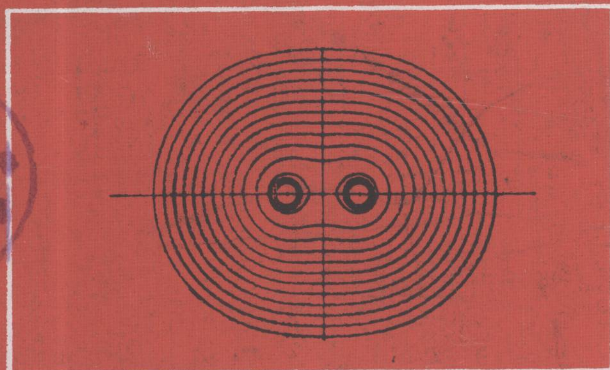
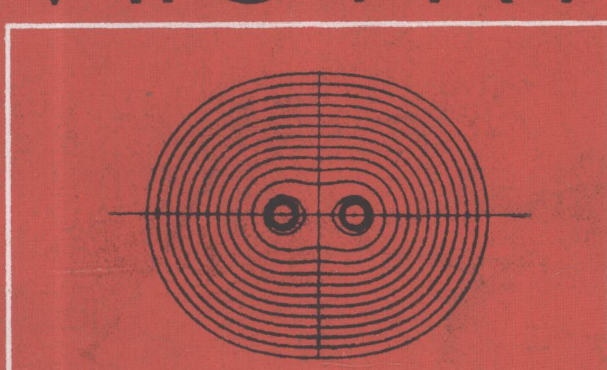
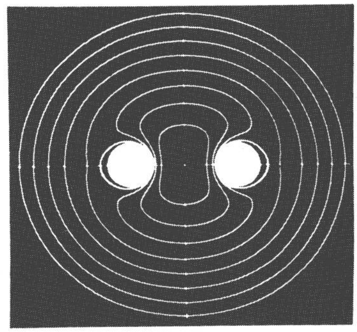
Donald I. Hamm



FUNDAMENTAL CONCEPTS OF CHEMISTRY





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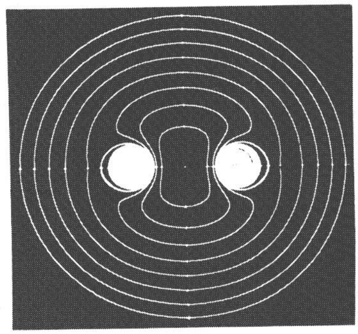

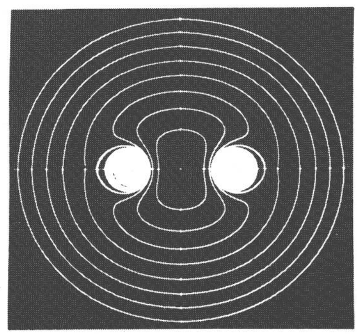

DONALD I. HAMM
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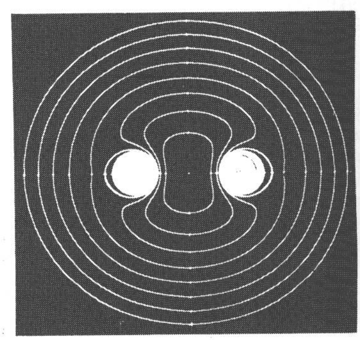

