WONDERS OF CHEMISTRY

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by

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PREFACE

CHEMISTRY is a closed book to many of us. We regard it as something difficult, hard to understand, and remote, when as a matter of fact it is inherently one of the most interesting of subjects. Instead of being remote, it is part and parcel of our daily lives. It sums up the whole process of nature. Each one of our every-day habits—eating, drinking, breathing—is nothing more nor less than a chemical reaction.

The recent World War brought us to a sharp realization of just what chemistry may mean for us in the future, either for weal or woe. On the one hand it produced insidious gases, powerful explosives and the deadliest agents of destruction that the world ever witnessed. On the other, it came to the aid of more than one nation by supplying nitrates for the soil and artificial clothing and foodstuffs.

To make us acquainted with some of the wonders of every-day chemistry is the purpose of this book. It is not concerned with the scientific side except incidentally. The author is a practical experimenter who knows whereof he speaks, and better still knows how to tell the reader about it in understandable language. He takes us behind the scenes, as it were, and points out the marvellous little elves called "atoms" actually at work. He presupposes no advance knowledge as he takes the reader on this fascinating trip through his laboratory. He first discusses the wonders of air and water, and that modern magic, liquid air. Then he takes up common acids and salts, metals and alloys, gases, explosives, and other topics of live interest. We learn something of the magic of coal tar, from which the most beautiful colors and delicate flavors are obtained. There are talks on photography, artificial diamonds, radium, and the electric blast furnace with its heat running into the thousands of degrees.

These are but a few of the marvels of chemistry, which are fascinating on their own account, and are also of tremendous importance to each one of us. While primarily addressed to young folks, this book has a message to older readers as well.

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CHAPTER I

THE WONDERS OF AIR

If you will go out into the open on a clear night and find the *North Star* and then look around a little you will see the constellation of the *Big Dipper* on one side of it and the constellation of *Cassiopeia*, which is formed like the letter *W*, on the other side of it. Now draw an imaginary line through the middle of the Big Dipper, the North Star and Cassiopeia and let it project beyond the latter when it will pass through a hazy patch of light, and this is the *Great Nebula of Andromeda*.

Where Our Atmosphere Came From.—On looking at this nebula through a powerful telescope you would instantly see that it is not made up of myriads of stars but of something that seems very much like fog, or vapor, or smoke, with a bright spot in its center and other and smaller bright spots scattered through it here and there, and these have quite a solid appearance. It was from just such a nebula as this that our *solar system* was made, our *sun* being formed of the bright central part, and our *earth* and the other planets growing from the smaller bright parts. This nebula contained all of the gases and other elements which go to make up the earth, together with its envelope of air.

How the Atmosphere Behaves.—The atmosphere, as the air surrounding the earth is called, is often likened to a great ocean, the lower part resting on the surface of it just as water does, and it stays there for the same reason, and that is because it has weight. While a little air has no appreciable weight, the atmosphere reaches upward to a height of from fifty to two hundred miles and the amount of it is enough to make it press on the surface of the earth, at sea level, with a weight of nearly fifteen pounds to the square inch. This pressure is always changing a little, as some parts of it become heated more than others, and in equalizing the temperature the air is put into motion, and in this way the *winds* are set up.

What the Atmosphere is Made Of.—While you cannot sense the air when it is perfectly still, you can *feel* it when it is moving, that is when a breeze, or the wind, is blowing, and you can then also *hear* the effects of it. Air is formed chiefly of two gases, *oxygen* and *nitrogen*, in the proportion of one part of the former to four parts of the latter.

These very unlike gases, however, are merely mixed together and not combined chemically; indeed if they were combined they would not form air but one of the *oxides* of *nitrogen*. The Chinese knew that air contained an active element, which is the oxygen in it, away back in the eighth century. They also knew that it would combine with sulphur, charcoal and some metals, and how to obtain it from saltpetre. The first person, however, to show that the air was formed of two gases was Leonardo da Vinci, who lived during the last half of the fifteenth century. But it was away along in the eighteenth century before the first pure sample of oxygen was made by Joseph Priestley, and this he did by heating *mercuric oxide*. He called the gas so obtained *dephlogisticated air*,[1] and a few years later the name *oxygen*[2] was given to it by Lavoisier, the greatest chemist of his time.

Nitrogen, the other chief gas of the air, was discovered by Rutherford, of Edinburgh, a couple of years before Priestley found a way to obtain oxygen. His experiment consisted of shutting up an animal in an air-tight compartment; he then removed the *carbon dioxide*, which was given off when the animal breathed, by absorbing it with charcoal, when he found that a gas still remained which would not support life.

But the fact that nitrogen existed in the air as a separate gas was first shown by Lavoisier. He called it *azote*, which means *without life*, and the French still use this name for it. We get the word *nitrogen* from the Latin *nitrum*, which means *saltpetre*. The oxygen of the air, then, is the gas that supports and sustains life, and the nitrogen simply serves to dilute and spread it about.

[1] In Priestley's day (1750) *phlogiston* was the name given to a supposed principle that was thought to be a necessary part of every substance which burns. Thus when he heated mercuric oxide he assumed that the phlogiston had been separated from the gas (oxygen) which remained, and hence he called the latter *dephlogisticated* air. It was Lavoisier who overthrew the phlogiston theory.

[2] The word oxygen means acid former, and Lavoisier believed that oxygen was the one essential constituent needed to form an acid. Later it was found to be nitrogen and not oxygen.

Other Substances in the Air.—Carbon Dioxide.— Here are two easy experiments which you should make. *First*, take a glass of *lime water* which is a clear and colorless solution, and blow through a straw into it when it will become milky white. *Second*, light a piece of candle and let it down into a bottle which has a little lime water in it; you will not have long to wait until a white crust will begin to form on it. These experiments show very clearly that not only your breath and the candle give off some kind of a gas but that the gas in each case is the same. This gas is often called *carbonic acid gas*, but its right name is *carbon dioxide*.

There is not very much carbon dioxide in the air compared with the oxygen and nitrogen, and it varies in different localities. In cities where fuels are burned the amount of it is in the neighborhood of six parts to 10,000 parts of air, while in the country there are only about three parts in 10,000 parts of air. The amount is kept pretty constant, for while growing vegetation absorbs large quantities of it, this is replaced all the time by animals which exhale it, burning fuels, decaying meats and vegetable matter and fermentation in wines, and in various other substances which keep giving it off.

