THE WONDER BOOK OF CHEMISTRY

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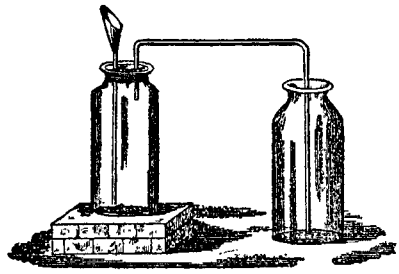
BY

JEAN-HENRI FABRE

TRANSLATED FROM THE FRENCH BY

FLORENCE CONSTABLE BICKNELL



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TRANSLATOR'S PREFACE

"What is the use of a book without pictures or conversations?" asks Alice, disgustedly, just before taking her departure for Wonderland, where she finds no lack of animated discourse.

This book, like its predecessors in the series, is conversational in form and has as many pictures as the subject-matter calls for.

All boys and some girls, as well as their elders, take more or less interest in the marvels of chemistry. To give an elementary but useful knowledge of these marvels, chiefly by means of simple experiments clearly described by the writer and easily performed at home by any wide-awake young reader, is the object of the following talks by "Uncle Paul."

The personal, biographical interest of the book is not to be overlooked. The boys Jules and Emile are the author's own children, faithfully portrayed even to the names they bear. In his captivating fashion the man of vast learning makes himself at once teacher and comrade to his young hearers, and we learn that "his chemistry lessons especially had a great success. With apparatus of his own devising and of the simplest kind

he could perform a host of elementary experiments, the apparatus as a rule consisting of the most ordinary materials, such as a common flask or bottle, an old mustard-pot, a tumbler, a goose-quill or a pipe-stem. A series of astonishing phenomena amazed their wondering eyes. He made them see, touch, taste, handle, and smell, and always 'the hand assisted the word,' always 'the example accompanied the precept,' for no one more fully valued the profound maxim, so neglected and misunderstood, that 'to see is to know.' " Though living creatures necessarily claimed the naturalist's first affections, he none the less "animates even the simple elementary bodies, celebrating the marvelous activities of the air, the violence of chlorin, the metamorphoses of carbon, the miraculous bridals of phosphorus, and the 'splendors which accompany the birth of a drop of water.' "

Concerning the eager young pupils, Jules and Emile, by this time well known to all readers of the series, a still further word may not be out of place. Emile, the younger, the "giddy-pate" of the narrative, impulsive and full of boyish curiosity and vigorous young life, is drawn for us with fidelity and a delightful touch of humor by the loving father. Jules is shown to us as more sedate and gifted with finer qualities, and with his grief-stricken parent we mourn his early death. "He was a youth of great promise, 'all fire, all flame'; of a serious nature; an exquisite being, of a precocious intelligence, whose rare aptitudes both for science and literature were truly extraordinary. Such too was the subtlety of

his senses that by handling no matter what plant, with his eyes closed, he could recognize and define it merely by the sense of touch. This delightful companion of his father's studies had scarcely passed his fifteenth year when death removed him. A terrible void was left in his heart, which was never filled. Thirty years later the least allusion to this child, however tactful, which recalled this dear memory to his mind, would wring his heart, and his whole body would be shaken by his sobs."[1] In a memorial foreward to the second volume of his "Souvenirs Entomologiques" the bereaved father pays loving tribute to this lost son and fellow-worker.

Thus it is said that the following chapters will be found to have a human and personal appeal to supplement their scientific interest. May they yield both pleasure and profit to their readers!

[1] The quoted passages are from Dr. C. V. Legros's "La Vie de J.-H.Fabre, Naturaliste," translated by Mr. Bernard Miall under the title, "Fabre, Poet of Science," and published by The Century Co.

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CHAPTER I

INTRODUCTION

UNCLE PAUL is a man of some learning who waters his lettuce-plants and weeds his cabbages and turnips in the quiet of a humble little village. Staying with him are his nephews, Emile and Jules, young scholars already grappling with the intricacies of the rule of three and the pitfalls of the past participle, and both of them very eager to learn. Jules, the elder, is even now beginning to suspect that school will not have taught him everything when he has mastered his grammar and arithmetic. Their uncle does his best to encourage the boys' desire for knowledge, convinced as he is that in the stern battle of life our best weapon is a trained intellect.

For some time past his family had noticed in him an unusual preoccupation. There was ripening in his mind a plan for teaching his nephews the rudiments of chemistry, that science so fruitful in its practical applications.

"What are these dear children going to be, some day?" he asked himself. "Will they be manufacturers, artisans, mechanics, farm laborers, or what? Who

knows? One thing, at any rate, is certain, and that is, whatever direction their activity takes it will be to their advantage to be able to give an account of the things they have accomplished. A little science is something that they must have. I should like my nephews to know what air is, and water; why we breathe, and why wood burns; the nutritive elements essential to plant life, and the constituents of the soil. And it is no vague and imperfect knowledge from hearsay I would have them gain of these fundamental truths, on which depend agriculture and the industrial arts and our health itself; I would have them know these things thoroughly from their own observation and experience. Books here are insufficient, and can serve merely as aids to scientific experiment. But how shall we manage it?"

In this wise did Uncle Paul ponder over his project, a project involving grave difficulties, such as the want of a laboratory and of all those ingenious devices without which it would at first seem impossible to undertake any serious experiments in chemistry, the only appliances at hand being the commonest of household utensils,—bottles and phials, jars and pitchers, plates and cups and earthen bowls, drinking-glasses and old mustard pots. It is true the distance to town was not great. For special occasions, but within the very modest limits set by an imperative economy, a few drugs and glass implements might be bought. Ten francs must be made to cover these extraordinary purchases. How, then, to impart some useful knowledge of chemistry with the help of little more than such simple appliances as the village could furnish—that was the problem.

