

Caveman Chemistry

***28 Projects, from the Creation of
Fire to the Production of
Plastics***

Kevin M. Dunn

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by Kevin M. Dunn

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Prologue

Bottom: Peter Quince!

Quince: What sayest thou, bully Bottom?

Bottom: There are things in this comedy of Pyramus and Thisby that will never please. First, Pyramus must draw his sword to kill himself; which the ladies cannot abide. How answer you that?

Snout: By'r lakin, a parlous fear.

Starvling: I believe we must leave the killing out, when all is done.

Bottom: Not a whit! I have a device to make all well. Write me a prologue, and let the prologue seem to say we will do no harm with our swords, and that Pyramus is not kill'd indeed; and for the more better assurance, tell them that I Pyramus am not Pyramus, but Bottom the weaver. This will put them out of fear.

Quince: Well; we will have such a prologue, and let it be written in eight and six.

— William Shakespeare, *A Midsummer Night's Dream*, ca. 1596 AD ¹

1 ♀

Bottom: No; make it half; let it be written in four and three.

Snout: Will not the readers be confused by the fictions?

Starvling: I fear it, I promise you.

Bottom: Masters, you ought to consider with yourselves: to bring in—God shield us!—a fiction among facts, is a most dreadful thing and there is no room for equivocation; we ought to look to it.

Snout: Therefore another prologue should probably tell each fact from each fiction.

Bottom: Nay, you must clearly distinguish the one from the other, giving each fiction a typographical symbol of some kind. And the author himself must speak the facts without embellishment or subterfuge of any kind and tell the reader plainly which ones are the facts.

1. Reference [24], Act III, Scene 1.

Quince: With such an inspiration, all is well. Come, sit down, every mother's son, and rehearse your parts; and so every one according to his cue.

2 ♠

There are three kinds of people in the world. The first kind believe what they see; they prefer to experience life as it unfolds, holding pre-conceived expectations in check until observations make all things plain. If you belong to this tribe, a Prologue or preface might spoil some of the fun of figuring things out for yourself. I advise you to skip it altogether and proceed without delay to [Chapter 1](#). The second kind see what they believe; they prefer to experience life with structure, pre-conceived expectations providing a plane from which to make observations. If this is your family, I wrote this Prologue to provide such a vantage point. The third kind don't believe that seeing is worth the effort; they have skipped the Prologue already, presuming that it is merely the conventional place for the author to thank his cronies for their invaluable support. If you are of this ilk, I need say nothing to you at all.

I teach chemistry at Hampden-Sydney College, a small liberal-arts college in central Virginia. The students here, by and large, do not come equipped with insatiable curiosity about my discipline and experience has convinced me that the profession of professing has more to do with motivation than with explanation; a student who is not curious will resist even the most valiant attempts at compulsory education; conversely, inquiring minds want to know. A great deal of my time, then, has been spent devising tricks, gimmicks, schemes and plots for leading stubborn horses to water, knowing full well that I can't *make* them think.

One day as I scuttled across campus, I overheard a tour guide gushing over the Federalist architecture; "If these walls could speak, what stories they would tell." They teach them to say things like that, you know. The phrase brought to mind a lyric from an old song; "If you could read my mind Love, what a tale my thoughts would tell." You know the one. I noticed myself humming it on the way to the post office. "Just like a paperback novel," it continued as I attempted to concentrate on my grading. "I never thought I could act this way, and I've got to say that I just don't get it." The tune wouldn't let go. It's probably playing in your head too, by now. "And I will never be set free. . . ." as long as there's this

song inside of me. It had begun to mutate. It ended up, “If I could read my own mind, what a tale this song would tell.”

That song began life as a simple phrase in the head of Gordon Lightfoot. The phrase combined with others to form lyrics. The lyrics enchanted family members, friends and record executives and eventually came to possess millions of radio listeners. And our heads are full of such things: songs, stories, plays, instructions. From the Gettysburg Address to the recipe for the perfect martini, from one mind to another traveling through time, if only they could speak. . .

Look into your own mind and grab the first recognizable bit of such thought-stuff you come across. Where did you get it? Where did the person you got it from, get it? Who was the first person to get it, or, to be more precise, to be got *by* it? Wouldn’t it be interesting if the thought itself could tell you its story? Wouldn’t that be an interesting premise for a book? “And you would read that book again. . .” unless the idea’s just too hard to take.

3 Θ

The actors are at hand; and by their show,
You shall know all, that you are like to know.

— *A Midsummer Night’s Dream*²

∇ You are probably wondering what the little symbol at the beginning of this sentence means. I will tell you. The book, as you will no doubt recall from the first section of this Prologue, is written in four and three. Four spirits, Fire, Earth, Air and Water narrate the chapters, which could get confusing were it not for the presence of these symbols intended to identify which spirit is speaking at any particular point. When the water spirit speaks, for example, the text will begin with the alchemical symbol for water: ∇. The astute reader will instantly surmise that since this paragraph began with the water symbol it is, in fact, narrated by the spirit, Water. In other words, I am that part of Doctor Dunn’s mental inventory having to do with *watery* things, those things having come to him from parents and teachers, and their parents and teachers in a long and steady stream back through history and into pre-history where

2. Reference [24], Act V, Scene 1.

we find the very first watery thought. Moving forward, this first watery thought passed from the first person who had it to the second person, where it accumulated new watery bits like a watery snowball until at last it dribbled, bit by bit, into the Doctor's mind. And yours, I might add. It is my job to provide a first-hand account of some of the major events in the watery quadrant of the history of chemical technology.

