THERE'S ADVENTURE
IN
CHEMISTRY

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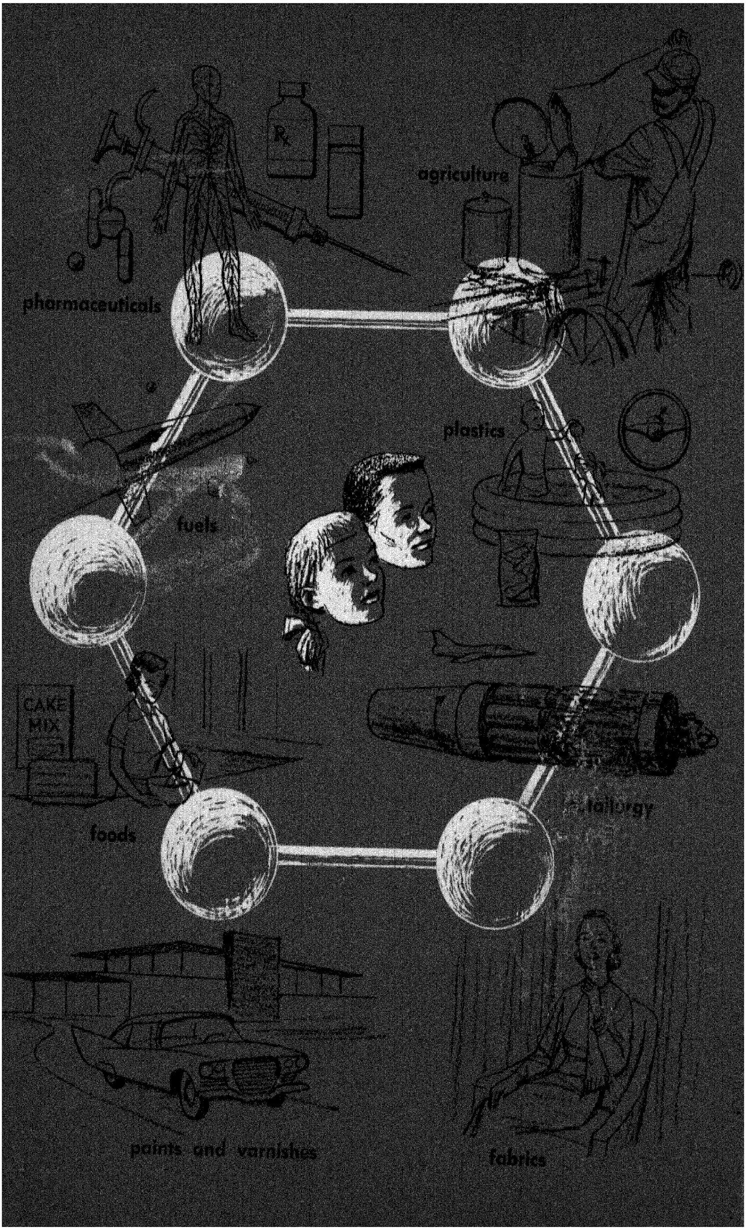
To S. M. G.

My First Chemistry Teacher

Who now understands all the secrets of chemistry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There's adventure in

chemistry

by JULIAN MAY

Illustrated by FRANK C. MURPHY

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Chicago 1957

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Chicago, Illinois J. M.

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FOREWORD

Many years ago I took my first course in chemistry and the wonder of that course has never been forgotten. During the nineteenth century chemists, using simple methods and in the light of simple theories which could be understood by a freshman student, learned remarkable things about the structure of matter.

Atoms and molecules actually exist, and early chemists came to know the numbers of atoms in each molecule and their exact arrangement relative to each other. The simple but powerful law of Avagadro that equal volumes of gasses at the same temperature and pressure contained the same number of molecules enabled us to get exact relative masses of molecules. The structures of the compounds of carbon with other elements, nitrogen, oxygen, hydrogen, etc., had been deduced with high probability from experiments in test tubes!

During the years since, the wonders of chemistry have advanced at a breath-taking pace. Today the breadth of our knowledge is so vast that no one comprehends more than a small part of the total. To me the more notable advances are (1) our knowledge of chemical thermodynamics or what factors determine the direction and extent of chemical reactions, (2) the theory of valence or what factors make atoms form molecules as they are observed,

(3) the detailed ways in which atoms rearrange themselves into new compounds and how rapidly they do so, and (4) the very intricate details of the compounds of carbon and particularly the ways in which these molecules form the structures and reactions of living organisms. This last subject is not at all complete and will surely occupy the minds of inquisitive and imaginative people for many years. It is my expectation that many of the young people who read this book will contribute much to this subject and will come to understand more about it than we do now.

During this century two important discoveries have dominated physical science, namely the quantum theory and radioactivity. The quantum theory, in principle, explains all of chemistry; the detailed mathematical calculations that are required to account exactly for the properties of water, for example, are beyond the capacity of our largest calculating machines. Radioactivity is dominating much of our thought at the present time both within scientific laboratories and outside them. One fascinating study on which much progress is being made deals with attempts to explain the origin of the elements themselves. They were made, it seems, on the interior of the stars under massive pressures and at billions of degrees of heat. Studies on radioactivity have made this development possible. Again, readers of this book may help with such magnificent studies when they master more of the subject.

The industrial applications of chemistry extend to all phases of industry, and they supply much of the material basis of our lives. Many young people will be fascinated with these aspects of the subject. Though nearly all my life has been spent in pure science, I am sure that had some small event shifted me toward industrial work, I could have done this and felt that my life was very interesting and worthwhile. So much of our necessities, our conveniences, and the beauty of our lives are contributed by the industrial application of chemistry.

We salute the youth of our land and wish them every success in their life's work! There is high adventure in chemistry, indeed, for those who make it a career.

HAROLD C. UREY

University of Chicago
Chicago, Ill.
September 1, 1957

PREFACE

To the Reader:

Chemistry is an art, as well as a science. As you perform the experiments in this book, you'll find that you're having fun—as well as learning more about the fascinating elements that make up the World of Chemistry.

None of the experiments in this book are dangerous. But there are rules that you will want to follow in the interests of safety and good chemical technique.

1. Keep your apparatus clean, and your working place uncluttered. Be especially careful when you are using a bunsen burner or other source of heat.
2. Always apply heat to glassware slowly and gradually, to avoid breakage. Never heat glassware that is wet on the outside.
3. Never let a hot glass flask cool if its delivery tube remains under water. Suction will draw water into the heated container and break it.
4. To insert a glass tube into a holed stopper, wet both and insert the tube with a twisting motion. When cutting glass tubing, always polish the cut end in a bunsen burner or gas flame.
5. Remove solid chemicals from their containers with a clean spatula or spoon. Don't let your chemicals become

contaminated by careless handling. Never replace leftovers—flush them down the toilet.

6. Never pour acids down the drain or into the toilet. Neutralize them with bicarbonate of soda first.

7. In mixing liquids, always keep your face as far away from the operation as possible.

8. To dilute an acid, always pour cool acid into water, Never pour water into an acid.

9. Do not inhale gases from chemicals. To detect odor, waft a bit of the gas toward you with your hand.

10. Do not touch any chemical with your hands. If any chemical is spilled on the skin, clothing, or table, wash the area with cold water, then rinse with bicarbonate of soda solution. If you should spill a strong acid, such as sulfuric, on your skin, wash it off under running water and neutralize with ammonia water. A strong alkali can be neutralized with vinegar or lemon juice.

11. If a chemical is accidentally swallowed, rinse the mouth with water, then drink a glass of milk mixed with egg whites. Try to induce vomiting. Always call a physician.

12. Keep your chemicals and apparatus out of the reach of small children.

13. Never mix chemicals just "to see what will happen." The result may be tragic.

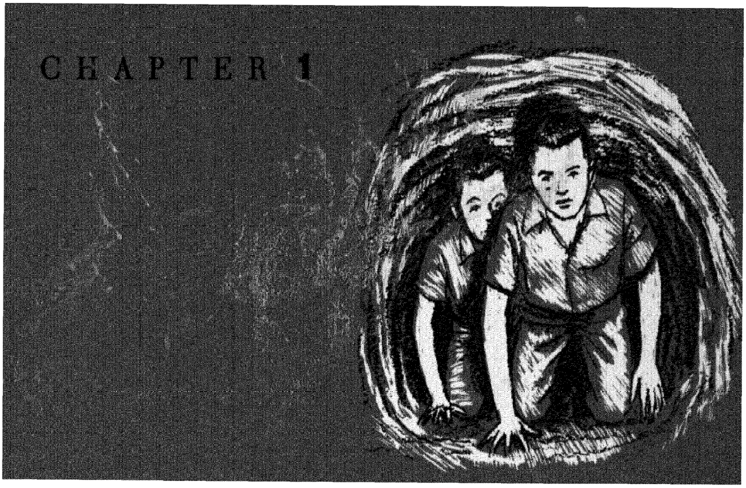
14. Treat scratches or burns immediately. If a chemical has entered the wound, always see a doctor at once. Some compounds are poisonous in very small amounts when introduced into the bloodstream.

15. Keep flammable chemicals at least *20 feet* from an open flame. Never generate quantities of hydrogen or other explosive gases. Have adequate ventilation when performing experiments involving smoke or fumes.

16. Remember that scientific hobbies are not for those who are careless and irresponsible. Work safely and carefully, and *know* what will happen before you start the experiment. If these rules are followed, experimenting can be your passkey to a fascinating hobby—and perhaps to an even more fascinating career.

J. M.

Chicago, Illinois



CHAPTER 1

The Egyptian cave

RANDY MORROW and his younger brother, Sam, crept down the narrow cave passage on their hands and knees. The only light came from a rock chamber ahead of them, where their Uncle Dan waited.

"Careful of the sharp rocks at the end of the tunnel, boys," came the voice of Uncle Dan. The sound echoed weirdly through the underground cavern.

"Can you give us a little more light?" Randy asked. Instantly, the beam of a powerful flashlight lit up the narrow tunnel.

Sam, aged nine, suddenly grabbed Randy's ankle urgently.

"What's wrong?" asked Randy in alarm.

"There's something—s-something crawling up my pants leg!"

"We'll get it out in a minute. Keep moving."

The tunnel came to a sudden end. The boys' uncle, who was twenty, helped them out into a large cave room, full of ghostly shadows and looming shapes.

Sam squealed and began to stamp one foot wildly. "It's still crawling up my leg! It might bite!"

"What, for Pete's sake?" asked Uncle Dan.

Randy shrugged. "Something took a fancy to Sam back there in the tunnel."

"Stand still for a second, Sam," Uncle Dan said. "Let's see what you've got there. Ah! Here he is!"

He held up a tiny squirming creature that had dropped out of Sam's pants leg. He held it close to the beam of the flashlight.

"A cricket!" Randy exclaimed. "Look how pale he is—and what long feelers he has!"

"This is a cave cricket," Uncle Dan said. "It lives its whole life underground."

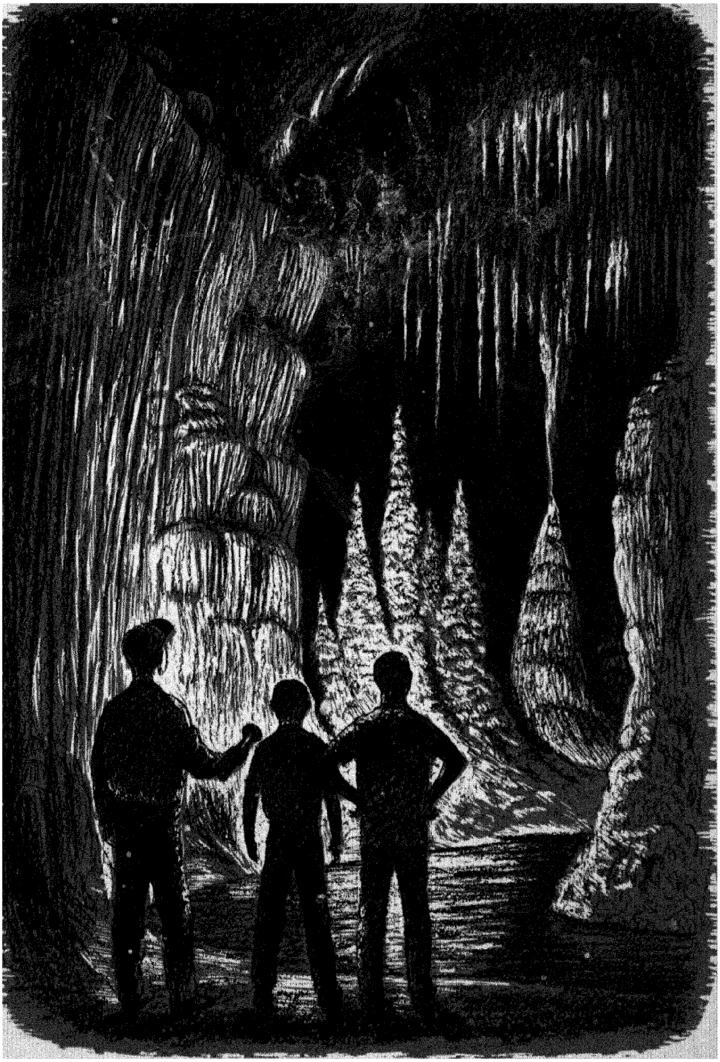
"Aw, *that* won't hurt me," said Sam in disgust. "I thought it was one of those poison spiders, like the ones that live in pyramids."

Randy said, "He read about those in a comic book once."

"There aren't any poisonous spiders in caves, Sam—or in pyramids either," Uncle Dan said.

"Shine your light around, and let's see what the cave looks like," Randy suggested.

His uncle obliged—and the boys gasped. The powerful beam moved slowly around a vast room formed out of solid rock. Glistening, pearly terraces and rippling draperies made out of stone made a breathtaking picture against



"Gosh!" Randy said. "I've never seen anything like it!"

the blackness of the many underground passages.

From the ceiling, colored stalactites hung, looking like titanic icicles that might break off at any moment. Beneath the stalactites were stalagmites, cone-shaped formations growing up from the floor. Many of the stalactites and stalagmites had grown until they met, forming pillars of stone.

"Gosh," Randy said in awe. "I've never seen anything like it! Look how all the rocks sparkle when the light hits them!"

"That's because of the water flowing over them," Uncle Dan explained. "Seeping water is responsible for all these beautiful rock formations."

Randy was kneeling beside a pool at the base of one of the stone cascades. "There's something in this pool, Uncle Dan," he said.

The light beam was directed into the depths of the water. In a small potlike depression in the pool floor were several spherical objects that looked like white marbles. "Cave pearls," Uncle Dan said. "Pretty aren't they?"

"Let's fish 'em out!" Sam exclaimed.

Uncle Dan shook his head. "If you took them out of the water, they wouldn't stay pretty. Before long, the outside would turn dusty and begin to flake off. The pearls are made of calcium carbonate, like all the rest of the formations you see. If calcium carbonate isn't kept wet, it crumbles to dust."

"What's calcium carbonate?" Sam asked. "Sounds like a chemical!"

Uncle Dan laughed. "It is a chemical, Sam. But not a very mysterious one. Lots of things are made out of calcium carbonate—limestone, marble, clam shells, coral, chalk, even egg shells. They have a different physical appearance, but they're all basically calcium carbonate."

Randy frowned. "Is that a mixture of calcium and carbon?"

"The chemical contains calcium, carbon, and oxygen," his uncle replied. "But it's not a mixture, it's a *compound.* There's a big difference. Let me try to explain it to you. First—do you know what an element is?"

"Sure," Randy said. "That's something like gold or oxygen or uranium that can't be broken down by ordinary chemical methods."

"Hey! Wait a minute!" Sam said. "Uranium breaks down in an atomic reactor!"

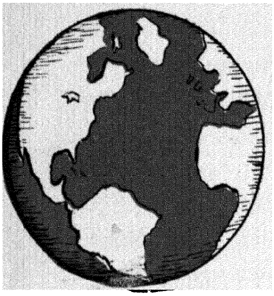
"Randy's still right," Uncle Dan said. "Elements can't be broken down by *ordinary* chemical methods, such as heating or treating with strong acids or alkalis. Elements can be broken down by means of atomic energy, but that's not a chemical method."

Uncle Dan told the boys that everything in the world was made up of atoms of the different elements. Some elements, like gold and silver and neon, stood alone. Other atoms, like calcium and aluminum and sodium, were never found in a pure state in nature. They were always found in chemical combination with other elements.

"And these chemical combinations are called compounds," Uncle Dan said. "Now let's try to see the difference between a compound and a mixture. Take calcium carbonate. We could get some little pieces af calcium metal, and a heap of powdered graphite—that's carbon—and mix them up. If we dumped the whole mess into a bottle filled with oxygen gas, we'd have a mixture of the three elements that make up calcium carbonate."

"I see," Randy said. "They'd be mixed up—but you'd be able to separate them again just by sifting."

Elements are everywhere



oxygen
silicon
aluminum
iron
calcium
sodium
potassium
magnesium
titanium

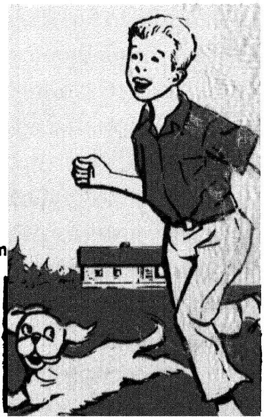
The earth contains at least 90 elements. But the nine listed make up over 99% of the planet's mass.

hydrogen
oxygen
sodium
chlorine
sulfur
magnesium
calcium
potassium
carbon
boron

The sea is mostly water, but it contains abundant mineral matter as well. No one has duplicated the composition of sea water exactly.

carbon
oxygen
hydrogen
nitrogen
potassium
phosphorus
calcium
magnesium
sulfur
molybdenum
boron
manganese
zinc
copper
iron

Plants contain large amounts of the first three elements, but require the others for proper growth.



carbon
oxygen
hydrogen
nitrogen
potassium
phosphorus
iron
calcium
copper
iodine
sulfur
sodium
chlorine
magnesium
manganese
cobalt
zinc

Animal life is formed largely from the first four elements. The others are essential to the health of warm-blooded animals.

"Right. But you can't do that with a compound. You could sift calcium forever without separating the elements. They lose their identity when they become part of a compound. We don't see silvery calcium or black carbon or transparent oxygen any more—we see a whitish powder, calcium carbonate."

Sam looked incredulous. "You mean a compound doesn't look anything like the elements it's made of?"

"Usually not. And the compound frequently doesn't have the same properties as the elements that make it up. Take common salt, sodium chloride. It's made of a poison gas and a shiny metal that's so chemically active that it has to be kept under kerosene so it doesn't start burning by itself!"

"Wow," Sam remarked.

"There's another thing about compounds. They always have the same proportion of the elements that make them up—while a mixture could have any proportion. Calcium carbonate is a compound. The units of a compound are called molecules. Each calcium carbonate molecule has one atom of calcium, one of carbon, and three of oxygen. And the way the molecules are arranged determines the physical appearance of the compound."

"Here's a stone icicle that's almost transparent," Randy said. "Do you mean that the molecules in this piece of stone are arranged differently from the ones in—say—the cave pearls?"

"Right," Uncle Dan said. "Same compound, different physical form."

Sam touched his finger to the tip of the stalactite. "These things are always dripping, aren't they."

"The dripping water is the cause of the stalactite. Nature's own chemistry in action!"

They peered at some tiny stalactites that were growing on the lip of a shelf on the cave wall. "Incidentally," Uncle Dan said, "you can keep stal*actites* and stal*agmites* separate in your mind if you remember that stalactites always stick *tight* to the ceiling!"

"How are they formed, though, Uncle Dan?" Randy asked.

"Well, first let's take the stone. Limestone is formed out of the shells of billions of tiny sea animals that died millions of years ago."

"Check," said Sam and Randy.

"Next, let's take rain. You know that rain water seeps through the ground. When the rain first falls, it picks up carbon dioxide gas from the air. The carbon dioxide dissolves in the water and forms a new chemical compound—carbonic acid. You guys know what an acid is, don't you?"

Randy said, "It's a sour sort of stuff that dissolves things, isn't it?"

"Acids are sour, and they're able to dissolve certain substances. Carbonic acid is pretty weak, but it *can* dissolve limestone!"

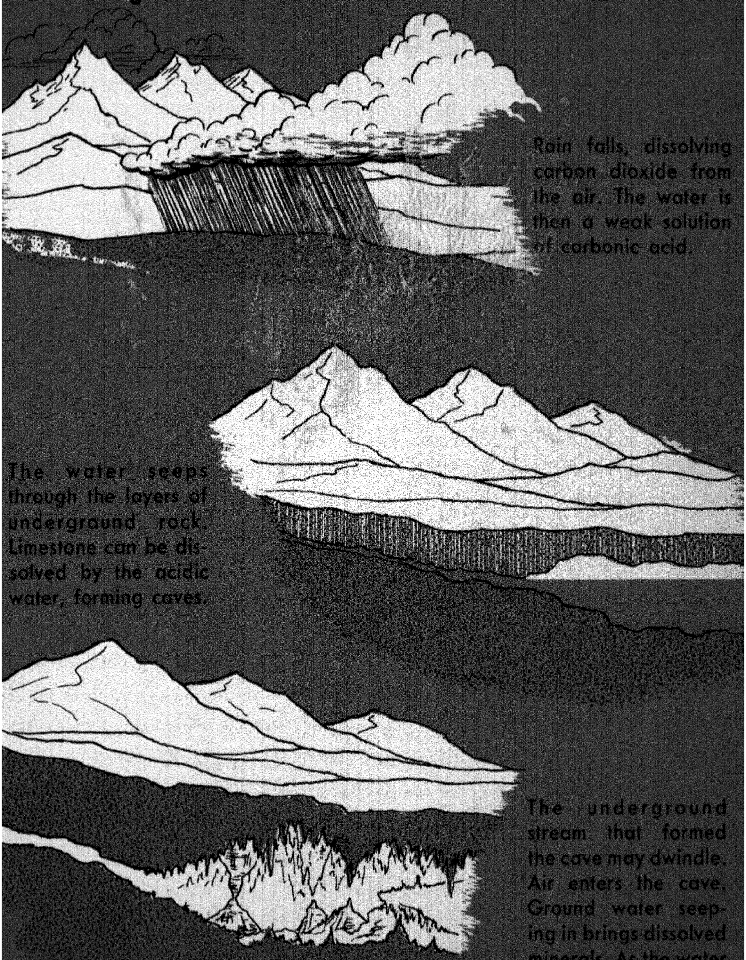
"I get it!" Randy cried. "The carbonic acid in the rainwater dissolves the limestone and makes the caves!"

Uncle Dan said that was right. It took millions of years to hollow a cave out of solid rock. And after the caves were formed, they began to fill up with rock again!

"Get the picture," the boys' uncle said. "There might have been an underground river running through here once that cut out the original cave. The river changed its course, and the cave filled with air. However—ground water seeps down into the cave, coming through the cracks in the walls and ceiling. Since the water has carbonic acid in it, it dissolves a little bit of the limestone as it passes

Chemical action goes on constantly in nature

The making of a cave



Rain falls, dissolving carbon dioxide from the air. The water is then a weak solution of carbonic acid.

The water seeps through the layers of underground rock. Limestone can be dissolved by the acidic water, forming caves.

The underground stream that formed the cave may dwindle. Air enters the cave. Ground water seeping in brings dissolved minerals. As the water drips from the cave walls, it leaves some mineral behind. Eventually, beautiful rock formations are built up.

down through the cave walls."

"But why wouldn't that just make the cave bigger instead of causing these rock icicles to form?" Randy wanted to know.

"The water seeping through the walls is under pressure," Uncle Dan said. "It takes up some calcium bicarbonate, which is formed when the acid meets the limestone. As the water drips out the crack, the pressure is released. Do you know what happens when you take the cap off a bottle of ginger ale?"

"It fizzes," Sam said.

"Right. It gives off some of the carbon dioxide that was dissolved in it. Ginger ale is a carbonic acid solution, too! And if our drop of cave water gives off some of its carbon dioxide, the water becomes less acid than it was before. And some of the calcium carbonate comes out of the liquid and is left on the tip of the rock icicle when the drop falls."

Randy protests, "But then it must take billions of drops of water to make just a tiny bit of rock!"

Uncle Dan nodded. "It does. But nature's not in any hurry. This cave was here millions of years before I discovered it. It may be here another million years—slowly filling up with more rock."

"What made the cave pearls?" Sam asked.

"Calcium compounds dissolved in the water of the pool began to collect around a little bit of dirt or something," Uncle Dan said. "The mineral was deposited in layers, and movements of the water kept the pearl turning so that it assumed a spherical shape."

The boys and their uncle climbed cautiously around the large cavern and admired the beautifully colored rock formations. Iron and other elements mixed in the calcium carbonate were responsible for the colors, Uncle Dan told them. Pure calcium carbonate was white.

"We'd better be moving out of here now," Uncle Dan said. "We can do some serious exploring some day when we have the proper equipment. There are a lot more rooms like this one, but we'll need rope and hard hats and other spelunking equipment."

"Spe-*what?*" Sam asked.

"Spelunking. That's the proper name for the art of exploring caves. Or you could call it speleology, if you like. We can do a lot of it this summer if you boys are interested."

"We sure are," Randy said enthusiastically. "Boy, this is going to be a swell vacation!"

Sam laughed. "And you were the one who didn't think there'd be anything exciting to do on Grandma's farm!"

Randy remembered ruefully that he had expressed this very thought when their father had suggested that the boys spend the summer with their grandparents in southern Illinois.

"That's the part of the state that's called Little Egypt," Mr. Morrow had said. "It's beautiful country—and the Mississippi River's not too far away. You kids will have a fine time."

At the time, Randy had had his doubts. But the prospects for summer fun had taken an upswing when Uncle Dan introduced them to his private cave.

"It'll be a lot of fun to go spelunking with you, Uncle Dan," Randy said. "Are there any more caves around?"

Uncle Dan nodded. "This region is full of them."

"Can I borrow the flashlight a minute?" Sam asked. "I want to see what those little things up there are."

The boy climbed onto a large rock ledge and shined the light on his discovery. It was a neat row of little stone tubes, like straws, hanging from an outcropping.

"Can't I take just one of these with me?" Sam pleaded. "I could keep it in a jar of water so it wouldn't spoil and—woops!"

There was a crash—and the cavern plunged into darkness. In his eagerness to examine the stone tubes, Sam had dropped the flashlight.

"We're trapped!" he wailed. "How are we going to find our way out *now?*"

"Calm down," came the voice of Uncle Dan from the blackness. "Just stand where you are and don't move. You too, Randy."

The boys heard groping sounds as their uncle located the flashlight on the cave floor. "Smashed the bulb," they heard him mutter.

"Can we feel our way to the exit?" Randy suggested.

"It's clear on the other side of the cave—with pools of water and lots of sharp rocks in the way. Wait a minute. Let me think."

Silence, as well as blackness, hung over the Morrow boys and their uncle. At last Uncle Dan spoke.

"Sam, can you still feel those stone straws?"

There was a tinkling sound. "I just broke one," Sam announced.

"Okay. Let me climb up there beside you. Randy, hang onto the back of my belt and follow me."

Randy and his uncle scrambled cautiously up to the ledge where Sam waited. The younger boy was told to hang onto Randy's belt. Then the three of them began to inch their way blindly along the shelf of rock.

"Where are we going, Uncle Dan?" Sam asked fearfully.

"I *think* we're near a hole in the rock where I stowed some junk last year. We'll try to locate it. I could kick myself for getting us into a jam like this. Every spelunker knows that you should never explore caves without bringing along at least three sources of light."

Randy and Sam stood silent while their uncle felt along the damp rock walls. "I'm sure the storage hole was near a soda-straw formation," Uncle Dan murmured. "But was this the one?"

Suddenly he gave a shout of joy. "It's here! I found the hole!"

Randy and Sam breathed a sigh of relief.

"There's a can of carbide and a miner's lamp in here. If I can just load the lamp by feel, we'll have light in a minute."

"We don't have any matches," Randy hesitated.

"Don't need them. The lamp has a flint and wheel to ignite it—like a cigarette lighter. I'm loading the lamp with carbide now. Then we'll put some water in it from one of the pools."

"Water?" Randy said incredulously. "To make fire?"

"When the water meets the carbide, acetylene gas is formed," Uncle Dan said. "The lamp burns the acetylene. Wait a minute now—we're going to back up."

The little procession moved backward slowly in the pitch blackness until they came to the soda-straw formation again. Then they descended to the cave floor. It took only a minute for Uncle Dan to locate a little pool of water and fill the chamber in the lamp.

"Now we're in business," he said gleefully, and thumbed the spark wheel. There was a pop, and a slender yellow flame lit the relieved faces of Sam and Randy.

"Hooray!" yelled Sam.

"Saved by chemistry," Randy said.

Quickly, they located the exit and squirmed out of the

"Saved by chemistry!"

cave into the sunlight.

The flame of the carbide lamp looked feeble and insignificant now. Uncle Dan showed the boys how the lamp worked. Water from the upper chamber of the lamp dripped down into the chamber of carbide below, producing the gas.

However, even as they watched, the flame flickered and went out.

"We made it just in time," Uncle Dan said grimly.

"What happened to the lamp?" Randy asked.

"I don't know. But we'd better find out before we try to use it in the cave again. I think you'd better take it over to the Chandler place and let Terry take a look at it."

"Who's Terry?" Randy asked.