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THE CHEMICAL ELEMENTS

Element	Symbol	Atomic Number	Atomic Weight
Actinium	Ac	89	[227]
Aluminum	Al	13	26.9815
Americium	Am	95	[243]
Antimony	Sb	51	121.75
Argon	Ar	18	39.948
Arsenic	As	33	74.9216
Astatine	At	85	[210]
Barium	Ba	56	137.34
Berkelium	Bk	97	[249]
Beryllium	Be	4	9.0122
Bismuth	Bi	83	208.980
Boron	B	5	10.811
Bromine	Br	35	79.909
Cadmium	Cd	48	112.40
Calcium	Ca	20	40.08
Californium	Cf	98	[251]
Carbon	C	6	12.01115
Cerium	Ce	58	140.12
Cesium	Cs	55	132.905
Chlorine	Cl	17	35.453
Chromium	Cr	24	51.996
Cobalt	Co	27	58.9332
Copper	Cu	29	63.54
Curium	Cm	96	[247]
Dysprosium	Dy	66	162.50
Einsteinium	Es	99	[254]
Erbium	Er	68	167.26
Europium	Eu	63	151.96
Fermium	Fm	100	[253]
Fluorine	F	9	18.9984
Francium	Fr	87	[223]
Gadolinium	Gd	64	157.25
Gallium	Ga	31	69.72
Germanium	Ge	32	72.59
Gold	Au	79	196.967
Hafnium	Hf	72	178.49
Helium	He	2	4.0026
Holmium	Ho	67	164.930
Hydrogen	H	1	1.00797
Indium	In	49	114.82
Iodine	I	53	126.9044
Iridium	Ir	77	192.2
Iron	Fe	26	55.847
Krypton	Kr	36	83.80
Kurchatorium	Ku	104	[260]
Lanthanum	La	57	138.91
Lawrencium	Lw	103	[257]
Lead	Pb	82	207.19
Lithium	Li	3	6.939
Lutetium	Lu	71	174.97
Magnesium	Mg	12	24.312
Manganese	Mn	25	54.9380

Element	Symbol	Atomic Number	Atomic Weight
Mendelevium	Md	101	[256]
Mercury	Hg	80	200.59
Molybdenum	Mo	42	95.94
Neodymium	Nd	60	144.24
Neon	Ne	10	20.183
Neptunium	Np	93	[237]
Nickel	Ni	28	58.71
Niobium	Nb	41	92.906
Nitrogen	N	7	14.0067
Nobelium	No	102	[254]
Osmium	Os	76	190.2
Oxygen	O	8	15.9994
Palladium	Pd	46	106.4
Phosphorus	P	15	30.9738
Platinum	Pt	78	195.09
Plutonium	Pu	94	[242]
Polonium	Po	84	[210]
Potassium	K	19	39.102
Praseodymium	Pr	59	140.907
Promethium	Pm	61	[147]
Protactinium	Pa	91	[231]
Radium	Ra	88	[226]
Radon	Rn	86	[222]
Rhenium	Re	75	186.2
Rhodium	Rh	45	102.905
Rubidium	Rb	37	85.47
Ruthenium	Ru	44	101.07
Samarium	Sm	62	150.35
Scandium	Sc	21	44.956
Selenium	Se	34	78.96
Silicon	Si	14	28.086
Silver	Ag	47	107.870
Sodium	Na	11	22.9898
Strontium	Sr	38	87.62
Sulfur	S	16	32.064
Tantalum	Ta	73	180.948
Technetium	Tc	43	[99]
Tellurium	Te	52	127.60
Terbium	Tb	65	158.924
Thallium	Tl	81	204.37
Thorium	Th	90	232.038
Thulium	Tm	69	168.934
Tin	Sn	50	118.69
Titanium	Ti	22	47.90
Tungsten	W	74	183.85
Uranium	U	92	238.03
Vanadium	V	23	50.942
Xenon	Xe	54	131.30
Ytterbium	Yb	70	173.04
Yttrium	Y	39	88.905
Zinc	Zn	30	65.37
Zirconium	Zr	40	91.22

Atomic weight values are based on carbon-12. Values listed in brackets denote mass numbers; these values are given for either the longest-lived or the best-known isotope.

