SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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Student Materials

Learning Sequence Item:

958

Oxidation

March 1996
Adapted by: Marian Gonzalez, Brett Pyle and Linda W. Crow

Contents

This micro-unit was adapted by Marian Gonzalez (Lowell H.S., San Francisco, Calif.),
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Student Sheet

Science as Inquiry

Watery Burning

Assemble the materials as instructed by your teacher. Record your observations below.

1. What type of reaction took place?

2. Explain why the paper was torn up into small pieces.

3. What does a combustion process require? How is it provided in this reaction?

Student Sheet

Science as Inquiry

When an Old Flame Dies

Record your observations for both parts of the experiment. Include drawings if you wish.

Part A: Paper Tube

Part B: Candle

1. Explain what caused the phenomenon you observed in part A.

2. Explain what keeps a candle burning. Could a candle burn without a wick? Explain why or why not.

Science as Inquiry

Burnin' Steel

Construct a data table to record your observations of the various materials as they are placed in a flame.

1. What caused the differences observed between the chunk of steel and the steel wool when they were placed in the flame?

2. What types of evidence do you look for to indicate that a substance has been oxidized?

3. Define oxidation in your own words.

Student Sheet

Science as Inquiry

Rusting

Using a clear container, place a plain iron nail in various conditions and record your observations of what happens to the nail. You may also want to place other metals, such as zinc or aluminum-coated nails, under the same conditions and record any differences.

1. Why did you set up more than one condition?

2. Discuss the differences you observed in the nails in the various containers.

3. Why is the steel hull of a ocean-going ship most likely to rust?

4. Blocks of zinc are often bolted to a ship's hull. Research why this is done.

5. Why aren't cars made out of aluminum, sterling silver, or 24K gold?

History and Nature of Science

XIII. Matter and Its Transformations

62. *Jean Rey on the Increase in Weight of Tin and Lead on Calcination*

Heaviness is so closely united to the primary matter of the elements, that when these are changed one into the other they always retain the same weight.

My chief care hitherto has been to impress on the minds of all the persuasion that air is heavy, inasmuch as from it I propose to derive the increase in weight of tin and lead when they are calcined. But before showing how that comes to pass, I must make this observation -- that the weight of a thing may be examined in two ways, viz. by the aid of reason, or with the balance. It is reason which has led me to discover weight in all the elements, and it is reason which now leads me to give a flat denial to that erroneous maxim which has been current since the birth of Philosophy -- that the elements mutually undergoing change, one into the other, lose or gain weight, according as in changing they become rarefied or condensed. With the arms of reason I boldly enter the lists to combat this error, and to sustain that weight is so closely united to the primary matter of the elements that they can never be deprived of it. The weight with which each portion of matter was endued at the cradle, will be carried by it to the grave. In whatever place, in whatever form, to whatever volume it my be reduced, the same weight always persists. But not presuming that my statements are on a parity with those of Pythagoras, so that it suffices to have advanced them, I support them with a demonstration which, as I conceive, all men of sense will accept. Let there be taken a portion of earth, which shall have in it the smallest possible weight, beyond which no weight can subsist: let this earth be converted into water by the means known and practised by nature: it is evident that this water will have weight, since all water must have it, and this weight will either be greater than that of the earth, or less than it, or else equal to it. My opponents will not say that it is greater, for they profess the contrary, and I also am of their opinion: smaller it cannot be, since we took the smallest weight that can exist: there remains then only the case that the two are equal, which I undertook to prove. What is shown of this particle may be shown of two, three, ora very great number -- in short, of all

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Essays of Jean Rey, Doctor of Medicine, On an Enquiry Into the Cause Wherefore Tin and Lead Increase in Weight on Calcination, Edinburgh and London, 1895. From Guerlac, H. (Ed.), *Selected Readings in the History of Science, Volume 2.* Ithaca: Henry Guerlac, 1953.

the element, which is composed of nothing else. The same proof may be extended to the conversion of water into air, of air into fire; and, conversely, of the last of these into the first. . . .

Formal response to the question, why Tin and Lead increase in weight when they are calcined.