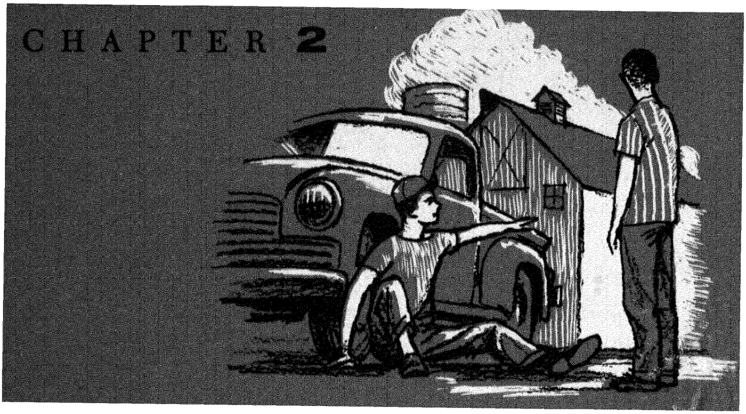
"The local mad chemist. Lives right down the road from us. Terry's got the doggondest lab set-up you ever saw. Whenever anybody around here has trouble with chemical-type things, they take it to Terry."

"Sounds like a fascinating character," Randy grinned. "Maybe I'll wander over for a minute before lunch."

"How about you, Sam?" Uncle Dan asked.

Sam stretched. "No mad chemists for me. I've had my adventure for the day. Me for the catfish and the lazy life!"

CHAPTER 2



The mad chemist

RANDY found the Chandler farm easily enough. It was scarcely a half mile down the road from his grandparents' place.

He heard a metallic clanging sound, and wandered around to the equipment yard in back of the farmhouse. Two denim-clad legs stuck out from beneath an old pick-up truck. The noise was coming from there.

"Hey!" Randy said.

The hammering stopped. A freckle-faced boy of about fourteen squirmed out from under the truck. "Hi," he said.

"My name's Randy Morrow. Are you Terry Chandler?"

"Nope, I'm Jerry Chandler. Terry's my twin."

"Oh," Randy said. "Well, my uncle, Dan Morrow, asked me to come down and look Terry up. It's about this carbide lamp that won't work."

"Chemistry, eh?" Jerry grinned. "That's Terry's department, all right. Automobiles are *my* meat. If you want to find Terry, just circle around the barn and look for an old chicken house on the other side of the pasture."

Randy thanked the other boy and moved on. The chicken house was easy to locate. He peered in through the long front window and saw chemical glassware and boxes and bottles neatly arranged on home-made shelves. But there was nobody working in there.

Suddenly, Randy heard a faint, hissing thud. A tremendous billow of thick white smoke rose from the back of the chicken house. Randy ran around to see what had happened, and nearly fell over a prone figure lying on its stomach in the weeds.

"Stand back! It's going off again!" cried a shrill voice.

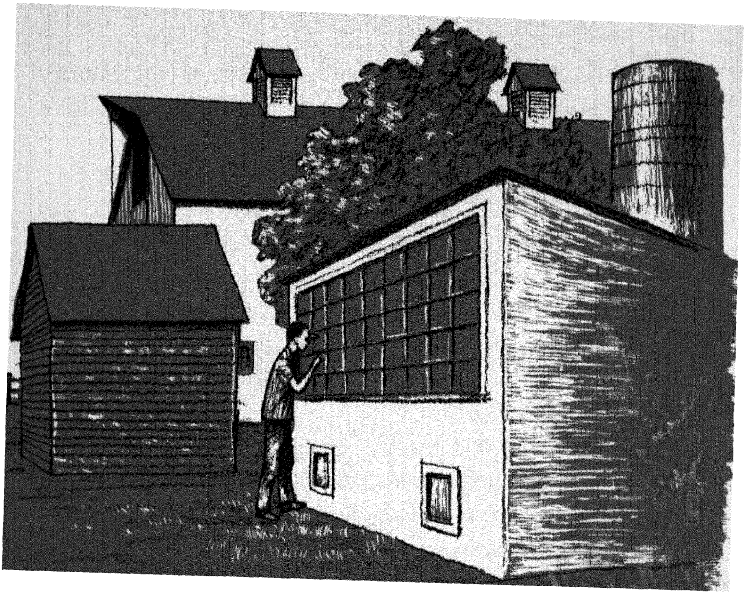
Randy backed off in amazement as another huge puff of smoke soared skyward. The wind caught the smoke and sent it swirling down on Randy and Terry Chandler.

"Run, kid!" Terry shouted. Randy did.

Terry scrambled forward on hands and knees and grabbed a large stirrup-pump fire extinguisher that stood ready in a clump of weeds. In a minute, water was playing on the source of the smoke, and the clouds had begun to disappear.

Randy was able to get a good look at Terry, who was dressed in blue jeans, a black rubber lab apron, and a pair of plastic goggles. A red bandanna handkerchief had been tied bandit-style around the mad chemist's face.

Finally the smoke died away. Terry picked up the fire extinguisher and came over to Randy.



Randy peered in through the window . . .

"Foof! Dad would have given me the dickens if that smoke had stampeded the cows!"

"Experiment run away from you?" Randy asked with a grin.

"I should say not. I always keep things in hand. The wind shifted on me, that's all. Here—hold this."

Terry dumped the fire extinguisher into Randy's arms and began to remove the goggles and bandanna.

"I don't remember seeing you before," Terry remarked. "You new in this neck of the woods?"

Randy nodded. "Visiting my grandparents for the summer. Name's Randy Morrow. I brought this carbide lamp for you to—holy smokes!"

Randy broke off and stared at Terry Chandler. The resemblance to Jerry was startling, but there was something else!

"Something wrong?" Terry asked.

Randy gulped. "I didn't know you were—I mean, my Uncle Dan didn't tell me that your name . . ." Randy trailed off in confusion.

"That my name was short for Theresa?" Terry said. "He's a real comedian, your Uncle Dan. Well, if you're too stuck-up to have anything to do with a girl, you might as well toddle along."

She took the fire extinguisher away from Randy and headed for her chicken-coop lab.

"No—wait a minute, Terry," Randy said. "I don't mind if you're a girl."

"How generous of you!" Terry said poisonously. She fumbled with the door latch, which stubbornly refused to open.

"Let me get that," Randy said. He had the door open in an instant.

"Thanks," said Terry briefly. She dumped the extinguisher on the floor and stared at Randy.

"Gee, Terry, don't be mad," Randy said. "Uncle Dan told me about your swell chemistry lab, and I just thought I'd come over and see you. I brought this carbide lamp to see if you can tell me what's wrong with it."

"Hmp," said Terry.

"Besides, I'd sure like to see your lab—if you want to show it to me."

"Are you really interested in chemistry?" Terry asked, still suspicious. "I don't want any messers in my lab."

"I'm really interested," Randy vowed. "I don't know much about chemistry—just the little bit I got in Junior

Terry began to remove the goggles and bandanna . . .

High, and what I managed to learn from a chemistry set."

"Chemistry sets are kid stuff," said Terry loftily.

"Oh—I don't know!" Randy smiled. "But I can see that you've got a real set-up here. *This* equipment isn't kid stuff."

"You bet your life it isn't," Terry said proudly. Randy could see her ruffled feelings were beginning to smooth down. "Would you like to see some of the stuff?"

"That'd be swell," Randy said.

The chicken house had a concrete floor and walls of wood. Terry explained that she had applied several coats of fireproof paint to the inside of the house. In one corner was an old porcelain-topped metal table. Several large pieces of sheet iron had been fastened to the walls around the table, and a flaring exhaust flue hung down to within a foot or so of the table top.

"That's for experiments that cause a lot of smoke, or throw sparks," Terry explained. "I've spent a lot of time trying to make this lab a safe place to work in." She paused significantly. "There's no danger in chemistry if you take the necessary precautions and use common sense."

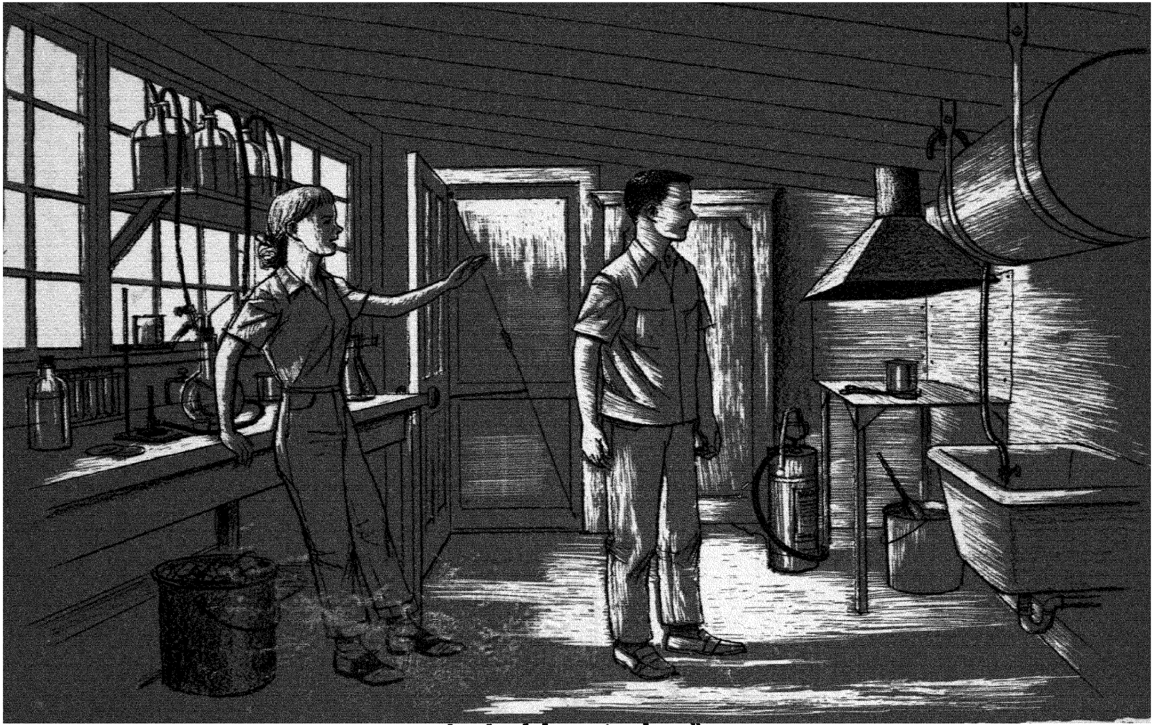
She told Randy that a chemist's workshop should be well-ventilated. Besides the ordinary water-type fire extinguisher, Terry also had a bucket of sand with a little shovel for putting out chemical fires that wouldn't respond to water.

Her main workbench was nearly eight feet long, set up in front of the long window that stretched across the front of the house. The table was of sturdy and much-scarred oak, and its top had been given several coats of black lab paint which would resist the attack of chemicals.

At each end of the table was a double gas stopcock for bunsen burners. Terry explained that she burned butane gas, the same gas that was used in rural cooking ranges. A tank of the gas was stored outside the house.

"I don't have any running water here," she said, "so I've rigged up a gravity-flow tank."

She pointed upward. Randy saw a large barrel that had



"I'm trying to make this lab a safe place."

been fastened firmly to the ceiling beams. A length of hose extended from each end. One piece of hose had been looped, and its open end fastened to a cleat on the ceiling above the barrel level. The other hose, of narrower diameter, extended down into an old sink. A pinchcock secured the end of the hose.

"To get water," Terry said, "you just release the pinchcock. When the barrel is empty, I just pump the barrel full again with my stirrup pump. That open hose fastened to the ceiling equalizes the air pressure in the barrel."

Terry explained that this ordinary water was used mostly for cleaning glassware—not for experiments.

"I use distilled water for that," she said, pointing to a rack holding three one-gallon bottles. Each one had been fitted with a siphon and a pinchcock.

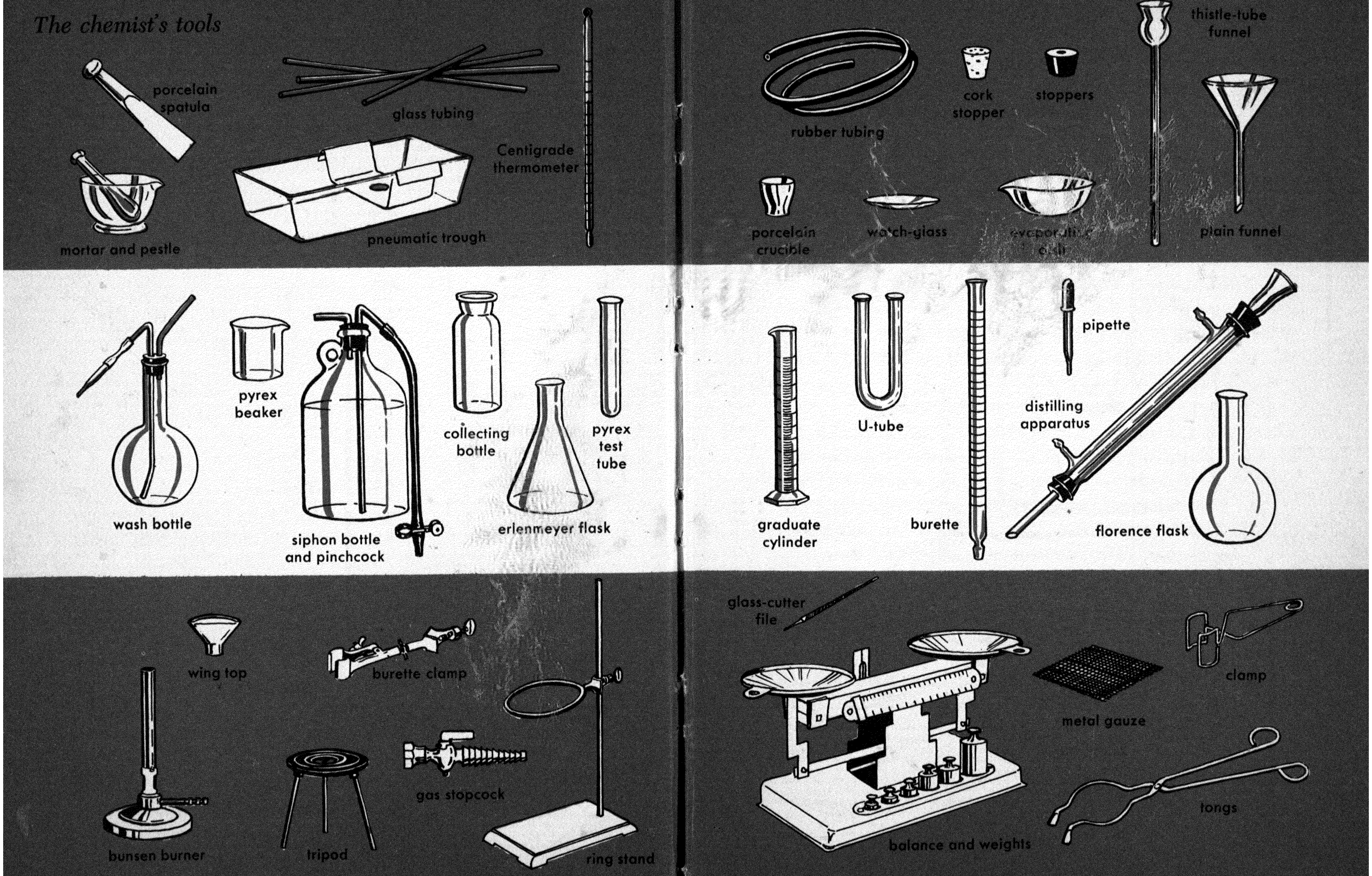
"After the glassware is washed with brushes and a detergent, I rinse everything with distilled water. You know that traces of chemicals left in the beakers and test tubes could spoil the next experiment."

She showed him a wash bottle, a flask with round sides and a long neck. A two-hole stopper had been inserted in the neck, and two pieces of bent glass tubing placed in the holes.

"This makes a handy source of distilled water to use during experiments," Terry said. "You blow into this tube, and the pressure of your breath forces water out the nozzle of the other tube."

An old wardrobe cabinet with sturdy doors had been converted into an equipment locker. Terry showed Randy her sets of beakers and test tubes, most of them made of Pyrex glass which would not shatter when subjected to extremes of temperature. She had two kinds of vase-shaped flasks—Florence flasks with round sides, and Erlen-

The chemist's tools



meyer flasks with slanting sides.

There were plain glass funnels and thistle-shaped ones with long tubes attached. The latter were used to add liquids to flasks closed by a stopper.

"What're these things that look like doll's coffee cups?" Randy asked.

"Those are porcelain crucibles. They're used for high-temperature work. The white dishes next to them are evaporating dishes, used for drying chemicals. Those things like transparent saucers are watch-glasses. They can be used for evaporating small amounts of liquid."

She showed him a porcelain mortar and pestle, used for grinding, a distilling apparatus, open-ended U-tubes, and glass tubing in many different diameters. There were coils of rubber tubing also, and boxes of rubber and cork stoppers of different diameters.

"These are my measuring instruments," Terry said. There was a sensitive scale with a set of weights that she kept in a dustproof plastic container. There were graduate cylinders and burettes for measuring liquids. A case held several thermometers calibrated in the Centigrade scale.

"All chemical measurements are done in the metric system," Terry said. "Weights are calculated in grams, and volume in liters or milliliters—those are thousandths of a liter. A cubic centimeter and a milliliter are the same thing."

The hardware was kept in a drawer. Randy saw tripods and ring stands and clamps and tongs. There were squares of metal gauze to be placed under beakers and flasks while they were heating.

"You must have your own private money tree to finance all this stuff," Randy said.

Terry shook her head. "I've been collecting it for years.

And by now my relatives know that I don't want perfume and jewelry and gloves and stuff on Christmas and birthdays. I keep a list of things that get broken, or special apparatus and chemicals that I need. I circulate the list just like a bride's wedding gift list!"

"What a racket," Randy grinned.

"Oh, I don't make it a one-way affair," Terry said. "All the relatives get chemistry-type gifts from me in return. I make up magic gardens and invisible ink and stuff for the kids, and spot removers and cold cream and glass ornaments for the aunts. One uncle grows roses. I make him batches of special fertilizer and insecticides. The uncle with the pack of hunting hounds gets jars of gookum for sore dog feet, and flea powder and stuff."

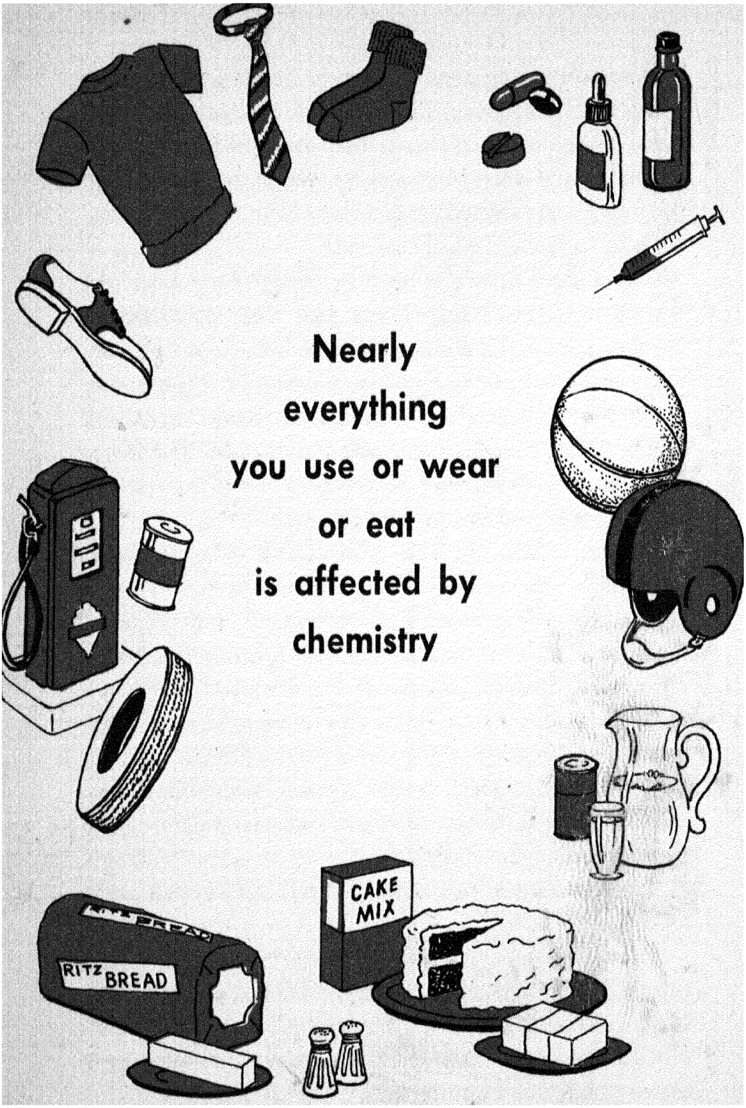
"It sounds like you have a lot of fun with chemistry, Terry."

"It's the most wonderful science of all. Just stop and think about it for a minute. Nearly everything you use or wear or eat is affected by chemistry. Your shirt is dacron—an artificial fiber. Your jeans were dyed with man-made indigo. Your teeth probably have plastic fillings in them. Your shoes are made of leather tanned by chemicals, and the heels are probably made of synthetic rubber. Your watch is full of metal alloys."

"I'm a walking chemical works, and I didn't even know it!" Randy laughed.

"Everybody is," Terry said positively. "Even the digestion of your food is a chemical process. And you wouldn't have the food to eat in the first place if chemicals didn't fertilize the plants and kill the bugs and diseases that attack plants and farm animals."

"I suppose chemistry *is* pretty important to the farmer," Randy said.



Nearly everything you use or wear or eat is affected by chemistry

"Let me show you my hydroponic garden," Terry said.

She showed Randy a glass tray full of clean white sand. Three husky tomato plants were growing in it. "They get all the plant food they need from chemicals dissolved in their water," Terry explained. "Hydroponics is the science of gardening without soil."

Randy nodded. "I saw plants growing like this when I visited Argonne National Laboratory. You know—that's a big atomic energy installation outside Chicago."

"Are you planning to study atomic energy?" Terry asked.

"I haven't decided yet," Randy admitted. "I've been trying to look into a lot of different science and engineering fields to find the one I like best."

"Looked into chemistry yet?" she asked.

"No—but I'd like to. Do you mean you'd help me perform some experiments? Show me how to get started?"

"I would if you were really serious. Chemistry isn't a field for nitwits. You have to observe precautions with dangerous chemicals, and you have to know what you're doing. Nobody but a flea-brain ever mixes chemicals together just to see what'll happen."

"I understand. You can hurt yourself with almost *anything* if you don't understand it. Chemistry is no different from electronics or atomic energy—or even spelunking!"

"I never heard of spelunking," Terry said. "Is that a science?"

"Cave exploring," Randy said. "And that brings me back to this carbide lamp! Can you tell me what's wrong with it?"

He set the lamp on Terry's workbench. She examined the two chambers, and the burner for the acetylene gas.

"Let's put some of this carbide in a test-tube," she said.

Using a porcelain spatula, she transferred a pinch of the powder to a tube.

"We'll add some distilled water with this pipette," she said, producing a device that looked exactly like a medicine dropper to Randy. A gas began to escape from the carbide.

"There comes the acetylene," she remarked. "At least the carbide is still good." She lit a match and applied it to the mouth of the tube. The acetylene ignited and burned with a very smoky flame.

"This is a simple reaction," Terry said offhandedly. "Calcium carbide plus water gives acetylene plus calcium hydroxide. Then when you burn the acetylene you get carbon dioxide and water. Do you know how to work out chemical formulas, Randy?"

"No," the boy admitted.

"It's not too hard," she said, watching the acetylene flame. After a moment, the fire went out. Terry examined the whitish residue in the tube. "This is the stuff bricklayers call slaked lime. Now let's look at that lamp."

She took the lamp apart and began to poke at the inside with a long wire. "What a mess! Carbide smeared all over the gas outlet! No wonder the thing didn't work right!"

"Uncle Dan loaded the thing in the dark," Randy admitted. "Is that all that's wrong with it?"

"Seems to be," she said. "We'll try it when I get finished cleaning it out."

She reassembled the lamp and loaded it with fresh carbide and water. This time when the gas was lit, the flame was large and bright.

"It ought to work fine now," Terry said. "Just be careful to keep it clean."

"Thanks a lot, Terry. Maybe I'd better be getting back to the farm for lunch."

Terry rose from the workbench and accompanied him to the door. "There's a shortcut between our place and the Morrow farm that you might want to use."

She described a route through the back pastures and around a hill. "You come out of the woods right behind your grandfather's barn."

She hesitated. "Maybe I'll be seeing you around."

Randy laughed. "I still haven't found out what that smoke screen was for."

"Just an experiment in oxidation. Phosphorus combining with oxygen."

"Sounds interesting," Randy said, "Do you suppose I could help you with some experiments?"

"First you'd have to learn a little about chemistry—so you'd know what you were doing," Terry said.

"Will you teach me?" Randy asked.

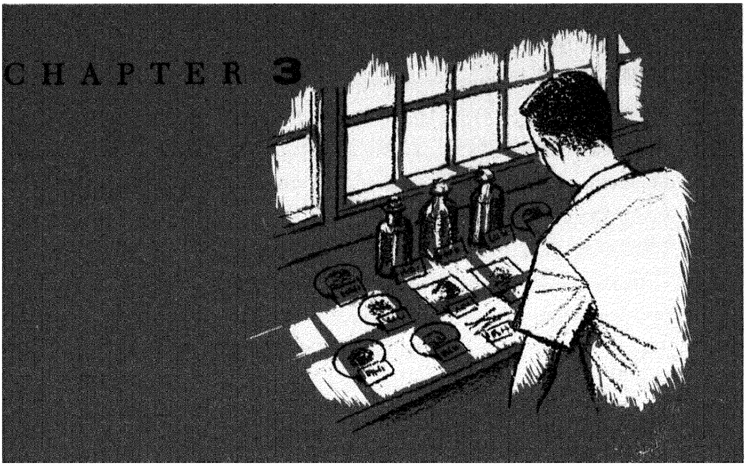
"Come over after lunch," she invited. "I'll work up some demonstrations and stuff."

"I'll be here," Randy said.

As he hurried away from the Chandler place and circled around the hill, he heard a strange sound. Looking back, he saw more clouds of smoke rising over the chicken house. But these puffs weren't white—they were red, white, and blue.

The mad chemist was at work again!

CHAPTER 3



Shuffling atoms around

When Randy returned to Terry Chandler's chicken-house lab, he found the workbench covered with bottles and dishes and pieces of paper with little piles of chemicals on them.

"Looks like Mom's kitchen does when my little brother finishes making fudge!" Randy laughed.

"Very funny," said Terry tartly. "This is a collection of elements I got together for you. I hope you know what *they* are."

"Sure," Randy said. He examined the collection. Terry had placed a little card beside each elemental substance. The card carried the name and the chemical symbol of the element.

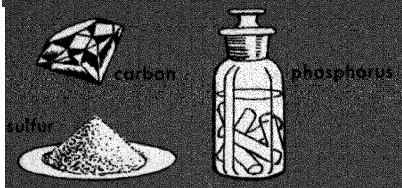
Aluminum	Al	(silvery metal)
Carbon	C	(black powder)
Copper	Cu	(reddish metal)
Gold	Au	(yellow metal)
Hydrogen	H	(colorless gas)
Iodine	I	(grayish crystals)
Iron	Fe	(gray metal)
Lead	Pb	(gray metal)
Magnesium	Mg	(silvery metal)
Mercury	Hg	(silvery liquid)
Nickel	Ni	(silvery metal)
Nitrogen	N	(colorless gas)
Oxygen	O	(colorless gas)
Phosphorus	P	(reddish powder)
Silver	Ag	(silvery metal)
Sulfur	S	(yellow powder)
Zinc	Zn	(silvery metal)

"Chemists use a sort of shorthand when they write their formulas," Terry said. "So each of the elements has a symbol of one or two letters."

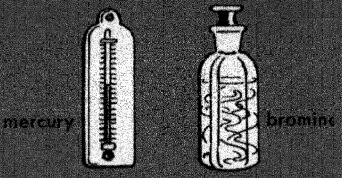
"I can see why the symbol for aluminum would be Al, and zinc Zn," said Randy. "But how about Au for gold and Hg for mercury?"

"Those elements have symbols based on their Latin names—not on the English ones," Terry explained. "Some elements have been known ever since ancient times. Au stands for *aurum,* Cu for *cuprum,* Fe for *ferrum,* and Pb for *plumbum.* The old name for mercury was *hydrargyrum.* Antimony, potassium, sodium, and tin used to be called *stibium, kalium, natrium,* and *stannum.* So their symbols are Sb, K, Na, and Sn. The only other element with a funny symbol is tungsten with W. That stands for wolfram,

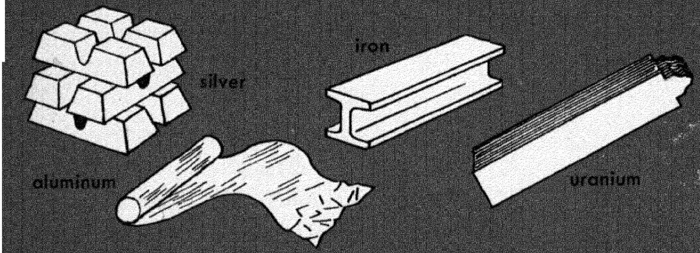
Elements have different forms



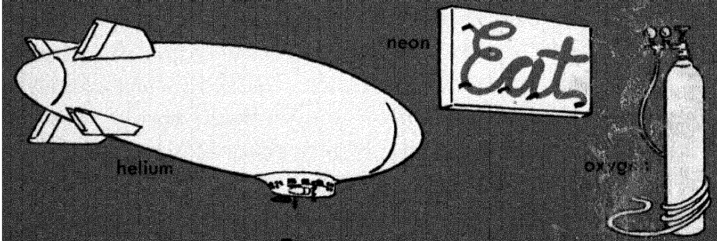
Solids



Liquids



Metals



Gases

Changes in temperature and pressure can cause an element to change its form. Gases can be changed into liquids or even solids by increasing pressure and lowering temperature. Metals can be changed into liquids or gases by high temperatures. A few elements, like carbon, have several forms even under ordinary conditions.

the ore that the element is found in."

