then we want it just to stay in that sort of integral form until the time when we want to use that adhesive tape, and then we want to be able to just unroll it and be able to then apply it and stick it. Now, that requires a lot more technology that one -- than one would normally think, because now we want to have a material that has a tape on one side that is very, very sticky and adherent, but yet it can't stick to the other side. But, at the same time, it has to stick well enough so that the adhesive just doesn't fall apart on its own.

Jet airplanes and
airplane parts

NARRATOR (NAT SOUND under):
Dr. Pocius also investigates adhesives that hold together airplane parts. Adhesives often back up the rivets that hold aluminum skin panels in place, and sometimes completely replace them.

INTERVIEW: Dr. Al Pocius cont.

DR. AL POCIUS (SYNC):
What we have here is a section of a helicopter rotor blade that has an extensive amount of adhesive bonding on it. The first thing that we see here is the fact that this structure that's inside of the rotor blade is a honeycomb structure. The honeycomb structure, in itself, is made by adhesively bonding strips of aluminum together and then stretching them apart to generate a honeycomb type of situation. And then the adhesives are used in order to join the honeycomb structure itself to the skins that are present on the helicopter rotor blade. The same type of structure is used in the control surfaces on aircraft -- that's the flaps and things that you see operational on an aircraft.

Fibers, building a jet airplane, airplane flying

NARRATOR (NAT SOUND under):
Some aircraft are made from synthetic fibers and adhesives forming a composite material similar to that in graphite tennis racquets. Pound for pound, the composite is stronger than aluminum, so it's beginning to replace aluminum in many advanced aircraft. Adhesives can withstand the severe stresses on jet planes because of the strong bonds they form with surface molecules.

Applying adhesives

DR. AL POCIUS (VO/SYNC):
Adhesives bond things together for the same reasons that materials remain as liquids or as solids. Typically, the forces that are there between molecules are there because of the electron cloud that surrounds any atom or molecule.

INTERVIEW: Dr. Al Pocius cont.

And as they're moving around the nucleus, any one point in time those electrons are on one side or the other side of the nucleus. And, at those points, they create an instantaneous charge separation, which then can cause an interaction between that atom or molecule and another atom or molecule.

Adhesive bonding

NARRATOR:
This instantaneous charge separation means simply that the positive portion of one molecule can attract the negative portion of another. This attraction is the main reason why adhesive molecules bond to a surface.

Catalysts, factory shots

NARRATOR (MUSIC under):
Catalysts. The effect of catalysts on chemical reactions also depends on molecules bonding with surfaces. But unlike the bonding of adhesives, molecules bond only briefly with catalyst surfaces. There they form new compounds much faster than they would on their own. Catalysts make modern chemistry possible. Chemical companies make nearly all their products with the aid of catalysts, and catalysts in your car's exhaust system convert pollutants to relatively harmless carbon dioxide and water. There are countless ways a molecule can react with a catalyst.

GRAPHIC: Generalized catalytic action on the surface, at the molecular level

NARRATOR (MUSIC under):
But it generally starts by bonding temporarily with catalyst atoms as it moves from one location to the next. The bonds formed with the catalyst may weaken the molecular bond and cause it to break. Other molecules striking the surface go through similar reactions. The atoms or fragments from the molecules continue moving around the catalyst surface. If two of them collide, they may join to form a new molecule. The catalyst has caused the reaction without being changed itself.

Chemist at work, computer analysis, model of molecule

NARRATOR (NAT SOUND under):
Until recently, there was no way to tell exactly how catalysts affected chemical reactions. All chemists could do was brew up new catalyst formulations and try them out to see what happened. But thanks to new technologies, researchers can now observe the behavior of molecules on catalyst surfaces. And with the knowledge gained from these observations, they can design catalysts to do specific jobs. Scientists at the National Bureau of Standards, outside Washington, D.C., have built a model of ammonia molecules on an iron catalyst. Catalyst surfaces are rarely smooth. They're usually broken up into different levels, or steps. Dr. Ted Madey.

INTERVIEW: Dr. Ted Madey, National Bureau of Standards

SUPER: Ted Madey

DR. TED MADEY (SYNC):
Each of the colors here represents iron atoms at a different atomic level. This is one atom step higher than that level, and this level is one atom step higher than this. (cont.)

