What MAKES UP *the* WORLD

By ELIZABETH LeMAY HAYES

What
MAKES UP *the* WORLD

UNIFORM WITH THIS VOLUME

HOW THE WORLD BEGAN
The Story of the Beginning of Life on Earth

HOW THE WORLD GREW UP
The Story of Man

HOW THE WORLD IS RULED
The Story of Government

THE WORLD OF ANIMALS
The Story of Animals

THE GARDEN OF THE WORLD
The Story of Botany

HOW THE WORLD IS CHANGING
The Story of Geology

THE WORLD'S MOODS
The Story of the Weather

THIS PHYSICAL WORLD
The Story of Physics

OTHER WORLDS THAN THIS
The Story of Astronomy

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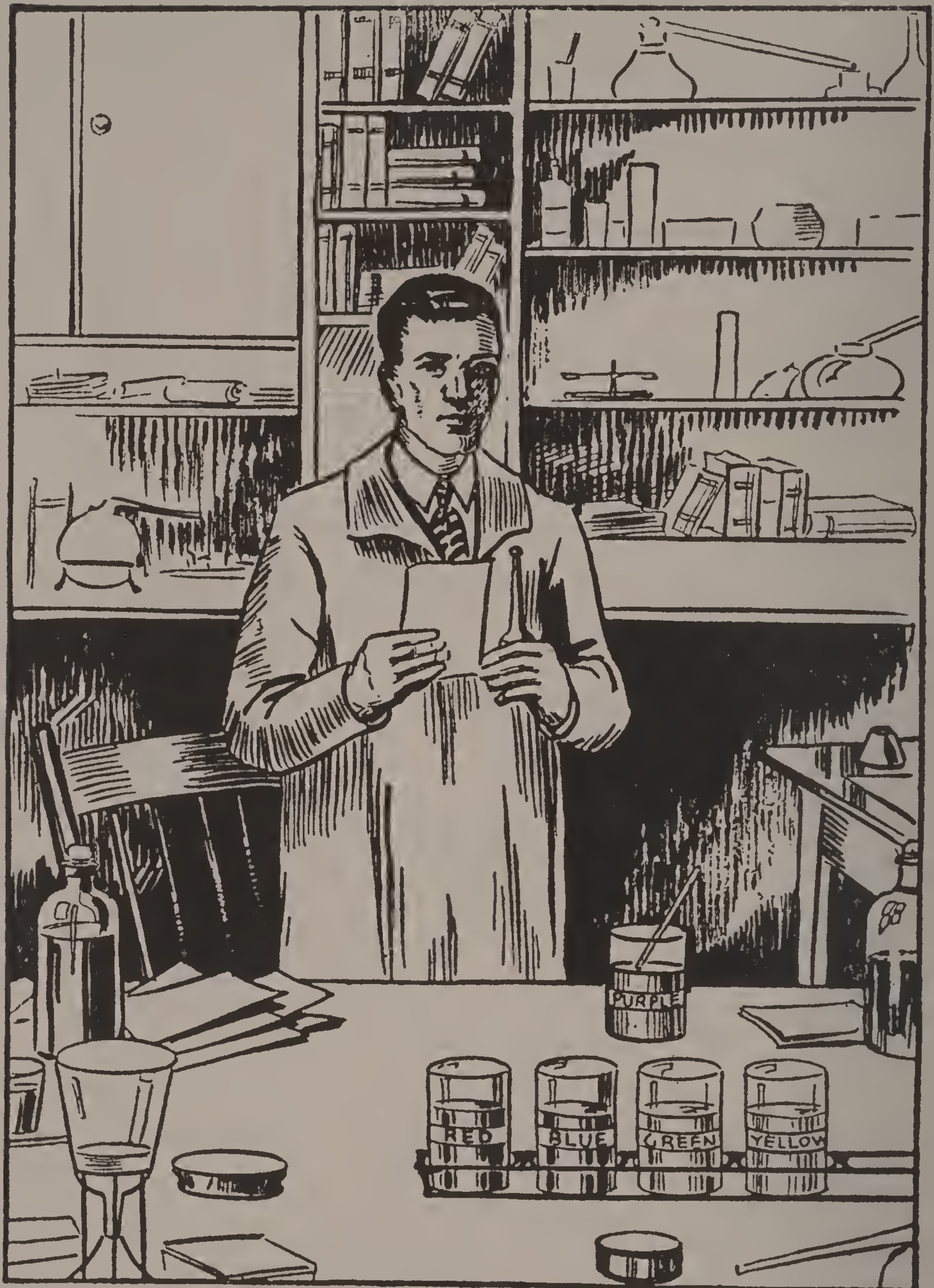
CHICAGO

Publisher's Note

This book presents in popular form the present state of science. It has been reviewed by a specialist in this field of knowledge. An excerpt from his review follows:

> *"What Makes Up the World tells something of the story of the transformation of matter—the story of chemistry in a very attractive and simple way. It should interest and stimulate children of ten years of age or older."*

Signed: JULIUS STIEGLITZ
Chairman of the Department of Chemistry
The University of Chicago



The chemist makes dyes of many colors out of sticky black coal tar

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By

ELIZABETH LEMAY HAYES

Drawings by
CHESTER THOMAS

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THE PUZZLE OF

FIRE, WATER, AIR AND EARTH

LONG ago, before men had decided whether the world was round or flat, and before they even suspected that it might be traveling around the sun instead of the sun around it, when the fastest ships were rowed by galley slaves and the speediest vehicles were horse-drawn chariots, men wondered what the world might be made of.

They had no microscopes then with which to examine things; none of the intricate and precise scientific equipment with which such problems are investigated nowadays had been invented yet. But they observed with their eyes and reasoned with their minds.

They saw earth and air and water. Everything else seemed to grow out of these and return again into them. Plants grew in the earth, using the air and water. Animals ate the plants and each other, and men ate both plants and animals. Both vegetable and animal matter eventually became earth again.

But they also saw fire, which was not earth or air or water. They could not understand fire. They decided that it, too, must be a thing apart and different.

The universe, then, they said, must be made of fire, earth, air and water. These were things, they thought, that could not be taken apart into other things. If any one of them were lacking, the world and all upon it could not exist at all.

They were almost right, *in their way,* for they could not divide the earth, or air, or fire, or water into anything else. But centuries later, as the race of men grew wiser, and by long and patient effort learned a little more, scientists discovered that earth and air and water could be taken apart. They found as many as ninety different materials went into the making of earth, air and water. Every few years another such material is discovered. And the end is not yet in sight as science progresses.

But fire, which puzzled men most of all, only began to be rightly understood about one hundred and fifty years ago. And the understanding of fire helps to explain many mysteries about what the world is made of.

CHAPTER I

THE FIRE MYSTERY

THE reason that fire remained a mystery for so long is that men thought it was a *substance*. They thought it was a sort of luminous, hot stuff that poured out of things as they burned. They came near to being right, but they were wrong.

What is fire?

Fire is not a material substance. It is *something happening*. Now just what is it that happens when something—say a candle—burns? If you watch a burning candle, you will see that it slowly becomes shorter—that is, the wax is being consumed. You will notice also that heat and light are being produced. But there are other things going on that you cannot see.

Suppose the candle were set in a shallow bowl of water, and a large glass jar were placed over it to prevent any fresh air from reaching the flame. Now what happens?

The candle burns just as usual for a moment. Then the flame suddenly shrinks, quivers, and goes out. Immediately the water rises in the jar, and if there was only a little water in the bowl there may be a sucking and gurgling noise as both water and air are *pulled* up into the jar!

Now what has happened here? Why did the candle go out? Why did the water rush up into the jar?

We have already noticed that the flame uses up the wax of the candle. It uses up something else as well. This something else is a part of the air. When the flame had used all of the air it could, it went out, and the water came in to take up the room in the jar which the used air had occupied.

But the candle didn't use all of the air in the jar. It used less than one-fifth of it. Why didn't it want the rest? For the same reason that you don't eat the apple core. Part of the apple is good for eating and part isn't. Part

The flame quivers and dies and the water suddenly rushes up into the jar of the air is good for burning and part is not. The part that is not is left in the jar.

Now the part of the air that is good for burning is called *oxygen*. When a candle burns, the wax is melted and changed by the heat into a vapor, and this vapor and the oxygen rush together with such enthusiasm and excitement that light and heat are produced. If the oxygen is taken away (as in the jar when the oxygen was all used up) the candle goes out.

Why does a candle have a wick?

If the burning of a candle is vapor from the wax combining with oxygen from the air, what has the wick to do with it? Why doesn't the wick burn off right down to the wax? Or, if the wax is all that is needed for the flame, what is the wick put in the candle for?

If there is any doubt in your mind that the wick is needed, just try to light the wrong end of the candle, where the wick does not stick out of the wax. The heat of the match flame will melt the wax, which will begin to drip, but it will not take fire.

The wick is there to help the wax to turn into vapor so that it can combine with the oxygen. It helps the wax up to where the oxygen can get at it.

Now why doesn't the wick burn right off and leave just a little puddle of wax in the top of the candle? If you look closely you will see that a candle flame is made of two colors. The inside of the flame is blue, and the outside of it is yellow.

The hottest part of the flame is this yellow outside part, because, being outside, it can get the most oxygen. The wick doesn't burn off the candle for the same reason that the flame isn't yellow all the way through. The part of the wick inside the flame cannot get enough oxygen to burn itself up.

The candle flame is blue and yellow

Watch someone who knows how to build a fire well. He will always put paper or wood shavings under the wood, and light the paper or other light material first. The heat from the burning paper will start the wood burning. This is because wood must be heated in order to form the gas which unites with the oxygen to make the flame. The necessary heat is supplied by the burning of the lighter materials—paper and shavings.

For the same reason it is necessary to light the wick of the candle so that the heat from the burning wick can melt and vaporize the wax.

Why does fire like a draft?

A fire in the fireplace won't burn well unless the chimney "draws." A fire in the furnace will not start up brightly unless there is a "draft." A bonfire or a campfire will not be a success unless the person who built it knew enough to arrange the sticks so that the air will come through it freely from underneath.

Now it stands to reason that if fire is something combining with oxygen, then the more oxygen that is furnished, the more light and heat there will be. If the air is very still, only the oxygen in the air that is near the fire is handy. But if the air is in motion, as it is when the chimney draws, or the draft in the furnace works well, then there is a large and steady supply of oxygen coming to combine with the fuel, and the fire burns brightly.

It is true that the candle flame doesn't need much of a draft, but that is because the candle flame is only a very tiny fire. The little cloud of burning gas which is the flame can very easily be blown away from the candle. The same wind that blows the flame off the candle cools the candle enough so that no more vapor is formed, and there is nothing to unite with the oxygen, and therefore no flame. This is what happens when you blow out a candle.

Why does water put out fire?

The candle went out when shut up in the jar because there was no more oxygen left in the jar. But why does throwing water on a fire put it out as long as there is still plenty of oxygen in the air around it?

The water does two things to the fire. It shuts away the oxygen from the fuel so that, like the candle in the glass jar, the fire lacks the oxygen to keep on burning. But water also cools the fuel, so that, like the candle when you blow it out, it is no longer hot enough to go on making gas to unite with the oxygen to form the flame.