▽ Well, *that* was clear as mud. I'm afraid that Water tends to run at the faucet sometimes, so if you want a firm foundation for understanding this book, you're better off listening to Earth. This book is about digging stuff out of the ground and making it into other, more valuable stuff. There are twenty-eight chapters and at least seven of them will teach you something useful. Each chapter starts with a section explaining how that particular chapter's stuff got invented. Then there's a section telling you what you need to know about why the stuff is the way it is. Each chapter wraps up with a section showing you how to make the stuff that the chapter's about. If you're not interested in making stuff, it'd be a waste of time for you to read this book because you're not going to get anything out of it if you're not willing to get your hands *earthy*.

△ If Water and Earth haven't convinced you that the Author is off his nut, I'm afraid there's not much I can do to help. I'm supposed to represent the element, air, in case you haven't figured it out. I know it's confusing, but there we are. The Author wanted to write an unusual book, an interesting book, a book that would entertain as well as instruct, but I'm sorry to say that *unusual* is as far as he got. It takes most readers until [Chapter 5](#) even to figure out that the book has characters, like actors in a play. To keep potential readers from chucking his masterpiece in with their empty pop bottles and pizza boxes, the Author has written this Prologue as a "device to make all well," but for that to work they would have to actually get through the Prologue without drifting off into a midsummer's daydream.

△ Let them slumber; this book is not for the lazy or the timid. It is a book of secrets to be carefully tended like an eternal flame, not casually browsed like a four-year-old fishing magazine in a dentist's office. Everyone who lays hands on it and often tries it out will think that a kind of key is contained in it. For just as access to the contents of locked houses is impossible without a key, so also, without this commentary all that appears in the Emerald Tablet of Hermes Trismegistos will give the reader a feeling of exclusion and darkness. The text is composed in four

and three; Fire, Earth, Air, and Water; Mercury, Sulfur, and Salt. In this way was the book created. From this there will be amazing applications, for this is the pattern.

Truly, without deceit. Certainly and absolutely. That which is Above corresponds to that which is Below and that which is Below corresponds to that which is Above in the accomplishment of the miracle of One Thing.

And just as all things come from One, so all things follow from this One Thing, in the same way.

Its father is the Sun; its mother is the Moon. The wind has carried it in its belly. Its nourishment is the Earth.

It is the father of every completed thing in the Whole World. Its strength is intact if it is turned towards the Earth. Separate the Earth by Fire, the fine from the gross, gently and with great skill.

It rises from the Earth to Heaven and descends again to the Earth, and receives power from Above and from Below. Thus thou wilt have the glory of the Whole World. All obscurity shall be clear to thee.

This is the strong power of all powers for it overcomes everything fine and penetrates everything solid. In this way was the World created. From this there will be amazing applications, for this is the pattern.

Therefore am I called Hermes Trismegistos, having the three parts of wisdom of the Whole World.

Herein have I completely explained the Operation of the Sun.

— *The Emerald Tablet of Hermes Trismegistos*

△ Right. I'm afraid you'll have to put up with a bit of pseudo-alchemical techno-babble in the course of this book. The Author might simply have described the nature of the elements, but for the more flamboyant elements of his nature. Fire is the main culprit, but Earth and Water have their moments, as well. "The text is composed in four and three." The Author might have simply said that the book has four characters and each chapter has three sections. If you ask me, this book should have rested on the periodic table, not on the Emerald Tablet.

△ The periodic table is fine, as far as it goes, but it says nothing of the Operation of the Sun.

▽ Transmutation, that is. Black gold, Texas tea. The Emerald Tablet's not so much about literally changing lead into gold, of course, but more about changing useless stuff into useful stuff.

▽ I believe it is more of an allegory about life and death, mortality and immortality, about coming into being and kicking the bucket. This book will follow that pattern, tracing the advance of chemical technology from a stone-age trickle to the babbling brooks of the Bronze Age to the stately rivers of the Iron Age to the confluence of tributaries in the Middle Ages to the polluted canals of the Industrial Revolution. But I am getting ahead of myself.

△ Indeed you are. The first chapter belongs to me.



Chapter 1. Lucifer (Charcoal)

Call me Lucifer, for I am the bringer of light. No angel was I born, nor devil neither. Nay, as animal I came into the world, and so I will acknowledge both horns and tail. My sin, if it must be called that, was not pride, but curiosity. Alas! The world has forgotten my story, amalgamated me with a host of unfashionable gods until I am beyond recognition.

Beasts among beasts, we lived and died in fear. Fear of the darkness which harbors terrors unseen. Fear of the cold which lulls us to sleep everlasting. Fear of the tooth and the claw which hound us both in wakes and in dreams. My child, would ye be one with Nature? Ye have only to sit still while she devours thee.

They say that it is evil, an indiscriminate destroyer of all in its path. They say that its proper abode is the pit. They say that he who would be its master must, little by little, inevitably become its slave. They say that to consort with it is to risk the utter annihilation of the whole world. And yet, from a timid brute, it has crowned the master of all Nature.

