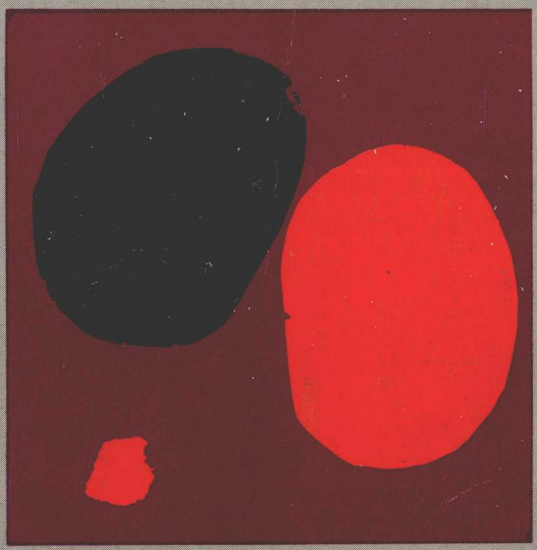
A BARNES & NOBLE OUTLINE

COLLEGE Chemistry

JOHN R. LEWIS



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THE BARNES & NOBLE OUTLINE SERIES

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COLLEGE CHEMISTRY

Ninth Edition

JOHN R. LEWIS
University of Utah

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College Chemistry

About the Author

John R. Lewis received the doctorate degree in physical chemistry from the University of Wisconsin in 1924. After teaching at Wisconsin University for an additional four years, he became an Associate Professor and, later, Professor of Chemistry at the University of Utah.

From 1942 to 1958 he was Head of the Department of Metallurgical Engineering, University of Utah. From 1958 to 1963 he taught metallurgy and did research in the same area. At present he is Professor Emeritus at the University of Utah.

Professor Lewis has published several papers and bulletins in the fields of physical chemistry, extractive metallurgy, and chemical education. He is a member of several professional, scientific, and honor societies, including the American Chemical Society, the Honor Society of Sigma Xi, and Phi Kappa Phi. He is listed in *American Men of Science*, *Who's Who in Engineering*, *Who Knows—And What*, and *Who's Who in America*.

Preface

The ninth edition of College Chemistry reflects another thorough revision. To keep up with progress in modern chemistry, some of the less important chapters have been deleted and others have been rearranged or combined. The chapters on atomic structure and the periodic classification of the elements have been revised so completely that they are, essentially, new material. A new chapter on the chemical bond has also been added. The revised book contains a number of important new tables, graphs, and figures that will be very useful to students and others. The appendixes have been enlarged to include (1) an activity table of the metals and (2) a table containing the electronic populations of atoms.

This new edition, like the earlier ones, summarizes the chemistry found in the latest editions of the most widely used general chemistry texts and also new texts that have recently come on the market. And, like the earlier editions, this new College Chemistry may be used as a textbook.

The author and publishers are grateful to students and others who have written to them concerning earlier editions. It is to be hoped that comments and suggestions regarding the ninth edition will also be forthcoming.

The author wishes to thank Dr. Gladys Walterhouse, Editor, of Barnes and Noble, Inc. for her excellent work in editing this book. It has been markedly improved through her valuable suggestions.

I wish to thank Mrs. Iris Adams for the careful work she did in typing part of the manuscript. My thanks are also due to Mrs. Dawn Ann Bailey for stenographic work and especially for the many courtesies she extended to the author. They made his tasks easier.

Finally great credit and appreciation are due my wife, Hazel, for the careful work she did in preparing the Index.

Periodic Table of the Elements

s Series of Representative Elements

Key

Atomic number → 11
Na
$3s^1$ ← Valence electron configuration
Atomic weight → 22.9898