There are other ways of putting out fire than by pouring on water. A good way to put out a fire out-of-doors is to shovel sand or dirt on it. The sand or dirt shuts the fuel away from the air, and puts out the fire by depriving it of oxygen and starving it to death.

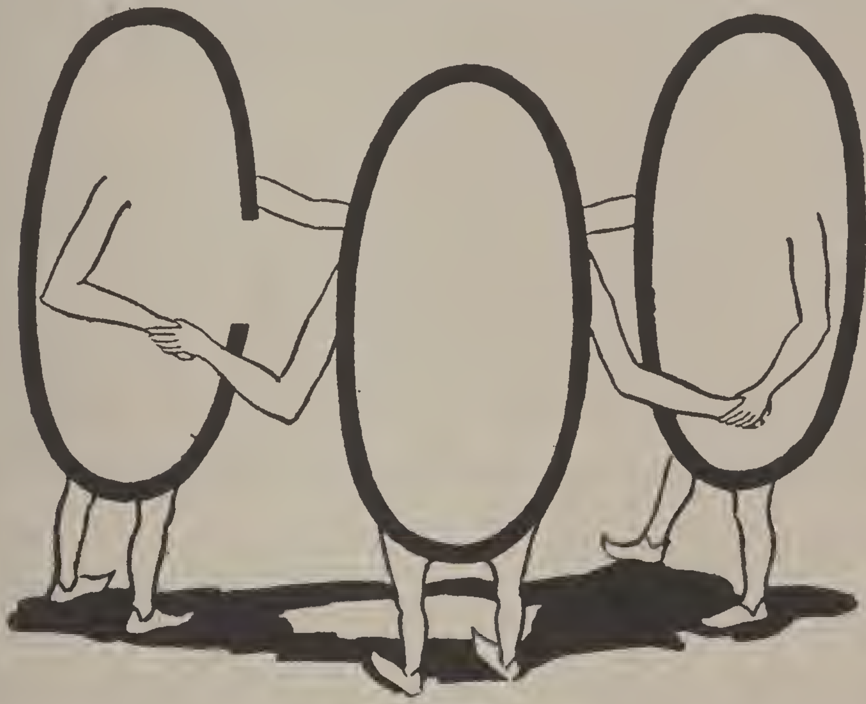
In the same way a fire may be stifled by throwing a piece of rug, or a coat over it. Even things that burn easily by themselves will put out fire by shutting the air away from it.

What becomes of the oxygen that goes into the fire?

Now the candle in the jar used up quite a bit of oxygen, as the water rising in the jar proved. What became of it? Once upon a time it might have been supposed that the fuel was actually destroyed in the burning, but now we know that nothing is ever really destroyed. It is merely transformed into something else.

Most of the things we burn are made of a material called *carbon*. The white wax of the candle is mostly carbon. Coal is almost pure carbon. Wood is largely carbon. Carbon is generally a solid stuff, but it is also found in many vapors or gases. That is what happens when the candle burns. The wax vapor that combines with the oxygen to make the candle flame contains carbon.

When the carbon and oxygen combine, they form a gas that you can neither see nor smell.



One atom of carbon always takes two atoms of oxygen to form a molecule of carbon dioxide

Its name is *carbon dioxide,* which means that each carbon atom has two hands, and takes an atom of oxygen by each hand. This little ring-around-the-rosy formation is neither carbon nor oxygen, but a molecule of the gas carbon dioxide.

One of the curious things about this new gas, carbon dioxide, is that it is very willing to dissolve in water, just as salt or sugar will. The carbon dioxide which was formed as the candle burned in the jar went into the water, and the water rose to take the place of the oxygen which had been in the jar.

There is always some carbon dioxide in the air. In large quantities in a shut-up room it makes people feel drowsy or even gives them headaches. But there is very little danger of its occurring in a quantity capable of doing much harm to you.

Sometimes, however, when a stove or a charcoal burner is burned in a closely shut-up room, the oxygen grows scarce and the carbon atom can find only one atom of oxygen to join hands with. The result is carbon mon-oxide, which is a deadly poison gas, and very dangerous because it can neither be seen nor smelled.

It is very important that a room with a fire in it should be well ventilated, and that an automobile engine (which burns gasoline, which is largely carbon) should never be started in a garage with closed doors, lest this poisonous gas should be given a chance to do harm.

Why does a match light when you strike it?

If a match would light only when exposed to a flame, there would be nothing extraordinary about it. But neither would it be useful. There are many things which will take fire when held to a flame; but a match ignites when it is scratched on something rough.

Rub your finger rapidly for several seconds on something slightly rough, such as a piece of woolen cloth. Soon the end of your fingers will feel noticeably warm. You have produced heat by *friction.*

The head of a match is made of a mixture in which there is a material called *phosphorus.* Pure phosphorus is so eager to combine with oxygen that it must be kept under water to keep it from bursting into flames.

The phosphorus used in the match head is combined and mixed with other substances so that it will not ignite until someone wants it to. When a match head is drawn rapidly over the sandpaper on the box, the friction produces a small amount of heat. This heat is sufficient to cause the phosphorus of the match head to begin combining with oxygen. The flare of the match head is enough to cause the wood of the match stick to begin to burn.

Before people learned about phosphorus and how to use its eagerness for oxygen in lighting their fires, lighting a fire was a very difficult and tiresome and disagreeable task.

Phosphorus is not the only substance that is very fond of oxygen. Dynamite and T.N.T., as well as fire crackers and Fourth of July fireworks, all contain substances so eager for oxygen that they will seize it suddenly and in large quantities at the first opportunity that offers. And that is how an explosion is made.

Why doesn't everything burn?

Why doesn't everyone like spinach? There are, fortunately, a number of things that don't care for oxygen and won't go half way to meet it. And oxygen doesn't care for them.

Then, too, there are many things that don't want any oxygen because they already have all that they can carry. That is the reason the carbon dioxide will not burn.

There is a material called asbestos, for instance, which is really a kind of stone. But it doesn't look like stone, for it can be made into cloth. The important thing about asbestos is that it absolutely will not burn, any more than stones will burn in a bonfire.

Because asbestos will not burn it is made into many useful things. Firemen wear gloves made of it, so that they need not burn their hands as they work to put out fires.

Of course, asbestos is only one of these nonburning substances. More and more of them are being used, nowadays, to make our homes and cities safe from the peril of fire.

But there are also many things which will burn, and which we use every day, without ever seeing them catch fire.

Just as some things, a match head, for instance, catch fire much more easily than others, so there are many things which can be burned, but only with great difficulty.

All metals can be burned. Yet our homes are heated with iron furnaces, and our food is cooked on the stove in aluminum saucepans and iron frying pans. Yet you never see these metals on fire.

A great amount of heat and a great quantity of oxygen are necessary for the burning of such substances as these metals. The fire which burns so furiously in the furnace on a cold day is not hot enough to melt the iron of the furnace, to say nothing of burning it. Therefore, so far as our everyday needs are concerned, the common metals which we use are safely considered to be fireproof.

CHAPTER II

FIRE'S COUSINS

EVERYONE has frequently seen the red or brownish scales of rust on iron or steel that has been left where air, particularly moist air, could get at it. Rust is so common a thing that we forget to wonder about it.

What is rust?

But common as it is, it is rather wonderful. For when we see a rusty nail, for instance, we are seeing the same thing that we see when we look at a bonfire.

In a fire, a part of the fuel is combining with oxygen to form carbon dioxide. In the nail, the iron itself is combining with oxygen to form *iron oxide,* which is usually called rust. But these two processes are not at all alike to watch.

The difference is that in the bonfire the combination is taking place so rapidly that light and heat are formed, and the effect is quite splendid to look at, and pleasant to feel from a little distance. But the rusty nail is carrying on the same process so slowly that there is no light, and no heat that anyone can feel. The iron is taking hundreds of times as long to do the very same thing.

One of the reasons we know that rusting iron is really taking oxygen out of the air and combining with it to form the rust, is that a piece of iron, allowed to rust all the way through, weighs quite a little more than the same piece of iron before the rusting process started. This is true because the weight of the rust equals the weight of the original iron, plus the weight of all the oxygen which it has taken from the air in becoming rust.

Why do we breathe?

If the question, "why do we breathe?" were answered "so that we may rust," it would seem very silly indeed. Perhaps the answer "so that we may burn" would seem a little less ridiculous and be a little nearer the truth.

What happens when we breathe? We pull some air down into our lungs. In the depths of our lungs the oxygen from the air is absorbed by the blood. The blood carries the oxygen supply to where it is needed to burn waste products, and to convert the food which we have eaten into energy. The oxygen and the food combine in our blood in a sort of a slow fire, which does not produce light, but which does produce heat and energy, or power.

The air in our lungs, from which the oxygen has been taken, and to which some carbon dioxide has been given back, is pushed out of the lungs by the action of the breathing muscles, and we are ready to take another breath and do it over again.

Now when something has been combined with oxygen, we say that it has been *oxidized*. When a candle burns, the carbon in it is oxidized to form carbon dioxide. When iron rusts, it is oxidized, and the result is iron oxide. When we breathe, certain carbon materials (for most of the food we eat is mainly carbon) are oxidized to form carbon dioxide, which is carried out with our outgoing breath. The heat and energy formed by the oxidizing process remain behind in our bodies to warm them and furnish the power for moving and living. The warmth of our bodies is proof that we are, in a sense, furnaces in which a kind of fire is burning.

How does the firefly work his lantern?

The firefly, and certain other insects and simpler forms of life, know a trick or two that man hasn't quite figured out yet. Possibly when we do find out how to make light in the firefly's way it may revolutionize our methods of lighting our cities and houses.

The remarkable thing about the firefly's lighting arrangements is that they produce the most economical form of light known. It is a light without heat. Every way man has of making light creates heat too, and wastes a lot of energy doing so. Hold your hand near an electric light bulb that has been burning for a few minutes and you will feel the heat that is going to waste.

But although we have not yet learned how the firefly does it, this much we know—the process requires oxygen, just as burning does.

The oxygen, which the firefly takes out of the air, is carried in the blood to where it is needed, just as ours is. But the firefly needs the oxygen for one more purpose than we do—he uses it to light his lantern.

Why does a rotting log glow in the dark?

If you have ever walked through the woods at night, and suddenly come upon a mass of pale, greenish light in the darkness, you may have thought, just for a moment, that you were seeing a ghost.

If you investigated your "ghost," however, you probably found it was a rotting log. But for a rotting log to glow by itself in the dark is sufficiently uncanny.

In the first place, the log is decaying. This process is very much the same thing as the rusting of a piece of iron, with this exception: while the rusting of iron is a simple process involving only the iron and the oxygen of the air, the decaying of animal or vegetable matter is much more complex because so many more materials are involved in the process.

Whereas iron is made of just one thing—iron

—animal or vegetable matter is made of very complex arrangements of a number of things. Furthermore, while iron and oxygen carry on the process of oxidation all by themselves, there are a number of fungi and bacteria willing and eager to help animal or vegetable matter decay.