Now I have made the preparations, nay, laid the foundations for my answer to the question of the sieur Brun, which is, that having placed two pounds six ounces of fine English tin in an iron vessel and heated it strongly on an open furnace for the space of six hours with continual agitation and without adding anything to it, he recovered two pounds thirteen ounces of a white calx; which filled him at first with amazement, and with a desire to know whence the seven ounces of surplus had come. And to increase the difficulty, I say that it is necessary to enquire not only whence these seven ounces have come, but besides them what has replaced the loss of weight which occurred necessarily from the increase of volume of the tin on its conversion into calx, and from the loss of the vapours and exhalations which were given off. To this question, then, I respond and sustain proudly, resting on the foundations already ladi, "That this increase in weight comes from the air, which in the vessel has been rendered denser, heavier, and in some measure adhesive, by the vehement and long-continued heat of the furnace: which air mixes with the calx (frequent agitation aiding) and becomes attached to its most minute particles: not otherwise than water makes heavier sand which you throw into it and agitate, by moistening it and adhering to the smallest of its grains." I fancy there are many who would have been alarmed by the sole mention of this response if I had given it at the beginning, who will now willingly receive it, being as it were tamed and rendered tractable by the evident truth of the preceding Essays. For those without doubt whose minds were preoccupied with the opinion that air was light, would have rushed to oppose it. Why (they would have said) does not one extract cold from heat, white from black, light from darkness, since so much heaviness is extracted from air, a thing inherently light? And those who chanced to have bestowed their credence on the heaviness of air, would not have been able to persuade themselves that it can every increase weight, being balanced in itself. On this account I was constrained to show that air had weight; which was recognisable by other means than the balance: and that evenwith the latter, a portion previously changed and made denser could manifest its weight. . . .

By a single experiment all opinions contrary to mine are entirely destroyed.

It is said of Hercules that no sooner had he cut off one of the heads of the Hydra which devastated the Lernaean marsh, than two others sprang forth. My condition is similar. The error that I combat teems with opinions, which are so many heads: if I cut off one, we see two appear. My labour is always on the increase: and I believe I should never have done if I only employed myself in cutting off one after the other. To give it the deathblow, I must gather my strength and make stiff my arm, in order that I may strike them all off at a single blow. Let him who will take heed: for now the fatal stroke will be dealt him. I have just read in Hamerus Poppius, in the third chapter of his book entitled *Basilica Antimonii* the new method which he practises to calcine antimony. He takes a certain quantity of it, weights it, and places it in the fashion of a cone on a slab of marble, then having a burning mirror, he opposes it to the Sun, and directs the pyramidal point of the reflected rays on the point of the cone of antimony, which straightway fumes abundantly, and in a little while, what the rays have touched is converted into a very white calx, which he separates with a knife, and conducts the rays on the remainder till all has become white: and then the calcination is ended. It is remarkable thing (he adds) that although in this calcination the antimony has lost much of its substance, by the vapours and fumes which are copiously exhaled, yet its weight augments instead of diminishing. Now if we seek the cause of this augmentation: will Cardan say that it is the vanishing of the celestial heat? It is even infused into it more largely by the solar beams. Will Scaliger say that it is the consumption of the aerated particles? But on being broken up into calx and increasing in volume, more of these are thrust into it. Will Caesalpinus allege soot? There is no fire to produce any. Would the vessel furnish something on its part? The rays are conducted so dextrously on the substance that they do not touch the marble. Will anyone suggest the vapours of charcoal? None is used in this affair. As to the volatile salts which have been so ingeniously brought forward, they here lose their savour and their charm. Peradventure someone will put humidity to the fore, as has quite lately been done. But whence would it come? from the marble? nay nay, that is not imaginable. From the air? still less, for thisoperation should succed best in the hottest days of Summer, in the most violent ardours of the Dog-days, when everything below is so heated, that even in the shade and in the night-time the air dries soaked linen, and parches the moist earth. And, during the day, where the Sun strikes, he burns our complexions, withers the grass, scorches fruits, dessicates wood,

History and Nature
of Science

70. *Lavoisier's Famous Sealed Note* (1772)

"About eight days ago I discovered that sulphur, in burning, far from losing weight, on the contrary gains it; that is to say that from a *livre* of sulphur one can obtain much more than a *livre* of vitriolic acid, making allowance for the humidity of the air; it is the same with phosphorus; this increase of weight arises from a prodigious quantity of air that is fixed during the combustion and combines with the vapours.