She pointed out that something could be learned from the elements simply by looking at their physical form. Some were solid, some gaseous, and one a liquid. Some were metals and some were not.

"There are different forms of the same element, too," she said. From a closed cabinet she took a jar of water and set it down beside the reddish heap of phosphorus powder.

"Here's another form of phosphorus called white phosphorus." Randy peered into the jar and saw several waxy sticks submerged in the water.

"White phosphorus is poisonous and catches fire if it's exposed to the air," Terry said. "That's why it has to be stored under water. Red phosphorus isn't poisonous and won't catch fire until it's heated to a high temperature. But both of these forms are the same element!"

"Carbon has several forms, too, hasn't it?" Randy asked.

"Sure. Amorphous carbon is this sooty black stuff. Graphite is silvery gray. And you know what diamonds look like. I don't have any samples of *that* form of carbon, though!"

They both laughed. Then Terry said it was time for some fun.

She removed the stoppered bottles containing hydrogen, oxygen, and nitrogen from the element collection and took off their identifying signs. Then she switched the bottles around like a carnival man playing the shell game.

"Now can you tell which element is which?" she asked mischievously.

"Not just by looking at the bottles," Randy admitted.

Terry nodded in satisfaction. "You'd have to examine the chemical properties of the gases. Shall we test them?"

"I'm ready!"

Terry got out three small squares of glass. Turning the bottles over, she removed the stoppers and quickly slid a glass plate under each bottle mouth. The bottles were set in a row on the workbench.

"Now we'll need a long, burning splinter," she said. "I'll hold the bottles up one at a time with the tongs. You bring the splinter close to the mouth of the bottle and push it inside slowly. Ready?"

"Ready," Randy said. He lit the narrow piece of wood, which was about 10 inches long. Terry held the first bottle ready.

Randy held the flame near the mouth of the bottle. Nothing happened. Slowly he pushed the splinter inside the bottle. As he did so, the flame diminished and finally went out.

"This bottle contains nitrogen," Terry stated. "Nitrogen doesn't support combustion, and it doesn't burn itself."

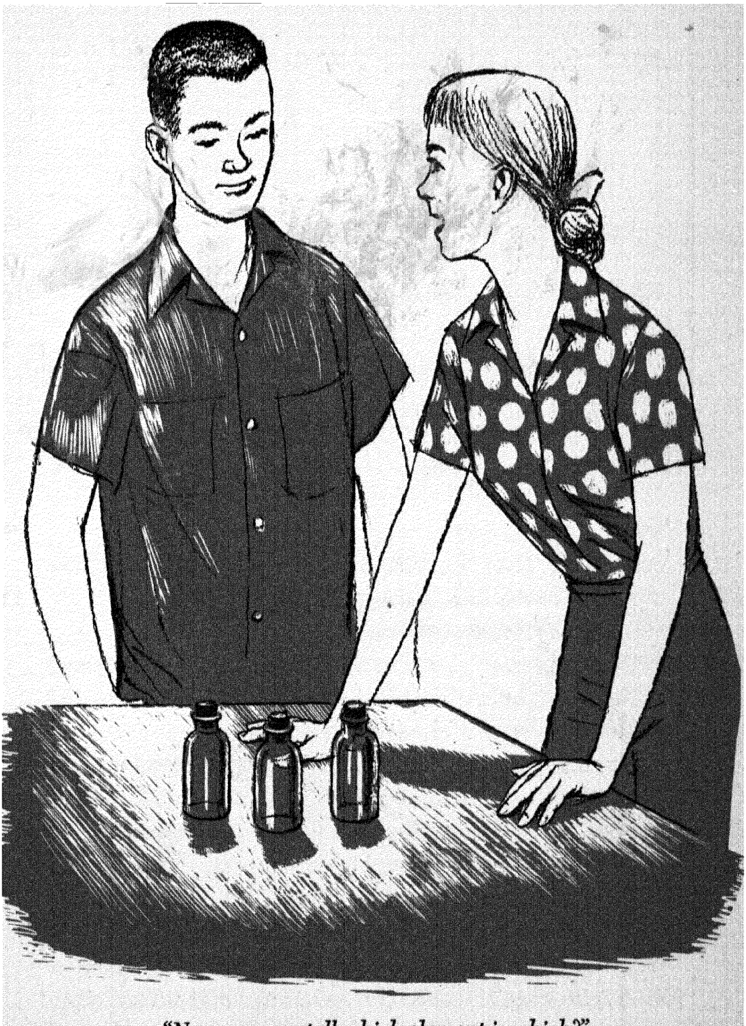
"Let's try the next bottle," Randy said. He lit the splinter again.

This time, the flame burned large and bright inside the bottle.

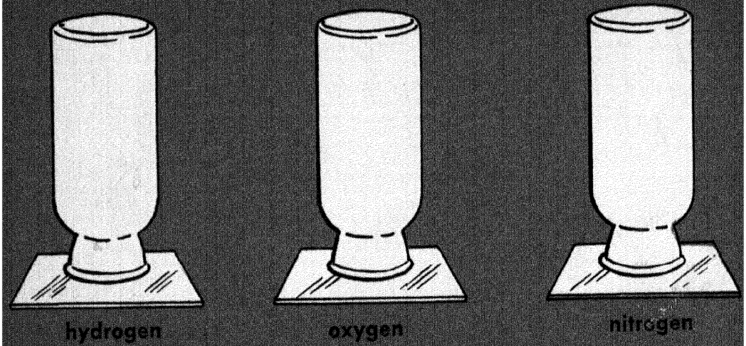
"Oxygen," Terry said. "It supports combustion, but it doesn't burn."

Something strange happened when they brought the flame near the last bottle. There was a faint pop, and pale blue flames began to lick along the mouth of the inverted bottle.

"Hydrogen burns, as you can see," Terry said. "It burns only when it's *not* mixed with air, though. If it's mixed with air, it explodes! This little jar contains only about 60 milliliters of hydrogen, which isn't enough to cause more than a cork-pop explosion. But nobody should gen-



"Now can you tell which element is which?"



Elements can be distinguished by their chemical properties

1 These three elements are similar in physical appearance.

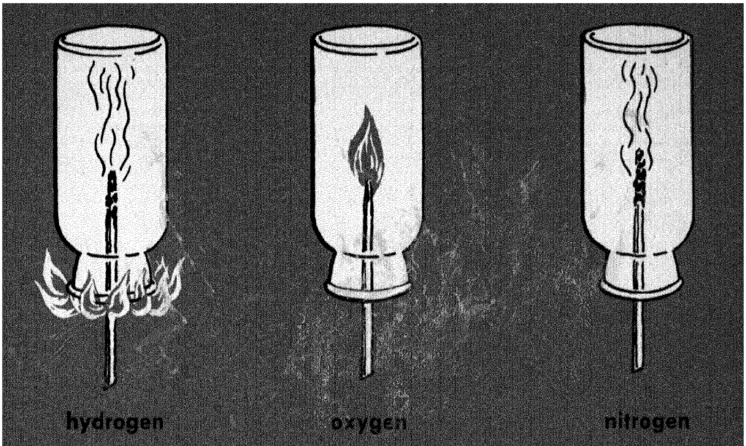
erate more than a small bottleful of hydrogen at one time—not unless he's interested in a trip to the moon without a rocket ship!"

"That makes it plain enough," Randy said. On Terry's instructions, he pushed the flaming splinter inside the bottle of hydrogen. The flame expired.

"Hydrogen burns, but it doesn't support combustion," Terry said.

"And now I know how to tell at least three elements apart," Randy said. "Incidentally, how did you make the gases, Terry?"

"By separating them from their compounds. You probably know that most elements aren't found by themselves in nature—they're found in chemical combination with other elements. The chemist has to separate them. Would



2 But they react differently when a burning splinter is plunged into them. Chemists test the properties of elements in many ways.

you like to whomp up a few elements?"

"You bet I would."

She got out a lab apron for Randy, and then put him to work replacing the element collection. Terry herself began to set up the experiments. By the time she was finished, the table was covered with apparatus. It all looked very mysterious and challenging.

Chemistry, Randy decided, was going to be fun.

"We'll make the three gases—oxygen, hydrogen, and nitrogen. This gadget here is a pneumatic trough. It's nothing but a pan of water with a shelf submerged in it. The shelf has a hole in it. First you fill this little bottle clear up to the top with water, then cover it with a glass plate, turn it over, and set it on the shelf."

Randy filled the 60-milliliter bottle and positioned its mouth over the hole in the shelf. Terry told him to remove the plate, and he did. Atmospheric pressure held the water in the bottle.

"We'll bubble the gases into the bottle through the hole in the shelf," Terry explained. "As the gas enters, the water in the bottle will be displaced."

She brought out a ring stand with a clamp on it, a bunsen burner, and a delivery tube of glass and rubber. A standard test tube and a one-hole rubber stopper completed the equipment needed for the preparation of oxygen.

"Now we'll take a piece of filter paper and get our chemicals. Oxygen is made from a mixture of potassium perchlorate with manganese dioxide."

She used a different wooden spatula for dipping each compound, thus making sure that the chemicals in their packages stayed uncontaminated. The circle of paper was placed on one pan of the balance, and a one-gram weight on the other pan.

"We need about one gram of manganese dioxide. Notice how I place the chemical on the paper until the balance pointer hits the zero mark."

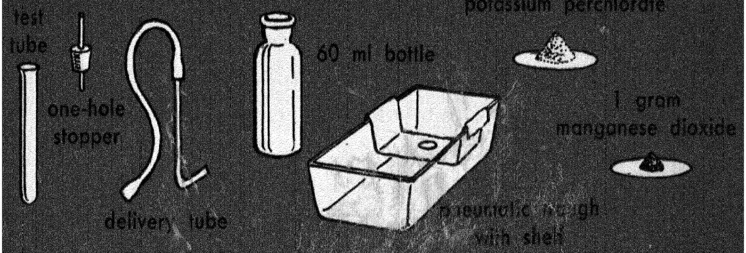
"I see," Randy said. "The weight of the manganese dioxide on one side is equal to the weight of the one-gram weight on the other side."

"Right. And now we'll get three grams of potassium perchlorate. Since we're going to mix these chemicals anyhow, we'll just mix them now while we're weighing."

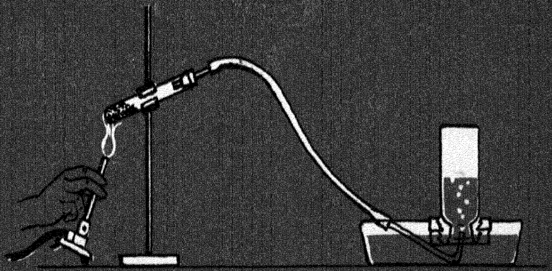
She added three more grams of weights, then placed the white potassium compound on top of the black manganese compound until the balance pointer registered zero once more.

"Now we'll mix the chemicals with the spatula and put

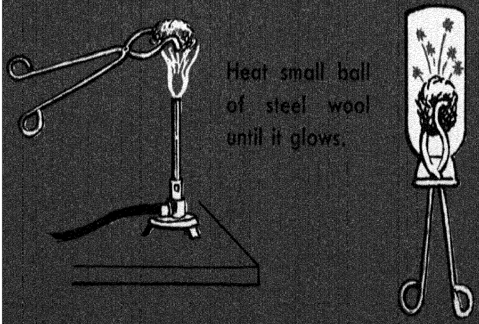
Making oxygen



1 Materials needed for experiment.



2 The apparatus set up and operating.



Heat small ball of steel wool until it glows.

When thrust into the oxygen, it will burn brilliantly, giving off sparks like a fireworks display.

3 Testing the properties of oxygen.

them in the test tube."

The test tube was clamped to the ring stand. One end of the rubber and glass delivery tube was inserted into the one-hole stopper, and the stopper in turn fitted into the test tube. The other end of the delivery tube went under water in the pneumatic trough.

"Now we're ready to heat the chemicals. We'll use the burner with the heat turned low. Notice how I heat the entire test tube by moving it up and down in the flame."

"Shouldn't the delivery tube be placed under the bottle?" Randy asked.

"Not yet," said Terry, watching the test tube. The mixture inside had started to bubble. "Oxygen is starting to be generated now. But we want to collect only the pure gas, not the air that was in the test tube when we started."

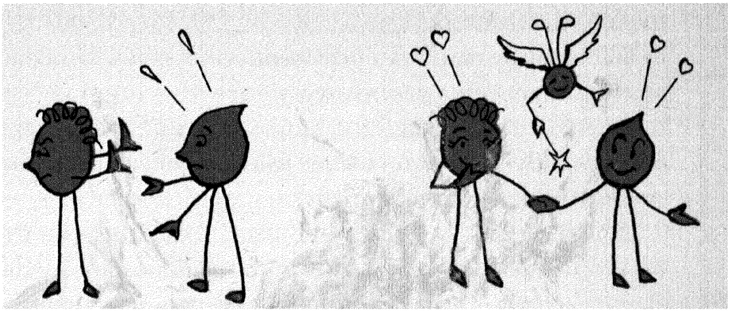
Bubbles began to come out of the submerged delivery tube. For a minute or two, Terry let them escape. Then she placed the delivery tube under the hole in the shelf and let the oxygen bubble up into the bottle. When the water in the bottle had been entirely replaced by oxygen, Terry directed Randy to slide a glass plate under the mouth and lift the bottle out of the trough.

"The oxygen comes from the breaking down of the potassium perchlorate," Terry said. "The manganese dioxide just serves as a catalyst. Do you know what that is?"

Randy admitted he didn't. Terry told him that catalysts affected the speed of certain reactions, apparently without being changed themselves.

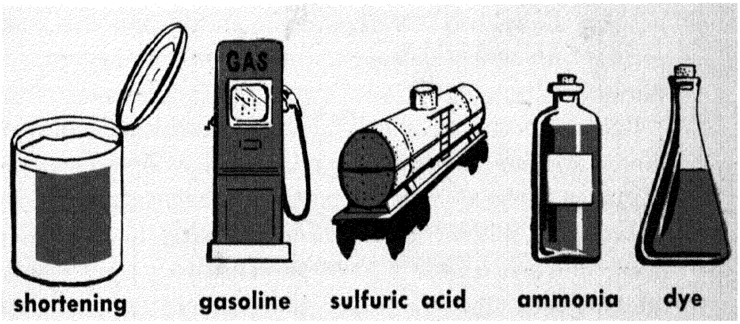
"We should have just as much manganese dioxide left in the test tube now as we did when we started heating," she said. "But the potassium perchlorate changed into

Catalysts—the magic helpers



Some elements that are ordinarily reluctant to unite . . .

Can be joined into compounds through the action of a catalyst. The catalyst itself remains unchanged



A few of the products made by catalytic action.

potassium chloride and oxygen gas."

She said that no one was exactly sure just how catalysts performed their useful work. The catalyst could speed up a reaction, or slow it down, or make possible certain reactions which would ordinarily take place only at very high temperatures.

"High-octane gasoline used to be manufactured only at high temperatures and pressures. But special catalysts that're used nowadays make it possible to produce the gasoline more easily—and to produce gas with higher octane ratings than ever before."

She told him that solid vegetable shortenings were made through adding hydrogen atoms to the molecules of liquid oil. Finely divided nickel particles were the catalyst in this reaction. Another important use of catalysts in industry involved the manufacture of ammonia. Iron and molybdenum helped atoms of nitrogen and hydrogen unite to form ammonia.

"But the most important catalyst is water," Terry said. "Lots of compounds won't react together when they're dry—but add water and it's a different story."

They set aside the oxygen-generating apparatus and prepared to make hydrogen. Randy got another water-filled collecting bottle and set it up in the pneumatic trough. Terry procured a bottle of hydrochloric acid and several pieces of zinc metal. A bottle with a two-hole stopper, a thistle tube, and a bent glass delivery tube made up the apparatus needed for this experiment.

"Since we just want a little bit of hydrogen, we'll only use one piece of zinc," Terry said. She placed the metal in the bottle and covered it with a little distilled water. Then the cork, with the delivery tube and thistle tube inserted in the holes, was placed tightly in the bottle.

"Notice how the end of the thistle tube is under water," Terry said. "That keeps outside air from entering the bottle and mixing with the hydrogen that we'll be making."

"I see," Randy said. "We don't want mixed air and hydrogen, because that could cause an explosion."

"Right."

Terry poured a little hydrochloric acid into a small beaker and then began to add it slowly to the zinc through the thistle tube. She added the acid carefully so that no air bubbles would go down the tube with the liquid. Presently, bubbles began to rise from the piece of zinc, and gas began to come out of the delivery tube.

"This gas is mixed with air from the bottle, so we won't collect it. A good way to tell if the hydrogen is pure is to collect a test tube full, then light it. If it burns without exploding, you know the gas is pure. If it pops—even a little bit—the gas isn't pure and you should let your generator operate for a little longer before you collect the gas into a larger container."

She told him it was also important to make sure that all the connections on the hydrogen generator were airtight, and *never* to allow a flame to come close to a hydrogen generator.

"Where does the hydrogen come from in this reaction?" Randy asked.

"From the hydrochloric acid," Terry replied. "All acids contain hydrogen. The hydrochloric acid molecule contains one atom of hydrogen and one of chlorine. Zinc is a metal that can force the hydrogen out of the acid molecule and take its place. Chromium and iron would do the same thing, only the reaction would take place more slowly. Aluminum and magnesium would cause a much more rapid reaction."

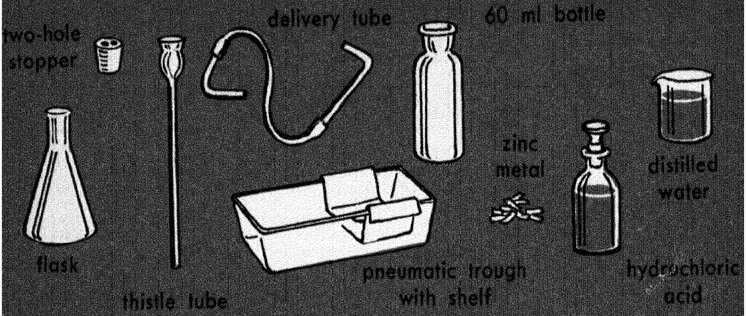
She told him that chemists had found out that different metals could have their chemical activity measured in relation to the activity of hydrogen.

"The more chemically active an element is, the more easily it can replace hydrogen from its compounds."

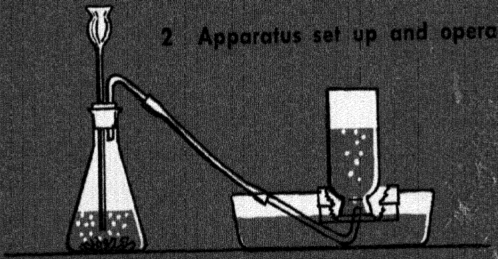
She rummaged around in a drawer and came up with a card, which she handed to Randy.

Making hydrogen

1 Materials needed for experiment.

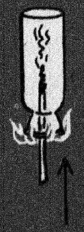


2 Apparatus set up and operating.

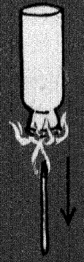


3 Test hydrogen with long lighted splinter.

Push splinter in—flame goes out, hydrogen ignites and burns with blue flame.



Pull splinter out, it begins to burn again as flame hits it.



CAUTION: Hydrogen mixed with air is explosive. Never generate more than a small bottleful of hydrogen at one time!

ACTIVITY SERIES OF COMMON METALS

Potassium
Calcium
Sodium
Magnesium
Aluminum
Zinc
Chromium
Iron
Nickel
Tin
Lead
HYDROGEN
Copper
Mercury
Silver
Platinum
Gold

"Potassium, calcium, and sodium will displace hydrogen from cold water," Terry said. "You know that water is a compound containing hydrogen and oxygen. If you dropped a lump of any of those elements into a beaker of water, they'd skip around wildly and liberate hydrogen gas together with lots of heat. Magnesium will displace hydrogen from boiling water, but not from cold water. The metals below magnesium and above hydrogen in the table won't displace hydrogen from water, but they will displace it from acids. The metals below hydrogen in the table won't displace hydrogen at all."

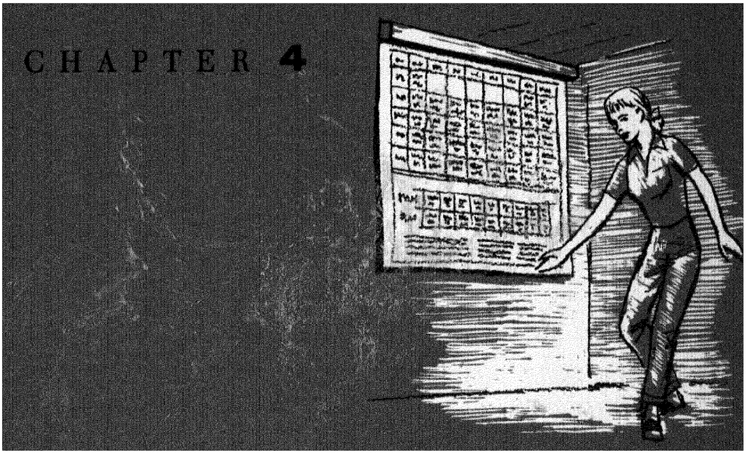
"Why do the elements act that way?" Randy asked.

"Chemical activity has to do with the way electrons are arranged," Terry said. "I can tell you about it, if you like. But that's one of the toughest parts of chemistry. Any nitwit can add one chemical to another and come up with a pretty color or a horrible smell. But someone who's really interested in chemistry won't be satisfied with that. They'll want to know *why* the reactions take place."

Randy looked her in the eye. "Don't try to scare *me* by telling me I might have to think a little. I told you I wanted to make a career out of science, and I know science isn't the place to look for a soft berth."

"Don't get sore," Terry smiled. "I can see that you're not a messer. So I will tell you about the electrons. But you'd better get your brain cells polished up—you're going to need every one of them!"

CHAPTER 4



Electrons cement atomic friendships

ON THE rear wall of Terry Chandler's lab, rolled up out of the way like a window shade, was a large chart. Terry pulled it down with a flourish.

"Meet the periodic chart of the elements," she said. "It's the atomic family tree. Read it from left to right, and you find the elements arranged according to their atomic numbers—that's the number of protons or positive charges in the atomic nucleus."

"I know about protrons," Randy said. "Dad explained them to me when I was learning about atomic energy. That science has to do mostly with the nucleus."

Periodic Table and the

Electron Levels	I A	II A	III B	IV B	V B	VI B	VII B	VIII B		
1st Period	1 H Hydrogen 1									
2nd Period	3 Li Lithium 2-1	4 Be Beryllium 2-2								
3rd Period	11 Na Sodium 2-8-1	12 Mg Magnesium 2-8-2								
4th Period	19 K Potassium 2-8-8-1	20 Ca Calcium 2-8-8-2	21 Sc Scandium 2-8-9-2	22 Ti Titanium 2-8-10-2	23 V Vanadium 2-8-11-2	24 Cr Chromium 2-8-13-1	25 Mn Manganese 2-8-13-2	26 Fe Iron 2-8-14-2	27 Co Cobalt 2-8-15-2	
5th Period	37 Rb Rubidium 2-8-18-8-1	38 Sr Strontium 2-8-18-8-2	39 Y Yttrium 2-8-18-9-2	40 Zr Zirconium 2-8-18-10-2	41 Nb Niobium 2-8-18-12-1	42 Mo Molybdenum 2-8-18-13-1	43 Tc Technetium 2-8-18-14-1	44 Ru Ruthenium 2-8-18-15-1	45 Rh Rhodium 2-8-18-16-1	
6th Period	55 Cs Cesium 2-8-18-18-8-1	56 Ba Barium 2-8-18-18-8-2	57-71 Lanthanides (Below)	72 Hf Hafnium 2-8-18-32-10-2	73 Ta Tantalum 2-8-18-32-11-2	74 W Tungsten 2-8-18-32-12-2	75 Re Rhenium 2-8-18-32-13 2	76 Os Osmium 2-8-18-32-14-2	77 Ir Iridium 2-8-18-32-17	
7th Period	87 Fr Francium 2-8-18-32-18-8-1	88 Ra Radium 2-8-18-32-18-8-2	89-103 Actinides Below	104	105	106	107			

LANTHANIDES	57 La Lanthanum 2-8-18-18-9-2	58 Ce Cerium 2-8-18-19-9-2	59 Pr Praseodymium 2-8-18-20-9-2	60 Nd Neodymium 2-8-18-21-9-2	61 Pm Promethium 2-8-18-22-9-2	62 Sm Samarium 2-8-18-23-9-2	63 Eu Europium 2-8-18-24-9-2
ACTINIDES	89 Ac Actinium 2-8-18-32-18-9-2	90 Th Thorium 2-8-18-32-19-9-2	91 Pa Protactium 2-8-18-32-20-9-2	92 U Uranium 2-8-18-32-21-9-2	93 Np Neptunium 2-8-18-32-22-9-2	94 Pu Plutonium 2-8-18-32-23-9-2	95 Am Americium 2-8-18-32-24-9-2

What the Table Means

Vertical columns indicate families of elements having similar chemical properties. The elements are arranged in order of their atomic numbers (colored numerals). The black numerals show the number of electrons in each level—from the one nearest the nucleus outward. Electrons in the outer levels determine chemical properties.

Electron Structure of Elements

	I B	II B	III A	IV A	V A	VI A	VII A	O	No. Electrons To Fill Levels*
								2 He Helium 2	FIRST 2
			5 B Boron 2-3	6 C Carbon 2-4	7 N Nitrogen 2-5	8 O Oxygen 2-6	9 F Fluorine 2-7	10 Ne Neon 2-8	SECOND 8
			13 Al Aluminum 2-8-3	14 Si Silicon 2-8-4	15 P Phosphorus 2-8-5	16 S Sulfur 2-8-6	17 Cl Chlorine 2-8-7	18 Ar Argon 2-8-8	THIRD 18
28 Ni Nickel 2-8-16-2	29 Cu Copper 2-8-18-1	30 Zn Zinc 2-8-18-2	31 Ga Gallium 2-8-18-3	32 Ge Germanium 2-8-18-4	33 As Arsenic 2-8-18-5	34 Se Selenium 2-8-18-6	35 Br Bromine 2-8-18-7	36 Kr Krypton 2-8-18-8	FOURTH 32
46 Pd Palladium 2-8-18-18	47 Ag Silver 2-8-18-18-1	48 Cd Cadmium 2-8-18-18-2	49 In Indium 2-8-18-18-3	50 Sn Tin 2-8-18-18-4	51 Sb Antimony 2-8-18-18-5	52 Te Tellurium 2-8-18-18-6	53 I Iodine 2-8-18-18-7	54 Xe Xenon 2-8-18-18-8	FIFTH 50
78 Pt Platinum 2-8-18-32-17-1	79 Au Gold 2-8-18-32-18-1	80 Hg Mercury 2-8-18-32-18-2	81 Tl Thallium 2-8-18-32-18-3	82 Pb Lead 2-8-18-32-18-4	83 Bi Bismuth 2-8-18-32-18-5	84 Po Polonium 2-8-18-32-18-6	85 At Astatine 2-8-18-32-18-7	86 Rn Radon 2-8-18-32-18-8	SIXTH 72
									SEVENTH 98

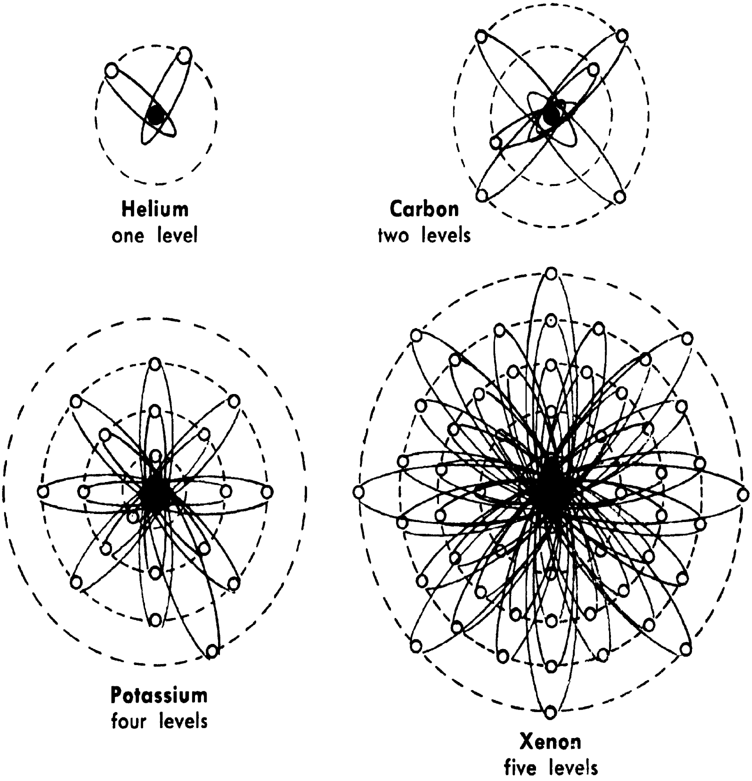
64 Gd Gadolinium 2-8-18-25-9-2	65 Tb Terbium 2-8-18-26-9-2	66 Dy Dysprosium 2-8-18-27-9-2	67 Ho Holmium 2-8-18-28-9-2	68 Er Erbium 2-8-18-29-9-2	69 Tm Thulium 2-8-18-30-9-2	70 Yb Ytterbium 2-8-18-31-9-2	71 Lu Lutecium 2-8-18-32-9-2
96 Cm Curium 2-8-18-32-25-9-2	97 Bk Berkelium 2-8-18-32-26-9-2	98 Cf Californium 2-8-18-32-27-9-2	99 Es Einsteinium 2-8-18-32-28-9-2	100 Fm Fermium 2-8-18-32-29-9-2	101 Mv Mendelevium 2-8-18-32-30-9-2	102 No Nobelium 2-8-18-32-31-9-2	103

Rules

- —No more than 8 electrons may occupy the outer level. (Pd and Ir seem to be exceptions.)
- —No more than 18 electrons may occupy the level below the outer level.