That is what is happening in the case of the glowing log. In the first place, it is oxidizing. In the second place, a fungus has settled down to help the work of decay along. And in the third place, this fungus, for unknown reasons of its own, is manufacturing a material which is also oxidizing. It is this stuff manufactured by the fungus which is burning with a very slow fire. This slow fire produces carbon dioxide just as the candle does, but much more slowly. It doesn't produce any noticeable heat, but it does give off enough light to startle one in the woods on a dark night.

What becomes of the carbon dioxide?

When you watch the solid wax of the candle disappearing into the flame, or a great log in the fire dwindling away to a few ashes, it may be hard to believe that nothing is being destroyed and lost. It is because the carbon dioxide (as well as some other oxides) into which the solid matter of the candle or log is being transformed is invisible. A thing is no less real for being invisible. Take air, for example. It is very real, as anyone would soon find out if he tried to get along without it.

We might think that with all the fires in the world producing carbon dioxide, and all the animals in the world, men included, giving it off with every breath, in the course of time the world would be full of carbon dioxide and there would be no free oxygen left.

And indeed, this could happen, in the course of time, were it not for one very important thing in nature's scheme of economy. Plants differ from animals in a number of very striking respects. One of them is the way in which they can manufacture their own food.

Plants take in carbon dioxide from the air, and, with energy which is filtered out of sunshine by their green coloring matter, they separate the oxygen from the carbon. They give back the pure oxygen to the air, and use the carbon to build up their own tissues.

Since animals cannot perform this trick, they have to get their food by eating the plant, which made it from the carbon dioxide, or by eating another animal, which ate the plant which "ate" the carbon dioxide.

All living things, both vegetable and animal, are made largely of carbon. When we eat lettuce, or spinach, or any vegetable or cereal, we are eating carbon which the plant itself extracted from the carbon dioxide of the air. But when we eat beefsteak, we are eating carbon which the steer took in in the form of grass, and which the grass took out of the air.

So we may imagine these things—carbon and oxygen, and many other materials as well, changing about from one combination to another, but never destroyed.

CHAPTER III

WATER

LONG ago, wise men would have laughed at this question and replied that water was —water. It could be frozen into ice; it could be vaporized into steam, but whether solid, liquid or gas it was still water. But of course, they did not have electric currents at their disposal, with which to take water apart and so find out what it is made of.

What is water made of?

But modern scientists can do this. An electric current is made to pass through the water. As it does so, a gas is seen to bubble up from the point where the electricity enters the water, and another gas from the point where the electricity leaves the water. One of these gases is oxygen: the very same stuff that is necessary for fire, for breathing, for rusting—all oxidation processes, as you know.

The other gas, of which there bubbles up just twice as much as of oxygen, is called *hydrogen*. Hydrogen is a very light gas, much lighter than air, which is used in balloons and airships and other lighter-than-air craft. It has one great disadvantage for this purpose. Although it is the lightest gas known, and therefore has the most lifting power, it is very willing to unite with oxygen, and burn, or explode. Many fatal accidents have happened to hydrogen-filled airships because of hydrogen's fondness for oxygen.

When an electric current is passed through water, oxygen and hydrogen come up in bubbles

If the water is weighed before it is separated into these two gases by the electricity, and the gases are carefully captured and weighed, it is found that the gases, together, weigh exactly as much as the amount of water which has disappeared in the process.

Why won't water burn?

We know that fire is only oxygen and some other substance combining with such rapidity and enthusiasm that light and heat are created.

And hydrogen is one of the best fuel gases known. Now if water is made of these two gases, *why can't we burn water?*

Why didn't the candle burn the carbon dioxide in the glass jar when the oxygen was gone? You will recall that in making carbon dioxide, each carbon atom took two atoms of oxygen by the hand, so to speak. The oxygen, held by the carbon, was no longer free to join with more carbon, and therefore there could be no more burning.

In the case of water, each atom of oxygen has joined itself to two atoms of hydrogen. Now there are very few things in the world that are as devoted to each other as these oxygen and hydrogen atoms. Consequently, being so well satisfied with each other, neither the oxygen nor the hydrogen is willing to let go of the other in order to combine with something else. Since burning is the combination of oxygen and another substance, water will not burn.

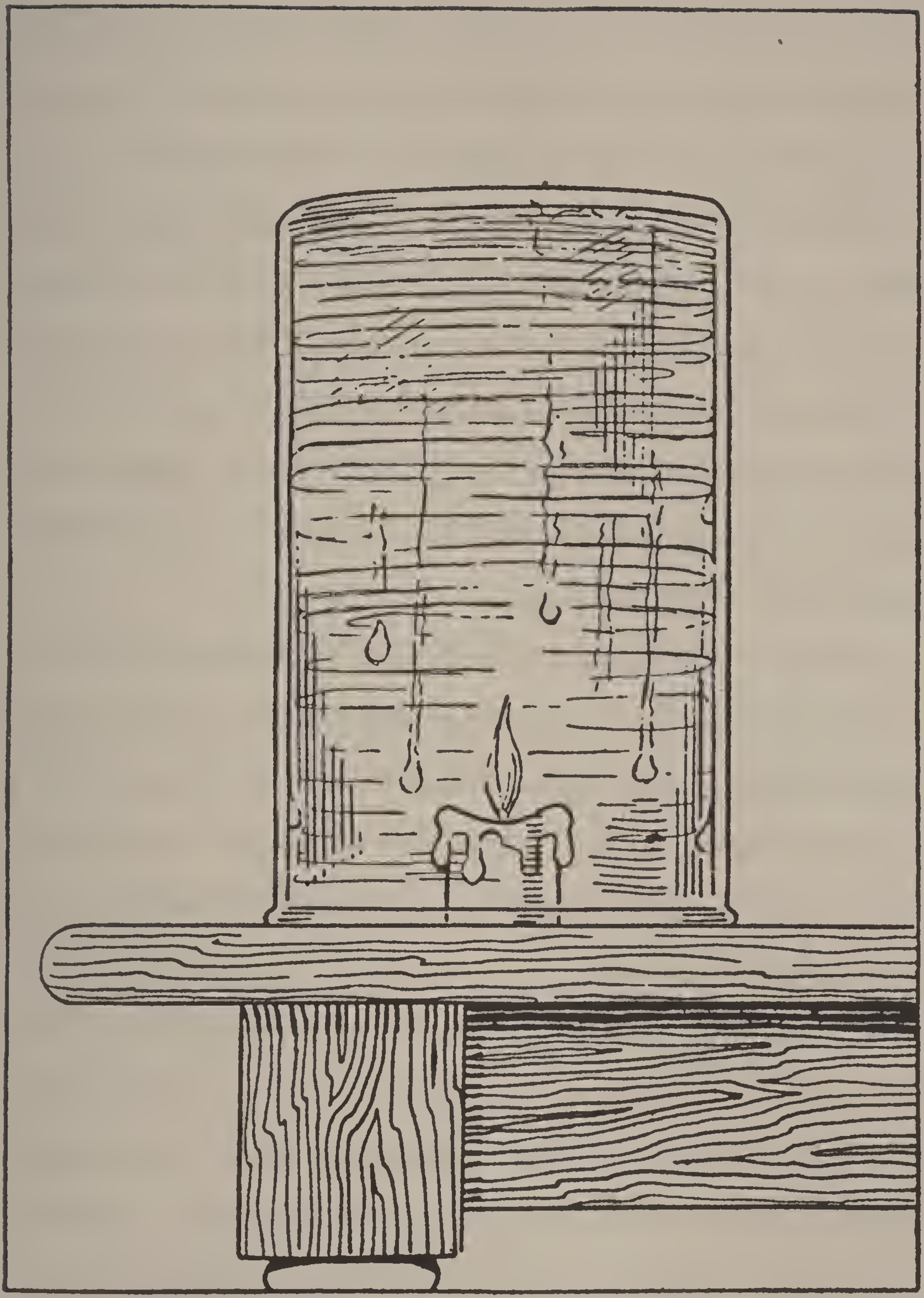
Sometimes, however, something does happen to cause the oxygen and hydrogen to let go of each other. If a few drops of water are sprinkled on a very hot fire, the exceedingly hot carbon in the fire may be so greedy for oxygen that it will actually snatch the oxygen away from the hydrogen. In that case, the hydrogen will immediately burn up too.

But that cannot be called water burning, for the water must cease to be water and become the two gases before the burning happens.

Can fire have water in it?

Carbon dioxide is carbon and oxygen in combination. Water is hydrogen and oxygen in combination; and if we want a longer name for it we can call it hydrogen oxide.

When the candle was burned under the jar, something else happened which wasn't mentioned before because there was enough to talk



When a candle is burned under a jar, water condenses on the inside of the glass about without it. As the candle burned under the jar, the glass clouded up, because a deposit of water vapor formed on the inside of the jar.

We can get the same effect by holding a cool glass over the spout of the tea kettle when there is steam coming out, or we can find it on the window panes when the air inside is warm and moist, and that outside is cold. It is just water which the air carries until it finds something cool to put it down on.

But where did the air in the glass jar pick up this water? We might suppose it came from the bowl of water in which the candle was sitting. But if there is no bowl of water at all the water vapor will gather on the glass while the candle burns inside.

We must remember that, while the wax of the candle is largely carbon, it is not *all* carbon. There are various other things in the wax, and one of them is hydrogen. When the candle burns, the carbon oxidizes to form carbon dioxide and the hydrogen oxidizes to form hydrogen oxide, which, of course, is water. The water is formed as a vapor in the air, and the air deposits it on the cooler glass.

What happens when hydrogen meets oxygen?

Suppose a jar of oxygen and a jarful of hydrogen were mixed together. What would happen? Would we have a jarful of water, just a jarful of mixed gases, or an explosion?

If the hydrogen and oxygen were just quietly put together, nothing would happen at all. There would be a jarful of mixed gases. Since both of these gases look like air, the mixture would look like air, but it would not be air.

But if anyone were careless enough to let this mixture of gases come into contact with a flame, or even the tiniest spark, something would happen immediately. There would be a tremendous explosion.

But suppose the hydrogen and oxygen were introduced to each other in a different way. Suppose the hydrogen were allowed to come out through a small jet, like a gas jet, and burn in the air, thereby taking the oxygen out of the air as it wanted it.

The result would be a small, colorless flame producing a great deal of heat. If a glass bell were arranged above this hydrogen flame, water would be seen condensing upon the glass, and finally rolling down in drops. Burning hydrogen produces hydrogen oxide, and nothing else. When hydrogen is burned, it might be said that the smoke and ashes are water.

What is hard water?

Of course we might say that water is hard when it is frozen solid. But that is not what is generally meant when we speak of water which is "hard."

The water which is produced by the hydrogen flame is pure water—that is, it contains nothing but hydrogen and oxygen. But the water we daily drink and wash in is not manufactured by a hydrogen flame. It comes from springs, wells and lakes. It seeps through rock and sand before it is finally brought to us by pipes to flow out through our faucets.

While it is pure enough so that it is good for drinking, it has other things in it besides hydrogen and oxygen.