The *choke-damp* of the miners is really carbon dioxide, and while it is not poisonous it will not support life; this is the reason why deaths often result when men in mines have to breathe too much of it. The human body, though, can stand a considerable amount of carbon dioxide above the usual three or six per cent. without causing death or even producing any untoward result, as is shown in works where it is made for charging mineral and soda waters.

Water Vapor.—Another substance that is always found in the air, however dry it may seem to be, is *water vapor*. When you step out of doors on a cold day you can see the water vapor that is in your warm breath every time you exhale it into the colder air. The amount of water vapor that the air can hold depends on the temperature of the latter. When the air contains as much water vapor as it can hold it is then said to be *saturated*, and hot air can be saturated with more water vapor than cold air.

The reason you can see your breath when you exhale it into cold air is because the warm air which you exhale is not saturated with water vapor, but as your breath strikes the cold air the latter is saturated with it, which makes it visible. This also explains why moisture collects on a tumbler of cold water when it is placed in a warm room and frost forms on a window pane when it is warm inside and cold outside. Since cold air has less power to hold water vapor than warm air, as the warm moisture-laden air begins to cool off in the night, the water vapor condenses into water and clings to the grass and other objects, and this is what we call *dew*.

When there is a thick fog or it begins to rain, it is because the atmosphere is saturated with water vapor. The amount of water vapor in the atmosphere determines its *humidity*, and when the saturation point is nearly reached, that is when the humidity is high, the pores of our bodies cannot throw off the excess water by evaporation and so we feel oppressed. And the reverse is also true, for when there is very little water vapor in the air, that is when the humidity is low, we perspire too freely and this, too, is unpleasant. Where hot air or steam is used to heat a room it tends to dry out the moisture in the air; this can be compensated for by placing a pan of water on the radiator or near the register so that the evaporation will make up for that which is lost.

Dust and Germs.—The air at all times contains dust of many varieties and germs of many kinds. When you are in a theatre and a *spotlight* is thrown from the gallery onto the stage you will see the course of the beam of light, but this is only because the light is reflected by the dust particles in its path,—for a beam of light itself cannot be seen.

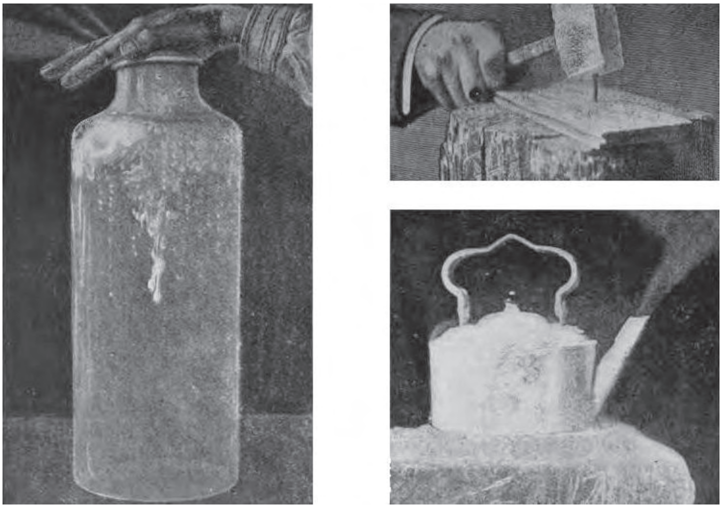
What we call dust is not made up of particles of dry matter alone, but frequently it contains millions of germs; that is, minute animals that are alive and kicking and which have the power, many of them, to produce disease unless our bodies are in such an excellent state of health as to be able to ward off their attacks. These germs for the most part are formed of single cells, and when we take them into our bodies where it is nice and warm and they have plenty of water and lots of good food, they start in to multiply at a great rate. Then there are yeasts that make wines ferment, and those of still another kind that cause meats and vegetables to decay. So you see there are good little germs as well as bad little germs.

Nitric Acid, Ammonia and Ozone.—Besides the chief gases which make up the atmosphere other substances are found in it which are very useful to us. The first of these is *nitric acid*, and this is the way it is formed in the upper layers of air: Whenever a flash of lightning takes place, the heat of it causes the oxygen and nitrogen to combine, and this produces the oxides of nitrogen; in turn these combine with the water vapor that is in the air, and the result is *nitric acid*. How nitric acid is extracted by electricity from the air and the many uses of it will be explained in a chapter further on.

There is also a very small amount of *ammonia* in the atmosphere and its presence there is due to decaying vegetable and animal matter which gives it off; it is then distributed through the air by diffusion. When there is enough of it in the air it is dissolved by the water vapor and later when it rains it is carried to the soil. There it is converted into compounds of ammonium and these are finally changed into nitric acid, which is a good food for the soil.

Ozone is a condensed form of oxygen, having three atoms of oxygen to a molecule instead of one, and this makes them act quite differently from one another. When an electric spark passes through the air it changes the oxygen into ozone, and so when there is an electric storm ozone is produced and some think that they can detect its presence by the peculiar refreshing odor, which is rather due to the cleanness of the air.

Recently Discovered Gases of the Air.—In 1894, Lord Rayleigh and Sir William Ramsay, British scientists



THE MARVELS OF LIQUID AIR

(a) In the glass jar experiment, liquid air first floats, then the oxygen sinks in bubbles, as the nitrogen boils. (b) Mercury is frozen solid into a hammer. (c) A teakettle containing liquid air boils when placed on a cake of ice.

of renown, discovered that the atmosphere contained traces of a new gas which they called *argon*. The way they came to make the discovery was like this: They had obtained some nitrogen from the air by removing the oxygen, when they found that it was heavier than the nitrogen they had made by decomposing an ammonia compound called ammonium nitrite.

After many experiments they came to the conclusion that there must be some other substance in the air which made the nitrogen heavier than that which they obtained from other substances, and this they discovered to be a gas. They called this gas *argon* from two Greek words which mean *inactive*, as all attempts thus far to make it combine with other elements have proved unsuccessful.

