



Raymond Chang | Jason Overby

18 8A	2 Helium 4.003	10 Neon Neon 20.18	18 Ar Argon 39.95	36 <b>Kr</b> Krypton 83.80	54 Xe Xenon 131.3	86 <b>Rn</b> Radon (222)	118 <b>Og</b> 0ganesson (294)	71 Lu Lutetium 175.0	103 Lr Lawrencium (257)	use the
	17 7A	9 F Fluorine 19.00	17 <b>CI</b> Chlorine 35.45	35 <b>Br</b> Bromine 79.90	<b>53</b> <b>I</b> lodine 126.9	85 At Astatine (210)	117 Ts Tennessine (294)	70 <b>Yb</b> Ytterbium 173.0	102 No Nobelium (254)	s text we i
	16 6A	8 O 0xygen 16.00	16 S Sultur 32.07	34 Selenium 78.96	52 Te Tellurium 127.6	84 Polonium (210)	116 Lv Livermorium (293)	69 <b>Tm</b> Thulium 168.9	101 Md Mendelevium (256)	lse. In thi
	15 5A	7 N Nitrogen 14.01	15 Phosphorus 30.97	33 <b>As</b> Arsenic 74.92	51 Sb Antimony 121.8	83 <b>Bi</b> Bismuth 209.0	115 Mc Moscovium (290)	68 Er Erhium 167.3	100 <b>Fim</b> Fermium (253)	t in wide 1
	14 4A	6 C Carbon 12.01	14 Si Silicon 28.09	32 <b>Ge</b> Germanium 72.59	50 <b>Sn</b> <sup>Tin</sup> 118.7	82 <b>Pb</b> Lead 207.2	114 FI Flerovium (289)	67 <b>Ho</b> Holmium 164.9	99 Es Einsteinium (254)	is not yet
	13 3A	5 B <sup>Boron</sup> 10.81	13 <b>Aluminum</b> 26.98	31 <b>Ga</b> llium 69.72	49 <b>In</b> Indium 114.8	81 Thallium 204.4	113 Nh Nihonium (286)	66 Dy Dysprosium 162.5	98 Cf Californium (249)	JPAC) but
			12 2 <b>B</b>	30 <b>Zn</b> Zinc 65.39	48 Cd Cadmium 112.4	80 <b>Hg</b> Merany 200.6	112 <b>Cn</b> Copemicium (285)	65 <b>Tb</b> Terbium 158.9	97 Bk Berkelium (247)	mistry (IU
			11 1B	29 Cu Copper 63.55	47 <b>Ag</b> Silver 107.9	79 Au Gold 197.0	111 <b>Rg</b> Roentgenium (272)	64 <b>Gd</b> Gadolinium 157.3	96 <b>Cm</b> Curium (247)	olied Cher
			10	28 <b>Ni</b> Nickel 58.69	46 <b>Pd</b> Palladium 106.4	78 Pt Platinum 195.1	110 Ds Darmstadium (269)	63 <b>Eu</b> Europium 152.0	95 Am Americium (243)	e and Ap <sub>l</sub>
	umber ass		9 — 8B —	27 Co Cobalt 58.93	45 <b>Rh</b> Rhođium 102.9	77 <b>Ir</b> Inđium 192.2	109 Mt Meitnerium (266)	62 Smrium 150.4	94 <b>Pu</b> Plutonium (242)	on of Pur
	Atomic nu Atomic m		∞	26 Fe Iron 55.85	44 <b>Ru</b> Ruthenium 101.1	76 <b>Os</b> 0smium 190.2	108 <b>Hs</b> Hassium (265)	61 Promethium (147)	93 Neptunium (237)	tional Uni
			7 7B	25 Mn Manganese 54.94	43 Tc Technetium (98)	75 <b>Re</b> Rhenium 186.2	107 <b>Bh</b> Bohrium (262)	60 Nd Neodymium 144.2	92 U Uranium 238.0	le Internat
	11 Na Sodium 22.99		6 6B	24 <b>Cr</b> Chromium 52.00	42 Mo Molybdenum 95.94	74 <b>W</b> Tungsten 183.9	106 Sg Seaborgium (263)	59 Pr Praseodymium 140.9	91 Protactinium (231)	nded by th
			5 5B	23 V Vanadium 50.94	41 <b>Nb</b> Niobium 92.91	73 <b>Ta</b> Tantalum 180.9	105 <b>Db</b> Dubnium (260)	58 <b>Ce</b> Cerium 140.1	90 <b>Th</b> Thorium 232.0	recommen
			4 4B	22 <b>Tri</b> Titanium 47.88	40 Zr Zirconium 91.22	72 <b>Hf</b> Hafnium 178.5	104 <b>Rf</b> Rutherfordium (257)			has been 1
			3B	21 Sc Scandium 44.96	39 Y Yutrium 88.91	57 La Lanthanum 138.9	89 <b>Ac</b> Actinium (227)	ds	als	signation
	2 2A	4 Beryllium 9.012	12 Mg Magnesium 24.31	20 Ca Calcium 40.08	38 Srontium 87.62	56 <b>Ba</b> Barium 137.3	88 <b>Ra</b> dium (226)	Metalloi	Nonmeta	group de
1 1A	1 H Hydrogen 1.008	3 Li Lithium 6.941	11 Na Sodium 22.99	19 <b>K</b> Potassium 39.10	37 <b>Rb</b> Rubidium 85.47	55 Cs Cesium 132.9	87 <b>Fr</b> Francium (223)			The 1–18

standard U.S. notation for group numbers (1A–8A and 1B–8B). In 2011 IUPAC revised the atomic masses of some elements. The changes are minor and they are not adopted in the present edition of this text.

