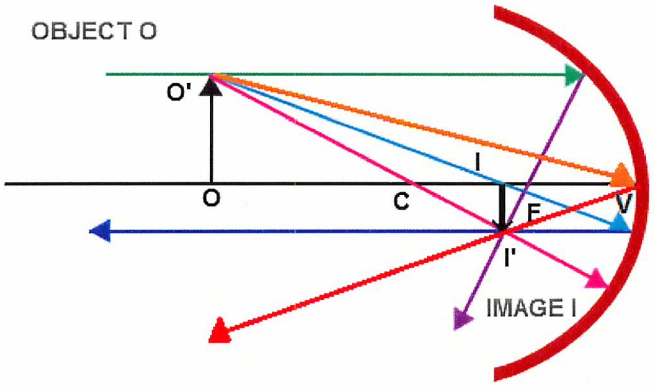
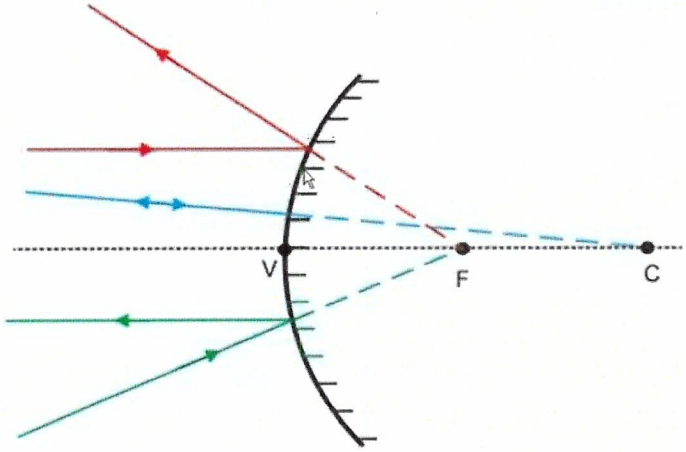
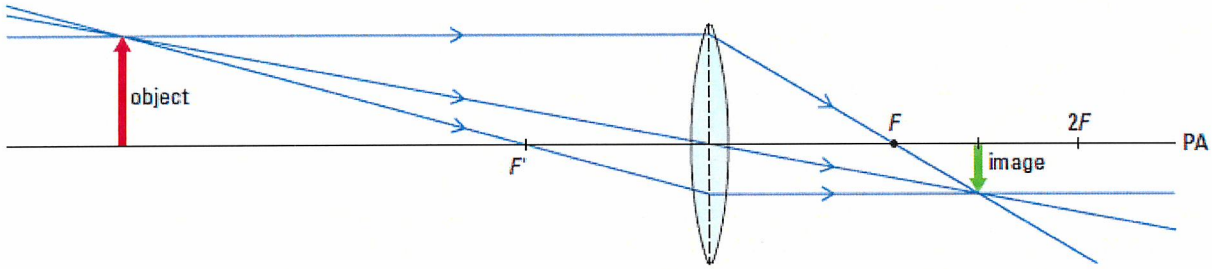
CONCAVE MIRRORS