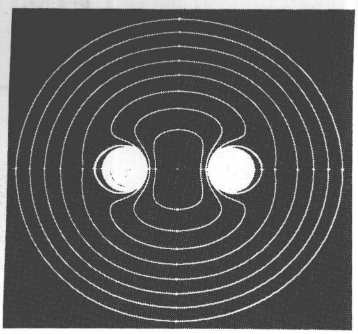
PERIODIC TABLE OF THE ELEMENTS

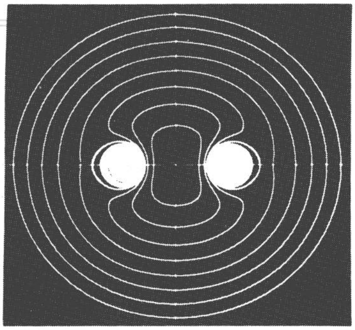
	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1 H 1.00797																	2 He 4.0026
2	3 Li 6.939	4 Be 9.0122											5 B 10.811	6 C 12.01115	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.183
3	11 Na 22.9898	12 Mg 24.312											13 Al 26.9815	14 Si 28.086	15 P 30.9738	16 S 32.064	17 Cl 35.453	18 Ar 39.948
4	19 K 39.102	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.942	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.71	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.909	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.905	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc (99)	44 Ru 101.07	45 Rh 102.905	46 Pd 106.4	47 Ag 107.870	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.9044	54 Xe 131.30
6	55 Cs 132.905	56 Ba 137.34	57 La 138.91	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 196.967	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.980	84 Po (210)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Ku (260)														

58 Ce 140.12	59 Pr 140.907	60 Nd 144.24	61 Pm (147)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.924	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.97
90 Th 232.038	91 Pa (231)	92 U 238.03	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (249)	98 Cf (251)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (254)	103 Lw (257)

Atomic weight values listed in parentheses are approximate.

fundamental concepts of CHEMISTRY





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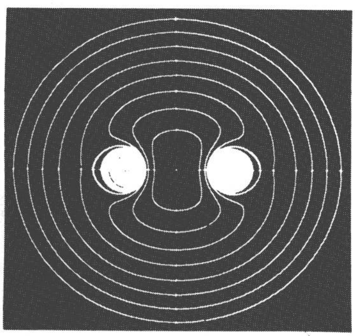

to

Jean Ann

PREFACE

In a previous text, *Chemistry: An Introduction to Matter and Energy*, I incorporated materials from the history and philosophy of our science within those studies which are usually presented in the beginning college chemistry course. I wished to share with my students, and with other students as well, the considerable satisfaction which I derive from looking into the evolution of our ideas.

I learned that many teachers share my interest in historical and philosophical considerations, and that quite as many do not. I have written this text from a desire to speak to the second group as well as to the first, and, through them, to their students. This text shares the theme of the former work: atomic-molecular theory. Here the theme is presented more succinctly.

The order in which the various facets of atomic-molecular theory are presented herein is easily modified. Most of our students have received a good introduction in their high school chemistry courses to the material treated in Chapters 1–3. Some instructors may wish to consider this material briefly or to assign it for outside reading. Those who wish to begin their courses with a consideration of subatomic theory will find that Chapters 11–14 can be treated very early; they can, in fact, be treated in advance of Chapters 5–10 very easily. Since the material on oxidation–reduction (Chapter 6) is treated as a unit, this subject can be introduced when the instructor sees fit to do so. The same can be said for the material on acids and bases (Chapter 10).

Chapters 17–19 (and some of the sections in Chapter 20) comprise a discourse on valence and bonding. We choose to begin the second term of our general course with this section. Some will want to consider it earlier. Again, the organization of the text will not preclude this. Some of our staff members consider equilibrium (Chapter 8) initially, then kinetics (Chapter 9); others follow the opposite order. We find the text amenable to either treatment.

Some of the options outlined above are here summarized.

Approach A.

Atomic theory through Avogadro. Chapters 1–3.
The structure of the nucleus and the distribution of electrons. Chapters 11–13.
Periodicity. Chapter 14.
Introduction to the chemistry of the metals. Chapters 15–16.
Heat. Chapters 4–5.
Electrochemistry. Chapter 6.
Acids and bases. Chapter 10.
Equilibrium. Chapter 8.
Rates of reactions. Chapter 9.
Valence and bonding: ionic compounds, covalent compounds, polar covalent compounds. Chapters 17–19.
The chemistry of the periodic groups: groups IIIA–VIIA, hydrogen, the rare gases, and the transition elements. Chapters 20–29.

Approach B.