#### The Elements with Their Symbols and Atomic Masses\*

Element         Symbol         Number         Mass'         Element         Symbol         Number         Mass'           Actinium         Ac         89         (27)         Mendevium         Md         101         (250)           Autinomy         An         95         (243)         Molybdenum         Mo         42         95,94           Autinony         Sb         51         121,8         Moscovium         Md         60         124,8           Arsenic         Ar         18         39,95         Neodymium         Nd         60         124,8           Astaine         Ar         85         (210)         Neptunium         Np         93         58,69           Barkin         Bar         50         (247)         Nikohum         Nh         113         (284)           Bartim         Bi         83         209,0         Nitrogen         N         7         14,01           Bohrium         Bh         107         (262)         Nobelum         No         102         (253)           Boron         B         5         10,81         Ognesson         0g         178         190,2           Cadmium         Cd <t< th=""><th></th><th></th><th>Atomic</th><th>Atomic</th><th>l</th><th></th><th>Atomic</th><th>Atomic</th></t<>			Atomic	Atomic	l		Atomic	Atomic
Actinium         Ac         89         (227)         Mendelevium         Md         101         (256)           Aluminum         Al         13         26/98         Mercury         Hg         80         2005           Aluminum         Al         13         26/98         Mercury         Hg         80         20534           Antinony         Sb         51         121.8         Mosovium         Mc         113         (286)           Argen         As         33         74.92         Ncom         Nc         10         201.8           Astatine         As         35         17.3         Nickel         Ni         28         55.69           Berkelium         Ba         56         137.3         Nickel         Ni         28         55.69           Berkelium         Ba         50         137.3         Nickel         Ni         21         27.11         11.01           Barium         Ba         107         (262)         Nobilum         Nb         41         29.21         13.01           Borium         Ca         20         40.08         Palatinum         Pd         46         10.02         14.01	Element	Symbol	Number	Mass <sup>+</sup>	Element	Symbol	Number	Mass <sup>+</sup>
Aluminum         Al         13         26.98         Mecuy Johann         III         80         2006           Antinony         Sh         51         121.8         Mocoynium         Moc         42         95.94           Antinony         Sh         51         121.8         Mocoynium         Mo         60         144.2           Arsnic         As         33         74.92         Non         No         10         2018           Bariam         Ba         56         137.3         Nickel         Ni         18         286.5           Beryllium         Be         4         90.01         Niobium         Nb         113         (284)           Beryllium         Be         4         90.02         Niobium         No         102         (253)           Bromine         Br         35         79.90         Osnium         Os         76         160.00           Californium         Ca         20         40.08         Palladyum         Pal         45         30.97           Carbon         Ca         6         12.01         Patiann         Pd         46         106.4           Californium         Ca         20	Actinium	Ac	89	(227)	Mendelevium	Md	101	(256)
Americulum         Ann         95         (243)         Molybelenum         Mo         42         95.94           Autimony         Sb         51         121.8         Moscovium         Mc         115         (288)           Arsenic         Ax         18         39.95         Neon         Ne         10         201.18           Astatine         At         85         (210)         Neptunium         Np         93         (237)           Barium         Ba         56         137.3         Nickel         N         12         (284)           Beryfilum         Bk         97         (247)         Nikonium         Nh         113         (284)           Beryfilum         Bk         97         (262)         Nobelium         No         102         (253)           Boron         B         5         108.1         Oggnesson         Og         118         (294)           Bromine         Cd         28         124.4         Oxygen         O         8         109.2           Cation         Cd         6         12.01         Platinum         Pd         15         30.97           Caton         Cd         28	Aluminum	Al	13	26.98	Mercurv	Hg	80	200.6
$ \begin{array}{c} \operatorname{Autimony} & \operatorname{Sb} & 51 & 1218 & \operatorname{Maccoviann} & \operatorname{Mc} & 115 & (288) \\ \operatorname{Argen} & \operatorname{Ar} & \operatorname{Ar} & \operatorname{Bs} & 39 + 55 & \operatorname{Nexdyminim} & \operatorname{Nd} & 60 & 144 + 2 \\ \operatorname{Auxinic} & \operatorname{As} & 33 & 74 + 92 & \operatorname{Nexol} & \operatorname{Ne} & 10 & 20.18 \\ \operatorname{Auxinic} & \operatorname{As} & 33 & 74 + 92 & \operatorname{Nexol} & \operatorname{Ni} & 128 & (217) \\ \operatorname{Barium} & \operatorname{Ba} & 55 & (210) & \operatorname{Neptuminm} & \operatorname{Nb} & 113 & (284) \\ \operatorname{Berkeliann} & \operatorname{Bk} & 97 & (247) & \operatorname{Nicbuinm} & \operatorname{Nb} & 113 & (284) \\ \operatorname{Berylinam} & \operatorname{Be} & 4 & 90.12 & \operatorname{Nicbuinm} & \operatorname{Nb} & 41 & 92.91 \\ \operatorname{Bismuth} & \operatorname{Bi} & 83 & 209.0 & \operatorname{Nitrogen} & \operatorname{N} & 7 & 14.01 \\ \operatorname{Borrium} & \operatorname{Bb} & 107 & (262) & \operatorname{Nobeliann} & \operatorname{No} & 102 & (233) \\ \operatorname{Borrium} & \operatorname{Bb} & 5 & 10.81 & \operatorname{Ogamesson} & Og & 118 & (294) \\ \operatorname{Borrium} & \operatorname{Cd} & 42 & 12.44 & \operatorname{Oxygen} & O & 8 & 16.00 \\ \operatorname{Calcium} & \operatorname{Cd} & 42 & 12.44 & \operatorname{Oxygen} & O & 8 & 16.00 \\ \operatorname{Calcium} & \operatorname{Cd} & 42 & 11.24 & \operatorname{Oxygen} & O & 84 & 16.00 \\ \operatorname{Calcium} & \operatorname{Cd} & 32 & 40.08 & Palladium & Pd & 46 & 166.4 \\ \operatorname{Califormium} & \operatorname{Cf} & 98 & (249) & \operatorname{Phosphorus} & P & 15 & 30.97 \\ \operatorname{Carbon} & C & 6 & 12.01 & Plaintum & Pt & 94 & (242) \\ \operatorname{Carboni} & \operatorname{Cc} & 35 & 132.9 & \operatorname{Polonium} & Po & 84 & (210) \\ \operatorname{Chorium} & \operatorname{Cc} & 27 & 58.93 & \operatorname{Protactinian} & Pa & 91 & (231) \\ \operatorname{Coperrictum} & \operatorname{Cc} & 27 & 58.93 & \operatorname{Protactinian} & Pa & 91 & (231) \\ \operatorname{Coperrictum} & \operatorname{Cc} & 29 & 63.55 & \operatorname{Radium} & \operatorname{Ra} & 86 & (222) \\ \operatorname{Darmstadium} & Db & 110 & (269) & \operatorname{Rheirum} & \operatorname{Ra} & 11 & (272) \\ \operatorname{Darmstadium} & Db & 105 & (260) & \operatorname{Rheirum} & \operatorname{Ra} & 11 & (272) \\ \operatorname{Darmstadium} & Db & 105 & (260) & \operatorname{Rheirum} & \operatorname{Ra} & 11 & (272) \\ \operatorname{Darmstadium} & Db & 100 & (253) & \operatorname{Saurium} & Sa & 14 & 28.99 \\ \operatorname{Galium} & \operatorname{Ga} & 31 & 67.33 & \operatorname{Rubrirdm} & Sa & 37 & 48. \\ 37.547 & 37.88 & 37.42 \\ \operatorname{Dyporoium} & Dp & 66 & 162.5 & \operatorname{Routgrinum} & Sa & 11 & (272) \\ \operatorname{Darmstadium} & Db & 105 & (260) & \operatorname{Rheirum} & Sa & 11 & (272) \\ \operatorname{Darmstadium} & Da & 11 & 22.99 \\ \operatorname{Galium} & \operatorname{Ga} & 31 & 67.33 & \operatorname{Sultren} & Sa & 14 & 28.99 \\ \operatorname{Galium} & \operatorname{Ga} & 31 & 67.33 & \operatorname{Sultrem} & Sa & 36 & 44 & 20.91 \\$	Americium	Am	95	(243)	Molybdenum	Mo	42	95.94
Arg         Trigon         Ar         Tis         Tis <thtis< <="" td=""><td>Antimony</td><td>Sb</td><td>51</td><td>121.8</td><td>Moscovium</td><td>Mc</td><td>115</td><td>(288)</td></thtis<>	Antimony	Sb	51	121.8	Moscovium	Mc	115	(288)
	Argon	Ar	18	39.95	Neodymium	Nd	60	144.2
Actaine         As         35 $r/2-$ Pecuation         Rep         10         20:16           Barium         Ba         56         137.3         Nickel         Ni         12         58:60           Berkelium         Be         4         9.012         Nihonium         Nih         113         (284)           Beryllium         Be         4         9.012         Nikobium         Nb         41         9.2291           Binnuth         Bi         107         (262)         Nobelium         No         102         (253)           Boron         B         5         10.81         Oganeson         0g         118         (294)           Bromine         Br         35         79.90         Osmium         Os         8         16.00           Cadroium         Ca         20         40.08         Palladium         Pd         46         106.4           Catifornium         Ca         20         40.08         Palladium         Pd         46         106.4           Catifornium         Ca         55         132.9         Polonium         Po         94         (210)           Chihorine         Cli         17	Arsonic	As	22	74.02	Noon	No	10	20.18
Astanne         At         63         (210)         Replanmant         Np         93         (257)           Barium         Ba         56         137.3         Nickel         Ni         28         38.69           Berkelium         Bk         97         (247)         Nibnium         Nh         41         32.44           Bisnuth         Bi         83         209.0         Nitrogen         N         7         14.01           Boron         B         5         10.81         Oganesson         Og         76         190.2         (253)           Bronine         Br         5         10.81         Oganesson         Og         76         190.2         (243)           Bronine         Cd         20         40.08         Palladium         Pd         46         106.4         106.4           Calcium         Ca         20         40.08         Palladium         Pd         46         106.0           Calcium         Ca         5         132.9         Polonium         Pu         84         (210)           Cerium         Cc         58         140.1         Pluonium         Pu         84         (211)         Copin	Arsenic	At	55 95	(210)	Nontunium	No	02	(227)
	Dominum	At	6J 54	(210)	Neptumum	NP N:	93	(237)
Berkellum         DK         97 $(247)$ Ninonium         Nn         113 $(254)$ Bisruth         Bi         83         209.0         Nitrogen         N         7         14.01           Bohrium         Bh         107 $(262)$ Nobelium         No         102 $(253)$ Boron         B         5         10.81         Oganesson         Og         76         190.2           Cadnium         Cd         48         112.4         Oxygen         O         8         16.00           Calcium         Cd         20         40.08         Paladium         Pd         46         106.4           Californium         Cf         98         (249)         Phosphorus         P         15         30.97           Carbon         C         6         12.01         Pataeodynium         Pu         78         195.1           Chorine         CI         17         35.45         Potassium         K         19         39.10           Chorine         CI         17         35.45         Potassium         F         9         104.92           Copert         Cu         29	Barium	Ba	20	137.3	Nickel	IN1	28	58.69
Berylium         Be         4         9.012         Niobium         No 41         92.91           Bohrium         Bh         107         (262)         Niorogen         N         7         14.01           Bohrium         Bh         107         (262)         Nobelium         No         102         (233)           Bronine         Br         35         79.90         Osmium         Os         8         16.00           Cadmium         Cd         48         112.4         Oxygen         O         8         16.00           Californium         Cd         6         12.01         Plainum         Pd         46         106.4           Carbon         C         6         12.01         Plainum         Pu         78         195.1           Cerium         Cc         55         132.9         Polonium         Po         84         (210)           Chronium         Cr         112         (285)         Protasium         Pa         91         (231)           Coperticium         Cn         112         (285)         Protasium         Pa         91         (231)           Coperticium         Cn         112         (255)	Berkelium	BK	97	(247)	Nihonium	Nh	113	(284)