But in the end it came about that one day Uncle Paul announced to his nephews that he proposed to enliven the monotony of their regular studies by introducing a little diversion. Without using the word "chemistry," which would have meant nothing to them, he spoke of certain interesting things he had to show them, of various wonderful experiments to be performed. Lively and curious, as are all children, Emile and Jules greeted this announcement with enthusiasm.

"When shall we begin?" they asked. "Tomorrow—to-day?"

"To-day, very soon. Give me five minutes for my preparations."

CHAPTER II

MIXING AND COMBINING

NO sooner said than done. Uncle Paul went to his neighbor the locksmith and from among the files on the artisan's work-bench selected something and wrapped it up in a piece of paper. Then he visited the apothecary and for a few cents bought a drug which he also wrapped in a bit of old newspaper, after which he returned home with his two packages.

"What is this?" he asked, opening one of the parcels before the children.

"It is a yellow powder that makes a little crackling sound when you rub it between your fingers," replied Emile. "I think it must be sulphur."

"And I," added Jules, "am sure it is sulphur. But we'll soon see."

So saying he took a pinch of the yellow powder and dropped it on some live coals from the kitchen fire, whereupon it began to burn with the blue flame and the suffocating odor of a sulphur match.

"That proves it, I hope," cried the lad, much pleased with himself at having found a quick way to demonstrate

the nature of the substance offered by his uncle. "It is sulphur and nothing else, for that is the only thing that burns with that blue flame and that smell that makes you cough."

"Yes, my boys," assented their uncle, "it is sulphur powdered very fine and called flowers of sulphur. And now what is this?"

He opened the second package and displayed its contents, consisting of a powdered metal, the fact of its being a metal showing clearly in its glittering particles.

"That looks very much like iron filings," declared the younger of the two observers.

"It does more than look like them," asserted the other; "it really is iron filings. Uncle Paul, you must have got them from the locksmith's".

"Though I must congratulate Jules on his cleverness and quickness," rejoined Uncle Paul, "I ought at the same time to warn him against jumping to conclusions. In the studies we are about to take up together it is best to exercise careful scrutiny before venturing on any assertions, as otherwise one would run the risk of making frequent mistakes. You say these metallic particles are iron filings; but lead filings, tin filings, zinc filings, iron filings—all are of very much the same appearance, being all light in color and having a bright luster. You declared the yellow powder to be sulphur after you had proved it by dropping a pinch on burning coals. Now find an equally decisive proof that these filings are of iron."

The boys put on their thinking-caps and looked at each other in mutual questioning, but no happy thought came at their bidding. To what test could they put those filings to prove that they were indeed of iron? It was a puzzling problem, that was certain. But at last Uncle Paul started the boys on the right track.

"How about the magnet," said he, "that horse-shoe shaped piece of iron bought by Jules at the last fair and added to his little cabinet of apparatus for making experiments in physics? Wouldn't it be just the thing to help you out in your present perplexity? Many a time I've seen you amusing yourselves with that magnet by making it draw to itself bits of iron, nails, needles. Does it have the same effect on lead?"

"No," replied Jules; "I have never been able to make it take up the least little bit of lead, though it will lift much heavier weights of iron,—a key, for example."

"Does it attract tin?"

"No; no more than lead."

"And zinc and copper—does it have any effect on them?"

"No more than on lead or tin. Ah! Now I have it. The magnet attracts only iron. That's the test we're after. Now we'll see."

Thereupon Jules ran upstairs, two steps at a time, and hastened to his cupboard where, on a pine shelf, were arranged his books and his little pieces of apparatus,—simple appliances and mostly of his own make. Eagerly catching up his magnet, he ran downstairs and brought

it almost in contact with the filings. Immediately there were clusters of them clinging to the two ends of the magnet, forming long beards of bristling appearance.

"See there," cried the lad, "how it makes the filings come to it! I am sure now they are iron, nothing but iron."

"Yes, my boy, they are iron," assented his uncle; "and it was the locksmith's work-bench that furnished me with the filings. Now, with this iron and this sulphur, which we have just proved to be iron and sulphur beyond any doubt, we will enter upon our study of chemistry. Give your attention to what I am about to do."

So saying, he emptied on a large sheet of paper both the flowers of sulphur and the iron filings, after which he mixed them thoroughly together by shaking the paper like a sieve and stirring its contents with his fingers.

"Look, now," said he; "what have we on the paper?"

"Oh, that's easy enough," Jules made answer; "it's just a mixture of sulphur and iron filings."

"Yes, a mixture; and could you still tell me the one substance from the other, all mixed together as they are?"

"Nothing easier," answered Emile, examining closely what was on the paper. "Here, for instance, are some grains of sulphur; I know them by their yellow color; and here are some of the iron filings, as you can tell by their shiny look."

"And would you undertake to separate the particles of one kind from those of the other,—to sort them all out?"

"Why not, if it really had to be done? I have good eyes, and with the help of a pin I could gather all the sulphur together on one side and all the iron on the other. Only, I doubt whether my patience would hold out to the end."

"Yes, it certainly would be a rather longer job than picking over a plate of beans; and Emile's patience, however great it may be, would be hardly equal to the task. Still, the thing is not impossible. In that little heap, which has now neither the yellow color of pure sulphur nor the lustrous gray of pure iron, but which has at once something of the two colors and is consequently of a greenish appearance—in that little heap of matter, I say, an eye of sufficient patience and a hand of sufficient dexterity could, between them, see and separate what is sulphur from the iron. But there are other ways of making the separation. Who will find one? Come, now, set your wits to work."

"I have it!" cried Jules, passing the ends or poles of his magnet back and forth through the mixture.

"Just what I was going to propose," said Emile, "if Jules had given me a moment to think about it. Now that Uncle has reminded us of the magnet, the rest comes of itself."