When rain falls, it absorbs some carbon

dioxide out of the air. As the rain water seeps through limestone under the ground, this carbon dioxide helps the water to dissolve some lime. Other mineral matter is dissolved while the water is underground.

All these things help the water to taste good, if there is not too much of them. The chances are that we should find the pure water produced by the hydrogen flame a little flat to taste because of its very purity.

But if water has a little too much of this stony material, it makes itself disagreeable in a number of ways. For instance, the tea kettle in which such water is heated acquires a thick coating of greyish yellow stony stuff on the bottom and sides. This happens because the carbon dioxide was holding the lime dissolved in the water. When the water was boiled, a good deal of the carbon dioxide bubbled away, and a corresponding amount of lime was dropped on the bottom of the kettle.

But the most inconvenient thing about the "hard" water is the way in which soap behaves in it. If we take two bowls, one of a soft water such as rain water, and one of a hard water containing a good deal of lime, and with a good cake of soap wash our hands first in one bowl and then in the other, we observe a great difference between the two kinds of water.

In the soft water the soap will lather up freely. In the hard water it will hardly lather at all. We notice little white curds of soap floating in the hard water, but they will not make soap suds. Why is this?

The soap, in hard water, combines with the mineral matter to form these curds. If we put enough soap in the hard water we can get almost as good a lather as with the soft water; but this strong mixture of soap and mineral-laden water is very harsh on the skin.

In the soft water, the soap is offered nothing to combine with except the dirt on your hands, which it does quickly and efficiently.

Chapter IV

AIR

WE ALREADY know that air has oxygen in it. We also know that it has more in it than oxygen. When the candle burned in the jar, less than one-fifth of the air in the jar was used up in the burning. If the candle had been able to use every last trace of oxygen, and the carbon dioxide formed could have been taken out of the jar without disturbing anything else, about four-fifths of the amount of the original air would have been left in the jar.

What is air made of?

We know one thing about this gas remaining in the jar after the oxygen has been removed from the air. We know that the candle will not burn in it. In other words, this gas will not *support combustion.*

If we were to put a live mouse into the jar, he would make no better of the situation than did the candle. A gas which will not support combustion will not support life, for, as you know, both are oxidation processes.

This gas, which is called *nitrogen,* is not nearly so eager to combine with things as is oxygen. In the atmosphere it is what we call an *inert* gas, which means that it is inactive.

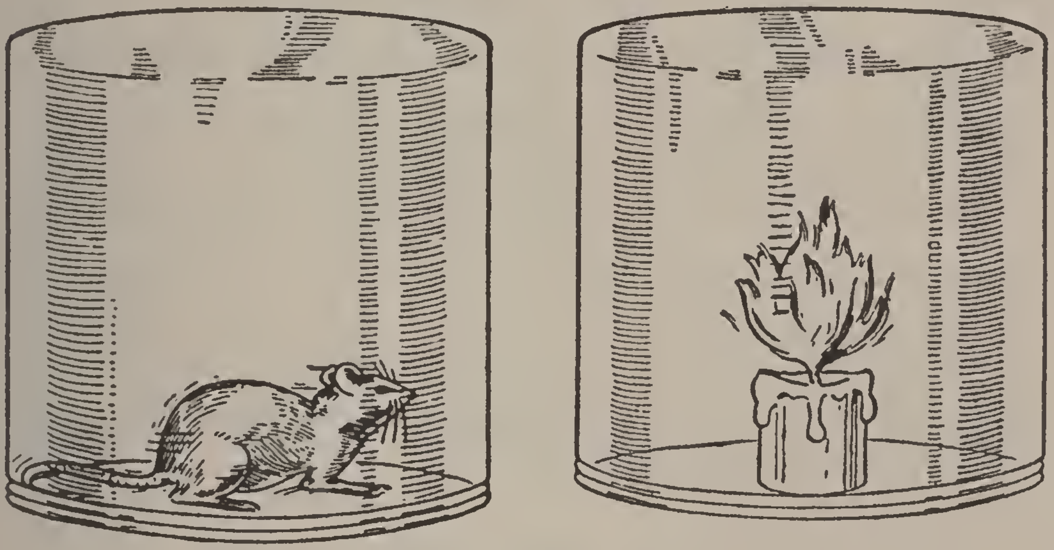
Air is approximately one-fifth oxygen and four-fifths nitrogen. Scientists, with their fine instruments, can find small quantities of other things in the air. There is always water in the air in the form of vapor. There is always a little carbon dioxide, and some hydrogen. There are traces of other gases which we do not know so well, such as argon, and a very small amount of helium.

What is nitrogen good for?

Really to appreciate what a good thing this inert gas called nitrogen is, we shall consider what it would be to get along without it. Since it is impractical to try such an experiment on ourselves, we might try it on something else.

You recall the behavior of the candle in the jar of air. Suppose we had a jar of oxygen under which to place our lighted candle. It would behave very differently.

The candle flame would be much larger than usual, and much hotter. The wax, exposed to this torch-like flame, would melt much more rapidly, and the candle would shrink before our eyes. But as soon as the oxygen in the jar were all converted into carbon dioxide, the candle flame would die down, flicker and go out, just as it did in the jar of ordinary air.



In an atmosphere of pure oxygen, combustion goes on at a terrific rate

If we put a mouse into a similar jar of oxygen, it would behave much as the candle did. That is, it would be several times as active as a mouse under normal conditions. The little creature would be possessed by a furious fever of activity.

If the mouse were left in the jar, and the jar were large enough to hold enough oxygen, the mouse would soon be worn out, just as the candle would soon be burnt up. The mouse was not made to live in an atmosphere of pure oxygen. Its little mechanism would soon wear out under such hard usage.

It is obvious, then, that none of us would live very long or very happily in an atmosphere of pure oxygen. But oxygen diluted with four parts of quiet, inert nitrogen, gives us just what we need. We have enough oxygen to supply ourselves with warmth and energy, but not enough to wear out our machinery doing so.

Does nitrogen ever combine?

But nitrogen is not always inert. It will combine with other elements. We wouldn't be alive if it didn't. Nitrogen, along with carbon, hydrogen and oxygen, is absolutely necessary to life for both plants and animals.

We might think it would be no problem at all for plants and animals to find all the nitrogen they need, since they get enough oxygen without difficulty, and there is four times as much nitrogen as oxygen in the air around us.

But the truth is that we can no more get any of this nitrogen out of the air by breathing it than a fish out of water can get oxygen out of the air. And even though plants can separate carbon out of carbon dioxide, they cannot take free nitrogen out of the air.

A fish out of water cannot get oxygen out of the air

But fortunately, there are many compounds of nitrogen in the soil. Good soil, such as plants grow well in, is full of this valuable material.

The plants take nitrogen out of the soil. Most of it they store up in their seeds. This nitrogen in the seeds is combined with a number of other materials into a substance which we call protein.

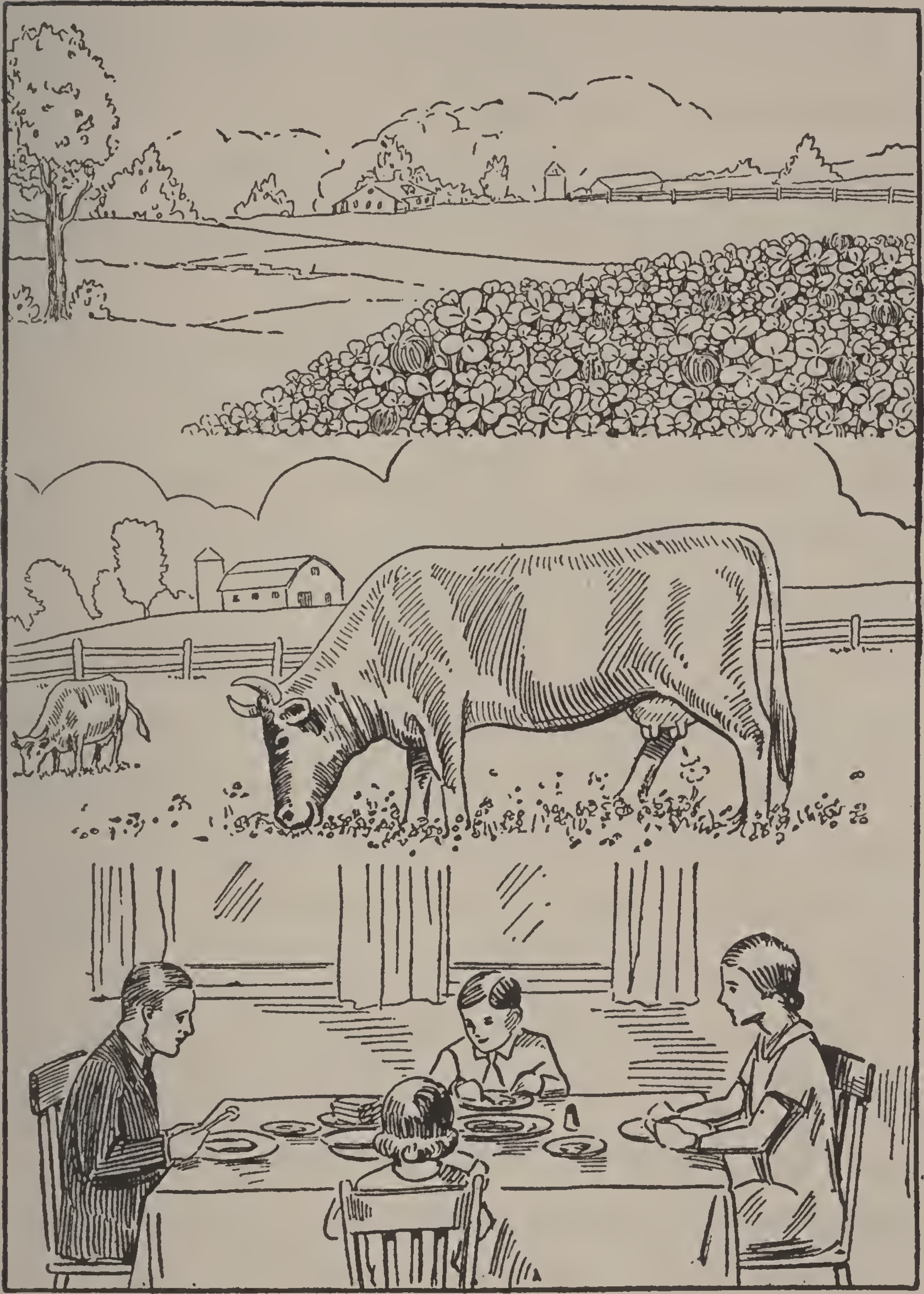
Protein is one of the types of food necessary to the health of animals and men, because it is from this source that they receive the nitrogen which the plants took out of the soil.

We get our proteins from the seeds of plants—such as cereals, beans and nuts—from the flesh of animals which have eaten proteins and stored them up in their own bodies, and from eggs.

What is carbon dioxide good for?

Carbon dioxide is a very good thing from the point of view of a plant, for the plant uses it to manufacture its foodstuff. Without green plants, there would be no life on the earth, for there could be nothing at all to eat. And without carbon dioxide the green plants couldn't carry on this important work.