p Series of Representative Elements

Noble Gases

	IA												IIIA	IVA	VA	VIA	VIIA	Noble Gases
1st period n = 1	1 H $1s^1$ 1.00797	IIA																2 He $1s^2$ 4.0026
2nd period n = 2	3 Li $2s^1$ 6.939	4 Be $2s^2$ 9.0122											5 B $2s^22p^1$ 10.811	6 C $2s^22p^2$ 12.01115	7 N $2s^22p^3$ 14.0067	8 O $2s^22p^4$ 15.9994	9 F $2s^22p^5$ 18.9984	10 Ne $2s^22p^6$ 20.183
3rd period n = 3	11 Na $3s^1$ 22.9898	12 Mg $3s^2$ 24.312	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	13 Al $3s^23p^1$ 26.9815	14 Si $3s^23p^2$ 28.086	15 P $3s^23p^3$ 30.9738	16 S $3s^23p^4$ 32.064	17 Cl $3s^23p^5$ 35.453	18 Ar $3s^23p^6$ 39.948
4th period n = 4	19 K $4s^1$ 39.102	20 Ca $4s^2$ 40.08	21 Sc $3d^14s^2$ 44.956	22 Ti $3d^24s^2$ 47.90	23 V $3d^34s^2$ 50.942	24 Cr $3d^54s^1$ 51.996	25 Mn $3d^54s^2$ 54.938	26 Fe $3d^64s^2$ 55.847	27 Co $3d^74s^2$ 58.9332	28 Ni $3d^84s^2$ 58.71	29 Cu $3d^{10}4s^1$ 63.54	30 Zn $3d^{10}4s^2$ 65.37	31 Ga $4s^24p^1$ 69.72	32 Ge $4s^24p^2$ 72.59	33 As $4s^24p^3$ 74.9216	34 Se $4s^24p^4$ 78.96	35 Br $4s^24p^5$ 79.909	36 Kr $4s^24p^6$ 83.80
5th period n = 5	37 Rb $5s^1$ 85.47	38 Sr $5s^2$ 87.62	39 Y $4d^15s^2$ 88.905	40 Zr $4d^25s^2$ 91.22	41 Nb $4d^45s^1$ 92.906	42 Mo $4d^55s^1$ 95.94	43 Tc $4d^55s^1$ (99)	44 Ru $4d^75s^1$ 101.07	45 Rh $4d^85s^1$ 102.905	46 Pd $4d^{10}$ 106.4	47 Ag $4d^{10}5s^1$ 107.870	48 Cd $4d^{10}5s^2$ 112.40	49 In $5s^25p^1$ 114.82	50 Sn $5s^25p^2$ 118.69	51 Sb $5s^25p^3$ 121.75	52 Te $5s^25p^4$ 127.60	53 I $5s^25p^5$ 126.9044	54 Xe $5s^25p^6$ 131.30
6th period n = 6	55 Cs $6s^1$ 132.905	56 Ba $6s^2$ 137.34	57 La $5d^16s^2$ 138.91	72 Hf $4f^{14}5d^26s^2$ 178.49	73 Ta $5d^36s^2$ 180.948	74 W $5d^46s^2$ 183.85	75 Re $5d^56s^2$ 186.2	76 Os $5d^66s^2$ 190.2	77 Ir $5d^76s^2$ 192.2	78 Pt $5d^96s^1$ 195.09	79 Au $5d^{10}6s^1$ 196.967	80 Hg $5d^{10}6s^2$ 200.59	81 Tl $6s^26p^1$ 204.37	82 Pb $6s^26p^2$ 207.19	83 Bi $6s^26p^3$ 208.980	84 Po $6s^26p^4$ (210)	85 At $6s^26p^5$ (210)	86 Rn $6s^26p^6$ (222)
7th period n = 7	87 Fr $7s^1$ (223)	88 Ra $7s^2$ (226)	89 Ac $6d^17s^2$ (227)	104 ?														

