GENERAL CHEMISTRY

BY

HARRY N. HOLMES

PROFESSOR OF CHEMISTRY
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The greatest advances in medicine are now chemical, where once they were biological. Our attack upon disease by beneficent drugs is chemical. So is the digestion of food. So are the most vital processes of animal and plant growth.

Chemistry treats of the composition and changes in composition of substances. It is also concerned with their properties and their energy relations.

We may go further and state that chemistry deals with the detection of substances, their separation from mixtures, and their preparation.

Separation of a desired substance from incidental impurities is illustrated well by the winning of gold from the sand or rock in which it occurs and by the removal of the rare gas krypton from air in which it occurs to the extent of one part in 1,000,000.

To facilitate gravity separations not hitherto possible Beams in 1934 operated a centrifuge of top-like form, spinning on a cushion of gas in a funnel-shaped enclosure. Rotation was caused by jets of air striking minute vanes on the sides of the top. A rotor, connected with the turbine by a slender piano wire passing through a lubricated hole, whirled in a vacuum. The rim moved 1390 miles an hour giving a centrifugal thrust equal to 7,000,000 times the force of gravity.

The ***detection*** of substances is managed so well by chemists that, for example, one part of poisonous mercury vapor in 20,000,000 parts of air may be recognized by the blackening of paper coated with sensitive selenious sulfide.

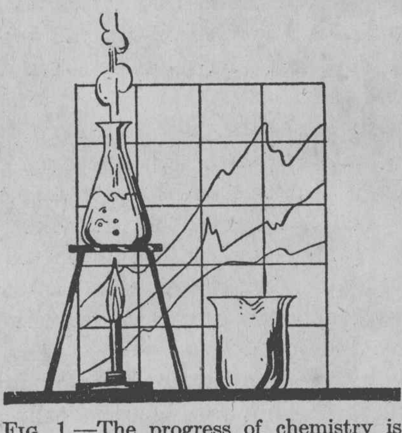

FIG. 1.—The progress of chemistry is closely related to chemical research.

The ***preparation*** of desired substances is so familiar to the chemist that he makes thousands of useful compounds that "never were before on land or sea."

Problems to be solved are pressing on the chemist from every side. It is only about forty years since eminent scientists were convinced of the sure and terrible approach of a world wheat famine. Their estimates were based on the exhaustion of known fertilizer sources. The chemist accepted this challenge and indefinitely postponed the threatened famine by "fixing" the limitless nitrogen of the air, and converting it into fertilizer acceptable to plants—one of the most important achievements of modern science. We are warned that petroleum will be exhausted in much less than a century, with the result that autos will lack gasoline, ships will lack fuel oil, and modern machinery will lack lubricants. The chemist has already looked ahead to this crisis and gives good promise of meeting it.

Physics is largely a study of the various forms of energy such as light, heat, electricity, sound, mechanical energy, etc., while chemistry deals more with matter. However, each science is forced to include both matter and energy in its field. Chemistry, like physics, is universal.

THE DOLLAR MEASURE OF A NUMBER OF CHEMICAL INDUSTRIES
(United States)

	1929	1933
Chemicals	$ 1,090,930,252	$ 702,963,724
Ceramics, Brick and Clay Products	411,472,613	107,978,000
Coke Oven Products	416,348,458	165,731,226
Drugs, Medicines and Cosmetics	646,795,185	401,469,978
Explosives and Fireworks	79,123,226	37,625,950
Fertilizers	232,510,936	94,958,766
Glass and Glassware	303,818,560	191,985,322
Glue, Gelatin and Adhesives	39,096,406	19,641,197
Leather, Tanned	481,340,299	237,202,228
Lime and Cement	303,324,918	103,121,331
Gas, Manufactured	512,652,595	291,092,688
Oils and Greases, Animal and Vegetable	601,308,320	232,050,507
Paints and Varnishes	568,975,838	288,916,047
Paper and Pulp	1,206,114,305	696,289,299
Petroleum Products	2,639,665,001	1,378,838,372
Rayon and Allied Products	149,546,107	156,931,519
Rubber Goods	1,117,460,452	472,743,587
Soap and Cleaning Prep.	360,971,162	240,378,108
Sugar	634,267,635	482,441,699
Other Products	683,646,247	292,516,933
Total for Process Industries	$12,479,368,515	$ 6,594,876,481
Total for All Industries	70,434,863,443	31,400,000,000