DR. TED MADEY cont:
As the ammonia molecule adsorbs on the surface, it's spinning, but it also has a probably of hopping about on the surface, and it can do so and find its way to a step edge, one of these step sites here between the top layer and the layer immediately beneath. Now, at a step, the electronic charge in the iron tends to slosh over and fill in the troughs in the layer beneath. The ammonia molecule has positive charge on the outward end, on the hydrogen end of the molecule. This positive charge on the ammonia interacts with this negative charge in the troughs, and the ammonia molecule actually tips over. Now, as it tips over, the hydrogen atoms on the ammonia start to bond with the iron atom at the step site, and ultimately the ammonia can dissociate into fragments. For example as shown over here. We have an NH species, where two hydrogen atoms have split off from the ammonia molecule. Back over here at another step, we've depicted an ammonia molecule which has broken up into NH2 species plus individual hydrogen atoms. The technique that we use to get information about the structure of molecules on surfaces involves the bombardment of the surface with low energy electrons and breaking of bonds. (cont.)

DR. TED MADEY cont:
For example, in the case of ammonia, as absorbed here, electronic bombardment breaks an NH bond and causes a hydrogen ion -- in this case as a proton -- to fly off in the direction of the ruptured bond. If this bond is broken, the ion would fly in this direction. If that bond is broken, the ion would fly in that direction. Now, in order to capture these ions, we place a detector above the surface to intercept the ion beams.

MONTAGE: Computer analysis of molecules, researchers in oil company lab, factory shots, textiles, tires, car bumper

NARRATOR (NAT SOUND under):
The hydrogen ion beans from a spinning molecule are thrown out in a circular pattern. They appear on the detector as a smoky ring. A computer converts the ring to a three-dimensional image that shows the distribution of the hydrogen ions and their energy levels. But a molecule that's bonded to the surface has stopped spinning, so it makes a different pattern. If it's got two hydrogens left, they show up on the detector as two large peaks at fixed locations. This type of pure research is one way scientists investigate catalyst's activity. But there's much more applied research to develop catalysts for a specific purpose. (cont.)

NARRATOR cont:
Oil companies, for example, invest considerable sums in equipment such as electron microscopes, to develop new catalysts to make fuels and chemicals from petroleum. Research and development here is a multi-million dollar gamble. There's no guarantee the money spent will produce anything useful. But, if it does, the payoff can be enormous. Just one catalyst breakthrough made more than half a billion dollars for Standard Oil of Ohio, now part of BP America. SOHIO researchers came up with a new catalytic process, in the late 1950s, that soon dominated all others in the production of acrylonitrile. That's the acrylic plastic that's made into textiles, tires, and car bumpers. Oddly enough, SOHIO researchers weren't even trying to produce acrylonitrile at first. They simply wanted to make a metal oxide catalyst, convert waste propane gas from petroleum refining into something more valuable. Dr. Jeanette Grasselli.

INTERVIEW: Dr. Jeanette Grasselli, BP America

SUPER: Jeanette Grasselli

DR. JEANETTE GRASSELLI (SYNC): The theory, the hypothesis at the time, was that we could take the oxygen from the catalyst, insert it into the propane, relatively unreactive molecule. So this was a tough technical objective. And, in turn, regenerate or take the catalyst back to its original oxidized form by using oxygen from the air.

Catalyst research, factory shots

NARRATOR (NAT SOUND under): But the theory didn't hold up. Propane was too stable to react, and the catalyst particles broke down in service. Management gave them three more months to show results, so they made some changes. They replaced propane with a more reactive refinery gas, propylene. They made their catalyst out of different metal oxides, and they added ammonia to promote or speed up the reaction.

INTERVIEW: Dr. Jeanette Grasselli cont.

DR. JEANETTE GRASSELLI (SYNC):
To our surprise, ammonia reacted, rather than just encouraging the reaction to go faster as a promoter, the ammonia reacted and became part of the reaction sequence, and we made acrylonitrile in one step.

Catalysts, plastic beads

NARRATOR (MUSIC and NAT SOUND under):
The researchers had struck pay dirt. Their new catalyst, combined with ammonia, had made a valuable plastic out of a nearly worthless gas.

INTERVIEW: Dr. Jeanette Grasselli cont.