"To hit on the way out of a difficulty after a moment's reflection is all very well, my young friend," rejoined his uncle; "but to hit on it immediately is still better.

However, you will get even with Jules very soon, I am sure. Now let us see how his method of sorting the two substances succeeds."

Jules went on passing his magnet through the mixture of iron filings and sulphur, with the result that the metallic particles were attracted to the two poles of the magnet and clung to them, while the sulphur was left behind. Again and again the magnet was plunged into the heap, and each time it was withdrawn loaded at its two extremities with long and thick beards of filings which the young operator detached with his finger-tips, and placed at one side. Not a particle of the sulphur clung to the magnet, or at least not by the force of attraction, the magnet exerting no such force on sulphur; and if any scattering particles were found among the iron filings set aside by themselves, it was simply because they had become enmeshed among the grains of metal. A second, similar sorting very easily separated them.

"That's the way to do it!" exclaimed Jules, delighted with the success of his operations. "That's the way, see! The magnet comes out each time loaded with filings, and the sulphur is left behind. If I went on, it wouldn't take me more than ten minutes to separate all the iron on the paper from the sulphur."

"It is unnecessary to continue, my dear child," said Uncle Paul. "Your method is perfect, being both expeditious and unfailing in its results. Now put the iron filings back with the sulphur and mix the two well together. Your magnet, so serviceable to us in

this process of sorting the two substances, is not at the disposal of every one. Wouldn't it be possible to get along without it, to make the desired separation in some other way? It is well, it is even indispensable, especially for us with our meager outfit, to learn how to do without what we do not possess, and nevertheless to attain results. Let us, then, dispense with our magnet and find some other way to separate the iron filings and the sulphur. Think a moment. I will help you. Which is the heavier of the two substances, the sulphur or the iron?"

"The iron," replied the two young chemists.

"And what would the iron do if we threw it into the water?"

"It would sink to the bottom."

"And the sulphur—what would that do? I mean finely powdered sulphur, flowers of sulphur, not sulphur in the lump, for that too would sink in water."

"I see!" Emile made haste to answer, lest he should again be outstripped in this race of wits by his elder brother. "I see! I will throw the whole mixture into a glass of water and the iron will sink to the bottom, but the sulphur—wait a minute—the sulphur—"

"Hush, Jules!" cautioned his uncle, as the lad showed signs of breaking in. "Let your brother finish."

"The sulphur," repeated Emile, his cheeks flushed with animation, "will stay on the surface; or perhaps it will sink, but not so fast as the iron, which is much heavier. Let's try it."

"I was confident, my good Emile," said his uncle, approvingly, "that you would soon get even with Jules. Yes, your idea is excellent, and if you hesitate a little in putting it into words, that is only because you are in some doubt as to how the sulphur will behave. I will put the thing to the test for you."

Uncle Paul thereupon took a large glass and filled it with water, into which he dropped a handful of the mixture, stirring the liquid at the same time with a small wooden stick. Having thus started a brisk movement in the glass, he paused and awaited results. Very soon the iron filings, because of their weight, had settled to the bottom, while the flowers of sulphur continued to circle about in the liquid. This liquid was next poured off into another glass, and when it came to rest the sulphur held in suspension gradually settled. Thus the two substances were collected, each by itself, the iron in the first glass, the sulphur in the second.

"You see, my young friends," said Uncle Paul, "it is accomplished quite as expeditiously as with the magnet, and the process calls for nothing that any one would not have at hand. Let us learn, I repeat, to do without what we lack and still to attain the end in view. It would be easy, you understand, for us to separate the two substances in the whole mixture by treating it a handful at a time in the manner just shown to you; but that is quite unnecessary for my present purpose. Let us sum up briefly what we have just learned. Two or more substances of different kinds form a mixture when their union does not prevent their being separated by the simple process of sorting, effected in one way

or another. The heap there before you is a mixture of sulphur and iron, and these can be separated either with the help of a magnet or with water, or given sufficient time and patience, a grain at a time by hand. So much for that. Now let us pass on to something else."

So saying, he put the mixture of iron filings and sulphur into a bowl, added a little water, and kneaded the mass with his fingers until it formed a thick paste. Then he took a bottle of clear glass, an old discarded bottle that had once contained some sort of syrup or medicine, and filled it with the paste. Finally, in order to heat the mass somewhat, the bottle thus filled was set in the sun, and as it was a summer day the result purposed by Uncle Paul was not long in being attained, thanks to the temperature.

"Now pay close attention," he admonished his pupils, "and you will see something curious."

The boys were all eyes, all attention, in their eagerness to lose nothing of this their first experiment in chemistry. What was going to happen in the bottle? They did not have very long to wait. A quarter of an hour had not passed before something remarkable took place: the contents of the bottle, at first greenish in color from the yellow of the sulphur and the gray of the iron, began gradually to turn black and present the appearance of soot, while at the same time jets of vapor accompanied by hissing sounds escaped from the mouth of the bottle and small quantities of the black substance were ejected as if by the force of an explosion.

"Jules," said his uncle, "take the bottle in your hand

a moment and, no matter what happens, don't loose your hold."

Unsuspectingly the boy approached and grasped the bottle firmly in his hand.

"Oh, wow!" he cried, with a start of pain and surprise; "it's hot, hot!" And all his self-control was needed to prevent his dropping the burning bottle. Replacing it on the ground more quickly than he had taken it up, he turned to his uncle, shaking his fingers like one who has inadvertently touched hot iron. "How it scorches, Uncle!" he continued. "You can't hold it more than a second, it's so hot. If the bottle had been over a fire I should have expected to find it hot; but there is no fire here to heat it, and yet it gets hot like that, all by itself! Who would have thought it?"