Energy Transformations.—The relation between matter and energy is very close. Matter is difficult to define with exactness, but we usually consider matter as anything that has mass or weight and that occupies space.

The term "energy" is applied to work or anything that can do work. Therefore light, heat, motion, and electricity are forms of energy. Chemical energy locked up in substances and the potential energy due to elevated position of bodies (such as a car on the top of a steep hill) are familiar to all of us.

The free transformation of one form of energy to another is vital to our existence and welfare. Chemical energy stored up in coal may be released as heat just as truly as the chemical energy contained in our food may be converted into the motion and heat of our animal bodies. When the composition of a given portion of matter is changed, energy may be released, yet, conversely, light, heat, and electrical energy may be applied to a portion of matter so as to force a change in composition. Heating limestone in the kiln changes it into lime and carbon dioxide. Light reduces the sensitive silver bromide on a photographic plate to metallic silver and bromine, and light also causes the dye in the wallpaper and curtains to fade. A sharp blow decomposes nitroglycerine, although, to be exact, it merely starts decomposition. Infinitely more energy is released than is accounted for by the sharp blow. A direct current of electricity decomposes silver salts in solution, depositing metallic silver on objects to be plated.

The Law of the Conservation of Energy, that ***in all ordinary transformations energy is neither created nor destroyed,*** is merely a generalized statement of a great many observations. We are coming to believe that there are some extraordinary transformations of matter into energy and energy into matter. There is strong evidence that some of the mass of the sun is lost only to reappear as radiant energy.

"Science is founded upon a belief that the world is reliable in its operation." (Arthur Compton.)

Substances.—A substance is a particular kind of material such as gold, sugar, common salt, or sulfur, with specific properties, while a body is merely a definite portion of material such as a bottle, a kettle, a stove, or a statue. A bottle may be shaped from the mixture of substances called glass, a kettle from the substance copper, a stove from the substance iron, and a statue from the substance marble; yet the glass could be shaped into a kettle or statue, and the marble into a bottle. Evidently, then, shape and size do not identify glass, although they may well serve in classifying bottles.

Elements.—Substances that we can decompose into two or more simpler substances are called ***compounds***. Limestone is a compound substance because on heating in the limekiln it breaks down into quicklime and carbon dioxide. Red mercuric oxide on being heated is decomposed into the colorless gas oxygen and the metal mercury. Hence both limestone and mercuric oxide are compounds. There are more than three hundred thousand known compounds.

An element is a substance that cannot be decomposed into two or more substances by our present ordinary chemical methods. While making this flat statement we must admit that methods at present unknown may become the common methods of the future. Until 1808 quicklime, now recognized as calcium oxide, was called an element but in that year Sir Humphry Davy prepared calcium and showed that it unites with oxygen of pure dry air to form a white solid identical with quicklime. There was then no denying that quicklime could be prepared by union of two simpler substances, is in fact a compound of calcium and oxygen. Familiar examples of elements are iron, copper, oxygen, gold, mercury, sulfur, and carbon. About ten of the elements are gases, mercury and bromine are liquids, and the rest are solids at ordinary temperatures.

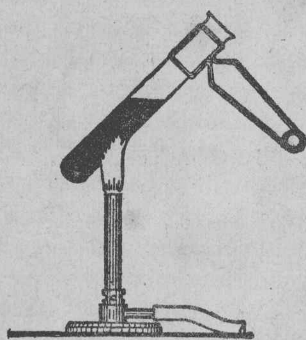

FIG. 2.—Heating mercuric oxide to obtain oxygen.