DR. JEANETTE GRASSELLI (SYNC):
At this point, I clearly remember the rockets went off in the hallway. Our research director had a way of, for every significant research achievement, setting off some rockets in the hallway, at which point everyone in the laboratory was alerted that a Eureka had, in fact, occurred.

Factory shots

NARRATOR (NAT SOUND under):
Management quickly saw the value of the new process and wasted no time building a plant to use it.

INTERVIEW: Dr. Jeanette Grasselli cont.

DR. JEANETTE GRASSELLI (SYNC):
In 1960, when our plant came on stream, acrylonitrile was selling for 28 cents a pound. We were making it for 14 cents a pound. And we shut down every other commercial process. Today, 90 percent of the world's acrylonitrile is still manufactured by the SOHIO process.

MONTAGE: Catalysts

NARRATOR (MUSIC and NAT SOUND under):
Catalysts are manufactured in many different shapes: powders, granular particles, even spaghetti-like extruded strands. They have to be rugged enough so they won't crumble in use. They must also have as much surface area as possible. The more surface area on each catalyst particle, the more molecules can react on it.

DS in lab

DON SHOWALTER (SYNC):
What difference does surface area make? Here we have a material in two different forms. It's a starch product. Here it is in pellet form. Here we've ground it into a fine powder. There's the same mass of material in both. However, the powder has millions of times more surface area than the pellets. (cont.)

DON SHOWALTER cont:
Now, what would happen if we added water to these? Water bonds with this material at the surface. Let's put the pellets into this beaker, and we'll add the water, just about a liter of water. Well, not much happens. There's not much surface area for the water to bond with. Now, what would happen if we did the same thing with the powder? I'll pour the powder into this beaker, and we'll pour the water in. And look at that! There's so much surface area in that powder that all the water is bonded to the finely divided material.

Catalyst research, computer models

NARRATOR (MUSIC and NAT SOUND under):
With most catalysts, the reacting surface is on the outside. But there's a special category of catalysts whose main reacting surface is in pores, or holes. They're called zeolites, or molecular sieves. By controlling the size of the pores, zeolite designers can tailor-make catalysts to react only with molecules of a specific size or shape. One of the pioneers in molecule sieve research is Union Carbide's Dr. Edith Flanigen.

INTERVIEW: Dr. Edith Flanigen, Union Carbide

SUPER: Edith Flanigen

DR. EDITH FLANIGEN (SYNC):
The name "molecular sieve" is derived from the fact that you can actually sieve molecules. We have here an N-Butane molecule, a normal paraffin, that can go through the pore and be absorbed in the cavity. On the other hand, if we take isobutane, which is a branch-chained paraffin, it's too large to go through the pore, and it's excluded.

Research, factory shots, chemists at work in labs, New Zealand sheep and mountains, Mobil's New Zealand plant, gas station

NARRATOR (MUSIC under):
Through the work of Dr. Flanigen and her colleagues, the company has become the world's largest synthetic zeolite producer. Other companies, too, have made major breakthroughs in the zeolite business. Mobil Synthetic Zeolite converts methanol, wood alcohol, directly into gasoline. It's a way to produce gasoline without the need for petroleum, a process that might be an answer to a future energy crisis. It already has been a salvation for one little country, New Zealand. They have no petroleum. (cont.)

NARRATOR cont:
But they do have plenty of natural gas, which is easily converted to methanol. So when oil prices skyrocketed in the 1970s, New Zealand asked Mobil to build a plant to convert methanol to gasoline with its zeolite catalyst. New Zealand will be well protected when the next oil crisis comes around.

SUPER: ON THE SURFACE

MONTAGE: Models of molecules, lab demonstrations, program graphics, surfactants, adhesives

NARRATOR (MUSIC under):
To review, the atoms or molecules that make up a surface have unsatisfied bonding capacity. Molecules on a liquid surface are under tension and act like an elastic skin. Surfactant molecules interrupt the bonding between surface molecules and break down the tension. The surfactant molecules in soaps and detergents can bond with oil and with water. Adhesive bonding is caused mainly by attractions between positive and negative portions of molecules. Molecules form temporary bonds with the atoms in catalyst surfaces. These bonds may weaken and break molecular bonds, causing new molecules to form. Zeolite catalysts, or molecular sieves, can be designed to react only with molecules of a specific shape and size.