Emile in his turn had to handle the wonderful bottle that of its own accord grew so hot as almost to burn any one touching it. First feeling of it cautiously with his finger-tips, then grasping it boldly in his hand, he set it down again not less quickly than Jules had done, while his looks showed the profound astonishment, the utter bewilderment, caused by this generation of heat from no apparent source.

"Water was poured on the mixture of iron filings and sulphur," said he to himself; "it was all wet with water, which is not exactly the right sort of fuel for a fire, and then the whole was set in the sunshine, which isn't what you could call hot, and pretty soon, for no reason that I can see, the mixture grew scorching hot. I can't understand it."

Ah, my little lad, Uncle Paul's chemical experiments will give you many another surprise before they are finished! He who enters on the study of chemistry finds himself transported to a new world, where marvel follows marvel in endless succession. But don't be too bewildered; keep your eyes open, remember what you see, and gradually light will dawn on these perplexing operations which now seem rather to partake of magic than of veritable science.

"We have now learned," resumed Uncle Paul, "at the cost of some little pain to you, that the contents of the bottle become heated, apparently of their own accord, and that this heat is not slight, but very considerable, even sufficient to give a burning sensation. All the rest that happened we must regard as merely resulting from this development of heat. The water with which I moistened the mixture was turned to steam, and hence produced the jets of white vapor that escaped from the bottle. From this vaporized water came also the hissing sounds, the little explosions, and the throwing out of solid matter. If I had at my disposal a larger quantity of iron filings and sulphur,—if my mixture, instead of being limited to a handful or two, had amounted to a full decaliter or more,—I could have produced some far more remarkable results. But I will content myself with describing to you a curious experiment that used to afford no little entertainment to the onlookers.

"A generous allowance of mingled iron filings and sulphur was placed at the bottom of a large hole in the ground, water was sprinkled over the mass, and a mound of damp earth was then heaped upon it. Soon

this little mound would begin to behave exactly like a volcano in eruption: the ground would tremble all about the base of the mound, the heaped-up mass would crack open here and there, and through the cracks would spurt jets of steam accompanied by hissing sounds, explosions, and even tongues of flame. This was called an artificial volcano; but I must not omit to add that real volcanoes are set in action by something quite different from what was going on in that buried mixture of iron filings and sulphur, though this is not the time or the place to explain the difference. However, there is nothing to prevent your employing some of your leisure moments in contructing a miniature volcano of your own with a small quantity of iron filings and an equal amount of powdered sulphur. Your mole-hill of moistened earth, small though it must be, will not lack interest for you: it will at least break open in cracks and send out hot steam."

Emile and Jules resolved to gather up all the iron filings they could at the locksmith's and to buy a few sous' worth of flowers of sulphur, with which they would, at the earliest opportunity, perform the experiment of the artificial volcano. Meanwhile, as they were discussing this project the agitation inside the bottle was gradually subsiding and the temperature rapidly falling, until the bottle became cool enough to be handled without inconvenience. Uncle Paul took it up and emptied its contents on a sheet of paper. What came out was a very black powder resembling soot.

"Now use your eyes," said he, "and see if you can

find any of the sulphur; try to discover even one little grain of it if no more."

The boys rummaged through the heap, stirring it with a pin and scrutinizing it very closely, but could not point to a single particle of sulphur after all their pains.

"Where can it be now?" queried the searchers. "What has become of all that sulphur? It must be there somehow, for we saw it put into the bottle, saw it plainly enough. It is somewhere in that black heap; nothing could be more certain. It hasn't been lost during the experiment, for it didn't come out of the bottle; nothing much except a little steam came out. It must be here, and yet we can't find the tiniest grain of it."

"Perhaps," suggested Jules, "we can't see it even if it is there because it has turned black; but we'll try it with fire and that will settle the question."

And convinced that he now had the solution of the mystery, Jules ran into the kitchen and fetched some live coals, on which he dropped a pinch of the black powder. But what was his disappointment when, after waiting a while and then blowing on the coals to make them burn more brightly, and after trying another pinch of the powder and then still another, each time from a different part of the heap, no ignition took place, no blue sulphurous flame showed itself!

"Well, I declare," exclaimed the bewildered lad, "that beats me! With all that sulphur somewhere in the powder, it won't burn."

"And the iron," said Emile, "I can't see that, either. There's nothing there but a sort of black soot, nothing at all that shines like iron. Let's try the magnet and see if it will separate any of the filings from the rest."

But the magnet produced as little effect as had the live coals; no more bristling beards, no more strings of iron filings clinging to the poles of the magnet, after these had been passed to and fro through the black powder. Nothing was attracted, nothing showed any tendency to adhere to the piece of magnetized iron.

"Well, that's strange," declared Emile, still pushing the magnet into the inert heap, now here, now there. "There's plenty of iron there, that's certain, and yet not a particle of it will stick to the magnet. If I hadn't seen the iron put there I should say there wasn't any in the whole heap."

"And I," chimed in Jules, "should say there wasn't a particle of sulphur there, if I hadn't seen it mixed with the iron. Yet of the two substances that certainly went into the heap, it now seems to contain not an atom; not a speck of sulphur, not a speck of iron can be found in what was made out of sulphur and iron."

Uncle Paul let his two nephews have their say, convinced that ideas thus born of personal observation are worth far more than those adopted on the authority of another. To see is to know. But after the boys had become thoroughly persuaded of their powerlessness to find and separate either the sulphur or the iron, then at last he intervened.

"Well," said he, "would you now undertake to sort the two substances, particle by particle?"

"It's no use," was the reply; "we can't find the least trace of either of them."

"How about using the magnet?"

"That's no good, either; it won't attract anything."

"Well, then, try water."

"I haven't much hope it will help us," answered Jules, "for the whole heap seems to be all of a kind, nothing heavy and nothing light. Still it may be worth trying."