Therefore, carbon dioxide is a very good thing, from everyone's point of view. But like many other things, carbon dioxide has its place.



The nitrogen compounds in the soil find their way into our bodies

One of its places, strangely enough, is in ice cream soda. The "fizz" in soda water and pop is simply carbon dioxide in solution. It gives the tang to ginger ale and root beer, and almost all of our familiar soft drinks.

Another queer place where carbon dioxide is a great help is in cake, biscuits, cookies, and other baked stuff. The cook puts in baking powder or soda to make these things light, but it is carbon dioxide which does the work. The soda which is used in baking (and which is also the chief part of the baking powder) is *bicarbonate of soda,* which name tells us that it contains a good deal of carbon and oxygen.

When the carbon and oxygen are combined with the moisture in the dough, and subjected to heat in the baking process, much carbon dioxide is given off. This carbon dioxide tries to escape in little bubbles, which become imprisoned in the dough, and make the air spaces which give the cake or biscuits their light and airy texture.

How is it that when we come into the house

When you smell dinner cooking it is because some of the food has flown through the air to meet you just before dinner time, there is frequently something waiting for us just inside the door to tell us what we are about to have to eat?

How does air carry messages to our noses?

This something is a smell or odor, and it speaks loudly of baked beans, or steak and onions, or apple pie, or gingerbread. We receive this message up inside our heads in a little chamber to which the nose is the corridor.

There it is received by some efficient reporters called the *olfactory nerves* which immediately flash the news to the brain, which is just behind them. That is how we come to know of it.

But the question is, how did the message come from the beefsteak in the pan to your nose near the front door?

Remember what happens to the candle wax when it is heated by the flame of the wick? It vaporizes—changes to a gas which contains some of the solid matter in the candle. When a beefsteak, or a pot of beans, or an apple pie, or almost any foodstuff is heated, some of it becomes vapor and mixes with the air.

Now flavors vaporize very easily. A large part of the sense of taste is really the sense of smell. As we eat, some of the vapor from the food we place in our mouths sneaks off up a back stairway, and gets to the olfactory nerves: so what we *taste,* we really *smell* too.

Since the taste part of foods vaporizes easily, naturally some of it vaporizes while the food is cooking. Along with a good deal of water, in the form of steam, and some carbon dioxide and other fumes if the food is allowed to burn, these smells go wandering off into the atmosphere.

Air is quite a lively substance, as we can readily believe by remaining in a room with an uncorked bottle of ammonia. Smells, especially strong smells, travel quite rapidly.

When we come in the front door and find a smell of gingerbread or doughnuts waiting just inside it, we know this: that a very small quantity of gingerbread or doughnut has actually got up out of the pan, and, in the form of vapor, has flown out to meet us.

The things which you smell the most are those which vaporize the most easily. Perfumes are substances which vaporize easily and which affect the olfactory nerves favorably. The scent of flowers comes from a tiny drop of nectar deep in the flower.

Some things have only a faint smell, such as unfinished wood. A clever lumberman can distinguish many kinds of wood by the scent of the freshly cut timber. But unless there were a great deal of it around you might not even notice that there was a scent to the wood.

Of course there are many things which have no odor at all, because no vaporization is going on sufficient to carry the message to your nose.

CHAPTER V

EARTH

THE ancients named fire, water and air "elements." But as we understand them now, fire is something happening; water is made of hydrogen and oxygen; and air is a mixture of oxygen and nitrogen. The fourth "element" of the ancients was earth. What do we find earth is made of?

What is earth made of?

We have discussed several materials: oxygen, nitrogen, hydrogen, carbon, and iron. Phosphorus, argon and helium have been named. These are only eight of the materials which modern scientists call the *elements*. There are at least eighty others.

What is an element? It is something which isn't made of anything else. There are many other things which contain more than one element. But an element alone, in its pure state, doesn't contain anything but itself. Thus, iron is an element. But rust cannot be an element, because it contains both iron and oxygen, and is therefore a *compound*.

There are many elements whose names will sound very familiar, and there are many others which are not so commonly known. Aluminum, copper, iron, gold, silver, lead, nickel, platinum, tin, zinc—all these are familiar because they are materials out of which are made many common objects which we see about us every day.

Iodine is familiar as a first-aid precaution for cuts and scratches, although the red liquid used for this purpose is not *pure* iodine. Helium is becoming a well known word through the use of this gas in lighter-than-air craft. We are acquainted with mercury as the silver liquid in thermometers. Phosphorus, as we know, is what makes matches light. Nearly everyone has heard of radium as something very valuable in the healing of disease, and we have seen it in exceedingly minute quantities on luminous watch dials and other things made to be seen in the dark.

To these we can now add as familiar acquaintances, carbon and the gases: oxygen, nitrogen and hydrogen.

Radium is used in luminous paint

But among the list of elements there are not a few which have astonished jawbreakers for names, and which we hardly ever hear of: molybdenum, praseodymium, ytterbium and zirconium, for instance. There are many of these long names in the list of elements, but we need not be bothered with them. They are unimportant to us because they occur in small quantities, and they are not commonly used by men, nor are they, so far as anyone knows, at all necessary to our welfare.

What elements are commonest?

The commonest element of all is that very important one—oxygen. It composes about half of the earth's crust. Most of it is not in its free form, of course, but largely in combinations with other things.

For example, plain sand is made up of grains of *quartz*. Quartz is the oxide of an element called *silicon*. Limestone contains oxygen, carbon, and an element called *calcium*. Both sand and limestone are very common things, and so an amazing amount of the world's supply of oxygen is imprisoned in them.

We already know that one-fifth of the atmosphere is oxygen. Water consists of two atoms of hydrogen to one atom of oxygen. But, inasmuch as an oxygen atom is just sixteen times as heavy as a hydrogen atom, eight-ninths of the weight of water is oxygen.

The next commonest thing is silicon, which probably constitutes a quarter of the crust of the earth. A great deal of silicon occurs in combination with oxygen in the form of sand.

Calcium (which is partner to oxygen and carbon in limestone), aluminum, iron, with three which are probably strange to you: magnesium, potassium, and sodium, are all very important in the composition of the earth.

We have been speaking of the earth's *crust* as if its center didn't matter at all. As a matter of fact, it doesn't matter much to us. The inside of the earth, except for a few thousand feet down, is inaccessible to us, and therefore unimportant. The inner parts of the earth are probably composed of the same substances as its outer parts.

The plants and animals which live upon the earth are made, mostly, out of carbon, oxygen, hydrogen, and nitrogen. Calcium (the same element that is in limestone), phosphorus (which lights the match), sulphur, potassium, iron and other substances are necessary for life.

It is hard to believe that our bodies are largely made of the same stuff as air and water, but it can be thought of in this way: The human body is about 65 per cent water. That accounts for quite a lot of oxygen and hydrogen. We eat a great deal of food which contains nitrogen, and a part of that nitrogen is stored up in the tissues in the form of protein, just as it was stored in the tissues of the steer from which the beefsteak came. But the bulk of our food is carbon. Naturally our bodies are built of the things we eat. There is nothing else they could be made of, so is it any wonder that we contain a lot of carbon?

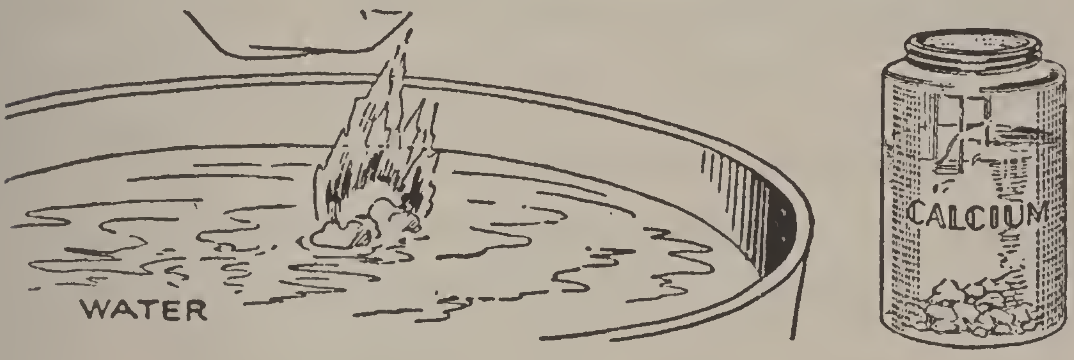
What does an element look like?

Some elements we know the appearance of very well. Gold, iron, copper, silver and others we see very often. We know, too, that there are elements that we do not see at all under normal conditions. The gases: oxygen, hydrogen, nitrogen and many less familiar ones, such as argon, look like nothing but empty space.

There are elements that no one would ever have seen in their pure state, had it not been for the scientists called chemists, who have separated them from the combinations in which they are always found.

Phosphorus and calcium, which are necessary in our bones and teeth, are two of these substances which existed nowhere in the world, except in combinations with other things, until chemists took the combinations apart. Pure phosphorus looks like white wax; but unless it is kept under water where no free oxygen can get at it, it immediately begins to rust into red phosphorus, or it catches fire and burns.

Calcium is really a metal, which resembles bright, white tin, but is soft enough to mould with the fingers. It would be very dangerous to mould it with the fingers, however, for the warmth and moisture of the hand is sufficient to set it on fire. Calcium is so eager to unite with oxygen that it will even take oxygen out of its combination with hydrogen. That is, calcium will burst into flames upon touching hot water! No wonder that all the calcium in the world was in combinations until chemists learned how to separate it out! In order to keep pure calcium from getting hold of oxygen and



The metal calcium bursts into flame when dropped in hot water burning all away, it is necessary to keep it bottled up in oil.

There is another element which behaves in the same strange way calcium does, *and we eat it every day!* Its name is *sodium.* It is in the soda and baking powder with which cakes, cookies and biscuits are made light; and common table salt is nearly half sodium! But we would not care to eat it in its pure form.

When is a diamond not a diamond?

That question is really a riddle. To answer it we must know what a diamond is. It is something with which we are quite familiar—carbon. But a diamond is *pure carbon.*

But here is the trick which makes the riddle. Pure carbon is not always diamond. There is a substance called *graphite,* of which the "lead" in your pencil is made. (A "lead" pencil contains no lead!) Graphite is also pure carbon. If we hold any cold object in the yellow part of a candle flame, we will soon find it covered with black soot. This, too, is pure carbon.

Now the strange thing is that each of these, diamond, graphite, and soot (or lampblack) is pure carbon. Pure carbon masquerades in these three forms. So we *might* say that a diamond is not a diamond when it is the lead in a pencil, or a flake of soot on some one's nose.

The soot which a candle flame deposits on any cold object is pure carbon

What happens to elements?

Is an element ever destroyed? No. It may combine, and so change its appearance, its habits, its name, and the amount of space it occupies. But there is one thing that it never changes—its weight.

It never actually gains or loses weight. There may be an apparent change of weight, but that can always be accounted for by the addition or disappearance of something else.

Iron, in rusting, seems to gain weight. But the weight it gains is that of the oxygen which it takes from the air.

The candle, in burning, may seem to lose weight, but if the carbon dioxide and water vapor which it produces were captured and weighed, it would be plain that part of the candle has changed form, but that nothing has actually been lost.