*The maximum is determined by the formula $2n^2$, where n is the number of the level.

Electrons are arranged in levels



Here are some typical atoms, showing the electrons in their levels. The levels are represented by dotted lines. The electrons do not stay in the same place, but whirl about the nucleus in complex paths.

Terry nodded. "And chemistry has to do mostly with the electrons *outside* the nucleus. Chemists don't usually think about protons and neutrons and other particles that make up the nucleus. To the chemist, the atom is a solid nucleus surrounded by a whirling cloud of electrons."

She said that electrons were tiny bits of negative electricity. An atom ordinarily had the same number of electrons outside its nucleus as protons inside—so that the positive and negative charges balanced.

"See how the atoms of the different elements are arranged on the chart," Terry suggested. "Hydrogen, number one, has only one electron. Helium has two, lithium three, beryllium four, and so on down to element 102, nobelium."

"I understand that," Randy said.

"All right. Now the next idea to grasp is that electrons are arranged in levels. The levels aren't flattened out, like the orbits of planets around a sun, but they're sort of spherical. More like the layers of skin on an onion. There can be as many as seven main levels for electrons to occupy. Each level is able to hold a certain maximum number of electrons."

Randy nodded. "I understand that, too. What's so tough about this?"

Terry ignored his remarks and went on. "As the atoms in the table get bigger and acquire more electrons, the energy levels are filled up in a nice, tidy manner—usually! Hydrogen starts out with one electron on the first level. Helium has two on the first level, and since that level has a maximum of two electrons on it, the next element adds its electron on the second level."

Randy said, "You mean that lithium has two electrons on the first level and one on the second?"

"Right. The second level has a capacity of eight electrons. So we just keep adding them on until we get to element 11, sodium, which starts off the third level. It has two electrons on the first, eight on the second, and one on the third level."

"I get it. And now I suppose that the third level begins to fill up. How many electrons can it hold?"

"Just eighteen," Terry said, "but now another rule has to come into play. It says that the *outer* level of an atom can never have more than eight electrons in it. So the third level fills up with eight, and element 19, potassium, adds its electron on the fourth level."

"I see. Its levels have two, eight, eight, and one—from the first level to the fourth."

"That's right. And the elements from number 20 through number 36 add electrons in their third and fourth levels until the third level has its full eighteen, and the fourth level has eight. Then rubidium, element 37, starts off the fifth level with one electron."

"And the fourth level fills up with eighteen just like the third did?" Randy asked.

"Yes. Cesium, element 55, has its electrons arranged two, eight, eighteen, eighteen, eight, and one—the last electron starting the sixth level. And now another rule takes effect. No more than eighteen electrons are ever found in the level next to the outer level."

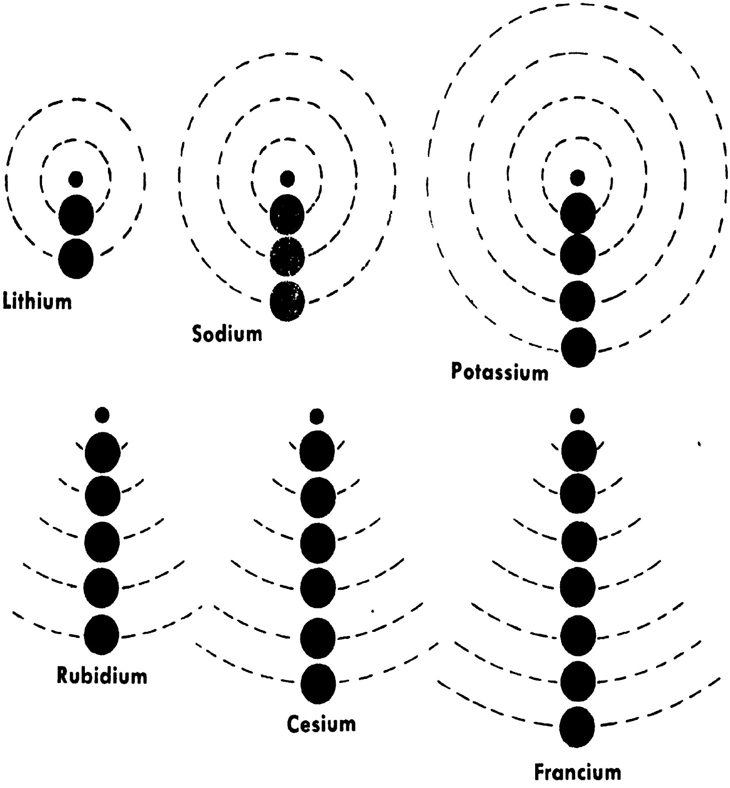
"But then where are we going to add the electrons?" Randy wanted to know.

"To the fourth level," Terry said. "It has a capacity of thirty-two. Fill up the fourth level with thirty-two, the fifth level with eighteen and the sixth with eight, and you're ready to start the seventh level off with one again."

Randy peered at the periodic chart. "Boy! That brings us all the way to element 87, francium. We won't fill up the rest of the levels—we've run out of elements!"

Terry said, "The rules for arranging electrons are no more complicated than those of a card game. It's fun to figure out what the structure of imaginary elements must be."

Elements in a family have similar properties



Although their atomic weights are different, these elements of the alkali metal family (IA) have similar chemical properties. This is because they all have one electron in the outer level, and eight (except lithium) in the next level.

Randy agreed. At first glance, the Periodic Table looked tough—but the more you studied it—the more fascinating it was!

"Let's look at some other interesting things about the arrangement of the electrons," Terry suggested. "Suppose you look at the chart and tell me why elements 3, 11, 19, 37, 55, and 87 are similar."

Randy located them on the chart. Lithium, sodium, potassium, rubidium, cesium, francium. They were arranged in a column, one under the other.

"Well—uh—let's see. Don't they each start a new level with a single electron in it?"

"Right. And the next lower level has eight electrons. The elements are arranged in a column because they have similar chemical properties. For one thing, they all react violently with water to release hydrogen. These elements make up one family of elements—the alkali family."

"What are the names of some other families?" Randy asked.

"Well, the elements in family VII A are members of the halogen family. That means 'salt-maker.' Family zero includes the inert gases like neon and argon. They don't form chemical compounds."

Randy said that he understood how the elements in a family had a similar electron arrangement. But how did this affect their chemical properties?

"I'm coming to that. There's a funny thing about elements. They seem to prefer eight electrons in the outer level. And if they don't have that many—and all but the inert gases don't—they tend to react chemically so that they *do* get those eight electrons."

She qualified this by saying that an element with electrons in only the first level would be satisfied to acquire two electrons.

"But the rest are struggling for eight. Let me draw a picture of a sodium atom for you." Its first level held two electrons, its second level eight, and its third level one.

"What would be the easiest way for this element to acquire eight electrons in its outer level?" Terry asked.

Randy thought a minute. "By getting rid of that one in the third level," he decided.

Terry agreed. Then she drew a chlorine atom. It had two electrons in the first level, eight in the second, and seven in the third. "And how could this one most easily get eight in the outer level?"

"By latching onto one more electron," Randy said promptly.

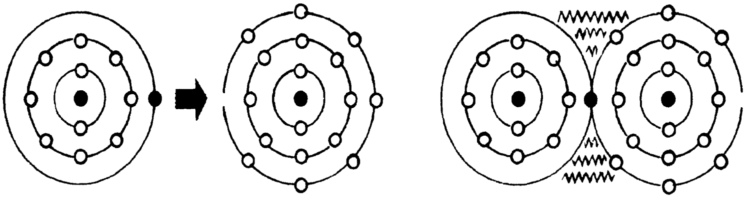
"So what do you think would happen if chlorine and sodium atoms met?"

"Oh—I get it! The atoms would come together! The sodium atom's outer electron would go to fill in the gap in chlorine's outer level."

"That's right. And the two atoms would be held together by an electrical bond to form a molecule of sodium chloride or common salt."

She told him that since sodium was anxious to give away its electron, it was regarded as becoming positively charged when it entered into chemical combination—since it now had 11 positive charges on its nucleus, but only 10 negative charges (electrons) to balance them. The chlorine in the molecule now had a negative charge, since it had one more negative charge than it had positive charges.

"The charge is called valence," Terry said. "We'd say that sodium has a positive valence of one—and chlorine has a negative valence of one. So one sodium atom would combine with one chlorine atom to produce a molecule with two atoms in it. Actually, the process wouldn't stop there. This salt molecule would tend to come together with other salt molecules to form a kind of super-molecule. It's



Stealing an electron to make a molecule

1 Sodium wants to give one electron away.

2 Chlorine needs one electron to make eight in outer level.

3 The elements come together by electrostatic attraction, forming molecule of salt.

Elements want to have eight electrons in their outer level. They tend to lose, steal, or share electrons so as to have eight. This is why elements are able to combine and form molecules. An element's combining capacity is called its *valence*.

cube-shaped—just like a salt crystal."

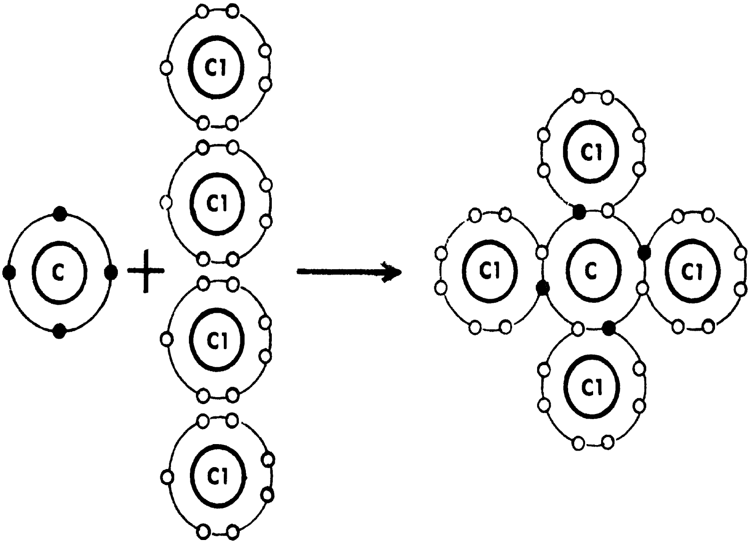
Terry and Randy went over the periodic table carefully. All of the elements in Family IA had one valence electron. Those in Family IIA had two electrons in the outer level, and they were likely to give away these two in order to stabilize themselves.

"Take magnesium. It has a valence of two. If you put a tiny pinch of magnesium powder into chlorine gas, the two elements would combine violently to produce magnesium chloride. But this time, it takes two chlorine atoms to dispose of the electrons that magnesium wants to give away. Aluminum has three valence electrons to give away, so it would take three chlorine atoms to combine with one aluminum atom."

"Does it just keep going on like this?" Randy asked.

"No—it gets more complicated in Families IV and V.

Electrons can be shared



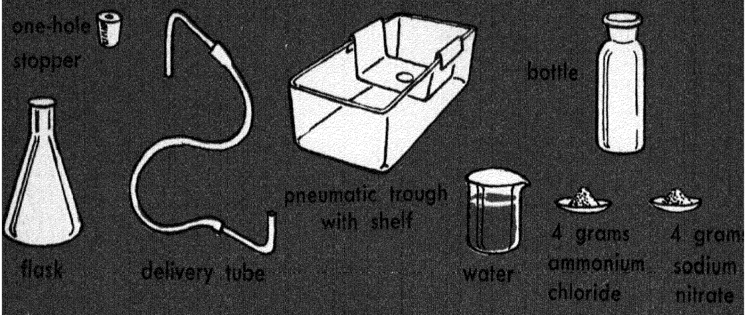
In this picture, only the outer level of electrons is shown. One carbon atom and four chlorine atoms are sharing electrons to form a molecule of carbon tetrachloride. Sharing electrons is called *covalence*.

These elements don't seem to give electrons away. They prefer to share them, and they also share different numbers of them with different elements—sometimes even with the same element. Look at carbon, there. When it combines with chlorine, it produces a carbon tetrachloride molecule. The four chlorine atoms join onto the carbon atom like this."

She drew a little picture showing how the electrons were shared.

"Of course, if an element has six or seven electrons, it's

Making nitrogen



1 *Materials needed for experiment*

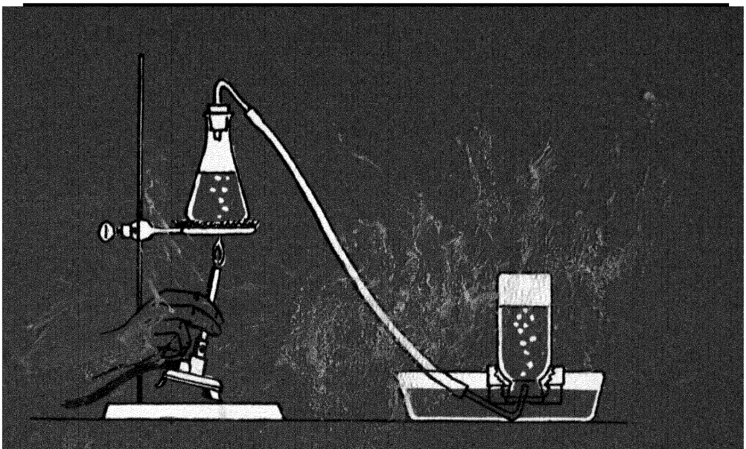
apt to be an electron hunter rather than an electron sharer or giver-upper. Oxygen has six in its outer level, and it always has a valence of negative two."

"I don't know why you thought this was going to be so hard for me to understand," Randy said. "So far, it seems easy."

She sighed. "I've oversimplified, things, I'm afraid. Actually, you have to understand that many elements—particularly those in Families IV and V—have several valences. You know carbon can unite with one atom of oxygen to form carbon monoxide, or with two to form carbon dioxide. Carbon is just one element that has several valences."

"Then how do you keep the chemical reactions straightened out?" Randy asked.

"Chemists just know from experience what's likely to



2 Apparatus set up and operating. Test this gas like oxygen and hydrogen were tested.

happen when you combine certain chemicals in a certain way."

Randy groaned. "But aren't there rules to keep things in line?"

Terry said seriously, "Rules in chemistry aren't *really* rules. I mean, they're not acted on by a board of master chemists who decide the laws that the elements will have to obey. Chemists observe the way chemicals act *first*—and then they try to formulate laws to account for their behavior and predict what they might do. The periodic table was worked out by the Russian scientist Mendeleev before anybody ever heard of electrons or valence. He just arranged the elements according to their properties."

"And the reasons why were found out later on," Randy said thoughtfully. "I see."

They began to set up the apparatus needed for the experimental production of nitrogen. This would be done by breaking down a nitrogen compound so that the pure gas would be freed.

"We'll heat four grams of ammonium chloride and four grams of sodium nitrite in this flask," Terry said. The flask would be heated very gently, and the gas passed through a delivery tube into a water-filled bottle.

"These two chemicals unite to produce ammonium nitrite and common salt," Terry said. "The ammonium nitrite is very unstable, and it breaks down into water and nitrogen."

She heated the flask only until the reaction began, then removed the bunsen flame. The first bubbles of gas were allowed to escape, since they were mixed with air from the flask. Eventually, they collected a bottle of nitrogen, and set it beside the bottles of hydrogen and oxygen that had already been obtained.

"Now that we've got 'em," Randy remarked, "what do we do with 'em?"

Terry laughed. "You and I won't be able to do much more than perform a few tricks. But an industrial chemist could do a lot! He could combine the hydrogen and the nitrogen to make ammonia—one of the most important commercial chemicals. He could combine the nitrogen and the oxygen to make nitrogen peroxide—then combine that with water to make nitric acid."

"What's that good for?"

"Lots of things. Nitrates are salts of nitric acid. Some of them are wonderful plant fertilizers. And if you have a reaction between nitric acid and some compounds of coal tar, you get chemicals used in making synthetic dyes. Plastics and explosives manufacturers use lots of nitric acid, too."

She told him that hydrogen, oxygen, and nitrogen were the most important gases known. Together with carbon, a nonmetallic element, they formed the basis for all living things. Proteins were made from all four elements. Carbohydrates and fats were made from hydrogen, oxygen, and carbon.

Terry said, "Calcium and phosphorus and iron are needed for health, too—and some other elements as well. But they don't form the building blocks of life. They seem to act more like chemical policemen to regulate the processes of life."

"But are these other elements *really* necessary?" Randy wanted to know.

"They really are." She stopped and thought a minute. "Tomorrow I'm supposed to go to my Uncle Henry's farm and test the soil in a new field he just bought. If you wanted to come along and help, maybe you could find out a little more about how chemicals affect living things."

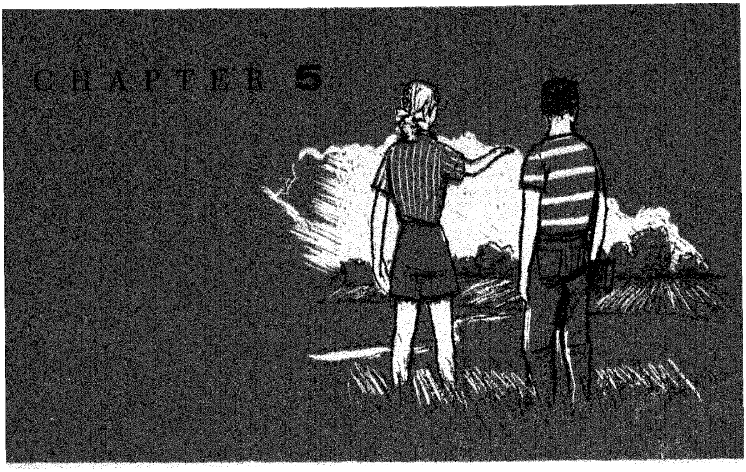
"That sounds like it'd be interesting," Randy said. "What do you test in the soil?"

"Whether it has the qualities of an acid or a base," Terry replied. "When we know that, we'll know what kind of chemicals have to be added to the ground to adapt it for the kinds of crops my uncle wants to grow. Some plants like acid soil—some like basic soil."

Randy hesitated, "Terry, I know that an acid is sour—but that's about all. And what's a base?"

"The chemists' name for an alkali," she said. "I'll be able to show you all about it tomorrow." She looked at Randy's face and laughed. "Don't let it confuse you. You're doing fine! Before you know it, the folks in this part of Egypt will have two mad chemists to laugh about instead of one!"

CHAPTER 5



Chemistry and corn

"What a view you get from up here!" Terry called. She stood among the trees on the crest of a hill that took up a large part of her uncle's new piece of acreage.

Randy, carrying the soil-testing kit, paused on the side of the hill and looked over the rolling land. Fields and pastures made a pattern in different shades of green. Darker colored shrubs and trees lined the beds of two creeks that passed through the property. Shrubs also predominated in a marshy area that formed the source of one of the creeks.

"Look at that corn," Randy said, pointing to the surrounding fields. "Think it'll be knee-high by the Fourth of

July?" He started to climb again.

"If this hot weather holds up," Terry said. "Corn needs heat and rain and the proper elements in the soil. My uncle can't do anything about the first two—that's up to Mother Nature! But he sure can do something about the soil."

She took the kit from Randy and opened it. It was a very simple device consisting of a porcelain plate. At one end was a depression, connected to a trough that ran down the plate to a smaller depression at the other end of the plate. Beside the trough were colored bands of various hues. The bands were marked with numbers from 4 to 9.

Terry had Randy obtain a soil sample from the hilltop, using a little spoon that came with the kit. A bit of the soil was placed in the larger depression on the plate.

"Now we'll make a little puddle out of the soil with this chemical indicator," Terry said. She added the liquid from its bottle, drop by drop, then let it stand for two or three minutes.

"The chemical indicator changes color according to the acid or alkaline character of the soil," Terry explained. "If you match the color with the band on the porcelain plate, you can tell just how acidic or alkaline the soil is."

She tipped the plate and allowed the liquid to run down the trough. It most nearly matched the color marked 8 on the scale.

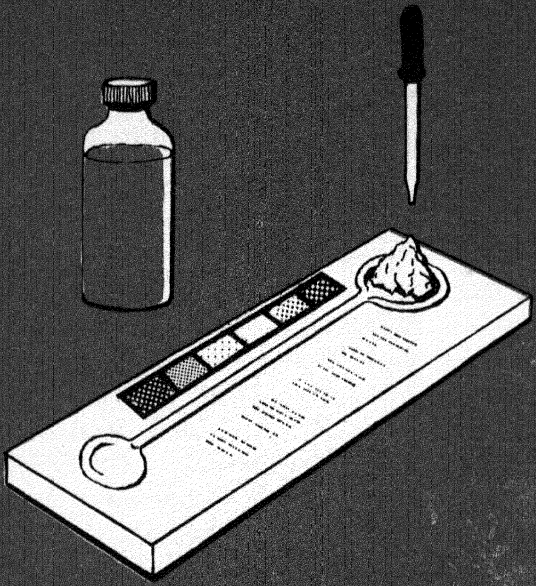
"There," Terry said. "This soil has a pH value of 8. That means it's alkaline."

"What's pH?" Randy asked.

"I can explain that if I tell you what makes an acid different from an alkali—from a base, I mean. Base is the proper name for chemicals with properties opposite from those of acids."

"I get it," Randy said.

Testing acid or alkali soils



Soil wet with the chemical indicator is placed in the upper depre sion. Liquid is allowed to run down the central trough to the lo depression. The color of the liquid is compared with the ban beside the trough. The bands show a color scale for acidity alkalinity.

"Okay. Now first—do you remember what an ion is?"

Randy said it was an atom with an electric charge—a positive charge if the atom had lost electrons, a negative charge if it had gained electrons.

"Right. And you'll remember that when atoms unite to form a compound, they can gain or lose or share electrons."

"I remember."

She sat down on the sparse grass that clothed the top of the hill. "Well, as it happens, the molecules of a compound are ordinarily electrically neutral. The individual atoms in the molecule have electrical charges, but the molecules themselves are neutral."

She said that this situation prevailed with *most* compounds—but it was not true for one of the most common, water. The great majority of the atoms in water were joined together as H_2O molecules—but a number of them were not joined firmly together. They were separated into a positively charged hydrogen ion and a negatively charged ion made up of an oxygen atom and a hydrogen atom.

"The negative ion has the formula OH, and it's called a hydroxyl ion. In water, there are exactly as many positive hydrogen ions as negative hydroxyl ions. This means that pure water is neither acid nor alkaline. It's chemically neutral."

"What's its value on the scale of the soil tester?" Randy asked.

"Pure water would have a pH value of 7," Terry said. "Don't worry about how the number is derived. Just remember that a chemically neutral solution has a pH value of 7. Values higher than 7 mean that the solution has an excess of negative hydroxyl ions. These solutions are called bases. Limewater and lye are common bases."

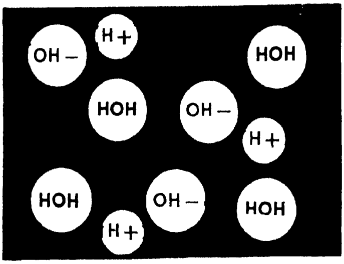
"How about acids?" Randy asked.

"Values below 7 on the pH scale indicate acids. Acid solutions have an excess of hydrogen ions in them. You'll notice I said *solutions*. The acid or alkali sample has to be dissolved in some solvent—which is usually water—before it will ionize and react to a pH test."

She told Randy that the commonest soils had pH values

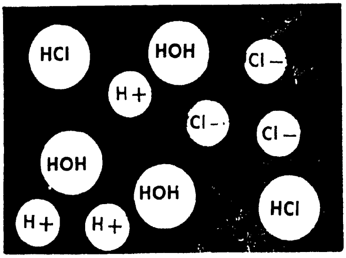
What makes an acid different from a base?

Neutral compound



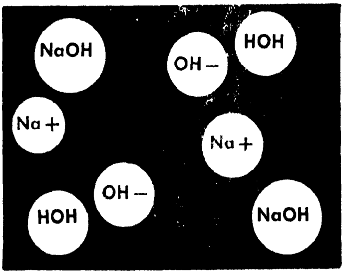
Water (HOH) is a chemically neutral compound. Some of its molecules are not firmly stuck together. Instead, they are separated into positive H ions and negative OH ions. Any compound that has the same number of H ions as OH ions (like water) is chemically neutral.

Acid compound



Hydrochloric acid (HCl) is a well-known acid compound. When in a solution with water, many of its molecules separate into H ions and Cl ions. The H ions give the solution its acid character. The more molecules that ionize, the stronger the acid.

Basic compound



Lye (NaOH) is a well-known base or alkali. It also ionizes in water. When its molecules separate, the solution contains OH ions. The more molecules that ionize, the more alkaline the solution is.

A solution of an acid can be neutralized by adding a base, and vice versa. If lye solution were added to the acid until the number of H ions matched the number of OH ions, the solution would be chemically neutral. Soil chemists want a neutral soil for most kinds of plants. They treat an acid or alkaline soil with chemicals to achieve this result.

between 4 and 9, and so the soil test kit was calibrated to those values.

"Actually," Terry remarked, "only an alkali desert out West would ever have a pH of 9. Very few plants will grow in a soil like that. Certainly nobody would ever try to raise crops on such land."

Randy frowned. "Gee—how about this soil on the hill, then?" It has a value of 8. Is it any good?"

Terry nodded. "This land would have to be chemically treated to make it less alkaline. It never would be the best land in the world, but it might grow forage. It's up to Uncle Henry to decide if it's worth rehabilitating. Let's test further down the hill."

They moved about half-way down. The weeds here were sturdier and greener looking. "Seems like the land ought to be better here," Randy remarked.

Terry nodded as she added liquid indicator to the soil. It had a pH value of about 7. "This is pretty good stuff. A soil that tests between 6 and 7 is good for nearly all types of crops."

"Why should the soil be more alkaline on top of the hill?" Randy asked.

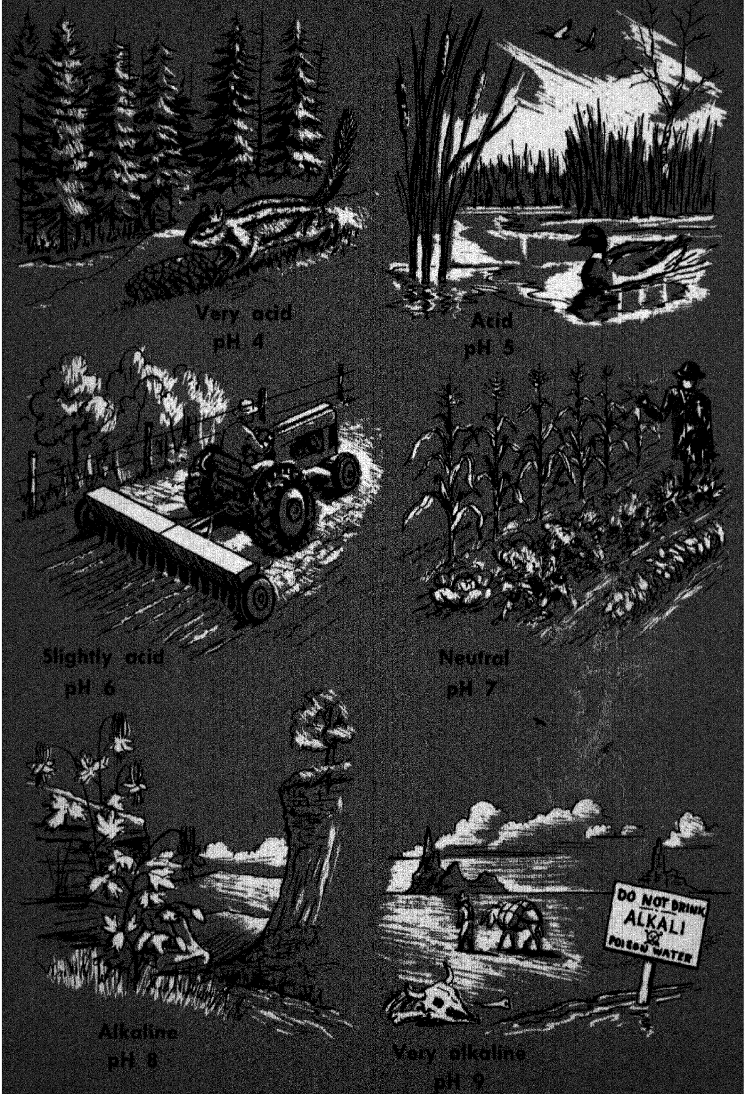
"Maybe because the rain washed most of the humus away," she said. "The hill is probably a limestone formation, and limestone makes for alkaline-type soils."