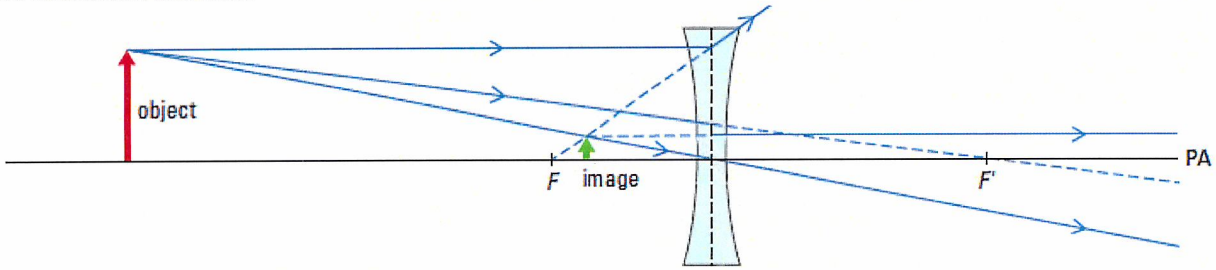
CONVEX MIRRORS



CONVERGING LENSES



DIVERGING LENSES

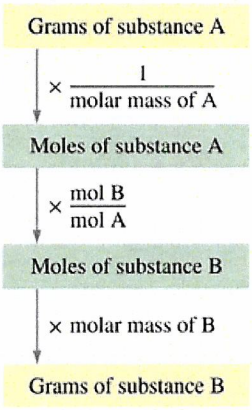


Physical Science Formula Sheet

Foundations of Chemistry

Avogadro's Number
6.022×10^{23}

$$M = \frac{m}{n} \qquad C = \frac{n}{V} \qquad m = MCV$$



$$\%yield = \frac{actual\ yield}{theoretical\ yield} \times 100$$

$$\%error = \frac{|experimental - theoretical|}{theoretical} \times 100$$

Heat

$$q_{system} + q_{surroundings} = 0 \qquad q = mc\Delta T \qquad \Delta H = \frac{q}{n}$$

Properties of Waves

$$\lambda = \frac{d}{cycles} \qquad f = \frac{cycles}{t} = \frac{1}{T} \qquad T = \frac{t}{cycles} = \frac{1}{f} \qquad v = \lambda f = \frac{d}{t} = \frac{\lambda}{T}$$

$$\theta_i = \theta_r \qquad v = 331 + 0.6T \qquad n_1 \sin\theta_1 = n_2 \sin\theta_2$$

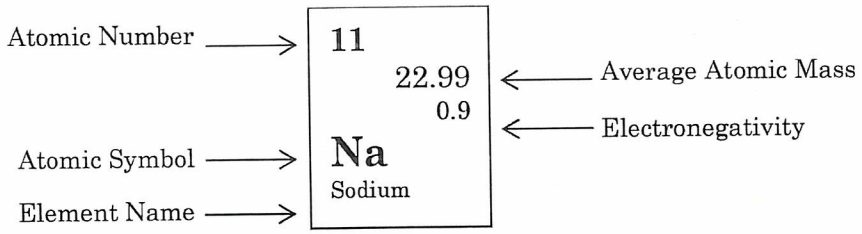
$$n_1 \sin\theta_c = n_2 \sin 90°$$

Table 1 Indexes of Refraction

Medium	Index of refraction (n)
vacuum	1.000000
gases (at 0°C, 101.3 kPa)	
air	1.000293
carbon dioxide	1.000450
hydrogen	1.000139
liquid (at 20°C)	
water	1.33
ethyl alcohol	1.36
glycerin	1.47
benzene	1.50
solid (at 20°C)	
ice (0°C)	1.31
glass (crown)	1.52
glass (flint)	1.65
sodium chloride	1.53
zircon	1.92
diamond	2.42

Note: Indexes are for yellow light (589 nm).