This discovery, which I have established by experiments that I regard as decisive, has led me to think that what is observed in the combustion of sulphur and phosphorus may well take place in the case of all substances that gain in weight by combustion and calcination: and I am persuaded that the increase in weight of metallic calces is due to the same cause. Experiment has completely confirmed my conjectures: I have carried out the reduction of litharge in closed vessels, with the apparatus of Hales, and I observed that, just as the calx changed into metal, a large quantity of air was liberated and that this air formed a volume a thousand times greater than the quantity of litharge employed. This discovery appearing to me one of the most interesting of those that have been made since the time of Stahl, I felt that I ought to secure my right in it, by depositing this note in the hands of the Secretary of the Academy, to remain sealed until the time when I shall make my experiments known. Paris, November 1, 1772. Lavoisier."

From Guerlac, H. (Ed.), *Selected Readings in the History of Science, Volume 2.* Ithaca: Henry Guerlac, 1953.

Science in Personal
and Social Perspectives

Fireside Dreams

You've just finished a day of vigorous skiing and, as the snow falls quietly outside in the darkness, you make a mug of hot chocolate, pick out a good book, and start a fire in the fireplace. You bring in some extra split logs so you won't have to make another trip outside. You relax on the rug and watch the fire for a moment as the wood starts burning.

Actually the wood itself does not burn. When you start a fire, the heat from the match or kindling breaks down the molecular structure of the wood and drives off vapors such as water, carbon monoxide, methane, hydrogen, methanol, and carbon dioxide. All these gases, except for water and CO_2, are combustible.

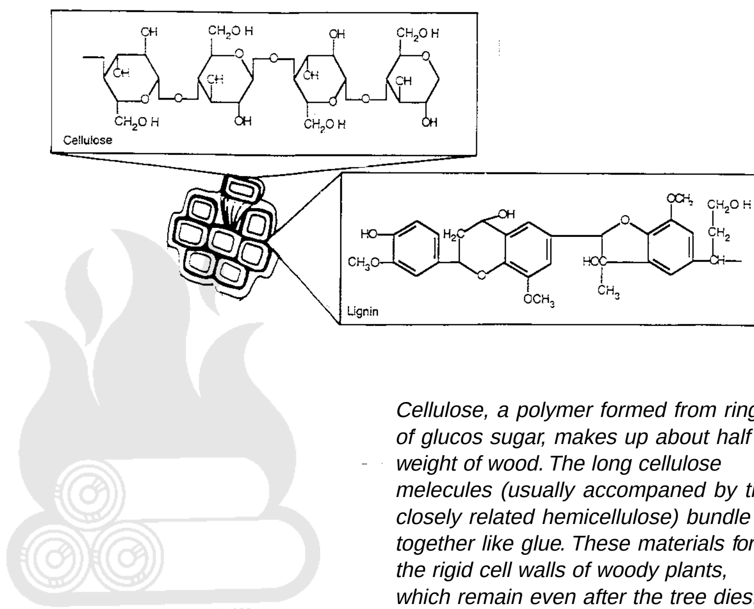
wood + heat —> combustible gases + solid char

It is the mixture of gases that burns:

$2H_2 + O_2 - 2H_20$ + heat

$2CO + O_2 - 2CO_2$ + heat

$CH_4 + 20_2 - CO_2 + 2H_20$ + heat



Cellulose, a polymer formed from rings of glucos sugar, makes up about half the weight of wood. The long cellulose melecules (usually accompanied by the closely related hemicellulose) bundle together like glue. These materials form the rigid cell walls of woody plants, which remain even after the tree dies. Wood also contains small amounts of phenols; ;terpenes; potassium, calcium, and magnesium salts; and smaller sugars—all of which are components of protoplasm, sap, and chemical defenses in a living tree.

By Gail Marsella. Reprinted with permission from "Fireside Dreams." *Chem Matters*, December 1988, pp. 13–15.

The hot gases expand, become buoyant, and rise above the logs, causing a draft that sucks air into the fireplace, feeding the fire with more oxygen. Heat energy must be supplied to the wood to decompose it inot combustible gases, but once the gases begin to burn, the wood fire pours out much more energy than it consumes. In these three reactions, the heat energy is all on the product (right) side of the equation.