d Series of Transition Metals

f Series of Transition Metals

Lanthanides	58 Ce $4f^15d^16s^2$ 140.12	59 Pr $4f^35d^06s^2$ 140.907	60 Nd $4f^45d^06s^2$ 144.24	61 Pm $4f^55d^06s^2$ (145)	62 Sm $4f^65d^06s^2$ 150.35	63 Eu $4f^75d^06s^2$ 151.96	64 Gd $4f^75d^16s^2$ 157.25	65 Tb $4f^95d^06s^2$ 158.924	66 Dy $4f^{10}5d^06s^2$ 162.50	67 Ho $4f^{11}5d^06s^2$ 164.930	68 Er $4f^{12}5d^06s^2$ 167.26	69 Tm $4f^{13}5d^06s^2$ 168.934	70 Yb $4f^{14}5d^06s^2$ 173.04	71 Lu $4f^{14}5d^16s^2$ 174.97
Actinides	90 Th $5f^06d^27s^2$ 232.038	91 Pa $5f^26d^17s^2$ (231)	92 U $5f^36d^17s^2$ 238.03	93 Np $5f^46d^17s^2$ (237)	94 Pu $5f^66d^07s^2$ (242)	95 Am $5f^76d^07s^2$ (243)	96 Cm $5f^76d^17s^2$ (247)	97 Bk $5f^96d^07s^2$ (247)	98 Cf $5f^{10}6d^07s^2$ (249)	99 Es $5f^{11}6d^07s^2$ (254)	100 Fm $5f^{12}6d^07s^2$ (253)	101 Md $5f^{13}6d^07s^2$ (256)	102 No $5f^{14}6d^07s^2$ (254)	103 Lw $5f^{14}6d^17s^2$ (257)

Table of International Atomic Weights (1968)

Values in parentheses are estimated for isotopes of longest half-life in most cases.

Element	Symbol	Atomic No.	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	(247)
Beryllium	Be	4	9.0122
Bismuth	Bi	83	208.980
Boron	B	5	10.811[a]
Bromine	Br	35	79.904[b]
Cadmium	Cd	48	112.40
Calcium	Ca	20	40.08
Californium	Cf	98	(252)
Carbon	C	6	12.01115[a]
Cerium	Ce	58	140.12
Cesium	Cs	55	132.905
Chlorine	Cl	17	35.453[b]
Chromium	Cr	24	51.996[b]
Cobalt	Co	27	58.9332
Copper	Cu	29	63.546
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	(257)
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[a]
Indium	In	49	114.82
Iodine	I	53	126.9044
Iridium	Ir	77	192.2
Iron	Fe	26	55.847[b]
Krypton	Kr	36	83.80
Lanthanum	La	57	138.91
Lawrentium	Lw	103	(256)
Lead	Pb	82	207.19
Lithium	Li	3	6.939
Lutetium	Lu	71	174.97
Magnesium	Mg	12	24.305
Manganese	Mn	25	54.9380
Mendelevium	Md	101	(257)
Mercury	Hg	80	200.59
Molybdenum	Mo	42	95.94
Neodymium	Nd	60	144.24
Neon	Ne	10	20.179
Neptunium	Np	93	(237)
Nickel	Ni	28	58.71
Niobium	Nb	41	92.906
Nitrogen	N	7	14.0067
Nobelium	No	102	(255)
Osmium	Os	76	190.2
Oxygen	O	8	15.9994[a]
Palladium	Pd	46	106.4
Phosphorus	P	15	30.9738
Platinum	Pt	78	195.09
Plutonium	Pu	94	(244)
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[a]
Silver	Ag	47	107.868[a]
Sodium	Na	11	22.9898
Strontium	Sr	38	87.62
Sulfur	S	16	32.064[a]
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

[a] The atomic weight varies because of natural variations in the isotopic composition of the element. The observed ranges are boron, ±0.003; carbon, ±0.00005; hydrogen, ±0.00001; oxygen, ±0.0001; silicon, ±0.001; sulfur, ±0.003.

[b] The atomic weight is believed to have an experimental uncertainty of the following magnitude; bromine, ±0.002; chlorine, ±0.001; chromium, ±0.001; iron, ±0.003; silver, ±0.003. For other elements the last digit given is believed to be reliable to ±0.5.

Table of Contents

Chapter 1
Introduction

Chemistry is one of the physical sciences. It contributes to the other physical sciences as well as to the biological sciences. As a matter of fact, chemistry occupies such an important place in the affairs of mankind that all students should have a basic knowledge of elementary chemistry in order to better understand what is going on around them. Our country's triumph in placing men on the moon was made possible through the contributions of many people, but especially by those trained in the physical sciences, including chemistry. In addition mathematicians, the various types of engineers, computer scientists, and many technicians in various disciplines worked as a team to accomplish this great feat. As students go through this book they will become aware of the many contributions chemistry has made in the past and will be in a position to appreciate worthwhile contributions made in the future.