Sir William Ramsay discovered three new gases in the atmosphere in 1898, when it became possible to make liquid air on a large scale, and these are *neon*, *xenon*, and *krypton*. Neon, named from the Greek word which means new, was separated from the air by letting a quart or so of liquid air evaporate. As the lighter gases passed off first, the heavier gases, of which *neon* is one, remained at the bottom of the container. It was shown by Ramsay that there is one part of neon in 100,000 parts of air.

The gas xenon, which means *stranger*, is another inactive chemical element that is left after the other gases have evaporated from liquid air. It is the heaviest of all the gases found in the air. Krypton, which means *hidden*, is another of the rare gases which Ramsay discovered in the air, and it has a density of about twice that of argon. It exists in the proportion of about one part to a million parts of air.

How Air Supports Life.—If the air supply is cut off from an animal it will quickly die of suffocation. As you know, man and all the more highly developed animals breathe by means of lungs and in doing so they take the oxygen from the air. It is the oxygen that supports life and after it is received into the lungs it is absorbed by the blood and carried to every part of the body.

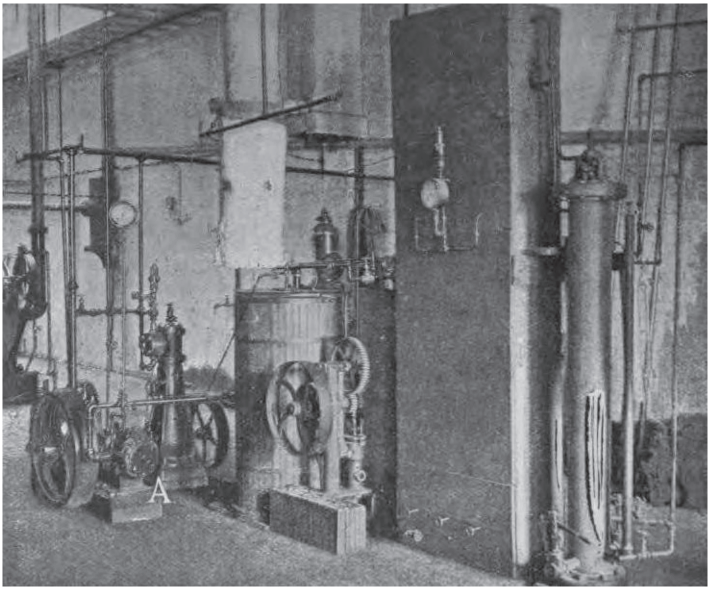
Now the cells of animals are made up very largely of carbon and hydrogen, and when the oxygen in the blood comes in contact with them they combine and produce two different compounds; that is, the oxygen which combines with the carbon of the cells produces *carbon dioxide*, and the oxygen which combines with the hydrogen produces *water*. The carbon dioxide is carried back by the blood to the lungs of the animal, where it is exhaled into the air, while the water is carried off by the kidneys, the lungs and the skin.

Plants breathe as well as animals, but they do this through little openings, called *stomata*, on the under side of their leaves. But, different from animals, plants inhale the carbon dioxide that is in the air, and this is where the carbon comes from, of which they are so largely formed. The carbon dioxide also combines with some of the water that the roots have absorbed and this forms *sugar*, *starch* and *cellulose*, which latter is the woody fibers of the plant. On combining with the water some oxygen is set free and this goes back into the air. From this cycle of operations you will see that there is a constant balance maintained between the oxygen that animals take out of the air and the plants take in, and the carbon dioxide that the plants take out of it and the animals exhale.

Experiments With Liquid Air.—How Liquid Air is Made.—In 1895, Linde, a Swedish chemist, discovered a process by which very low temperatures could be obtained—temperatures as low, nearly, as minus 200 degrees—and this method has since been used for the production of *liquid air*. This process consists of compressing ordinary air and taking the heat out of it by making it flow through pipes immersed in cold water. When the compressed air is cool it is allowed to escape through a nozzle when the air expands, and this again very greatly lowers its temperature.

The chilled stream of air is next made to flow around the pipe which carries the air after it is cooled with water and before it escapes through the nozzle, and this process is repeated so that each time a lower temperature is had until finally a point is reached at which the air becomes a liquid. This is the process that is now in general use for liquefying air and other gases.

The Apparatus Used.—The apparatus of a liquid air plant is generally made up of a two-stage air compressor, that is a compressor having two cylinders, a low pressure and a high pressure one, and this is driven by steam or electric power. The air which is to be liquefied has the water vapor and carbon dioxide extracted from it when



APPARATUS FOR MAKING LIQUID AIR

it is admitted into the first cylinder of the compressor, where it is compressed to about 200 pounds to the square inch.

The air under this pressure then flows through a coil of pipe immersed in cold water, and when it is thoroughly cooled it is allowed to flow through a small nozzle into the second cylinder of the compressor, where it is compressed to 2,000 pounds to the square inch. It is again made to flow through a coil of pipe and is cooled to a still lower temperature by the air which has previously been compressed and cooled, and this changes it into a liquid.

About Liquid Air.—The liquid air thus produced has a pale, sky-blue color, and if allowed to flow out on a plate or into a common bottle it will instantly commence to boil, as ordinary air is so much hotter than it is, and it will continue to boil until all of it has evaporated into the air again. How to keep liquid air after having obtained it was a great problem to the scientists for a while, but Sir James Dewar solved it by inventing a bottle with a double wall—a bottle within a bottle—and then pumping the air out of the space between them. This construction insulates the inside bottle from the outside one so that it takes a long time for the heat of the air outside to penetrate through the vacuum and reach it. This is the origin of the *thermos bottle* which is now so popular for keeping hot liquids hot and cold liquids cold.

Experiments With Liquid Air.—If you have a quart or so of liquid air you can perform magical marvels the like of which the old and honored tribe of Hindu *fakirs* never dreamed. Among these is freezing some mercury into the shape of a hammer; when it sets to a solid it looks very much like silver, and you can use it to drive nails. Drop a hollow rubber ball into a glass of liquid air and when it is frozen it becomes as brittle as though it were made of glass; now throw it on the floor and it will break into a hundred pieces. A beefsteak when frozen in liquid air will ring out like a gong if you strike it with a hammer, but you must not strike it too hard or it will fly to pieces. These are just a few of the many startling experiments that you can make with liquid air, and what it may lead to in the future no one knows.