RH at chemical plant

ROALD HOFFMANN (SYNC):
The study and utility of surfaces illustrates one point that I want to leave with you, and this is the interplay of pure and applied chemistry. Are these two parts of our science, pure and applied chemistry, separate? In no way. They are intermingled with each other at every step. It's impossible to build a modern chemical plant without a fundamental understanding of heat and energy transfer -- of the properties of surfaces that are in that plant. And the problems that arise in that industry feed back and generate problems for university professors to study. What's marvelous is how it all fits together. A process that's developed in a laboratory can be taken, with a few years of hard labor, to a multi-million dollar business. A problem in production, the failure of a catalyst, economic pressure from the competition, can lead to entirely new fundamental chemistry.

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THE WORLD OF CHEMISTRY

Program #21

CARBON

Producer John Ketcham

Air Script: October 31, 1988

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THE WORLD OF CHEMISTRY

Program #21: Carbon
Producer John Ketcham
Air Script: October 31, 1988

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MONTAGE: Nature shots, assembly line machinery, grocery store, pills, plastics, paint, graphic, chemists at work in labs, fire

NARRATOR (MUSIC and NAT SOUND under):
The element essential for life is carbon. Plants and animals alike are made of carbon compounds. Why does nature find carbon so essential? The diversity of life reflects the complexity of carbon compounds. But there's more. Paints, pills, and plastics are all made from carbon compounds, too. So are glues and dyes. How can that be? How can one atom be so versatile? The largest and most organized branch of chemistry, organic chemistry, is devoted to unraveling the mysteries of carbon.

SUPER: CARBON

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH at chemical plant

ROALD HOFFMANN (SYNC):
Nearly every molecule in my body, or in this pine tree, or in a virus such as the AIDS virus, is made of carbon. There are other essential elements, oxygen, nitrogen, even iron. These add variety and function, but the underlying structure of biological molecules is built on the carbon atom. These carbon compounds can be simple, like acetic acid, or they can be complex, like the elegant giant oxygen carrier in our blood, hemoglobin. But in every living organism there are thousands of organic molecules. Chemists have made millions of carbon-containing molecules that have never existed on earth before. A natural question is, why carbon? Well, carbon forms four bonds readily to itself, to other elements. Other atoms also form four bonds, or even more, but those bonds are usually labile and weak. The bonds that carbon forms are strong, and they persist even in the presence of water and of oxygen. They allow carbon to build chains, rings, molecules of incredible complexity. They allow our bodies to function, these plants to work. Carbon is really unique.

MONTAGE: Nature shots, microorganisms, chemical plant shots, factory assembly lines, nylon

NARRATOR (MUSIC and NAT SOUND under):
Fall in the Blue Ridge Mountains. Winter's gone and summer's not far off. Our natural world is constantly changing. Every living thing which surrounds us, the plants and animals, from the smallest single organism to the enormous, all are based on one essential element, carbon. Some scientists suggest that life couldn't exist anywhere in the universe without carbon. Not far away, crude oil is being separated into many different compounds, and those, in turn, are being made into fuels, fabrics, and pharmaceuticals. Synthetic carbon-based products are everywhere. It's hard to imagine life without them. But nylon has only been around for 50 years.

Archival footage: nylon and nylon factory, chemists in labs, archival drawings of lab work, archival photograph of Wohler

NARRATOR (MUSIC under):
Nylon was quickly made into everything from parachutes to carpeting. Today we take organic synthesis for granted, but until the 19th Century, people believed that certain compounds could only be made by living things with divine intervention of a vital force. (cont.)

NARRATOR cont:
An unexpected experiment in a Heidelberg laboratory changed that belief. Friedrich Wohler, a well-known German scientist, set out to synthesize a salt, ammonium cyanate.

EQUATIONS

Though the solid he made had the same molecular formula, it was not a salt. Many experiments later, it was found to be urea, a covalent compound, a compound already isolated from human urine. Wohler had made an organic compound out of inorganic materials.

Chemists at work in labs, computer models

NARRATOR (NAT SOUND under):
Today, we can make simple carbon compounds or ones that are incredibly complex. How can carbon form such a variety of compounds? The secret lies in its ability to form strong covalent bonds with itself.