Periodic Table of Elements



( ) Indicates mass of the most stable isotope

1																	18
1.01 2.2 **H** Hydrogen	2											13	14	15	16	17	2 4.00 — **He** Helium
3 6.94 1.0 **Li** Lithium	4 9.01 1.6 **Be** Beryllium											5 10.81 2.0 **B** Boron	6 12.01 2.6 **C** Carbon	7 14.01 3.0 **N** Nitrogen	8 16.00 3.4 **O** Oxygen	9 19.00 4.0 **F** Fluorine	10 20.18 — **Ne** Neon
11 22.99 0.9 **Na** Sodium	12 24.31 1.3 **Mg** Magnesium	3	4	5	6	7	8	9	10	11	12	13 26.98 1.6 **Al** Aluminum	14 28.09 1.9 **Si** Silicon	15 30.97 2.2 **P** Phosphorus	16 32.07 2.6 **S** Sulfur	17 35.45 3.2 **Cl** Chlorine	18 39.95 — **Ar** Argon
19 39.10 0.8 **K** Potassium	20 40.08 1.0 **Ca** Calcium	21 44.96 1.4 **Sc** Scandium	22 47.87 1.5 **Ti** Titanium	23 50.94 1.6 **V** Vanadium	24 52.00 1.7 **Cr** Chromium	25 54.94 1.6 **Mn** Manganese	26 55.85 1.8 **Fe** Iron	27 58.93 1.9 **Co** Cobalt	28 58.69 1.9 **Ni** Nickel	29 63.55 1.9 **Cu** Copper	30 65.41 1.7 **Zn** Zinc	31 69.72 1.8 **Ga** Gallium	32 72.64 2.0 **Ge** Germanium	33 74.92 2.2 **As** Arsenic	34 78.96 2.6 **Se** Selenium	35 79.90 3.0 **Br** Bromine	36 83.80 — **Kr** Krypton
37 85.47 0.8 **Rb** Rubidium	38 87.62 1.0 **Sr** Strontium	39 88.91 1.2 **Y** Yttrium	40 91.22 1.3 **Zr** Zirconium	41 92.91 1.6 **Nb** Niobium	42 95.94 2.2 **Mo** Molybdenum	43 (98) 2.1 **Tc** Technetium	44 101.07 2.2 **Ru** Ruthenium	45 102.91 2.3 **Rh** Rhodium	46 106.42 2.2 **Pd** Palladium	47 107.87 1.9 **Ag** Silver	48 112.41 1.7 **Cd** Cadmium	49 114.82 1.8 **In** Indium	50 118.71 2.0 **Sn** Tin	51 121.76 2.1 **Sb** Antimony	52 127.60 2.1 **Te** Tellurium	53 126.90 2.7 **I** Iodine	54 131.29 2.6 **Xe** Xenon
55 132.91 0.8 **Cs** Cesium	56 137.33 0.9 **Ba** Barium	57-70 *	71 174.97 1.0 **Lu** Lutetium	72 178.49 1.3 **Hf** Hafnium	73 180.95 1.5 **Ta** Tantalum	74 183.84 1.7 **W** Tungsten	75 186.21 1.9 **Re** Rhenium	76 190.23 2.2 **Os** Osmium	77 192.22 2.2 **Ir** Iridium	78 195.08 2.2 **Pt** Platinum	79 196.97 2.4 **Au** Gold	80 200.59 1.9 **Hg** Mercury	81 204.38 1.8 **Tl** Thallium	82 207.20 1.8 **Pb** Lead	83 208.98 1.9 **Bi** Bismuth	84 (208.98) 2.0 **Po** Polonium	85 (209.99) 2.2 **At** Astatine	86 (222.02) — **Rn** Radon
87 (223.02) 0.7 **Fr** Francium	88 (226.03) 0.9 **Ra** Radium	89-102 **	103 (262.11) — **Lr** Lawrencium	104 (265.12) — **Rf** Rutherfordium	105 (268.13) — **Db** Dubnium	106 (271.13) — **Sg** Seaborgium	107 (270) — **Bh** Bohrium	108 (277.15) — **Hs** Hassium	109 (276.15) — **Mt** Meitnerium	110 (281.16) — **Ds** Darmstadtium	111 (280.16) — **Rg** Roentgenium	112 (285.17) — **Cn** Copernicium	113 (284.18) — **Nh** Nihomium	114 (289.19) — **Fl** Flerovium	115 (288.19) — **Mc** Moscovium	116 (293) — **Lv** Livermorium	117 (294) — **Ts** Tennessine	118 (294) — **Og** Oganesson

*§ Lanthanoid Series

57 138.91 1.1 **La** Lanthanum	58 140.12 1.1 **Ce** Cerium	59 140.91 1.1 **Pr** Praseodymium	60 144.24 1.1 **Nd** Neodymium	61 (145) — **Pm** Promethium	62 150.36 1.2 **Sm** Samarium	63 151.96 — **Eu** Europium	64 157.25 1.2 **Gd** Gadolinium	65 158.93 — **Tb** Terbium	66 162.50 1.2 **Dy** Dysprosium	67 164.93 1.2 **Ho** Holmium	68 167.26 1.2 **Er** Erbium	69 168.93 1.3 **Tm** Thulium	70 173.04 — **Yb** Ytterbium

**¥ Actinoid Series

89 (227.03) 1.1 **Ac** Actinium	90 232.04 1.3 **Th** Thorium	91 231.04 1.5 **Pa** Protactinium	92 238.03 1.7 **U** Uranium	93 (237.05) 1.3 **Np** Neptunium	94 (244.06) 1.3 **Pu** Plutonium	95 (243.06) — **Am** Americium	96 (247.07) — **Cm** Curium	97 (247.07) — **Bk** Berkelium	98 (251.08) — **Cf** Californium	99 (252.08) — **Es** Einsteinium	100 (257.10) — **Fm** Fermium	101 (258.10) — **Md** Mendelevium	102 (259.10) — **No** Nobelium