In a wasteland of its own making did I find it starving and gasping. The destroyer of worlds reduced to a silent gray infant. With my own breath did I restore its complexion until the murky dusk gave way to the gentle dawn. With my own heart did I incubate and nurture it until the savage winter gave way to an early spring. With my own hand did I feed it until at last its forked tongue licked at my fingers and, for the first time in my life, I was not afraid. My child, can ye feel the warmth of its gentle touch? Beware its teeth, lest it bite thee.

Old and tired am I now and can care for the infant no longer. Who will feed it when I am gone? Who will guide it with wisdom? Who will protect it from its enemies? Who will tame its terrible wrath? My child, have ye the will to bring the light into the world? Cherish these tools for the day that ye find need of them.

1.1 ♀

△ It all began with a spark. A rather unremarkable animal roamed the African savanna that scorching summer day. Slower than a lion, small-

er than an elephant, weaker than a gorilla, dumber than a hyena, she¹ survived the same as anyone else, by finding enough to eat until being eaten in her turn. If she were a little faster, a little bigger, a little stronger, a little smarter, or just plain lucky, she might live long enough to beget children to take their turn at the cyclical feast. And so it might have continued for another day, another year, another eternity, were it not for the spark.

Δ A spark, dry wood, a stiff breeze, and in the blink of an eye the world went crazy as it had done before and would do again. Animals rushed to and fro, the air took on a peculiar smell, the earth glowed with sunlight from within and was left black and warm. A bounty remained for scavengers who braved the heat, for food was everywhere, not running, not fighting, not resisting, just lying there for the taking. This was her lucky day! The meat was so warm, so tender, so tasty, salted by the ashes, and seasoned by the charcoal. Many flocked to the carbonaceous cornucopia and the party continued long into the night. And just as the stars appeared in the black heavens, so did they litter the blackened earth. This spectacle had presented itself to countless generations, but on this day it was truly seen for the very first time.

Δ How did this unremarkable animal differ from her father and mother, her uncles and aunts? They recalled similar episodes from seasons past. The old ones even used to boast about how much better the wildfires were when they were children. But our hero turned her attention from the abundant delicacies to the stars that lay smoldering on the ground. She poked at one with a stick, as she would a termite mound, and it produced a child—a *star on a stick*! She waved it about, and it glowed brighter and brighter. That was the moment *I* was born.

Δ Before you can proceed with the Work, you need to understand exactly who *I* am. It is, perhaps, easier to begin with who I am not; I am not the mortal Dunn, whose name graces the cover of this book. Neither am I that original fire-maker, dead these half million years. I am not fire itself. No, I am nothing more and nothing less than an *I-dea*, the I-dea of fire, currently living among many other I-deas in the mind of Dunn.

Δ I started as just another I-dea floating around in the primordial soup which was the unremarkable African's mind. There I bumped into other I-deas: facts, observations, whims, appetites, notions, questions and answers. As simple I-deas merged into more complex ones, as weak I-deas

1. No one can know the gender of this first fire-maker. I have chosen a female.

were displaced by stronger ones, I came to the realization that for the first time in *my* life, *I* was in control. I did not have to helplessly watch while my mortal body shivered with cold or cowered in the darkness. I called the shots now. From just another I-dea I grew into a really good I-dea, a powerful I-dea, an I-dea worth telling.

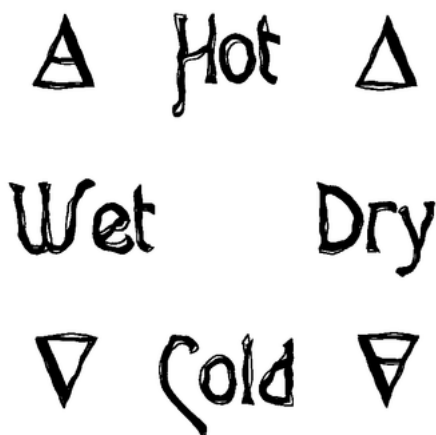
Δ And I was told. The original animal told her friend, the friend told his nephew, the nephew his daughter and the daughter her husband. By the time the original animal died I had, like the prolific fire itself, found fresh tinder of my own; not grass and twigs, but the minds of hundreds of mortals. From these humble beginnings I spread across the globe and through the centuries until at last I came to possess the mind of the mortal Dunn. And so the telling continues; as fresh mortal eyes scan these pages, I wonder what I will find on the other side. Will the indigenous I-deas welcome me or will they consider me a threat? Will they erect fire-walls to protect their delicate habitat or will they stoke the hearth and celebrate my coming? If there is no home for me there, the mortal will shut its eyes and put down this book, content to live out its few remaining days in darkness. But you, my child, have continued to the next sentence and thanks to your hospitality, I have found a place to temporarily alight on my long journey into the future.

Δ It is fashionable these days to long for a simpler life, one without atom bombs and toxic waste, one without chemotherapy and smokestacks. But even the most enthusiastic back-to-nature-ists among us would be loath to leave the inviting warmth of the campfire for life in the cold, the wet, the dark, and the dangerous habitats from which we emerged. Even the most radical Luddite would ask for a hut with a fireplace. Yet no culture on the planet has remained content to keep the home-fire burning while rejecting its gifts: pottery, metals, glass and many others. No, fire is the original Pandora's Box. This book is an introduction to that box, how we have opened it little by little, and the skills and materials we have taken from it.