"I see," Randy said. "Where would we find acid soils?"

Terry thought for a minute. "That swampy place down there would probably have acid soil. Piney woods have acid soil, too. If we tested the earth with our soil kit, we might find a pH of around 4 or 5."

She told him that some plants, like potatoes, watermelons, tobacco, pineapple, and cranberries, required an acid soil for best growth. Blueberries needed an especially

Acid and alkaline soils have distinctive characteristics



acid soil, which was the reason why they could not usually be grown in the home garden.

"On the other hand, spinach needs an alkaline soil," Terry said. "Very few plants like soil with a pH above 7.5, though. Most vegetables and fruits do best in a pH range from 6 to 7."

"A farmer really has to know his chemistry, doesn't he?" Randy commented. He studied the soil guide that was fixed to the testing kit. It said:

pH 4—*Very acid*	Peat bogs and the floor of coniferous forests.
pH 5—*Acid*	Poorly drained soils, land with rotted wood, fields and gardens that have been treated with much fertilizer and no lime.
pH 6—*Slightly acid*	Ordinary garden soil in regions without limestone.
pH 7—*Neutral*	Many ordinary garden soils, especially those that have been limed; compost, rotted manure and leaf mold.
pH 8—*Alkaline*	Limestone soils, ordinary soils that have been heavily limed; salt marshes.
pH 9—*Very alkaline*	Alkali deserts.

Randy asked, "Why is the pH value of the soil so important?"

"It seems to have something to do with the plants' ability to take up necessary minerals from the soil," Terry said. "You know that plants make their own food, and that we harvest the food to eat ourselves or to feed domestic animals. Well, plants make their food out of air and water and the minerals taken from the soil. Chemists have been able to point out fifteen elements that plants need for growth."

She said that the basic building blocks—carbon, hydrogen, and oxygen—came from air and water. Nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur were taken from the soil in fairly large amounts. So-called "trace" elements were needed in very small amounts and seemed to regulate plant growth. They included iron, boron, manganese, zinc, copper and molybdenum.

"After we take more soil tests, we can wander down to the implement shed," Terry suggested. "Uncle Henry keeps his fertilizers and other farm chemicals there. We can see some of the different ways chemistry is used in agriculture."

As they passed by the barn, Randy saw a pile of manure that had been neatly heaped inside a wire enclosure to rot.

"I'm not much of a farmer," Randy said, "but isn't manure a good source of plant minerals?"

"It sure is—and it's one of the oldest fertilizers. Manure is rich in nitrogen, phosphorus, and potassium—the three elements most likely to be missing from soils. Notice how the heap has straight sides and a dished-in top. That's so rain water won't wash the valuable minerals away. The manure stays here until it rots, because fresh manure contains a lot of straw and is apt to be too strong for most types of plants."

They went into the implement shed, and Terry showed Randy bags of various kinds of fertilizers.

"Notice the numbers on the bags," she said. They read 4-12-4, 4-8-4, and 5-10-5. "Those figures show the percentage of nitrogen, phosphoric acid, and potash available from the fertilizer. Some plants require more of one mineral than another. 4-8-4 and 4-12-4 are particularly good for flowers and vegetables. 5-10-5 is fine for roses."

She showed him some small bags of special fertilizer that she had compounded for her aunt's bulb garden and for the tomato field.

"How about the trace elements?" Randy asked. "Do fertilizers contain them, too?"

"Not usually. Naturally fertile soil like we have here in southern Illinois contains all the trace elements plants need. We don't have to add them. But if you were growing plants on acid soil, you might have to add magnesium and calcium. Fruit trees and woody plants need iron. Some washed-out soils in the eastern states need to have boron added to them, and southern fruit trees sometimes need zinc."

Randy was examining the bags of chemicals. "What's this?"

Terry looked. The bag was labeled *Krilium.*

"That's not a fertilizer at all," she said. "That's a soil conditioner."

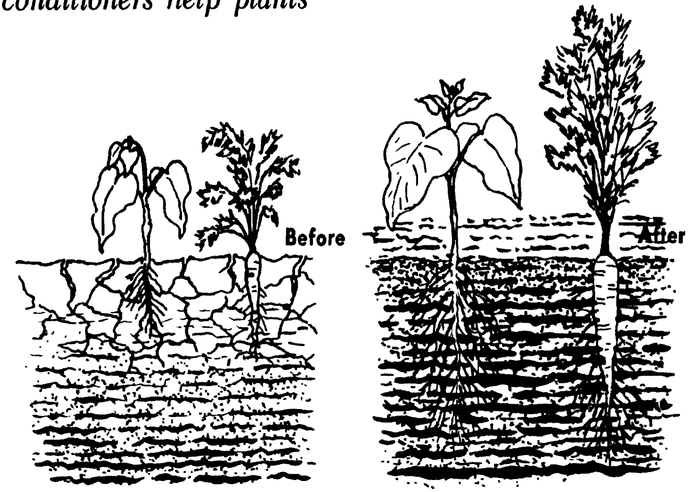
"What's that?"

"It's a material that makes the soil more porous—keeps it from getting hard after it's water-soaked, then dried. Soil conditioners make it easier for the plant roots to move through the ground. Crops like carrots and beets have a good shape and grow bigger in conditioned soil."

"I see," Randy said. "Soil conditioners would be especially good in clay soils, I'll bet. Part of our lawn at home has clay in it. When it gets hot in the summer, the ground turns to solid rock!"

"Soil conditioner would fix it up," Terry said. "But you

Soil conditioners help plants



**Sunbaked clay soil becomes almost rocklike.
Plant roots cannot grow properly.**

Soil conditioner such as Krilium or compost helps break up soil particles, gives roots room to grow.

should add fertilizer as well. And compost."

"What's compost?" Randy asked.

"A kind of vegetable manure that you can make. Regular manure is expensive for people who live in towns like you do, Randy. But you could make a compost heap that would be a good source of plant food. Compost is a natural soil conditioner, too."

She told him that compost was nothing more than rotted plants. A compost heap could be made from leaves, lawn clippings, vegetable scraps, even the droppings of pets. The pile was confined inside a form of chicken wire and mixed up frequently to allow it to decay.

"This stuff is worth its weight in gold when it's all decayed," Terry said. "When decay hits a material, bacteria and molds and other tiny plants get to work and change its chemical composition. Bacteria work on a dead plant and break down its leaves and stem and roots into plant foods again. Bacteria do the same work on animal matter."

Randy exclaimed, "Sure! I've read about the cycle between plants and animals and bacteria. Isn't it called the nitrogen cycle?"

Terry nodded. "It shows how the building-block element nitrogen is taken out of the air and made available to plants and animals."

Terry and Randy went outside to a pasture that grew beside the cow barn. The girl knelt and pulled up a sturdy clover plant for Randy to look at.

"See these little lumps on the roots?" she asked. "Special bacteria live in them. They have the ability to take nitrogen gas from the air. Ordinary plants can't do this. They must have their nitrogen combined in a compound with other elements before they can use it."

"So the bacteria change free nitrogen into compounds?" asked Randy.

"That's right. The bacteria grow with plants like clover, alfalfa, and cowpeas. The plants use some of the nitrogen, but a lot of it is left in the soil to enrich it. If the farmer plows under a crop of alfalfa and lets it decay, he gains a lot of valuable nitrate fertilizer. Then corn or some other crop that needs nitrogen badly can be grown on the land."

She told him that the process of crop rotation involved this principle. It was far less expensive to grow a crop of clover or alfalfa every three years to renew soil nitrogen compounds than it was to apply the compounds as commercial fertilizer.

"See these little lumps on the roots!" she asked.

Animals entered the nitrogen cycle when they ate plants. The plants contained nitrogen compounds obtained from the soil. Animals used the nitrogen in building muscle and other protein tissue. Animal body wastes were rich in nitrogen compounds. When these wastes were returned to the soil, or when dead animal bodies decayed, other bacteria broke them down into simpler nitrogen compounds that could be re-used by plants.

"And the cycle goes round and round," Terry said. "There's another way that nitrogen in the air can be changed into compounds for plants to use. That's the work of lightning!"

"Lightning?" Randy repeated, astonished.

"Yes. The strong electric arc causes the nitrogen and oxygen in the air to unite and form nitric oxide. Rain carries the compound to the earth where plants can use it. Theoretically, it should be possible to replace the nitrogen in the soil by simply returning organic waste materials to it."

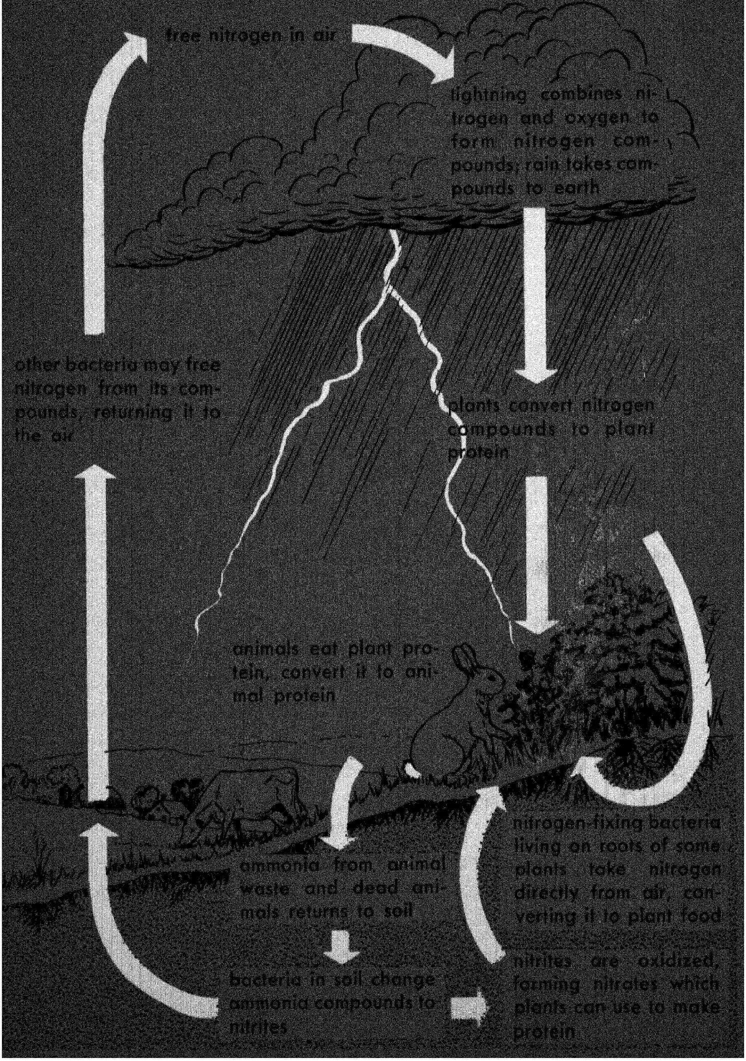
"But this doesn't work out—I know that," Randy said. "Otherwise, synthetic fertilizer manufacturers would go broke. But what breaks up the natural nitrogen cycle? Why does soil get worn out?"

Terry told him that intensive modern agriculture methods, which produced large amounts of crops from a small plot of soil, were responsible. Left to herself, nature would never produce a crop of corn that averaged 50 or more bushels to the acre. Yet that was the goal of corn growers in this part of the country. The corn was needed as food for livestock, and the livestock in turn served as food for man.

"So the only answer is commercial fertilizer," Terry said. "And huge quantities of it are produced every year. Nitro-

The nitrogen cycle

The nitrogen cycle recurs again and again. It is essential to the lives of plants and animals.



gen in fertilizers is in the form of ammonium salts or nitrates. Phosphorus in fertilizers is in the form of calcium phosphate. Potassium is in the form of potassium chloride or potassium sulfate."

"So a fertilizer isn't really a mixture of nitrogen and phosphorus and potassium," Randy said.

"Good grief, no!" Terry exclaimed. "It's a mixture of *compounds* of those elements. Plants can't use the elements in their pure form. But they can use the elements in their compounds."

Terry and Randy went to the farmhouse then, to hand in the soil analysis they had made. They found Terry's Aunt Clara in the kitchen, making strawberry jelly. Terry made the introductions.

"Smells good!" Randy said enthusiastically. He watched while Terry's aunt removed the simmering kettle from the range and placed the hot fruit in a dripping bag.

"It will be good," the farmer's wife said. "I'm making it from wild strawberries. Those are sweeter and have a better flavor than any of the commercial kinds."

"Aunt Clara's getting ready for the county fair early. Her jelly wins prizes every year," Terry said. "That's because she's such a good chemist!"

"Chemist? Me?" Aunt Clara said in astonishment. "Don't be silly, Terry."

"Every good cook is a chemist," Terry persisted. "And foods are the most important chemical compounds we use."

Terry pointed out that Aunt Clara was filtering the fruit juice with the dripping bag, just as chemists filtered many substances. Sugar would be added to the fruit juice to preserve it, because bacteria could not grow in a heavy sugar solution. Lemon juice and pectin would be added to the juice to cause the formation of the semisolid jelly.

"The production of jellies is part of colloid chemistry," Terry said. "And when jelly doesn't jell, that means that the housewife chemist has goofed. Lots of other foods are prepared by chemical methods. Take cakes. The baking powder that makes cakes light contains two chemical compounds that react to produce carbon dioxide gas. The gas bubbles make the dough light."

"Terry can find chemistry in everything," her aunt smiled.

"It *is* in everything!" Terry said. "Well, Aunt Clara, we'll have to be getting on. I'll leave this soil analysis sheet with you."

"Thanks, dear. If you want a ride to your place, I think you can catch Jimmy. He has to go to town to get a part for the water pump."

Later on, back at Terry's laboratory, Randy helped clean the soil testing kit and pack it away until it was needed again. "I'll never be able to think of soil as just dirt any more," he said. "It'll seem more like a batch of chemicals!"

"It's more than that, of course," Terry said. "But plants *can* be made to grow just by furnishing them with the chemicals. Real soil isn't essential for most plants."

"Oh. You mean hydroponic gardening. Like those tomato plants of yours."

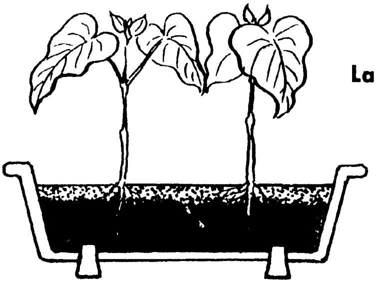
He bent over the plants, that grew vigorously out of the clean white sand in their pan. "Growing plants without soil! Looks almost like magic!"

"Anybody can do it," Terry scoffed. "Even you. Want the formula?"

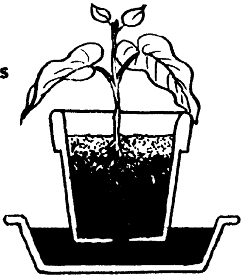
"Sure! I can start the garden at Grandma's now, and take it home with me later. Maybe I can raise some vegetables in the house this winter!"

Growing plants without soil

Large plants

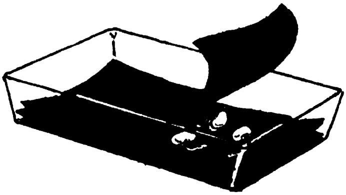


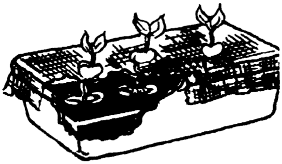
Plants rooted in sand, soaked in nutrient solution. To drain off solution every two weeks, remove stoppers and pour fresh tap water through sand to wash it. Put in fresh nutrient.



A painted flowerpot also makes a good container fo soilless plant growing. Be sure there is a hole in bottom for proper drainage

Seedlings





Germinate seeds between sheets of blotting paper moistened with weak nutrient solution.

When leaves appear, transfer seedlings to piece of cheesecloth stretched over pan of nutrient solution. Do not wet leaves or seed —only roots. Keep solution level at constant height.

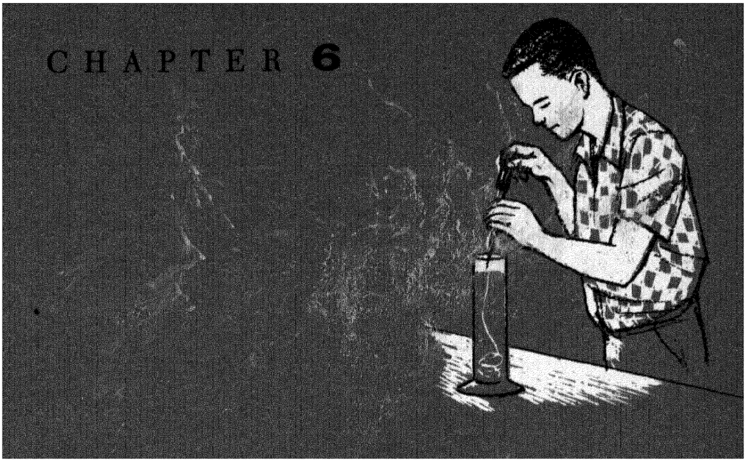
She nodded, and began to scribble on a piece of paper, then handed the paper to Randy. “Here’s what you’ll need.”

Randy studied the sheet. “This doesn’t seem hard. Any other instructions?”

“Just be sure that the plants get plenty of sunlight,” Terry said.

“Thanks a lot, Terry.” Randy folded the paper carefully and put it into his pocket. "Think there's any hope for me as a chemist?"

"That's for you to find out for yourself," she told him with a smile.



CHAPTER 6

Rainbow round my shoulder

"Look at this good shirt of yours, Sam," Grandma Morrow mourned. "Just ruined! Why couldn't you wear something old when you went spe-lunkering?"

"Spelunking, Grandma," Sam said. He looked ruefully at the shirt. A large orange stain of iron rust streaked downward from one pocket. "We got all wet in the cave. I forget about those old lucky horseshoe nails I put in my pocket."

Randy stuck his head in the laundry room. "Anybody seen Uncle Dan?"

"You won't find him today," Grandma Morrow said. "He took some young lady to the harness races."

A large stain of rust streaked the pocket.

"Aw, gee!" Sam exclaimed. "Why didn't he let us know he was going? I'd *like* to see a harness race."

His grandmother laughed. "I guess three men to one girl isn't your uncle's idea of a date. Maybe your grandpa will take you down to watch the trotters some afternoon."

Randy was staring at the stained shirt. "Holy smoke! That one's sure ready for the rag bag."

"I'm afraid so," Grandma Morrow sighed. "I've tried bleach and ordinary stain remover on it, but nothing happens."

"Say, wait a minute!" Randy said.

"Why?" Sam asked.

"Terry Chandler said she made up spot removers for her relatives. Maybe she'd know a way to get this mess cleaned up."

"You might be right, boy," Grandma said. "At any rate, she couldn't make it any worse!"

"I'll take the shirt over to her lab right now," Randy said. He grabbed up the garment and headed for the back door.

"Wait!" Sam called. "I want to see the mad chemist, too!"

Randy gave his little brother a disgusted look. "She's not a mad chemist. She's okay."

Sam curled his lip. "Anybody that'd mess around with a lot of smelly old chemicals—"

"If your nose is that tender, why do you want to come along?"

"It's my shirt, isn't it?" Sam muttered. "I gotta protect my interests."

Reluctantly, Randy let Sam accompany him to Terry's chicken-coop lab.

"This is my kid brother, Sam," Randy said in introduction. "He managed to mess up this good shirt with some rusty iron nails and we wondered if you could take the stain out."

Terry examined the shirt. "Looks like cotton," she pronounced. "Yes, I think I can fix it up."

She rummaged in her chemical cabinet and came up with a jar of white powder. "Citric acid. We'll make up a solution with one part citric acid and nine parts water."

Using the cylinder graduate and a beaker, she prepared the solution. Randy was asked to spread the shirt out with the stained part stretched over a shallow dish.

"Now we'll apply the acid solution with this pipette."

Sam watched the procedure with interest. "That pipette gizmo looks just like a medicine dropper to me," he commented.

"A scientist uses the proper name for his tools," Terry said witheringly.

Sam pretended not to notice. "Hey! Look at that old stain start to go!"

He was right. The stain had begun to lighten and turn grayish. Terry continued to apply the citric acid solution. Then she rinsed the stain in clear water, and lathered the spot with detergent. When she gave it a final rinse, the iron rust was gone.

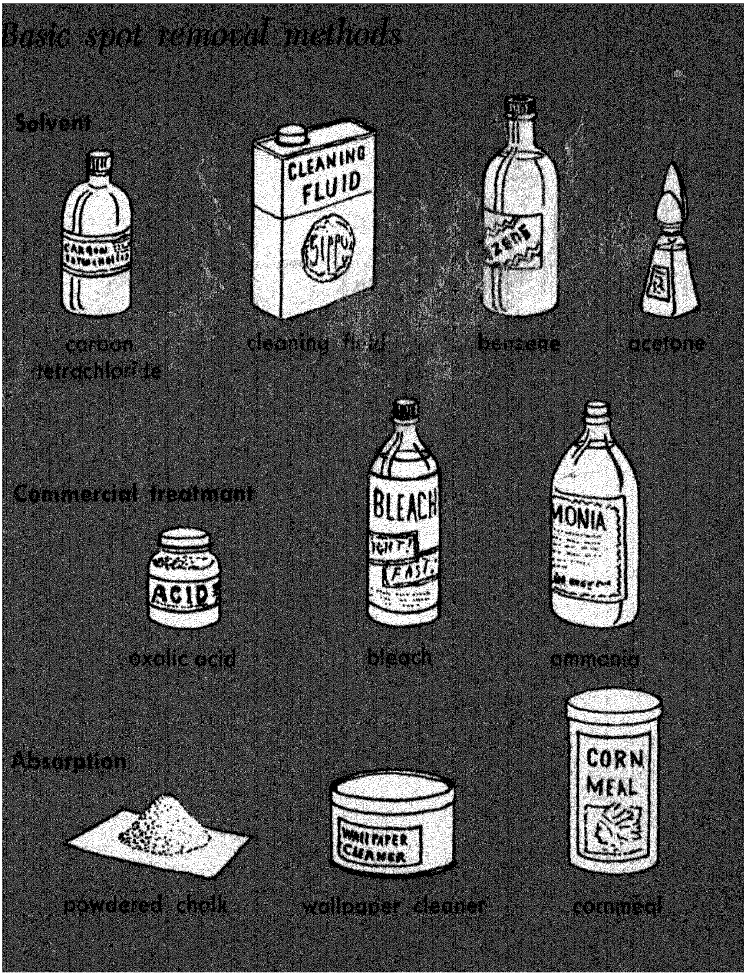
"That was pretty sharp," Sam said grudgingly. "Now I won't have to explain to Mom about the shirt."

"Grandma said her bleach couldn't faze the stain," Randy remarked.

"Just a matter of choosing the right chemical," Terry said. "Ordinary household bleach does its work by *adding* oxygen to the stain compound. That bleaches out some kinds of stains, but it only makes iron rust worse. Citric acid takes oxygen *out* of the rust stain."

She told them that spot removal chemistry was a fascinating field for the amateur chemist. Of course, some fabrics—especially colored fabrics—didn't respond to treatment by inexperienced hands. But many kinds of stains could be removed by simple chemical methods.

"You see, there are three basic ways of taking out spots," Terry said. "You can dissolve it, like grease dissolves in carbon tetrachloride; you can treat the stain chemically, like we did with the rust; or you can soak it up in some powdery stuff like chalk."



Not only was it important to know the nature of the stain, she said, but it was equally important to know the nature of the fabric that the stain was on.

"Take a solution of lye—that's sodium hydroxide. This is a very strong alkali. It works as a fine bleach on cotton, but it'll dissolve wool! On the other hand, a strong acid like sulfuric will ruin cotton, but it won't hurt wool."

Nail polish remover, which was mostly acetone, was a good solvent for some kinds of paints and varnishes. But it spelled doom for acetate rayon fabrics. The liquid dissolved not only the spot, but the fabric as well!

"Synthetic fibers have to be treated with care," Terry said. "Of course some of them, like nylon, are even more resistant to the action of chemicals than natural fibers."

"I suppose making synthetic fibers is an important part of the chemical industry," Randy commented. Terry agreed.

"It must be pretty tricky to make that stuff," Sam said.

"Not really," Terry smiled. "Want to try it?"

"Sure!"

"We'll make the kind of rayon called Bemberg," she said. "Rayon is made out of cellulose, just like natural plant fibers. What we'll do is dissolve some cellulose, squirt it through a tiny hole, and make it harden again into a thread."

"Sounds simple enough," Randy said. "Let's go."

Terry produced lab aprons for Randy and Sam. Then she gathered the chemicals and apparatus they would need.

distilled water
copper sulfate
10% sodium hydroxide solution
28% ammonium hydroxide solution

100 ml beaker
scale
200 ml cylinder
graduate cylinder
500 ml cylinder
pipette bulb

4 or 5 sheets filter paper
5% sulfuric acid solution
200 ml beaker
glass stirring rod
4-inch glass tube with fine aperture at one end
funnel

First, Terry said, they would make the cellulose solvent. She weighed 5 grams of copper sulfate and dissolved it in 100 milliliters of water. Then, using a small beaker, she slowly added the 10% solution of sodium hydroxide and stirred. A pale blue substance began to form, settling down into the bottom of the beaker.

"What's that stuff?" Sam asked.

"Copper hydroxide precipitate," Terry said. "We'll keep on adding the sodium hydroxide until the precipitate stops forming."

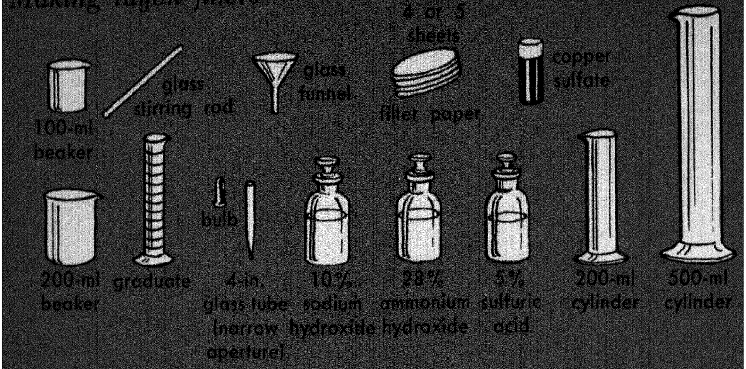
When that happened, she poured the precipitate and liquid into the 200 milliliter cylinder. She intended to wash the copper hydroxide. This was done by adding distilled water to the cylinder, stirring vigorously, then letting the precipitate settle to the bottom. The clear liquid at the top was then poured off and discarded. More water was added, and the precipitate stirred up again.

"Randy, you take over the precipitate washing," Terry said. "Wash it about six times. Sam, you can tear up that extra filter paper into tiny little pieces."

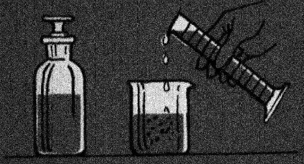
Terry herself set to work to make the tube with the narrow opening that would be used to squirt out the cellulose solution. The tube was called a spinneret, because it resembled a spider's web-spinning organ. She planned to make one out of an ordinary piece of glass tubing.

First she placed a wing top on her bunsen burner and lit the gas. Then a length of tubing was heated carefully

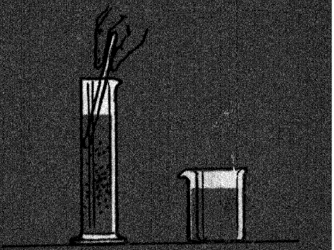
Making rayon fibers



Materials needed for experiment

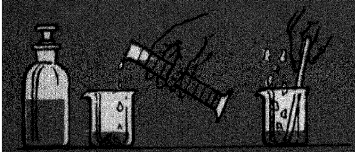


1 Dissolve 5 grams copper sulfate in 100 milliliters water. Add 10% sodium hydroxide until precipitate stops forming.

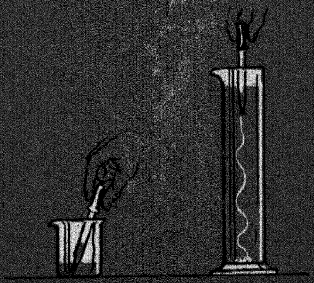


2 Wash precipitate in 200-ml cylinder by adding water, stirring, letting settle, pouring off liquid. Do this six times. Filter.

Performing the experiment



3 Place washed precipitate in 100-ml beaker. Add small amount of 28% ammonium hydroxide until precipitate dissolves. Dissolve scraps of filter paper in this solution.



4 Fill 500-ml cylinder with 5% sulfuric acid. With spinneret (glass tube and bulb) take some of dissolved paper solution and squirt slowly into acid. Colorless strand that forms is rayon.

along one inch of its length. As the glass softened, Terry pulled on both ends of the tube. Like hot candy, the glass drew out, its bore in the heated spot becoming narrower and narrower.

Terry removed the tube from the flame. The middle section now had a "wasp-waist." When the glass had cooled, Terry snapped the wasp-waist in two, and cut off part of the glass from the other end of the tube as well. The finished spinneret was inserted into the pipette bulb. It resembled a medicine dropper with a very tiny opening.

"All finished with the precipitate," Randy said.

"And if I rip this paper any smaller, you'll need a magnifying glass to see the pieces," Sam said.

"Then we'll filter the precipitate and put it into this 100 milliliter beaker."

She folded the remaining paper disk into quarters, then fitted it into the glass funnel. The precipitate was filtered, and the resulting jellylike substance placed in the beaker. With a test tube, Terry added a little bit of the 28% ammonium hydroxide, and stirred until the precipitate had dissolved. The beaker now contained a beautiful blue liquid.