A pinch of the black stuff was dropped into water and stirred into the liquid, but it all sank very soon to the bottom of the glass, without the slightest tendency to any separation.

"So, then," resumed Uncle Paul, "sorting is no longer possible by any of the methods that at first succeeded so well. And that is not all: the appearance and the properties of the mass before us have undergone such a change that, if you did not know beforehand what was there, you would never suspect the presence of the two ingredients."

"But who in the world would ever imagine this black stuff was made of sulphur and iron?" the boys exclaimed.

"The appearance of the mass is changed, as I say," their uncle admitted. "The sulphur had a beautiful yellow color, the iron a lustrous gray, whereas the substance resulting from their combination is neither

yellow nor gray nor lustrous; it is, on the contrary, of a deep, dull black. And the properties are likewise altered: the sulphur was found to take fire readily and to burn with a blue flame accompanied by stifling fumes, but this black substance refuses to ignite when it is placed on glowing coals; and the iron filings were attracted by the magnet, which has no effect on the black powder here. Hence we must conclude that this powder is neither sulphur nor iron, but some third substance of a wholly different nature. Shall we call it a mixture of sulphur and iron? Certainly not, for it is no longer possible to divide the mass into those two ingredients by any process of sorting, the properties of sulphur and of iron having given place to others showing nothing in common with the first two. We have, then, to do with an association far more intimate than that known as 'mixture,'—with one that is known in chemistry as 'combination.' Mixture leaves to the mingling substances their distinctive qualities intact; combination causes them to disappear, and substitutes others in their place. After mixture it is always possible to separate the ingredients by some simple process of sorting applicable to the given case; after combination this is never possible. Hence we may say that two or more substances are combined when they can no longer be separated by the process of sorting, in the customary sense of that word; when, in short, their characteristic properties have disappeared and given place to others.

"Observe, also, my young friends, that these new properties resulting from combination can by no means be predicted from the nature of the combining

substances. Who would ever imagine, with no previous study of these curious things, that sulphur, yellow and readily combustible, could enter into the formation of a black and incombustible powder? And who would think that iron, with its metallic luster and its quick response to the magnet, could be capable of entering into the composition of a substance having a dull black color and no tendency whatever to be attracted by the magnet? Such things are impossible of prediction without previous knowledge. Combination, as you will have occasion to note again and again, works a fundamental change in matter, turning white to black and black to white, sweet to bitter and bitter to sweet, harmless substances to deadly poison and deadly poison to something entirely harmless. Watch well the result when two or more substances combine.

"Still another point demands serious attention. In the process of combining, our mixture of iron filings and sulphur became much heated by spontaneous action; in fact, it grew so burning hot that it was impossible to hold the bottle in one's hands. Jules will long remember the surprise caused him by this unexpected heat. In this connection I must tell you that this rise in temperature is nothing exceptional, nothing peculiar to the combining of iron and sulphur. Every time two or more substances enter into combination there is heat generated, sometimes so slight as to be detected only by the most delicate instruments; sometimes, and more often, of a degree unbearable to the touch; and sometimes, again, of such intensity as to be apparent to the eye in glowing redness or even blinding incandescence. In short, whenever

combination takes place there is more or less heat; and, conversely, whenever heat or light is manifested it is almost always a sign that combination is going on."

"I should like to ask a question, Uncle Paul," Jules interposed. "When coal burns in a furnace, is there a combination going on between different substances?"

"Certainly there is."

"One of the substances, then, must be the coal, mustn't it?"

"Yes, one is the coal."

"And the other?"

"The other is contained in the air. It is invisible, but none the less it is there. We shall consider it at length in its proper place."

"And the wood that burns in the fireplace and gives out heat and light?"

"There too we have a combination that includes the substance of the wood and that other substance contained in the air."

"And lamps and candles that we use for light?"

"Combination there also."

"Then every time I set fire to anything I start a combination?"

"Precisely; you cause two different substances to combine."

"What a funny thing it is, combination!"

"More than funny, my boy; it is useful beyond your power to imagine, and that is why I wish you not to remain ignorant of the marvelous transformations it brings about."

"And will you tell us all about these wonderful things?"

"So far as I am able I will tell you about them, if you will both pay close attention."

"Oh, there's no danger of our not doing that. We won't lose a word, and we'll remember it all, too. I like this kind of lesson ever so much better than long division and conjugation of verbs. Don't you Emile?"

"I should say so!" was the emphatic reply. "I wish I could have lessons like this all day and every day. I'd leave my grammar any time to help make an artificial volcano."

"My dear young friends," their uncle admonished them, "don't let your enthusiasm for chemistry cause you to slight your grammar, if you wish to keep on good terms with me. Chemistry has its place but so has language and no small place, either. Don't neglect your conjugations, hard though they may seem to you. But now let us return to our subject of combination.

"It is, as I have said, always accompanied by heat, sometimes by light. Explosions, detonations, flashes of light, luminous outbursts, and brilliant sparks—all the dazzling display of an exhibition of fireworks, in short—are by no means exceptional when two substances come together in chemical combination. In the act of

thus coming together the two substances unite in the closest of bonds; they marry, as we might say, and heat and light make haste to celebrate the nuptials just as pinwheels and Roman candles celebrate weddings with us. Do not laugh at my comparison; it is apter than you think. Chemical combination is like marriage; it makes one out of two.

"Now I have to tell you what this substance is that has resulted from the marriage of sulphur and iron. We cannot call it sulphur, as it is no longer sulphur; nor can we call it iron, as it is no longer iron. Neither would it do to call it a mixture of sulphur and iron, for what was a mixture in the beginning has ceased to be one now. Its name in chemistry is sulphid of iron, a name that enables us to remember the two substances united in the bonds of chemical matrimony,—iron, which we here write out unchanged, and sulphur, which appears somewhat disguised in the word 'sulphid.' "

CHAPTER III

THE SLICE OF TOAST

THE boys had made their little artificial volcano, and it had proved to be a success, the mole-hill of moist earth becoming much heated, cracking open, and giving vent to spurts of steam accompanied by sharp hissings. All had turned out to the complete satisfaction of the young experimenters, and the resulting sulphid of iron, on being examined at leisure and subjected to every test their imagination could suggest, was declared to be the same substance as that produced by their uncle. At this point he joined them.