1.2 ∇

As a teenager I once set fire to a field of wheat chaff. I didn't do it maliciously; in fact, the farmer I was working for that summer paid me to do it. As it was, the field was a fire hazard but by choosing a time when the wind was at the right speed and from the proper direction, we could

Figure 1-1. Aristotle's Elements

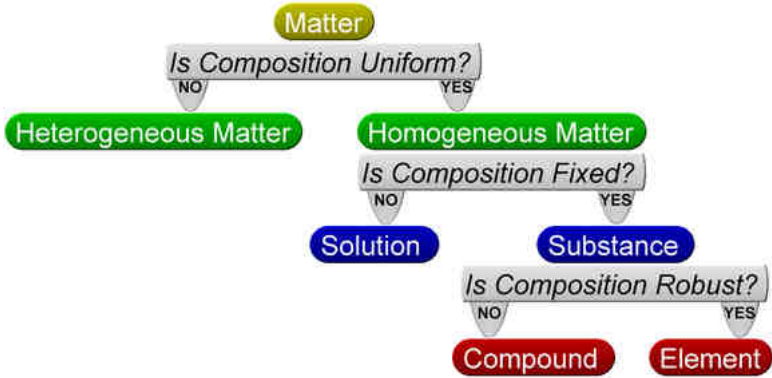


control the course of the fire, eliminating the danger of an accidental fire and returning nutrients to the soil. But none of that mattered to me—I was awestruck by the spectacle of the fire itself. Our fascination with fire is something primal, irresistible, and ancient, passed from one human being to another since the dawn of time. I call that part of human nature—the part that thrills to a fireworks display, the part that slouches before a fireplace, the part that insists on dinner by candle light—I call that part “Lucifer.” I have given Lucifer an independent voice in this book, separate and distinct from my own. Lucifer’s pronouncements are preceded by the alchemical symbol for fire, *an upward-pointing triangle reminiscent of a flame*. In addition, you will be haunted by three other spirits, those of Earth, Air, and Water, but for the moment it falls to me, the twenty-first century chemist, to describe the phenomenon of fire.

Lucifer was alive and well in 350 BC. Driven by curiosity, philosophers engaged in a lively debate on the nature of the universe; was it made of infinitely many kinds of substances or just a few? Aristotle summarized the opposing viewpoints:

Anaximenes and Diogenes make air prior to water, and the most primary of the simple bodies, while Hippasus of Metapontium and Heraclitus of Ephesus say this of fire, and Empedocles says it of the four elements, (adding a fourth—earth—to those which have been named); for these, he says, al-

Figure 1-2. Lavoisier's Elements



ways remain and do not come to be, except that they come to be more or fewer, being aggregated into one and segregated out of one.

Anaxagoras of Clazomenae, who, though older than Empedocles, was later in his philosophical activity, says the principles are infinite in number; for he says almost all the things that are made of parts like themselves, in the manner of water or fire, are generated and destroyed in this way, only by aggregation and segregation, and are not in any other sense generated or destroyed, but remain eternally.²

Aristotle divided the world into opposites, noting, for example, that things are either hot or cold, never both. They are either wet or dry, never both. But a thing *can* be both hot and dry or cold and wet. And so **fire** was assigned dominion over things “hot and dry.” **water** included all things “cold and wet,” **earth** described anything that was “cold and dry,” and **air**, anything “hot and wet,” as illustrated in Figure 1-1.

If longevity is a sign of success, the I-dea of “element” must be considered a great one, having held sway for more than two millennia. And the division into four makes a certain logical sense, but there was always the temptation to view these elements as “ingredients.” The practical questions asked by crafts people and artisans had less to do with logic than with logistics. “How much of which ores will produce a ton of copper?” “What kinds of herbs, and in what proportions, will cure a fever?” “What fertilizers will yield the best crops?” “Which plant will dye cloth a per-

2. Reference [2] *Metaphysica*, p. 984a.

manent blue color?” The four elements are descriptive, not prescriptive. They describe qualities, not quantities. Any attempt to view them as the literal ingredients of nature is fraught with difficulty. Let us examine each of these elements in turn, beginning with earth.

Wood, being cold and dry, belongs to the earthy domain. Look at it closely and you will see that its composition is not *uniform*; there are dark areas and light areas. The composition of the wood in the light areas is different from that in the dark areas; it cannot be a single substance because it is clearly **heterogeneous**. Most of the matter encountered in nature is heterogeneous. A handful of earth can be separated into sand and clay, decayed leaves and insects. The sky is divided into a blue expanse across which distinct white clouds roam. Water contains algae and fish and scum. Look at most matter closely enough and you will see non-uniformities and these are the hallmark of heterogeneous matter. Even blood and milk are heterogeneous when viewed under a microscope; Blood consists of the colorless plasma and the colored cells, while milk consists of the colorless whey and various suspended solids and liquids.

Heterogeneous matter can be separated into its constituents by mechanical means, by sorting, sifting, filtering, or sometimes by just letting it settle. For wood, this would entail grinding the wood to a powder and separating the white bits from the brown. I might do this with tweezers and a magnifying glass, or I might find an easier, more ingenious method (see [Chapter 14](#), for example) for achieving the separation, but in the end, I would have the white pile and the brown pile, each one uniform in appearance and composition. I would have rendered the wood **homogeneous**. Let us call the white pile *cellulose* for future reference, and move on from earth to a consideration of air.