"This is our cellulose solvent," she said. "Now comes your job, Sam. I want you to start adding your bits of paper to this solvent. Keep things stirred up with the glass rod. You'll have to keep dissolving paper until this blue liquid gets gooey. It might take quite a bit of stirring."

Sam settled down at one corner of the workbench.

"Are we just going to sit around until Sam's finished?" Randy asked.

"Why don't we test a dye?" Terry suggested. "That's an important part of textile chemistry. Sam can watch."

She told him that a dye was an agent that gave more or less permanent color to a fiber. It could do this by reacting chemically with the cloth, or by simply adhering firmly to the fibers. A good dye did not fade when exposed to sunlight, and it did not wash out easily.

"We'll try indigo. Everybody knows what color indigo is. Blue jeans are dyed with it. Genuine indigo is a dye made from the leaves and flowers of the indigo plant. But nowadays, synthetic indigo made from coal tar is used."

Taking a test tube, she mixed 2 grams of indigo powder with 1½ grams of sodium hydroxide. Using the small graduate cylinder, she added 25 milliliters of water to dissolve the two chemicals.

Next, a ring stand with metal gauze was set up, and a beaker filled with 250 milliliters of water was put on to heat. Randy stood by with a Centigrade thermometer to test the temperature. By moving the ring up and adjusting the flame of the burner, he was able to heat the water to the 50° C. required.

Terry procured a clamp and fastened it to the stand. The test tube was fixed in this and suspended in the heated water. When the contents of the tube were warmed, Terry added 1½ grams of sodium hyposulfite, stirring well.

"We'll let this stand for a while in the water bath," Terry said. "Actually, it should take about 30 minutes for the indigo to react. The solution will turn pale yellow when it's ready for use."

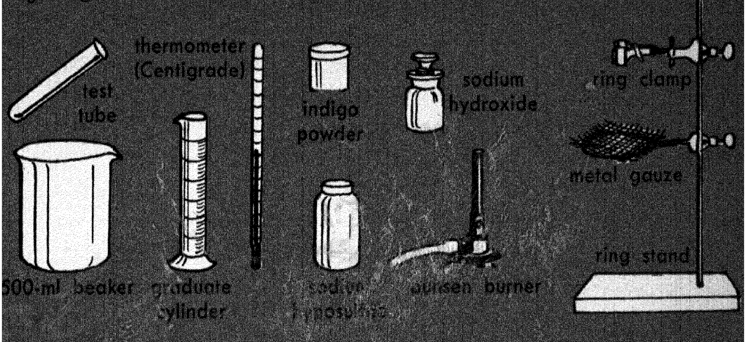
"This gookum is pretty much finished," Sam said.

Terry inspected the syrupy liquid. "I think so, too. Let's spin some rayon."

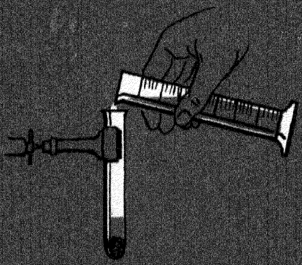
The large glass cylinder was filled with 5% sulfuric acid solution. Then Terry invited Randy to take up a little of the dissolved cellulose and squirt it slowly into the acid.

"Hey, look!" Sam said.

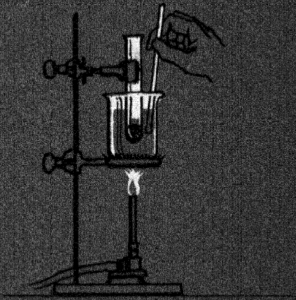
Dyeing with indigo



Materials needed for experiment

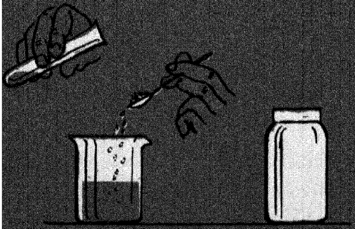


1 Mix 2 grams indigo powder with 1½ gram sodium hydroxide in test tube. Add 25 milliliters distilled water. Stir.

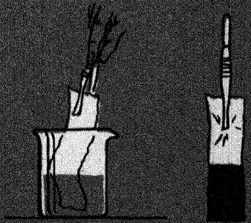


2 Set up beaker with 250 milliliters of water. Heat to 50° C. Suspend test tube in water. Heat, add 1½ grams sodium hyposulfite to tube. Heat for 30 minutes, testing temperature constantly.

Performing the experiment



3 When tube contents are clear yellow, add a few crystals sodium hyposulfite to beaker water (50°



4 Dip white cloth in beaker, using tweezers. Remove cloth. It will turn blue upon exposure to air. Further

A thin cord of solid cellulose was forming. Randy squeezed out the entire contents of the pipette, then fished out the rayon with a stirring rod. It was clear white, firm and flexible, rather like a guitar string.

"Of course, real rayon thread would be spun from a much finer opening," Terry said. "Then it would be stretched and washed and dried. The thread could be dyed before it was woven into cloth, or afterwards."

"Is real rayon made from paper?" Sam asked.

"The cellulose comes from wood, or from the waste fibers of cotton mills. There are other ways of making rayon, too. This process we worked out is called the cuprammonium process. Other processes are the viscose process and the cellulose acetate process."

"Is nylon made out of cellulose, too?" Sam asked.

"No, it's made out of coal, air, and water. It's not like natural fibers at all."

Randy had gone over to inspect the indigo solution. "This liquid in the test tube is clear now," he announced.

"Then we're ready to use it," Terry said. "First we'll make a vat to dip the cloth into."

She tested the temperature of the water that had been used to heat the test tube. It was 50° C., the proper heat. A few crystals of the sodium hyposulfite were added to the water and dissolved. She allowed the solution to stand while she prepared several strips of cotton cloth. A pair of tongs would be used to dip the cloth into the liquid.

"I thought you said indigo was a blue dye," Sam said.

"I did."

"But that stuff in the test tube is yellow!"

Terry explained why. Ordinarily, indigo did not dissolve in water. In order to dissolve the dye, the oxygen in the indigo compound had to be removed by the sodium hyposulfite. The resulting compound, indigo white, was soluble in a solution of sodium hydroxide.

"Now in order to get a blue color, all we have to do is add oxygen to the indigo white to make it turn into indigo blue again. Let's try it."

The contents of the test tube were added to the 250 milliliters of sodium hyposulfite solution. Terry stirred the liquid very slowly, then dipped one of the pieces of cloth.

"It's still white," Sam said, peering into the beaker.

Terry lifted the cloth out and waved it gently in the air. In a moment, it began to turn light blue.

"The oxygen in the air is combining with the indigo white," she said. "Presto! Indigo blue!"

"Let me try a piece," Randy said.

He dipped his cloth, exposed it to the air, then dipped it again. As the process was repeated, the color became darker and darker blue.

"The dye won't wash out of the cloth because indigo blue isn't soluble in water," Terry said.

She told them that some dyes would not cling to fibers unless the latter had been prepared by soaking them in a mordant. A mordant was a colorless compound that would stick to the fibers and accept the dye. Alum and potassium dichromate were mordants used with vegetable dyes. Some common synthetic dyes were used with mordants of aluminum sulfate, or salts of iron, chromium, or tin.

"I suppose synthetic dyes are the only kinds used today," Randy said.

"That's generally true for textile dyeing, I think," Terry said. "Foods and cosmetics are still colored with vegetable dyes because the synthetic ones tend to be poisonous. Most of the synthetic dyes are made out of coal tar products."

A boy chemist and aniline dye

In 1856, when only 18 years old, William Perkin discovered the first aniline dye—a purple shade called mauve. His discovery opened a wonderful new world of synthetic dyes.

"Could we make some?" Sam asked.

"It wouldn't be easy. But it's a funny thing about synthetic dyes—the first one was discovered by a boy! He revolutionized the dye industry."

Terry told them what she could remember of the history of William Perkin. In 1856, when Perkin was an 18-year-old student, he discovered the purple aniline dye named mauve.

"He discovered the dye accidentally while he was trying to make quinine," Terry said. "He was rinsing out his test tube, and the mess inside gave off this purple color. Some people might just have scrubbed a little harder, but not our boy Perkin! He had to know where the purple came from—and he found out. Now there are over 1,000 kinds of synthetic dyes."

"And a *boy* started it all?" Sam asked unbelievingly.

Terry nodded solemnly.

Sam looked serious. "Of course, I suppose there wouldn't be much chance of that happening again. By now, nearly all of the important chemicals must be discovered."

Terry laughed. "Not much! Fibers and dyes are just one branch of synthetics. Besides that there's drugs and rubber and plastics, and a whole slew of petroleum and coal products."

"Synthetics is part of organic chemistry, isn't it?" Randy asked.

"Yes. Organic chemistry deals with the carbon compounds that are similar to those found in living things. Chemists used to have to make organic compounds out of plant and animal substances. But now they can build lots of compounds directly out of the elements that compose them."

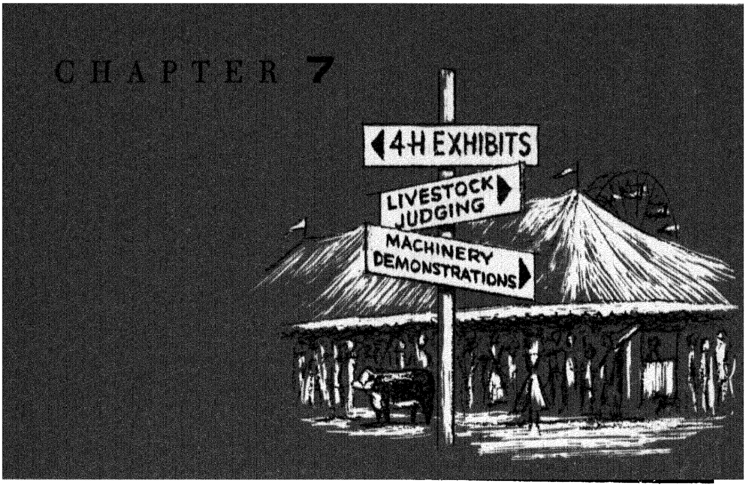
Terry glanced out of the chicken-house window. The cows were beginning to wend their way back to the barn to be milked. "Time to clean up around here, you guys."

She put Randy and Sam to work washing out glassware. Sam whispered to his brother, "Whomping up that rayon and testing the dye was fun. But I still think this place needs a mad chemist to liven it up."

Suddenly, before he could prevent it, a slippery graduate cylinder popped out of Sam's hands and smashed in the sink.

Then Sam's day was complete. The chemist who bawled him out for his clumsiness was very mad indeed.

CHAPTER 7



Polymers at the fair

THE summer days went by swiftly for Randy and Sam. The boys and their Uncle Dan seemed to have explored nearly every cave in Egypt by the time July came to a close. Randy's hydroponic garden had been planted in a large plastic dishpan. It contained a half dozen sturdy young Brussels sprouts plants.

"Brussels *sprouts?*" Sam had commented incredulously, when Randy told him what he planned to grow.

"You bet your life," Randy had told him. "They're the best vegetable of all. Nothing beats Brussels sprouts slathered in butter. And for once, I'm going to have all I want!"

The boys had visited Terry's lab from time to time, but for the last two weeks now she seemed to have disappeared.

"Everybody in the county's getting ready for the fair at the end of August," Grandma Morrow had said. "You never saw such feeding and currying of livestock and canning and suchlike. I dare say your friend Terry is working on some project, too."

But if she was, she didn't intend to let the boys in on it. So they helped Uncle Dan, who was a member of the Future Farmers of America, to get his baby beef cattle ready for the livestock judging.

One afternoon, scarcely a week before the County Fair, Sam came dashing madly into the barn to find Randy and Uncle Dan. "Your prize steers, Uncle Dan!" he yelled urgently. "Something's scaring them!"

"What?" Uncle Dan's face darkened with anger.

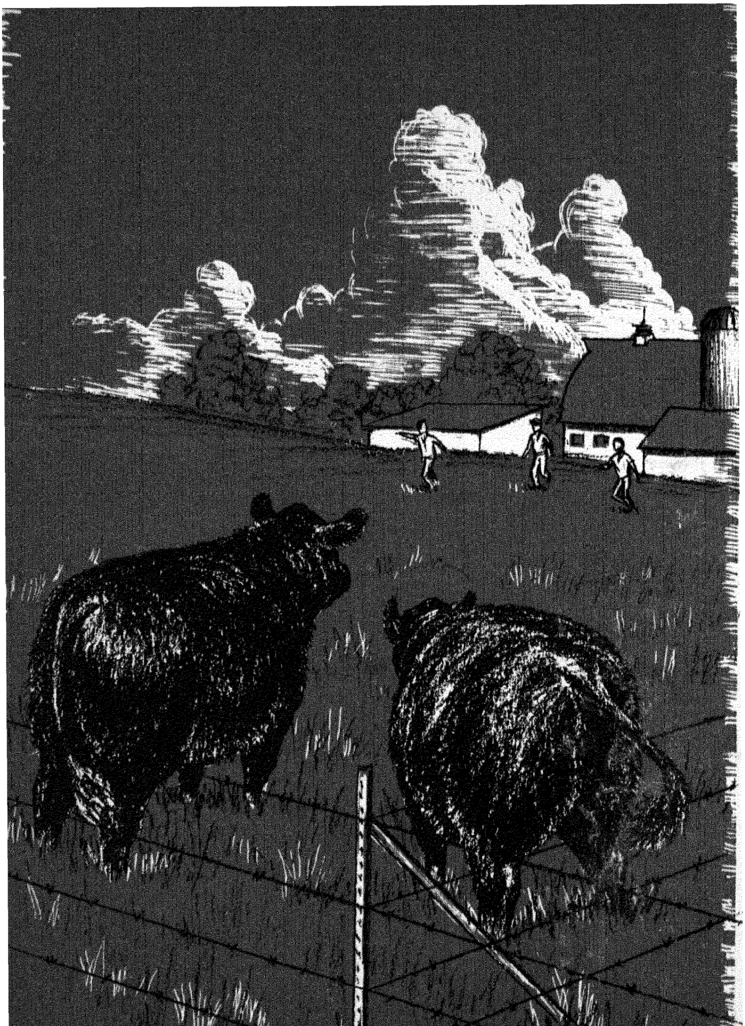
"All I could see was something funny moving in the tall grass in back of the pasture. And Forry and Harry were ramping around working themselves into a real lather!"

"Let's go!" Randy said, and plunged outside. He reached the pasture before the other two. In one corner of the enclosure stood the two young steers, slightly the worse for wear. They still rolled their eyes in alarm and snorted apprehensively from time to time.

Uncle Dan scanned the surrounding fields fiercely. "Nothing in sight now," he said. "But something sure scared these guys." He began to talk soothingly to the big animals, and they slowly calmed down.

"Why don't Sam and I take a look around?" Randy suggested. "Maybe we can locate whatever started the fuss. It could be some stray mongrel out looking for trouble."

The boys' young uncle nodded. "Just the same, I think



In one corner stood the young steers.

I'll bring these guys into the feeding lot to cool off. You boys see what you can find."

Leaving Uncle Dan to drive the steers back, Randy and Sam set out on their trek across the fields. It was a warm, cloudless day. Waves of rich-smelling warmth rose from the fields of clover. As the boys waded through the knee-high greenery, squads of insects fluttered up before them.

"Will you look at all the orange butterflies," Sam exclaimed. A cloud of the gaudy little flyers hovered over a muddy pond in one corner of the field.

The boys skirted the water and climbed through the fence into the woodlands beyond. Under the oaks, the air was cooler. But there was no sign of anything that might have frightened the cattle.

"Are you *sure* you saw something?" Randy asked his brother skeptically.

"Didn't you get a look at Forry and Harry?" Sam countered. "They saw it too. I've got witnesses. It was something white and wavy. It acted real spooky—popping up a little, then disappearing."

Randy grunted noncommittally.

"I tell you, I did see something. Hey! Look!" Sam pointed to an opening in the trees. There, in a wild meadow overgrown with large weeds, was a moving shape. It was white. It appeared, then disappeared.

"Come on!" Randy said. He dashed forward into the meadow—then stopped short.

"Terry Chandler!"

The girl chemist looked up from the weeds and frowned. She held a large butterfly net by the handle and the bottom of its bag.

"It got away!" she cried in disappointment, lowering the net. "The only spangled fritillary I've seen today—and you scared it away!"

"That's not the only thing that's been scared," Randy said. "Do you know that net of yours scared my uncle's prize steers out of a week's growth?"

"Who, me?" Terry asked.

"That's what I saw!" Sam piped up. "The butterfly net! It sure looked weird, flapping in the weeds."

"Well, I'm sorry if I scared the blue ribbon beeves," Terry said. "They must have delicate dispositions."

Sam said. "Oh, they'll be all right. We were worried about them because the fair is so close. Uncle Dan would raise the roof if they cut themselves on the barbed wire fence or got off their feed before the cattle contest."

"I'll stay away from there after this," the girl said. "I've got enough orange butterflies now, anyhow."

"Enough for what?" asked Randy.

"Enough for the fair," Terry said. "Well, so long." She picked up her net and a knapsack and started off.

"Hey!" Sam called. "How can butterflies go to the fair?"

"That's for me to know," Terry said slyly.

"Come off it, Terry," Randy said. "Aren't we your pals?"

She looked at them coolly. "Well, I guess you can't steal the idea. Come on down to the lab and I'll show you what I'm whomping up."

On the way to the Chandler farm, Terry managed to snare another spangled fritillary, which imprudently happened to perch on a milkweed plant right in their path. The girl folded the net carefully over the brown and silver speckled insect, then took a little bottle from her knapsack and uncovered it.

"Naphtha," she explained. "It kills butterflies very quickly. Much better than cyanide bottles and that kind of rubbish."

"That's what I saw!" Sam piped up.

She removed the deceased fritillary carefully from the net and placed it in a cotton-lined box.

The lab bench, the boys discovered, had been converted into an insect-collector's paradise. Large sheets of blotting paper covered its surface. Sewing thread spools were everywhere. Each pair of spools, Randy quickly discovered, served to hold down the spread wings of a butterfly that lay on its back on the blotting paper.

"I redampen the butterflies with naphtha," Terry explained, "then spread their wings. After a day or so of drying, the wings become set in the spread position. Then I can start making the ornaments."

She showed the boys what she had been making for the County Fair—and Sam and Randy exclaimed in astonishment. The metal table in the corner of the room was covered with shining cubes of clear plastic. Inside of each block was a butterfly and a group of graceful plants.

"You *made* these?" Randy marveled.

"Certainly. The specimens are embedded in thermosetting plastic. I make bookends and paperweights and things out of them to sell at the fair. The proceeds go to buy more things for my lab."

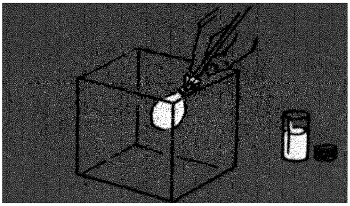
"Show us how it works," Randy requested.

So Terry did. First, she took a glass mold and rubbed a small amount of mold-release compound on the inside. This would permit removal of the finished casting.

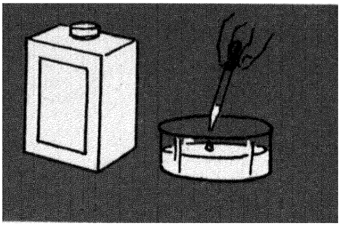
Next, she poured a small amount of liquid plastic into a beaker and added the catalyst that would cause it to harden. The mold was filled about half-way with this mixture, which Terry allowed to set a little. Then she arranged a dried butterfly, a fern frond, and a tiny spray of clover blossoms on the surface of the still sticky fluid. Then more plastic was mixed with the catalyst and used to

"You made these?" Randy marveled.

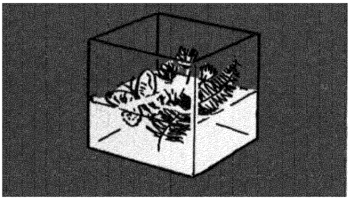
Embedding specimens in plastic



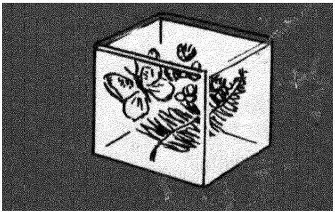
1 Rub mold interior with mold release compound.



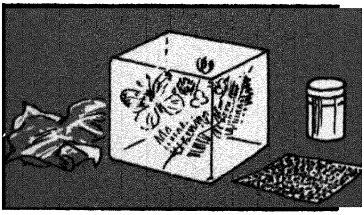
2 Pour plastic into a container, add catalyst.



3 Partially fill mold, let plastic start to harden. Arrange specimens.



4 Mix more plastic with catalyst, cover specimens, let harden.



5 Turn out casting. Sand and polish with buffer compound.

There are several brands of embedding plastic on the market. Follow the directions that come with the materials. Animal, vegetable, and mineral substances can be embedded in plastic to produce beautiful and interesting ornaments.

cover the specimens. When the plastic had hardened, Terry turned the casting out onto the lab bench.

"Now it has to be polished." She worked the block over with sandpaper, then applied buffing compound and rubbed the plastic until it glittered.

"And here you are!" She dropped the finished ornament into Randy's hands. "Compliments of the house."

Randy stammered his thanks. "It's very pretty, Terry. I know Mom will like it."

"These go over big at the fair," the girl chemist said smugly. "You know, you can embed almost anything in this thermosetting plastic. It makes good jewelry, too."

Her masterpiece was a very large plastic block mounted as a lamp base. It contained several brightly colored zinnia flowers arranged with handsome striped tiger swallowtail butterflies that seemed to hang suspended over the flowers.

"Ought to get a good price for that one," she said. "Jerry rigged up the lamp wiring for it."

"These are really sharp, all right," Sam said. "Boy—what won't you chemists think up next!"

Terry grinned. "That's the secret of our success. You never know!"

She said that this was only one of the marvelous modern plastics that had been developed. Some were thin and transparent. Others were strong enough to use in home construction. Everything from artificial teeth to helicopter bodies could be made out of plastic.

"Plastics is one of the fastest growing branches of chemistry," she said. "You know from your own experience that more and more plastic things are put on the market every year."

"How are plastics made?" Randy asked.

"Maybe first I should tell you what a plastic *is*," Terry suggested. "But let's talk while we work. These gadgets have to be finished in time."

So Terry put Randy and Sam to work smoothing blocks of plastic, while she worked on embedding the butterflies and plants. While they worked, she told them about plastic molecules and their peculiar habits.

"You know that ordinary molecules are able to hook together to form solid things. They usually form geometric shapes called crystals. But plastics are different. Their molecules hook together in groups or long chains called *polymers*. A chain might have thousands of molecules in it."

The process of joining molecules into chains was called polymerization. Terry compared it to a group of folk dancers on a floor. Before the music starts, the individuals mill around in all directions. But when the dance begins, they join hands in orderly lines and move together.

"Take styrene, one of the materials that polymerizes into plastic. It starts out as a liquid. As it's heated, it gets thicker and thicker, and finally turns into a solid—polystyrene plastic. There hasn't been any real chemical change, but the substance you end up with is much different from the one you start with."

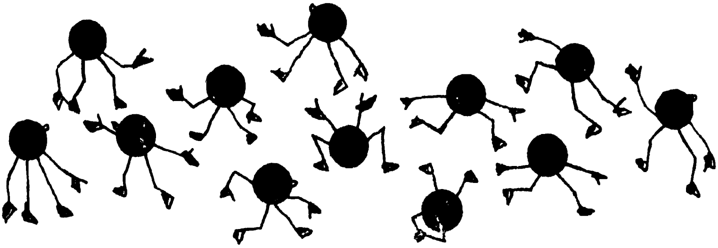
"What makes one plastic different from another?" Sam asked.

"Their properties depend on the kind of molecules you start out with—the building blocks are called *monomers*—and on the number of links in your polymer chain."

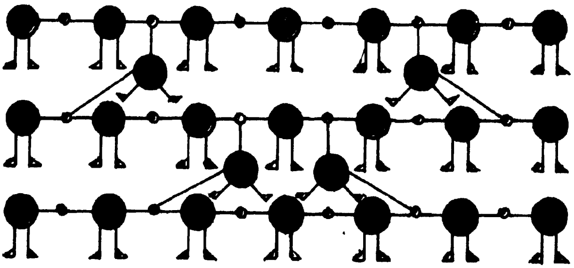
She said that other kinds of plastics could be made by causing two different kinds of molecules to form chains. These were called co-polymers. Buna-S synthetic rubber was a co-polymer formed from styrene and another organic compound named butadiene.

Randy wrinkled his brow. "Could you make chains with more than two different molecules in them?"

Polymerization of one type of plastic



Before heating, styrene is liquid. Molecules move in all directions.



After heating, polystyrene, a solid, is formed. Molecules have linked together in chains, like dancers. Linking is called polymerization.

"They're tackling that problem now," Terry said. "Someday it might be possible to build a plastic with whatever properties might be wanted—just by linking different types of monomers."

There were many families of plastics. The cellulosics were the oldest. They were made of cellulose and nitric acid. Cellulose nitrate was one of the first plastics produced commercially. It was used to make eyeglass frames, piano keys, slide rules and many kinds of novelties. Cellulose acetate was a tough plastic that could be transparent or highly colored. It was used for toys, packaging, and protective coverings.

Phenolic plastics came only in dark colors. Made from phenol and formaldehyde, these plastics were resistant to the effects of heat and were good insulators. Appliance handles, radio and television cabinets, bakelite electrical insulators and electronic components were also made from phenolic plastics. Phenolic resins were important in industry as binding agents, and as ingredients in laminated sheets, gears, and bearings.

"Our TV cabinet is red," Sam said. "It *can't* be made out of phenolic plastic."

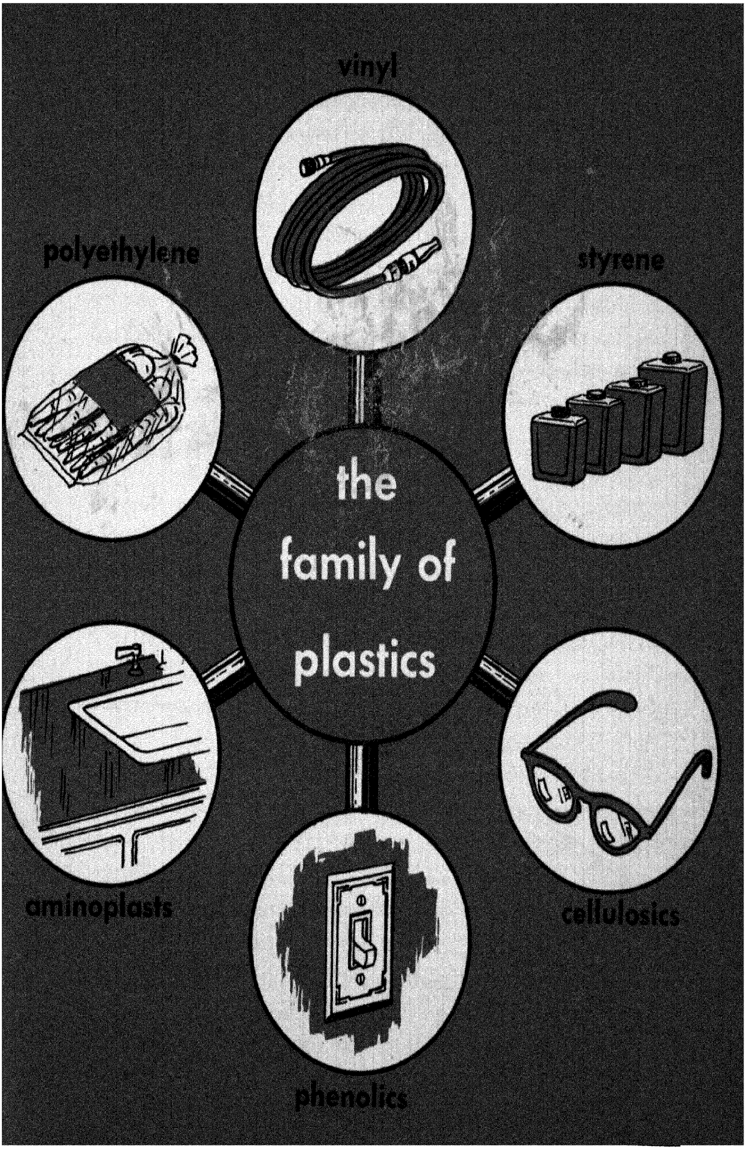
"It's probably made out of urea plastic. That's made from ammonia and formaldehyde. Urea is used for lots of tough plastic articles like electric shaver cases and TV cabinets."

"What's that stuff that plastic raincoats are made from?" Randy asked.

"That's vinyl," Terry replied. "It's made out of things like chlorine and acetylene and ethylene. That's the plastic that's taking the place of rubber in so many ways. Floor tiles and garden hose and shower curtains and upholstery are made from vinyl. Lots of other things we use every day are, too."

"Gee," Sam said, "I thought that plastic was just plastic! But all these different chemical names—"

Terry laughed. "We've only scratched the surface. Don't forget polyethylene, the squeeze-bottle plastic—and polystyrene, that's used for making toys, wall tile, phonograph records, and I don't know what-all. Acrylic plastics like lucite and plexiglas are used for false teeth and brush


vinyl
polyethylene
styrene
the family of plastics
aminoplasts
cellulosics
phenolics

handles and instrument dials."

"What's this stuff?" Randy asked, holding up one of the paperweights.

