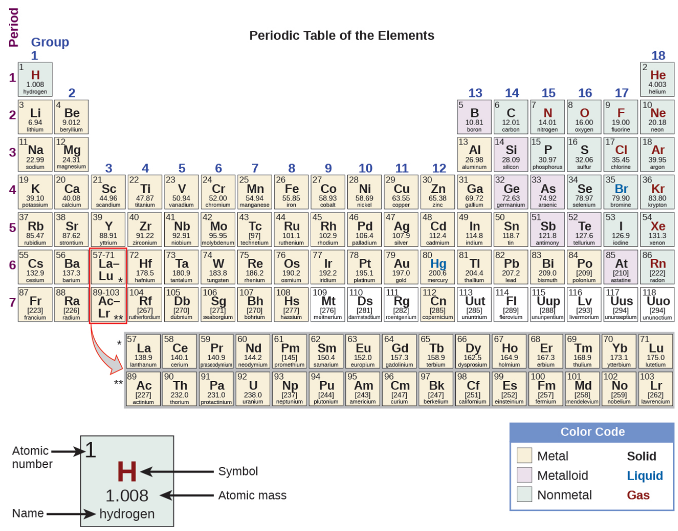
APPENDIX A: THE PERIODIC TABLE



Graphical version of the periodic table of the elements. The 18 columns are labeled "Group" and the 7 rows are labeled "Period." Below the table to the right is a box labeled "Color Code" with different colors for metals, metalloids, and nonmetals, as well as solids, liquids, and gases. To the left of this box is an enlarged picture of the upper-left most box on the table. The number 1 is in its upper-left hand corner and is labeled "Atomic number." The letter "H" is in the middle in red indicating that it is a gas. It is labeled "Symbol." Below that is the number 1.008 which is labeled "Atomic Mass." Below that is the word hydrogen which is labeled "name." The color of the box indicates that it is a nonmetal. Each element will be described in this order: atomic number; name; symbol; whether it is a metal, metalloid, or nonmetal; whether it is a solid, liquid, or gas; and atomic mass.

Below, please find the periodic table of the elements in table/text format.

Periodic Table of Elements in Tabular Format

Period (Row)	Group (Column)	Atomic Number	Symbol	Name	Atomic Mass	State of Matter at Room Temperature	Type of Element	Family	Common Ion	Valence Electrons	Outer Shell Electron Configuration	Electronegativity Values
1	1	1	H	Hydrogen	1.008	gas	nonmetal	–	H^+	1	$1s^1$	2.1
1	18	2	He	Helium	4.003	gas	nonmetal	Noble gas	no ion	2	$1s^2$	–
2	1	3	Li	Lithium	6.94	solid	metal	Alkali metal	Li^+	1	$2s^1$	1.0
2	2	4	Be	Beryllium	9.01	solid	metal	Alkaline earth metal	Be^{2+}	2	$2s^2$	1.5
2	13	5	B	Boron	10.81	solid	metalloid	–		3	$2s^22p^1$	2.0
2	14	6	C	Carbon	12.01	solid	nonmetal	–	C^{4+}	4	$2s^22p^2$	2.5
2	15	7	N	Nitrogen	14.01	gas	nonmetal	Pnictogen	N^{3-}	5	$2s^22p^3$	3.0
2	16	8	O	Oxygen	16.00	gas	nonmetal	Chalcogen	O^{2-}	6	$2s^22p^4$	3.5
2	17	9	F	Fluorine	19.00	gas	nonmetal	Halogen	F^-	7	$2s^22p^5$	4.0
2	18	10	Ne	Neon	20.18	gas	nonmetal	Noble gas	no ion	8	$2s^22p^6$	–
3	1	11	Na	Sodium	22.99	solid	metal	Alkali metal	Na^+	1	$3s^1$	0.9
3	2	12	Mg	Magnesium	24.30	solid	metal	Alkaline earth metal	Mg^{2+}	2	$3s^2$	1.2
3	13	13	Al	Aluminum	26.98	solid	metal	–	Al^{3+}	3	$3s^23p^1$	1.5
3	14	14	Si	Silicon	28.08	solid	metalloid	–		4	$3s^23p^2$	1.8
3	15	15	P	Phosphorus	30.97	solid	nonmetal	Pnictogen	P^{3-}	5	$3s^23p^3$	2.1
3	16	16	S	Sulfur	32.06	solid	nonmetal	Chalcogen	S^{2-}	6	$3s^23p^4$	2.5
3	17	17	Cl	Chlorine	35.45	gas	nonmetal	Halogen	Cl^-	7	$3s^23p^5$	3.0
3	18	18	Ar	Argon	39.79	gas	nonmetal	Noble gas	no ion	8	$3s^23p^6$	–
4	1	19	K	Potassium	39.10	solid	metal	Alkali metal	K^+	1	$4s^1$	0.8
4	2	20	Ca	Calcium	40.08	solid	metal	Alkaline earth metal	Ca^{2+}	2	$4s^2$	1.0
4	3	21	Sc	Scandium	44.96	solid	metal	Transition metal			$4s^23d^1$	1.3
4	4	22	Ti	Titanium	47.87	solid	metal	Transition metal			$4s^23d^2$	1.5
4	5	23	V	Vanadium	50.94	solid	metal	Transition metal			$4s^23d^3$	1.6
4	6	24	Cr	Chromium	52.00	solid	metal	Transition metal	Cr^{3+} Cr^{6+}		$4s^13d^5$	1.6
4	7	25	Mn	Manganese	54.94	solid	metal	Transition metal	Mn^{2+}		$4s^23d^5$	1.5
4	8	26	Fe	Iron	55.85	solid	metal	Transition metal	Fe^{2+} Fe^{3+}		$4s^23d^6$	1.8
4	9	27	Co	Cobalt	58.93	solid	metal	Transition metal	Co^{2+}		$4s^23d^7$	1.9
4	10	28	Ni	Nickel	58.69	solid	metal	Transition metal	Ni^{2+}		$4s^23d^8$	1.9
4	11	29	Cu	Copper	63.55	solid	metal	Transition metal	Cu^+ Cu^{2+}		$4s^13d^{10}$	1.9
4	12	30	Zn	Zinc	65.38	solid	metal	Transition metal	Zn^{2+}		$4s^23d^{10}$	1.6
4	13	31	Ga	Gallium	69.72	solid	metal	–			$4s^23d^{10}4p^1$	1.6
4	14	32	Ge	Germanium	72.63	solid	metalloid	–			$4s^23d^{10}4p^2$	1.8
4	15	33	As	Arsenic	74.92	solid	metalloid	Pnictogen	As^{3-}		$4s^23d^{10}4p^3$	2.0
4	16	34	Se	Selenium	78.97	solid	nonmetal	Chalcogen	Se^{2-}		$4s^23d^{10}4p^4$	2.4
4	17	35	Br	Bromine	79.90	liquid	nonmetal	Halogen	Br^-		$4s^23d^{10}4p^5$	2.8
4	18	36	Kr	Krypton	83.80	gas	nonmetal	Noble gas	no ion		$4s^23d^{10}4p^6$	–
5	1	37	Rb	Rubidium	85.47	solid	metal	Alkali metal	Rb^+		$5s^1$	0.8
5	2	38	Sr	Strontium	87.62	solid	metal	Alkaline earth metal	Sr^{2+}		$5s^2$	1.0