Granted, air may have dust or fog in it, but let us filter it until it is clean and dry. No matter how closely I look at this sample, it is the same everywhere, i.e. its composition is *uniform*. There are no light bits and dark bits: it is clearly homogeneous. I may now ask whether or not this air is an element. This question was explored by *Antoine Lavoisier* late in the eighteenth century.³ Mercury was boiled in air for 12 days, during which time a red solid formed on the surface of the mercury. At the end of the experiment, 42–43 cubic inches of the original 50 cubic inches of air remained. This gas extinguished candles and suffocated animals

3. Reference [\[17\]](#), pp. 34–35.

immersed into it, and he called it **nitrogen**. The red solid was collected and, when heated, produced 7-8 cubic inches of gas. Either this was an amazing coincidence, or this was the same 7-8 cubic inches which went missing from the original air. This new gas, in contrast to nitrogen, caused candles to burn more brightly than in normal air, and was breathable by animals. Lavoisier gave it the name **oxygen** and concluded that air was not an element, but a mixture of nitrogen and oxygen. Today, air is recognized as a **solution** of 78% nitrogen and 21% oxygen,⁴ but these percentages are not fixed. A solution has a uniform but *variable* composition. Air is still air if it has 18% or 25% oxygen. Its composition may vary from city to suburb, from mountain to valley, or from the first to the twenty-first century.

Whereas a solution is described by its percentage composition, which may vary, a pure **substance** has a *fixed* composition. The solution called air can be separated into the substances nitrogen and oxygen. While there are many methods for separating a solution into its substances, we will consider three in detail. **Recrystallization** will be discussed in [Chapter 8](#), **distillation** in [Chapter 16](#), and **chromatography** in [Chapter 22](#).

Earth is heterogeneous; air is a solution; what about water? Filter it so that it is homogeneous; distill it until it is pure. The question remains, “Is it an element, or is it a combination of other materials?” All of our work in defining a pure substance has been leading up to this fundamental distinction. The evidence that water is a compound is also summarized in *Elements of Chemistry*. First, Lavoisier decomposed water by passing steam over iron. 100 parts (by weight) of water decomposed into 15 parts of hydrogen and 85 parts of oxygen. Furthermore, 15 parts of hydrogen combined with 85 parts of oxygen to produce 100 parts of water. He concluded that pure water is composed of 15% hydrogen and 85% oxygen. These proportions have been refined over the years as our ability to weigh gases has improved; water is precisely 11.190% hydrogen and 88.810% oxygen. Any sufficiently careful experiment will confirm these percentages, and they are the same for water collected and purified anywhere. Water is *never* 25% hydrogen or 3% hydrogen; its composition is fixed and this is what makes it a substance rather than a solution.

While the composition of water is fixed, it is not *robust*; after all, Lavoisier had showed that it can be decomposed into hydrogen and oxygen. A

4. The remaining 1% consists of argon, carbon dioxide, and a host of less abundant gases.

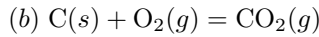
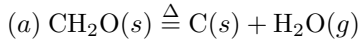
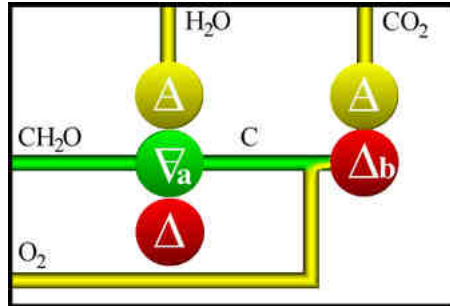
Table 1-1. Formulae for Some Common Substances

Compound	Formula
Cellulose	CH_2O
Carbon Dioxide	CO_2
Water	H_2O
Element	Formula
Carbon(Charcoal)	C
Oxygen	O_2
Nitrogen	N_2

substance is classified as a **compound** when it can be decomposed into two or more other substances. Similarly, cellulose, the white homogeneous solid separated from wood, becomes black when charred. Careful observations reveal that when cellulose is heated in a closed container, it decomposes primarily into the substances, charcoal and water. When *one* substance decomposes into *two*, it must be a compound.

With earth, air, and water stripped of their elemental status, one might wonder whether any substance can resist such analysis. While even fire has not survived as an element, one of its products, charcoal, has done so. According to Lavoisier, “As charcoal has not been hitherto decomposed, it must, in the present state of our knowledge, be considered as a simple substance.”⁵ Lavoisier’s notion of a “simple substance,” or **element**, is thus provisional; while a compound is a pure substance which has been decomposed, an element is one which, so far, has resisted all such attempts. Charcoal’s composition is *robust*. Unlike wood, charcoal can be heated in the absence of oxygen without suffering further decomposition. That is not to say that charcoal is *inert*; charcoal burns in the presence of oxygen to produce a gas with a fixed composition, that is, two substances combine to make *one* substance. To show that charcoal is a compound we would have to turn one substance into *two* substances. No process has yet been found for doing so and since the time of Lavoisier, charcoal has been known as the element, *carbon*, after the French word for coal.