"In the black powder now remaining at the heart of your artificial volcano," said he, "there is iron and there is sulphur. No possible doubt as to that can lurk in your minds after you have seen this substance prepared and, what is more, have prepared it yourselves with your own hands. Nevertheless, there is no sign of either any iron or any sulphur in this black powder, so utterly different is it in color and general appearance from both those substances. Had I begun by showing you this powder already made, without telling you of what it was composed, you would most certainly never have suspected it to contain any sulphur or any iron; and had

I told you its ingredients without letting you witness the combining process, you would, I am sure, have taken your uncle's word for it, but at the same time you would have been no little astonished. 'What,' you would have exclaimed, 'sulphur in that stuff, there, which is not in the least yellow and will not burn? And iron, too, where there isn't the faintest shine of iron and nothing sticks to the magnet?' In short, you would have believed me because of your trust in my word, but you would not have had the certainty that comes from seeing the thing done.

"This certainly I have given you by means of the experiment performed before your very eyes, and you have further strengthened that certainty by performing the experiment yourself. We are, then, all three of us, firmly convinced that in this black substance before us there are both sulphur and iron. And now another question arises: Is it possible to make the iron and the sulphur here combined resume each its original form? Can the combination be undone and the two ingredients recovered as they were in the beginning? Yes, my young friends, the thing is possible, but no simple process of sorting will suffice to disunite the two substances. You remember how all your attempts to accomplish this were so much wasted effort. What combination has joined together, no sorting can put asunder. To effect the separation, it is necessary to resort to scientific methods belonging to the domain of chemistry; and as your acquirements in that domain are still of the slightest, I will not invoke the aid of those methods. Besides, for our present purposes the actual

separation of the sulphur and the iron is of very little importance. Inasmuch as the black powder does really contain them, it is incontestable that they can, by the requisite means, be obtained from that powder; and that is all I wish to impress upon you at present."

"There can't be any doubt," Jules assented, "that a substance made of iron and sulphur must furnish iron and sulphur when properly treated. No one could dispute that. All the same, I should like to see the iron filings come back as iron and the flowers of sulphur come back as sulphur."

"I repeat, my dear child, that the operation would not be difficult, but it would call for drugs quite unknown to you and would be a mysterious and perplexing performance in your eyes. Let us see but little at a time and see that little plainly; that is the way to acquire substantial and lasting knowledge.

"But, now that we are on the subject, I will say to you that what is done by combination is not always the easiest thing in the world to be undone. These chemical marriages, signalized by manifestations of heat and light, unite substances in bonds so close that to sever them it is necessary to employ methods known only to advanced science. However easy the act of union, the disunion is difficult. Combination takes place of itself; separation is a more arduous undertaking. We have lately seen the iron and the sulphur combine in a short time with no aid from us; but if now we should try to separate them, we should meet with enormous

resistance, which only the most skilful methods could overcome.

"There are instances, however, in which quite the opposite is to be noted, combination being so difficult and delicate a process as to defy our utmost endeavors, but separation offering so little of resistance that a mere nothing, almost, will accomplish it. There are substances that dissolve their partnership with peculiar ease: a shock, a jar, a breath, an imperceptible trifle, will suffice to effect the severance. You touch them, you merely move them a little, and *piff!* there is an explosion before you can snatch your hand away, with a flying of particles in this direction and that as if no such thing as union had ever existed. There are chemical marriages between incompatible natures that sigh only for divorce."

"And are there really," asked Emile, "substances that fly apart, that go *piff!* just from being touched?"

"Yes, my child, there certainly are. You yourself are familiar with some of them. Those New Year's bonbons done up in particolored paper and known to you as snappers—don't they recall anything to your mind?"

"Why, yes; each bonbon has a rebus to be guessed, and then there's a little strip of parchment that gives a pop when you pull it by both ends at once. What is it that makes the little explosion?"

"It is a substance made by combining different ingredients which fly asunder as soon as they are disturbed by the parting of the two pieces of parchment forming the strip. You see how easy the act of separation is in this case: just disturb the slumbers of the explosive

material by pulling at the two ends of the strip, and that is enough to cause a disruption accompanied by a sharp report. In like manner a house of cards collapses at a mere touch.

"A similar substance causes the explosion of the toy torpedoes that give a pop when you throw them on the ground, and to this substance is due also the explosive quality in the percussion-caps of guns, the cap being ignited by the fall of the hammer when the trigger is pulled. A quick spurt of flame is produced, and this penetrates the touch-hole and discharges the powder in the gun-barrel. Consider for a moment the construction of these percussion-caps. At the bottom of the little cup-shaped bit of copper forming the cap you can see a white substance deposited in a thin coating on the metal. It is the fulminating-powder, made of several ingredients carefully combined in accordance with chemical science and ready to fly apart with violence at the mere shock imparted by the hammer. But this is enough about these touchy and noisily dangerous substances, so prone to separate into their elements with a loud report as soon as we have joined those elements together. Let us proceed to something harmless. What should you say there is in a slice of bread?"

"I should say—I should say," Emile hastened to answer, "that there is flour." And with that he thought he had said the last word on the subject.

"True," assented his uncle, "but what is there in flour?"

"In flour? What can there be in it except flour?"

"But what if I told you there was carbon, or what amounts to the same thing, charcoal, in flour?"