Period (Row)	Group (Column)	Atomic Number	Symbol	Name	Atomic Mass	State of Matter at Room Temperature	Type of Element	Family	Common Ion	Valence Electrons	Outer Shell Electron Configuration	Electronegativity Values
5	3	39	Y	Yttrium	88.91	solid	metal	Transition metal			$5s^2 4d^1$	1.2
5	4	40	Zr	Zirconium	91.22	solid	metal	Transition metal			$5s^2 4d^2$	1.4
5	5	41	Nb	Niobium	92.91	solid	metal	Transition metal			$5s^1 4d^4$	1.6
5	6	42	Mo	Molybdenum	95.95	solid	metal	Transition metal			$5s^1 4d^5$	1.8
5	7	43	Tc	Technetium	98.91	solid	metal	Transition metal			$5s^1 4d^6$	1.9
5	8	44	Ru	Ruthenium	101.1	solid	metal	Transition metal			$5s^1 4d^7$	2.2
5	9	45	Rh	Rhodium	102.9	solid	metal	Transition metal			$5s^1 4d^8$	2.2
5	10	46	Pd	Palladium	106.4	solid	metal	Transition metal	Ag^+		$4d^{10}$	2.2
5	11	47	Ag	Silver	107.9	solid	metal	Transition metal	Cd^{2+}		$5s^1 4d^{10}$	1.9
5	12	48	Cd	Cadmium	112.4	solid	metal	Transition metal			$5s^2 4d^{10}$	1.7
5	13	49	In	Indium	114.8	solid	metal	–			$5s^2 4d^{10} 5p^1$	1.7
5	14	50	Sn	Tin	118.7	solid	metal	–			$5s^2 4d^{10} 5p^2$	1.8
5	15	51	Sb	Antimony	121.8	solid	metalloid	Pnictogen			$5s^2 4d^{10} 5p^3$	1.9
5	16	52	Te	Tellurium	127.6	solid	metalloid	Chalcogen	Te^{2-}		$5s^2 4d^{10} 5p^4$	2.1
5	17	53	I	Iodine	126.9	solid	nonmetal	Halogen	I^-		$5s^2 4d^{10} 5p^5$	2.5
5	18	54	Xe	Xenon	131.3	gas	nonmetal	Noble gas	no ion		$5s^2 4d^{10} 5p^6$	–
6	1	55	Cs	Cesium	132.9	solid	metal	Alkali metal	Cs^+		$6s^1$	0.7
6	2	56	Ba	Barium	137.3	solid	metal	Alkaline earth metal	Ba^{2+}		$6s^2$	0.9
6	3	57	La	Lanthanum	138.9	solid	metal	Lanthanide			$6s^2 5d^1$	1.0-1.2
6	n/a	58	Ce	Cerium	140.1	solid	metal	Lanthanide			$6s^2 4f^2$	1.0-1.2
6	n/a	59	Pr	Praseodymium	140.9	solid	metal	Lanthanide			$6s^2 4f^3$	1.0-1.2
6	n/a	60	Nd	Neodymium	144.2	solid	metal	Lanthanide			$6s^2 4f^4$	1.0-1.2
6	n/a	61	Pm	Promethium	145.0	solid	metal	Lanthanide			$6s^2 4f^5$	1.0-1.2
6	n/a	62	Sm	Samarium	150.4	solid	metal	Lanthanide			$6s^2 4f^6$	1.0-1.2
6	n/a	63	Eu	Europium	152.0	solid	metal	Lanthanide			$6s^2 4f^7$	1.0-1.2
6	n/a	64	Gd	Gadolinium	157.3	solid	metal	Lanthanide			$6s^2 4f^7 5d^1$	1.0-1.2
6	n/a	65	Tb	Terbium	158.9	solid	metal	Lanthanide			$6s^2 4f^9$	1.0-1.2
6	n/a	66	Dy	Dysprosium	162.5	solid	metal	Lanthanide			$6s^2 4f^{10}$	1.0-1.2
6	n/a	67	Ho	Holmium	164.9	solid	metal	Lanthanide			$6s^2 4f^{11}$	1.0-1.2
6	n/a	68	Er	Erbium	167.3	solid	metal	Lanthanide			$6s^2 4f^{12}$	1.0-1.2
6	n/a	69	Tm	Thulium	168.9	solid	metal	Lanthanide			$6s^2 4f^{13}$	1.0-1.2

Period (Row)	Group (Column)	Atomic Number	Symbol	Name	Atomic Mass	State of Matter at Room Temperature	Type of Element	Family	Common Ion	Valence Electrons	Outer Shell Electron Configuration	Electronegativity Values
6	n/a	70	Yb	Ytterbium	173.0	solid	metal	Lanthanide			$6s^2 4f^{14}$	1.0-1.2
6	n/a	71	Lu	Lutetium	175.0	solid	metal	Lanthanide			$6s^2 4f^{14} 5d^1$	1.0-1.2
6	4	72	Hf	Hafnium	178.5	solid	metal	Transition metal			$6s^2 4f^{14} 5d^2$	1.3
6	5	73	Ta	Tantalum	180.9	solid	metal	Transition metal			$6s^2 4f^{14} 5d^3$	1.5
6	6	74	W	Tungsten	183.8	solid	metal	Transition metal			$6s^2 4f^{14} 5d^4$	1.7
6	7	75	Re	Rhenium	186.2	solid	metal	Transition metal			$6s^2 4f^{14} 5d^5$	1.9
6	8	76	Os	Osmium	190.2	solid	metal	Transition metal			$6s^2 4f^{14} 5d^6$	2.2
6	9	77	Ir	Iridium	192.2	solid	metal	Transition metal			$6s^2 4f^{14} 5d^7$	2.2
6	10	78	Pt	Platinum	195.1	solid	metal	Transition metal	Pt^{2+}		$6s^1 4f^{14} 5d^9$	2.2
6	11	79	Au	Gold	197.0	solid	metal	Transition metal	Au^+ Au^{3+}		$6s^1 4f^{14} 5d^{10}$	2.4
6	12	80	Hg	Mercury	200.6	liquid	metal	Transition metal	Hg_2^{2+} Hg^{2+}		$6s^2 4f^{14} 5d^{10}$	1.9
6	13	81	Tl	Thallium	204.4	solid	metal	–			$6s^2 4f^{14} 5d^{10} 6p^1$	1.8
6	14	82	Pb	Lead	207.2	solid	metal	–			$6s^2 4f^{14} 5d^{10} 6p^2$	1.9
6	15	83	Bi	Bismuth	209.0	solid	metal	Pnictogen			$6s^2 4f^{14} 5d^{10} 6p^3$	1.9
6	16	84	Po	Polonium	209	solid	metal	Chalcogen			$6s^2 4f^{14} 5d^{10} 6p^4$	2.0
6	17	85	At	Astatine	210	solid	metalloid	Halogen	At^-		$6s^2 4f^{14} 5d^{10} 6p^5$	2.2
6	18	86	Rn	Radon	222	gas	nonmetal	Noble gas	no ion		$6s^2 4f^{14} 5d^{10} 6p^6$	–
7	1	87	Fr	Francium	223	solid	metal	Alkali metal	Fr^+		$7s^1$	0.7
7	2	88	Ra	Radium	226	solid	metal	Alkaline earth metal	Ra^{2+}		$7s^2$	0.9
7	3	89	Ac	Actinium	227	solid	metal	Actinide			$7s^2 6d^1$	1.1
7	n/a	90	Th	Thorium	232	solid	metal	Actinide			$7s^2 6d^2$	1.3
7	n/a	91	Pa	Protactinium	231	solid	metal	Actinide			$7s^2 5f^2 6d^1$	1.4
7	n/a	92	U	Uranium	238	solid	metal	Actinide			$7s^2 5f^3 6d^1$	1.4
7	n/a	93	Np	Neptunium	237	solid	metal	Actinide			$7s^2 5f^4 6d^1$	1.4-1.3
7	n/a	94	Pu	Plutonium	244	solid	metal	Actinide			$7s^2 5f^6$	1.4-1.3
7	n/a	95	Am	Americium	243	solid	metal	Actinide			$7s^2 5f^7$	1.4-1.3
7	n/a	96	Cm	Curium	247	solid	metal	Actinide			$7s^2 5f^7 6d^1$	1.4-1.3
7	n/a	97	Bk	Berkelium	247	solid	metal	Actinide			$7s^2 5f^8 6d^1$	1.4-1.3
7	n/a	98	Cf	Californium	251	solid	metal	Actinide			$7s^2 5f^{10}$	1.4-1.3
7	n/a	99	Es	Einsteinium	252	solid	metal	Actinide			$7s^2 5f^{11}$	1.4-1.3
7	n/a	100	Fm	Fermium	257	solid	metal	Actinide			$7s^2 5f^{12}$	1.4-1.3
7	n/a	101	Md	Mendelevium	258	solid	metal	Actinide			$7s^2 5f^{13}$	1.4-1.3
7	n/a	102	No	Nobelium	259	solid	metal	Actinide			$7s^2 5f^{14}$	1.4-1.3

Period (Row)	Group (Column)	Atomic Number	Symbol	Name	Atomic Mass	State of Matter at Room Temperature	Type of Element	Family	Common Ion	Valence Electrons	Outer Shell Electron Configuration	Electronegativity Values
7	n/a	103	Lr	Lawrencium	262	solid	metal	Actinide			$7s^2 5f^{14} 6d^1$	–
7	4	104	Rf	Rutherfordium	261	solid	metal	Transition metal			$7s^2 5f^{14} 6d^2$	–
7	5	105	Db	Dubnium	268	solid	metal	Transition metal			$7s^2 5f^{14} 6d^3$	–
7	6	106	Sg	Seaborgium	269	solid	metal	Transition metal			$7s^2 5f^{14} 6d^4$	–
7	7	107	Bh	Bohrium	270	solid	metal	Transition metal			$7s^2 5f^{14} 6d^5$	–
7	8	108	Hs	Hassium	269	solid	metal	Transition metal			$7s^2 5f^{14} 6d^6$	–
7	9	109	Mt	Meitnerium	277	unknown	unknown	Transition metal			$7s^2 5f^{14} 6d^7$	–
7	10	110	Ds	Darmstadtium	281	unknown	unknown	Transition metal			$7s^2 5f^{14} 6d^8$	–
7	11	111	Rg	Roentgenium	281	unknown	unknown	Transition metal			$7s^2 5f^{14} 6d^9$	–
7	12	112	Cn	Copernicium	285	solid	metal	Transition metal			$7s^2 5f^{14} 6d^{10}$	–
7	13	113	Nh	Nihonium	286	unknown	unknown	–				–
7	14	114	Fl	Flerovium	289	solid	metal	–				–
7	15	115	Mc	Moscovium	288	unknown	unknown	Pnictogen				–
7	16	116	Lv	Livermorium	293	unknown	unknown	Chalcogen				–
7	17	117	Ts	Tennessine	294	unknown	unknown	Halogen				–
7	18	118	Og	Oganesson	294	unknown	unknown	–				–

Links & Resources

Watch The Periodic Table: Crash Course Chemistry #4 (11:21 min) (https://youtu.be/0RRVV4Diomg)

Watch The Periodic Table Explained (3:06 min) (https://www.youtube.com/watch?v=wXRHz5ZEIK0)

For suggestions on accessible periodic tables for those with low/no vision, visit:

- Accessible Periodic Table Options – Perkins School for the Blind (https://www.perkins.org/resource/accessible-periodic-table-options/)

- Accessible Periodic Table of Elements – American Chemical Society (acs.org) (https://www.acs.org/education/students/highschool/olympiad/prepare-for-exams/accessible-periodic-table.html)
- Independence Science Periodic Table of the Elements (https://independencescience.com/wp-content/uploads/2020/11/ptable_trends.html)

Low vision and braille versions of the periodic table are available.