Saskatchewan Ministry of Education

PERIODIC TABLE OF IONS

TABLE OF POLYATOMIC IONS

acetate	CH_3COO^-	dihydrogen phosphate	$H_2PO_4^-$	oxalate	$C_2O_4^{2-}$
arsenate	AsO_4^{3-}	hydrogen carbonate	HCO_3^-	perchlorate	ClO_4^-
arsenite	AsO_3^{3-}	hydrogen oxalate	$HC_2O_4^-$	periodate	IO_4^-
benzoate	$C_6H_5COO^-$	hydrogen sulfate	HSO_4^-	permanganate	MnO_4^-
borate	BO_3^{3-}	hydrogen sulfide	HS^-	peroxide	O_2^{2-}
bromate	BrO_3^-	hydrogen sulfite	HSO_3^-	phosphate	PO_4^{3-}
carbonate	CO_3^{2-}	hydroxide	OH^-	pyrophosphate	$P_2O_7^{4-}$
chlorate	ClO_3^-	hypochlorite	ClO^-	sulfate	SO_4^{2-}
chloride	Cl^-	iodate	IO_3^-	sulfite	SO_3^{2-}
chlorite	ClO_2^-	monohydrogen phosphate	HPO_4^{2-}	thiocyanate	SCN^-
chromate	CrO_4^{2-}	nitrate	NO_3^-	thiosulfate	$S_2O_3^{2-}$
cyanate	CNO^-	nitrite	NO_2^-	**POSITIVE POLYATOMIC IONS**	
cyanide	CN^-	orthosilicate	SiO_4^{4-}	ammonium	NH_4^+
dichromate	$Cr_2O_7^{2-}$			hydronium	H_3O^+

KEY: atomic number → 26 Fe^{3+} ← ion charge; iron (III) ← ion name (IUPAC); symbol → Fe^{2+} iron (II)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H^+ hydrogen																1 H^- hydride	2 He helium
3 Li^+ lithium	4 Be^{2+} beryllium											5 B boron	6 C carbon	7 N^{3-} nitride	8 O^{2-} oxide	9 F^- fluoride	10 Ne neon
11 Na^+ sodium	12 Mg^{2+} magnesium											13 Al^{3+} aluminum	14 Si silicon	15 P^{3-} phosphide	16 S^{2-} sulfiide	17 Cl^- chloride	18 Ar argon
19 K^+ potassium	20 Ca^{2+} calcium	21 Sc^{3+} scandium	22 Ti^{4+} titanium (IV); Ti^{3+} titanium (III)	23 V^{3+} vanadium(III); V^{5+} vanadium (V)	24 Cr^{3+} chromium (III); Cr^{2+} chromium (II)	25 Mn^{2+} manganese(II); Mn^{4+} manganese(IV)	26 Fe^{3+} iron (III); Fe^{2+} iron (II)	27 Co^{2+} cobalt (II); Co^{3+} cobalt (III)	28 Ni^{2+} nickel (II); Ni^{3+} nickel (III)	29 Cu^{2+} copper (II); Cu^+ copper (I)	30 Zn^{2+} zinc	31 Ga^{3+} gallium	32 Ge^{4+} germanium	33 As^{3-} arsenide	34 Se^{2-} selenide	35 Br^- bromide	36 Kr krypton
37 Rb^+ rubidium	38 Sr^{2+} strontium	39 Y^{3+} yttrium	40 Zr^{4+} zirconium	41 Nb^{5+} niobium (V); Nb^{3+} niobium(III)	42 Mo^{6+} molybdenum	43 Tc^{7+} technetium	44 Ru^{3+} ruthenium(III); Ru^{4+} ruthenium(IV)	45 Rh^{3+} rhodium	46 Pd^{2+} paladium(II); Pd^{4+} paladium(IV)	47 Ag^+ silver	48 Cd^{2+} cadmium	49 In^{3+} indium	50 Sn^{4+} tin (IV); Sn^{2+} tin (II)	51 Sb^{3+} antimony(III); Sb^{5+} antimony(V)	52 Te^{2-} telluride	53 I^- iodide	54 Xe xenon
55 Cs^+ cesium	56 Ba^{2+} barium	57 La^{3+} lanthanum	72 Hf^{4+} hafnium	73 Ta^{5+} tantalum	74 W^{6+} tungsten	75 Re^{7+} rhenium	76 Os^{4+} osmium	77 Ir^{4+} iridium	78 Pt^{4+} platinum(IV); Pt^{2+} platinum(II)	79 Au^{3+} gold (III); Au^+ gold (I)	80 Hg^{2+} mercury (II); Hg^+ mercury (I)	81 Tl^+ thallium (I); Tl^{3+} thallium(III)	82 Pb^{2+} lead (II); Pb^{4+} lead (IV)	83 Bi^{3+} bismuth(III); Bi^{5+} bismuth(V)	84 Po^{2+} polonium(II); Po^{4+} polonium(IV)	85 At^- astatide	86 Rn radon
87 Fr^+ francium	88 Ra^{2+} radium	89 Ac^{3+} actinium															