Bismuth         Bi         83         209.0         Nittogen         N         7         14.01           Boronn         B         5         10.81         Oganesson         Og         118         (294)           Boronne         Br         35         79.90         Osmium         Os         76         190.2           Cadnium         Cd         48         112.4         Oxygen         O         8         160.0           Calcium         Ca         20         40.08         Palladium         Pd         46         106.4           Caliorn         C         6         12.01         Platinum         Pt         15         30.97           Carbon         C         6         12.01         Platinum         Pt         94         (242)           Cerium         Cs         55         132.9         Polonium         Po         84         (210)           Chorine         C1         17         35.45         Potascinum         Pn         61         (147)           Coper         Cu         29         63.55         Radium         Ra         88         (226)           Curium         Cn         10         (260)	Beryllium	Be	4	9.012	Niobium	Nb	41	92.91
Bohrum         Bh         107         (262)         Nobelium         No         102         (233)           Boron         B         5         10.81         Oganesson         Og         118         (294)           Broninie         Br         35         79.90         Osmium         Os         8         16.00           Caldium         Ca         20         40.08         Palladium         Pd         4         6         106.4           Californium         Ca         20         40.08         Palladium         Pd         4         6         106.4           Californium         Ca         5         132.9         Polonium         Pd         8         102.1           Cerium         Cc         55         132.9         Polonium         Po         84         (210)           Chronium         Cc         27         58.93         Promethium         Pn         61         (147)           Copernicium         Cn         112         (285)         Protectinium         Pa         91         (231)           Copernicium         Cn         112         (285)         Protectinium         Ra         88         (226)           C	Bismuth	B1	83	209.0	Nitrogen	Ν	7	14.01
Boron         B         5         10.81         Oganesson         Og         118         (294)           Cadnium         Cd         48         112.4         Oxygen         O         8         1600           Calcium         Ca         20         40.08         Palladium         Pd         46         106.4           Calcion         C         6         12.01         Phosphorus         P         15         30.97           Carbon         C         6         12.01         Platinum         Pt         75         30.97           Carbon         C         6         53         132.9         Polonium         Po         84         (210)           Cesium         Cs         55         132.9         Promethium         Pn         61         (147)           Cobalt         Co         27         58.93         Promethium         Pn         61         (147)           Copper         Cu         29         63.55         Radom         Ra         88         (226)           Curium         Cm         96         (247)         Radom         Ra         88         (226)           Darmstaditium         Ds         105	Bohrium	Bh	107	(262)	Nobelium	No	102	(253)
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Boron	В	5	10.81	Oganesson	Og	118	(294)
Cadicium         Cd         48         112.4         Oxygen         O         8         16.00           Calciorn         Ca         20         40.08         Palladium         Pd         46         106.4           Carbon         C         6         12.01         Phosphorus         P         15         30.97           Carbon         C         6         12.01         Platinum         Pt         78         195.1           Cerium         Cc         58         140.1         Plutonium         Pu         94         (242)           Cesium         Cs         55         132.9         Polonium         Po         84         (210)           Chlorine         C1         17         35.45         Potassium         K         19         39.10           Chorium         Cn         112         (285)         Protactinium         Pa         91         (231)           Copper         Cu         29         63.55         Radon         Rn         86         (222)           Daristadium         Ds         105         (260)         Rhodum         Rh         45         102.9           Curium         Cn         99	Bromine	Br	35	79.90	Osmium	Os	76	190.2
Calcium         Ca         20         40.08         Palladium         Pd         46         106.4           Californium         Cf         98         (249)         Phosphorus         P         15         30.97           Carbon         C         6         12.01         Platinum         Pt         78         195.1           Cerium         Cs         55         132.9         Polonium         Po         84         (210)           Chronium         Cr         24         52.00         Pracedymium         Pr         59         140.9           Cobalt         Co         27         58.93         Promethium         Pn         61         (147)           Coperricium         Cn         112         (285)         Protactinium         Pa         91         (231)           Coperricium         Cn         10         (269)         Rhenium         Ra         88         (220)           Durium         Db         105         (260)         Rhenium         Rg         111         (272)           Einsteinium         Es         99         (24)         Rubidium         Rb         37         8547           Dysprosium         Fa	Cadmium	Cd	48	112.4	Oxygen	0	8	16.00
	Calcium	Ca	20	40.08	Palladium	Pd	46	106.4
	Californium	Cf	98	(249)	Phosphorus	Р	15	30.97
$\begin{array}{ccc} Cerium & Ce & 58 & 140.1 \\ Cesium & Cs & 55 & 132.9 \\ Cisum & Cs & 55 & 132.9 \\ Chorine & Cl & 17 & 35.45 \\ Chornium & Cr & 24 & 52.00 \\ Chornium & Cr & 24 & 52.00 \\ Copernicium & Cn & 112 & (285) \\ Copernicium & Cn & 112 & (285) \\ Copernicium & Cn & 112 & (285) \\ Copernicium & Cn & 96 & (247) \\ Copernicium & Cn & 96 & (247) \\ Copernicium & Ds & 110 & (269) \\ Curium & Db & 105 & (260) \\ Dubnium & Db & 105 & (260) \\ Dubnium & Db & 105 & (260) \\ Dysprosium & Dy & 66 & 162.5 \\ Dubnium & Es & 99 & (254) \\ Curium & Er & 68 & 167.3 \\ Erbium & Er & 68 & 167.3 \\ Fernium & Fn & 100 & (253) \\ Fernium & Fn & 100 & (253) \\ Samarium & Fn & 100 & (253) \\ Fernium & Fn & 100 & (253) \\ Samarium & Sm & 62 & 150.4 \\ Flexorium & Fl & 114 & (289) \\ Scandium & Fi & 81 & 104 & (257) \\ Fernium & Fn & 100 & (253) \\ Samarium & Sm & 62 & 150.4 \\ Fluctrine & F & 9 & 19.00 \\ Seaborgium & Sg & 106 & (263) \\ Francium & Fr & 87 & (223) \\ Galdinium & Gd & 64 & 157.3 \\ Galolinium & Gd & 64 & 157.3 \\ Galolinium & Ge & 32 & 72.59 \\ Galolinium & Ge & 32 & 72.59 \\ Gold & Au & 79 & 197.0 \\ Strontium & Fr & 38 & 87.62 \\ Hasium & Hs & 108 & (265) \\ Tantalum & Tr & 73 & 180.9 \\ Helium & He & 2 & 4.003 \\ Techerium & Tr & 33 & 180.9 \\ Helium & Ha & 108 & (265) \\ Tantalum & Tn & 53 & 117 & (294) \\ Indium & In & 49 & 114.8 \\ Terobium & Tr & 73 & 180.9 \\ Helium & Ha & 108 & (265) \\ Tantalum & Tn & 53 & 117 & (294) \\ Indium & In & 49 & 114.8 \\ Ternosine & Ts & 117 & (294) \\ Indium & In & 49 & 114.8 \\ Ternosine & Ts & 117 & (294) \\ Indium & In & 49 & 114.8 \\ Ternosine & Ts & 117 & (294) \\ Indium & Ir & 77 & 192.2 \\ Thorium & Tn & 53 & 117 & (294) \\ Indium & Ir & 77 & 192.2 \\ Thorium & Tn & 59 & 188.9 \\ Ican & Fe & 26 & 55.85 \\ Thulium & Tn & 59 & 118.7 \\ Lawrencium & Lx & 116 & (293) \\ Keron & Ke & 54 & 131.3 \\ Luteium & Lx & 116 & (293) \\ Keron & Ke & 54 & 131.3 \\ Luteium & Lx & 116 & (293) \\ Keron & Ke & 54 & 131.3 \\ Luteium & Lu & 71 & 175.0 \\ Yttrium & Y & 39 & 88.91 \\ Manganese & Mn & 25 & 54.94 \\ Zinc & Zn & Zn & 30 & 65.39 \\ \end{array}$	Carbon	С	6	12.01	Platinum	Pt	78	195.1
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Cerium	Ce	58	140.1	Plutonium	Pu	94	(242)
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Cesium	Cs	55	132.9	Polonium	Po	84	(210)
	Chlorine	Cl	17	35.45	Potassium	K	19	39.10
	Chromium	Cr	24	52.00	Praseodymium	Pr	50	140.9
CoolaitCo2736.93FrometiniumFullof(14)(15)(16)	Cobalt	Co	24	58.03	Promothium	Dm	61	(147)
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Coparnicium	Co	112	(285)	Protectinium	r III Do	01	(147) (221)
CopperCu2903.53RaduliiRad88(220)CuriumCm96(247)RadonRn86(222)DarmstadtiumDb105(260)RheniumRh45102.9DysprosiumDy66162.5RoetgeniumRg111(272)EinsteiniumEs99(254)RubidiumRb3785.47ErbiumEu63152.0RutherfordiumRf104(257)FermiumFm100(253)SamariumSm62150.4FluorineF919.00ScaborgiumSg106(263)FanciumFr87(223)ScleniumSe3478.96GadliniumGa3169.72SilverAg47107.9GermaniumGe3272.59SodiumNa1122.99GoldAu79197.0StrontiumSt1632.07HassiumHs108(265)TantalumTa73180.9HeliumHe24.003TechnetiumTe52127.6HydrogenH11.008TennessineTs117(294)IndiumIn49114.8TerbiumTb65158.9IodineI53126.9ThatlumTh90232.0IronFe2655.85ThuiumTh69	Copermentin	Cii	20	(203)	Piotacumum	ra De	91	(231)
	Copper	Cu	29	03.33	Radium	Ka D.	88	(220)
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Curium	Cm	96	(247)	Radon	Rn	86	(222)
	Darmstadtium	Ds	110	(269)	Rhenium	Re	75	186.2
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Dubnium	Db	105	(260)	Rhodium	Rh	45	102.9
EinsteiniumEs99(254)RubidiumRb3785.47ErbiumEr68167.3RutheniumRu44101.1EuropiumEu63152.0RutherfordiumRf104(257)FermiumFm100(253)SamariumSm62150.4FleroviumFI114(289)ScandiumSc2144.96FluorineF919.00ScaborgiumSg106(263)FranciumFr87(223)SeleniumSe3478.96GadolniumGa3169.72SilverAg47107.9GermaniumGe3272.59SodiumNa1122.99GoldAu79197.0StrontiumSr3887.62HafniumHf72178.5SulfurS1632.07HassiumHs108(265)TantalumTa73180.9HeliumHe24.003TechnetiumTc43(99)HolmiumIn49114.8TerbiumTb65158.9IodineI53126.9ThallumTl81204.4IrdiumIr77192.2ThoriumTh90232.0IronFe2655.85ThuliumTm69168.9KryptonKr3683.80TinSn50118.7 </td <td>Dysprosium</td> <td>Dy</td> <td>66</td> <td>162.5</td> <td>Roentgenium</td> <td>Rg</td> <td>111</td> <td>(272)</td>	Dysprosium	Dy	66	162.5	Roentgenium	Rg	111	(272)
ErbiumEr68 $167.3$ RutheniumRu44 $101.1$ EuropiumEu63 $152.0$ RutherfordiumRf $104$ $(257)$ FermiumFm $100$ $(253)$ SamariumSm $62$ $150.4$ FleoviumFl $114$ $(289)$ ScandiumSc $21$ $44.96$ FluorineF9 $19.00$ SeaborgiumSg $106$ $(263)$ FranciumFr87 $(223)$ SeleniumSe $34$ $78.96$ GadoliniumGd64 $157.3$ SiliconSi $14$ $28.09$ GalliumGa $31$ $69.72$ SilverAg $47$ $107.9$ GermaniumGe $32$ $72.59$ SodumNa $11$ $22.99$ GoldAu79 $197.0$ StrontiumSr $38$ $87.62$ HafniumHf72 $178.5$ SulfurS $16$ $32.07$ HassiumHs $108$ $(265)$ TantalumTa $73$ $180.9$ HeliumHe2 $4.003$ TechnetiumTc $43$ $99)$ HolinumHo $67$ $164.9$ TelluriumTe $52$ $127.6$ HydrogenH1 $1.008$ TennessineTs $117$ $(294)$ IndiumIn $49$ $114.8$ TerhumTh $65$ $158.9$ IodineI $53$ $126.9$ ThalliumTh $81$	Einsteinium	Es	99	(254)	Rubidium	Rb	37	85.47
EuropiumEu $63$ $152.0$ RutherfordiumRf $104$ $(257)$ FermiumFm $100$ $(253)$ SamariumSm $62$ $150.4$ FleroviumFI $114$ $(289)$ ScandiumSc $21$ $44.96$ FluorineF9 $19.00$ SeaborgiumSg $106$ $(263)$ FranciumFr $87$ $(223)$ SeleniumSe $34$ $78.96$ GadoliniumGd $64$ $157.3$ SiliconSi $14$ $28.09$ GalliumGa $31$ $69.72$ SilverAg $47$ $107.9$ GermaniumGe $32$ $72.59$ SodiumNa $11$ $22.99$ GoldAu $79$ $197.0$ StrontiumSr $38$ $87.62$ HafniumHf $72$ $178.5$ SulfurS $16$ $32.07$ HassumHs $108$ $(265)$ TantalumTa $73$ $180.9$ HeliumHe $2$ $4.003$ TechnetiumTc $43$ $(99)$ HolniumHo $67$ $164.9$ TelluriumTe $52$ $127.6$ HydrogenH1 $1.008$ TennessineTs $117$ $(294)$ IndiumIn $49$ $114.8$ TerbiumTh $90$ $232.0$ IronFe $26$ $55.85$ ThuliumTm $65$ $158.9$ IodineI $53$ $126.9$ ThaliumTi <td>Erbium</td> <td>Er</td> <td>68</td> <td>167.3</td> <td>Ruthenium</td> <td>Ru</td> <td>44</td> <td>101.1</td>	Erbium	Er	68	167.3	Ruthenium	Ru	44	101.1