Attribution & References

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- Figure 3 from "3.6 The Periodic Table (https://boisestate.pressbooks.pub/chemistry/chapter/3-6-the-periodic-table/)", Figure 2 from "3.7 Molecular and Ionic Compounds (https://boisestate.pressbooks.pub/chemistry/chapter/3-7-molecular-and-ionic-compounds/)", Figure 4 from "3.4 Electronic Structure of the Atoms (General configurations) (https://boisestate.pressbooks.pub/chemistry/chapter/3-4-electronic-structure-of-atoms-electron-configurations/)", Figure 3 from "4.2 Covalent Bonding (https://boisestate.pressbooks.pub/chemistry/chapter/4-2-covalent-bonding/)" In *General Chemistry 1 & 2* by Rice University, a derivative of *Chemistry (Open Stax)* by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson and is licensed under CC BY 4.0. Access for free at *Chemistry (OpenStax) (https://openstax.org/books/chemistry/pages/1-introduction)* .
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References

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Periodic Table of the elements. (2023). www.periodictable.one.

APPENDIX B: ESSENTIAL MATHEMATICS

Exponential Arithmetic

Exponential notation is used to express very large and very small numbers as a product of two numbers. The first number of the product, the *digit term*, is usually a number not less than 1 and not greater than 10. The second number of the product, the *exponential term*, is written as 10 with an exponent. Some examples of exponential notation are:

$$\begin{aligned} 1000 &= 1 \times 10^3 \\ 100 &= 1 \times 10^2 \\ 10 &= 1 \times 10^1 \\ 1 &= 1 \times 10^0 \\ 0.1 &= 1 \times 10^{-1} \\ 0.001 &= 1 \times 10^{-3} \\ 2386 &= 2.386 \times 1000 = 2.386 \times 10^3 \\ 0.123 &= 1.23 \times 0.1 = 1.23 \times 10^{-1} \end{aligned}$$

The power (exponent) of 10 is equal to the number of places the decimal is shifted to give the digit number. The exponential method is particularly useful notation for every large and very small numbers. For example, 1,230,000,000 = 1.23×10^9, and 0.00000000036 = 3.6×10^{-10}.

Addition of Exponentials

Convert all numbers to the same power of 10, add the digit terms of the numbers, and if appropriate, convert the digit term back to a number between 1 and 10 by adjusting the exponential term.

Example B.1

Adding Exponentials

Add 5.00 × 10^{-5} and 3.00 × 10^{-3}.

Solution

$$3.00 \times 10^{-3} = 300 \times 10^{-5}$$
$$(5.00 \times 10^{-5}) + (300 \times 10^{-5}) = 305 \times 10^{-5} = 3.05 \times 10^{-3}$$

Subtraction of Exponentials

Convert all numbers to the same power of 10, take the difference of the digit terms, and if appropriate, convert the digit term back to a number between 1 and 10 by adjusting the exponential term.

Example B.2

Subtracting Exponentials

Subtract 4.0 × 10^{-7} from 5.0 × 10^{-6}.

Solution

$$4.0 \times 10^{-7} = 0.40 \times 10^{-6}$$
$$(5.0 \times 10^{-6}) - (0.40 \times 10^{-6}) = 4.6 \times 10^{-6}$$

Multiplication of Exponentials

Multiply the digit terms in the usual way and add the exponents of the exponential terms.

Example B.3

Multiplying Exponentials

Multiply 4.2 × 10^{-8} by 2.0 × 10^{3}.

Solution

$$(4.2 \times 10^{-8}) \times (2.0 \times 10^{3}) = (4.2 \times 2.0) \times 10^{(-8)+(+3)} = 8.4 \times 10^{-5}$$

Division of Exponentials

Divide the digit term of the numerator by the digit term of the denominator and subtract the exponents of the exponential terms.

Example B.4

Dividing Exponentials

Divide 3.6×10^{5} by 6.0×10^{-4}.

Solution

$$\frac{3.6 \times 10^{-5}}{6.0 \times 10^{-4}} = (\frac{3.6}{6.0}) \times 10^{(-5)-(-4)} = 0.60 \times 10^{-1} = 6.0 \times 10^{-2}$$

Squaring of Exponentials

Square the digit term in the usual way and multiply the exponent of the exponential term by 2.

Example B.5

Squaring Exponentials

Square the number 4.0×10^{-6}.

Solution

$$(4.0 \times 10^{-6})^2 = 4 \times 4 \times 10^{2 \times (-6)} = 16 \times 10^{-12} = 1.6 \times 10^{-11}$$

Cubing of Exponentials

Cube the digit term in the usual way and multiply the exponent of the exponential term by 3.

Example B.6

Cubing Exponentials

Cube the number 2×10^{4}.

Solution

$$(2 \times 10^4)^3 = 2 \times 2 \times 2 \times 10^{3 \times 4} = 8 \times 10^{12}$$

Taking Square Roots of Exponentials

If necessary, decrease or increase the exponential term so that the power of 10 is evenly divisible by 2. Extract the square root of the digit term and divide the exponential term by 2.

Example B.7

Finding the Square Root of Exponentials

Find the square root of 1.6×10^{-7}.

Solution

$$1.6 \times 10^{-7} = 16 \times 10^{-8}$$

$$\sqrt{16 \times 10^{-8}} = \sqrt{16} \times \sqrt{10^{-8}} = \sqrt{16} \times \sqrt{10}^{-\frac{8}{2}} = 4.0 \times 10^{-4}$$

Significant Figures

A beekeeper reports that he has 525,341 bees. The last three figures of the number are obviously inaccurate, for during the time the keeper was counting the bees, some of them died and others hatched; this makes it quite difficult to determine the exact number of bees. It would have been more accurate if the beekeeper had reported the number 525,000. In other words, the last three figures are not significant, except to set the position of the decimal point. Their exact values have no meaning useful in this situation. In reporting any information as numbers, use only as many significant figures as the accuracy of the measurement warrants.

The importance of significant figures lies in their application to fundamental computation. In addition and subtraction, the sum or difference should contain as many digits to the right of the decimal as that in the least certain of the numbers used in the computation (indicated by underscoring in the following example).

Example B.8

Addition and Subtraction with Significant Figures

Add 4.383 g and 0.0023 g.

Solution

$$\begin{array}{r} 4.38\underline{3}\text{ g} \\ 0.002\underline{3}\text{ g} \\ \hline 4.38\underline{5}\text{ g} \end{array}$$

In multiplication and division, the product or quotient should contain no more digits than that in the factor containing the least number of significant figures.

Example B.9

Multiplication and Division with Significant Figures

Multiply 0.6238 by 6.6.

Solution

$$0.623\underline{8} \times 6.\underline{6} = 4.\underline{1}$$

When rounding numbers, increase the retained digit by 1 if it is followed by a number larger than 5 ("round up"). Do not change the retained digit if the digits that follow are less than 5 ("round down"). If the retained digit is followed by 5, round up if the retained digit is odd, or round down if it is even (after rounding, the retained digit will thus always be even).

The Use of Logarithms and Exponential Numbers

The common logarithm of a number (log) is the power to which 10 must be raised to equal that number. For example, the common logarithm of 100 is 2, because 10 must be raised to the second power to equal 100. Additional examples follow.

Table B.1: Logarithms and Exponential Numbers

Number	Number Expressed Exponentially	Common Logarithm
1000	10^3	3
10	10^1	1
1	10^0	0
0.1	10^{-1}	−1
0.001	10^{-3}	−3

What is the common logarithm of 60? Because 60 lies between 10 and 100, which have logarithms of 1 and 2, respectively, the logarithm of 60 is 1.7782; that is,

$$60 = 10^{1.7782}$$

The common logarithm of a number less than 1 has a negative value. The logarithm of 0.03918 is −1.4069, or

$$0.03918 = 10^{-1.4069} = \frac{1}{10^{1.4069}}$$

To obtain the common logarithm of a number, use the *log* button on your calculator. To calculate a number from its logarithm, take the inverse log of the logarithm, or calculate 10^x (where *x* is the logarithm of the number).