Basic Definitions. *Chemistry* is the science that investigates the composition and structure of matter, the changes that matter undergoes, the amounts and kinds of energy necessary for these changes, and the laws that govern change. Let us now define the important terms used in this definition.

Science is classified or systematized knowledge. It is gained and verified by observation and correct scientific thinking. In many cases scientific relationships can be expressed by mathematical equations. Science may be divided into the physical sciences, such as physics, chemistry, and geology, and the biological sciences, such as botany and zoology.

Matter is anything that occupies space and has mass. Experience shows that in ordinary chemical changes (or reactions) matter can be neither created nor destroyed. This statement is not true for nuclear reactions (see Chapter 14). Matter that is homogeneous, such as sulfur, sugar, water, or silver, is called a *substance.*

Matter may exist in three different physical forms or states:

solid, liquid, and gaseous. Solids are rigid and have a definite form, usually crystalline. Liquids flow and assume the shape of the vessel in which they are stored. Gases diffuse and "fill" any container in which they are placed. It is possible to change a substance from one physical state to another by changing the conditions under which it is maintained. Changes of temperature or pressure are frequently used to bring about these transformations. For example, if the pressure remains constant, the physical state of water depends upon the temperature. Ice (water in the crystalline state) is stable below 0°C, water (as liquid) is stable from 0°C to 100°C, and steam (water vapor) is stable above 100°C.

Matter. Ordinary matter is made up of elements and compounds. An element used to be thought of as a substance that had not yet been chemically decomposed to give two or more simplier substances. In terms of more recent classifications, an element is a substance the properties of which give it a definite place in the periodic table (see inside front cover), or a substance all the atoms of which have the same nuclear charge (atomic number).

Thus hydrogen and oxygen are elements because they have never been decomposed into simpler substances. Water is not an element because it can be decomposed into hydrogen and oxygen. An up-to-date periodic table provides for 103 elements. Some of the elements, such as uranium and radium, are radioactive. These elements are so interesting that they are given special consideration in Chapter 14.

A *compound* is a substance composed of two or more elements chemically combined in definite proportions by weight. When the term *weight* is used we assume the value used is the value obtained at sea level. Compounds are homogeneous. The constituent elements of a compound have lost their original identity and they can be separated only by chemical means. The energy stored within a compound is not equal to the sum of the energies possessed by the uncombined elements. Water, sodium chloride (table salt), and sucrose (cane or beet sugar) are examples of compounds. Water is made up of hydrogen and oxygen. The properties of water are quite different from the properties of its constituent elements. The same is true for sodium chloride and sucrose.

A body made up of two or more substances which retain their

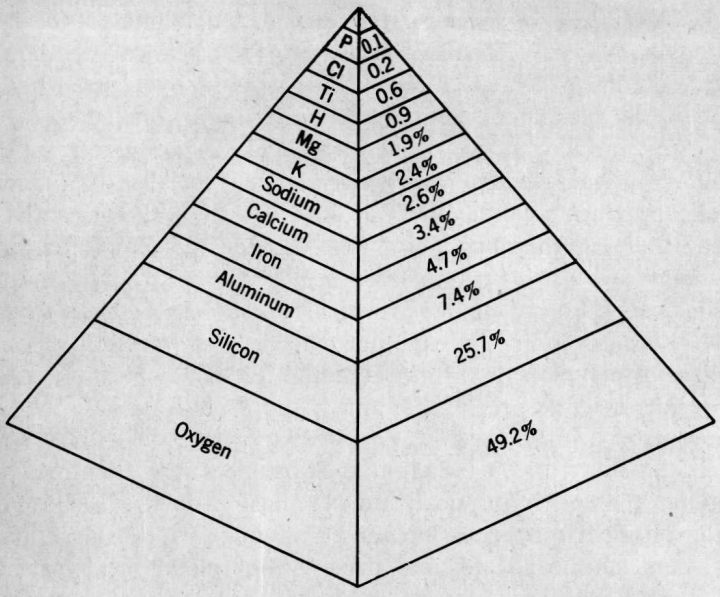

Fig. 1-1. Elemental composition of earth's crust.

own properties is called a *mixture.* Mixtures are heterogeneous, variable in composition, separable into their constituents by mechanical means, and composed of substances that retain their own energy contents. There is no gain or loss in chemical energy upon forming or destroying a mixture. Salt and pepper can be mixed together and then separated from each other without the gain or loss of chemical energy. A *solution* is a homogeneous body the composition of which can vary continuously within certain limits.