CHAPTER II

THE MARVELS OF WATER

When the world was in the making there were terrific lightning storms and these great electrical discharges, together with the heat generated by the mighty upheavals of primordial matter, caused the hydrogen and the oxygen to combine chemically as *water vapor* in the atmosphere. This vapor finally fell as liquid water and blanketed the earth and this was the origin of the lakes, seas, and rivers.

What Water Is.—Different from the air, which is a mere mechanical mixture of its two constituent gases, water is formed of free oxygen and free hydrogen in the proportion of one part of the former and two parts of the latter by volume, that is by bulk. Now, these gases will not combine at ordinary temperatures, neither will they burn when they are combined. This, obviously, is a very wise provision, for so inflammable are each of these gases separately that a mere spark would suffice to ignite them, and so fire the whole world.

When oxygen and hydrogen are merely mixed together, like the nitrogen and oxygen of the air, they are very explosive, and when they explode they combine chemically, the resultant product of which is the liquid we call *water*. If a jet of hydrogen is burned in a jet of oxygen they will not explode provided the correct proportions of each gas are maintained. Under these conditions the flame thus produced is, with the exception of the electric arc, the hottest that we know how to make. To obtain the oxy-hydrogen flame a special nozzle is used, and when the flame is directed on a piece of lime it heats it to incandescence and this makes a dazzling light. This *oxy-hydrogen* light, as it is called, was used for years in stereopticons and for spotlights in theatres before the electric light displaced it.

There are two laboratory experiments you can make which prove that water is really formed of oxygen and hydrogen. One of these is to decompose it with a current of electricity, and the other is to combine the two gases by igniting them with an electric spark. To decompose water is easy, for you need only to invert two test-tubes filled with water in a tumbler of water and bring one end of one of the wires of an electric battery under and into one test-tube, and the other wire from the battery under and into the other test-tube. (See Chapter XIII.)

Water that is ordinarily pure will not conduct an electric current, and to make it do so you must put a few drops of sulphuric acid into it. This done, switch on the current and you will see a lot of little bubbles form on each of the ends of the wires, or *electrodes*, and, presently, you will also observe that the water in the upper ends of the tubes is falling, and, moreover, that it falls twice as fast in one tube as it does in the other. This is because the spaces in the tubes are being filled with gases which displace the water as it is formed and that twice as much hydrogen is being formed as oxygen.

As these gases have no color you cannot see them and so to know they are actually there and to tell them apart you must make some kind of a test. This you can do by removing the tube, closed end up, in which there is the least water and holding a lighted match to the mouth of it. There will be a miniature explosion, which is the proof that it contains hydrogen gas and it will burn with a flame that is just about the color of air. To test the other tube for oxygen, remove the tube, closed end up, light a match and blow out the flame of it so that only a kindling spark remains; push it into the tube when it will instantly burst into a flame again, and this proves that it contains oxygen.

Further tests will show that the sulphuric acid added to the water to make it a conductor remains after the water has been *electrolyzed*, as it is called. While the above experiment proves that oxygen and hydrogen have been separated out from the water it does not prove that water is formed of them and nothing else. To show this conclusively you need a laboratory apparatus called a *eudiometer;* this consists of a graduated tube so that two volumes of hydrogen and one volume of oxygen can be passed into it. In the upper end of the tube, which is closed, a pair of platinum wires is sealed in so that a small spark-gap is formed.

Now as long as the hydrogen and the oxygen in the tube are not subjected to heat they will remain merely mixed, but the instant that an electric spark is made to jump across the spark-gap the two gases will explode and chemically combine when a minute drop of water will be produced. Since it takes more than 2,000 volumes of the mixed gases to make one volume of water it is easy to see why the resultant amount of the latter is so very small.

How Water Behaves.—Water in its pure state has neither taste nor odor. If you will hold a glass of it between your eyes and a source of light it will appear to be without color, but if you look at a large quantity of it as, for instance, a lake, it takes on a blue color. This is often supposed to be due to the reflection of the sky, but, as a matter of fact, it is the natural color of the water itself when it is pure or nearly so.

There are three states that water can take on and these are (1) *liquid*, (2) *steam*, and (3) *ice*. At all temperatures between 212 degrees above zero and 32 degrees above zero, using a *Fahrenheit*[3] thermometer, water remains a liquid. When it is heated to 212 degrees it boils at sea-level, and oppositely when it is cooled to 32 degrees it freezes.

When water boils it is converted into true steam, and this is a vapor that cannot be seen. When this vapor passes into the colder air it condenses into minute drops of water. An easy experiment to show that true steam cannot be seen is to take a flask, such as chemists use,

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[3] Fahrenheit, a German physicist, who lived 1686–1736, invented the mercurial thermometer, and made the scale that gives the boiling point of water at 212 degrees and the freezing point at 32 degrees.

partly fill it with water and heat it over the flame of an alcohol lamp or a Bunsen burner. When it boils you will know that steam is being generated and yet you cannot see it in the space above the water. The moment you uncork the flask, though, you will see the so-called steam rising from it in the air.

It is well known that all metals, except certain alloys, and many other solid substances, when heated and which are then allowed to cool, contract; that is they shrink a little. Water, when cooled, likewise shrinks until it reaches a temperature of plus 39 degrees, Fahrenheit, which is seven degrees above its freezing-point. Water is then the heavier. As the temperature falls from 39° to 32° it expands, and the colder water (32°) is at the top of the vessel, as it begins to solidify, that is, to change into ice.

Since the density of ice is less than water it weighs proportionately less, and this is the reason why ice forms on the surface of water as well as floats on top of it. If water continued to shrink as it became ice it would sink and choke up the waterways and besides it might never melt. The mighty force set up by water when it begins to freeze is a phenomenon that you are probably well acquainted with, for it is then that it bursts water-pipes, cracks milk bottles and plays havoc in general. At the end of this chapter we shall tell you how artificial ice is manufactured.

Kinds and Uses of Water.—There is, of course, only one kind of water chemically, but physically there are many different kinds depending on whether it is impure or pure, that is, contains foreign substances or not. Pure water, as you have seen, consists of hydrogen and oxygen and contains nothing else, and this may be obtained in quantities by distilling ordinary water. Rain water is, generally speaking, as free from impurities as is ever found in nature, but as it always contains other substances, it cannot be really called pure. Well and spring water that look so clear and sparkling contain mineral substances of various kinds, while surface water fairly teems with germs, some of which are harmless, while others produce virulent diseases.