The heat from the fire increases. The cat purrs contendedly on the rug. The clothes, wet from skiing, dry quickly. Lulled by the muted roar of the draft in the chimney, you start to doze, but it gets uncomfortable near the fire, and you move farther away.

Wood is a favorite fuel, in part, because its combustion products are so stable that a great deal of energy is liberated when it burns. The only reason wood doesn't burst into flame the minute you split the logs is that it needs a little energy input to get started, but it doesn't take much. The energy in a single match can start a ragging fire in dry wood, and that fire will not stop until either the wood or the oxygen runs out.

Wood is composed primarily of polymers-cellulose, hemicellulose, and lignin. When heated, the chemical bonds in these polymers absorb heat energy, become strained, begin to stretch, and finally break. A piece of the polymer flies off. When molecules break like this, they often form radicals, very reactive molecules and molecular fragments that have unpaired electrons. Much of the heat of the fire comes from the reactions in which radicals react with each other to pair up their electrons.

Other reactions occur, too. Let's say the piece of polymer that breaks off is a molecule of methane gas, CH_4. When the molecule is heated, its bonds absorb energy and stretch to the breaking point. An oxygen molecule can react with this "activated" methane to form carbon dioxide and water and release heat energy.

Much of the heat produced in the combustion process goes toward stretching and breaking other bonds and warming the resulting gas molecules to their reaction temperature. These new reactions produce more CO_2, H_2), and heat, making everything hotter still. In short, the fire's own heat keeps it going. It is the excess heat from this process that warms the room or goes up the chimney.

Because there isn't always enough oxygen for complete combustion, some of the molecules may burn only partly. Soot and hot vapors are swept up the chimney where they cool, condense on the chimney walls, and form creosote-a mixture of soot and gummy tars. This mixture collects inside the chimney and must be cleaned out by a chimney sweep.

Chimney Fires

Creosote is a combustible mixture of soot and tarry wood compounds that, if not periodically removed, may catch fire. A chimney fire is especially dangerous because the rising hot gases draw fresh air into the chimney's bottom at a rapid rate, transforming the chimney into a blowtorch. Temperatures may become high enough to damage the masonry of the chimney and even ignite wood that is in contact with the outside of the chimney.

Your eyes are getting tired of reading in the flickering light, so you put down you book and stare at the colors of the flames.

The top part of the flame is bright yellow. The color is caused by small carbon particles that break off of the fireplace grate and are swept upward by the draft. The particles are heated red-hot, then yellow-hot, and begin to react with oxygen to form CO, but the combustion is slow because most of the carbon is inside the solid particle, where it isn't exposed to oxygen. The particles glow yellow-hot, lending their color to the flame as they are carried upward.

If a flame has a lot of oxygen, if doesn't have much yellow color because the carbon particles burn to colorless carbon dioxide before they get a chance to glow. On the other hand, a fire that doesn't have enough oxygen has many carbon particles that don't burn completely, and these are swept as glowing yellow sparks up the chimney, where they cool and form black smoke.

The wood components that do not form gases remain on the fireplace grate as a black solid, called char. Some of the char burns slowly without visible flame-smoldering. Oxygen combines with carbon radicals on the surface of the char, forming carbon monoxide and then carbon dioxide, as well as heat, which causes the surface to glow red.

Near the base of the flame is an area of faint blue. When the gaseous radicals and molecules react to form their products and energy, part of the energy given off may take the form of light instead of heat. The energy produced by the combustion reaction excites electrons to higher energy levels. The energy may be passed from one electron to another, changed into energy of motion, or emitted as a particular wavelength of light. Near the base of the flame the reactions give off mostly blue wavelengths.

The red glow of the embers (char) and the yellow of the carbon particles occur in much the same way. Trillions of electrons from trillions of different hot atoms and molecules emit light of different color—all at the same time. The wavelengths of light that are most intense and most common determine the colors we actually see. The other colors may be there, but they are drowned out by the majority.

The glow of the embers dims. You consider putting another log on the fire, but decide against it. You have burned three logs, and all that remain are a few handfuls of ash, some dark streaks on the bricks, and the faint smell of smoke. The last ember goes out, and the room starts to cool off. You close the chimney flue so the cold outside air can't get in. You're finished with the book, the hot chocolate, and the fire, and it's time to crawl into the sleeping bag.

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