"What, charcoal in flour?"

"Yes, my boy, charcoal,—a lot of it."

"Oh, Uncle, you are only in fun! We don't eat charcoal."

"Ah, my young sir, you don't believe it? But didn't I tell you that chemical combination can turn black to white, sour to sweet, the uneatable to nourishing food? Furthermore, I will show you some of this charcoal that is found in bread; or, rather, I don't need to do that, as you have seen it hundreds of times and it will be enough now to jog your memory. Tell me: don't you often toast your bread a little over the fire before crumbling it into milk for your breakfast?"

"Why, yes, I let it get crisp and brown. It's ever so much better that way; it goes better with milk when it is toasted just enough to make a crunching sound when you break it. In the winter, when the stove is hot, you can do it just right."

"But what if you forget your slice of bread on the stove? What if you let it toast too long? What happens to it then? Come, now, tell me, from your own remembrance of the thing, for I wouldn't on any account influence your opinion in this serious matter. What would happen if your bread stayed on the stove a whole hour?"

"That's easy enough to answer: it would all turn to charcoal. I've seen it happen lots of times."

"Well, then, tell me, where did the charcoal come from?—out of the stove?"

"Oh, no, not at all!"

"Then from the bread itself?"

"Yes, it must have come from the bread."

"But from no substance can there come anything that was not there before; nothing can furnish what it does not already have. Consequently, bread, which yields charcoal after being exposed some time to the action of fire, must itself contain charcoal, or carbon if we choose to use that word."

"Why, that's so! I hadn't thought of it before."

"There are many other things, my little lad, that you have seen again and again without grasping their significance, because no one has set you on the right road. I shall often turn these common occurrences to account by showing you to what important truths they open the way when you reflect on them a little. Reflection now makes you aware that bread contains quantities of carbon."

"I admit that bread contains carbon," assented Jules. "The proof is there before your eyes, plain enough. But, as Emile says, we don't eat charcoal, and we do eat bread; charcoal is black, and bread is white."

"If the charcoal, or the carbon, were alone," replied his uncle, "it would be black and uneatable, as you have described it, and it would remain so indefinitely. But it is not alone and by itself in bread; it is associated or combined with other things, and the combination has

none of the qualities you have named as belonging to charcoal, just as sulphid of iron has none of the qualities belonging to sulphur and iron. These other qualities found in bread are driven out by excessive heat, and the charcoal remains, with all the characteristics peculiar to it,—blackness, hardness, brittleness, unpalatability,—in short, unmistakable charcoaliness. The heat of the stove undoes the work of combination, sundering what was joined together in the bread. That is the whole secret of the transformation of a slice of bread into a slice of charcoal when the toasting process has gone too far. Now let us inquire into the other things that accompany the carbon in white bread. They are known to you; you have seen them, and you have smelt their disagreeable odor when heat drives them out."

"I don't quite understand you," said Jules, "unless you mean that bad-smelling smoke that comes from bread when it is turning to charcoal."

"Exactly; you have my meaning. That smoke was part of the bread it came from. The charcoal and the offensive fumes you know so well would, if recombined as they were at first, constitute precisely the slice of bread as it was before being subjected to the action of heat. Heat wrought the separation, dissipating some of the constituent elements in the air and leaving behind, stripped of its previous disguise, the black and uneatable substance so well known to you as charcoal."

"Then those bad-smelling fumes and the charcoal, with nothing else, make bread, and two things that

couldn't be eaten separately form by their union our chief food?"

"You have put it quite correctly: substances that by themselves, far from yielding nourishment, would be positively harmful if eaten, become by combination transformed into excellent food."

"I must believe you, Uncle Paul, because you say it is so; but—but—"

"I understand, my young friend, your hesitation and your 'buts'. On first hearing these things one can hardly believe them, so at variance are they with accepted notions. Therefore I do not ask you to take my bare word; you must be convinced by something other than my authority. Did I not at the very beginning prepare the way for these startling developments by means of a perfectly conclusive experiment? Recall the black substance that we obtained in the medicine-bottle. Recall that sulphur now no longer sulphur and that iron now no longer iron. Why should there be anything more surprising in the fact that charcoal and some bad-smelling fumes can cease to be what they now are, and can become bread?"

"You are right, Uncle, and the best thing to do is to take your word for it."

"To take my word for it sometimes may be necessary, as when the proof of an assertion would entail explanations too difficult for you to follow; but as far as possible I shall impose nothing on you as an article of faith, choosing rather to let you see, touch, and conclude for yourselves. I wish you to see the light and

to witness the evidence, not to retain a mere mass of truths accepted on the authority of my word. In bread decomposed by heat I show you charcoal and call your attention to certain peculiar odors or fumes. What, now, is the natural inference?"

"That bread consists of that charcoal and those fumes united. It is too plain to be doubted."

"Yes, when facts speak we must accept what they say without heeding the counter-suggestions of long habit. These facts tell us that bread may be resolved by the action of heat into charcoal and certain vapors. Let us grasp that truth and acknowledge ourselves convinced."

"One other thing puzzles me," said Jules, "and it is the hardest puzzle yet. You say that the charcoal and the vapors separated by heat would, if recombined, make the bread again as it was before. Then, doesn't fire destroy any of the bread?"

"The word 'destroy' has more than one meaning, my boy. If in using it you mean that a slice of bread, after being subjected to intense heat, no longer exists as bread, you are quite right: the resultant charcoal and vapors are in no sense bread, but merely the substances of which bread is formed. If, on the other hand, you mean that the bread is reduced to nothing, you are greatly mistaken, for there is not a particle of matter in existence that can by any force or device at our command be put out of existence."

"But that was just what I meant,—reduced to nothing,

put out of existence. We speak of fire as destroying or annihilating everything."