FermiumFm100(253)SamariumSm62150.4FleroviumFl114(289)ScandiumSc2144.96FluorineF919.00SeaborgiumSg106(263)FranciumFr87(223)SeleniumSe3478.96GadoliniumGd64157.3SiliconSi1428.09GalliumGa3169.72SilverAg47107.9GermaniumGe3272.59SodiumNa1122.99GoldAu79197.0StrontiumSr3887.62HafniumHf72178.5SulfurS1632.07HassiumHs108(265)TantalumTa73180.9HeliumHe24.003TechnetiumTc43(99)HolmiumHo67164.9TelluriumTe52127.6HydrogenH11.008TennessineTs117(294)IndiumIn49114.8TerbiumTb65158.9IodineI53126.9ThaliumTh80232.0IronFe2655.85ThuliumTm69168.9KryptonKr3683.80TinSn50118.7LanhanumLa57138.9TitaniumTi2247.88 <td>Europium</td> <td>Eu</td> <td>63</td> <td>152.0</td> <td>Rutherfordium</td> <td>Rf</td> <td>104</td> <td>(257)</td>	Europium	Eu	63	152.0	Rutherfordium	Rf	104	(257)
FleroviumFl114(289)ScandiumSc2144.96FluorineF919.00SeaborgiumSg106(263)FranciumFr87(223)SeleniumSe3478.96GadoliniumGd64157.3SiliconSi1428.09GalliumGa3169.72SilverAg47107.9GermaniumGe3272.59SodiumNa1122.99GoldAu79197.0StrontiumSr3887.62HafniumHf72178.5SulfurS1632.07HassiumHs108(265)TantalumTa73180.9HeliumHe24.003TechnetiumTc43(99)HolmiumHo67164.9TelluriumTe52127.6HydrogenH11.008TennessineTs117(294)IndiumIn49114.8TerbiumTb65158.9IodineI53126.9ThalliumTI81204.4IridiumIr77192.2ThoriumTh90232.0IronFe2655.85ThuliumTm69168.9KryptonKr3683.80TinSn50118.7LanthanumLa57138.9TitaniumTi2247.88 <td>Fermium</td> <td>Fm</td> <td>100</td> <td>(253)</td> <td>Samarium</td> <td>Sm</td> <td>62</td> <td>150.4</td>	Fermium	Fm	100	(253)	Samarium	Sm	62	150.4
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	Flerovium	Fl	114	(289)	Scandium	Sc	21	44.96
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Fluorine	F	9	19.00	Seaborgium	Sg	106	(263)
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Francium	Fr	87	(223)	Selenium	Se	34	78.96
GalliumGa3169.72SilverAg47107.9GermaniumGe32 $72.59$ SodiumNa1122.99GoldAu79197.0StrontiumSr3887.62HafniumHf72178.5SulfurS1632.07HassiumHs108(265)TantalumTa73180.9HeliumHe24.003TechnetiumTc43(99)HolmiumHo67164.9TelluriumTe52127.6HydrogenH11.008TennessineTs117(294)IndiumIn49114.8TerbiumTb65158.9IodineI53126.9ThalliumTh81204.4IridiumIr77192.2ThoriumTh90232.0IronFe2655.85ThuliumTm69168.9KryptonKr3683.80TinSn50118.7LawrenciumLr103(257)TugstenW74183.9LeadPb82207.2UraniumU92238.0LithumLi36.941VanadiumV2350.94LivermoriumLv116(293)XenonXe54131.3LutetiumLu71175.0YtterbiumYb70173.0 <tr< td=""><td>Gadolinium</td><td>Gd</td><td>64</td><td>157.3</td><td>Silicon</td><td>Si</td><td>14</td><td>28.09</td></tr<>	Gadolinium	Gd	64	157.3	Silicon	Si	14	28.09
GermaniumGe3272.59SodiumNa1122.99GoldAu79197.0StrontiumSr3887.62HafniumHf72178.5SulfurS1632.07HassiumHs108(265)TantalumTa73180.9HeliumHe24.003TechnetiumTc43(99)HolmiumHe24.003TechnetiumTc43(99)HolmiumHo67164.9TelluriumTe52127.6HydrogenH11.008TennessineTs117(294)IndiumIn49114.8TerbiumTb65158.9IodineI53126.9ThalliumTl81204.4IridiumIr77192.2ThoriumTh90232.0IronFe2655.85ThuliumTm69168.9KryptonKr3683.80TinSn50118.7LawrenciumLa57138.9TitaniumTi2247.88LawrenciumLi36.941VanadiumV2350.94LivermoriumLv116(293)XenonXe54131.3LutetumLu71175.0YtterbiumYb70173.0MaganeseMn2554.94ZincZn3065.39 </td <td>Gallium</td> <td>Ga</td> <td>31</td> <td>69.72</td> <td>Silver</td> <td>Ag</td> <td>47</td> <td>107.9</td>	Gallium	Ga	31	69.72	Silver	Ag	47	107.9
GoldAu79197.0StrontiumSr3887.62HafniumHf72178.5SulfurS1632.07HassiumHs108(265)TantalumTa73180.9HeliumHe24.003TechnetiumTc43(99)HolmiumHe24.003TechnetiumTc43(99)HolmiumHo67164.9TelluriumTe52127.6HydrogenH11.008TennessineTs117(294)IndiumIn49144.8TerbiumTb65158.9IodineI53126.9ThalliumTl81204.4IridiumIr77192.2ThoriumTh90232.0IronFe2655.85ThuliumTm69168.9KryptonKr3683.80TinSn50118.7LawrenciumLr103(257)TungstenW74183.9LeadPb82207.2UraniumU92238.0LithiumLi36.941VanadiumV2350.94LivermoriumLv116(293)XenonXe54131.3LutetiumLu71175.0YtterbiumYb70173.0MagnesiumMg1224.31YttriumY3988.91<	Germanium	Ge	32	72.59	Sodium	Na	11	22.99
HafniumHf72178.5SulfurS1632.07HassiumHs108(265)TantalumTa73180.9HeliumHe24.003TechnetiumTc43(99)HolmiumHo67164.9TelluriumTe52127.6HydrogenH11.008TennessineTs117(294)IndiumIn49114.8TerbiumTb65158.9IodineI53126.9ThalliumTl81204.4IridiumIr77192.2ThoriumTh90232.0IronFe2655.85ThuliumTm69168.9KryptonKr3683.80TinSn50118.7LanthanumLa57138.9TitaniumTi2247.88LawrenciumLr103(257)TungstenW74183.9LeadPb82207.2UraniumU92238.0LithiumLi36.941VanadiumV2350.94LivermoriumLv116(293)XenonXe54131.3LuetiumLu71175.0YtterbiumYb70173.0MaganeseMn2554.94ZincZn3065.39ManganeseMn2554.94ZincZn3065.39 <td>Gold</td> <td>Au</td> <td>79</td> <td>197.0</td> <td>Strontium</td> <td>Sr</td> <td>38</td> <td>87.62</td>	Gold	Au	79	197.0	Strontium	Sr	38	87.62
HassiumHs101217.0TantalumTa73180.9HassiumHe24.003TechnetiumTc43(99)HolmiumHo67164.9TelluriumTe52127.6HydrogenH11.008TennessineTs117(294)IndiumIn49114.8TerbiumTb65158.9IodineI53126.9ThalliumTl81204.4IridiumIr77192.2ThoriumTh90232.0IronFe2655.85ThuliumTm69168.9KryptonKr3683.80TinSn50118.7LanthanumLa57138.9TitaniumTi2247.88LawrenciumLr103(257)TungstenW74183.9LeadPb82207.2UraniumU92238.0LithiumLi36.941VanadiumV2350.94LivermoriumLu71175.0YtterbiumYb70173.0MagnesiumMg1224.31YttriumY3988.91MarganeseMn2554.94ZincoZn3065.39MeitneriumMt109(266)ZirconiumZr4091.22	Hafnium	Hf	72	178.5	Sulfur	S	16	32.07
InstantInstantInstantInstantInstantInstantInstantInstantHeliumHe24.003TechnetiumTc43(99)HolmiumHo67164.9TelluriumTe52127.6HydrogenH11.008TennessineTs117(294)IndiumIn49114.8TerbiumTb65158.9IodineI53126.9ThalliumTl81204.4IridiumIr77192.2ThoriumTh90232.0IronFe2655.85ThuliumTm69168.9KryptonKr3683.80TinSn50118.7LanthanumLa57138.9TitaniumTi2247.88LawrenciumLr103(257)TungstenW74183.9LeadPb82207.2UraniumU92238.0LithiumLi36.941VanadiumV2350.94LivermoriumLv116(293)XenonXe54131.3LutetiumLu71175.0YtterbiumYb70173.0MagnesiumMg1224.31YttriumY3988.91ManganeseMn2554.94ZincZn3065.39MeitneriumMt109(266)ZirconiumZr <td>Hassium</td> <td>Hs</td> <td>108</td> <td>(265)</td> <td>Tantalum</td> <td>Ta</td> <td>73</td> <td>180.9</td>	Hassium	Hs	108	(265)	Tantalum	Ta	73	180.9
IndianInc <t< td=""><td>Helium</td><td>He</td><td>2</td><td>4 003</td><td>Technetium</td><td>Tc</td><td>43</td><td>(99)</td></t<>	Helium	He	2	4 003	Technetium	Tc	43	(99)
InfinitianInd <td>Holmium</td> <td></td> <td>67</td> <td>164.0</td> <td>Tollurium</td> <td>То</td> <td>+J 52</td> <td>127.6</td>	Holmium		67	164.0	Tollurium	То	+J 52	127.6
InyulogenInI1.005Tennessnie1s117 $(294)$ IndiumIn49114.8TerbiumTb65158.9IodineI53126.9ThalliumTl81204.4IridiumIr77192.2ThoriumTh90232.0IronFe2655.85ThuliumTm69168.9KryptonKr3683.80TinSn50118.7LanthanumLa57138.9TitaniumTi2247.88LawrenciumLr103(257)TungstenW74183.9LeadPb82207.2UraniumU92238.0LithiumLi36.941VanadiumV2350.94LivermoriumLu71175.0YtterbiumYb70173.0MagnesiumMg1224.31YttriumY3988.91ManganeseMn2554.94ZincZn3065.39MeitneriumMt109(266)ZirconiumZr4091.22	Ludrogon	ПО Ц	1	104.9	Tennossino	To	117	(204)
IndumIn49114.8TerbulnTb65138.9IodineI53126.9ThalliumTl81204.4IridiumIr77192.2ThoriumTh90232.0IronFe2655.85ThuliumTm69168.9KryptonKr3683.80TinSn50118.7LanthanumLa57138.9TitaniumTi2247.88LawrenciumLr103(257)TungstenW74183.9LeadPb82207.2UraniumU92238.0LithiumLi36.941VanadiumV2350.94LivermoriumLu71175.0YtterbiumYb70173.0MagnesiumMg1224.31YttriumY3988.91ManganeseMn2554.94ZincZn3065.39MeitneriumMt109(266)ZirconiumZr4091.22	Indiana	11 Ta	1	114.0	Tenhessine	18	117	(294)
Iodine15.3 $126.9$ Inalitum1181 $204.4$ IridiumIr77 $192.2$ ThoriumTh90 $232.0$ IronFe26 $55.85$ ThuliumTm69 $168.9$ KryptonKr36 $83.80$ TinSn $50$ $118.7$ LanthanumLa $57$ $138.9$ TitaniumTi $22$ $47.88$ LawrenciumLr $103$ $(257)$ TungstenW $74$ $183.9$ LeadPb $82$ $207.2$ UraniumU $92$ $238.0$ LithiumLi3 $6.941$ VanadiumV $23$ $50.94$ LivermoriumLv $116$ $(293)$ XenonXe $54$ $131.3$ LutetiumLu $71$ $175.0$ YtterbiumYb $70$ $173.0$ MagaeseMn $25$ $54.94$ ZincZn $30$ $65.39$ MeitneriumMt $109$ $(266)$ ZirconiumZr $40$ $91.22$	Indium	In	49	114.8	Terbium		65	158.9
IridiumIr $77$ $192.2$ ThoriumTh $90$ $232.0$ IronFe $26$ $55.85$ ThuliumTm $69$ $168.9$ KryptonKr $36$ $83.80$ TinSn $50$ $118.7$ LanthanumLa $57$ $138.9$ TitaniumTi $22$ $47.88$ LawrenciumLr $103$ $(257)$ TungstenW $74$ $183.9$ LeadPb $82$ $207.2$ UraniumU $92$ $238.0$ LithiumLi $3$ $6.941$ VanadiumV $23$ $50.94$ LivermoriumLv $116$ $(293)$ XenonXe $54$ $131.3$ LutetiumLu $71$ $175.0$ YtterbiumYb $70$ $173.0$ MagnesiumMg $12$ $24.31$ YttriumY $39$ $88.91$ ManganeseMn $25$ $54.94$ ZincZn $30$ $65.39$ MeitneriumMt $109$ $(266)$ ZirconiumZr $40$ $91.22$	Iodine	1	53	126.9	Thallium	11	81	204.4
IronFe2655.85ThuliumTm69168.9KryptonKr3683.80TinSn50118.7LanthanumLa57138.9TitaniumTi2247.88LawrenciumLr103(257)TungstenW74183.9LeadPb82207.2UraniumU92238.0LithiumLi36.941VanadiumV2350.94LivermoriumLv116(293)XenonXe54131.3LutetiumLu71175.0YtterbiumYb70173.0MagnesiumMg1224.31YttriumY3988.91ManganeseMn2554.94ZincZn3065.39MeitneriumMt109(266)ZirconiumZr4091.22	Iridium	lr	77	192.2	Thorium	Th	90	232.0
KryptonKr3683.80TinSn50118.7LanthanumLa57138.9TitaniumTi2247.88LawrenciumLr103 $(257)$ TungstenW74183.9LeadPb82207.2UraniumU92238.0LithiumLi36.941VanadiumV2350.94LivermoriumLv116 $(293)$ XenonXe54131.3LutetiumLu71175.0YtterbiumYb70173.0MagnesiumMg1224.31YttriumY3988.91ManganeseMn2554.94ZincZn3065.39MeitneriumMt109 $(266)$ ZirconiumZr4091.22	Iron	Fe	26	55.85	Thulium	Tm	69	168.9
LanthanumLa57138.9TitaniumTi2247.88LawrenciumLr103 $(257)$ TungstenW74183.9LeadPb82207.2UraniumU92238.0LithiumLi36.941VanadiumV2350.94LivermoriumLv116 $(293)$ XenonXe54131.3LutetiumLu71175.0YtterbiumYb70173.0MagnesiumMg1224.31YttriumY3988.91ManganeseMn2554.94ZincZn3065.39MeitneriumMt109 $(266)$ ZirconiumZr4091.22	Krypton	Kr	36	83.80	Tin	Sn	50	118.7
LawrenciumLr103 $(257)$ TungstenW74183.9LeadPb82207.2UraniumU92238.0LithiumLi36.941VanadiumV2350.94LivermoriumLv116 $(293)$ XenonXe54131.3LutetiumLu71175.0YtterbiumYb70173.0MagnesiumMg1224.31YttriumY3988.91ManganeseMn2554.94ZincZn3065.39MeitneriumMt109 $(266)$ ZirconiumZr4091.22	Lanthanum	La	57	138.9	Titanium	Ti	22	47.88
Lead         Pb         82         207.2         Uranium         U         92         238.0           Lithium         Li         3         6.941         Vanadium         V         23         50.94           Livermorium         Lv         116         (293)         Xenon         Xe         54         131.3           Lutetium         Lu         71         175.0         Ytterbium         Yb         70         173.0           Magnesium         Mg         12         24.31         Yttrium         Y         39         88.91           Manganese         Mn         25         54.94         Zinc         Zn         30         65.39           Meitnerium         Mt         109         (266)         Zirconium         Zr         40         91.22	Lawrencium	Lr	103	(257)	Tungsten	W	74	183.9
Lithium         Li         3         6.941         Vanadium         V         23         50.94           Livermorium         Lv         116         (293)         Xenon         Xe         54         131.3           Lutetium         Lu         71         175.0         Ytterbium         Yb         70         173.0           Magnesium         Mg         12         24.31         Yttrium         Y         39         88.91           Manganese         Mn         25         54.94         Zinc         Zn         30         65.39           Meitnerium         Mt         109         (266)         Zirconium         Zr         40         91.22	Lead	Pb	82	207.2	Uranium	U	92	238.0
Livermorium         Lv         116         (293)         Xenon         Xe         54         131.3           Lutetium         Lu         71         175.0         Ytterbium         Yb         70         173.0           Magnesium         Mg         12         24.31         Yttrium         Y         39         88.91           Manganese         Mn         25         54.94         Zinc         Zn         30         65.39           Meitnerium         Mt         109         (266)         Zirconium         Zr         40         91.22	Lithium	Li	3	6.941	Vanadium	V	23	50.94
LutetiumLu71175.0YtterbiumYb70173.0MagnesiumMg1224.31YttriumY3988.91ManganeseMn2554.94ZincZn3065.39MeitneriumMt109(266)ZirconiumZr4091.22	Livermorium	Lv	116	(293)	Xenon	Xe	54	131.3
Magnesium         Mg         12         24.31         Yttrium         Y         39         88.91           Manganese         Mn         25         54.94         Zinc         Zn         30         65.39           Meitnerium         Mt         109         (266)         Zirconium         Zr         40         91.22	Lutetium	Lu	71	175.0	Ytterbium	Yb	70	173.0
Manganese         Mn         25         54.94         Zinc         Zn         30         65.39           Meitnerium         Mt         109         (266)         Zirconium         Zr         40         91.22	Magnesium	Mg	12	24.31	Yttrium	Y	39	88.91
Meitnerium Mt 109 (266) Zirconium Zr 40 91.22	Manganese	Mn	25	54.94	Zinc	Zn	30	65.39
	Meitnerium	Mt	109	(266)	Zirconium	Zr	40	91.22