Elements may change their forms in an infinite number of combinations, and these combinations are ceaselessly going on all around us. But never, so far as all the scientists have ever found out, does that which was a *something* ever become a *nothing*.

CHAPTER VI

CHANGES

IF WE asked a chemist how elements got together, he would probably answer with a set of books so large and long that it would take years to read them, and so difficult that it would take years more to understand them. That is how big the question is.

How do elements get together?

The first thing to know about how elements get together to form other things, is that when two elements are brought together, one of two things happens. Sometimes, as when the oxygen and hydrogen gases were mixed in the jar, the atoms of both kinds just wander about among each other like people in a crowd, none of whom are going anywhere, and no one of whom is walking with anyone else.

But at other times, the atoms seek each other out and join hands in certain combinations. In carbon dioxide, each carbon atom took two oxygen atoms, and they joined together in a sort of ring-around-the-rosy combination which was the molecule of the new material known as carbon dioxide.

In a mixture, the atoms wander about separately, paying no attention to each other

In the first case, when the atoms do not "join hands," we say that the two elements are *mixed,* or that a *mixture* has been made. In the second case, when the atoms of two or more different substances have joined hands to form a molecule of a new substance, we say that they have entered into *combination,* or that they have united to form *a compound.*

What is a mixture?

In a mixture, the substances which have mixed do not lose their original characteristics.

In a compound, the atoms group themselves into molecules which are all exactly alike

For example—free oxygen in its pure state supports combustion.

In air, which is a mixture, the oxygen, mixed though it is with four times its own quantity of nitrogen, still supports combustion. The speed of the combustion has been slowed down by the quantity of nitrogen which gets in the oxygen's way, more or less, but oxygen has still its characteristic eagerness to combine with certain other things.

In water, which is a compound, although there is eight times as much oxygen as hydrogen by weight, the oxygen shows no signs of its usual desire to enter into a combustion process. In short, the oxygen in water is no longer oxygen, to judge by its behavior, but merely a part of water.

This is always true of mixtures: each substance keeps its own identity or personality although it may be modified by other substances in the mixture. But in a compound, each substance ceases to be itself and becomes merely a part of the compound.

What is a compound?

A compound, then, may be something quite different from the materials it was made of. Water, for instance, is a liquid which neither burns nor supports combustion. Yet we know that it is made of two gases: hydrogen, which burns; and oxygen, which supports combustion. But it is not at all like either of them.

Furthermore, a compound is made up of molecules, each of which contains a certain number of atoms of each material which entered into the compound. The number of each kind of atoms in a molecule of any certain compound never varies.

Carbon dioxide, for instance, has a molecule made up of one carbon atom and two oxygen atoms. Nothing in the world that anyone could do could persuade a single molecule of carbon dioxide to take in another atom of anything, and *remain carbon dioxide.* It might turn into something else, but as long as it is carbon dioxide its molecules will be made of one atom of carbon and two of oxygen.

It is as if the elements were the letters of the alphabet, and compounds were words. Any given word must always be spelled the same way. The word *go,* for instance, must always have one *g* and one *o*. If it has two *o's,* it is *goo,* which does not mean the same thing as *go.*

Neither does *got,* nor *ago,* nor *goat. Go* to be *go,* must be spelled g-o.

In the same way, water, to be water, must be made of two atoms of hydrogen and one of oxygen. If it were made of two atoms of each, it would not be water, but peroxide of hydrogen, which is something quite different. The deadly gas carbon monoxide is always made of one atom of carbon and one of oxygen. It can be persuaded to pick up another atom of oxygen for each of its molecules, but then it is no longer carbon *mon*oxide, but carbon *di*oxide instead.

There are endless numbers of compounds, just as there is an almost endless number of words. But each separate compound has always the same materials in the same proportions.

What causes things to combine?

Some things don't seem to require any particular condition to form combinations or compounds. Iron and oxygen, for example, have to be kept apart by a layer of paint, or they will begin combining without any cause or excuse except their own desire to do so. Those excitable substances, phosphorus, calcium, sodium, and potassium, combine much more readily with oxygen than iron does. They even burst into flames without anyone's having gone to the trouble to set fire to them.

But fortunately, not everything combines as readily as these do, or we should find ourselves in a world of flames.

Hydrogen and oxygen seem to be attracted to each other. But we can safely mix hydrogen and oxygen gases together, and nothing will happen at all *unless we supply heat.* But even a very small spark will ignite the whole of the mixed gases, which will combine at once into water, scattered in minute form through the air by the force of the explosion with which the combination takes place.

The carbon of a candle does not begin to unite with oxygen until the candle is lit—that is, until heat is supplied. Heat is one of the most important things in bringing about combinations. Many substances which show no desire to combine at ordinary temperatures combine readily when they are heated.

Oxygen and nitrogen, we know, do not combine readily, or we should soon have no air to breathe. But they can be coaxed into combining by a very great heat. The compound thus formed contains one atom of nitrogen to one atom of oxygen. This compound when cool can be changed to another which has one atom of nitrogen to two atoms of oxygen. When this is combined with water, the resulting compound has a molecule which consists of one atom of hydrogen, one atom of nitrogen, and three atoms of oxygen.

This stuff is a liquid called nitric acid. Although it is made from the same elements as air and water, it is a very different thing. It is so powerful and destructive that it will eat up metal. Cloth touched by it disappears as if suddenly burnt up; and when it is spilled on skin, the skin immediately becomes brown and dead, and a while later peels off.

Fortunately, it is very difficult to make nitrogen combine with oxygen and hydrogen to form this terrible acid, for what kind of a world would it be if it rained nitric acid? Not a comfortable one to live in!

There are other things which help elements to combine. Electricity is one. Some things will combine only if another substance is present, but this other substance does not join in the combination. This process is not very well understood, even by chemists.

Do things come uncombined?

Substances can separate into the original elements that composed them. If they couldn't, this old world would some day reach a point where all of all its eighty or ninety elements had settled down in compounds, and nothing more could happen.

As we already know, compounds can be taken apart. Green plants take apart carbon dioxide to get the carbon for their food. The scientist with the electric current can take apart water. If it were not possible to take iron out of its combinations with other things in iron ore, we would not be living in an "age of steel."

There are compounds in which the elements seem so little pleased with each other that only the slightest excuse is enough to jar them apart, like people looking for a quarrel. Such combinations are called *unstable compounds,* while steady combinations, such as water, which can be taken apart only with great difficulty, are called *stable compounds.*

Water, or oxide of hydrogen, can be persuaded to take on an extra atom of oxygen, becoming peroxide of hydrogen. We are well acquainted with this liquid as an antiseptic which "fizzes" when it is put on an open wound, or applied to organic matter.

Peroxide of hydrogen is an unstable compound. That extra atom of oxygen in each molecule seems to feel that "three's company and four's a crowd." The extra oxygen atom is on the continual lookout for a more congenial situation to be in.

If we leave the peroxide of hydrogen bottle uncorked, the stuff will lose its strength. In other words, the oxygen atoms will escape, one from each molecule, and what is left in the bottle will be just water.

But if we put peroxide of hydrogen on an open wound, these extra oxygen atoms get very busy. Oxygen is one of the best purifiers known. The little bubbles that immediately begin to form are evidence of the way in which the oxygen goes to work at once at disinfecting.

Almost anything will come out of a combination if it meets something else which has a stronger attraction for it than the partner it already has. For instance, hydrogen is combined with carbon in the candle wax. But as soon as the opportunity comes for that hydrogen to join oxygen—that is when heat is supplied—the hydrogen immediately deserts. The hydrogen-carbon combination is thereby broken up and rearranged.

There are few things that have a greater attraction for oxygen than hydrogen has, but among these few are calcium and sodium. The oxygen deserts the hydrogen to join the calcium and sodium—and even the stable compound hydrogen oxide is broken up, or, as the chemist would say, *decomposed*.

Whenever a compound is broken up into simpler compounds, or into its original elements, it is decomposed. Water is decomposed by an electric current, and hydrogen and oxygen are produced.

Much that is now known about the earth and what it is made of has resulted from man's learning to take things apart.

CHAPTER VII

THE STORY OF CHEMISTRY

TO WONDER what things are made of, and how, and what they are good for, is one of the most natural things in human nature.

How were things found out?

Even a baby shows this trait. A baby is not much of a scientist, because his equipment is so limited. But he has eyes to see, fingers to feel, and a mouth to taste. When he finds a strange object he grasps it. If he can, he picks it up. He turns it over several times with his curious fingers, looking at it closely. Then he subjects it to what is, for him, the final test—he puts it in his mouth to see if it is good to eat. If it is not, he may later try to pull it apart to find out how it is made.

The earliest scientists had little more to work with than the baby has. Lacking the equipment, they framed elaborate theories about what things are made of. One of the most reasonable of these was the theory that the world is made of earth, air, water, and fire.

But even at that time, some men had learned that certain things could be separated out of "earth." Copper and gold (which are sometimes found in their pure form in rocks) were taken out of the rocks and made into useful and beautiful articles. Iron, which is the most useful metal of all, was not known then, for it is usually found combined with oxygen and mixed with impurities in the form of a rusty dirt. Men, in those days, did not suspect that this reddish dirt contained a metal more useful than copper or gold.

But gold they considered very beautiful. Because of its beauty and because it does not rust or tarnish, it became very valuable. Certain men began to think that perhaps gold could be manufactured. Of course, anyone learning to make gold would at once become very rich and powerful, and would be in a position, if he wished, to rule the world.

A number of men, then, began to try to do this tremendous thing. These men were called alchemists.

Why did the alchemists give up?

No one knows exactly how long ago it was that men began to try to make gold. But it is certain that the first alchemists had very little knowledge with which to go about the task.

There were no microscopes or implements of that kind. Electricity was quite undreamed of. They had no equipment with which to procure pure elements with which to work. Indeed, they knew of no elements but earth, air, water, and fire, which we now know are not elements at all.

The first alchemists had little beside fire to help them. It was probably not long before they learned to *distill*—that is, to heat a substance and catch the steam or vapor which comes off it, and then, by cooling, to condense this vapor into a liquid.

Gradually they learned a number of other tricks for taking things apart or putting them together. In the course of hundreds of years, the alchemists began to discover that there were many different and distinct materials in the earth, which we know now as elements.

In trying to combine various things to make gold, they produced mixtures and compounds which disclosed more elements.

We know now what the alchemists did not know—that gold is one of these elements, and that an element cannot be made of anything but itself. The alchemists were working at a hopeless task. But, while it was impossible for them to realize their goal, they did something else quite as valuable to the world. They laid the foundations of a great science, known to the world as chemistry.

Alchemy became chemistry gradually, as the hope that gold could be manufactured became more and more improbable in the light of the truths which had been learned in the long and futile search.

What is an atom?

Strangely enough, the idea of the atom originated back in the time when the elements were thought to be earth, air, water, and fire.

Little by little, the alchemists laid the foundations for the science of chemistry

The ancient Greeks wondered whether matter could be divided indefinitely. That is, if you took a quantity of some pure substance, and then took half of it, and half of that, and half of that and so on, would you ever arrive at anything that couldn't be divided?