Water is the natural drink of man, but as he grew in curiosity and knowledge he experimented with its effect on other substances and so found among other things, that certain herbs, fruit and grains when steeped, boiled and distilled with water produced drinks that were pleasing to the taste and stimulating to the system. Water, however, is necessary to the well-being of all living things, since they themselves, whether plants or animals, are formed of three-fourths part of it. Hence the matter of providing a supply that is free from harmful substances is a vital one to the human race.

And this is also true in the arts and industries, for many kinds of water contain substances which make them unsuitable for certain purposes and, what is more to the point, they are actually injurious, as you will presently see.

About Drinking Water.—Drinking water, or *potable water* as it is called, plays a large part in determining the state of the health, and, consequently, it is important that it should be of the right kind. Now, as already stated, water from springs and deep wells is generally free from germs, but it always contains more or less mineral matter. As the water soaks through the soil the germs in it become attached to the particles of the latter and are not carried down with it; on the other hand, as the water comes in contact with the minerals of the soil it dissolves some of them and carries them along in solution.

If a well is dug, a pump is driven, or the stream finds its way to the surface, as a spring, the water will be pure and wholesome because the disease germs have been filtered out of it. Should the underground stream reach the sea, it carries the mineral substances with it, and when the sea water evaporates, only pure water goes up and, this comes down again as rain.

You can easily find out the amount of foreign matter there is in any kind of water, for all you need to do is to fill a porcelain dish with some of it and heat it over an alcohol, or a Bunsen, flame until it has all evaporated, when the solid matter will remain behind. Where the water seeps through soil containing granite rock very little of the latter will be dissolved away, but where the water comes in contact with limestone large amounts of the latter will be dissolved.

Soft and Hard Water.—Rain water and other kinds of water that contain very little mineral matter are called *soft water*, while, oppositely, water that contains limestone and other mineral substances is called *hard water*. As a matter of fact, water of any kind that contains enough mineral matter to make soap curdle is hard water. Where there are more than twenty-five parts of mineral matter in a million parts of water it does not affect it to the extent of making it hard, but where there are more than fifty parts of mineral matter in a million parts of water it makes it quite hard.

There are two kinds of hard water, and these are: (1) *temporary* hard water, and (2) *permanent* hard water. The difference between them is that you can get rid of the hardness of the first kind by boiling it, since it contains limestone, and this is precipitated, that is, it is thrown down, and deposited on the inside of the kettle. But boiling will not remove the hardness of the second kind for the reason that it contains *gypsum*, or, rather, calcium sulphate, which cannot be precipitated in this way. You can, however, soften permanent hard water to some extent by adding *sal soda* to it, as this tends to precipitate the gypsum when sodium sulphate is left in solution.

How Soap Acts on Water.—When you put soap into soft water it makes it lather or suds, because there is little or no mineral matter in it. But when you put soap into hard water it combines with the mineral substances chemically and forms a compound that cannot be dissolved. If, however, you precipitate the limestone that is in hard water by boiling, or the gypsum by adding sal soda to it as described above, the soap and water will then lather or suds freely.

Where hard water is the only kind available for use in the home it becomes quite an item of expense for it wastes the soap in proportion to its hardness. Not only this, but where it is very hard, the mineral substances get into the pores of the skin and the soap will have very little effect in getting them out. So, too, they lodge between the meshes of goods that are washed and in the same way and for the same reason it is quite impossible to get them clean. Nearly all laundry soaps and washing powders have an excess of soda in them to soften hard water and this has a very bad effect on the goods.

Boiler Water and Boiler Scale.—If you will look into a teakettle you will see, if you use well water in it, that the inside of it is incrusted, or has *fur* on it, as it is sometimes called. This is, of course, the precipitate of the mineral matter caused by boiling the water. Where hard water is used for running engines and steam plants the same action takes place, though on a larger scale and with a more destructive effect. That is to say, the inside of the boiler and tubes becomes coated with the mineral matter and this prevents the heat from passing through them and wastes the coal. There are other disadvantages in using hard water in boilers, and among them are: (1) the boiler scale and boiler plate, of which the boiler is made, expand at different rates and this often leads to weakening the seams; (2) the scale may cause the tubes to get red-hot and this not only shortens the life of the boiler but may cause it to explode; (3) it pits the tubes of the boiler, and (4) it causes the water to foam.

The easiest and cheapest method of keeping a boiler from scaling and pitting and the water from foaming is to use soft water, but this is not always practical. The next best thing is to get rid of the hardness of the water if hard water must be used. If the hardness is temporary the water can be boiled before it is used in the boiler or it can be treated by adding *milk of lime* which is made by stirring slaked lime in water.

To soften boiler water whose hardness is permanent, lime water is added to it, but the amount used must be according to the amount of mineral matter there is in it. Where boiler water has both limestone and gypsum in it so that it has both temporary and permanent hardness, both can be removed by adding a solution of crude caustic soda to it. What is called the *permutit process* is also widely used for softening boiler water. Permutit is a coarse kind of sand, and when the water to be used is filtered through it the mineral substances react with the sand, and the sodium, which is in the sand, replaces the calcium in the water. The sodium compound goes into the boiler with the water but has no action except to clean it.

Purifying Water on a Big Scale.—To provide water in sufficient quantities to supply cities has been one of the great problems of civilized mankind, but it is only during the last fifty years or so that the necessity for purifying water for drinking purposes has been fully taken into account. Now there are several ways by which water can be purified and among the more important are by: (1) *boiling*, (2) *aeration*, (3) *chemical processes*, (4) the *ozone process*, (5) *biological processes*, (6) the *coagulation method*, and (7) *mechanical separation*.

For purifying water on a small scale, as for home use, boiling is the simplest and best method. But for purifying water on a large scale the last-named six methods given above are employed either separately or in combination. Aerating the water is done either by throwing it into the air or else letting it fall over a steep hill of rocks. In either case when the water comes into contact with the air some of the oxygen of the latter is dissolved out of it. While this treatment improves the water it does not purify it to any great extent.