\*All atomic masses have four significant figures. These values are recommended by the Committee on Teaching of Chemistry, International Union of Pure and Applied Chemistry. <sup>†</sup>Approximate values of atomic masses for radioactive elements are given in parentheses.

# CHEMISTRY



## **Raymond Chang**

Williams College

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The opening sentence of this text is, "Chemistry is an active, evolving science that has vital importance to our world, in both the realm of nature and the realm of society." Throughout the text, Chemistry in Action boxes and Chemical Mysteries give specific examples of chemistry as active and evolving in all facets of our lives.

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## List of Videos



The videos below are correlated to Chemistry. Within the chapter are icons letting the student and instructor know that a video is available for a specific topic. Videos can be found in the Connect ebook.

Absorption of Color (23.5) Acid Ionization (15.5) Acid-Base Titrations (16.4) Activation Energy (13.4) Alpha, Beta, and Gamma Rays (2.2)  $\alpha$ -Particle Scattering (2.2) Aluminum Production (21.7) Atomic and Ionic Radius (8.3) Atomic Line Spectra (7.3) Base Ionization (15.6) Buffer Solutions (16.3) Catalysis (13.6) Cathode Ray Tube (2.2) Chemical Equilibrium (14.1) Chirality (23.4, 24.2) Collecting a Gas over Water (5.6) Cu/Zn Voltaic Cell (18.2) Cubic Unit Cells and Their Origins (11.4) Current Generation from a Voltaic Cell (18.2) Diffusion of Gases (5.7) Dissociation of Strong and Weak Acids (15.4) Dissolution of an Ionic and a Covalent Compound (12.2) Electron Configurations (7.8) Emission Spectra (7.3) Equilibrium Vapor Pressure (11.8) Formation of a Covalent Bond (9.4) Formation of Ag<sub>2</sub>S by Oxidation-Reduction (4.4) Formation of an Ionic Compound (2.7)

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## Preface

The thirteenth edition follows the long tradition of sustaining a firm foundation in the concepts of chemical principles and instilling an appreciation of the important role chemistry plays in our daily lives. We believe that it is our responsibility to help both instructors and students in their pursuit of this goal by presenting a broad range of chemical topics in a logical format. At all times, we strive to balance theory and application and to illustrate principles with applicable examples whenever possible.

As in previous editions, our goal is to create a test that clearly and concisely explains abstract concepts yet comprehensive enough that students are prepared to make the move forward in the chemistry curriculum. Encouraging feedback from instructors and students alike reaffirm that this approach is effective.

#### **Review of Concepts and Facts**

In previous editions, Review of Facts questions were provided throughout various sections of the book as a way for students to quickly gauge their understanding of a concept just presented. We have now expanded these checks to be a Review of Concepts and Facts provided at the end of most sections in a chapter. Over 170 new questions have been added to the Review of Concepts and Facts boxes ensuring students have ample opportunity to practice and review the major concepts and facts presented in that section. The answers to each of these questions are provided at the end of the chapter.