5. Reference [17], p. 208.

Equation 1-1. The Combustion of Cellulose**Figure 1-3. Fire as a Process**

Let us now examine the nature of **fire** using the **combustion** of wood in air as an example. Wood is a heterogeneous material composed chiefly of cellulose; air is a solution composed mainly of nitrogen and oxygen, so let us sharpen our discussion of fire by considering only the reaction of cellulose with oxygen. The combustion of cellulose occurs in two stages. When cellulose is heated, it does not burn immediately; it first releases steam and turns from white to black, that is, it *chars*, becoming charcoal. It is this hot charcoal which burns when it comes into contact with oxygen, producing a new gas, carbon dioxide. The heat released by the combustion causes more cellulose to char, producing more steam and charcoal. Since cellulose, steam (water), charcoal, oxygen, and carbon dioxide are all substances, they can be represented by chemical **formulae**, as defined in Table 1-1. Reactions involving these substances are represented by the **equations** shown in Equation 1-1. An equation is said to be *balanced* if the amount of each element is the same on either side of the equal sign. Equation (a) describes the *charring* of cellulose and (b) describes the *combustion* of charcoal. In such equations the attributes (s), (l) and (g) refer to the states *solid*, *liquid* and *gas*.

The equations of Equation 1-1 correspond to the process schematic of Figure 1-3, and *vice versa*. In such a schematic the cellulose reactant enters from the left and moves into reactor (a), a **furnace**, where it is

charred. The lower circle of the furnace, bearing the alchemical symbol for fire, represents any source of heat. The middle circle, bearing the symbol for earth, represents the transformation of the solid cellulose into solid charcoal. The top circle, bearing the symbol for air, represents the gases produced in the furnace, in this case water vapor. Because water is a waste product in this reactor, it exits to the top of the figure, as if it were going up a chimney. The intended product of the reactor, charcoal, exits to the right. *The convention established here is that reactants enter a reactor from the left, useful products exit to the right, and waste products exit to the top or bottom of a schematic.*

Reactor (b) is a **burner**, represented by the alchemical symbol for fire. The reactants, charcoal and oxygen, enter from the left and carbon dioxide goes up the chimney. Taken together, the two reactors of Figure 1-3 give a pictorial representation of the corresponding reactions for the combustion of cellulose. Study them carefully, as the conventions established here will allow us to represent quite complicated chemical processes using simple figures.



Material Safety

We live in a litigious society. Consequently lawn mowers must carry warnings that they are not to be used for trimming hedges. Sand destined for the sand-box must carry a hazardous material warning. In short, manufacturers are forced to warn consumers of every conceivable danger, no matter how bizarre, involving their products. Given this atmosphere, I had better tell you that the projects described in this book require a certain amount of common sense to be completed safely. A stupid or careless person will, no doubt, be able to find ingenious ways to hurt *himself*⁶ no matter how many warnings are given. And, incredibly, far from being embarrassed by *his*⁷ stupidity, he may believe that someone

6. In the case of non-characters of indefinite gender, pronouns have been chosen by coin toss. An initial coin toss established the convention that “heads” would result in a female pronoun and *vice versa*. One toss was allowed for each pronoun and this toss was never second-guessed. Any suspicions of gender bias should therefore be attributed to the coin, not to the author. Such pronouns are listed in the index under *He/his* and *She/her*.

7. When a string of pronouns or adjectives refer to a non-character of indefinite gender, the first one has been chosen by coin toss and subsequent references made to agree with it.

else should have protected him from his own stupidity. If you intend to make fire, do I really have to tell you to be careful? Do not make fire near flammable materials. Do not make fire in small, unventilated places. Avoid inhaling smoke. If you are stupid, careless, or unwilling to accept responsibility for your own safety, let me ask you to save us all a lot of trouble by putting this book away and taking up some safer activity, like sitting quietly or walking carefully in slow circles.



Research and Development

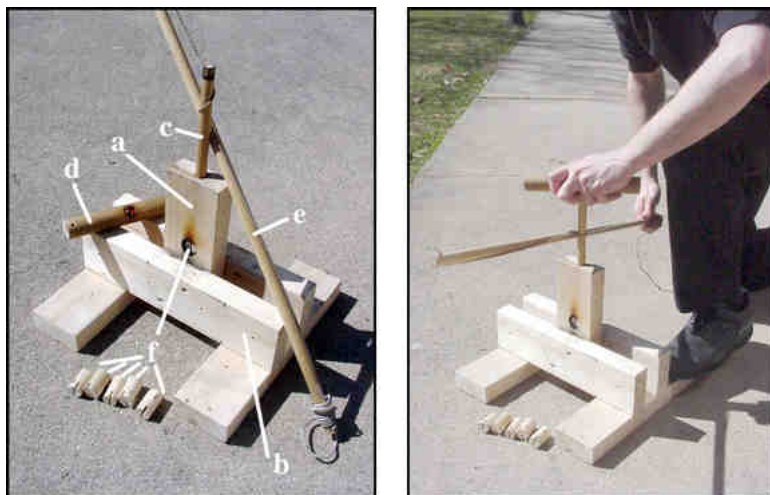
Before proceeding with your work, you must master the following material:

- Know the meanings of those words from this chapter worthy of inclusion in the *index* or *glossary*.
- Know the alchemical symbols for the four Aristotelian elements.
- Be able to classify materials as solutions, compounds, and elements.
- Know the composition and properties of wood, charcoal, and air.
- Know formulae for cellulose, water, carbon dioxide, oxygen, nitrogen, and charcoal.
- Know the equations for the charring of cellulose to produce charcoal and for the combustion of charcoal.
- Be able to reproduce [Figure 1-3](#) and to explain the process it symbolizes.
- Be able to explain the nature of I-deas.