One of the chemical processes consists of adding bleaching powder to the water, when chlorine is liberated and this gas kills off all the harmful germs. *Ozone*, which is a vigorous form of oxygen, is produced by electric discharges in the air and this when introduced into the water also kills off the germs. Ozone is far better than chlorine for this purpose, as an excess of the former in the water cannot be detected, whereas any excess of the latter gives the water a bad taste. The most curious of all methods for purifying water is that of putting germs that are harmless to the human system into the water and these kill off the harmful germs. This is known as a *biological process*.

Another curious way of ridding water of germs is by the *coagulation process*. In this process a harmless glue-like substance is put into the water, and the germs and other impurities stick to it. The mass is then separated out from the water when the latter is left comparatively pure. In the *sedimentation method* much of the impurities, including the germs, falls to the bottom, but it does not get rid of all of them. Usually after sedimentation the water is passed through mechanical or sand filters which remove the rest of the germs and other impurities.

How Artificial Ice is Made.—Making Ice With Ammonia.—Ammonia is one of the easiest gases to liquefy, and this property is taken advantage of in making artificial ice. To liquefy ammonia gas all that is necessary is to compress it, causing it to lose heat. Then, when the pressure is removed, the liquefied ammonia expands into a gas again and as it does so it absorbs a large amount of heat. In this latter operation the heat which it absorbs is taken from water which surrounds the ammonia pipes and this produces a freezing temperature.

The apparatus used for the manufacture of ice by the ammonia process consists of a compressor driven by an engine or other source of power, a water-cooled series of pipes, and a cooling-tank. Ammonia gas is passed into the compression cylinder where it is compressed and liquefied, then it is passed through a series of pipes on which cold water drips.

It is next allowed to expand into a gas, and as it does so it flows through another series of pipes immersed in a tank of *brine*, that is a solution of salt and water, which will not freeze at the temperature of ordinary water. As the ammonia flows through these pipes it absorbs the heat of the brine until the temperature of the latter drops to below plus 32 degrees Fahrenheit, which is the freezing-point of ordinary water. Sheet-steel cans filled with distilled water are immersed in the brine, and thus the water in them is frozen.

CHAPTER III

FIRE, HEAT, AND FUEL

To make and to use fire belongs to mankind alone. None of the animals, not even the manlike apes, such as the gibbon, orang and chimpanzee, know how to use fire, much less how to make it. But when the first man was evolved, something like a million years ago, his first real exploit that set him above the monkey family was to use fire. Then, with the coming of modern man, or *Homo-sapiens* (which means man-wise), came the knowledge of how to make a fire when and where he wanted it.

Origin of Ways of Making Fire.—It is easy to guess that before primitive man had learned how to make fire for himself he obtained it from the hot ashes, or lava, that was thrown out, or flowed down, into a valley from some volcano, or that he found a tree ablaze which the lightning had struck, or the dried grass burning where a meteor had fallen. As to the method he first employed to make a fire it seems reasonably certain that it was either by striking two stones together or by rubbing a stick of wood against another and softer piece.

The *concussion* method, as the first is called, was carried on through the ages, with the slight modification of using a piece of steel in the place of one of the rocks, until the middle of the last century when matches came into general use. The first friction match was, however, invented as far back as the fifteenth century. Robert Boyle, who was one of the first of the real chemists, discovered, in 1680, how to obtain *phosphorus*, and under his direction Godfrey Hawkwitz made a match by dipping a wood splint in *sulphur* and then securing a bit of phosphorus to it.

The reason phosphorus is used is because it ignites at a very low temperature; in fact, *yellow phosphorus* will take fire when it is exposed to air, while *red phosphorus* must be heated a trifle before it will do so, and a little friction is all that is needed. Owing to the danger and trouble of using the phosphorus, which was evidently of the yellow kind, and also to its high cost, the match did not come into general use until more than one hundred and fifty years later.

What Fire and Flame Are.—When a substance combines violently with oxygen, which the air supplies in unlimited quantities, both heat and light are produced, and we say that the substance is *burning* while we call the phenomenon *fire*. The act or operation of something *burning* is called *combustion*, but burning and combustion are words that are generally used to mean the same thing. Many substances which burn contain hydrogen and other gases, and when these are ignited they stream forth into the air and produce *light*. In nearly all kinds of flame the light is set up by solid particles formed chiefly of carbon suspended in the gas and heated to incandescence—that is white hot.

Burning and the Kindling Point.—Before you can make a piece of paper or wood burn you must heat it, and until you have heated it to a certain degree of temperature it will not take fire. The lowest temperature at which paper, wood, or any other substance will ignite is called its *kindling point*, or *kindling temperature*, and this differs with different substances. That different substances have different kindling points is taken advantage of in making parlor matches; that is one end of the splint is dipped into melted paraffin and this is coated with a compound of phosphorus and chlorate of potassium.

Now when you strike the match the heat developed by the friction fires the phosphorus and frees the oxygen of the chlorate of potassium and in burning this heats the paraffin until its kindling point is reached and it takes fire; this in turn heats the wood splint until its kindling point is reached when it finally takes fire. That a substance must have its temperature raised to the kindling point before it can ignite is a wise precaution of nature, for if it did not prevail, the moment any kind of combustible material came into contact with oxygen it would take fire. Bear in mind that the kindling point of a substance is the *lowest* temperature at which it will ignite and that it has nothing to do with the temperature set up by the substance when it is burning.

When Things Burn in Air.—To make a substance burn, you must have plenty of oxygen present and raise the temperature of the substance to the kindling point. The oxygen that is in the air furnishes enough of this gas for all ordinary burning purposes and most materials that burn, especially those we use for fuel, are composed chiefly of carbon, hydrogen and such substances as will combine readily with oxygen when they are raised to the kindling point.

Temperatures that are very much higher than those when ordinary substances burn can be had by burning aluminum in oxygen which is set free from some of the oxides of metals such as *ferric oxide*, that is iron rust. The great affinity of aluminum for oxygen when it is fired makes it burn at a temperature high enough to melt any of the metals. This forms the basis of welding and producing pure metals known as the Goldschmidt *thermit process* and you will find more about it in the chapter on *metals*.

How to Start and Put Out a Fire.—To start a fire easily you must have an excess of oxygen and this is the reason why you use paper or shavings first, and kindling wood next before you put on the wood or coal. This is also why you fan the fire with your hat, blow on it with your mouth or, better, with a bellows blower. To keep the fuel burning after it takes fire there must be sufficient oxygen and hydrogen to combine fast enough to keep the temperature higher than the kindling point, and to set free the products of combustion.