GRAPHIC: Carbon bonding

NARRATOR (MUSIC under):
Carbon is a relatively small atom, with four valence electrons with which it can form a variety of covalent bonds. If these bonds are all single bonds, the geometry of the molecule looks like this, a tetrahedron. (cont.)

NARRATOR cont:
Here each of the four carbon electrons bonds with one electron from a hydrogen atom to form methane, the major component in natural gas. Two carbon atoms can share a pair of electrons and form single bonds with each other, as in this molecule, ethane. Each carbon atom is bonded to three hydrogen atoms and to another carbon. It can form double bonds with itself. In this example, the four available bonds of each carbon include two single bonds with hydrogen atoms and a double bond with another carbon, where two pairs of electrons are shared. This is ethylene. Notice the geometry of the molecule has changed. Carbon can also form a triple bond with another carbon atom. It does this by sharing three pairs of electrons. Again, the geometry changes. This is acetylene, which is burned in welders' torches. Carbon-to-carbon bonds are fairly strong and are not easily broken. Carbon atoms can form compounds with long chains like this one, with 18 carbon atoms linked together. They can form rings, which can be simple, or complex.

MONTAGE: Race cars, oil and petroleum, butane lighters on assembly line

NARRATOR (MUSIC and NAT SOUND under):
We've been looking at compounds of carbon and hydrogen, hydrocarbons, which include most of the fuels we use, petroleum, gas, gasoline. All are mixtures of hydrocarbons. Analysis of these mixtures reveals an amazing variety of hydrocarbons. Some have the same molecular formulas, but different structures. These are isomers. The butane in these lighters is a good example.

GRAPHIC: Hydrocarbon isomers

NARRATOR (MUSIC under):
Butane is a simple hydrocarbon with 4 carbon atoms and 10 hydrogen atoms. The carbon atoms can form a simple chain, or there can be side chains, like this. Both of these compounds have the same molecular formula, C4H10, but they are two distinct compounds, butane and isobutane, and they have different properties. Here's another example, pentane. It has five carbon atoms, C5H12. We'll take away the hydrogen atom so we can concentrate on the carbon skeleton. The five carbon atoms can be arranged in three different ways, as a single chain, or a chain with one or two branches. (cont.)

NARRATOR cont:
Each of the three compounds are different. They have their own physical and chemical properties, but they have the same molecular formula, $C5H12$. Compounds that have the same formulas but different structures are called structural isomers. It gets complicated. The more carbon atoms in the molecules, the higher the number of possible isomers. The hydrocarbon with 8 carbons, octane, a major component of gasoline, has 18 possible isomers. A molecule with 20 carbons has over one-third of a million potential isomers.

MONTAGE: Hair spray, products on grocery store shelves, refrigerator, archival nylon footage, computer models

NARRATOR (MUSIC and NAT SOUND under):
Butane and isobutane are both in this hair spray, so are many other carbon compounds. While the number of combinations of hydrogen and carbon atoms seems endless, organic compounds do not only include carbon and hydrogen. Refrigerants contain halogens as well. Nylon has nitrogen and oxygen also in its structure. Combined with nitrogen, oxygen, sulfur, and phosphorous, we get even more varieties.

MONTAGE: Chemical plant shots, gas station, chemists at work in labs, assembly line shots, drinking soda pop

NARRATOR (MUSIC and NAT SOUND under):
How can we sort through this universe of carbon compounds? There is an organization to it. Organic compounds contain structures called functional groups, that have a predictable chemical behavior wherever they appear. They make ethyl alcohol here. Sugar cane and corn stalks are being digested by yeast and converted to ethyl alcohol. The hope is that someday gasoline will be replaced by a renewable fuel such as ethyl alcohol. The millions of organic compounds can be identified according to the nature and the number of the functional groups they contain. How?

EQUATIONS

Alcohols, and there are many, all have this OH bonded to a saturated carbon atom. This OH is known as the alcohol functional group. Another functional group characterizes acids. Citric acid and acetic acid are probably familiar to you. We know acetic acid as a dilute solution in water, vinegar.

EQUATION

Organic acids have this carboxyl functional group, in which a carbon atom forms a double bond with an oxygen atom, and a single bond to an OH group. (cont.)