CHANGES IN MATTER. Matter undergoes physical and chemical changes. In a physical change the composition of the substance is not altered and the substance retains its identity. A rubber band will stretch and a copper wire will bend, but each object retains its identity. In a chemical change substances lose their identity, and the new substances formed have new physical and chemical properties. Thus, when a wax candle is burned in oxygen, the wax is changed into two new substances, carbon dioxide and water.

When elements or compounds combine, that is, react with each other to form more complex substances, the process may be

called *chemical combination.* For example, if a mixture of iron filings and flowers of sulfur is heated, the chemical compound iron sulfide is formed. *Chemical decomposition* occurs when a compound such as mercuric oxide is thoroughly heated. Metallic mercury and oxygen are formed. In *simple replacement* reactions an uncombined element may replace an element already in chemical combination with another element. If a strip of iron is placed in a water solution of copper sulfate the iron replaces the copper. A *double replacement*, or *double decomposition*, as it is usually called, is a chemical change in which two substances react to give two new substances. For example, when a silver nitrate solution is added to a table salt solution (sodium chloride solution), silver chloride, a white precipitate, and a sodium nitrate solution are formed.

IDENTIFICATION OF MATTER. Substances are identified by enumerating their physical and chemical properties. The common physical properties include color, odor, taste, solubility in solvents, physical state, and density. For metals such as iron, gold, and silver, malleability, ductility, and conduction of heat and of electricity may also be included under physical properties. A physical description of hydrogen would entail stating that it is a colorless, odorless, tasteless gas that is slightly soluble in water and has the lowest density of any chemical substance. Chemical properties of substances are expressed in terms of the stability of the substance toward heat, light, and shock, and of its behavior when placed in contact with other substances at ordinary or elevated temperatures. See p. 184 for a list of the chemical properties of chlorine.

CLASSIFICATION OF ELEMENTS. Of the 103 known elements about 70 are metals and 33 are nonmetals. There is no sharp dividing line between the two groups; therefore, a few elements have properties of both.

With the exception of mercury (a liquid) *metals* are crystalline solids that are malleable and ductile and good conductors of heat and electricity. Excluding gold and copper, the metals are essentially silver-colored. The density of metals varies considerably, from lithium, sodium, and potassium, which are lighter than water, to platinum, which is about twenty times heavier than water.

The physical properties of *nonmetals* that are solids at ordinary temperatures can be summarized by saying that they have com-

paratively low densities, are poor conductors of heat and electricity, are brittle (if solid), and, in many cases, have characteristic colors. For example, sulfur is pale yellow, bromine is reddish brown, chlorine is greenish yellow, phosphorus is white or red, and carbon is transparent or black. It is interesting to note that of the known elements only two are liquids at ordinary temperatures, mercury, a metal, and bromine, a nonmetal.

CLASSIFICATION OF COMPOUNDS. In general, compounds are classified according to their composition and properties. Those of similar composition and properties are grouped together. This enables one to remember the chemistry of many more compounds than would be possible if each were considered separately. For example, *acids* and *bases* are the names of two groups of compounds, the constituent members of which have properties in common. Acids contain hydrogen that is replaceable by metals. Water solutions of acids have a sour taste, will change litmus paper from blue to red, and will neutralize bases. If, to a glass of water, one adds several drops of hydrochloric acid or a few drops of sulfuric acid, the addition of acid gives the water a sour taste. Further, if a strip of magnesium ribbon is added to the glass of water containing acid, it reacts with the water solution, liberating a gas, i.e., hydrogen. Bases are oxides or hydroxides of metals. A base will neutralize an acid. If the base is soluble it will change the color of litmus paper from red to blue.