The natural logarithm of a number (ln) is the power to which *e* must be raised to equal the number; *e* is the constant 2.7182818. For example, the natural logarithm of 10 is 2.303; that is,

$$10 = e^{2.303} = 2.7182818^{2.303}$$

To obtain the natural logarithm of a number, use the *ln* button on your calculator. To calculate a number from its natural logarithm, enter the natural logarithm and take the inverse ln of the natural logarithm, or calculate e^x (where *x* is the natural logarithm of the number).

Logarithms are exponents; thus, operations involving logarithms follow the same rules as operations involving exponents.

1. The logarithm of a product of two numbers is the sum of the logarithms of the two numbers.
$$\log xy = \log x \ + \ \log y,\backslash;\text{and}\backslash;\ln xy = \ln x \ + \ \ln y$$
2. The logarithm of the number resulting from the division of two numbers is the difference between the logarithms of the two numbers.
$$\log \frac{x}{y} = \log x \ - \ \log y,\backslash;\text{and}\backslash;\ln \frac{x}{y} = \ln x \ - \ \ln y$$
3. The logarithm of a number raised to an exponent is the product of the exponent and the logarithm of the number.

$$\log\, x^n\ = n\log\, x\ \text{and}\backslash;\ln\, x^n\ = n\ln\, x$$

The Solution of Quadratic Equations

Mathematical functions of this form are known as second-order polynomials or, more commonly, quadratic functions.

$$ax^2\ +\ bx\ +\ c = 0$$

The solution or roots for any quadratic equation can be calculated using the following formula:

$$x = \frac{-b \pm \sqrt{b^2\ -\ 4ac}}{2a}$$

Example B.10

Solving Quadratic Equations

Solve the quadratic equation $3x^2 + 13x - 10 = 0$.

Solution

Substituting the values $a = 3$, $b = 13$, $c = -10$ in the formula, we obtain

$$x = \frac{-13 \pm \sqrt{(13)^2\ -\ 4\ \times\ 3\ \times\ (-10)}}{2\ \times\ 3}$$

$$x = \frac{-13 \pm \sqrt{169\ +\ 120}}{6} = \frac{-13 \pm \sqrt{289}}{6} = \frac{-13 \pm 17}{6}$$

The two roots are therefore

$$x = \frac{-13\ +\ 17}{6} = \frac{2}{3}\ \text{and}\ x = \frac{-13\ -\ 17}{6} = -5$$

Quadratic equations constructed on physical data always have real roots, and of these real roots, often only those having positive values are of any significance.

Two-Dimensional (x–y) Graphing

The relationship between any two properties of a system can be represented graphically by a two-dimensional data plot. Such a graph has two axes: a horizontal one corresponding to the independent variable, or the variable whose value is being controlled (x), and a vertical axis corresponding to the dependent variable, or the variable whose value is being observed or measured (y).

When the value of y is changing as a function of x (that is, different values of x correspond to different values of *y*), a graph of this change can be plotted or sketched. The graph can be produced by using specific values for (*x*,*y*) data pairs.

Example B.11

Graphing the Dependence of *y* on *x*

Table B.2: X and Y values for Graph

x	*y*
1	5
2	10
3	7
4	14

This table contains the following points: (1,5), (2,10), (3,7), and (4,14). Each of these points can be plotted on a graph and connected to produce a graphical representation of the dependence of *y* on *x*.

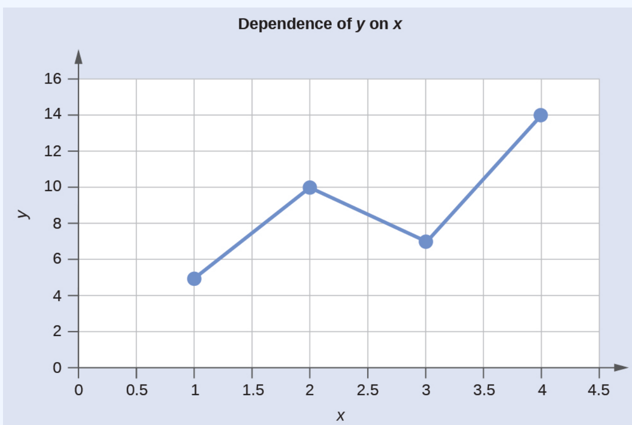

Figure B.1: XY graph of data in Table B.2

If the function that describes the dependence of *y* on *x* is known, it may be used to compute x,y data pairs that may subsequently be plotted.

Example B.12

Plotting Data Pairs

If we know that $y = x^2 + 2$, we can produce a table of a few (x,y) values and then plot the line based on the data shown here.

Table B.3: XY values

x	$y = x^2 + 2$
1	3
2	6
3	11
4	18

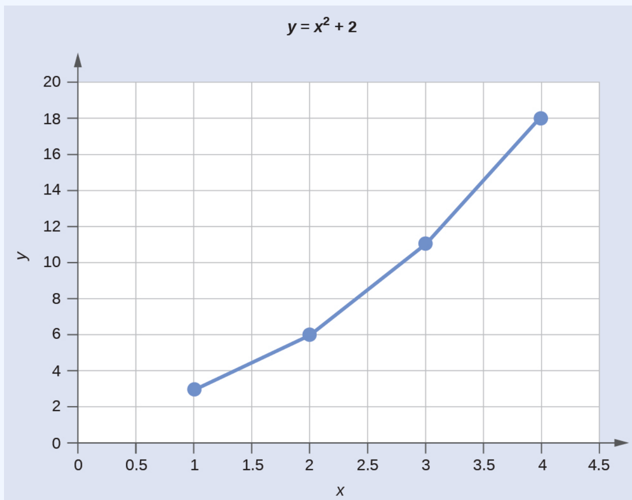

Figure B.2: XY graph of data in Table B.3

Attribution & References

APPENDIX C: UNITS AND CONVERSION FACTORS

Units of Length, Mass, Energy & Pressure

Table C.1: Units of Length

Unit	Equivalent Units
meter (m)	= 39.37 inches (in.) = 1.094 yards (yd)
centimeter (cm)	= 0.01 m (exact, definition)
millimeter (mm)	= 0.001 m (exact, definition)
kilometer (km)	= 1000 m (exact, definition)
angstrom (Å)	= 10^{-8} cm (exact, definition) = 10^{-10} m (exact, definition)
yard (yd)	= 0.9144 m
inch (in.)	= 2.54 cm (exact, definition)
mile (US)	= 1.60934 km

Table C.2: Units of Volume

Unit	Equivalent Units
liter (L)	= 0.001 m^3 (exact, definition) = 1000 cm^3 (exact, definition) = 1.057 (US) quarts
milliliter (mL)	= 0.001 L (exact, definition) = 1 cm^3 (exact, definition)
microliter (µL)(µL)	= 10^{-6} L (exact, definition) = 10^{-3} cm^3 (exact, definition)
liquid quart (US)	= 32 (US) liquid ounces (exact, definition) = 0.25 (US) gallon (exact, definition) = 0.9463 L
dry quart	= 1.1012 L
cubic foot (US)	= 28.316 L

Table C.3: Units of Mass

Unit	Equivalent Units
gram (g)	= 0.001 kg (exact, definition)
milligram (mg)	= 0.001 g (exact, definition)
kilogram (kg)	= 1000 g (exact, definition) = 2.205 lb
ton (metric)	=1000 kg (exact, definition) = 2204.62 lb
ounce (oz) (avoirdupois)	= 28.35 g
pound (lb) (avoirdupois)	= 0.4535924 kg
ton (short)	=2000 lb (exact, definition) = 907.185 kg
ton (long)	= 2240 lb (exact, definition) = 1.016 metric ton

Table C.4: Units of Energy

Unit	Equivalent Units
4.184 joule (J)	= 1 thermochemical calorie (cal)
1 thermochemical calorie (cal)	= 4.184×10^{7} erg
erg	= 10^{-7} J (exact, definition)
electron-volt (eV)	= 1.60218×10^{-19} J = 23.061 kcal mol^{-1}
liter·atmosphere	= 24.217 cal = 101.325 J (exact, definition)
nutritional calorie (Cal)	= 1000 cal (exact, definition) = 4184 J
British thermal unit (BTU)	= 1054.804 J[1]

Table C.5: Units of Pressure

Unit	Equivalent Units
torr	= 1 mm Hg (exact, definition)
pascal (Pa)	= N m^{-2} (exact, definition) = kg m^{-1} s^{-2} (exact, definition)
atmosphere (atm)	= 760 mm Hg (exact, definition) = 760 torr (exact, definition) = 101,325 N m^{-2} (exact, definition) = 101,325 Pa (exact, definition)
bar	= 10^{5} Pa (exact, definition) = 10^{5} kg m^{-1} s^{-2} (exact, definition)

Attribution & References

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Notes

1. BTU is the amount of energy needed to heat one pound of water by one degree Fahrenheit. Therefore, the exact relationship of BTU to joules and other energy units depends on the temperature at which BTU is measured. 59 °F (15 °C) is the most widely used reference temperature for BTU definition in the United States. At this temperature, the conversion factor is the one provided in this table.