The fact that radium is constantly giving off helium nuclei does not force us to call radium a compound, for this is no ordinary chemical process. We can neither start it nor stop it.

At the beginning of the Christian era the scientific world knew only seven elements—gold, silver, copper, tin, lead, iron, and mercury. Up to the time of Lavoisier, 1750, only seventeen were known.

Although now ninety elements are known, many of them are unusual. Oxygen makes up one-half the known crust of the earth and silicon one-fourth. Fully 96 per cent of the mass of meteorites is due to iron, oxygen, magnesium and silicon.

The Peary meteor found in Greenland and now resting in the Museum of Natural History, New York, weighs 36 tons and is worth several million dollars, as a museum specimen.

It takes seventy-four elements to make up one per cent of the earth's crust. The great majority of chemists have never seen nor worked with all the elements; in fact some of the elements are

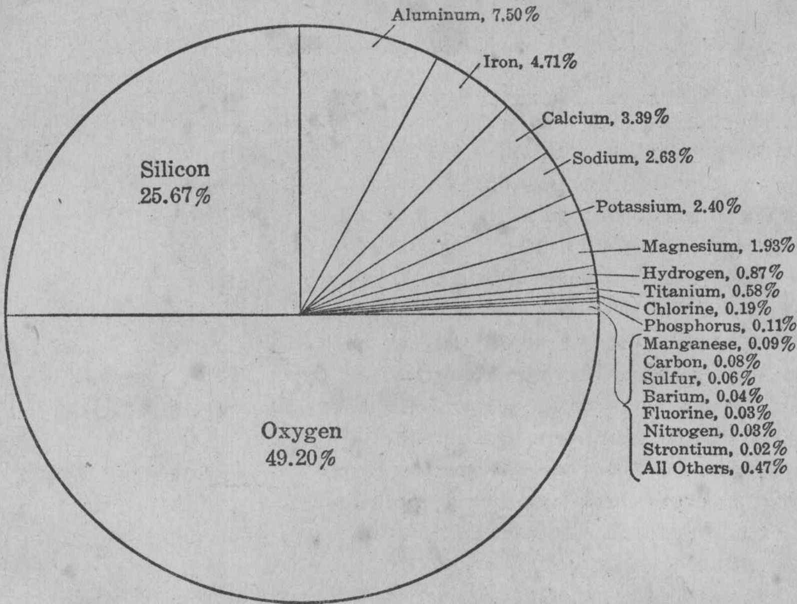

FIG. 3.—Percentage of the elements in the earth's crust.

mere curiosities with no known use. But there is always the exciting possibility that the museum specimen of today may become of invaluable service to the world tomorrow. How short a time it has been since tungsten was of little consequence and radium unknown! Tellurium is almost useless now, but who can predict its future? Neon, an inert gas which Sir William Ramsay found in the air in the proportion of one part in 80,000, had only academic interest until we recently began to employ neon lighting tubes for beacons and advertising. Its pink-orange glow is penetrating and arresting.

ELEMENTS OF THE HUMAN BODY

(Per cent weight)

Oxygen	65.00	Sodium	0.10
Carbon	20.20	Magnesium	0.07
Hydrogen	10.00	Iron	0.01
Nitrogen	2.50	Iodine	0.00004
Calcium	2.50	Fluorine	a trace
Phosphorus	1.14	Silicon	a trace
Potassium	0.11	Arsenic	a trace
Sulfur	0.14		

EXERCISE

1. Aluminum is now made from bauxite ore, yet common clay is rich in this metal. Why, then, does aluminum cost much more than iron, although more abundant in the earth's crust?