58 Ce^{3+} cerium	59 Pr^{3+} praseodymium	60 Nd^{3+} neodymium	61 Pm^{3+} promethium	62 Sm^{3+} samarium(III); Sm^{2+} samarium(II)	63 Eu^{3+} europium (III); Eu^{2+} europium (II)	64 Gd^{3+} gadolinium	65 Tb^{3+} terbium	66 Dy^{3+} dysprosium	67 Ho^{3+} holmium	68 Er^{3+} erbium	69 Tm^{3+} thulium	70 Yb^{3+} ytterbium(III); Yb^{3+} ytterbium(II)	71 Lu^{3+} lutetium
90 Th^{4+} thorium	91 Pa^{5+} protactinium(V); Pa^{4+} protactinium(IV)	92 U^{6+} uranium (VI); U^{4+} uranium (IV)	93 Np^{5+} neptunium	94 Pu^{4+} plutonium(IV); Pu^{6+} plutonium(VI)	95 Am^{3+} americium(III); Am^{4+} americium(IV)	96 Cm^{3+} curium	97 Bk^{3+} berkelium(III); Bk^{4+} berkelium(IV)	98 Cf^{3+} californium	99 Es^{3+} einsteinium	100 Fm^{3+} fermium	101 Md^{2+} mendelevium (II); Md^{3+} mendelevium (III)	102 No^{2+} nobelium(II); No^{3+} nobelium(III)	103 Lr^{3+} lawrencium

List of Common Multivalent Ions

The following elements form **multivalent ions**, and therefore require a Roman numeral charge when writing the name of the compound. Rare and synthetic elements are not included in this list.

Element	Sym.	Possible Charges	Element	Sym.	Possible Charges
Titanium	Ti	+2, +3, +4	Tin	Sn	+2, +4
Vanadium	V	+2, +3, +4, +5	Rhenium	Re	+4, +6, +7
Chromium	Cr	+2, +3, +6	Osmium	Os	+3, +4
Manganese	Mn	+2, +3, +4, +7	Iridium	Ir	+3, +4
Iron	Fe	+2, +3	Platinum	Pt	+2, +4
Cobalt	Co	+2, +3	Gold	Au	+1, +3
Nickel	Ni	+2, +3	Mercury	Hg	+1, +2
Copper	Cu	+1, +2	Thallium	Tl	+1, +3
Niobium	Nb	+2, +5	Lead	Pb	+2, +4
Molybdenum	Mo	+3, +6	Bismuth	Bi	+3, +5
Palladium	Pd	+2, +4	Polonium	Po	+2, +4

Steps to Determine Charge from the Chemical Formula

1. Find total negative charge on all anions.
2. Divide value by number of cations to give charge on one multivalent cation.

Activity Series Chart

Metals

Name	Symbol
Lithium	Li
Potassium	K
Barium	Ba
Strontium	Sr
Calcium	Ca
Sodium	Na
Magnesium	Mg
Aluminum	Al
Manganese	Mn
Zinc	Zn
Iron	Fe
Cadmium	Cd
Cobalt	Co
Nickel	Ni
Tin	Sn
Lead	Pb
Hydrogen	H
Copper	Cu
Silver	Ag
Mercury	Hg
Gold	Au

Most Active ↑ ↓ Least Active

Non-Metals

Name	Symbol
Fluorine	F
Chlorine	Cl
Bromine	Br
Iodine	I

***

Elements **CANNOT** replace anything **ABOVE** them. The reaction **DOES NOT OCCUR** in this situation.