Terry replied, "It's a thermosetting plastic. Thermosets are plastics which harden when they're heated. Thermoplasts are plastics that get soft when they're heated."

Randy studied the butterfly inside one of the blocks. "You know," he said, "you're missing a good bet by not putting other things in these blocks."

Terry bristled. "Everybody liked the butterflies *last* year."

"But why not try something different this year?" Randy suggested. "Go into business with Sam and me. Let us give you some of our new ideas."

"Ideas," she said contemptuously, "are worth a penny a peck."

"Not *our* ideas. Look. We'll invest in some of this plastic gunk ourselves and make our own paperweights. Let us display our stuff in your booth, and we'll cut you in for a percentage. You won't have to do a thing."

Terry looked at Randy dubiously. "You won't cut prices on me or pull any dirty tricks, will you?"

Randy stood at attention. "On my honor as an Eagle Scout!"

"And mine as a Lion Cub Scout!" Sam chimed in.

Terry gave them a superior smile. "Okay, kids. I get my plastic from the General Biological Supply House on 8200 South Hoyne in Chicago. It costs $2.50 a pound. Frankly, I'm not going to worry too much about your competition. Butterflies sold like hot cakes last year, and they'll sell that way again this year!"

Later, on their way back to their grandparents' farm, Randy and Sam hashed over the idea they had thought of.

"It sounds good to me, Randy," Sam said. "But do you think we'll have time? There's barely a week before the fair, and we have to send for the plastic and everything."

"Let me give this a good think," Randy said. "I've got it. We'll call Dad, and he can pick up the plastic when he goes into the city. Then he can send it to us special delivery. In the meanwhile, we can be getting the stuff that we want to embed."

"Okay," Sam said, "but we're going to look mighty silly if our stuff isn't ready on time."

In the days that followed, the boys worked feverishly on their project. Their Uncle Dan pleaded in vain for help in grooming Forry and Harry for the stock show; the boys were awfully sorry, but they had to get their own stuff ready. So Uncle Dan brought the steers to beefy perfection by himself.

In three days, the plastic arrived from Chicago, and Randy and Sam were able to get to work casting and polishing. They appropriated a corner of the sun porch for their activities and refused to be distracted by anything.

Finally, on the day before the fair, they surveyed the pile of gleaming blocks that they had made.

"Think they'll sell?" Sam whispered.

"If they don't," Randy said, "we'll be able to build the only plastic-block doghouse in the U.S.A."

They arrived at the fairgrounds early, bringing their paperweights in close-packed boxes. The booth that Terry occupied was in the handicraft section.

Every one of the tentlike canvas cubicles was filled with colorful wares. Patchwork quilts, wood carvings, hand-knitted garments, copper jewelry—everything seemed to be represented. Terry was the only one who offered plastic craftwork, though.

"Your things sure look nice," Randy said, eyeing the rows of bookends, paperweights, and pendants. The butterflies were brilliant in the sunlight. Suspended in the clear plastic, they almost looked as though they were still alive.

"I'm waiting to see your masterpieces," she smiled.

"Hold onto your wig," Sam said, and started to unpack the Morrow efforts.

Terry's eyes opened wide. The superior smile was slowly replaced by a look of grudging admiration as the boys laid their novelties, one by one, on the corner of the counter reserved for them.

"A customer!" Sam whispered sharply, giving his brother a dig in the ribs.

"Not really, youngsters," said a portly man in a tan suit who had come up to the booth. On his lapel was a ribbon emblazoned: *Committee.* "I'm just checking to see that everything's all right on this end of the fairgrounds."

He glanced over the butterflies. "Very lovely pieces of work, young lady."

"One would look awfully nice on your desk, Dr. Varney," Terry suggested.

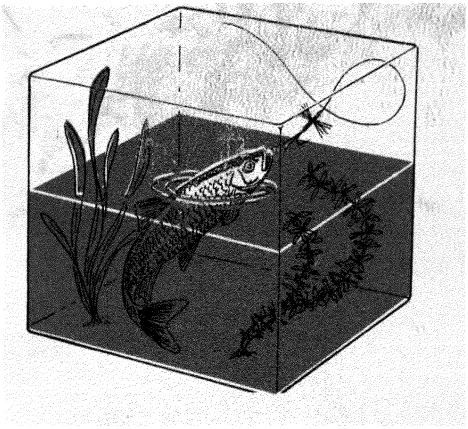
The doctor regarded her paperweights thoughtfully. "Not quite to my style, child. A little too—uh—fussy for me."

He started to move on, then caught a glimpse of Sam and Randy's wares. The boys looked at him pleadingly.

"Wait—a—minute!" Dr. Varney exclaimed. "Now here's a thing any man would like for a paperweight!"

He picked up one of the boys' products.

The plastic was in two shades. The bottom half of the weight was pale green, the top half was clear. Springing



out of the green part was a silver minnow, looking for all the world as though it were leaping from the surface of a still pond. Suspended in the plastic above the fish's mouth was a miniature dry fly on a hook, tied to a plastic line. A few pieces of water weed completed Randy and Sam's idea of a man-style paperweight.

"I'll take it," the doctor said decisively. "Butterflies are all right for the womenfolks, but give me a nice outdoor design like this anytime!"

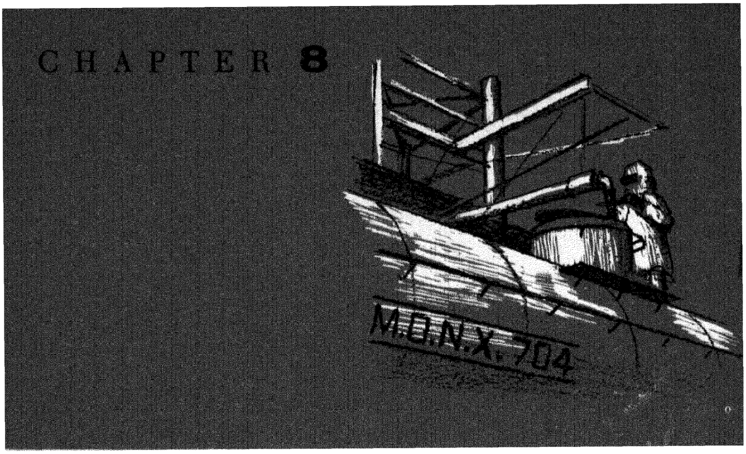
"And there," said Randy when the doctor had departed, "goes proof of another important principle of chemistry."

"What, for goodness sake?" Terry asked.

"Manufacturing a chemical product is important—but putting it across to the customer is even more important!"

For once, Terry had nothing to say.

CHAPTER 8



Putting chemistry to work

"Dad's coming!" Sam yelled, pounding down the stairs into the farmhouse. "I saw his car from the upstairs window!"

Randy looked up eagerly from an experiment he and Terry Chandler had been working on. "He wasn't supposed to be here until next week! Come on, Sam—let's meet him!"

The two Morrow boys rushed out to the drive, slamming the screen door behind them.

Grandma Morrow looked into the kitchen to find Terry sitting rather forlornly at the table. "Looks like you've been deserted, dear," the older woman said.

Terry said, "I'd feel the same if I hadn't seen my Dad all summer. Randy's always talking about his father. He must be swell."

"He's a science writer," Grandma explained. "Does articles for newspapers and magazines. Writes up all that complicated scientific stuff so that even *I* can understand it."

Loud voices were approaching, and in a minute Randy and Sam had escorted their father into the kitchen. Mr. Morrow swept Grandma off the ground and gave her a big kiss.

"That's for keeping my two wild animals out of my hair so that I could get my book done." He produced a titanic box of candy, tied with a big lilac ribbon. "And *that's* to keep you fat and sassy!"

"You never did have any respect for your elders," Grandma said tartly, but her eyes were shining.

Mr. Morrow turned to Terry, "I don't believe I know this young lady with the test tubes."

Randy hastened to make the introduction. "This is Terry Chandler, Dad. We've had a lot of fun this summer doing chemical experiments together. She got us into the plastic paperweight business, too!"

"Terry's trying to get Randy to be a chemist when he grows up," Sam said.

"Have you convinced him?" Mr. Morrow asked her.

"I've tried," she said earnestly. "Gee, Mr. Morrow—there isn't *any* career that offers more of a challenge than chemistry."

"What branch of chemistry have you decided on as your life's work, Terry?" Mr. Morrow asked.

"Research," said the girl. "Probably in some branch of agricultural chemistry."

"That's a fine choice. Research chemists are genuine pioneers."

Randy said, "I think chemical engineering might be more my meat, Dad. I like the idea of taking new chemical discoveries and putting them to work."

"If you did enter chemistry, son, you'd be part of one of America's fastest growing industries. By 1975, it'll probably be four times as big as it is now. Modern living is absolutely dependent on chemistry."

He sat down at the table for some of Grandma's berry pie and a big glass of fresh milk. "What's this experiment you're working on?"

Sam said, "A magic coral garden! We're going to grow rock plants in this rose bowl Grandma gave us."

"A coral garden?" Mr. Morrow looked puzzled.

"Sodium silicate and crystal seeds," Terry explained. "We fill the bowl with a solution of half water glass—sodium silicate—and half water. The pebbles on the bottom will be anchorage for our mineral 'plants.' "

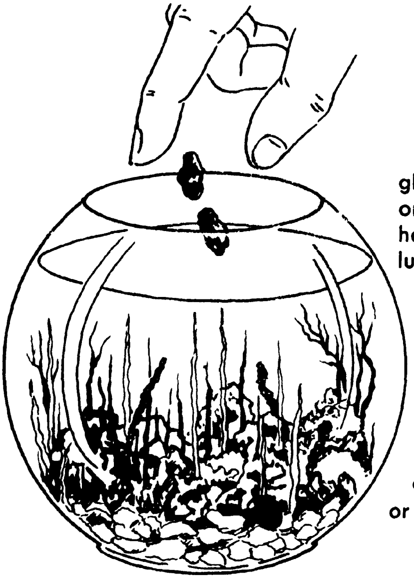
She and Randy had previously prepared the solution and placed it in the rose bowl. Now they took a piece of paper, on which were heaps of rather large, colored crystals.

"We've got copper sulfate and cobalt chloride and nickel sulfate," Randy said. "Also manganese chloride and the sulfates of zinc and ferrous iron. All we have to do to start the garden, is drop these crystals into the solution."

Everybody took one pile of crystals except Grandma Morrow, who took two. Then the crystals were dropped in and they all watched the bowl intently to see what would happen.

"They're growing!" Sam exclaimed. And he was right. Some of the crystals were already sending off fragile mineral offshoots that rose toward the surface of the liquid.

A magic coral garden



glass container with one-half water, one-half water-glass solution.

clean sand or fine pebbles

Add large crystals of copper sulfate, cobalt chloride, nickel chloride, manganese chloride, zinc sulfate, ferrous sulfate. A garden of minerals will grow. After one day, siphon off solution, replace carefully with plain water.

Each crystal sent up many coral-like branches. There were blue, pink, white, green, and violet branches—twisting and spiralling gracefully upward.

"My land," said Grandma. "Isn't that the prettiest thing you ever saw?"

"The garden will keep on growing all day," Terry said. "Then you should get a siphon tube and take out the liquid, which'll get pretty cloudy by then. Put in fresh water, and the garden will last for a long time. The plants are solid mineral—just like the cave formations."

"Are those carbonates?" Sam asked.

"No—they're silicates—compounds of metals with silicon and oxygen," Terry said.

"This garden will make a nice memento of you boys," Grandma said. "I'll be real sorry to have you go."

Mr. Morrow said, "As a matter of fact, I'm not quite ready to haul them off yet, Mom. I came early because I have to make a trip to St. Louis—to get material for an article on phosphorus I'm doing for a woman's magazine. I'm visiting the Monsanto Chemical Company to get background material."

"Phosphorus?" Randy said in a surprised voice. "For a woman's mag? Why should they be interested in phosphorus? That's the stuff Terry uses to make her smoke screens. You can't even keep the stuff in air without it catching fire. It has to be stored under water."

Mr. Morrow smiled. "But phosphorus is very important to every housewife. Isn't it, Terry."

"Why, sure!" she said excitedly. "You make detergent, and baking powder, and—"

"Whoa!" Mr. Morrow said. "This could grow into an encyclopedia!"

"Is that a real big chemical plant in St. Louis?" Randy asked.

"There are a lot of research labs there, and several different manufacturing plants—including the phosphate plant I plan to visit."

"I don't suppose," Randy hesitated, "you could use any junior observers?"

Three young faces looked at Mr. Morrow eagerly. He said, "Something might—I say *might*—be arranged."

"Whoopee!" Sam screamed.

"Look out for the coral garden!" Terry cried in alarm.

"I'll be leaving for the city tomorrow at 6:30 a.m. If you three are ready, I'll take you along."

Sam stood beside the car and gazed up at the towers and tanks of the chemical factory. "This place has a certain atmosphere," he said.

Terry sniffed delicately. "What *is* that?"

"They make many kinds of organic chemicals at this division of Monsanto," Mr. Morrow said. "I'll tell you one thing that I smell—vanilla!"

The three young people sniffed experimentally again. "You're right!" Randy said.

"Let's go inside," Mr. Morrow suggested.

The large lobby room contained an interesting series of dioramas—miniature scale models of the many different Monsanto plants. Terry and the boys examined these in fascination while Mr. Morrow talked to the receptionist.

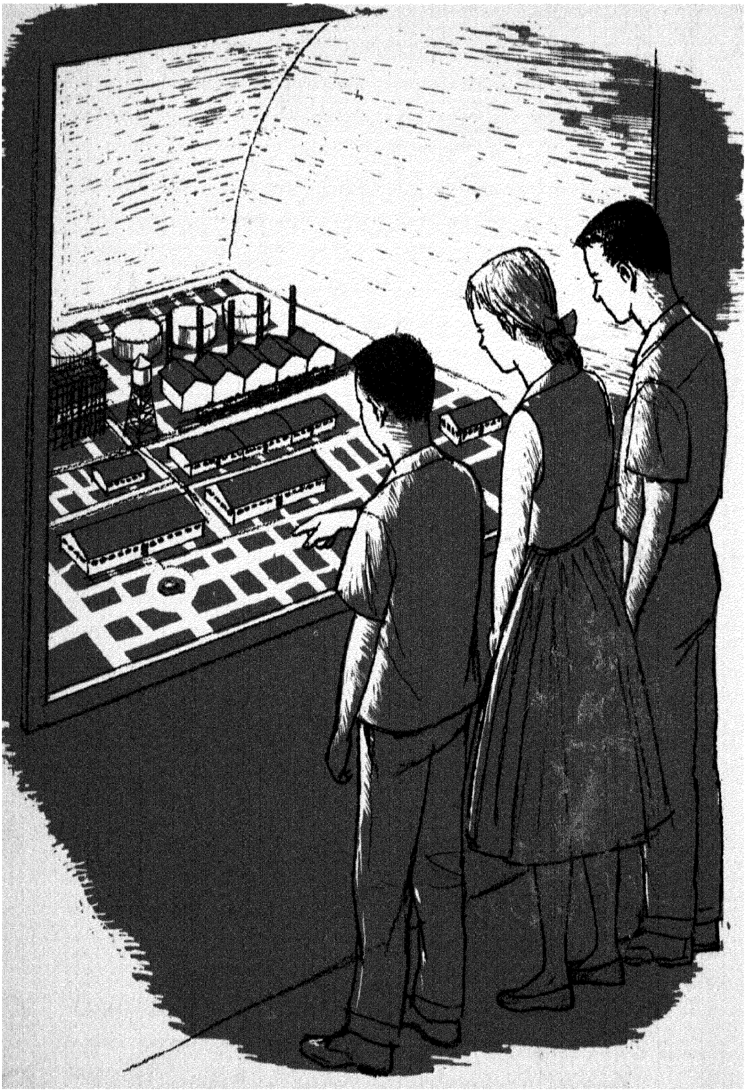
In a moment, Sam and Randy's father came back. "You kids are in luck. There's a group of boys and girls from the Y.M.C.A. making a tour of the research labs today. You can join them while I spend some time looking through the company's file of photographs."

"How about the phosphorus?" Sam asked.

"The phosphate plant isn't located here. It's outside town in the suburb of Carondelet. After you've had a taste of chemical research, we can investigate some of the problems of chemical engineering."

A man came up to Mr. Morrow and introduced himself as Bob LeGrand of the public relations department.

"I'll escort you youngsters over to the research labs and we'll find hat guided tour. It just started about 10 minutes ago, so you won't have missed much. So many boys and



They examined the miniature plant in fascination girls are interested in chemistry these days, that we conduct several tours of our installations every week."

They hurried through the well-lighted corridors. On all sides were the offices in which the business of the great chemical company was carried on. Finally, they reached the research labs. In one rather small, cheerful room, they found a group of about 10 boys and girls clustered around a young man in a white lab coat.

"Here's the tour," said Mr. LeGrand. He moved up to another man who seemed to be in charge of the group and whispered a few words to him.

"This is Mr. Tetley, the Y counselor," Mr. LeGrand said.

"Glad to have you join our tour," the counselor said. "Just call me Sam."

"Sam is my name, too!" said Randy's brother.

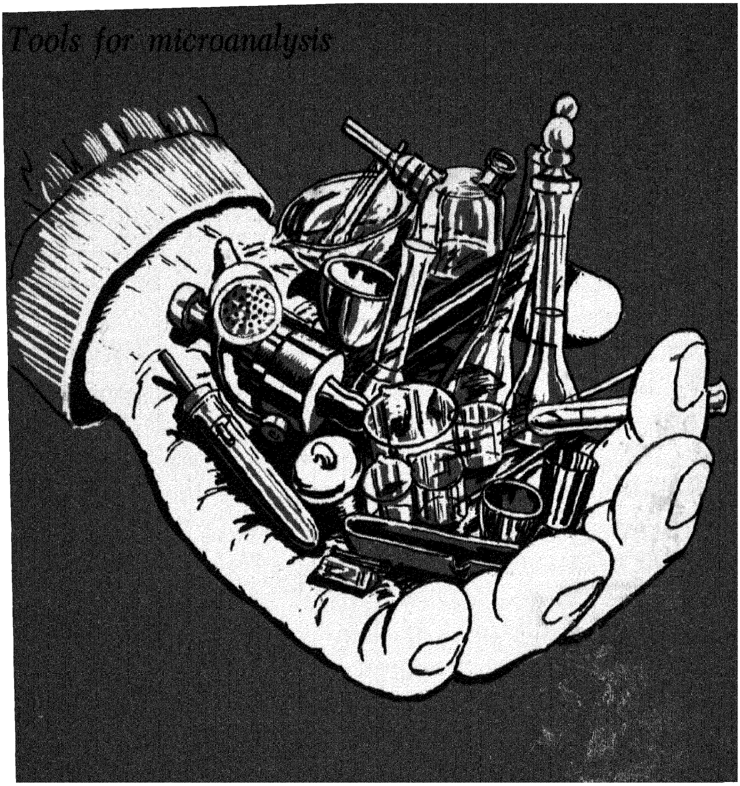
"Then call me Sam Squared. I'm about twice as big as you are! Let's go over and listen. This chemist, Mr. Barlow, is telling us about microanalysis."

Terry and Sam edged closer. "See you later, Dad," Randy whispered, and followed the others.

On the lab bench were a collection of retorts, beakers, evaporating dishes, and flasks. But they looked as though they had been made for a chemist only a foot high!

"At the start of a project," Mr. Barlow was saying, "you might have only a tiny quantity of a new chemical to work with. Yet you want to test it to determine its properties. These little beakers, micropipettes and other tools are used in microanalysis. They make it possible for us to handle little pinches of stuff and still get accurate results."

They were also shown fine balances, cased in glass to protect them from changes in the atmosphere, that could weigh to the ten-millionth of an ounce. They also saw an electronic device that could measure the pH of a com-



Tools for microanalysis

pound with fantastic accuracy.

"After the microanalysis gives results, the compound might be tested on a larger scale. The testing isn't just done by one man—it's carried on by a research team."

"Can you give us an example of how chemical problems are solved?" one girl asked.

"Well, one piece of research involved finding a chemical weedkiller for corn. One man conceived the original idea. Then a team of 25 went to work with him, synthesizing over 400 different compounds and testing their effectiveness on actual growing plants."

"Doesn't working in a group take some of the creativeness out of the work?" Terry asked.

The chemist said, "Everyone in the team is expected to contribute to the scientific thinking. Of course, the group leader is responsible for the investigation—and his experience and example should inspire the others."

Mr. Barlow pointed out that a well-coordinated team could do what no individual—no matter how brilliant—could hope to accomplish. In a scientific group, individuals spark each other, he said, and a common problem could be attacked from many different points of view instead of just one. An overly bold member might be cooled off by his more conservative team-mate, for instance; the logical thinker might be presented with a fruitful off-beat approach by the intuitive thinker.

"The days are gone when a chemist locked himself into a dark, smelly alchemist's lab and worked by himself for weeks at a time. The team member works on his section of the problem and uses his own tactics. But the emphasis is on cooperation and interchange of ideas—rather than on lone-wolf activities."

They moved through the brilliantly illuminated laboratories where men and women worked on hundreds of different problems in chemistry. One team of women, a group leader and her three associates, were working on synthetic food flavorings.

Terry asked the leader, "Is chemistry really a good field for women?"

"The number of women in chemistry is increasing every year," she said. "You'll find women chemists in every branch of the science, but there *are* certain fields that seem to attract more women than others."

"I suppose you mean food and cosmetics chemistry," Randy said.

"Those are two," the woman agreed. "But you'll find women active in all types of research and analytical chemistry, and in biochemistry—the chemistry of living things."

"I'm interested in chemicals that keep people healthy," one tall, shy youth said.

"Then you might be interested in pharmaceutical research," the Y.M.C.A. counselor said. Then Mr. Barlow suggested they visit one of the labs that did research on new drugs.

"This group is testing calcium compounds being developed for patients who have a deficiency of that element," Mr. Barlow said. "There are many compounds that contain calcium, but the problem is to get it in a form that the human body can use efficiently."

The group learned that aspirin, the original "wonder drug," was first produced in the United States by Monsanto. The company now lead the world in the production of this drug.

"Yet the action of aspirin is still not fully understood," Mr. Barlow said. "Medical researchers are still investigating to learn why it has the effects it does."

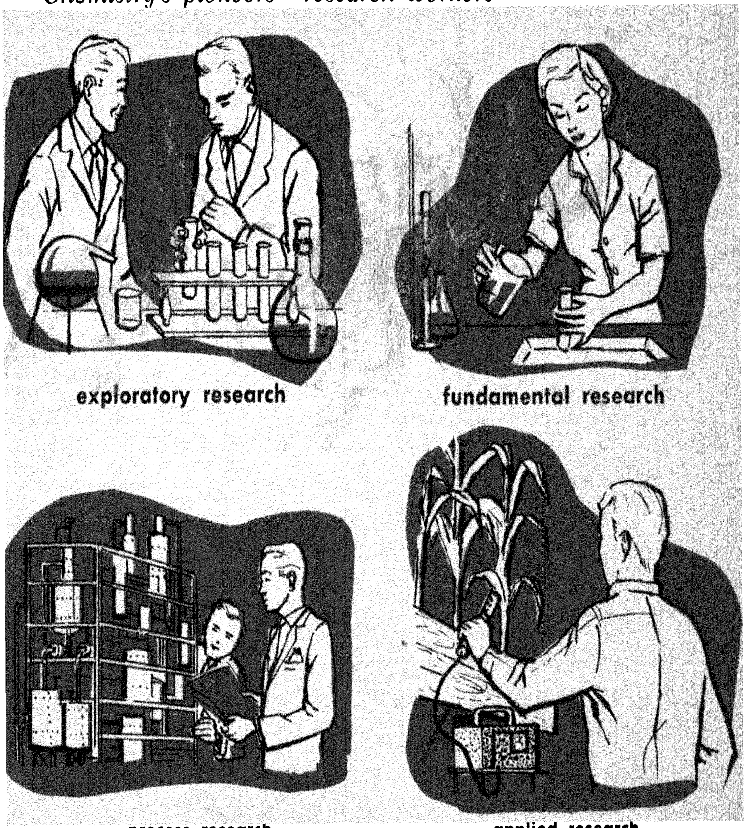
A determined-looking boy said, "Research is a mighty important part of chemistry. But can't we get an over-all picture of it? What *are* the different types of research?"

"Well, here's one way you might classify it."

Many of the boys and girls pulled out notebooks and pencils as Mr. Barlow sketched his ideas.

"Fundamental research," he said, deals with increasing our knowledge of the unknown. The work might or might

Chemistry's pioneers—research workers



exploratory research

fundamental research

process research

applied research

not have practical application at the moment. The worker in fundamental research is free to follow up any promising clue that might turn up in the course of his investigations.

"Not every chemist has the temperament for fundamental research," Mr. Barlow continued, "It demands superhuman patience and a persistence in the face of countless defeats. But for the gifted person whose temperament makes him want to penetrate the frontiers of human knowledge, fundamental research is more than an occupation—it is a foundation on which he can build a satisfying life.

"Industrial organizations like Monsanto sponsor basic research in many chemical fields. Universities and foundations spend the majority of their research funds in basic research," Mr. Barlow went on.

"Exploratory and applied research deal with new products and new uses for previously developed products. Exploratory research utilizes known principles, but has much of the 'challenge of the unknown' which characterized fundamental research. Chemists in this field synthesize new chemicals, study new types of reactions, and investigate new techniques of analysis."

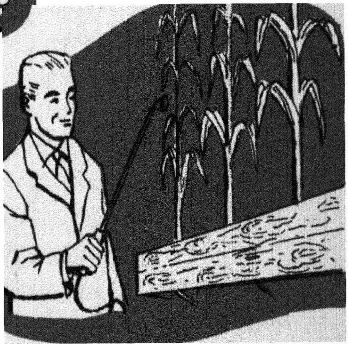
Among other things, Mr. Barlow told the attentive group that applied research involved deliberate investigations of problems that had immediate practical importance. This was work with special appeal to the problem-solver—the inventive, imaginative worker who enjoyed putting knowledge to work. Top men in the applied research field needed a broad knowledge of the chemical and physical properties of the products they worked with, as well as an understanding of the needs of the customers who would buy the products.

A branch of research that had a close relation to engineering was process research. Its aims were to lower the cost of producing products by improving the yield and bettering quality. Many chemicals that could easily be produced in a laboratory on a small scale were difficult to produce in large quantities. The work required broad training in fundamentals, and a knowledge of the techniques of industrial chemistry.

Radioactive tracers in chemistry

Radioactive tracers help scientists follow the action of many types of chemicals.

Weed-killing chemical is synthesized with radioactive material in its molecules.



Weed-killer is sprayed on growing corn plants. Chemical kills weeds, but also enters corn. Does chemical injure corn?

Technician follows path of chemical in plant by using geiger counter, learns that chemical is assimilated harmlessly.

"That would be one way of subdividing chemical research," Mr. Barlow said. "You can also subdivide it according to the branch of chemistry treated—analytical, organic, inorganic, or physical chemistry. Nuclear chemistry is a brand-new field that's related to atomic energy."

"Does this company do work in atomic energy?" Sam asked.

"We operate Mound Laboratory in Miamisburg, Ohio, for the Atomic Energy Commission. And we use tracer isotopes in many other branches of chemistry."

"How do they work?" a girl asked.

Mr. Barlow told them how radioactive tracers were useful in tracing the action of the weed killer that had been developed for corn growers.

"The weed-killing chemical was synthesized with a trace of radioactive material in its molecules. Then the killer was sprayed on corn plants and our technicians traced its progress as it was absorbed by the growing corn. By using a geiger counter, the technician could tell just where the chemical went when it entered the corn, and he could be sure it was assimilated harmlessly."

A very small boy, almost lost in the group of boys and girls, began to wave his hand.

"Can I answer your question?" Mr. Barlow smiled.

"I'd like to be a chemist!" the little fellow said. "It sounds exciting! But would that mean I'd hafta take a lot of *arithmetic?*"

Everybody laughed. Mr. Barlow said, "I can see that's a dirty word to *you*, son. Well, I'm going to tell you something that might surprise you. When you talk to vocational counselors, they tell you that it's essential that a chemist be good in mathematics. But do you know what?"

"What?"

"I, for one, don't think that higher mathematics is as important as a broad knowledge of other chemical principles. The chemist doesn't need as much math as the physicist or atomic scientist. The engineer does need math—especially the slide-rule variety—as a basic tool.

"But the organic chemist and the biophysicist need no heavy training in math—and these are big fields that offer a wealth of challenge and opportunity."

"How about money?" piped up someone in the rear.

"Money, too," Mr. Barlow laughed. "But remember that your salary is determined by your experience and by your natural abilities."

Terry said, "But don't the top people in the field tend to get bogged down in administration? I'm not interested in paper work—I want to work in chemistry!"

