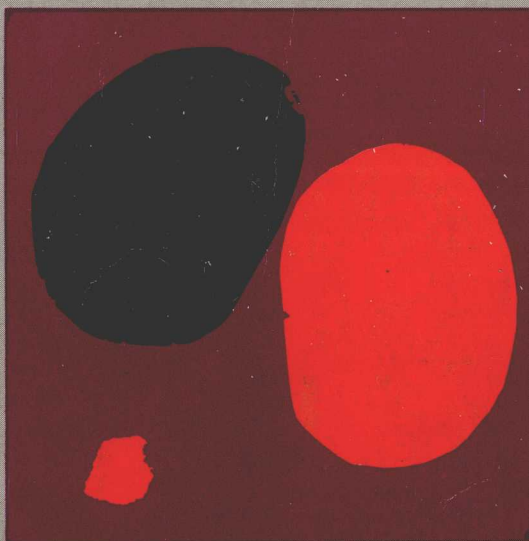




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COLLEGE Chemistry

JOHN R. LEWIS



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COLLEGE CHEMISTRY

Ninth Edition

JOHN R. LEWIS
University of Utah



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By John R. Lewis

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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.

s Series of Representative Elements

Periodic Table of the Elements

Noble Gases

1st period n = 1	IA		IIA		Key	Valence electron configuration		p Series of Representative Elements										Noble Gases	
	1	H 1 ¹	2	He 1 ²		Atomic number — \rightarrow 11	Na 3 ¹	Atomic weight — \rightarrow 22.9898	III A	IV A	V A	VI A	VII A	VIII A	IX A	X A	XI A	12	He 1 ²
2nd period n = 2	3	Li 2 ¹	4	Be 2 ²					5	6	7	8	9	10				10	Ne 2 ²
3rd period n = 3	11	Na 3 ¹	12	Mg 3 ²					13	14	15	16	17	18				18	Ar 3 ³
4th period n = 4	19	K 4 ¹	20	Ca 4 ²					21	22	23	24	25	26	27	28	29	30	Kr 4 ⁴
5th period n = 5	37	Rb 5 ¹	38	Sr 5 ²					39	40	41	42	43	44	45	46	47	48	Xe 5 ⁵
6th period n = 6	55	Cs 6 ¹	56	Ba 6 ²					57	58	59	60	61	62	63	64	65	66	Xe 5 ⁵
7th period n = 7	87	Fr 7 ¹	88	Ra 7 ²					89	90	91	92	93	94	95	96	97	98	Xe 5 ⁵