NARRATOR cont:
If you react an alcohol, like ethyl alcohol, with an organic acid, like acetic acid,

EQUATIONS

another functional group is created, an ester. In this case, ethyl acetate. Esters have properties which are distinctly different from either alcohols or acids. Alcohols and acids are fairly common. But you're also acquainted with esters, because esters are used in the flavor and fragrance industry.

INTERVIEW: A. Allen Bednarczyk, V.P. Scientific Affairs, Quest International, shots of soda pop assembly lines

SUPER: A. Allen Bednarczyk, V.P. Scientific Affairs, Quest International

A. ALLEN BEDNARCZYK (VO/SYNC):
If a company wants to produce a carbonated beverage, that company will know how to carbonate the water, package it, distribute it, but they would come to a company like Quest International to provide the orange flavor, the cola flavor, grape flavor.

Shots of Quest International

NARRATOR (MUSIC and NAT SOUND under):
This is Quest International in Owings Mills, Maryland. They make flavors here -- orange, grape, raspberry, banana. At Quest they're looking for that something extra.

Shots of Quest International

A. ALLEN BEDNARCZYK (VO):
To make a flavor, the first thing we have to do is find out what Mother Nature did in her particular food to give us the flavor of a banana or a strawberry or raspberry.

Shots of Quest International

NARRATOR (MUSIC under):
The Quest chemists analyze natural flavors, the chemistry of a banana, and then they try to duplicate it in the lab.

INTERVIEW: A. Allen Bednarczyk cont.

A. ALLEN BEDNARCZYK (SYNC):
You can mix together 20 or 30 chemicals, smell them and it smells like a peach or strawberry, and it's seen nothing but a test tube. This is terrific.

Archival footage of perfume smelling, archival photographs of lab work, fragrance testing

NARRATOR (MUSIC under):
Using esters in the flavor industry isn't new, but in the hundred years or so that chemists have been duplicating nature's flavors and inventing new ones, business has grown. Quest supplies flavors to about 200 of the world's most well-known food companies. But esters are used to do more than flavor soda pop and candy. One of the world's most secretive industries uses esters, too, to add fragrance to perfumes. Chemists can mix up new smells, but it's up to the best-trained noses to pass them or fail them. There is a limit to human tolerance of new smells and tastes.

Shots of testing and tasting new flavors

A. ALLEN BEDNARCZYK (VO):
We're not going to start mixing together chemicals and saying, "Here, taste this," because if the public can't relate to that flavor, if it's not a flavor that they're familiar with, after generations and generations, they're going to reject it.

RH at chemical plant

ROALD HOFFMANN (SYNC):
It's interesting to analyze organic molecules to find out what atoms are there, to see how the carbon chain is connected up. (cont.)

ROALD HOFFMANN cont:
It's even more fun to make them in the laboratory, to use those functional groups as logical building blocks to assemble complex molecules. Some of the things that we make in that way will be similar to what there is in nature already, and some of the molecules will be entirely new. The making of molecules is called synthesis. Synthesis can be done as a game. It can be done as an intellectual exercise. Think, for instance, of the challenge of plotting the strategy to make a molecule as complex as DNA. Synthesis is also potentially valuable and profitable.

MONTAGE: Aspirin on assembly lines, stone sculpture of Hippocrates, willow trees, archival photographs of Bayer Company and chemists in the lab

NARRATOR (MUSIC under):
Over 2,000 years ago, Hippocrates recommended chewing willow bark to relieve pain. It worked. By the mid-1800s, it was known that the active ingredient was salicylic acid. But willow bark was bitter medicine. It wasn't until 1899 that the German Bayer Company began the industrial conversion of salicylic acid to acetylsalicylic acid. This was easier to take. (cont.)

NARRATOR cont:
Today, nearly 36 billion aspirin are used every year in the United States alone. That's a lot of headache relief. Aspirin has two functional groups, an acid and an ester. How is it made?

DS in lab

DON SHOWALTER (SYNC):
Now, I have a little salicylic acid here on this paper. I am going to introduce it into this test tube. I weighed out 138 milligrams of salicylic acid. Let's see if I can transfer it all into this small test tube. Good, it's all in there. All right. Next thing I must add is one drop of phosphoric acid. That's used as a catalyst, to speed up the reaction, huh? And then the other active ingredient now, the major reactant, is acetic anhydride. I need to add point 3 milliliters of that. If we remember, in the laboratory many times we will uses the measurement of 20 drops per milliliter. So that means I should add six drops for point 3 milliliters. Five and six. And we'll shake it up a little bit and mix up all the reactants. And then we need to heat it for five minutes at 90 degrees. I have a little water bath here, and let me check the temperature. It looks good, it's right in that region. And we'll put it in there and heat it now for about five minutes. (cont.)