Properties.—To identify different substances we must know, not size and shape, but such characteristics or properties as color, odor, taste, hardness, crystalline form, melting point, boiling point, density, solubility in water or in other solvents, ability to conduct electricity, and index of refraction. We may even ask if the given substance burns in the air. The student readily recognizes sulfur as such because it is a yellow solid found in nature in rhombic crystals, melting at about 115° C., insoluble in water but soluble in carbon disulfide. If still undecided, he burns it in the air, notes the blue flame, and throws aside all doubts after one breath of the choking gas formed. In recognizing lead a student is particularly interested in its softness and its low melting point. Sugar he knows at once by its sweet taste, although indiscriminate tasting is not to be recommended. Hydrogen sulfide once smelled is never forgotten and never separated from the thought of rotten eggs. In fact we pay money for specific properties of substances. Copper would not sell for ten cents a pound to the amount of over a million tons yearly if it were not such an excellent conductor of electricity. Obviously, if glass were opaque or if it dissolved readily in water, it would have no market for use as window panes.

EXERCISES

2. How do you recognize copper, lead, paraffin, salt, vinegar, ammonia, water, alcohol, gold, silver, soap, gasoline?

3. What properties make rubber useful? Gold? Diamonds? Water? Asphalt?

Changes.—Changes in properties seem to be necessary to life itself. Earth, air, and water are transformed by nature's chemical processes into green grass, trees, flowers, and yet each year these beautiful new products decay and return to earth, air, and water. Iron in moist air rusts with a sharp change in properties, but the change is not hopeless, for great quantities of rusty old iron and steel are annually sent to steel mills to be converted into good steel. All of the rust is changed chemically.

When a platinum wire is highly heated, only a few properties change. Instead of the usual silver white, the color changes to red as the temperature rises, yet the hot platinum differs in very few respects from cold platinum. Moreover, on cooling, all of its usual properties are resumed. A physical change has taken place.

If pure white sugar is heated to a high temperature, it turns black and gives off steam. The black cinder left no longer tastes sweet nor will it dissolve in water. In fact nearly all the properties of the sugar are changed. The student cannot mix the steam and the black cinder (carbon) with any prospect of combining them into the sugar from whence they came. The change is chemical and, in this instance, hopelessly permanent. None of the resulting products have the same composition as the sugar, nor the same properties.

A ***physical change*** is a temporary change in certain properties such as color, density, conduction of electricity, and ductility. When the original conditions are restored, the original properties return. Ice may be melted and the resulting liquid water changed into steam without any change in the composition of the water. On cooling sufficiently, all of its usual properties are restored. Such changes in water are chiefly physical.

A ***chemical change*** is a very definite permanent change of certain properties with formation of new substances and is always accompanied by a gain or loss of energy. Wherever a chemical change takes place we have a chemical reaction.

Lavoisier as early as 1785 believed that ***in chemical reactions the mass of the system is not changed.*** (Law of Conservation of Mass.) Naturally this belief came from careful weighing of the reacting materials and *all* the products. In the instance of burning wood the gaseous products as well as the ashes must be caught and weighed.

Landolt demonstrated the above law with a sealed glass tube shaped like a V. After one of the reacting substances had been introduced into one leg of the tube and the other into the second leg, the tube was sealed, cooled, accurately weighed, and then tilted so as to mix the two reagents. After restoring the original temperature the tube with its contents (a complete system) was again weighed. Within the limits of human experimental error there was no change in weight. Reaction evidently consists in rearrangement of constituent elements.

EXERCISE

4. Give a few illustrations of physical and chemical changes.

Pure Substances and the Law of Definite Composition.[1]—***Every pure compound has a definite composition.*** Water from any portion of the earth, if pure, is composed of hydrogen and oxygen in the proportion of 1 part of hydrogen to 7.94 parts of oxygen by weight. If other elements are present, they represent impurities and can readily be separated from the water. Any mixture of alcohol and water might look like water, but it would not be a pure substance. Incidentally it would not boil at 100° C. under one atmosphere pressure as does water, nor would it act chemically towards other substances exactly as does water. Sugar and clean white sand might be mixed very deceptively, but the analysis would show a very different composition from sugar. Such a material would not be a pure substance. If the sand were removed (How could you do it?), the remaining sugar would have the same percentage of carbon, hydrogen, and oxygen as any other specimen of pure sugar.