Atomic theory through Avogadro. Chapters 1–3.
Heat. Chapters 4–5.
The structure of the nucleus and the distribution of electrons. Chapters 11–13.
Electrochemistry. Chapter 6.
Periodicity. Chapter 14.
Groups IA and IIA. Chapters 15–16.
Valence and bonding: ionic compounds, covalent compounds, polar covalent compounds. Chapters 17–19.
Group VIIA. Chapter 20.
Equilibrium. Chapter 8.
Rates of reactions. Chapter 9.
Acids and bases. Chapter 10.
The chemistry of the periodic groups: groups IIIA–VIA, hydrogen, the rare gases, and the transition elements. Chapters 21–29.

Approach C.

Atomic theory through Avogadro. Chapters 1–3.
The structure of the nucleus and the distribution of electrons. Chapters 11–13.
Periodicity. Chapter 14.
Valence and bonding: ionic compounds, covalent compounds, polar covalent compounds. Chapters 17–19.
Heat. Chapters 4–5.
Rates of reaction. Chapter 9.
Equilibrium. Chapter 8.
Electrochemistry. Chapter 6.
Acids and bases. Chapter 10.
Groups IA and IIA. Chapters 15–16.
Group VIIA. Chapter 20.
The chemistry of the periodic groups: groups IIIA–VIA, hydrogen, the rare gases, and the transition elements. Chapters 21–29.

Finally, I would point out that certain of the more difficult sections on thermodynamics (free energy and entropy, for example) and chemical physics (the quantitative aspects of kinetic–molecular theory and the details of J. J. Thomson's experimental work which led to the discovery of the electron, to cite two instances) can be omitted without doing severe damage to the continuity of the material included herein. We consider many sections such as these because we regard them to be among the more beautiful of the "chemical ideas," rather than as necessary to our course. We recognize, however, even on our examinations, that beauty and the beholder have a mutual debt.

I would thank again my teachers and colleagues: H. C. Brown, C. D. Kochakian, G. E. Castleberry, Edward Neparko, Harold M. White, Rolan Decker, Ralph L. Asbury, Stuart Burchett, Bobby Gunter, Fred Von Wicklen, Earl A. Reynolds, and H. F. Timmons.