#### Summary of Concepts & Facts

- The study of chemistry involves three basic steps: observation, representation, and interpretation. Observation refers to measurements in the macroscopic world; representation involves the use of shorthand no-tation symbols and equations for communication; inter-pretations are based on atoms and molecules, which belong to the microscopic world.
   The scientific method is a systematic approach to re-search that begins with the gathering of information through observation and measurements. In the process, hypotheses, laws, and theories are devised and tested.
   Chemists study matter and the changes it undergoes.
- 3. Chemists study matter and the changes it undergoes The substances that make up matter have unique physi-cal properties that can be observed without changing their identity and unique chemical properties that, when they are demonstrated, do change the identity of the
- substances. Mixtures, whether homogeneous or he geneous, can be separated into pure components by physical means. The simplest substances in chemistry are elements Compounds are formed by the chemical combination of
- atoms of different elements in fixed proportions All substances, in principle, can exist in three states: solid, liquid, and gas. The interconversion between these states can be effected by changing the temperature.
- SI units are used to express physical quantities in all sciences, including chemistry.
- To Numbers expressed in service of the form  $N \times 10^{\circ}$ , where N is between 1 and 10, and n is a positive or negative integer. Scientific notation helps us handle very large and very small quantities.

### Student Hot Spots

The adaptive reading tool SmartBook<sup>®</sup> now gives authors a detailed analysis of student performance on various learning objectives and concepts. With this powerful insight into the ideas and concepts students struggle with, we are now able to provide strategically-placed notifications about access to additional learning resources. Identified areas of particularly difficult content are now denoted with a margin note called "Student Hot Spots". These are intended to direct students to additional learning resources specific to that

content. Students now have access to over 1,000 digital learning resources throughout the SmartBook® version of this text. Included in these learning



resources are over 200 videos of chemistry faculty solving actual problems or explaining concepts.

In the electronic version of this text, all the learning resources for the Student Hot Spots are readily available.

STUDENT HOT SPOT
Student data indicate you may struggle with this content. View the following video, "Converting Element Mass into Moles and Atoms," to make sure you understand the concept before moving on.
<
6022+1030 Element Conversions 107.9 mon
How many moles and atoms are in 47.36g silver?
47.359 Ag [1mol 107.95 = 1383 =
47.36g.Pg 1 mol 6022×10 <sup>48</sup> atoms 2.643×10 <sup>58</sup> atoms Pg
▶ aquive a set of the set of

Further, access to student results has guided the editing of content in many chapters. While many of the changes are subtle, some are more comprehensive. The ability to edit based on real time assessment data from students is the new paradigm for textbook authoring. Undoubtedly this changes how we provide and enhance learning materials for our students in the future!

#### Learning Objectives

All chapters now have a comprehensive list of learning objectives provided to help facilitate instructors' assessment of their students. Every learning objective item is tagged by its location in the chapter. Further, each learning objective is written using only appropriate action verbs based on Bloom's taxonomy.

#### Learning Objectives

- · Outline Dalton's hypotheses about the nature of matter. (Section 2.1)
- Understand the concept of the atom and the nature of an element. (Section 2.2)
- Assess the importance of experiments conducted by Thomson, Millikan, Röntgen, and Rutherford, and how they influenced our understanding of the nature and structure of atoms. (Section 2.2)
- Summarize the different types of radiation that radioactive substances can produce. (Section 2.2) · Describe the location and physical properties of electrons, protons, and neutrons. (Section 2.2)
- · Explain the nature and importance of isotopes. (Section 2.3)
- Calculate the mass number of an isotope. (Section 2.3)
- Utilize the mass number of an isotope to solve for the number of electrons, protons, or neutrons, given other relevant information. (Section 2.3)
- Recognize the general organization of the periodic table with respect to metals, metalloids, nonmetals, groups, and periods. (Section 2.4)
- · Differentiate between molecules and ions. (Section 2.5)
- Classify chemical formulas as either molecular or empirical. (Section 2.6)
- · Determine formulas of ionic compounds. (Section 2.6)

### **Questions and Problems**

The Review Questions and Problems at the end of each chapter have been reorganized so that they fully correlate to a given section. In many cases, the heading for a group of questions was revised to reflect the title of a section. These changes should increase the ease with which students and instructors alike can identify appropriate questions and problems for practice or assignments.

#### **Art Program and Design**

For this edition, the art program was thoroughly revised to impart a more modern look and enhance visibility. Clear graphics are a vital component of the student learning process and as such, all graphs, periodic tables, and other figures have been updated with a new look and color scheme. In some instances, illustrations have been replaced with scientifically accurate photographs for enhanced chemical context. Many chapter opening photographs have been updated for new insights into various chemical topics and applications.



In addition to the more than 170 new Review of Concepts & Facts questions that have been added throughout the chapters, following are just a few of the highlights of the  $13^{\text{th}}$  edition content revision.

#### Chapter 1

- A revised discussion of the difference between intensive and extensive properties is provided.
- Table 1.3 has been expanded to include the common prefix peta-.
- A more detailed discussion of accuracy and precision has been included.

**Chapter 3** The language concerning limiting reactants versus limiting reagents has been made consistent.

**Chapter 7** A new worked example concerning quantum numbers has been included.

**Chapters 2, 7, 8, 19, and 23** Figures and tables throughout have been updated to reflect the newest additions to the periodic table.

## **Problem Solving**

The development of problem-solving skills has always been a major objective of this text. The two major categories of learning are shown next.

**Worked examples** follow a proven step-by-step strategy and solution.

- **Problem statement** is the reporting of the facts needed to solve the problem based on the question posed.
- **Strategy** is a carefully thought-out plan or method to serve as an important function of learning.
- **Solution** is the process of solving a problem given in a stepwise manner.
- **Check** enables the student to compare and verify with the source information to make sure the answer is reasonable.
- **Practice Exercise** provides the opportunity to solve a similar problem in order to become proficient in this problem type. The Practice Exercises are available in the Connect electronic homework system. The margin note lists additional similar problems to work in the end-of-chapter problem section.

**End-of-Chapter Problems** are organized in various ways. Each section under a topic heading begins with Review Questions followed by Problems. The Additional Problems section provides more problems not organized by section, followed by the problem type Interpreting, Modeling & Estimating.

Many of the examples and end-of-chapter problems present extra tidbits of knowledge and enable the student to solve a chemical problem that a chemist would solve. The examples and problems show students the real world of chemistry and applications to everyday life situations.

#### Visualization

**Graphs and Flow Charts** are important in science. In *Chemistry*, flow charts show the thought process of a concept and graphs present data to comprehend the concept. A significant number of Problems and Review of Concepts & Facts, including many new to this edition, include graphical data.

**Molecular art** appears in various formats to serve different needs. Molecular models help to visualize the three-dimensional arrangement of atoms in a molecule. Electrostatic potential maps illustrate the electron density distribution in molecules. Finally, there is the macroscopic to microscopic art helping students understand processes at the molecular level.

**Photos** are used to help students become familiar with chemicals and understand how chemical reactions appear in reality.

**Figures of apparatus** enable the student to visualize the practical arrangement in a chemistry laboratory.

## **Study Aids**

#### **Setting the Stage**

Each chapter starts with the Chapter Outline and A Look Ahead.

- **Chapter Outline** enables the student to see at a glance the big picture and focus on the main ideas of the chapter.
- A Look Ahead provides the student with an overview of concepts that will be presented in the chapter.

### Tools to Use for Studying

Useful aids for studying are plentiful in *Chemistry* and should be used constantly to reinforce the comprehension of chemical concepts.

- Marginal Notes are used to provide hints and feedback to enhance the knowledge base for the student.
- Worked Examples along with the accompanying Practice Exercises are very important tools for learning and mastering chemistry. The problemsolving steps guide the student through the critical thinking necessary for succeeding in chemistry. Using sketches helps student understand the inner workings of a problem. Similar problems in the end-of-chapter problems section are listed at the end of the examples, enabling the student to apply new skill to other problems of the same type. Answers to the Practice Exercises are listed at the end of the chapter problems.
- **Key Equations** are highlighted within the chapter, drawing the student's eye to material that needs to be understood and retained. The key equations are also presented in the chapter summary materials for easy access in review and study.
- **Summary of Concepts & Facts** provides a quick review of concepts presented and discussed in detail within the chapter.
- **Key Words** are a list of all important terms to help the student understand the language of chemistry.

### **Testing Your Knowledge**

- **Review of Concepts & Facts** lets students pause and check to see if they understand the concept presented and discussed in the section occurred. Answers to the Review of Concepts can be found in the Student Solution Manual.
- **End-of-Chapter Problems** enable the student to practice critical thinking and problem-solving skills. The problems are broken into various types:
  - By chapter section. Starting with Review Questions to test basic conceptual understanding, followed by Problems to test the student's skill in

solving problems for that particular section of the chapter.

- Additional Problems uses knowledge gained from the various sections and/or previous chapters to solve the problem.
- Interpreting, Modeling & Estimating problems teach students the art of formulating models and estimating ballpark answers based on appropriate assumptions.

## **Real-Life Relevance**

Interesting examples of how chemistry applies to life are used throughout the text. Analogies are used where appropriate to help foster understanding of abstract chemical concepts.

- **End-of-Chapter Problems** pose many relevant questions for the student to solve. Examples include Why do swimming coaches sometimes place a drop of alcohol in a swimmer's ear to draw out water? How does one estimate the pressure in a carbonated soft drink bottle before removing the cap?
- **Chemistry in Action** boxes appear in every chapter on a variety of topics, each with its own story of how chemistry can affect a part of life. The student can learn about the science of scuba diving and nuclear medicine, among many other interesting cases.



**Chemical Mystery** poses a mystery case to the student. A series of chemical questions provide clues as to how the mystery could possibly be solved. Chemical Mystery will foster a high level of critical thinking using the basic problemsolving steps built up throughout the text.

#### CHEMICAL MYSTERY

#### Who Killed Napoleon?



same. Elemental arsenic is not that harmful. The commonly used poison is actually arsenic(III) le, As; $O_3$ , a white compound that dissolves in water, is tasteless, and, if administered is cloud by added to grandfather's winc to haten this demise so that his grandon could

In 1832 the English chemist James Marsh devised a procedure for detecting arsenic This test, which now hears Marh's name, combines hydrogen formed by the reaction be tween zime and sufficience and with a sample of the suspected poion. If Ax<sub>2</sub>O<sub>2</sub> is present, it reacts with hydrogen to form a toxic gas, aranie (AMH). When aratine gas is heated, it do composes to form ascric, which is recognized by its metallic laster. The Marh test is a



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A robust set of questions, problems, and interactive figures are presented and aligned with the textbook's learning goals. The integration of ChemDraw by PerkinElmer, the industry standard in chemical drawing software, allows students to create accurate chemical structures in their online homework assignments. As an instructor, you can edit existing questions and write entirely new problems. Track individual student performance-by question, assignment, or in relation to the class overall-with detailed grade reports. Integrate grade reports easily with Learning Management Systems (LMS), such as WebCT and Blackboard-and much more. Also available within Connect, our adaptive SmartBook has been supplemented with additional learning resources tied to each learning objective to provide point-in-time help to students who need it. To learn more, visit www.mheducation.com.