***

Solubility of Common Compounds in Water

Rule	Negative Ions	Positive Ions	Solubility
1	essentially all	Li^+, Na^+, K^+, Rb^+, Cs^+, Fr^+	soluble
2	essentially all	H^+	soluble
3	essentially all	NH_4^+	soluble
4	Chlorate, ClO_3^- nitrate, NO_3^- perchlorate, ClO_4^-	essentially all	soluble
5	acetate, CH_3COO^-	Ag^+	low solubility
		all others	soluble
6	fluoride, F^-	Mg^{2+}, Ca^{2+}, Ba^{2+}, Pb^{2+}	low solubility
		all others	soluble
7	bromide, Br^- chloride, Cl^- iodide, I^-	Ag^+, Pb^{2+}, Hg_2^{2+}, Cu^+, Tl^+	low solubility
		all others	soluble
8	sulfate, SO_4^{2-}	Ca^{2+}, Sr^{2+}, Ba^{2+}, Ra^{2+}, Pb^{2+}, Ag^+, Hg_2^{2+}	low solubility
		all others	soluble
9	sulfide, S^{2-}	Li^+, Na^+, K^+, Rb^+, Cs^+, Fr^+, H^+, NH_4^+, Be^{2+}, Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, Ra^{2+}	soluble
		all others	low solubility
10	hydroxide, OH^-	Li^+, Na^+, K^+, Rb^+, Cs^+, Fr^+, H^+, NH_4^+, Sr^{2+}, Ba^{2+}, Ra^{2+}, Tl^+	soluble
		all others	low solubility
11	carbonate, CO_3^{2-} phosphate, PO_4^{3-} sulfite, SO_3^{2-}	Li^+, Na^+, K^+, Rb^+, Cs^+, Fr^+, H^+, NH_4^+	soluble
		all others	low solubility

*considered soluble if they give ion concentrations above 0.1 mol/L at room temperature

(Adapted from *Chemistry: Experimental Foundations*, by Parry, R. W.; Steiner, L. E.; Tellefsen, R. L.; Dietz, P. M.

Table of Specific Heat Capacities (25°C, 1 atm)

Substance	c (J/g·°C)	Substance	c (J/g·°C)
Air	1.012	Lead	0.128
Aluminum	0.897	Lithium	3.560
Ammonia (liquid)	4.700	Magnesium	1.023
Asphalt	0.920	Marble	0.858
Brass	0.380	Mercury	0.138
Calcium	0.650	Methanol	2.549
Carbon dioxide (gas)	0.839	Nickel	0.440
Concrete	0.880	Nitrogen (gas)	1.040
Copper	0.387	Oxygen (gas)	0.918
Diamond	0.509	Potassium	0.750
Ethanol	2.460	Sand	0.290
Ethylene glycol	2.200	Silver	0.236
Gasoline	2.220	Sodium	1.230
Glass	0.837	Soil (typical)	1.046
Gold	0.129	Steam (100°C)	2.009
Graphite	0.710	Sulfur	0.730
Helium (gas)	5.300	Tin	0.210
Human tissue	3.500	Vegetable oil	2.000
Hydrogen (gas)	14.267	Water (0°C - 100°C)	4.184
Ice (-10°C – 0°C)	2.093	Wood	0.420
Iron/Steel	0.449	Zinc	0.390

HEAT OF SOLUTION DATA FOR AQUEOUS SOLUTIONS

Some heats of solutions and heats of hydration for dilute solutions in pure water at 15 °C.