APPENDIX D: FUNDAMENTAL PHYSICAL CONSTANTS

Fundamental Physical Constants

Table D.1: Fundamental Physical constants

Name and Symbol	Value
atomic mass unit (amu)	$1.6605402 \times 10^{-27}$ kg
Avogadro's number	6.0221367×10^{23} mol^{-1}
Boltzmann's constant (k)	1.380658×10^{-23} J K^{-1}
charge-to-mass ratio for electron (e/m_e)	$1.75881962 \times 10^{11}$ C kg^{-1}
electron charge (e)	$1.60217733 \times 10^{-19}$ C
electron rest mass (m_e)	$9.1093897 \times 10^{-31}$ kg
Faraday's constant (F)	9.6485309×10^{4} C mol^{-1}
gas constant (R)	8.205784×10^{-2} L atm mol^{-1} K^{-1} = 8.314510 J mol^{-1} K^{-1}
molar volume of an ideal gas, 1 atm, 0 °C	22.41409 L mol^{-1}
molar volume of an ideal gas, 1 bar, 0 °C	22.71108 L mol^{-1}
neutron rest mass (m_n)	$1.6749274 \times 10^{-27}$ kg
Planck's constant (h)	$6.6260755 \times 10^{-34}$ J s
proton rest mass (m_p)	$1.6726231 \times 10^{-27}$ kg
Rydberg constant (R)	$1.0973731534 \times 10^{7}$ m^{-1} = $2.1798736 \times 10^{-18}$ J
speed of light (in vacuum) (c)	2.99792458×10^{8} m s^{-1}

Attribution & References

Except where otherwise noted, this page is adapted from "Appendix D: Fundamental Physical Constants (https://boisestate.pressbooks.pub/chemistry/back-matter/appendix-d-fundamental-physical-constants/)" In *General Chemistry 1 & 2* by Rice University, a derivative of *Chemistry (Open Stax)* by Paul Flowers, Klaus Theopold, Richard Langley & William R. Robinson and is licensed under CC BY 4.0. Access for free at

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APPENDIX E: POLYATOMIC IONS

Common Polyatomic Ions

Table E.1: Common Polyatomic Ions

Name	Symbol
Acetate	$C_2H_3O_2^-$
Amide	NH_2^-
Ammonium	NH_4^+
Arsenate	AsO_4^{3-}
Borate	BO_3^{3-}
Bromate	BrO_3^-
Carbonate	CO_3^{2-}
Chlorate	CIO_3^-
Chlorite	CIO_2^-
Chromate	CrO_4^{2-}
Cyanide	CN^-
Dichromate	CrO_7^{2-}
Dihydrogen phosphate	$H_2PO_4^{2-}$
Hydrogen carbonate	HCO_3^-
Hydrogen oxalate	$HC_2O_4^-$
Hydrogen phosphate	HPO_4^{2-}
Hydrogen sulfate (bisulfate)	HSO_4^-
Hydrogen sulfite (bisulfate)	HSO_3^-
Hydroxide	OH^-

Name	Symbol
Hypobromite	BrO^{-}
Hypochlorite	ClO^{-}
Hypoiodite	IO^{-}
Iodate	IO_3^{-}
Nitrate	NO_3^{-}
Nitrite	NO_2^{-}
Oxalate	$C_2O_4^{2-}$
Perchlorate	ClO_4^{-}
Periodate	IO_4^{-}
Permanganate	MnO_4^{-}
Peroxide	O_2^{2-}
Phosphate	PO_4^{3-}
Phosphite	PO_3^{3-}
Sulfate	SO_4^{2-}
Sulfite	SO_3^{2-}
Thiocyanide	SCN^{-}

Attribution & References

APPENDIX F: WATER PROPERTIES

Properties of Water at Various Temperatures

Water Densities

Table F.1: Water Density (kg/m^3) at Different Temperatures (°C)

Temperature[1]	Density
0	999.8395
4	999.9720 (density maximum)
10	999.7026
15	999.1026
20	998.2071
22	997.7735
25	997.0479
30	995.6502
40	992.2
60	983.2
80	971.8
100	958.4

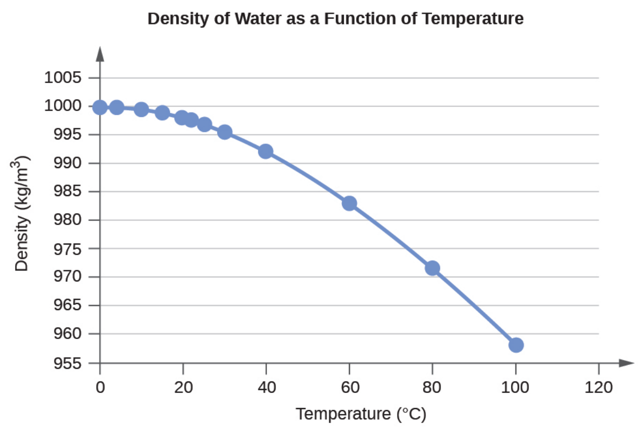

Figure F.1: Density of water (kg/m^3) as a function of Temperature (^{o}C)

Water Vapour Pressures

Table F.2: Water Vapor Pressure (in torr and Pa) at Different Temperatures (°C)

Temperature	Vapor Pressure (torr)	Vapor Pressure (Pa)
0	4.6	613.2812
4	6.1	813.2642
10	9.2	1226.562
15	12.8	1706.522
20	17.5	2333.135
22	19.8	2639.776
25	23.8	3173.064
30	31.8	4239.64
35	42.2	5626.188
40	55.3	7372.707
45	71.9	9585.852
50	92.5	12332.29
55	118.0	15732
60	149.4	19918.31
65	187.5	24997.88
70	233.7	31157.35
75	289.1	38543.39
80	355.1	47342.64
85	433.6	57808.42
90	525.8	70100.71
95	633.9	84512.82
100	760.0	101324.7

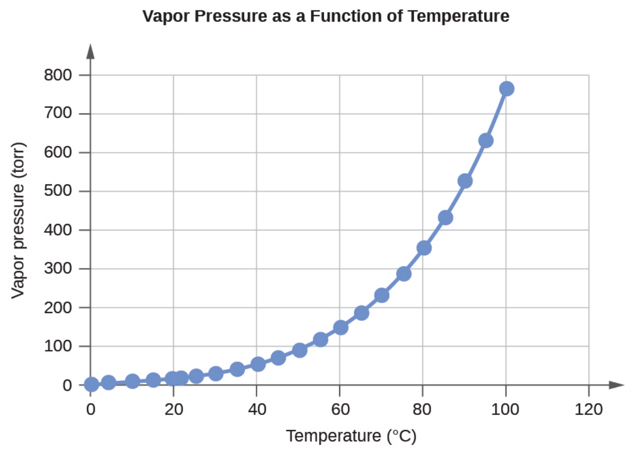

Figure F.2: Vapour pressure (torr) of water as a function of temperature (^{o}C).

K_W of Water

Table F.3: Water K_W and pK_W at Different Temperatures (°C)

Temperature	K_W 10^{-14}	pK_W ^{2}
0	0.112	14.95
5	0.182	14.74
10	0.288	14.54
15	0.465	14.33
20	0.671	14.17
25	0.991	14.00
30	1.432	13.84
35	2.042	13.69
40	2.851	13.55
45	3.917	13.41
50	5.297	13.28
55	7.080	13.15
60	9.311	13.03
75	19.95	12.70
100	56.23	12.25

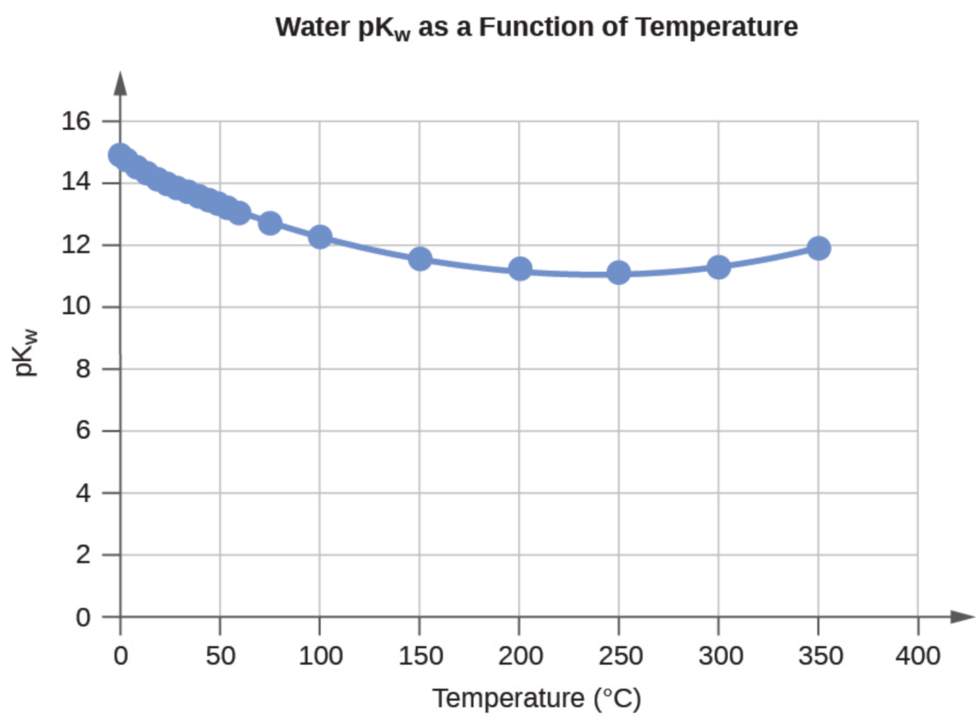

Figure F.3: pKw of water at various temperatures (°C)