DON SHOWALTER cont:
Well, it looks like our have five minutes is about up. We'll take the test tube out of there with our mixture, and I want to add some cool water to that. Now the water will react with the excess acetic anhydride, forming acetic acid. All right, a little bit more. All right. Now we'll let it cool. And as the mixture now cools, we should see crystals form of acetylsalicylic acid, aspirin. What I have to do, it has to get cooler -- oh, here it goes now. Look at that. See that cloudiness now turning into a more and more dense mixture now so the aspirin is precipitating out of there. Okay. Let's see if we can filter it now and see if we can recover any product, huh? So I'll turn on this suction over here. I have a suction setup, suction filtration. And let's see if we got any aspirin out of there, huh? What we can do is turn off that suction, and I'll lift up that filter paper, see what we've got. Oh, look at that. Now there's the aspirin we made. Let's see if we can scrape it onto here so I can get a good look at that. That's acetylsalicylic acid. Well, we did it, but I'm sure glad I don't have a headache now, because we have just made about one-third of the acetylsalicylic acid that is in one aspirin tablet.

Aspirin on assembly line, plant roots

NARRATOR (MUSIC and NAT SOUND under):
The billion-dollar aspirin industry began with willow bark. Chemists were able to isolate and then improve on the naturally occurring pain reliever, salicylic acid. Are there other natural wonder drugs? The use of plants in folk medicine has a long history. Dr. Kathlyn Parker.

INTERVIEW: Dr. Kathlyn Parker, Brown University

SUPER: Kathlyn Parker, Brown University

DR. KATHLYN PARKER (SYNC/VO):
There's a really long history of folk medicine based on plants, especially actually in the Near East and the Far East, in China.

Making folk medicines

Now the question is which of these things really works and how much of it is just a rumor or is it really true?

NARRATOR (MUSIC under):
Scenes like this have been repeated in India for thousands of years, and Dr. Parker has found there's some truth to folk medicine.

DR. KATHLYN PARKER (SYNC/VO):
First of all, you check out the plant which is rumored to be good, and check its extracts to see if there's any activity there.

INTERVIEW: Dr. Kathlyn Parker cont.

This molecule is called frederickamyacin. Frederickamyacin is an antibiotic which is of some interest as a possible anti-tumor compound. This comes from a soil organism, a bacterium which is found in the soil in Frederick, Maryland, which is right around the corner.

Chemist working in lab

NARRATOR (NAT SOUND under):
What Dr. Parker and other researchers do is, first, analyze the substance in the lab. If they find an active part of the molecule, they look further.

INTERVIEW: Dr. Kathlyn Parker cont.

DR. KATHLYN PARKER (SYNC/VO):
Then, if you are really interested in drug development, you have to isolate the active component, purify it, determine its structure, and then it gets handed over to the pharmaceutical people who decide how to package it.

Drugs and medicine bottles on assembly lines

DR. KATHLYN PARKER cont:
For some pharmaceuticals, what you really need is to be able to make a large amount of stuff really cheap. One solution is that you would develop methods so that it was so cheap to make something that you could distribute it to people in a way that they could afford it.

Third World footage, chemists at work in labs, assembly line, aspirin on shelf

NARRATOR (MUSIC and NAT SOUND under):
The need for inexpensive and effective medicine is crucial in developing countries. The population that would directly benefit would be children. How is small-scale laboratory synthesis converted into economic industrial synthesis? Where do raw materials come from? Are the challenges of the laboratory very different from those of mass production? Once the salicylic acid was isolated from willow bark and then converted in the laboratory, how was aspirin mass-produced? It all starts with benzene. But what chemical trail leads to aspirin on the drugstore shelf?

GRAPHIC: Simplified reaction pathways to aspirin, and from benzene

NARRATOR:
Aspirin, as we saw, was made from salicylic acid. The salicylic acid was made by treating phenol with carbon dioxide and sodium hydroxide. Phenol comes from cumin hydroperoxide, which is made from cumin, which is derived from benzene, and benzene is used to manufacture many products, not only aspirin, but polystyrene, and plastics, dyes and drugs, detergents and glue -- they're all molecules derived from benzene.