The difference between pure compounds and mechanical mixtures is evident from this ***Law of Definite Composition.*** The proportions in any mechanical mixture may be varied considerably without any abrupt change in properties as in the sand-sugar material, but if the proportions of carbon, hydrogen, and oxygen in pure sugar were changed, the substance would no longer be sugar. As a matter of fact, alcohol is composed of the same elements as sugar and can be made from it, but the percentage composition is different. Thousands of pure substances contain only these three elements, but in each case either the proportions or the arrangement of these elements are different. The formation of compounds is always attended by a pronounced energy change. Not so with mere mixtures.

[1] Often called the *Law of Definite Proportions.*

In a mixture the properties are the sum of the properties of the constituents, as demonstrated so tastefully in a well-flavored soup. The properties of a compound, however, are independent of the properties of the substances used in making it.

A classic illustration of the difference between a mechanical mixture and a chemical compound is found in an experiment with iron and sulfur. If very fine iron filings are mixed with flowers of sulfur, it may be shown that the sulfur still retains its own characteristic properties as does the iron, and that each may be removed by simple mechanical means. A magnet attracts the iron as if the sulfur were not present. Carbon disulfide dissolves the sulfur out of the mixture as if the iron were not present and, on filtration, a clear solution (the filtrate) is obtained. This yields the sulfur if allowed to evaporate.

If the mixture of iron and sulfur is heated in a test tube, interesting color changes are observed. Finally the mixture glows brightly, even after it is removed from the flame. Evidently heat is given off by some sort of action between the two elements. On breaking the tube a black solid is obtained which is not attracted by the magnet and from which sulfur is not dissolved by carbon disulfide. The conclusion is that neither free iron nor free sulfur is present, and that they have combined to form a compound. A reaction took place which when well started gave off considerable heat.

The experiment goes as described if the two elements are taken in a very definite proportion. If more iron than is called for by that proportion is used, some free iron is left over. If more sulfur than is called for is used, some sulfur is left over. The hard black solid obtained in the above experiment is a compound called iron sulfide. It has several properties quite different from those of iron or sulfur.

Measurement.—The metric system of measurement (Appendix) is used by scientists and should be used by our general public. Accuracy, sometimes extreme accuracy, of measurement is fundamental to scientific progress.

Even 1/1000 of a second is vital—if you're Professor Edgerton of the Massachusetts Institute of Technology, perfecting a stroboscopic camera whose shutter clicks 1000 times a second.

Babcock's invention of the centrifuge method of determining the percentage of fat in milk put the dairy industry on a scientific basis.

Scientific Reasoning.—Many illustrations of sound reasoning will follow later but here is an interesting example of faulty reasoning.

"Van Helmont planted a willow in a weighed quantity of dry earth, supplied it with water only, and at the end of five years found that it had gained 164 pounds in weight, while the earth had lost only 2 ounces. Here was ingenious proof that practically all the new substance of the willow was made of water—convincing proof—until one hundred years later Ingenhousz and Priestley showed that plants absorb carbon from carbon dioxide in the air."

EXERCISES

5. Is granite a mixture or compound? How about brass, flour, iron rust, sugar, ice cream, and wine?
6. In general how do you distinguish between compounds and mixtures?
7. What type of change takes place when water freezes? When lard melts? When iron rusts? When a loaf of bread is scorched? When coal burns?
8. What type of change is observed when a rubber band is stretched? When a rubber band is burned?
9. Define a body, a substance, a compound, an element, a chemical reaction, atomic weights, a combining weight (or equivalent weight).
10. State the Laws of Definite Composition, Conservation of Mass and Energy, and Multiple Proportions.
11. Examine a few drops of the very inflammable liquid called carbon disulfide. Is it a mixture of carbon and sulfur or a compound of those two elements?
12. There are a dozen or more materials in a motor car. Are they elements, compounds or mixtures?
13. What does the sun have to do with the electricity generated by a great waterfall?
14. When sand, lime and soda are fused together to form glass is the change physical or chemical?
15. If, while camping in the wilds, you upset all the salt on the white sandy beach what would you do to recover the precious salt?
16. How could you separate a mixture of oxygen and ammonia?