d Series of Transition Metals

VIII

IIIB		IVB		VB		VIB		VIIB		IB		IIB							
21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Cu	30	Zn
39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh	46	Pd	47	Ag	48	Cd
57	La	58	Ce	59	Pr	60	Nd	61	Pm	62	Sm	63	Eu	64	Gd	65	Tb	66	Dy
71	Lu	72	Hf	73	Ta	74	W	75	Re	76	Os	77	Ir	78	Pt	79	Au	80	Hg
89	Ac	90	Th	91	Pa	92	U	93	Np	94	Pu	95	Am	96	Cm	97	Bk	98	Cf
101	La	102	Hf	103	Ta	104	W	105	Re	106	Os	107	Ir	108	Pt	109	Au	110	Hg
121	La	122	Hf	123	Ta	124	W	125	Re	126	Os	127	Ir	128	Pt	129	Au	130	Hg
139	La	140	Hf	141	Ta	142	W	143	Re	144	Os	145	Ir	146	Pt	147	Au	148	Hg
157	La	158	Hf	159	Ta	160	W	161	Re	162	Os	163	Ir	164	Pt	165	Au	166	Hg
173	La	174	Hf	175	Ta	176	W	177	Re	178	Os	179	Ir	180	Pt	181	Au	182	Hg
191	La	192	Hf	193	Ta	194	W	195	Re	196	Os	197	Ir	198	Pt	199	Au	200	Hg
209	La	210	Hf	211	Ta	212	W	213	Re	214	Os	215	Ir	216	Pt	217	Au	218	Hg
227	La	228	Hf	229	Ta	230	W	231	Re	232	Os	233	Ir	234	Pt	235	Au	236	Hg
245	La	246	Hf	247	Ta	248	W	249	Re	250	Os	251	Ir	252	Pt	253	Au	254	Hg
263	La	264	Hf	265	Ta	266	W	267	Re	268	Os	269	Ir	270	Pt	271	Au	272	Hg
281	La	282	Hf	283	Ta	284	W	285	Re	286	Os	287	Ir	288	Pt	289	Au	290	Hg
309	La	310	Hf	311	Ta	312	W	313	Re	314	Os	315	Ir	316	Pt	317	Au	318	Hg
327	La	328	Hf	329	Ta	330	W	331	Re	332	Os	333	Ir	334	Pt	335	Au	336	Hg
345	La	346	Hf	347	Ta	348	W	349	Re	350	Os	351	Ir	352	Pt	353	Au	354	Hg
363	La	364	Hf	365	Ta	366	W	367	Re	368	Os	369	Ir	370	Pt	371	Au	372	Hg
381	La	382	Hf	383	Ta	384	W	385	Re	386	Os	387	Ir	388	Pt	389	Au	390	Hg
409	La	410	Hf	411	Ta	412	W	413	Re	414	Os	415	Ir	416	Pt	417	Au	418	Hg
427	La	428	Hf	429	Ta	430	W	431	Re	432	Os	433	Ir	434	Pt	435	Au	436	Hg
445	La	446	Hf	447	Ta	448	W	449	Re	450	Os	451	Ir	452	Pt	453	Au	454	Hg
463	La	464	Hf	465	Ta	466	W	467	Re	468	Os	469	Ir	470	Pt	471	Au	472	Hg
481	La	482	Hf	483	Ta	484	W	485	Re	486	Os	487	Ir	488	Pt	489	Au	490	Hg
509	La	510	Hf	511	Ta	512	W	513	Re	514	Os	515	Ir	516	Pt	517	Au	518	Hg
527	La	528	Hf	529	Ta	530	W	531	Re	532	Os	533	Ir	534	Pt	535	Au	536	Hg
545	La	546	Hf	547	Ta	548	W	549	Re	550	Os	551	Ir	552	Pt	553	Au	554	Hg
563	La	564	Hf	565	Ta	566	W	567	Re	568	Os	569	Ir	570	Pt	571	Au	572	Hg
581	La	582	Hf	583	Ta	584	W	585	Re	586	Os	587	Ir	588	Pt	589	Au	590	Hg
609	La	610	Hf	611	Ta	612	W	613	Re	614	Os	615	Ir	616	Pt	617	Au	618	Hg
627	La	628	Hf	629	Ta	630	W	631	Re	632	Os	633	Ir	634	Pt	635	Au	636	Hg
645	La	646	Hf	647	Ta	648	W	649	Re	650	Os	651	Ir	652	Pt	653	Au	654	Hg
663	La	664	Hf	665	Ta	666	W	667	Re	668	Os	669	Ir	670	Pt	671	Au	672	Hg
681	La	682	Hf	683	Ta	684	W	685	Re	686	Os	687	Ir	688	Pt	689	Au	690	Hg
709	La	710	Hf	711	Ta	712	W	713	Re	714	Os	715	Ir	716	Pt	717	Au	718	Hg
727	La	728	Hf	729	Ta	730	W	731	Re	732	Os	733	Ir	734	Pt	735	Au	736	Hg
745	La	746	Hf	747	Ta	748	W	749	Re	750	Os	751	Ir	752	Pt	753	Au	754	Hg
763	La	764	Hf	765	Ta	766	W	767	Re	768	Os	769	Ir	770	Pt	771	Au	772	Hg
781	La	782	Hf	783	Ta	784	W	785	Re	786	Os	787	Ir	788	Pt	789	Au	790	Hg
809	La	810	Hf	811	Ta	812	W	813	Re	814	Os	815	Ir	816	Pt	817	Au	818	Hg
827	La	828	Hf	829	Ta	830	W	831	Re	832	Os	833	Ir	834	Pt	835	Au	836	Hg
845	La	846	Hf	847	Ta	848	W	849	Re	850	Os	851	Ir	852	Pt	853	Au	854	Hg