"Then, in the literal sense of those words, we talk foolishly, for again I assure you that nothing in the whole universe, not even the tiniest grain of sand, is ever annihilated. Neither fire nor any other agency can annihilate even the finest thread of a spider's web."

"Listen, now, with close attention, for the subject is worth it. We will suppose a fine house is built, with spacious halls, splendid apartments, chambers, kitchen, vestibule, piazza, doors, windows,—in short, everything belonging to a comfortable and attractive abode. In building it the workmen had to place in their proper positions countless materials, such as cut stone, brick, rubble-stone, mortar, tiles, beams, boards, laths, plaster, metal fixtures, and so on. The house stands there, stanch and proud and suited to the requirements of the most exacting. Can it be destroyed? All too easily. Call back the masons with their picks and crowbars and hammers, and if necessary they will tear down the building much more quickly than they put it up. The fine mansion will soon be nothing but a shapeless pile of ruins, or rubbish; it will be destroyed as a house.

"But will it be annihilated, reduced to nothing? Evidently not. Does there not remain an enormous heap of materials,— of stone, brick, wood, iron,—of everything, in fact, that went to the building of the house? The house, then, is not annihilated, and what is more, not a particle that entered into its construction has been reduced to nothing. Even the last grain of sand

used in mixing the mortar is sure to be in existence somewhere. The wind may have blown away some of the plaster-dust as the house was being torn down; but that dust, of a fineness hardly visible, is nevertheless undestroyed, however widely dispersed by the wind; and if it cannot now be gathered up, we can at least see it in our mind's eye, scattered in this direction and that. Of the entire building, therefore, that has been demolished not a particle of dust has been annihilated.

"Well, now, fire in its turn is a demolisher, but nothing more. It demolishes buildings made of many materials combined, but it never reduces to nothing the smallest particle, the minutest grain of dust, in those materials. We subject to its destructive power a mouthful of bread, and destruction follows, but never anything like annihilation; for what is left, after the fire has played its part, is just as truly matter as was the bread itself. That residue is in the form of charcoal and certain fumes or vapors, the charcoal remaining in a little mass by itself, the vapors being dissipated and no longer traceable, even as the plaster-dust was lost to view. Rid yourselves, then, forever, of the foolish notion of annihilation."

"But—"

"There goes Jules again with another of his 'buts'! What is your difficulty this time, my lad?"

"When you burn a stick of wood in the fireplace, isn't it reduced to nothing, or almost nothing? There's only a pinch of ashes left at the end. I see how the ashes come from what was once wood, but they amount to so

little they can't represent all that has been demolished by the fire. The greater part of the wood, then, must have been reduced to nothing."

"Your observation shows a thoughtful mind, and is of the kind I like. Accordingly, I hasten to answer you. I just spoke of the plaster-dust blown away by the wind in the demolition of our supposed house. Is it not plain that, the walls being built largely of powdery materials capable of being caught up by a passing breeze, a considerable part would be thus borne away in various directions, leaving behind a proportionately diminished heap of refuse?"

"Certainly; I admit that."

"If, now, it were possible in a work of masonry for the whole structure to be swept away as impalpable dust, what would remain?"

"Nothing, of course."

"But would the building on that account have been reduced to nothing?"

"Why, no; it would have been turned into fine dust scattered all about."

"Just so with your stick of wood, my little friend: fire resolves it into its constituent elements, some of which are far more impalpable than the finest dust. These are lost to view, being dissipated here and there in the boundless atmosphere, and as we find nothing left but a handful of ashes we are prone to believe the rest has been annihilated, whereas it still exists, indestructible,

floating in the atmosphere and having a limpidity, a colorlessness, as complete as that of the air itself."

"Then a stick of wood that has just been burnt up in the fireplace is mostly scattered in the air in a sort of fine dust that we can't see?"

"Yes, my boy; and the same is to be said of all fuel that we burn to obtain either heat or light."

"Now I see why wood, when it is burned, seems to be reduced to nothing. What was the wood has, as you say, been mostly carried away without our seeing it, somewhat as the plaster-dust of a house that is being torn down is blown away by the wind."

"Note also, my boys, that out of the materials left when a house is torn down, another house can be built, different in form and on another site if desired. The heap of ruins will thus become once more a finished structure. But, further, there is no reason why these same materials could not be used for making other things, the stones for one purpose, the bricks for another, the wood for still another, so that the ruins of our demolished house would enter into various constructions having each its own form and purpose and character.

"Somewhat thus is it with matter in general. Let us suppose two, three, or four substances, each of a different nature from the others, to enter into combination. They function all together in a certain manner; they dispose themselves so as to form what I will call a kind of building; and by thus associating they produce a substance quite different from any of the constituent substances, just as our finished house is neither sand

nor lime, nor plaster, nor brick, nor, in fine, any of the materials used by the builders.

"After a while, for some reason or other, these combined substances separate, and the chemical structure is demolished. The ruins are left; there has been no loss of matter. What will nature do with these ruins? Perhaps any one of a thousand things; perhaps use a little of this ingredient for one purpose, a little of that for another, and so on until the result is a great variety of productions, all very different from the original substance. What went to make something black, will, it may be, now enter into the formation of a white substance; what was a part of something sour, may contribute to the making of something sweet; and what helped to constitute a poison, is likely enough to be found again in an article of food, just as the bricks of a former conduit may by a totally different application serve in the construction of a chimney and thus make a passage for smoke and flames instead of for water.

"Thus it is that nothing is ever annihilated, despite all appearances to the contrary, appearances that so often deceive us because we do not observe accurately. Let us pay closer attention, and we shall perceive that all matter persists, indestructible. It enters into an infinite variety of combinations, forever uniting and separating and uniting again, some of its manifold forms being every moment destroyed and every moment renewed, in an endless series of transformations, without the loss or gain of a single particle in the whole universe."