Petroleum plant shots

NARRATOR (MUSIC and NAT SOUND under):
We produce about five million tons of benzene every year for America's chemical industry. Most of it comes from petroleum, and each of the benzene derivatives can be manufactured at different locations and then shipped to other factories by pipeline or train. America's chemical industry is connected by a vast network which supports the eventual production of millions of products. Dr. Mary Good, President of Engineered Materials Research, Allied Signal Corporation.

INTERVIEW: Dr. Mary Good, President of Engineered Materials Research, Allied Signal Corporation

SUPER: Mary Good, Allied Signal Corp.

DR. MARY GOOD (SYNC/VO):
You really have a huge network from the raw materials which are primarily petroleum to the refinery situation, which is primarily the place in which you get starting materials. And those starting materials are then used to make petrochemicals. The petrochemicals then are used to make all kinds of things, from plastics to medicines, drugs to whatever.

Chemical plant shots

I would guess that if you looked at it, probably 25 to 40 percent of the population of the country, in one way or another, is probably dependent upon that infrastructure.

NARRATOR (MUSIC under):
One of the reasons for the size of that chemical network is the number and variety of products produced by it. Another reason: the chemical industry, like all industries, makes its money on volume.

INTERVIEW: Dr. Mary Good cont.

DR. MARY GOOD (SYNC):
These are not high margin kinds of things, normally. So you can't afford to make mistakes and you can't afford to have waste. It's not in anybody's economic interest to have them.

Chemical plant shots

NARRATOR (MUSIC under):
Due to the size of he industry, mistakes can happen, and inefficient chemical processing can produce waste.

DR. MARY GOOD (VO/SYNC):
You're gonna see a lot of work, I think, on, on redesigning chemical processes to make -- to reduce waste. In other words, just not to have it reformed if possible. You're gonna have a -- see a lot of effort in recycling.

INTERVIEW: Dr. Mary Good cont.

If people could have some understanding of the volume of chemicals that are made in the United States every day, if you could then put in perspective the very small number of incidents that happen, one would have a better feeling for what the risk-benefit kinds of ratios are.

SUPER: CARBON

MONTAGE: Nature shots, program graphics, chemical plant shots, aspirin, nylon, factory shots

NARRATOR (MUSIC under):
To review: All living things are primarily made of carbon compounds. Natural variety, and the seemingly unending development of new organic compounds is possible, in part because of the versatility of carbon in forming covalent bonds. It can form single, double, or triple bonds with itself and other elements. Structural isomers have the same molecular formula, but the atoms in the carbon skeleton are arranged differently. Each isomer has distinct properties. Handling this huge number of substances would be impossible if it were not for the existence of functional groups. Compounds like benzene are the source of a host of other useful substances. The challenges posed by synthesis change as production moves from the laboratory to the factory. Factors that must be considered are cost and availability of raw materials, and the ability to reduce and dispose of the waste.

RH at chemical plant

ROALD HOFFMANN (SYNC):
The chemistry of carbon, organic chemistry, is at the same time the most logical and the most highly developed part of our science. The logic you've seen in isomers and in functional groups. And you've gotten the hint of the complexity, for instance, in that marvelous structure of frederickamyacin that Dr. Parker discussed, or in the industrial synthesis of aspirin? You know, science is a curious mixture of discovery and creation. Discovery I take in the sense of revealing or uncovering some perhaps hidden laws of nature. Creation is, of course, the making of things. Now, if you ask scientists what they do, they tend to stress discovery. But artists, writers, painters, musicians, would tend to emphasize just the opposite, creation. Artists might reveal the essence of nature or of some emotion, but the fundamental achievement of the artist is the creation of a new reality. Well, the making of molecules brings chemistry pretty close to the arts. For what we do is we create, with our hands, with our minds, the objects, molecules, of our own study and appreciation. (cont.)

ROALD HOFFMANN cont:
The synthesis of molecules, be it of aspirin, of an antitumor agent, of nylon made here at Du Pont by Wallace Caruthers 50 years ago, the synthesis both plan and design is an artistic achievement of the highest order.

Credits, Closing Montage, Closing Music

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