The way to put out a fire is just the reverse of kindling and keeping it going. Where a fire has just started, a quick way to put it out is to smother it with a blanket as this keeps the oxygen away from it and the carbon dioxide around it. Where a building is burning water is thrown on it, as this takes up much of the heat by absorbing it, keeps the temperature below its kindling point, while the steam that is formed prevents the air from supplying more oxygen to it. Fire extinguishers are made so that when they are opened they will generate carbon dioxide, or some other vapor that will not burn or support combustion, and the pressure of these gases throws a stream of water on the blazing material.

About Spontaneous Combustion.—When oxygen combines with other substances whose temperature has been raised above the kindling point it oxidizes them and they either decay or rust. The chemical action is quite like burning but, of course, there is very little heat developed and usually no light is produced. When oxygen combines with some substances, as for instance linseed oil in which wool is soaked, the heat developed may not be released; if it is kept in by the wool until it becomes hot enough to raise the temperature to the kindling point, the material takes fire and this is called *spontaneous combustion*.

Heat is a Form of Energy.—Heat is a form of energy and not a form of matter as it was once thought to be. Heat can be produced in different ways, as for instance by friction, by passing a current through a wire which has resistance, and by chemical action. The latter method is the one that we are interested in here as a means of producing heat. Now all substances of whatever kind are made up of little particles of matter called *atoms*, and when a substance is burning, the action of the carbon and hydrogen atoms in combining with the oxygen gives rise to vibrations in the ether which permeates and surrounds all matter. It is by these vibrations in the ether that the light and heat are transmitted from the burning body. If the vibrations of the ether come into contact with your body they act on the *thermal nerves* of it and in this way you get the sensation of heat.

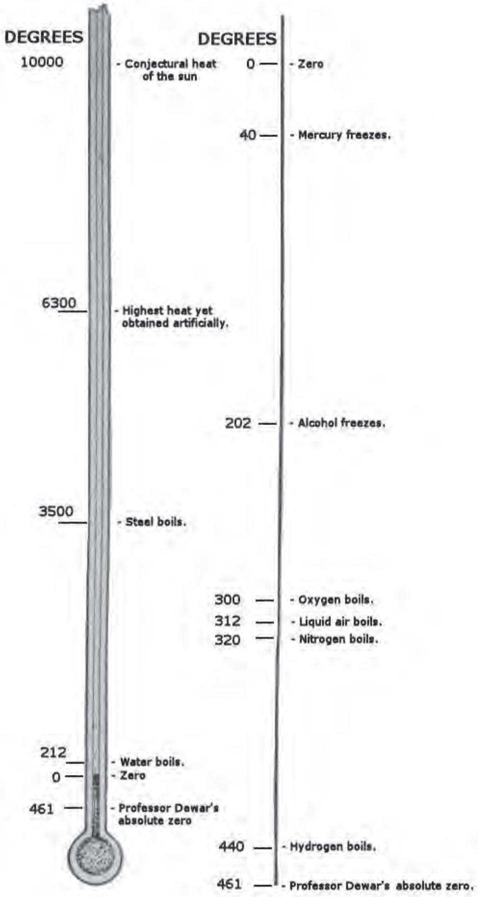
Heat as a Power Producer.—There are different ways by which power can be produced as, for instance, by using the wind, the water and heat. Heat is the most dependable and easiest controlled source of power, and it has the great advantage of being available at any place any time where there is fuel. To use heat to produce power, fuel is either burned under a boiler and the steam generated in the latter is then made to drive the piston of an engine, or it is burned directly in the cylinder of an engine and so drives the piston.

In either case the reciprocating motion of the piston thus obtained is converted into rotary motion by means of the crankshaft; the power thus developed is easily converted into other powers as, for instance, hydraulic pressure, compressed air, and electricity. From this you will see that by combining two or more substances by burning them the chemical energy can be released to furnish power.

The Meaning of Temperature.—When you pick up an object you say it is *warm* or *cool*, or *hot* or *cold*, but why do you say it and what do you mean by it? Just this. The chemical action going on in your body heats it to about 98 degrees Fahrenheit and if the object that you say is *warm* or *hot* is heated more than your body, it gives heat to you until the temperatures are the same. If the object feels *cool* or *cold* then the heat of your body is imparted to it until the heat of both is equalized. This extent of the heat of objects and things in general is called its temperature and it is measured in *degrees*.

To Measure Temperature.—The degree of heat of a body, that is the temperature of it, is measured by that familiar little instrument called a *thermometer*. This device consists of a glass tube having a very small bore and with a bulb on its lower end. The bulb is then filled with mercury and the upper end of the tube is sealed off. The tube is mounted on a *scale* having the *degrees* marked on it. Now mercury is a metal that remains a liquid at ordinary temperatures and like all other metals, except certain alloys, it expands when it is heated and contracts when it is cooled, hence it rises and falls in the tube as the temperature of the air, or whatever it is in contact with, changes.

The way the scale of a thermometer is marked off into degrees so that it will show the difference of temperature accurately, and hence measure it, is by placing the thermometer in melting ice and then marking off the point where the mercury has fallen in the tube, and this is the freezing point. This done, it is placed in boiling water and the point marked off where the mercury has risen in the tube, and this is the boiling point. The scale between these two points is divided into an equal number of spaces and a few like spaces are marked off above and below the freezing and boiling points.



THE EXTREMES OF TEMPERATURE

This thermometer shows a variation from 10,000 degrees of heat to absolute zero, 461 degrees below our Fahrenheit zero. This is over 400 degrees below the point where mercury freezes.

Two kinds of thermometer scales are in general use in the United States, namely the *Centigrade scale* and the *Fahrenheit scale*. The freezing point on a Centigrade scale is marked *0* and the boiling point *100* and the scale in between is divided into 100 equal spaces. This thermometer is used for scientific work. The freezing point of a Fahrenheit scale is marked *32*, and the boiling point *212*, hence the scale is divided into 180 equal parts. This thermometer is in use for domestic purposes generally, among English-speaking peoples.