Some of them thought that such a thing would be arrived at, and called that thing an *atom,* which, in their language, meant a thing which could not be cut.

Only a little over a hundred years ago, the same theory was brought out, argued over a great deal, and finally accepted as true.

No one has ever yet seen an atom. It is the way substances behave which has persuaded scientists that atoms really exist. It is much too difficult a subject to be explained here. But although no one has yet seen an atom, the camera, which has a much more perfect eye than anything living, has caught pictures of atoms. In these pictures, atoms make little streaks, for an atom will not stand still to have its picture taken.

The reason that there is only a certain number of elements in the world, is that there are only that many kinds of atoms. Compounds, you remember, are made of groups of atoms, which are called molecules. Molecules are also too small to be seen, even with the most powerful microscopes.

What is the mystery of radium?

Radium is one of the more recently discovered of the elements. From the very first, it was evident that this new element had some tricks all its own.

It was named *radium* because, before it was even found, its *rays* or *radiations* were noticed. As radium was studied, it was found that it produced three different kinds of rays.

One of them resembles light, except that it is invisible, and can pass right through most things. A photographic plate, which is much more sensitive in some ways than the corresponding part of the human eye, is able to pick up these rays as if they were light.

Another of the three kinds of radium rays is a sort of electricity.

But the greatest wonder of all is the other ray of radium. It has been found that this ray is made up of a stream of helium atoms traveling at an enormous rate of speed!

Now radium is considered an element, and so is helium. Contrary to all rules and regulations for elements, radium seems to be making another element—helium—out of itself!

Radium, in giving off its three kinds of rays, gradually decays. Scientists, studying the rate at which radium wastes itself away, have figured out that even if, at one time, the whole world had been made of radium there would be none of it left by now!

But radium does exist in the world now, although in very small quantities. There has probably never been a much greater quantity of it than there is now. Therefore, something must be making radium about as fast as radium is decaying. This thing which produces radium is believed to be the element known as *uranium*.

The more scientists learn, the more they find there is to learn. The mystery about radium is one of the many interesting things that have still to be learned about.

Someone will some day find out an explanation for the radium mystery. As yet we can only guess about it.

Can the alchemists' dream come true?

This much can be said in explanation. An atom is not a tiny particle of solid matter, like a small grain of sand. It is believed to be made up of tiny charges of electricity. Some atoms are very complex, while others are quite simple.

Uranium and radium have very complex atoms. In the natural decay of radium, electrical particles and helium particles are shot out of the radium atoms as they break down, just as rocks, smoke and ashes are thrown out of an erupting volcano. Naturally, the radium atom, in giving out the helium and electricity, is itself changed to something else.

The disintegration of radium may be thought of as a process of simplifying the complex atoms of radium into simpler atoms representing other elements.

Now it is quite possible that one element can be transformed into another element having a simpler atom. This has actually been accomplished in quite a number of cases, but only on a very minute scale.

It is possible, therefore, that someone may someday change some other material into gold. Perhaps the gold so created would be more costly than natural gold. But still, the alchemists dream may yet come true.

The great science of chemistry is full of such exciting possibilities as this. Columbus, setting sail across an unknown sea, with a whole world waiting ahead of him to be discovered, had no greater possibilities before him than the chemists of today and tomorrow.

CHAPTER VIII

EVERYDAY CHEMISTRY

THERE are many people who think that scientists, such as chemists, have no real part in the life of the world, but live in a sort of world of their own, surrounded by their queer apparatus and thinking in terms of formulae and equations.

What does chemistry do for the world?

But it is a very great mistake to think that the scientists, particularly the chemists, are not extremely practical folk. It is easy to realize that such striking discoveries as helium and radium, with the great advancement they have brought to aviation and to medicine, are the direct result of the chemists' researches.

It is not so easy to see, but it is quite as true, that almost everything which happens to us in our daily lives, almost everything we use, is in some way helped, regulated or improved by the knowledge which chemists and other scientists have given the world.

The houses that we live in are built of wood, stone, mortar, concrete, plaster, metal and glass. Of these, only wood and stone are simple products of nature. The rest are made by man by processes which are basically chemical.

The food we eat comes from the soil, through the medium of plants, or of animals which eat plants. Famine or plenty, poverty or prosperity depends largely upon whether the soil produces poorly or generously. The chemist, studying the soil, can tell the farmer how to make even poor soil grow good crops.

In the past, mankind has worn clothes made mostly of cotton and flax, which are plant fibres, wool from sheep, and silk from the cocoon of a caterpillar. But man the chemist has learned to make a kind of silk out of wood, or cornstalks, and the worthless part of cotton.

Man has learned to take a greasy stuff called petroleum out of the earth, and make it into a thin clear liquid—gasoline—which he uses to make his modern chariots speed very many times faster than the horse-drawn chariots of the ancients.

He has taken a sticky black stuff out of coal, and out of this coal tar he has created not only medicines, but fragrant perfumes, delicious flavors, and hundreds of beautiful dye tints with which cloth is colored.

The chemist, it seems, has far outstripped the fondest dreams of the alchemists, who hoped only to make gold. But although the chemist has almost seemed to dip into the realm of magic, his greatest gifts to mankind are of a more practical, everyday aspect.

The release of the power in gasoline, the making of simple but useful materials such as mortar, the discovery of scientific principles for the raising of crops, and the manufacture of everyday commodities such as glass bottles and jars—it is by such ways as these that our civilization has been advanced.

Gasoline is made of the same materials as the candle. Of course, there are many kinds of gasolines, and they are not exactly alike. A molecule of gasoline is a rather complicated affair, but it is made up of atoms of carbon and of hydrogen. There may be some other kinds of atoms in the molecules of different kinds of gasoline, but the carbon and hydrogen are the important things.

How does gasoline make the engine go?

In an automobile engine, there are a number of *cylinders*. Each cylinder is like a little round room. There is a sort of movable plug, which is called a piston, filling the open end of the cylinder.

A lever is attached to this piston, so that when the piston moves, the lever moves too. The motion of the lever is finally transferred to the wheels of the car. The wheels turn, and the car moves.

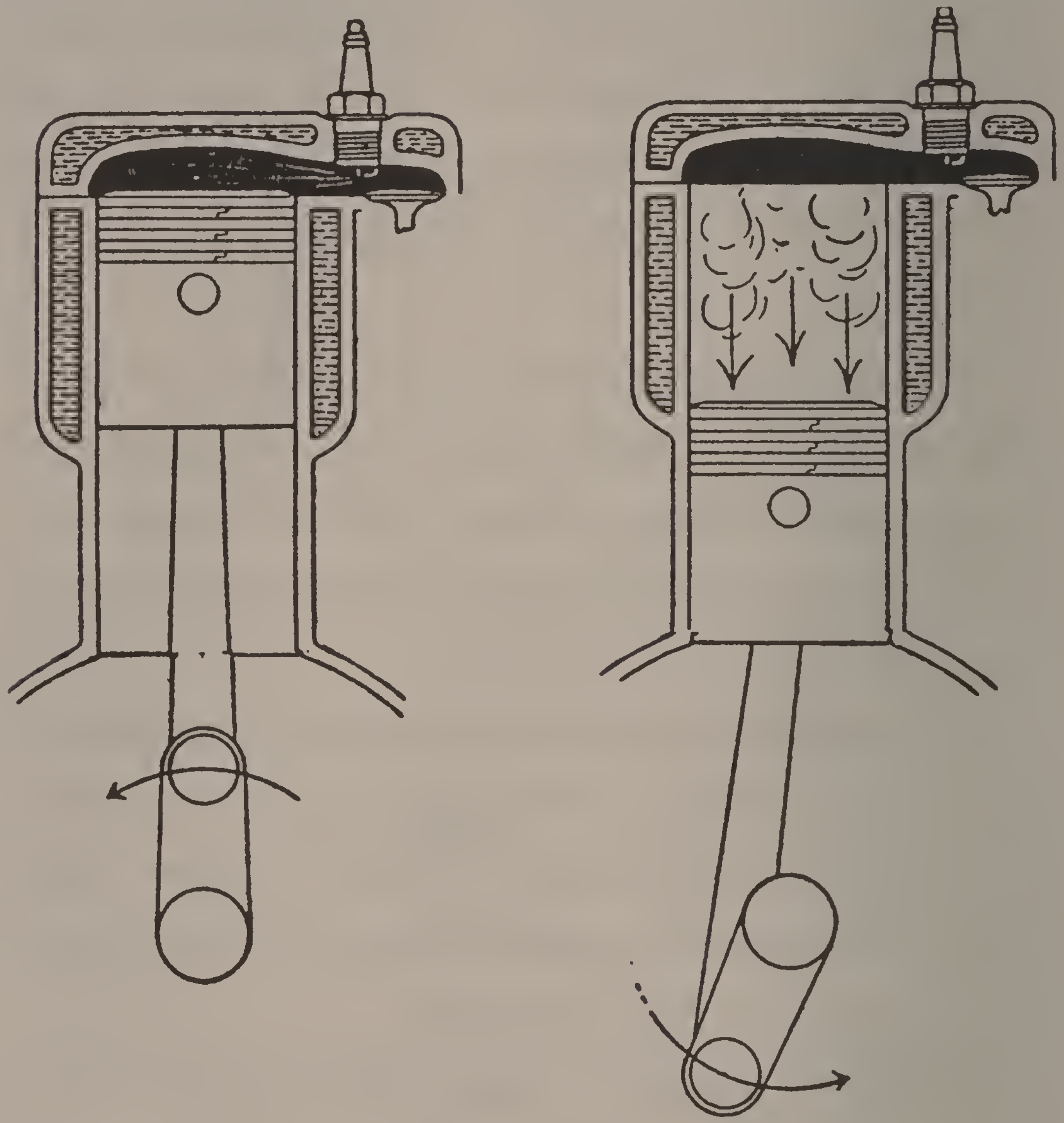
Now this is what happens inside the cylinder. Gasoline, mixed with air, is sprayed into the cylinder. A spark is shot through it. The carbon and hydrogen of the gasoline need only this spark to start combining with the oxygen of the air.

The combination takes place very quickly. The hydrogen and oxygen form water vapor, and the carbon and oxygen form carbon dioxide. The water vapor and the carbon dioxide gas both want a great deal more space than they did as gasoline and air, and they want it very suddenly.

So they push the piston out of their way in order to take the room they need. The sudden thrust which the explosion gives the piston is carried to the wheels, and the automobile moves forward as the driver desires.

In the meantime, the cylinder is emptied and the piston pushed back up into position, ready for another explosion. The cylinders take turns so that the repeated thrusts of the pistons gives a smooth flow of power.

Hydrogen is more eager for oxygen than carbon is. If there is any shortage of oxygen, it is the carbon which gets left out. Furthermore, when a gasoline engine is first started, the engine is cold. Now, carbon needs more heat in order to start combining with oxygen than hydrogen needs. While the engine is too cold for all the carbon to unite with oxygen, some of the carbon may combine with one atom of oxygen instead of two.