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- Animations Numerous full-color animations illustrating important processes are also provided. Harness the visual impact of concepts in motion by importing these files into classroom presentations or online course materials.
- **PowerPoint Lecture Outlines** Ready-made presentations that combine art and lecture notes are provided for each chapter of the text.
- **Computerized Test Bank** Over 3,000 test questions that accompany *Chemistry* are available utilizing the industry-leading test generation software TestGen. These same questions are also available and assignable through Connect for online tests.
- **Instructor's Solutions Manual** This supplement contains complete, worked-out solutions for *all* the end-of-chapter problems in the text.



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## 

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#### **Student Solutions Manual**

Students will find answers to the Practice Exercises and detailed solutions for selected problems from the text in the Student Solutions manual. In addition, there are problem-solving strategies and tutorial solutions that surround each chapter's most important topics and problem types.



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- Attend classes regularly and take careful notes.
- If possible, always review the topics discussed in class the same day they are covered in class. Use this book to supplement your notes.
- Think critically. Ask yourself if you really understand the meaning of a term or the use of an equation. A good way to test your understanding is to explain a concept to a classmate or some other person.
- Do not hesitate to ask your instructor or your teaching assistant for help.

The thirteenth edition tools for *Chemistry* are designed to enable you to do well in your general chemistry course. The following guide explains how to take full advantage of the text, technology, and other tools.

- Before delving into the chapter, read the chapter *outline* and the chapter *introduction* to get a sense of the important topics. Use the outline to organize your note taking in class.
- At the end of each chapter you will find a summary of facts and concepts, the key equations, and a list of

key words, all of which will help you review for exams.

- Definitions of the key words can be studied in context on the pages cited in the end-of-chapter list or in the glossary at the back of the book.
- Careful study of the worked-out examples in the body of each chapter will improve your ability to analyze problems and correctly carry out the calculations needed to solve them. Also take the time to work through the practice exercise that follows each example to be sure you understand how to solve the type of problem illustrated in the example. The answers to the practice exercises appear at the end of the chapter, following the questions and problems. For additional practice, you can turn to similar problems referred to in the margin next to the example.
- The questions and problems at the end of the chapter are organized by section.
- The back inside cover shows a list of important figures and tables with page references. This index makes it convenient to quickly look up information when you are solving problems or studying related subjects in different chapters.

If you follow these suggestions and stay up-to-date with your assignments, you should find that chemistry is challenging, but less difficult and much more interesting than you expected.

-Raymond Chang and Jason Overby



A scanning tunneling microscope probes individual small molecules when they adsorb on graphene, a single-atom thin sheet of carbon atoms. ©Science Source

## **CHAPTER OUTLINE**

- 1.1 Chemistry: A Science for the Twenty-First Century
- **1.2** The Study of Chemistry
- 1.3 The Scientific Method
- **1.4** Classifications of Matter
- 1.5 The Three States of Matter
- **1.6** Physical and Chemical Properties of Matter
- 1.7 Measurement
- 1.8 Handling Numbers
- 1.9 Dimensional Analysis in Solving Problems
- 1.10 Real-World Problem Solving: Information, Assumptions, and Simplifications

## Chemistry The Study of Change



## A LOOK AHEAD

- ▶ We begin with a brief introduction to the study of chemistry and describe its role in our modern society. (1.1 and 1.2)
- Next, we become familiar with the scientific method, which is a systematic approach to research in all scientific disciplines. (1.3)
- We define matter and note that a pure substance can either be an element or a compound. We distinguish between a homogeneous mixture and a heterogeneous mixture. We also learn that, in principle, all matter can exist in one of three states: solid, liquid, and gas. (1.4 and 1.5)
- ► To characterize a substance, we need to know its physical properties, which can be observed without changing its identity and chemical properties, which can be demonstrated only by chemical changes. (1.6)
- Being an experimental science, chemistry involves measurements. We learn the basic SI units and use the SI-derived units for quantities like volume and density. We also become familiar with the three temperature scales: Celsius, Fahrenheit, and Kelvin. (1.7)
- Chemical calculations often involve very large or very small numbers and a convenient way to deal with these numbers is the scientific notation. In calculations or measurements, every quantity must show the proper number of significant figures, which are the meaningful digits. (1.8)
- ▶ We learn that dimensional analysis is useful in chemical calculations. By carrying the units through the entire sequence of calculations, all the units will cancel except the desired one. (1.9)
- Solving real-world problems frequently involves making assumptions and simplifications. (1.10)

Chemistry is an active, evolving science that has vital importance to our world, in both the realm of nature and the realm of society. Its roots are ancient, but as we will see, chemistry is every bit a modern science.

We will begin our study of chemistry at the macroscopic level, where we can see and measure the materials of which our world is made. In this chapter, we will discuss the scientific method, which provides the framework for research not only in chemistry but in all other sciences as well. Next we will discover how scientists define and characterize matter. Then we will spend some time learning how to handle numerical results of chemical measurements and solve numerical problems. In Chapter 2, we will begin to explore the microscopic world of atoms and molecules.

## **1.1** Chemistry: A Science for the Twenty-First Century

*Chemistry* is *the study of matter and the changes it undergoes.* Chemistry is often called the central science, because a basic knowledge of chemistry is essential for students of biology, physics, geology, ecology, and many other subjects. Indeed, it is central to our way of life; without it, we would be living shorter lives in what we would consider primitive conditions, without automobiles, electricity, computers, CDs, and many other everyday conveniences.

Although chemistry is an ancient science, its modern foundation was laid in the nineteenth century, when intellectual and technological advances enabled scientists to break down substances into ever smaller components and consequently to explain many of their physical and chemical characteristics. The rapid development of increasingly sophisticated technology throughout the twentieth century has given us even greater means to study things that cannot be seen with the naked eye. Using computers and special microscopes, for example, chemists can analyze the structure of atoms and molecules—the fundamental units on which the study of chemistry is based—and design new substances with specific properties, such as drugs and environmentally friendly consumer products.



The Chinese characters for chemistry mean "the study of change."



(a)

(b)



**Figure 1.1** (a) The output from an automated DNA sequencing machine. Each lane displays the sequence (indicated by different colors) obtained with a separate DNA sample. (b) A graphene supercapacitor. These materials provide some of the highest known energy-to-volume ratios and response times. (c) Production of photovoltaic cells, used to convert light into electrical current. (d) Ethanol for fuel use is produced by distillation from corn.

(a): ©Science Source; (b): Courtesy of Richard B. Kaner; (c): ©David Parker/Seagate/Science Source; (d): ©David Nunuk/Science Source

It is fitting to ask what part the central science will have in the twenty-first century. Almost certainly, chemistry will continue to play a pivotal role in all areas of science and technology. Before plunging into the study of matter and its transformation, let us consider some of the frontiers that chemists are currently exploring (Figure 1.1). Whatever your reasons for taking general chemistry, a good knowledge of the subject will better enable you to appreciate its impact on society and on you as an individual.

## **1.2** The Study of Chemistry

Compared with other subjects, chemistry is commonly believed to be more difficult, at least at the introductory level. There is some justification for this perception; for one thing, chemistry has a very specialized vocabulary. However, even if this is your first course in chemistry, you already have more familiarity with the subject than you may realize. In everyday conversations we hear words that have a chemical connection, although they may not be used in the scientifically correct sense. Examples are "electronic," "quantum leap," "equilibrium," "catalyst," "chain reaction," and "critical mass." Moreover, if you cook, then you are a practicing chemist! From experience gained in the kitchen, you know that oil and water do not mix and that boiling water left on the stove will evaporate. You apply chemical and physical principles when you use baking soda to leaven bread, choose a pressure cooker to shorten the time it takes to prepare soup, add meat tenderizer to a pot roast, squeeze lemon juice over sliced pears to prevent them from turning brown or over fish to minimize its odor, and add vinegar



**Figure 1.2** A simplified molecular view of rust (Fe<sub>2</sub>O<sub>3</sub>) formation from iron (Fe) atoms and oxygen molecules (O<sub>2</sub>). In reality, the process requires water, and rust also contains water molecules. BAE Inc (Alamy Stock Photo

to the water in which you are going to poach eggs. Every day we observe such changes without thinking about their chemical nature. The purpose of this course is to make you think like a chemist, to look at the *macroscopic world*—the things we can see, touch, and measure directly—and visualize the particles and events of the *microscopic world* that we cannot experience without modern technology and our imaginations.

At first some students find it confusing that their chemistry instructor and textbook seem to be continually shifting back and forth between the macroscopic and microscopic worlds. Just keep in mind that the data for chemical investigations most often come from observations of large-scale phenomena, but the explanations frequently lie in the unseen and partially imagined microscopic world of atoms and molecules. In other words, chemists often *see* one thing (in the macroscopic world) and *think* another (in the microscopic world). Looking at the rusted nails in Figure 1.2, for example, a chemist might think about the basic properties of individual atoms of iron and how these units interact with other atoms and molecules to produce the observed change.

### **1.3** The Scientific Method

All sciences, including the social sciences, employ variations of what is called the *scientific method, a systematic approach to research*. For example, a psychologist who wants to know how noise affects people's ability to learn chemistry and a chemist interested in measuring the heat given off when hydrogen gas burns in air would follow roughly the same procedure in carrying out their investigations. The first step is to carefully define the problem. The next step includes performing experiments, making careful observations, and recording information, or *data*, about the system—the part of the universe that is under investigation. (In the examples just discussed, the systems are the group of people the psychologist will study and a mixture of hydrogen and air.)

The data obtained in a research study may be both *qualitative, consisting of general observations about the system,* and *quantitative, comprising numbers obtained by various measurements of the system.* Chemists generally use standardized symbols and equations in recording their measurements and observations. This form of representation not only simplifies the process of keeping records, but also provides a common basis for communication with other chemists.



**Figure 1.3** The three levels of studying chemistry and their relationships. Observation deals with events in the macroscopic world; atoms and molecules constitute the microscopic world. Representation is a scientific shorthand for describing an experiment in symbols and chemical equations. Chemists use their knowledge of atoms and molecules to explain an observed phenomenon.

When the experiments have been completed and the data have been recorded, the next step in the scientific method is interpretation, meaning that the scientist attempts to explain the observed phenomenon. Based on the data that were gathered, the researcher formulates a *hypothesis, a tentative explanation for a set of observations*. Further experiments are devised to test the validity of the hypothesis in as many ways as possible, and the process begins anew. Figure 1.3 summarizes the main steps of the research process.