863	La	864	Hf	865	Ta	866	W	867	Re	868	Os	869	Ir	870	Pt	871	Au	872	Hg
881	La	882	Hf	883	Ta	884	W	885	Re	886	Os	887	Ir	888	Pt	889	Au	890	Hg
909	La	910	Hf	911	Ta	912	W	913	Re	914	Os	915	Ir	916	Pt	917	Au	918	Hg
927	La	928	Hf	929	Ta	930	W	931	Re	932	Os	933	Ir	934	Pt	935	Au	936	Hg
945	La	946	Hf	947	Ta	948	W	949	Re	950	Os	951	Ir	952	Pt	953	Au	954	Hg
963	La	964	Hf	965	Ta	966	W	967	Re	968	Os	969	Ir	970	Pt	971	Au	972	Hg
981	La	982	Hf	983	Ta	984	W	985	Re	986	Os	987	Ir	988	Pt	989	Au	990	Hg
1009	La	1010	Hf	1011	Ta	1012	W	1013	Re	1014	Os	1015	Ir	1016	Pt	1017	Au	1018	Hg
1027	La	1028	Hf	1029	Ta	1030	W	1031	Re	1032	Os	1033	Ir	1034	Pt	1035	Au	1036	Hg
1045	La	1046	Hf	1047	Ta	1048	W	1049	Re	1050	Os	1051	Ir	1052	Pt	1053	Au	1054	Hg
1063	La	1064	Hf	1065	Ta	1066	W	1067	Re	1068	Os	1069	Ir	1070	Pt	1071	Au	1072	Hg
1081	La	1082	Hf	1083	Ta	1084	W	1085	Re	1086	Os	1087	Ir	1088	Pt	1089	Au	1090	Hg
1109	La	1110	Hf	1111	Ta	1112	W	1113	Re	1114	Os	1115	Ir	1116	Pt	1117	Au	1118	Hg
1127	La	1128	Hf	1129	Ta	1130	W	1131	Re	1132	Os	1133	Ir	1134	Pt	1135	Au	1136	Hg
1145	La	1146	Hf	1147	Ta	1148	W	1149	Re	1150	Os	1151	Ir	1152	Pt	1153	Au	1154	Hg
1163	La	1164	Hf	1165	Ta	1166	W	1167	Re	1168	Os	1169	Ir	1170	Pt	1171	Au	1172	Hg
1181	La	1182	Hf	1183	Ta	1184	W	1185	Re	1186	Os	1187	Ir	1188	Pt	1189	Au	1190	Hg
1209	La	1210	Hf	1211	Ta	1212	W	1213	Re	1214	Os	1215	Ir	1216	Pt	1217	Au	1218	Hg
1227	La	1228	Hf	1229	Ta	1230	W	1231	Re	1232	Os	1233	Ir	1234	Pt	1235	Au	1236	Hg
1245	La	1246	Hf	1247	Ta	1248	W	1249	Re	1250	Os	1251	Ir	1252	Pt	1253	Au	1254	Hg
1263	La	1264	Hf	1265	Ta	1266	W	1267	Re	1268	Os	1269	Ir	1270	Pt	1271	Au	1272	Hg
1281	La	1282	Hf	1283	Ta	1284	W	1285	Re	1286	Os	1287	Ir	1288	Pt	1289	Au	1290	Hg
1309	La	1310	Hf	1311	Ta	1312	W	1313	Re	1314	Os	1315	Ir	1316	Pt	1317	Au	1318	Hg
1327	La	1328	Hf	1329	Ta	1330	W	1331	Re	1332	Os	1333	Ir	1334	Pt	1335	Au	1336	Hg
1345	La	1346	Hf	1347	Ta	1348	W	1349	Re	1350	Os	1351	Ir	1352	Pt	1353	Au	1354	Hg
1363	La	1364	Hf	1365	Ta	1366	W	1367	Re	1368	Os	1369	Ir	1370	Pt	1371	Au	1372	Hg
1381	La	1382	Hf	1383	Ta	1384	W	1385	Re	1386	Os	1387	Ir	1388	Pt	1389	Au	1390	Hg
1409	La	1410	Hf	1411	Ta	1412	W	1413	Re	1414	Os	1415	Ir	1416	Pt	1417	Au	1418	Hg
1427	La	1428	Hf	1429	Ta	1430	W	1431	Re	1432	Os	1433	Ir	1434	Pt	1435	Au	1436	Hg
1445	La	1446	Hf	1447	Ta	1448	W	1449	Re	1450	Os	1451	Ir	1452	Pt	1453	Au	1454	Hg
1463	La	1464	Hf	1465	Ta	1466	W	1467	Re	1468	Os	1469	Ir	1470	Pt	1471	Au	1472	Hg
1481	La	1482	Hf	1483	Ta	1484	W	1485	Re	1486	Os	1487	Ir	1488	Pt	1489	Au	1490	Hg
1509	La	1510	Hf	1511	Ta	1512	W	1513	Re	1514	Os	1515	Ir	1516	Pt	1517	Au	1518	Hg
1527	La	1528	Hf	1529	Ta	1530	W	1531	Re	1532	Os	1533	Ir	1534	Pt	1535	Au	1536	Hg
1545	La	1546	Hf	1547	Ta	1548	W	1549	Re	1550	Os	1551	Ir	1552	Pt	1553	Au	1554	Hg
1563	La	1564	Hf	1565	Ta	1566	W	1567	Re	1568	Os	1569	Ir	1570	Pt	1571	Au	1572	Hg
1581	La	1582	Hf	1583	Ta	1584	W	1585	Re	1586	Os	1587	Ir	1588	Pt	1589	Au	1590	Hg
1609	La	1610	Hf	1611	Ta	1612	W	1613	Re	1614	Os	1615	Ir	1616	Pt	1617	Au	1618	Hg
1627	La	1628	Hf	1629	Ta	1630	W	1631	Re	1632	Os	1633	Ir	1634	Pt	1635	Au	1636	Hg
1645	La	1646	Hf	1647	Ta	1648	W	1649	Re	1650	Os								