Specific Heat Capacity for Water

Specific heat capacity for water (liquid) = 4184 J·K^{-1}·kg^{-1} = 4.184 J·g^{-1}·°C^{-1}
Specific heat capacity for ice (solid) = 1864 J·K^{-1}·kg^{-1}
Specific heat capacity for steam (gas) = 2093 J·K^{-1}·kg^{-1}

Table F.4: Standard Water Melting and Boiling Temperatures and Enthalpies of the Transitions

State	Temperature (K)	Δ*H* (kJ/mol)
melting	273.15	6.088
boiling	373.15	40.656 (44.016 at 298 K)

Water Cryoscopic (Freezing Point Depression) and Ebullioscopic (Boiling Point Elevation) Constants

Cryoscopic constant – K_f = 1.86°C·kg·mol^{-1}
Ebullioscopic constant – K_b = 0.51°C·kg·mol^{-1}

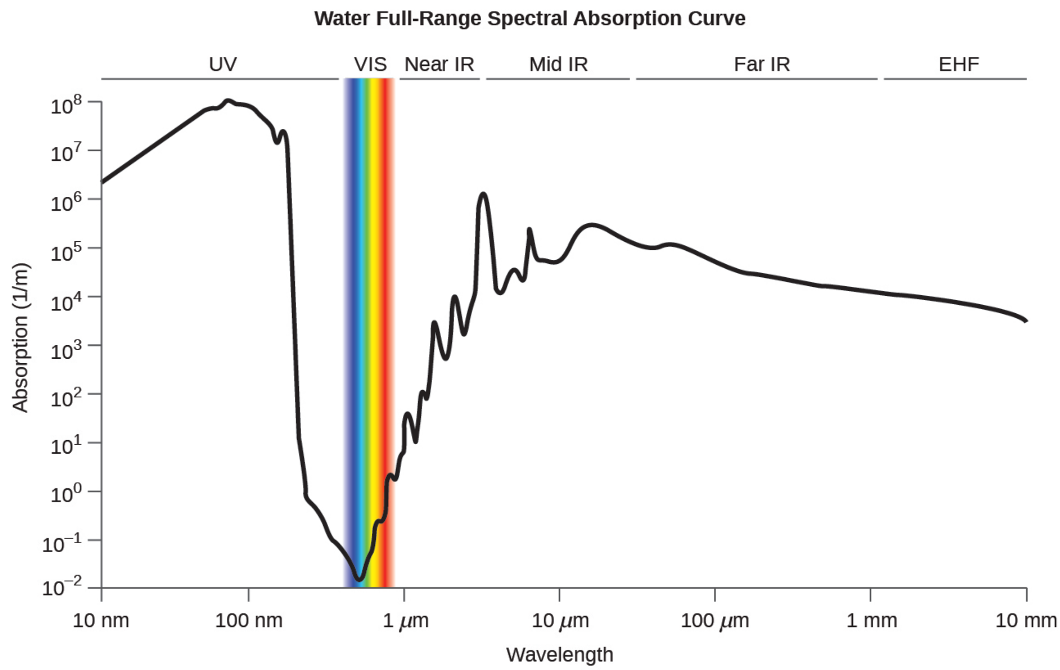

Figure F.4: Water full-range spectral absorption curve. This curve shows the full-range spectral absorption for water. The y-axis signifies the absorption in 1/cm. If we divide 1 by this value, we will obtain the length of the path (in cm) after which the intensity of a light beam passing through water decays by a factor of the base of the natural logarithm e (e = 2.718281828).

Attribution & References

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Notes

1. Data for t < 0 °C are for supercooled water
2. $pK_w = -\log_{10}(K_w)$

APPENDIX G: COMPOSITION OF COMMERCIAL ACIDS AND BASES

Commercial Acids and Bases

Table G.1: Composition of Commercial Acids and Bases

Acid or Base[1]	Density (g/mL)[2]	Percentage by Mass	Molarity
acetic acid, glacial	1.05	99.5%	17.4
aqueous ammonia[3]	0.90	28%	14.8
hydrochloric acid	1.18	36%	11.6
nitric acid	1.42	71%	16.0
perchloric acid	1.67	70%	11.65
phosphoric acid	1.70	85%	14.7
sodium hydroxide	1.53	50%	19.1
sulfuric acid	1.84	96%	18.0

Attribution & References

Notes

1. Acids and bases are commercially available as aqueous solutions. This table lists properties (densities and concentrations) of common acid and base solutions. Nominal values are provided in cases where the manufacturer cites a range of concentrations and densities.
2. This column contains specific gravity data. In the case of this table, specific gravity is the ratio of density of a substance to the density of pure water at the same conditions. Specific gravity is often cited on commercial labels.

3. This solution is sometimes called "ammonium hydroxide," although this term is not chemically accurate.

APPENDIX H: STANDARD THERMODYNAMIC PROPERTIES FOR SELECTED SUBSTANCES

Thermodynamic Properties

Table H.1: Standard Thermodynamic Properties for Selected Substances

Substance	ΔH_f° (kJ mol^{-})	ΔG_f° (kJ mol^{-1})	S_{298}° (J K^{-1} mol^{-1})
aluminum			
$Al(s)$	0	0	28.3
$Al(g)$	324.4	285.7	164.54
$Al^{3+}(aq)$	–531	–485	–321.7
$Al_2O_3(s)$	–1676	–1582	50.92
$AlF_3(s)$	–1510.4	–1425	66.5
$AlCl_3(s)$	–704.2	–628.8	110.67
$AlCl_3{\cdot}6H_2O(s)$	–2691.57	–2269.40	376.56
$Al_2S_3(s)$	–724.0	–492.4	116.9
$Al_2(SO_4)_3(s)$	–3445.06	–3506.61	239.32
antimony			
$Sb(s)$	0	0	45.69
$Sb(g)$	262.34	222.17	180.16
$Sb_4O_6(s)$	–1440.55	–1268.17	220.92
$SbCl_3(g)$	–313.8	–301.2	337.80
$SbCl_5(g)$	–394.34	–334.29	401.94
$Sb_2S_3(s)$	–174.89	–173.64	182.00
$SbCl_3(s)$	–382.17	–323.72	184.10
$SbOCl(s)$	–374.0	—	—
arsenic			
$As(s)$	0	0	35.1
$As(g)$	302.5	261.0	174.21
$As_4(g)$	143.9	92.4	314
$As_4O_6(s)$	–1313.94	–1152.52	214.22
$As_2O_5(s)$	–924.87	–782.41	105.44
$AsCl_3(g)$	–261.50	–248.95	327.06
$As_2S_3(s)$	–169.03	–168.62	163.59
$AsH_3(g)$	66.44	68.93	222.78
$H_3AsO_4(s)$	–906.3	—	—

Substance	ΔH_f° **(kJ mol⁻)**	ΔG_f° **(kJ mol^{-1})**	S_{298}° **(J K^{-1} mol^{-1})**
barium			
Ba(*s*)	0	0	62.5
Ba(*g*)	180	146	170.24
Ba^{2+}(*aq*)	–537.6	–560.8	9.6
BaO(*s*)	–548.0	–520.3	72.1
$BaCl_2$(*s*)	–855.0	–806.7	123.7
$BaSO_4$(*s*)	–1473.2	–1362.3	132.2
beryllium			
Be(*s*)	0	0	9.50
Be(*g*)	324.3	286.6	136.27
BeO(*s*)	–609.4	–580.1	13.8
bismuth			
Bi(*s*)	0	0	56.74
Bi(*g*)	207.1	168.2	187.00
Bi_2O_3(*s*)	–573.88	–493.7	151.5
$BiCl_3$(*s*)	–379.07	–315.06	176.98
Bi_2S_3(*s*)	–143.1	–140.6	200.4
boron			
B(*s*)	0	0	5.86
B(*g*)	565.0	521.0	153.4
B_2O_3(*s*)	–1273.5	–1194.3	53.97
B_2H_6(*g*)	36.4	87.6	232.1
H_3BO_3(*s*)	–1094.33	–968.92	88.83
BF_3(*g*)	–1136.0	–1119.4	254.4
BCl_3(*g*)	–403.8	–388.7	290.1
$B_3N_3H_6$(*l*)	–540.99	–392.79	199.58
HBO_2(*s*)	–794.25	–723.41	37.66
bromine			
Br_2(*l*)	0	0	152.23
Br_2(*g*)	30.91	3.142	245.5