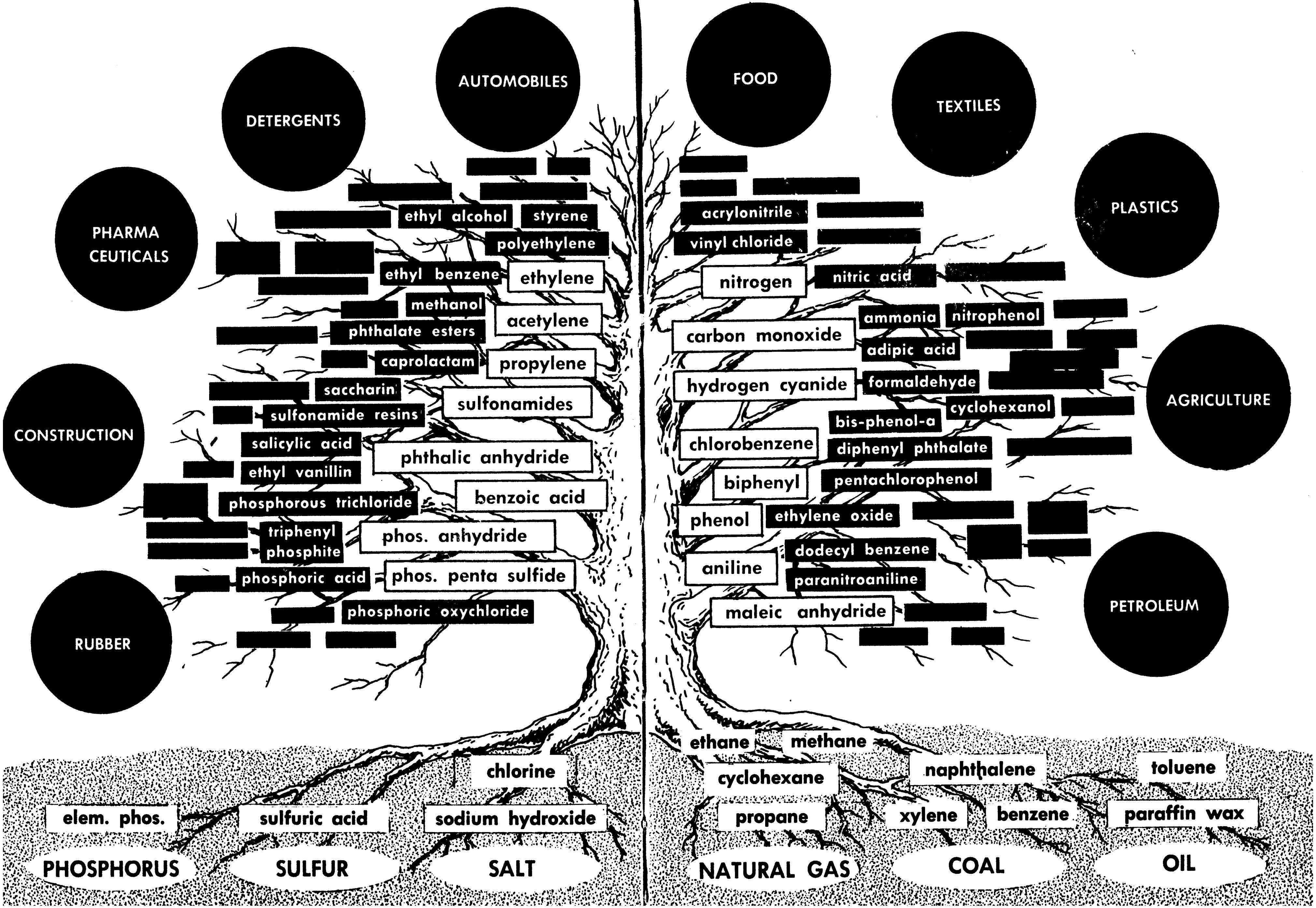
"A top job usually does bring administrative responsibilities. But it doesn't have to—at least not in our organization. We have positions of Scientist, Technologist, Senior Scientist, and Senior Technologist that are designed to allow specially qualified individuals the freedom they need to follow special lines of investigation. These people don't have administrative duties. Yet they have the salaries and prestige that go with top-level work."

The group of boys and girls toured several other laboratories in the research section, and Mr. Barlow told them something of the thousands of different products produced by the company—not only chemicals that were end-products in themselves, like fertilizers and pharmaceuticals—but the great family of chemical intermediates.

"These are the chemicals that are used to make other chemical products. Many of them have jaw-breaker names that only a chemist could love. Like tetrapropenylsuccinic anhydride, for example. But these are the raw materials for plastics, dyes, textiles, detergents, and other chemical products that are used by everyone."

The tour ended before an exhibit that represented the

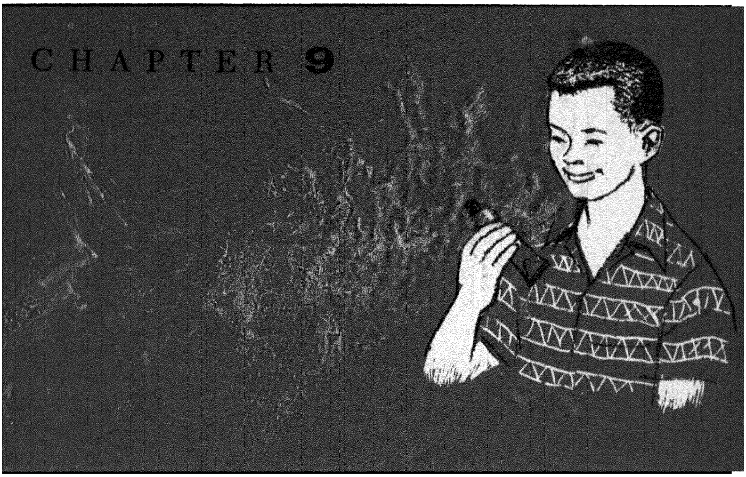
Tree of Chemical Technology



tree of chemical technology. At the roots of the tree, the boys and girls saw the most important raw materials of chemistry—salt, coal, air, oil, sulfur, phosphate rock, water, and limestone. From these roots the many-branched tree of technology spread its branches.

Branches that are still growing.

CHAPTER 9



Should I be a chemist?

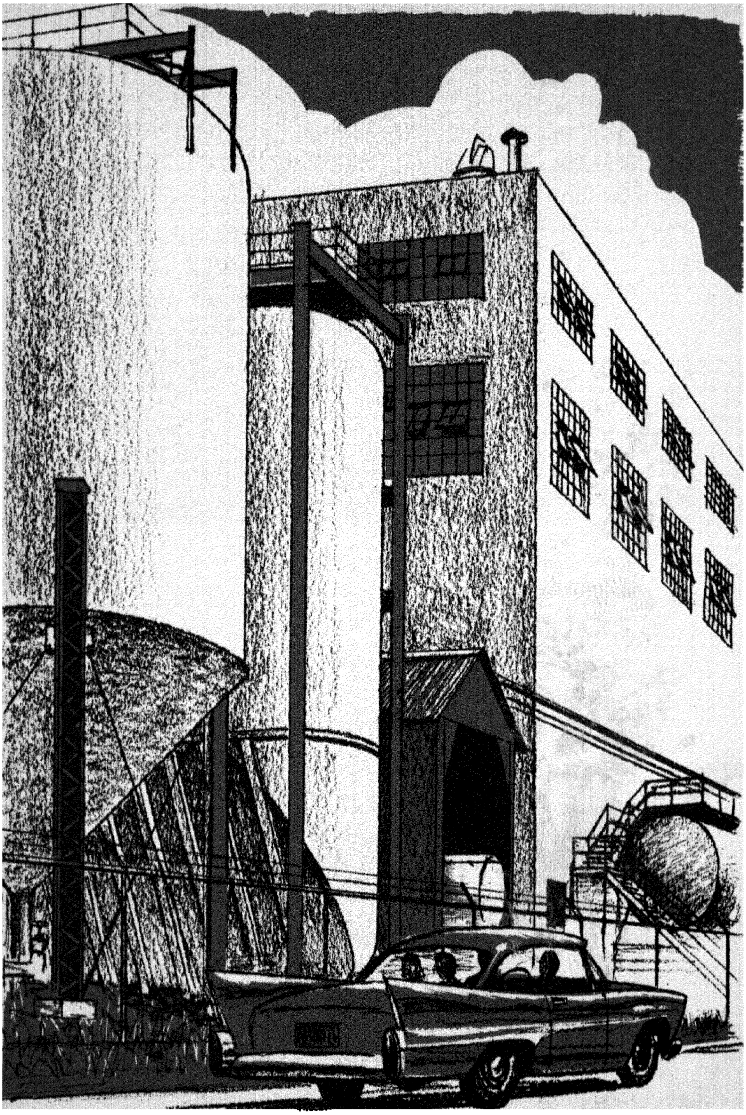
"Did you get the photos that you'll need for your article, Dad?" Randy asked. They had left the main plant of the chemical company and were heading for the phosphate plant at Carondelet.

"I picked out a bale of stuff we might use. Thank goodness that's the editor's grief—not mine!"

The car pulled into the plant parking lot. "Hey!" Sam said. "No smell!"

"Phosphate compounds aren't famous for their odors," Mr. Morrow said. "If they were, they probably couldn't do many of the jobs they do now."

"Why, Dad?" Sam asked.



They headed for the phosphate plant.

"You'll see. We'll go in and meet Dr. Freiberg, the chemist who's going to guide us around the plant."

Dr. Freiberg didn't look like the conventional picture of a scientist at all. With his brightly flowered sport shirt, natty slacks, and deep tan, he resembled a tourist fresh from the beach at Waikiki.

"Glad to know you!" he said heartily to Mr. Morrow. "Always glad to meet a writer. Confidentially, I write a little science-fiction on the side myself." He added sadly, "Never manage to sell any, though."

He shook hands with the Morrow boys and Terry. "You kids writers, too? *Children's Digest* maybe?"

Randy laughed. "We're Dad's parasites. Will we be in the way?"

"No, no!" Dr. Freiberg reassured them. "I put on my best act before a big audience anyway. Shall we start off?"

In a laboratory nearby, Dr. Freiberg showed them a beaker of the principal raw material used at the plant—phosphoric acid.

"You drink some of this stuff every week," he told his guests. Taking another beaker, he filled it with water and added a little sugar. Randy was instructed to taste it.

"Just sweet, isn't it," Dr. Freiberg remarked. "Now let me add a couple of drops of phosphoric acid. Taste!"

"Now it tastes sort of sweet and sour," Randy said. "Almost like pop without the bubbles."

"That's the ticket. Phosphoric acid is a basic ingredient in many kinds of soft drinks—especially cola drinks. That's what gives 'em their tart flavor."

The chemist said that phosphoric acid was used to make many phosphate chemicals. The calcium phosphates were made by treating lime with the acid.

"We'll see just how the phosphates are manufactured in a few minutes. First I want to show you how one of them can be used."

He took a small container of dicalcium phosphate and placed some of the white powder in a beaker. "This stuff is an abrasive. Because it's just a little softer than tooth enamel, it's used in all kinds of toothpaste. I'm going to make you some toothpaste."

"Right here? Right now?" Sam said in surprise.

Dr. Freiberg nodded. "First we'll add a couple of gums that'll serve as a binding agent for the abrasive and other chemicals."

He stirred two clear liquids into the abrasive, which he said were carboxymethylcellulose and sorbital. "Different toothpastes might have other gums—like gum arabic, for example. These two are used by one of the large toothpaste manufacturers."

Then he added another liquid with a long name which was simply an organic soap—put in the paste to kill germs. "The ad-men give these soaps fancy names, but they're *still* just soaps."

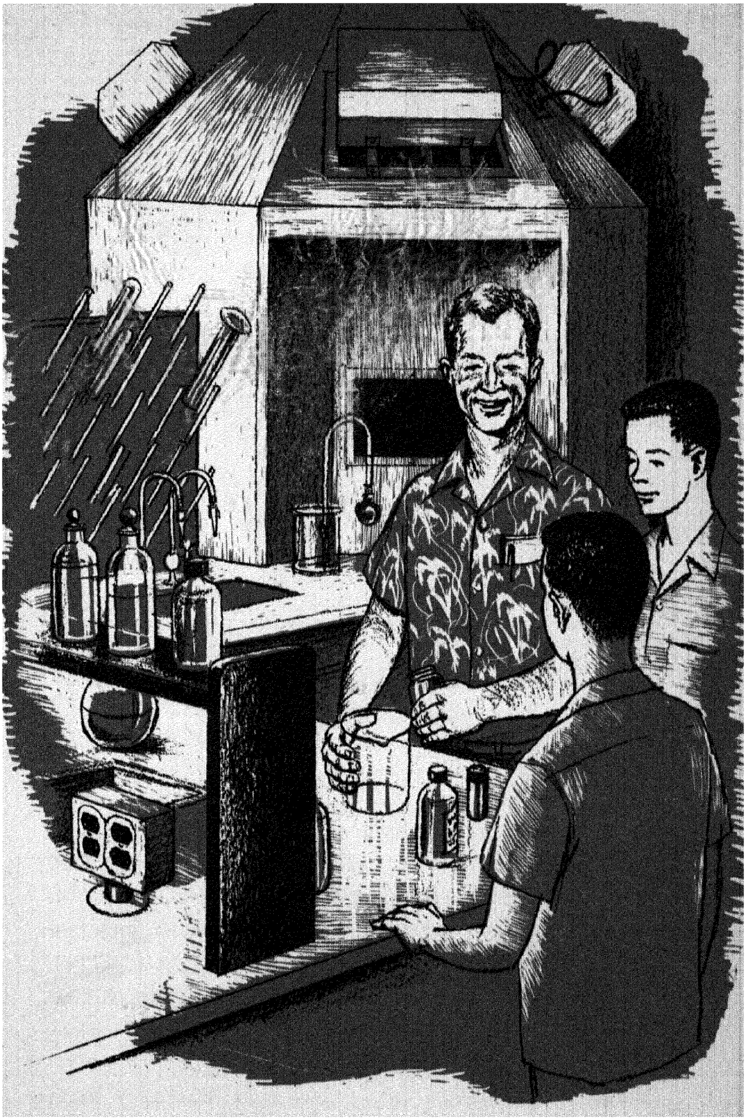
The last ingredients were saccharin, for sweetening, and a few drops of aromatic flavoring oil. Dr. Freiberg mixed everything vigorously, then produced a metal cylinder that was easily recognized as a toothpaste tube with the bottom open. The product of the experiment was poured into the tube, and the chemist folded over the end and crimped it.

"Here you are, young man," he said, handing the tube to Sam. "Your own private brand of toothpaste!"

Sam stared at the tube in awe. "Is it *really* toothpaste?"

"Taste it."

Sam unscrewed the cap and cautiously sampled the white stuff in the tube. "It tastes just like—"



"I'm going to make you some toothpaste!"

They were fascinated by the equipment.

Dr. Freiberg held his finger to his lips. "Shh! We used the formula for one of the well-known brands. Of course you recognize it. Monsanto doesn't make toothpaste, you understand, but we do make the abrasive that goes into many of the well-known kinds."

Sam clutched his tube jealously as they began to tour the plant. "My own private toothpaste!" he gloated. "Wait till I show the kids at home!"

Randy, in particular, was fascinated by the many kinds of equipment used in chemical manufacture. Monocalcium phosphate, a vital ingredient in baking powders and cake mixes, was produced in a huge spray drying apparatus. Dicalcium phosphate was used not only as an abrasive, but as a diet supplement and an ingredient in medicines.

"You can see now why it's a good thing that phosphates have no unpleasant smell," Mr. Morrow said. "No one would be interested in baked goods or dentifrices with a peculiar odor."

Dr. Freiberg told them how one engineering problem, that of transporting the fine, dustlike phosphate products, had been solved.

"The powders are mixed with a stream of fast-moving air so that they behave more like liquids than solids. They can be piped along to the storage bins or bagging machines without much trouble."

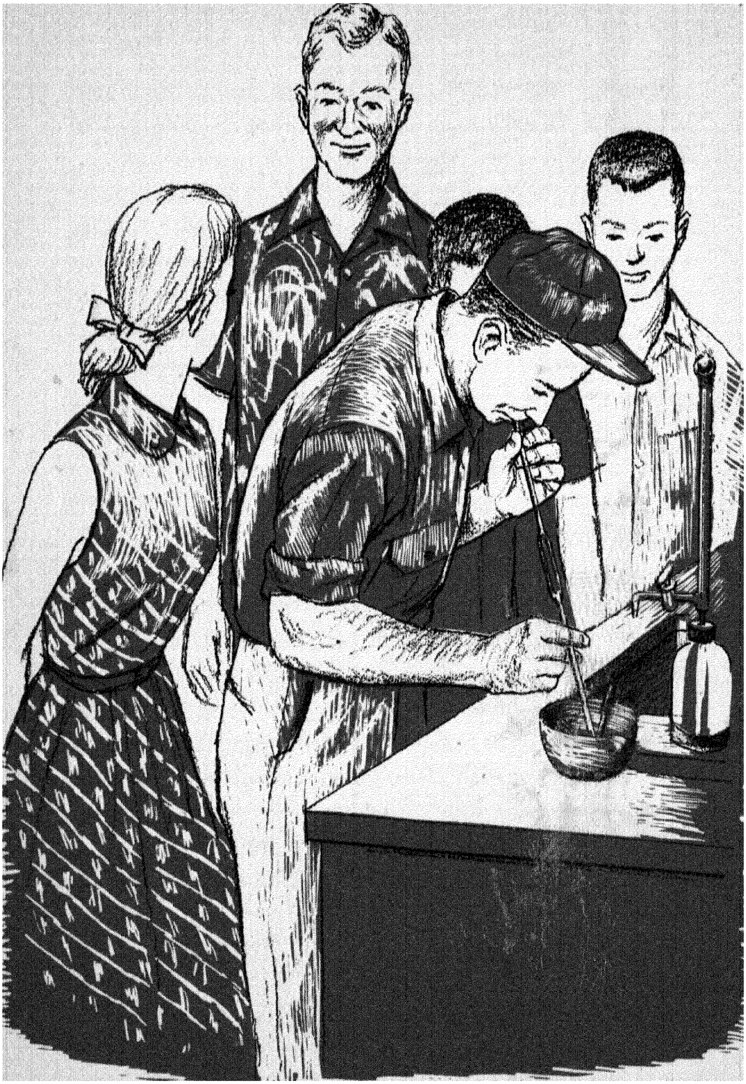
Other phosphates made by the plant included sodium and potassium phosphates, the first used in detergents, the second used in making soap, textiles, drugs, and many other products.

"Chemical technology has changed a lot in the 80-odd years that this plant has been in production," Dr. Freiberg said. "Back in the early days, things like mixing and measuring were done by hand. Now, more and more operations in chemical manufacturing are done automatically."

Terry pointed out a small lab bench in the midst of the machinery. "Don't tell me analysis is carried on here!"

"Why certainly," the chemist said. "The quality of the products is checked all along the line. We run rough analyses right here in the plant. Finer analysis work is done back in the labs in the main building. Each batch of chemicals has to meet basic requirements of purity and chemical activity or it must be re-processed. You'll find that this testing is done in all branches of the chemical industry."

"How does chemical engineering work?" Randy asked.



"Don't tell me analysis is carried on here!" Terry said.

"I mean, suppose a research team comes up with a good chemical that you want to manufacture. How do you get it into production?"

"First we'd build a pilot plant. It would be much smaller than the full-scale plant that would eventually produce the chemical on a commercial scale. The engineers in the pilot plant would design new equipment and collect data."

Some of the things the engineer would deal with included handling of materials, standard operations like grinding, mixing, filtering, and distilling, and establishing plant economics. The pilot plant engineers would work closely with the research men to determine which method of manufacture was least expensive and produced the highest quality finished product.

"Then plant engineers and design engineers would go to work on the full-scale plant. And finally, production engineers get the finished show on the road. Of course, not only chemical engineers work in our plants. Mechanical and electrical engineers make big contributions to production."

Mr. Morrow said, "And don't forget sales engineering. The person who sells chemical products is a trained specialist. He studies the customer's needs and supplies him with the product that can best fill the need."

"What kind of education does a chemist need?" Randy asked.

"A B.S. in science or an engineering degree is basic," Dr. Freiberg said, "although there are many jobs that a trained high school grad could fill. With your B.S., you could become part of a research team, or begin to specialize in the field of your choice. The beginning pay is higher for those with master's or doctor's degrees—but long-term success in the field depends on you and your abilities, not on your degree."

"I'm planning to enter the agricultural chemistry field," Terry said.

"That's an interesting field for women. Women do well as technical writers and librarians, too—besides doing lab work."

Randy said, "I've been trying to discover whether chemistry is the field for me. What do you think it takes to make a good chemist, Dr. Freiberg?"

The scientist rubbed his chin thoughtfully. "If you *like* science and experimenting, if you have curiosity and enthusiasm and patience, and if your mind is orderly and alert—chances are you'll make a good chemist or chemical engineer."

He suggested that Randy study the field and talk to his vocational guidance counselor at school to learn more about his special talents and aptitudes.

"But of course the best way to know chemistry is to work in chemistry. You won't find chemicals are mysterious after you've performed experiments with them. You'll take chemistry courses in school, but nothing beats the adventures you have in your own home lab."

"You can say that again," Terry said fervently.

"She's got a swell home lab," Randy put in with a grin.

"Then she's well along the road to a fine career. Of course chemistry isn't a lazy man's way of earning a living —no science career is. But people cut out for science need more than a paycheck. They need work that will give them a sense of personal satisfaction as well."

Before they left, the Morrows and Terry looked over a chart from Dr. Freiberg's file. It outlined the opportunities in the chemistry field:

OPPORTUNITIES IN CHEMISTRY AND CHEMICAL ENGINEERING

Industry

- Research
  - Fundamental
  - Exploratory
  - Process
  - Applied
  - Engineering
- Analysis
- Pilot Plant
- Design Engineering
- Plant Engineering
- Chemical and Plastics Production
- Process Investigation
- Technical Sales
- Product Development
- Sales Engineering
- Technical Writing
- Technical Librarian
- Petroleum Chemistry
- Metallurgy

Other Fields

- Teaching
- Patent Work
- Consulting
- Testing

Institutes and Foundations

- Petroleum Research
- Coal Research
- Gas Research
- Paper Research
- Food Research
- Agricultural Research
- Medical Research
- Biochemical Research

Government Service

- Health
- Agriculture
- Natural Resources
- Commerce
- Safety
- Defense
- Atomic Energy
- Food and Drug

The time had come to say good-bye to Dr. Freiberg. The chemist shook hands with everyone and said he hoped they had got all the data they needed.

"I'll be able to write a fine article, thanks to you," Mr. Morrow said.

"And how about you young people?" Dr. Freiberg asked. "Did this little tour make the chemical industry seem a little less mysterious to you?"

"It sure did," Randy agreed. "And I'm going to get some books on chemical engineering when I get home."

"I'm going to try out some of the new angles you mentioned in my home lab," Terry said.

"And how about this young fellow?" asked the chemist, clapping Sam on the back.

"There's just one thing I wanta do right now," Sam said. "That's test this toothpaste!"

Sam and Randy had finally packed their suitcases and stowed them in the car. The hydroponic garden with its Brussels sprouts plants was firmly wedged in the back seat where it would be safe.

"Gee, it's been a swell summer, Grandma," Randy said. "Be sure to give our regards to Terry once in awhile. And remind her to send me the formula for Bakelite plastic she promised me!"

"I will, dear."

Uncle Dan said good-bye, too, and promised to take them spelunking again next summer if they liked.

Sam pulled a long face, "But it was sure too bad about poor Forry and Harry."

Mr. Morrow asked, "Who?"

"Forry and Harry. Uncle Dan's steers. Forry won the Reserve Grand Championship at the county fair. But a

"It's been a swell summer, Grandma!"

man from a big packing house bought him and Harry . . ."

". . . And by now they must be just sirloins and prime ribs," Randy added.

Uncle Dan laughed. "The steers were raised for food, boys. We couldn't keep them for pets, you know. Don't feel bad. I'll be raising more next year. Maybe I can name two of them Randy and Sam."

"Hey! No fair!" Sam exploded indignantly.

And everybody joined in the laughter.

"It sure was a chemical summer, though," Randy said thoughtfully. "You know, maybe I *will* study chemical engineering."

"It would make a fine career," Mr. Morrow said. "Well, time to shove off!"

Everybody shouted good-bye and waved madly, until the farmhouse disappeared behind one of the rolling hills of Little Egypt. Randy asked his father to sound the horn as they passed the Chandler place, and dimly, through the chicken-house window, the Morrows could see the girl chemist wave as they sped past.

"We're going to set up a lab of our own at home," Randy said positively. "Sam, you and I are going to have a lot of fun this fall working out some of our own chemical experiments. Plastics, synthetic rubber—"

"And toothpaste," Sam said. "Lots and lots of toothpaste."

"Sam's chosen his specialty already, I see," the boys' father smiled.

"I haven't, though," Randy said. "I want to investigate all of the branches of chemistry. Foods, plastics, drugs, textiles—everything."

For a career, Randy knew, was more than a way of earning a livelihood. It was a big factor in personal happiness as well. The career he chose had to offer a challenge, it had to be important, it had to be satisfying.

And chemistry filled the bill very nicely indeed.

THE END

TESTING YOUR CHEMISTRY I.Q.

by ROBERT OAKES JORDAN

1. Many rock formations, like stalactites and stalagmites are made of: a) rock salt b) sodium carbonate c) calcium carbonate

2. Both sodium carbonate and calcium carbonate are called: a) elements b) mixtures c) solutions d) compounds

3. The substance of the earth and its atmosphere is divided chemically into: a) compounds b) mixtures c) elements d) electrons

4. Catalysts are used in chemical processes to: a) slow down the action b) speed up the action c) color the chemicals for identification d) remove the bad smell

5. There are ______________ elements in the periodic chart of elements. a) 92 b) 66 c) 100 d) 102

6. All atoms are composed of a nucleus and ______ electron rings called orbits. a) 3 b) 4 c) 6 d) only odd numbered rings e) any number

7. Active elements are those that can lose their outer orbital electrons with: a) difficulty b) ease c) fission d) a proton from the nucleus

8. In making a compound of two elements two atoms ______________ electrons in their orbital rings. a) manufacture b) delete c) evaporate d) exchange

9. Valence is the relative combining capacity of one ________________________ with another. a) atom b) electron c) compound d) mixture

10. An ion is an electrical charged atom of a ____________________ charge. a) negative b) positive c) neutral d) static

11. The term 'ph' indicates the relative position of a substance with regard to its:
a) atomic weight b) acidity c) specific gravity

12. The famous alkaline desert might be rated at a 'ph' ____________________. a) 4 b) 9 c) 7

13. In soil iron, zinc, manganese, boron, copper are called ____________________ elements.
a) trace b) binding c) compound

14. Hydroponic gardens are made up of primarily ______________.
a) sterile earth b) humus c) water and sand d) nitrogen

15. The fibers made by man are called: a) naturals b) synthetics c) coal tars d) sanforized

16. Many man made fibers are produced from ________________ products. a) plastic b) animal c) air and water d) coal tar

17. The oldest form of man made plastics were composed of: a) nylon b) cellulose acetates c) coal tars d) oil

18. Most dark or black plastics are made of: a) coal tars b) urea resins c) phenolic resins d) styrene

19. Thermoset plastics are ____________________ by heat.
a) hardened b) softened c) unaffected

20. Thermoplasts are plastics that are ________________ by heat.
a) hardened b) softened c) unaffected

21. In the group of modern plastics .... is the one that is unaffected by relatively high temperatures.
a) nylon b) mylar c) teflon d) plexiglas

22. The word plastic means: a) a material made by man b) a material that can be a substitute c) a material that can be molded to a specific shape

23. Phosphorus has a wide use in the home today in the .... products.
a) food b) paint c) plastic d) detergent

24. A solution is the act of dispersing a gas, liquid, or solid in another gas, liquid, or solid .... chemical change. a) without b) with c) to show

25. A tincture is usually a mixture of some medical substance with: a) water b) soda c) alcohol d) mild acid

26. Table salt is a compound of two otherwise poisonous elements one of which is sodium and the other:
a) fluorine b) hydrocine c) chlorine

27. Casein as used in some forms of plastic is obtained from: a) milkweed b) soybeans c) coal tar d) cows milk

28. When the atoms of a substance are rearranged to form a molecule of the same substance but of greater weight this process is called: a) condensation b) evaporation c) filtration d) polymerization

29. The simple unfused form of a compound is called a:
a) protein b) monomer c) polymer
d) prolamine

30. The agent added to plastic compounds to give them flexibility is called: a) a solvent b) a resinoid c) a plasticizer d) a lignin

31. The weight per unit volume of a substance is called its:
a) mass b) density c) specific gravity
d) velocity

32. The extensive properties of a particular piece of substance are weight, dimension, and:
a) mass b) specific gravity c) volume

33. Most measurements of weight, size and volume in chemistry are made in the ________ system.
a) English b) Standard U.S. c) B.T.U.
d) Metric

34. The first wonder drug is called: a) aspirin
b) penicillin c) castor oil d) auriomicin
d) salvorsan (606)

35. Tracer isotopes are used to ________ the process of certain compounds and elements in plant and animal growth. a) destroy b) chart c) speed-up
d) slow-down

36. Rust on a piece of iron is caused by: a) nitrogenation
b) water c) foreign acids d) oxidation

37. A piece of iron that rusts ________ in weight.
a) increases b) decreases c) stays the same

38. A chemical change in any substance or group of substances is called: a) distillation
b) an action c) a reaction d) fusion

39. The reactions any substance goes through is its:
a) velocity b) chemical properties
c) change of state

40. All matter is classified into two groups of substances: one is heterogeneous (mixtures) and the other is ________ (pure substances).
a) homogeneous b) compounds c) solids

ANSWERS TO *TESTING YOUR CHEMISTRY IQ*

1. c
2. d
3. c
4. b & a
5. d
6. e
7. c
8. d
9. a
10. a & b
11. b
12. b
13. a
14. c
15. b
16. a & d, b & c
17. b
18. c
19. a
20. b
21. c
22. c
23. d & a
24. a
25. c
26. c
27. d
28. a
29. b
30. c
31. b
32. c
33. d
34. a
35. b
36. d
37. a
38. c
39. b
40. a