Table of International Atomic Weights (1968)

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

Element	Sym- bol	Atomic No.	Atomic Weight	Element	Sym- bol	Atomic No.	Atomic Weight
Actinium	Ac	89	(227)	Mercury	Hg	80	200.59
Aluminum	Al	13	26.9815	Molybdenum	Mo	42	95.94
Americium	Am	95	(243)	Neodymium	Nd	60	144.24
Antimony	Sb	51	121.75	Neon	Ne	10	20.179
Argon	Ar	18	39.948	Neptunium	Np	93	(237)
Arsenic	As	33	74.9216	Nickel	Ni	28	58.71
Astatine	At	85	(210)	Niobium	Nb	41	92.906
Barium	Ba	56	137.34	Nitrogen	N	7	14.0067
Berkelium	Bk	97	(247)	Nobelium	No	102	(255)
Beryllium	Be	4	9.0122	Osmium	Os	76	190.2
Bismuth	Bi	83	208.980	Oxygen	O	8	15.9994 ^a
Boron	B	5	10.811 ^a	Palladium	Pd	46	106.4
Bromine	Br	35	79.904 ^b	Phosphorus	P	15	30.9738
Cadmium	Cd	48	112.40	Platinum	Pt	78	195.09
Calcium	Ca	20	40.08	Plutonium	Pu	94	(244)
Californium	Cf	98	(252)	Polonium	Po	84	(210)
Carbon	C	6	12.01115 ^a	Potassium	K	19	39.102
Cerium	Ce	58	140.12	Praseodymium	Pr	59	140.907
Cesium	Cs	55	132.905	Promethium	Pm	61	(147)
Chlorine	Cl	17	35.453 ^b	Protactinium	Pa	91	(231)
Chromium	Cr	24	51.996 ^b	Radium	Ra	88	(226)
Cobalt	Co	27	58.9332	Radon	Rn	86	(222)
Copper	Cu	29	63.546	Rhenium	Re	75	186.2
Curium	Cm	96	(247)	Rhodium	Rh	45	102.905
Dysprosium	Dy	66	162.50	Rubidium	Rb	37	85.47
Einsteinium	Es	99	(254)	Ruthenium	Ru	44	101.07
Erbium	Er	68	167.26	Samarium	Sm	62	150.35
Europium	Eu	63	151.96	Scandium	Sc	21	44.956
Fermium	Fm	100	(257)	Selenium	Se	34	78.96
Fluorine	F	9	18.9984	Silicon	Si	14	28.086 ^a
Francium	Fr	87	(223)	Silver	Ag	47	107.868 ^a
Gadolinium	Gd	64	157.25	Sodium	Na	11	22.9898
Gallium	Ga	31	69.72	Strontium	Sr	38	87.62
Germanium	Ge	32	72.59	Sulfur	S	16	32.064 ^a
Gold	Au	79	196.967	Tantalum	Ta	73	180.948
Hafnium	Hf	72	178.49	Technetium	Tc	43	(99)
Helium	He	2	4.0026	Tellurium	Te	52	127.60
Holmium	Ho	67	164.930	Terbium	Tb	65	158.924
Hydrogen	H	1	1.00797 ^a	Thallium	Tl	81	204.37
Indium	In	49	114.82	Thorium	Th	90	232.038
Iodine	I	53	126.9044	Thulium	Tm	69	168.934
Iridium	Ir	77	192.2	Tin	Sn	50	118.69
Iron	Fe	26	55.847 ^b	Titanium	Ti	22	47.90
Krypton	Kr	36	83.80	Tungsten	W	74	183.85
Lanthanum	La	57	138.91	Uranium	U	92	238.03
Lawrentium	Lw	103	(256)	Vanadium	V	23	50.942
Lead	Pb	82	207.19	Xenon	Xe	54	131.30
Lithium	Li	3	6.939	Ytterbium	Yb	70	173.04
Lutetium	Lu	71	174.97	Yttrium	Y	39	88.905
Magnesium	Mg	12	24.305	Zinc	Zn	30	65.37
Manganese	Mn	25	54.9380	Zirconium	Zr	40	91.22
Mendelevium	Md	101	(257)				