1.3 Θ

Few people in the twenty-first century remember how to make fire, to really make fire, from scratch, as it were. If you are to make the long journey from caveman⁸ to chemist, you must learn this skill, which precedes all others. To make fire you need wood and air, both of which are easy to come by, but the central problem of fire-starting is getting enough heat to initiate the combustion of charcoal. The easiest, though

8. Throughout this book I use the word *caveman* in a gender-neutral sense. I prefer the ring of *caveman* and *human* to *caveperson* and *huperson*.

Figure 1-4. The Fire Kit

least convenient solution, is to simply wait for a lightning strike as the original Lucifer did. Once people began making stone tools, it became apparent that certain stones sparked when struck together, and that if you caught the spark in a flammable material, you could start a fire. The modern cigarette lighter is the child of this technology. In addition to stone, wood itself was used for making tools, though it leaves little evidence in the archeological record. When wood is rubbed together, the friction generates heat, sometimes enough heat to ignite the wood. The modern friction match is based on this phenomenon. With the invention of the glass lens in the fifteenth century, fire could be started by focusing the light of the Sun on a combustible material, a technology that has delighted children and terrified ants ever since.

None of the ancient methods of fire-making are easy to learn, and all of the modern methods are so easy as to be trivial. For this book, I wanted a method which would be easy enough for most people to master, while preserving some of the challenge of traditional methods. Flint and steel is not too demanding but it requires steel, which was unknown in Paleolithic times. The magnifying glass, though entertaining, is also too recent a development for our purposes. This leaves fire by friction, the method I have chosen for consideration. One of the most popular tools for making fire by friction is the bow-drill. Reliable, portable and quick,

it has remained my favorite method over the years, but like learning to ride a bicycle, it requires practice. To facilitate this practice I have devised “training wheels,” as it were, for the bow-drill.

Figure 1-4(L) shows the complete fire kit. A brief overview of its parts and operation will be given first, with details to follow. The “training wheels” consist of the guide (a) and supports (b), all cut from standard 2x4 inch⁹ lumber. The guide is 9 inches tall and has two holes drilled at right angles to one another. The vertical hole is 5/8 inches in diameter and approximately 4 inches deep. The horizontal hole is 1 inch in diameter and goes completely through the guide. The holes must be drilled so that they intersect one another, that is, so that you may look down through the vertical hole into the horizontal one. The four supports are 14 inches long and must be screwed or pegged to the guide and to one other so that they securely hold the guide upright.

The vertical hole in the guide accommodates the spindle, (c), a 9-inch length of 5/8-inch diameter hardwood dowel rod. Such rod can be purchased inexpensively at hardware stores and craft shops. Since the spindle will be gradually consumed, you should have several of them on hand. The spindle should turn freely; if it sticks, enlarge the vertical hole with sandpaper until the spindle is free to turn. The top of the spindle will be held by a block, (d), a piece of wood with a shallow hole large enough to hold the spindle without binding. To keep from burning through the block, this hole should be drilled large enough to snugly fit a half-inch copper “endcap,” available wherever plumbing supplies are sold. The inside of this endcap should be lubricated with fat or oil so that downward pressure may be applied to the spindle as it turns. In addition to the spindle and block, you will need a bow, (e).

It is *not* necessary that the bow be either flexible or curved. In fact, a 3-foot length of 5/8-inch diameter dowel rod will work admirably. Your bow will need a bow-string, for which a 6-foot length of 1/8-inch diameter nylon cord will serve. The bow needs one hole at each end large enough to accommodate the nylon cord. The cord is knotted at one end, passes through both holes in the bow, and is simply wrapped around the bow at the other end, allowing the tension of the bow-string to be ad-

9. Throughout the book I use both English and metric units, as convenient. Chapter 3 will discuss unit conversions so that people may adapt projects to the materials available to them.

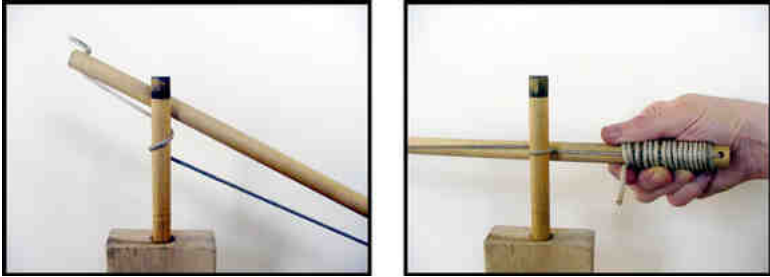
Figure 1-5. Yucca and Mullein

justed. The bow-string will be wrapped around the spindle in such a way that motion of the bow turns the spindle.

[Figure 1-4](#) shows the fire kit in operation. The left foot is placed on the support with the shin parallel to the guide. The left hand,¹⁰ braced against the knee, grips the lubricated block and applies downward pressure on the spindle. The bow is held parallel to the ground with the right hand and as it moves back and forth, the spindle turns freely in the guide. The lower end of the spindle presses against a piece of wood, the fire-board, which sits in the 1-inch hole in the guide. It is friction of the spindle against the fire-board which will produce the heat needed for our fire.