Energy. We may define *energy* as the ability to do work. Matter always possesses energy in one form or another. Energy acts upon matter to produce chemical and physical changes. *Heat*, *light*, *kinetic* (*mechanical*), *electrical*, and *chemical* are the words used to describe different forms of energy. In ordinary chemical changes energy can neither be created nor be destroyed, but it can be changed from one form to another. This is a statement of the *law of conservation of energy*. When carbon combines chemically with oxygen, an oxide of carbon is formed. Chemical energy causes the reaction of carbon and oxygen to form, let us say, carbon dioxide. At the same time, however, heat is liberated and light may also be produced. In a lead storage battery chemical energy is changed to electrical energy. In 1905 Einstein developed an equation which indicated that matter can be converted into energy. We shall consider this in more detail in Chapter 14. We shall also give consideration to atomic energy in Chapter 2.

Divisions of Chemistry. The science of chemistry covers a

broad field. Because of this fact it is generally divided into several areas of study. *General Chemistry* is a survey of the entire field of chemistry with particular emphasis on fundamental concepts and elementary laws. Textbooks in this branch of chemistry are given such titles as *General Chemistry*, *College Chemistry*, *Modern Chemistry*, *Introduction to Chemistry*, and *Essentials of Chemistry*. *Analytical Chemistry* is concerned with the detection, separation, and determination of substances and their constituents. Qualitative analysis identifies the constituents; quantitative analysis determines their amounts. *Physical Chemistry* is concerned with the laws underlying chemical changes. Where possible these laws are expressed mathematically. *Organic Chemistry* is the study of the compounds of carbon. There are more than a million compounds of carbon and so they are given special consideration. *Biochemistry* is the study of the compounds and chemical changes that are associated with living processes. Most of these compounds contain carbon. *Nuclear Chemistry* is treated in general chemistry texts and in modern texts in physical chemistry. Chapter 14 in this book is devoted to this subject and summarizes some of the results obtained when atomic nuclei are bombarded with suitable projectiles.

Other Important Definitions. *Fact.* An event or an occurrence is a fact. That which is true is a fact.

(1) It is a fact that two United States astronauts spent several hours on the moon. (2) It is a fact that water contains hydrogen and oxygen.

Hypothesis. (1) A generalization based on a few facts. (2) A tentative explanation of experimental facts. Sometimes more than one hypothesis has been advanced to explain a given set of experimental facts. If this is the case, then the hypothesis which best explains the facts and which also explains newly discovered facts, in the same area, will be retained and the others discarded.

Theory. A statement or statements based on many facts and on reason that explains facts and laws. A very satisfactory hypothesis may be advanced to become a theory. A well-established theory is not likely to be discarded. However, it may be revised to fit new facts.

Law. A concise statement that summarizes a large number of facts. Often a law can be stated by a mathematical equation. In the statement of the law there is no attempt to explain why the law is true. Thus Boyle's gas law states that at constant tempera-

ture, the volume of a given mass of gas varies inversely with the pressure applied. Note that there is no attempt to explain why the gas expands or contracts with a pressure change. The kinetic theory accounts for this behavior of the gas.

Units of Measurement. The English system of measurement used in the United States, except for certain scientific work, is awkward and inconvenient. Table 1-1 illustrates this fact. Further, the conversion from one unit to another is always a nuisance.

Table 1-1

The English System of Measurement

Length Units

12 inches = 1 foot
3 feet = 1 yard
5280 feet = 1 mile
1760 yards = 1 mile
16.5 feet = 1 rod
5.5 yards = 1 rod

For lengths less than one inch, the units are common fractions such as:

1/2, 1/4, 1/8, 1/16, 1/32, etc.

Volume Units

4 gills = 1 pint
2 pints = 1 quart
4 quarts = 1 gallon

Mass Units (Avoirdupois)

437½ grains = 1 ounce
16 ounces = 1 pound
2000 pounds = 1 ton

The metric system used in western European countries and for certain scientific work in the United States is a decimal system. Therefore the conversion of one unit to another is simple and rapid.

The unit of *length* is the meter. Originally one meter was taken as one ten-millionth (.0000001) of the distance from the north pole to the equator. Recently the meter was more accurately defined as 1,650,763.73 wave lengths of the orange-red light emitted when krypton is excited by an electric discharge.