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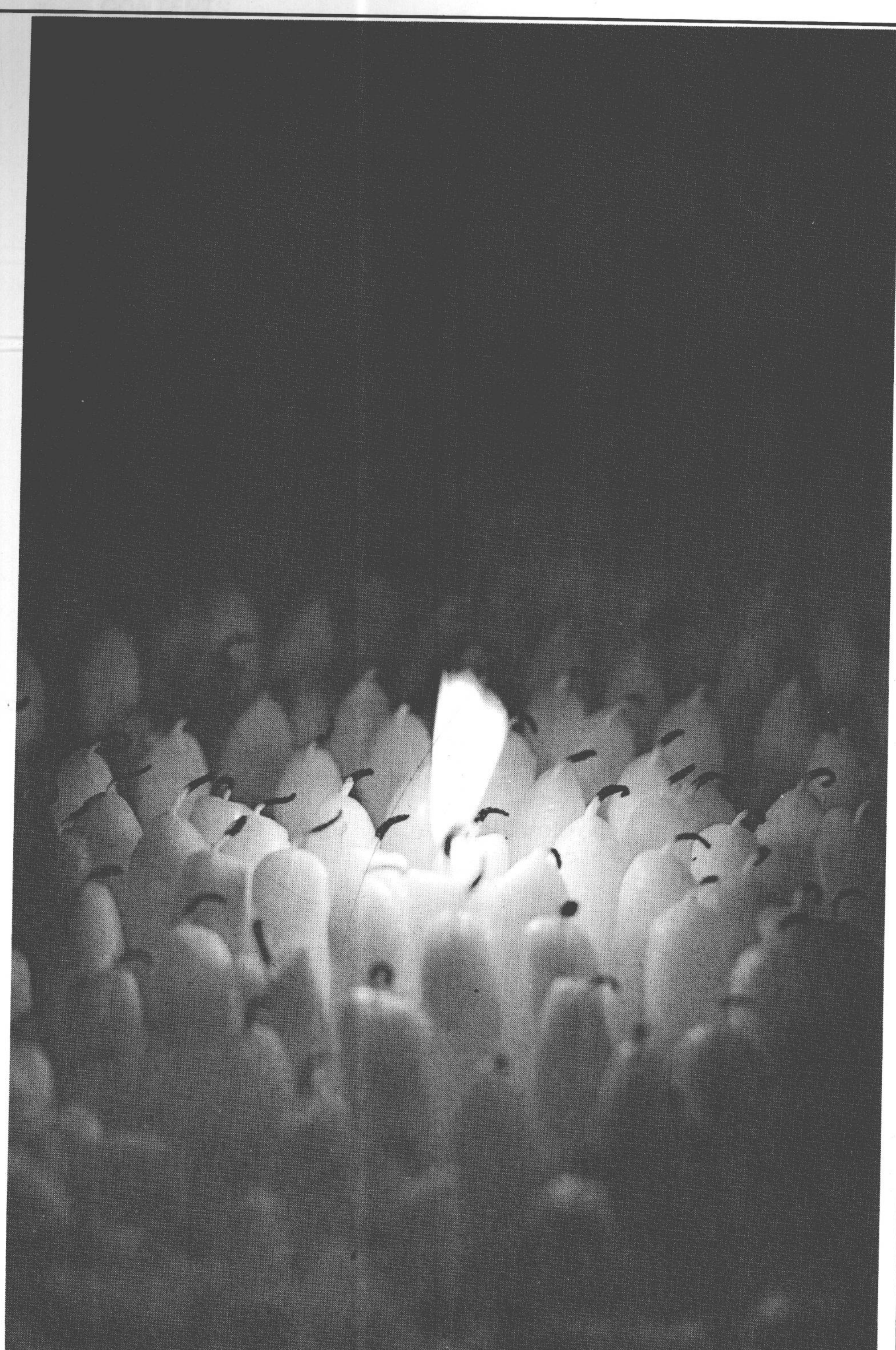
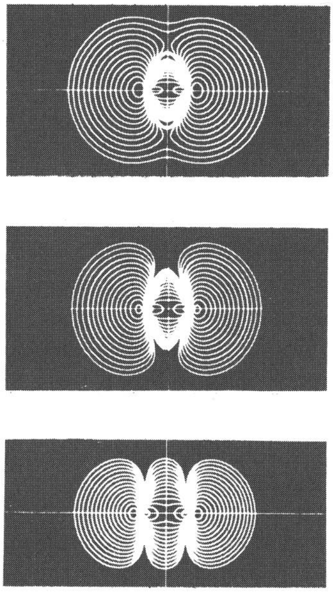


CONTENTS



1

an introduction to chemistry

Michael Faraday gave his *Lectures on The Chemical History of a Candle* several times to an audience of young persons at the Royal Institution in London. He gave the lectures for the last time at Christmas, 1860. Faraday described the components involved in the manufacture of the candle and of its wick. He described the capillary action of the wick and the production by the flame, not only of light, but also of carbon dioxide and water. He discussed the nature of the atmosphere in which the candle burns. Faraday clearly demonstrated that if one knew enough about the candle, one would also know a great deal of chemistry. *Photograph by Matson-Jones, courtesy of Abbott Laboratories.*

Chemistry is concerned with the study of *matter*. Three aspects of matter are considered to be of primary importance. Initially there is interest in the *properties* or characteristics of matter. The properties of matter serve to distinguish different substances. We know that water and alcohol are distinct substances because they have different melting points, different boiling points, and different densities. When we study various substances we study these and other properties. Is a sample of matter found in nature a good conductor of electricity? A good fuel? Does it have physiological properties? Can it serve as a foodstuff? Is it a good solvent? To answer these questions and many others of a similar nature we study the properties of matter with the tools which chemistry affords.

Secondly, there is interest in the *composition* of matter. The *composition* of a substance refers to the components present in the substance and their abundance. If a material found in nature is not a good conductor of electricity, does it consist of simpler materials which by themselves are good conductors? Does a powdery earth conceal iron or aluminum or copper or lead? If so, how much does it contain? Questions such as these lead the chemist to study the composition of matter.