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CHAPTER OUTLINE

An excellent and most effective study habit will be formed if the student will read carefully the chapter and then recall the most important facts or principles by looking at the following outline of topics. If forced to glance at the earlier pages to jog his memory, he should persevere until the outline alone will give him a clear picture of the essentials of the chapter.

1. What Is Chemistry?
   What are some of its problems?
2. Energy Transformations.
   How many forms of energy can you get out of a lump of coal?
   Is energy ever lost in any of these transformations?
3. Substances.
   What is the difference between a substance and a body?
4. Elements.
   There are about ninety known elements, possibly ninety-two, and yet there are nearly three hundred thousand substances. Explain.
   Quicklime can be heated to extraordinarily high temperatures without yielding any simpler substances. How did Davy prove it to be a compound?
   What elements make up 97 per cent of the earth's crust?
5. Properties.
   Of what use are properties of substances?
6. Changes.
   Physical change.
   Chemical change.
   Landolt's proof of the Conservation of Mass.

CHAPTER II

COMBINING PROPORTIONS BY WEIGHT

Joseph Black in England, 1755, made the first quantitative studies of chemical changes, the first studies in which the materials taking part in those changes were accurately weighed or measured.

Combining Proportions.—The Law of Definite Composition created an interest in the *ratio* of the weights of elements combined in a pure compound. These combining weight ratios are easily calculated from the analysis of pure compounds. Since most elements unite directly with oxygen, it is possible to learn from actual experiment what weight of each element will combine directly with a fixed weight of oxygen. These numbers may then be compared.

Berzelius arbitrarily chose the number 100 as representing the "fixed weight" in grams, or parts of oxygen, but he might just as well have used some other number. In fact, during the century elapsed since Berzelius' time chemists have agreed that it is most convenient to assign the value eight parts (or grams) as the fixed weight of oxygen to be compared. Since eight grams of oxygen unite directly with 1.008 g. of hydrogen (to form water), this choice insures a value of at least unity for hydrogen, the lightest known substance.

In the following table are listed the relative weights in which some of the elements combine with eight grams of oxygen.

Substance	Percentage Composition by Analysis		Number of Grams of the Element Uniting with 8 Grams of Oxygen
Magnesium oxide.......	Magnesium	60.32	12.16
	Oxygen	39.68	
Copper oxide...........	Copper	79.9	31.80
	Oxygen	20.1	
Water.................	Hydrogen	11.19	1.008
	Oxygen	88.81	
Aluminum oxide........	Aluminum	52.94	9.00
	Oxygen	47.06	
Carbon dioxide.........	Carbon	27.27	3.00
	Oxygen	72.73	
Calcium oxide..........	Calcium	71.43	20.03
	Oxygen	28.57	

From this table a partial list of combining proportions may be derived.

Oxygen	= 8.0	Hydrogen	= 1.008
Magnesium	= 12.16	Aluminum	= 9.0
Copper	= 31.8	Carbon	= 3.0
Calcium	= 20.03		

Since 1.008 g. of hydrogen are evidently equivalent in combining value (as in water) to 8 g. of oxygen, it might be conjectured that the weight of any element uniting with 1.008 g. of hydrogen would probably unite (if at all) with exactly 8 g. of oxygen. In the case of chlorine, 35.46 g. unite exactly with 1.008 g. of hydrogen, and, true to the above assumption, 35.46 g. of chlorine unite with 8 g. of oxygen.