The gasoline and air combine to form carbon dioxide and water vapor which demand much more space

Here we have the deadly poison carbon monoxide gas, which you can neither see nor smell. There is very little danger from it in the open air. But if a cold gasoline engine is started in a closed garage, carbon monoxide may accumulate faster than it can get away. Many people have been overcome in closed garages, due to ignorance of this poisonous gas.

What is mortar?

Mortar is the stuff that holds the bricks together in a brick wall. But what is it made of? What makes it so hard that, in an old wall, it is harder than even the bricks themselves?

The story starts with limestone. Limestone has a molecule made of an atom of calcium, an atom of carbon, and three atoms of oxygen. Limestone is put in a sort of great oven, called a lime kiln, and baked.

In this baking process, the carbon atom and two oxygen atoms fly away together as carbon dioxide. What is left has an atom of calcium and one of oxygen. It is therefore oxide of calcium, but it is always called *lime*.

Plain white mortar is made by mixing lime, sand, and water. When this is spread between the bricks, two things begin to happen.

The water begins to dry out, or evaporate. But while the water is drying *out,* something else is coming *in.* The mortar soaks up carbon dioxide from the air.

When mortar is spread between bricks a chemical action begins

When limestone was baked, carbon dioxide came out of it, and lime was left. If carbon dioxide comes back in and joins the lime, what do you have but limestone again, this time with sand in it?

That is exactly what mortar is. But to look at a piece of limestone, would you have supposed that it could be made to lie between bricks, binding them together? The sand makes the mortar stronger. The older the mortar is, the stronger it becomes, for all of the lime is gradually changed back to limestone by the carbon dioxide from the air.

How does chemistry help the plants grow?

Man, in his long process of learning, has frequently learned things by accident, long before he learned *why* they were so. He probably learned that a fire needs a draft thousands of years ago, although nothing was known about oxygen until about the same time that the American colonists first began to think about fighting for their freedom.

In the same way, farmers discovered that certain things, such as manure, seem to have a good effect upon crops. It is probable that they also found by experience that things grew better if the same crops were not always planted in the same fields. But just why these things are so, no one, then, knew.

For, of course, no one knew about nitrates, those compounds of nitrogen which plants must take out of the soil in order to live. Animals have to get these same nitrates from the plants. But animals don't use all of the nitrates which they eat. Therefore, when a farmer spreads manure from his barn upon a field, he gives back to the field some of the very same nitrates which the plants have taken out of it and which the farmer's animals have eaten but not used.

Since nitrogen does not combine very easily with other things, there are not many places in the world where nitrogen compounds are found in abundance. In South America, in the Republic of Chile, there is a large quantity of a nitrate called Chile saltpeter. It is made of nitrogen, sodium, and oxygen.

Before the war, all the great countries of the world bought saltpeter of Chile, to put on their fields to make their crops grow. But unfortunately, saltpeter is also used in making gunpowder and explosives. During the war, no country could get enough of it. In the United States, men began to make nitrogen compounds by taking nitrogen out of the air to give to the crops to make them grow.

When farmers first found that by changing the crops in their fields from year to year, they got more produce, they probably did not know why it was so.

Just as green plants, and nothing else, can take carbon out of carbon dioxide, so a certain kind of bacteria can do what no other plant or animal can—take nitrogen out of the air and put it in the soil in the form of compounds which plants can use.

These bacteria, which are so tiny that only with a powerful microscope can they be seen at all, live in little nodules or bumps on the roots of certain plants. The clover plant is one of the most important of these.

If a farmer grows clover in a field one year, there will be enough nitrogen left over in the soil so that he can grow a good crop of something else there the next year. This is called *rotation of crops,* for rotation means nothing more than taking turns.

What is glass?

Glass was probably first discovered by accident, and it is very likely that this accident happened in Egypt.

Egypt has a very sandy soil, and sand is dioxide of silicon. Glass is mostly silicon. It seems quite possible that all of the materials necessary to make a small piece of glass might be present in a burning straw stack on the sandy soil of Egypt. Even the heat necessary to fuse, or melt together, the materials would be supplied by the fire.

It may be that some ancient Egyptian, stirring around in the ashes where his straw stack had burned, found something that the world had never seen before—a little blob of glass.

But accidental as the first glass making may have been, today it is very scientific.

Glass is a mixture of compounds. It can be made of various materials, but silicon and oxygen, usually in the form of sand, are the most

Glass was probably first discovered by accident in ancient Egypt important and are always necessary. Glass usually contains some calcium in the form of lime, and some sodium or potassium. Sodium is used in soft glass, and potassium is used in hard glass. Although all glass may seem hard to you, it would not seem so if you were a glass cutter by trade.

Many other materials may be put in glass to change its quality or its color. Iron is an impurity in glass which makes it look greenish. Since it is difficult to get all the iron out, cheap bottles are often green.

The purpose for which the glass is to be used determines what it shall be made of. If it is to be used for spectacles, it is very important that it shall be perfectly clear and flawless. If it is for milk bottles, it needs to be white, so that the milk won't look queer in it, and it needs to be tough, so that the bottles won't break very easily.

All the materials, together with some broken glass, are melted up together in an enormous sort of kettle. The dirt and impurities can be skimmed off the top. Then it is ready to be made into window panes or bottles or spectacle lenses or whatever it was meant for.

To make plate glass, the thick, heavy liquid glass is poured out on a great flat table and rolled with big rollers. Bottles are made by blowing the glass as if it were a soap bubble, but with a mould around it to shape it. There is no danger of this kind of a bubble bursting if it touches something, for it is very tough.

Imagine, if you can, a time when windows were made of oiled paper or skins instead of glass. A little light came in, but of course you couldn't see out. Instead of bottles there were earthenware jugs and leather bags. Instead of drinking glasses people used mugs and metal cups, or dippers made from gourds.

What is rubber?

When Columbus crossed the Atlantic he found the natives of Santo Domingo playing with balls made from the gum of a tree. Another explorer found that in South America certain Indians smeared this gum over their coats to keep dry in the rain.

When a lump of this stuff was sent to the man who had discovered oxygen, he cut it up and gave the pieces to his friends to use in rubbing out pencil marks when they made mistakes. They asked him what the queer bits of gum were, and he replied that they were "India rubbers."

To this day we call the gum of the caoutchouc tree "rubber," whether we are using it to rub out our mistakes or to keep our feet dry or to tire our automobile wheels.

But it was many years after rubber was used to erase with before it was used for other purposes. The stuff was sticky in hot weather, and smelled very unpleasant.

About a hundred years ago, scientists learned that if rubber is mixed with some sulphur and treated with heat it becomes quite a different thing. It becomes the tough, stable, elastic solid which we are familiar with in the form of hot water bottles, rubber heels, and balls.

This process is commonly known as "vulcanizing." If a greater quantity of sulphur is used, the product is a hard, almost brittle substance. This hard rubber is used for combs, pen holders, knobs, handles, and many sorts of useful articles.

Vulcanized rubber has become so tremendously useful that not enough caoutchouc trees grow in the world to supply all the rubber that men would like. Consequently, scientists have been searching for years to find a new source from which rubber might be made.

In order to make rubber, it is necessary to know what rubber is composed of. Pure rubber has a molecule made of ten atoms of carbon and sixteen atoms of hydrogen. It can be decomposed by heat into a compound called *isoprene,* which has a molecule of *five* atoms of carbon and *eight* of hydrogen.

It is easy enough to make the rubber molecules split in two to form isoprene molecules. But it took the chemists many years to persuade isoprene molecules to join together in pairs to make rubber molecules.

Isoprene is a clear liquid. It can be made out of turpentine, which is made from the sap of a kind of pine tree. It can be made from starch, which in turn can be made from potatoes, and corn, and many other things.

Isoprene can be made out of saw dust, and it can even be made out of coal and lime. The scientists who have been working for many years on this fascinating problem have discovered many ways of making isoprene, for isoprene is made of only carbon and hydrogen, and these are very common elements.

But the rubber that is being used for tires and overshoes and the thousand and one everyday purposes of this useful stuff, is still made from caoutchouc tree gum. And the reason for this is that rubber made out of potatoes, or turpentine, or sawdust, or any of these other substances, is too expensive.

But the hunt for cheaper rubber goes on. Someday a way will be found for making rubber which will cost less than caoutchouc gum rubber, and then rubber will be used for many more things than it is now. It will be a quieter world when houses are built of rubber and streets are paved with it, for rubber deadens sound, as a pair of rubber heels will show.

What is a synthetic?

The work of the chemist, in general, is divided into two great parts: *analysis,* which means taking things apart; and *synthesis,* which means building things up out of other and simpler things.

Thus, the chemist *analyzed* rubber and found it was made of carbon and hydrogen in a certain compound. But when the chemist made rubber out of potatoes, he *synthesized* rubber, or made *synthetic* rubber.

It is much easier to take things apart than it is to put them together, just as it is easier to break things than to make them. Only in the last fifty or a hundred years has the science of chemistry advanced to the point of synthetic or creative chemistry.

Always in the past, if man wanted a material, he had to look about him and find it. Perhaps what he found didn't fit his purpose very well, but it was the best he had, and he had to use it. Creative chemistry makes it possible for him to create something which exactly fits his requirements.

What is rayon?

For instance, for thousands of years man has depended upon a caterpiller to spin the fibre to make his finest fabrics. The silk worm spins a tiny thread of silk for his own purpose, not for man's. The worm makes the thread of the thickness and length which just suit his own requirements in making himself a good cocoon.

Man, if he wanted silk, had to take what the worm made, and make the best of it. But what has synthetic chemistry to do with silk?

The carbon which green plants take out of the carbon dioxide from the air is used to make a substance called cellulose. Wood is mostly cellulose; so is cotton; so is the cornstalk. Cellulose is composed of carbon, hydrogen, and oxygen.

Cellulose can be dissolved in certain chemicals. In this liquid form, it can be squirted out through tiny holes, just as toothpaste comes out of the tube. This is the very method by which spiders, silk worms, and other little creatures spin their silk threads. If the toothpaste dried to form a sort of rope, you would have exactly the same kind of thing on a larger scale.

The threads made in this way can be just as long and just as thick or thin as man, the maker, wants to make them. Instead of being a few inches long, like the best cotton fibres, or many feet long, like silk fibres, the artificial silk, or rayon, fibre can be made any length that the cloth maker wants it.

Rayon can be made of cornstalks, or of the fuzz that sticks to cotton seeds, or of spruce trees. It is not yet as strong as silk, but there is every reason to believe that it may someday be made so. And it is already much less expensive and very widely used.

Once man was entirely dependent for his shelter and food and clothing upon things which he could find about him, almost ready for use. Primitive men lived in caves for houses; they ate berries and nuts and roots and the flesh of the animals which they could kill; they were clothed in the skins of these same animals.

As time went on they learned to use more and more of the things about them. They hewed logs to make warmer, dryer shelters than the caves had been. They learned to cultivate crops in order to provide more plentiful and nourishing food. They learned to spin and weave cloth from the wool of sheep and the fibres of the flax and cotton plants.

Now man is learning to create the materials which he needs out of other, less useful things. The synthetic products which man will make in the future will be as much better suited to man's use as the modern house is better and more comfortable than the dark, damp caves which man once called home.