Substance	ΔH°_f (kJ mol^{-})	ΔG°_f (kJ mol^{-1})	S°_{298} (J K^{-1} mol^{-1})
Br(*g*)	111.88	82.429	175.0
Br^-(*aq*)	–120.9	–102.82	80.71
BrF_3(*g*)	–255.60	–229.45	292.42
HBr(*g*)	–36.3	–53.43	198.7
cadmium			
Cd(*s*)	0	0	51.76
Cd(*g*)	112.01	77.41	167.75
Cd^{2+}(*aq*)	–75.90	–77.61	–73.2
CdO(*s*)	–258.2	–228.4	54.8
$CdCl_2$(*s*)	–391.5	–343.9	115.3
$CdSO_4$(*s*)	–933.3	–822.7	123.0
CdS(*s*)	–161.9	–156.5	64.9
calcium			
Ca(*s*)	0	0	41.6
Ca(*g*)	178.2	144.3	154.88
Ca^{2+}(*aq*)	–542.96	–553.04	–55.2
CaO(*s*)	–634.9	–603.3	38.1
$Ca(OH)_2$(*s*)	–985.2	–897.5	83.4
$CaSO_4$(s)	–1434.5	–1322.0	106.5
$CaSO_4{\cdot}2H_2O$(*s*)	–2022.63	–1797.45	194.14
$CaCO_3$(*s*) (calcite)	–1220.0	–1081.4	110.0
$CaSO_3{\cdot}H_2O$(*s*)	–1752.68	–1555.19	184.10
carbon			
C(*s*) (graphite)	0	0	5.740
C(*s*) (diamond)	1.89	2.90	2.38
C(*g*)	716.681	671.2	158.1
CO(*g*)	–110.52	–137.15	197.7
CO_2(*g*)	–393.51	–394.36	213.8
CO_3^{2-}(*aq*)	–677.1	–527.8	–56.9

Substance	ΔH_f° **(kJ mol⁻)**	ΔG_f° **(kJ mol^{-1})**	S_{298}° **(J K^{-1} mol^{-1})**
$CH_4(g)$	−74.6	−50.5	186.3
$CH_3OH(l)$	−239.2	−166.6	126.8
$CH_3OH(g)$	−201.0	−162.3	239.9
$CCl_4(l)$	−128.2	−62.5	214.4
$CCl_4(g)$	−95.7	−58.2	309.7
$CHCl_3(l)$	−134.1	−73.7	201.7
$CHCl_3(g)$	−103.14	−70.34	295.71
$CS_2(l)$	89.70	65.27	151.34
$CS_2(g)$	116.9	66.8	238.0
$C_2H_2(g)$	227.4	209.2	200.9
$C_2H_4(g)$	52.4	68.4	219.3
$C_2H_6(g)$	−84.0	−32.0	229.2
$CH_3CO_2H(l)$	−484.3	−389.9	159.8
$CH_3CO_2H(g)$	−434.84	−376.69	282.50
$C_2H_5OH(l)$	−277.6	−174.8	160.7
$C_2H_5OH(g)$	−234.8	−167.9	281.6
$HCO_3^-(aq)$	−691.11	−587.06	95
$C_3H_8(g)$	−103.8	−23.4	270.3
$C_6H_6(g)$	82.927	129.66	269.2
$C_6H_6(l)$	49.1	124.50	173.4
$CH_2Cl_2(l)$	−124.2	−63.2	177.8
$CH_2Cl_2(g)$	−95.4	−65.90	270.2
$CH_3Cl(g)$	−81.9	−60.2	234.6
$C_2H_5Cl(l)$	−136.52	−59.31	190.79
$C_2H_5Cl(g)$	−112.17	−60.39	276.00
$C_2N_2(g)$	308.98	297.36	241.90
$HCN(l)$	108.9	125.0	112.8
$HCN(g)$	135.5	124.7	201.8
cesium			
$Cs^+(aq)$	−248	−282.0	133

Substance	ΔH_f° **(kJ mol⁻)**	ΔG_f° **(kJ mol^{-1})**	S_{298}° **(J K^{-1} mol^{-1})**
chlorine			
$Cl_2(g)$	0	0	223.1
$Cl(g)$	121.3	105.70	165.2
$Cl^-(aq)$	−167.2	−131.2	56.5
$ClF(g)$	−54.48	−55.94	217.78
$ClF_3(g)$	−158.99	−118.83	281.50
$Cl_2O(g)$	80.3	97.9	266.2
$Cl_2O_7(l)$	238.1	—	—
$Cl_2O_7(g)$	272.0	—	—
$HCl(g)$	−92.307	−95.299	186.9
$HClO_4(l)$	−40.58	—	—
chromium			
$Cr(s)$	0	0	23.77
$Cr(g)$	396.6	351.8	174.50
$CrO_4^{2-}(aq)$	−881.2	−727.8	50.21
$Cr_2O_7^{2-}(aq)$	−1490.3	−1301.1	261.9
$Cr_2O_3(s)$	−1139.7	−1058.1	81.2
$CrO_3(s)$	−589.5	—	—
$(NH_4)_2Cr_2O_7(s)$	−1806.7	—	—
cobalt			
$Co(s)$	0	0	30.0
$Co^{2+}(aq)$	−67.4	−51.5	−155
$Co^{3+}(aq)$	92	134	−305.0
$CoO(s)$	−237.9	−214.2	52.97
$Co_3O_4(s)$	−910.02	−794.98	114.22
$Co(NO_3)_2(s)$	−420.5	—	—
copper			
$Cu(s)$	0	0	33.15
$Cu(g)$	338.32	298.58	166.38

Substance	ΔH_f° (kJ mol⁻)	ΔG_f° (kJ mol^{-1})	S_{298}° (J K^{-1} mol^{-1})
Cu^{+}(*aq*)	51.9	50.2	–26
Cu^{2+}(*aq*)	64.77	65.49	−99.6
CuO(*s*)	−157.3	−129.7	42.63
Cu_2O(*s*)	−168.6	−146.0	93.14
CuS(*s*)	−53.1	−53.6	66.5
Cu_2S(*s*)	−79.5	−86.2	120.9
$CuSO_4$(*s*)	−771.36	−662.2	109.2
$Cu(NO_3)_2$(*s*)	−302.9	—	—
fluorine			
F_2(*g*)	0	0	202.8
F(*g*)	79.4	62.3	158.8
F^{-}(*aq*)	−332.6	−278.8	−13.8
F_2O(*g*)	24.7	41.9	247.43
HF(*g*)	−273.3	−275.4	173.8
hydrogen			
H_2(*g*)	0	0	130.7
H(*g*)	217.97	203.26	114.7
H^{+}(*aq*)	0	0	0
OH^{-}(*aq*)	−230.0	−157.2	−10.75
H_3O^{+}(*aq*)	−285.8		69.91
H_2O(*l*)	−285.83	−237.1	70.0
H_2O(*g*)	−241.82	−228.59	188.8
H_2O_2(*l*)	−187.78	−120.35	109.6
H_2O_2(*g*)	−136.3	−105.6	232.7
HF(*g*)	−273.3	−275.4	173.8
HCl(*g*)	−92.307	−95.299	186.9
HBr(*g*)	−36.3	−53.43	198.7
HI(*g*)	26.48	1.70	206.59
H_2S(*g*)	−20.6	−33.4	205.8

Substance	ΔH_f° (kJ mol^{-})	ΔG_f° (kJ mol^{-1})	S_{298}° (J K^{-1} mol^{-1})
$H_2Se(g)$	29.7	15.9	219.0
iodine			
$I_2(s)$	0	0	116.14
$I_2(g)$	62.438	19.3	260.7
$I(g)$	106.84	70.2	180.8
$I^-(aq)$	−55.19	−51.57	11.13
$IF(g)$	95.65	−118.49	236.06
$ICl(g)$	17.78	−5.44	247.44
$IBr(g)$	40.84	3.72	258.66
$IF_7(g)$	−943.91	−818.39	346.44
$HI(g)$	26.48	1.70	206.59
iron			
$Fe(s)$	0	0	27.3
$Fe(g)$	416.3	370.7	180.5
$Fe^{2+}(aq)$	−89.1	−78.90	−137.7
$Fe^{3+}(aq)$	−48.5	−4.7	−315.9
$Fe_2O_3(s)$	−824.2	−742.2	87.40
$Fe_3O_4(s)$	−1118.4	−1015.4	146.4
$Fe(CO)_5(l)$	−774.04	−705.42	338.07
$Fe(CO)_5(g)$	−733.87	−697.26	445.18
$FeCl_2(s)$	−341.79	−302.30	117.95
$FeCl_3(s)$	−399.49	−334.00	142.3
$FeO(s)$	−272.0	−255.2	60.75
$Fe(OH)_2(s)$	−569.0	−486.5	88.
$Fe(OH)_3(s)$	−823.0	−696.5	106.7
$FeS(s)$	−100.0	−100.4	60.29
$Fe_3C(s)$	25.10	20.08	104.60
lead			
$Pb(s)$	0	0	64.81
$Pb(g)$	195.2	162.	175.4