^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

1	Introduction	1
2	Atomic Structure	11
3	The Periodic Classification of the Elements	32
4	The Chemical Bond	41
5	Atomic Weights, Symbols, Formulas, Equations, and Valence	49
6	Acids, Bases, Salts, Nomenclature	58
7	Gases and the Kinetic Theory	69
8	Liquids and Solids	83
9	Oxygen and Hydrogen	91
10	Water and Solutions	103
11	Solutions of Nonelectrolytes and of Electrolytes	117
12	Chemical Equilibrium	128
13	Oxidation and Reduction	137
14	Nuclear Chemistry	145
15	Electrochemistry	157
16	Thermal Energy and Chemical Reactions	166
17	The Colloidal State	172
18	The Halogen Family	179
19	The Nitrogen Family	192
20	The Sulfur Family	213
21	Group IVA Elements	222
22	Metallurgy, General Properties of Metals, Alloys	239
23	The Alkali Metals (Group IA)	247
24	The Alkaline Earth Metals (Group IIA)	254
25	Group IIIA Elements	264
26	Group IB Metals	271
27	Group IIB Metals	281
28	Group VIII Metals—Other Industrial Metals	286
29	Organic Chemistry	306
30	Chemical Calculations	334

Appendixes

I	Important Definitions	357
II	A Short List of Scientists	371

III	The Metric System	374
IV	Vapor Pressures of Water	374
V	Borax Bead Tests	375
VI	Flame Tests	375
VII	Solubility Rules and Data	376
VIII	Tests for the Common Cations	378
IX	Tests for the Common Anions	384
X	Table of Common Chemicals, Their Chemical Names, Formulas, and Common Uses	387
XI	The Activity Series of Metals	392
XII	Electron Populations of the Atoms of the Elements	394
XIII	General Review Questions and Answers	399
XIV	Four-Place Logarithms and Antilogarithms	410
	Index	415

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 simpler 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

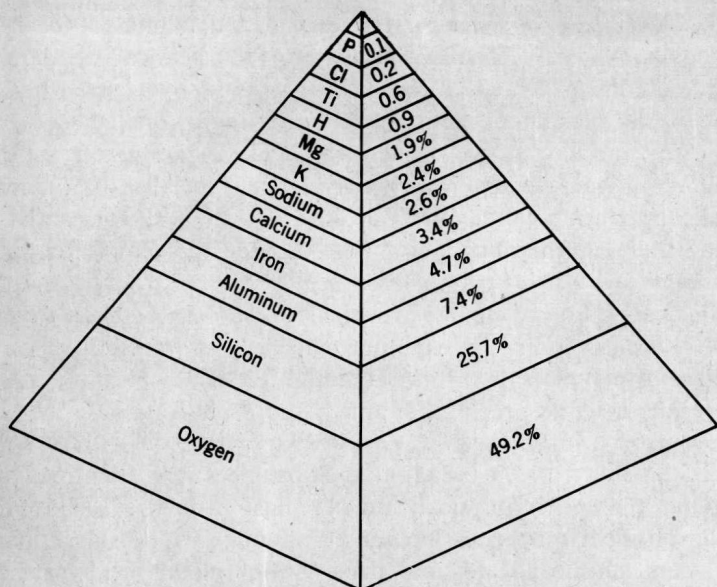


Fig. 1-1. Elemental composition of earth's crust.

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)	
$437\frac{1}{2}$ 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.