Thirdly, we are interested in the *transformation* of one kind of matter into another kind. If it is determined that a powdery earth contains iron and another component, how can the earth (or ore) be made to change into iron? What are the secrets of nature involved in the burning of wood, coal, and oil? How do water, soil, and a seed of wheat become a beautiful plant? Can man produce transformations which nature does not with laboratory techniques not found in nature? If nature does not yield a substance which will prevent or cure a disease, can we transform what she does give into a drug which will? Since the varieties of matter that nature presents are limited, the chemist studies the secrets of the transformations of one substance into another.

Although chemistry deals primarily with matter, it cannot afford to deal with matter exclusively. If we wish to transform one substance into another, there must be an accompanying exchange of energy. Sometimes energy is given up, as with the burning of fuels. At other times changes require the addition of energy, as with the decomposition of water. As it turns out, material processes and energy exchanges are inseparable. Consequently chemists must maintain an accurate account of the energy exchanges which accompany the reactions they study.

These are the principal kinds of *observations* which concern the chemist. He does more, however, than observe; he is concerned with accounting for why things happen as they do. We would like to think that there is a cause for everything we observe, and that such causes can be understood by man. Relationships between cause and effect, however, are not always immediately discernible. It is for this reason that chemistry often takes on the character of a contest, not only when we are involved in research, but also when we follow the research of others. It is a contest in which one is hunting for the causes—sometimes barely hidden, sometimes expertly camouflaged—of the effects observed by the senses. Why does heating iron ore with carbon yield iron and carbon dioxide? Why does aspirin relieve pain? Why is carbon tetrachloride volatile and sodium chloride nonvolatile? Why does liquid sodium chloride conduct a current whereas liquid carbon tetrachloride does not? Why does one reaction give off energy, another require it?

In understanding the "why" of things chemists have found *atomic theory* the most powerful construction yet devised. For this reason, the development of atomic theory has been chosen as the principal theme of this book. Hopefully this theme will always remain apparent, in spite of the many observations (properties, compositions, and transformations) that we must study in order to give atomic theory meaning.

COMPOUNDS

When a sample of mercuric oxide is heated, the sample decomposes and a pair of different substances, mercury and oxygen, results. Chemists determine the composition of mercuric oxide by decomposing a weighed sample of this material and weighing either the mercury or the oxygen so obtained (or both). One gram of mercuric oxide yields 0.9261 g of mercury and 0.0739 g of oxygen. This result is invariably obtained (when pure mercuric oxide is employed). Because the same result is always obtained, we say that mercuric oxide has a *definite* (or invariant) *composition.* This means, too, that the weights of mercury and oxygen obtained from the decomposition of mercuric oxide are directly proportional to the weight of mercuric oxide decomposed.

1.0000 g mercuric oxide yields 0.9261 g mercury
plus 0.0739 g oxygen
2.0000 g mercuric oxide yields twice 0.9261 g mercury
plus twice 0.0739 g oxygen
3.0000 g mercuric oxide yields three times 0.9261 g mercury
plus three times 0.0739 g oxygen

Literally millions of substances display these characteristics. That is, they can be decomposed and they exhibit invariant composition. We call such substances *compounds.* Because so many substances display invariant composition, we underscore this behavior in the *law of definite proportions: compounds display invariant composition.*

EXERCISES

1-1. Calculate the percent composition in mercuric oxide.

1-2. Calculate the weight of mercury which would result from the decomposition of 25 g of mercuric oxide.

ELEMENTS

Many compounds decompose at elevated temperatures. A number of other substances do not. When we heat mercury and oxygen, we succeed only in raising their temperatures. Many compounds are decomposed by the action of electric current. In this way hydrogen and oxygen are obtained from water, and sodium and chlorine are obtained from molten sodium chloride. In contrast, electric current does not decompose hydrogen, oxygen, mercury, sodium, or chlorine.

When iron oxide is heated with carbon, iron and carbon dioxide result. This reaction reveals that iron oxide is a compound, since it provides a pair of substances which appear in the products: iron and the oxygen in the carbon dioxide. Hydrogen,