Solute	Products	Heat of solution
EXOTHERMIC		
$CH_2O_2(l)$ (methanoic acid)	$H^+(aq)+CHO_2^-(aq)$	−0.86 kJ/mol
$C_2H_4O_2(l)$ (acetic acid)	$H^+(aq)+C_2H_3O_2^-(aq)$	−1.5 kJ/mol
$CH_4O(l)$ (methanol)	$CH_4O(aq)$	−0.2 kJ/mol
$CaCl_2(s)$	$Ca^{2+}(aq) + 2Cl^-(aq)$	−82.9 kJ/mol
$CaCl_2(s)$	$CaCl_2{\cdot}2H_2O(aq)$	−240 kJ/kg
$Ca(OH)_2(s)$	$Ca^{2+}(aq) + 2OH^-(aq)$	−16.2 kJ/kg
$CO_2(g)$	$CO_2(aq)$	−19.4 kJ/mol
$H_2O_2(l)$	$H_2O_2(aq)$	−3.5 kJ/mol
$H_2O(l)$	$H^+(aq)+OH^-(aq)$	−58 kJ/mol
$H_2SO_4(l)$	$2H^+(aq)+ SO_4^{2-}(aq)$	−96.2 kJ/mol
$MgSO_4(s)$	$Mg^{2+}(aq)+ SO_4^{2-}(aq)$	−91.2 kJ/mol
$HCl(g)$	$H^+(aq)+Cl^-(aq)$	−74.8 kJ/mol
$HClO_4(l)$	$H^+(aq)+ClO_4^-(aq)$	−88.8 kJ/mol
$HNO_3(l)$	$H^+(aq)+NO_3^-(aq)$	−33.3 kJ/mol
$KOH(s)$	$K^+(aq)+OH^-(aq)$	−56 kJ/mol
$LiBr(s)$	$Li^+(aq)+Br^-(aq)$	−49 kJ/mol
$LiBr{\cdot}H_2O(s)$	$Li^+(aq)+Br^-(aq)$	−23 kJ/mol
$LiBr{\cdot}2H_2O(s)$	$Li^+(aq)+Br^-(aq)$	−9 kJ/mol
$LiCl(s)$	$Li^+(aq)+Cl^-(aq)$	−37 kJ/mol
$LiOH(s)$	$Li^+(aq)+OH^-(aq)$	−23.6 kJ/mol
$NaOH(s)$	$Na^+(aq)+OH^-(aq)$	−44.3 kJ/mol
$NH_3(g)$	$NH_3(aq)$	−30.5 kJ/mol
$O_2(g)$	$O_2(aq)$	−11.7 kJ/mol
$SO_2(g)$	$SO_2(aq)$	−39.5 kJ/mol
ENDOTHERMIC		
$C_{12}H_{22}O_{11}(s)$ (sugar)	$C_{12}H_{22}O_{11}(aq)$	5.4 kJ/mol
$C_6H_{12}O_6(s)$ (glucose)	$C_6H_{12}O_6(aq)$	11 kJ/mol
$C_6H_{12}O_6{\cdot}H_2O(s)$ (glucose monohydrate)	$C_6H_{12}O_6{\cdot}H_2O(aq)$	19 kJ/mol
$CO(NH_2)_2(s)$ (urea)	$CO(NH_2)_2(aq)$	15 kJ/mol
$KBr(s)$	$K^+(aq)+Br^-(aq)$	20 kJ/mol
$KCl(s)$	$K^+(aq)+Cl^-(aq)$	17 kJ/mol
$KClO_3(s)$	$K^+(aq)+ClO_3^-(aq)$	42 kJ/mol
$KMnO_4(s)$	$K^+(aq)+ MnO_4^-(aq)$	44 kJ/mol
$KNO_3(s)$	$K^+(aq)+NO_3^-(aq)$	35 kJ/mol
$NaC_2H_3O_2{\cdot}3H_2O(s)$	$NaC_2H_3O_2{\cdot}3H_2O(aq)$	150 kJ/kg
$NaCl(s)$	$Na^+(aq)+Cl^-(aq)$	3.9 kJ/mol
$NaHCO_3(s)$	$Na^+(aq)+HCO_3^-(aq)$	16.7 kJ/mol
$NaNO_3(s)$	$Na^+(aq)+NO_3^-(aq)$	20.4 kJ/mol
$NH_4Cl(s)$	$NH_4^+(aq)+Cl^-(aq)$	14.6 kJ/mol
$NH_4NO_3(s)$	$NH_4^+(aq)+NO_3^-(aq)$	25.7 kJ/mol
$K_2SO_4(s)$	$2K^+(aq)+SO_4^{2-}(aq)$	23.8 kJ/mol

ADDITIONAL DATA. When HCl(aq) dissolves in NaOH(aq), forming $Na^+(aq)+Cl^-(aq)$, 57 kJ/mol are