After a large amount of data has been collected, it is often desirable to summarize the information in a concise way, as a law. In science, a *law* is *a concise verbal or mathematical statement of a relationship between phenomena that is always the same under the same conditions.* For example, Sir Isaac Newton's second law of motion, which you may remember from high school science, says that force equals mass times acceleration (F = ma). What this law means is that an increase in the mass or in the acceleration of an object will always increase its force proportionally, and a decrease in mass or acceleration will always decrease the force.

Hypotheses that survive many experimental tests of their validity may evolve into theories. A *theory* is a *unifying principle that explains a body of facts and/or those laws that are based on them.* Theories, too, are constantly being tested. If a theory is disproved by experiment, then it must be discarded or modified so that it becomes consistent with experimental observations. Proving or disproving a theory can take years, even centuries, in part because the necessary technology may not be available. Atomic theory, which we will study in Chapter 2, is a case in point. It took more than 2000 years to work out this fundamental principle of chemistry proposed by Democritus, an ancient Greek philosopher. A more contemporary example is the search for the Higgs boson discussed in the Chemistry in Action essay, "The Search for the Higgs Boson."

Scientific progress is seldom, if ever, made in a rigid, step-by-step fashion. Sometimes a law precedes a theory; sometimes it is the other way around. Two scientists may start working on a project with exactly the same objective, but will end up taking drastically different approaches. Scientists are, after all, human beings, and their modes of thinking and working are very much influenced by their background, training, and personalities.

The development of science has been irregular and sometimes even illogical. Great discoveries are usually the result of the cumulative contributions and experience of many workers, even though the credit for formulating a theory or a law is usually given to only one individual. There is, of course, an element of luck involved in scientific discoveries, but it has been said that "chance favors the prepared mind." It takes an alert and well-trained person to recognize the significance of an accidental discovery and to take full advantage of it. More often than not, the public learns only of spectacular scientific breakthroughs. For every success story, however, there are hundreds of cases in which scientists have spent years working on projects that ultimately led to a dead end, and in which positive achievements came only after many wrong turns and at such a slow pace that they went unheralded. Yet even the dead ends contribute something to the continually growing body of knowledge about the physical universe. It is the love of the search that keeps many scientists in the laboratory.

## **CHEMISTRY** in Action

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## The Search for the Higgs Boson

n this chapter, we identify mass as a fundamental property of matter, but have you ever wondered: Why does matter even have mass? It might seem obvious that "everything" has mass, but is that a requirement of nature? We will see later in our studies that light is composed of particles that do not have mass when at rest, and physics tells us under different circumstances the universe might not contain *anything* with mass. Yet we know that *our* universe is made up of an uncountable number of particles with mass, and these building blocks are necessary to form the elements that make up the people to ask such questions. The search for the answer to this question illustrates nicely the process we call the scientific method.

Current theoretical models tell us that everything in the universe is based on two types of elementary particles: bosons and fermions. We can distinguish the roles of these particles by considering the building blocks of matter to be constructed from fermions, while bosons are particles responsible for the force that holds the fermions together. In 1964, three different research teams independently proposed mechanisms in which a field of energy permeates the universe, and the interaction of matter with this field is due to a specific boson associated with the field. The greater the number of these bosons, the greater the interaction will be with the field. This interaction is the property we call mass, and the field and the associated boson came to be named for Peter Higgs, one of the original physicists to propose this mechanism.

This theory ignited a frantic search for the "Higgs boson" that became one of the most heralded quests in modern science. The Large Hadron Collider at CERN in Geneva, Switzerland (described in Chapter 19), was constructed to carry out experiments designed to find evidence for the Higgs boson. In these experiments, protons are accelerated to nearly the speed of light in opposite directions in a circular 17-mile tunnel, and then allowed to collide, generating even more fundamental particles at very high energies. The data are examined for evidence of an excess of particles at an energy consistent with theoretical predictions for the Higgs boson. The ongoing process of theory suggesting experiments that give results used to evaluate and ultimately refine the theory, and so on, is the essence of the scientific method.



Illustration of the data obtained from decay of the Higgs boson into other particles following an 8-TeV collision in the Large Hadron Collider at CERN. ©Thomas McCauley/Lucas Taylor, CERN/Science Source

On July 4, 2012, scientists at CERN announced the discovery of the Higgs boson. It takes about 1 trillion proton–proton collisions to produce one Higgs boson event, so it requires a tremendous amount of data obtained from two independent sets of experiments to confirm the findings. In science, the quest for answers is never completely done. Our understanding can always be improved or refined, and sometimes entire tenets of accepted science are replaced by another theory that does a better job explaining the observations. For example, scientists are not sure if the Higgs boson is the only particle that confers mass to matter, or if it is only one of several such bosons predicted by other theories.

But over the long run, the scientific method has proven to be our best way of understanding the physical world. It took 50 years for experimental science to validate the existence of the Higgs boson. This discovery was greeted with great fanfare and recognized the following year with a 2013 Nobel Prize in Physics for Peter Higgs and François Englert, another one of the six original scientists who first proposed the existence of a universal field that gives particles their mass. It is impossible to imagine where science will take our understanding of the universe in the next 50 years, but we can be fairly certain that many of the theories and experiments driving this scientific discovery will be very different than the ones we use today.

#### **Review of Concepts & Facts**

- **1.3.1** Which of the following statements is true?
  - (a) A hypothesis always leads to the formulation of a law.
  - (b) The scientific method is a rigid sequence of steps in solving problems.
  - (c) A law summarizes a series of experimental observations; a theory provides an explanation for the observations.
- **1.3.2** A student collects the following data for a sample of an unknown liquid. Which of these data are qualitative measurements and which are quantitative measurements?
  - (a) The sample has a volume of 15.4 mL.
  - (b) The sample is a light yellow liquid.
  - (c) The sample feels oily.
  - (d) The sample has a mass of 13.2 g.

## **1.4** Classifications of Matter

We defined chemistry in Section 1.1 as the study of matter and the changes it undergoes. *Matter* is *anything that occupies space and has mass*. Matter includes things we can see and touch (such as water, earth, and trees), as well as things we cannot (such as air). Thus, everything in the universe has a "chemical" connection.

Chemists distinguish among several subcategories of matter based on composition and properties. The classifications of matter include substances, mixtures, elements, and compounds, as well as atoms and molecules, which we will consider in Chapter 2.

#### **Substances and Mixtures**

A *substance* is *a form of matter that has a definite (constant) composition and distinct properties.* Examples are water, ammonia, table sugar (sucrose), gold, and oxygen. Substances differ from one another in composition and can be identified by their appearance, smell, taste, and other properties.

A *mixture* is a combination of two or more substances in which the substances retain their distinct identities. Some familiar examples are air, soft drinks, milk, and cement. Mixtures do not have constant composition. Therefore, samples of air collected in different cities would probably differ in composition because of differences in altitude, pollution, and so on.

All mixtures are classified as either homogeneous or heterogeneous. When a spoonful of sugar dissolves in water we obtain a *homogeneous mixture* in which *the composition of the mixture is the same throughout*. If sand is mixed with iron filings, however, the sand grains and the iron filings remain separate (Figure 1.4). This type of mixture is called a *heterogeneous mixture* because *the composition is not uniform*.

Any mixture, whether homogeneous or heterogeneous, can be created and then separated by physical means into pure components without changing the identities of the components. Thus, sugar can be recovered from a water solution by heating the solution and evaporating it to dryness. Condensing the vapor will give us back the water component. To separate the iron-sand mixture, we can use a magnet to remove the iron filings from the sand, because sand is not attracted to the magnet [see Figure 1.4(b)]. After separation, the components of the mixture will have the same composition and properties as they did to start with.

#### **Elements and Compounds**

Substances can be either elements or compounds. An *element* is a substance that cannot be separated further into simpler substances by chemical methods. To date, 118 elements have been positively identified. Most of them occur naturally on Earth. The others have been created by scientists via nuclear processes, which are the subject of Chapter 19 of this text.



**Figure 1.4** (a) The mixture contains iron filings and sand. (b) A magnet separates the iron filings from the mixture. The same technique is used on a larger scale to separate iron and steel from nonmagnetic objects such as aluminum, glass, and plastics. (a and b): ©McGraw-Hill Education/Ken Karp

For convenience, chemists use symbols of one or two letters to represent the elements. The first letter of a symbol is *always* capitalized, but any following letters are not. For example, Co is the symbol for the element cobalt, whereas CO is the formula for the carbon monoxide molecule. Table 1.1 shows the names and symbols of some of the more common elements. The symbols of some elements are derived from their Latin names—for example, Au from *aurum* (gold), Fe from *ferrum* (iron), and Na from *natrium* (sodium)—whereas most of them come from their English names.

Atoms of most elements can interact with one another to form compounds. Hydrogen gas, for example, burns in oxygen gas to form water, which has properties that are distinctly different from those of the starting materials. Water is made up of two parts hydrogen and one part oxygen. This composition does not change, regardless of whether the water comes from a faucet in the United States, a lake in Outer Mongolia, or the ice caps on Mars. Thus, water is a *compound, a substance composed of atoms of two or more elements chemically united in fixed proportions*. Unlike mixtures, compounds can be separated only by chemical means into their pure components.

The relationships among elements, compounds, and other categories of matter are summarized in Figure 1.5.

Table 1.1		Some Commo				
	Name	Symbol	Name	Symbol	Name	Symbol
	Aluminum	Al	Fluorine	F	Oxygen	0
	Arsenic	As	Gold	Au	Phosphorus	Р
	Barium	Ba	Hydrogen	Н	Platinum	Pt
	Bismuth	Bi	Iodine	Ι	Potassium	Κ
	Bromine	Br	Iron	Fe	Silicon	Si
	Calcium	Ca	Lead	Pb	Silver	Ag
	Carbon	С	Magnesium	Mg	Sodium	Na
	Chlorine	Cl	Manganese	Mn	Sulfur	S
	Chromium	Cr	Mercury	Hg	Tin	Sn
	Cobalt	Со	Nickel	Ni	Tungsten	W
	Copper	Cu	Nitrogen	Ν	Zinc	Zn



Figure 1.5 Classification of matter.

#### **Review of Concepts & Facts**

**1.4.1** Which of the following diagrams represent elements and which represent compounds? Each color sphere (or truncated sphere) represents an atom. Different colored atoms indicate different elements.



## **1.5** The Three States of Matter

All substances, at least in principle, can exist in three states: solid, liquid, and gas. As Figure 1.6 shows, gases differ from liquids and solids in the distances between the atoms. In a solid, atoms (or molecules) are held close together in an orderly fashion with little



**Figure 1.6** *Microscopic views* of a solid, a liquid, and a gas.