The Chemistry of Fuel.—Substances of any kind which will burn and thus develop heat can be used for fuels. A substance that makes a good fuel is one whose constituents will combine easily with the oxygen of the air, gives off a large amount of heat, and is so plentiful that it is cheap. The best fuels are those which are formed chiefly of carbon and hydrogen, for when these combine with the oxygen of the air they develop large amounts of heat and leave little or no ash behind.

When *hydro-carbons*, as fuels which contain carbon and hydrogen are called, burn they give off water vapor and carbon dioxide. If the burning process is not perfect then some of the carbon will pass off into the air and it is this visible product that we call *smoke*. Other foreign substances in fuels such as particles of rock and other minerals are left behind in the form of ashes.

And now let us find out what happens when fuel burns. In the first place, the hydrogen in it is set free and when this burns it makes a flame, or blaze. Then the carbon is heated to incandescence and combines with the oxygen of the air to make carbon dioxide which also passes off into the air. When a fire burns there is nothing wasted so far as nature is concerned, for the weight of the gases given off and the ashes that remain exactly equal that of the fuel used, plus the oxygen absorbed from the air.

Kinds and Qualities of Fuels.—Solid Fuels.—There are many kinds of fuels but all of them may be classified under three general heads, namely those that are solid, those that are liquid, and those that are gaseous. Wood, peat and coal are the chief solid fuels, petroleum and alcohol are the most widely used liquid fuels, while natural and manufactured gases are the chief gaseous fuels.

Wood was the first substance used for fuel and it furnished the only source of heat for mankind throughout the ages until some two centuries ago. Then came the discovery of coal and later petroleum. Wood for fuel is obtained by cutting down trees, but before it is used it must be *seasoned*, that is it must be split and piled up so that the water in it will dry out. Wood consists largely of *cellulose* (see Chapter X on *Paper Making*), a substance made up of carbon, hydrogen and oxygen. Hard wood is preferable to soft wood for fuel, for the harder it is, the longer it lasts.

Wood charcoal is simply charred wood. There are two ways of making it. In the older way cordwood is built up in a conical pile which is then covered with a layer of dirt. Some small holes are made through the layer at the bottom and a large hole is made through the top so that enough oxygen will be supplied to the wood to drive out the water, gases, alcohol, and acetic acid in it, but not enough to make the carbon combine, and, hence, nearly pure carbon in the form of charcoal remains. A more recent method of making charcoal is to heat the wood in a closed iron retort without any air whatever, and in this way the alcohol and other products of the wood can be saved.

COKE OVENS NEAR ALTOONA, PA

These ovens are filled from overhead with soft coal. The doors are sealed during firing.

Peat is a kind of fuel that we who live in the United States know little about, but in Ireland and some other European countries it is used extensively. Peat is partly decayed vegetable matter so that it is neither wood nor coal. It is composed chiefly of moss which, when it dies, furnishes a bed for a new growth. As these various growths die they form a thick layer and this then breaks up under the action of the water that covers it into loose particles. Before it can be used for fuel it is cut out of the peat bog and laid in the sun to dry out. It then has somewhat the appearance of coal but different from the latter, nearly one-third of it is oxygen. It also contains a great deal of mineral matter which of course remains behind as ashes.

When the world was young, that is to say in the *carboniferous period*,[4] extensive areas were covered with swamps, the air was heavy and the temperature was tropical. This climatic condition caused ferns to grow in size as large as our present-day trees and as they died they were covered with water and underwent a process of partial deoxidation, or removal of oxygen. Then the great storms covered them over with soil and rock, and the pressure forced the gases out of them and left more or less pure carbon, or coal.

There are two kinds of coal in use: *bituminous*, or soft coal, and *anthracite*, or hard coal. The difference between them is that bituminous coal contains a great

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[4] This is believed to have been about eighteen million years ago, when there were great swamps and fern forests and the first reptiles appeared.

deal of gas and many other substances including tar, and about whose marvels we shall tell you later.

Anthracite coal is formed chiefly of carbon, because the pressure of the soil on it was sufficiently great to force out the gases and other matter, leaving practically pure carbon behind, hence it burns with little flame. By enclosing bituminous coal in a closed retort and heating it, coke results, just as charcoal results when wood is burned in a retort. Also the various by-products can be recovered from it including the valuable coal tar which was once thought to be worthless and was thrown away.

Liquid Fuels.—Of the liquid fuels crude *petroleum* and *alcohol* are the most widely used. Crude petroleum, so called from the Latin words *petra* which means *rock* and *oleum* which means *oil*, is a thick, heavy oil from which fuel and other oils and products are obtained. It was first discovered in Pennsylvania but it has since been found in nearly every country on the globe. It is held in pockets in what is called oil bearing sandstones, hence the name petroleum, or *rock-oil*, and in conglomerates known as oil sands.

These oil pockets, or pools, are usually at considerable depths from the surface of the earth and to reach them wells are drilled through the intervening strata of earth. To separate the various oils from the crude petroleum it must be distilled, or refined, as it is called, and instead of doing this at the oil fields it is done at other places. Thus the petroleum obtained in the oil regions of Oklahoma is pumped through a pipe line to refineries in New Jersey.

At these refineries there are great stills and into these the crude petroleum is put, and heated. As each of the various oils in the petroleum has a different boiling point they pass off in vapors at different temperatures. This is what is called *fractional distillation*. In this way, then, the *gasoline*, *benzine* and *kerosene*, which are light oils are produced. Then there are the heavier oils used for lubricating, vaseline, and paraffin, while at the bottom of the still after the run is made a very hard cake remains.

Alcohol for fuel is made by fermenting grains, or other starchy materials, and molasses and sawdust. It is largely formed of hydrogen, hence burns with a colorless flame which is free from soot and has a high heat value. It makes an exceedingly convenient fuel where a small, hot flame is needed and it is sufficiently explosive to use in internal combustion engines.

Gaseous fuels may be either *natural* or *manufactured*. *Natural gas*, like petroleum with which it is usually associated, is found in airtight pockets in various localities. It is always under pressure and by drilling wells it issues forth in a stream. In the districts where it is found it is used exclusively as a fuel, for it is at once cheap and has a high fuel value. Illuminating gas is made either by heating soft coal in closed retorts when it is called *coal gas*, or by forcing a stream of air over the coal after it has been heated to incandescence, when it is called *water gas*.