Not just any wood will work for the fire-board; it needs to combine strength, flammability, and low density. If you choose the wrong wood, your path will be filled with nothing but frustration. When looking for fire-board materials, low-density wood is best, as its low thermal conductivity allows heat to build up faster than it can be carried off. Think balsa, not mahogany. I have found yucca, shown in [Figure 1-5\(L\)](#), to be an excellent choice, and it is commonly available throughout North America as an ornamental plant. It can be recognized by its tuft of leaves

10. Left and right may be reversed for left-handed Lucifers.

Figure 1-6. The Bow

at the base, its stalks reaching for the sky, and its fist-shaped fruits. Harvest the stalks in the fall, after the fruits have fallen. Mullein, shown in [Figure 1-5\(R\)](#), is another wood suitable for the fire-board. Strip off the leaves and let the stalk dry. Whichever wood you choose, cut it into short lengths that will fit into the 1-inch hole in the guide.

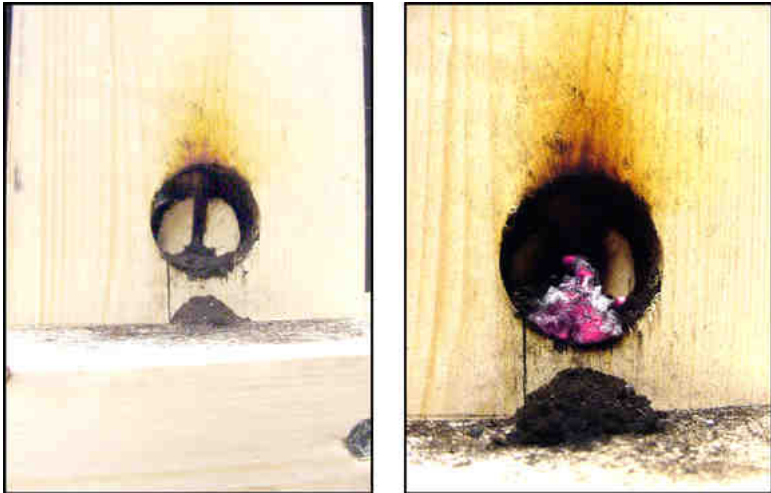
Now that the overview is complete, let us look at some details, starting with the bow. [Figure 1-6\(L\)](#) shows the far end of the bow, where the bow-string is knotted. The bow-string passes through a hole in the bow and is wrapped once around the spindle in the direction shown; if the bow-string is wrapped in the wrong direction, it may bind. The bow-string passes from the spindle through the hole in the near end of the bow. With the bow at an acute angle to the ground, the bow-string is pulled as tight as possible and then wrapped around the bow, forming a handle, as shown in [Figure 1-6\(R\)](#). Wrapping the bow-string rather than knotting it allows its tension to be re-adjusted quickly. When the bow is brought parallel to the ground the bow-string will come under tension, gripping the spindle tightly.

[Figure 1-7\(L\)](#) shows the “business end” of the spindle, the end which contacts the fire-board. A fresh spindle will be white and its end flat, but as it is used the end will char and assume a conical shape. Several fire-boards may need to be consumed before this ideal condition is established. [Figure 1-7\(R\)](#) shows details of the fire-board, with a notch, or *chimney*, cut into the end and a hole burned into the top by friction with the spindle. This particular fire-board has already made a fire and consequently its hole is relatively deep. I pre-notch my fire-boards and place them into the guide so that the tip of the spindle is near the vertical chim-

Figure 1-7. The Spindle and the Fire-board

ney. As the spindle burns a hole in the fire-board, charred wood dust, or *punk*, spills out of the chimney. It is this hot punk which will give birth to the ember.

Figure 1-8 shows the fire-board with its chimney in the guide. As the bow turns the spindle and pressure is applied with the block, the fire-board will begin to smoke and punk will spill from the chimney. If the pressure from the block is too light, no smoke will appear; if it is too heavy, the spindle will burn all the way through the fire-board before the punk catches fire. Therefore heavy pressure may be applied until smoke appears and then only enough pressure to maintain a thick, heavy smoke. The optimal bowing technique is to use long, smooth, steady strokes rather than short, rapid ones. Two or three strokes per second are quite sufficient. Try to make the pushing stroke with the same speed and pressure as the pulling stroke. The bow should move parallel to the ground and alongside your hips, rather than into your stomach. If you manage the block and bow gently and with great skill, the smoke will become thicker and thicker until the pile of punk itself begins to smoke. When this happens, stop bowing and blow on the hot punk; if blowing on it increases the amount of smoke, the punk very likely contains an ember. Keep blowing until the ember appears, as shown in Figure 1-8(R). A natural Lucifer may get an ember from the very first fire-board,

Figure 1-8. A Star Is Born

but most people will go through two or three of them before achieving success. Once you have learned to make fire with the guide, you can try doing it *au naturale*; the guide will have trained you in the proper technique.



Quality Assurance

Δ There is no room for equivocation. Either you have brought a red-hot glowing ember into the world or are content to live in darkness. Having succeeded, you should record your exploits in a notebook. [Appendix B \(page 382\)](#) describes a suitable format. Describe your procedure in sufficient detail that you would be able to use it to reproduce your performance at some later date, for experimental reproducibility is one of the most important I-deas in science. Take one of your living embers and burn a hole through a page in your notebook as an everlasting witness to your achievement.