Fluorine will not unite with oxygen but will unite with silver to form silver fluoride. The combining weight of fluorine is obtained in terms of silver which is, in turn, obtained in terms of chlorine, etc.

Oxygen	Hydrogen	Chlorine	Silver	Fluorine
8 g.	1.008 g.	35.46 g.	107.88 g.	19 g.

In other words, 19 g. of fluorine are equivalent to 8 g. of oxygen because 19 g. of fluorine combines with 107.88 g. of silver which combines with 35.46 g. of chlorine which combines with 1.008 g. of hydrogen which combines with 8 g. of oxygen.

EXERCISE

1. Predict how many grams of magnesium combine with 35.46 g. of chlorine. How many grams of aluminum, and of copper, unite with 35.46 g. of chlorine?

It is evidently reasonable to state that ***a combining weight of any element is the number of grams of that element that combine with 8 g. of oxygen.***

Since there are instances where two elements combine in different proportions to form a series of compounds, we may suspect that it is possible for some elements to have at least two combining weights. The two oxides of carbon illustrate this fact.

	Oxygen	Carbon
Carbon dioxide	8 g.	3 g. (= 1 × 3 g.)
Carbon monoxide	8 g.	6 g. (= 2 × 3 g.)

The two oxides of hydrogen may also be cited.

	Hydrogen	Oxygen
Water	1.008 g.	8 g. (= 1 × 8 g.)
Hydrogen peroxide	1.008 g.	16 g. (= 2 × 8 g.)

The five oxides of nitrogen are radically different in properties, yet all contain only nitrogen and oxygen.

	NITROGEN	OXYGEN
Nitrous oxide	14 g.	8 g. (= 1 × 8 g.)
Nitric oxide	14 g.	16 g. (= 2 × 8 g.)
Nitrogen trioxide	14 g.	24 g. (= 3 × 8 g.)
Nitrogen tetroxide	14 g.	32 g. (= 4 × 8 g.)
Nitrogen pentoxide	14 g.	40 g. (= 5 × 8 g)

It is evident that the elements combine in the ratio of their combining weights or simple whole multiples of these. ***The Law of Multiple Proportions*** (a mere generalization) is often stated as follows: ***If two or more elements form a series of compounds, the different weights of one which combine with a definite weight of another stand to each other in the ratio of small whole numbers.***

The combining weight of magnesium relative to oxygen, for example, may be determined in the laboratory by heating a weighed quantity of this metal in a porcelain crucible. The cover is kept on during the heating, which is gentle at first, but finally reaches the limit of the flame. After cooling, crucible and ash, magnesium oxide, are weighed, heated again, and weighed. The operation is repeated until there is no further gain in weight. After a final weighing the gain in weight due to combination of oxygen of the air with the metal is easily calculated. By a simple proportion the number of grams of magnesium reacting with 8 g. of oxygen is found.

A correction must be made for the small amount of magnesium nitride resulting from union of magnesium with nitrogen.

The combining weight of copper may be determined by passing air or pure oxygen through a glass tube containing a weighed amount of heated copper powder. Black copper oxide is formed. Or copper oxide may be torn apart with the aid of hot hydrogen and the loss in weight noted. For example, the student may weigh out black copper oxide in a small porcelain boat or narrow dish and, after placing

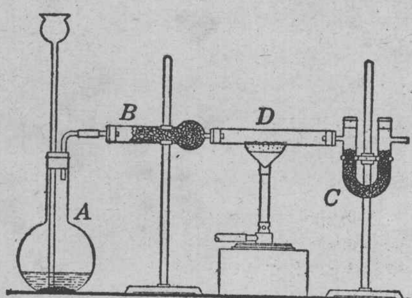

FIG. 4.—Reduction of copper oxide in *D* by hydrogen from *A* which has been dried in *B*. The water formed is collected in the weighed drying tube *C*.