Substance	ΔH_f° (kJ mol⁻)	ΔG_f° (kJ mol^{-1})	S_{298}° (J K^{-1} mol^{-1})
Pb^{2+}(*aq*)	−1.7	−24.43	10.5
PbO(*s*) (yellow)	−217.32	−187.89	68.70
PbO(*s*) (red)	−218.99	−188.93	66.5
$Pb(OH)_2$(*s*)	−515.9	—	—
PbS(*s*)	−100.4	−98.7	91.2
$Pb(NO_3)_2$(*s*)	−451.9	—	—
PbO_2(*s*)	−277.4	−217.3	68.6
$PbCl_2$(*s*)	−359.4	−314.1	136.0
lithium			
Li(*s*)	0	0	29.1
Li(*g*)	159.3	126.6	138.8
Li^+(*aq*)	−278.5	−293.3	13.4
LiH(*s*)	−90.5	−68.3	20.0
Li(OH)(*s*)	−487.5	−441.5	42.8
LiF(*s*)	−616.0	−587.5	35.7
Li_2CO_3(*s*)	−1216.04	−1132.19	90.17
magnesium			
Mg^{2+}(*aq*)	−466.9	−454.8	−138.1
manganese			
Mn(*s*)	0	0	32.0
Mn(*g*)	280.7	238.5	173.7
Mn^{2+}(*aq*)	−220.8	−228.1	−73.6
MnO(*s*)	−385.2	−362.9	59.71
MnO_2(*s*)	−520.03	−465.1	53.05
Mn_2O_3(*s*)	−958.97	−881.15	110.46
Mn_3O_4(*s*)	−1378.83	−1283.23	155.64
MnO_4^-(*aq*)	−541.4	−447.2	191.2
MnO_4^{2-}(*aq*)	−653.0	−500.7	59
mercury			

Substance	ΔH°_f **(kJ mol^{-})**	ΔG°_f **(kJ mol^{-1})**	S°_{298} **(J K^{-1} mol^{-1})**
$Hg(\mathit{l})$	0	0	75.9
$Hg(\mathit{g})$	61.4	31.8	175.0
$Hg^{2+}(\mathit{aq})$		164.8	
$Hg^{2+}(\mathit{aq})$	172.4	153.9	84.5
$HgO(\mathit{s})$ (red)	−90.83	−58.5	70.29
$HgO(\mathit{s})$ (yellow)	−90.46	−58.43	71.13
$HgCl_2(\mathit{s})$	−224.3	−178.6	146.0
$Hg_2Cl_2(\mathit{s})$	−265.4	−210.7	191.6
$HgS(\mathit{s})$ (red)	−58.16	−50.6	82.4
$HgS(\mathit{s})$ (black)	−53.56	−47.70	88.28
$HgSO_4(\mathit{s})$	−707.51	−594.13	0.00
nickel			
$Ni^{2+}(\mathit{aq})$	−64.0	−46.4	−159
nitrogen			
$N_2(\mathit{g})$	0	0	191.6
$N(\mathit{g})$	472.704	455.5	153.3
$NO(\mathit{g})$	90.25	87.6	210.8
$NO_2(\mathit{g})$	33.2	51.30	240.1
$N_2O(\mathit{g})$	81.6	103.7	220.0
$N_2O_3(\mathit{g})$	83.72	139.41	312.17
$NO_3^-(\mathit{aq})$	−205.0	−108.7	146.4
$N_2O_4(\mathit{g})$	11.1	99.8	304.4
$N_2O_5(\mathit{g})$	11.3	115.1	355.7
$NH_3(\mathit{g})$	−45.9	−16.5	192.8
$NH_4^+(\mathit{aq})$	−132.5	−79.31	113.4
$N_2H_4(\mathit{l})$	50.63	149.43	121.21
$N_2H_4(\mathit{g})$	95.4	159.4	238.5
$NH_4NO_3(\mathit{s})$	−365.56	−183.87	151.08
$NH_4Cl(\mathit{s})$	−314.43	−202.87	94.6

Substance	ΔH_f° **(kJ mol⁻)**	ΔG_f° **(kJ mol^{-1})**	S_{298}° **(J K^{-1} mol^{-1})**
$NH_4Br(s)$	−270.8	−175.2	113.0
$NH_4I(s)$	−201.4	−112.5	117.0
$NH_4NO_2(s)$	−256.5	—	—
$HNO_3(l)$	−174.1	−80.7	155.6
$HNO_3(g)$	−133.9	−73.5	266.9
oxygen			
$O_2(g)$	0	0	205.2
$O(g)$	249.17	231.7	161.1
$O_3(g)$	142.7	163.2	238.9
phosphorus			
$P_4(s)$	0	0	164.4
$P_4(g)$	58.91	24.4	280.0
$P(g)$	314.64	278.25	163.19
$PH_3(g)$	5.4	13.5	210.2
$PCl_3(g)$	−287.0	−267.8	311.78
$PCl_5(g)$	−374.9	−305.0	364.4
$P_4O_6(s)$	−1640.1	—	—
$P_4O_{10}(s)$	−2984.0	−2697.0	228.86
$PO_4^{3-}(aq)$	−1277	−1019	−222
$HPO_3(s)$	−948.5	—	—
$HPO_4^{2-}(aq)$	−1292.1	−1089.3	−33
$H_2PO_4^{2-}(aq)$	−1296.3	−1130.4	90.4
$H_3PO_2(s)$	−604.6	—	—
$H_3PO_3(s)$	−964.4	—	—
$H_3PO_4(s)$	−1279.0	−1119.1	110.50
$H_3PO_4(l)$	−1266.9	−1124.3	110.5
$H_4P_2O_7(s)$	−2241.0	—	—
$POCl_3(l)$	−597.1	−520.8	222.5
$POCl_3(g)$	−558.5	−512.9	325.5
potassium			

Substance	ΔH_f° **(kJ mol⁻)**	ΔG_f° **(kJ mol^{-1})**	S_{298}° **(J K^{-1} mol^{-1})**
K(*s*)	0	0	64.7
K(*g*)	89.0	60.5	160.3
K^+(*aq*)	–252.4	–283.3	102.5
KF(*s*)	–576.27	–537.75	66.57
KCl(*s*)	–436.5	–408.5	82.6
rubidium			
Rb^+(*aq*)	–246	–282.2	124
silicon			
Si(*s*)	0	0	18.8
Si(*g*)	450.0	405.5	168.0
SiO_2(*s*)	–910.7	–856.3	41.5
SiH_4(*g*)	34.3	56.9	204.6
H_2SiO_3(*s*)	–1188.67	–1092.44	133.89
H_4SiO_4(*s*)	–1481.14	–1333.02	192.46
SiF_4(*g*)	–1615.0	–1572.8	282.8
$SiCl_4$(*l*)	–687.0	–619.8	239.7
$SiCl_4$(*g*)	–662.75	–622.58	330.62
SiC(*s, beta cubic*)	–73.22	–70.71	16.61
SiC(*s, alpha hexagonal*)	–71.55	–69.04	16.48
silver			
Ag(*s*)	0	0	42.55
Ag(*g*)	284.9	246.0	172.89
Ag^+(*aq*)	105.6	77.11	72.68
Ag_2O(*s*)	–31.05	–11.20	121.3
AgCl(*s*)	–127.0	–109.8	96.3
Ag_2S(*s*)	–32.6	–40.7	144.0
sodium			
Na(*s*)	0	0	51.3
Na(*g*)	107.5	77.0	153.7

Substance	ΔH_f° **(kJ mol⁻)**	ΔG_f° **(kJ mol^{-1})**	S_{298}° **(J K^{-1} mol^{-1})**
$Na^+(aq)$	−240.1	−261.9	59
$Na_2O(s)$	−414.2	−375.5	75.1
$NaCl(s)$	−411.2	−384.1	72.1
strontium			
$Sr^{2+}(aq)$	−545.8	−557.3	−32.6
sulfur			
$S_8(s)$ (rhombic)	0	0	256.8
$S(g)$	278.81	238.25	167.82
$S^{2-}(aq)$	41.8	83.7	22
$SO_2(g)$	−296.83	−300.1	248.2
$SO_3(g)$	−395.72	−371.06	256.76
$SO_4{}^{2-}(aq)$	−909.3	−744.5	20.1
$S_2O_3{}^{2-}(aq)$	−648.5	−522.5	67
$H_2S(g)$	−20.6	−33.4	205.8
$HS^-(aq)$	−17.7	12.6	61.1
$H_2SO_4(l)$	−813.989	690.00	156.90
$HSO_4{}^{2-}(aq)$	−885.75	−752.87	126.9
$H_2S_2O_7(s)$	−1273.6	—	—
$SF_4(g)$	−728.43	−684.84	291.12
$SF_6(g)$	−1220.5	−1116.5	291.5
$SCl_2(l)$	−50	—	—
$SCl_2(g)$	−19.7	—	—
$S_2Cl_2(l)$	−59.4	—	—
$S_2Cl_2(g)$	−19.50	−29.25	319.45
$SOCl_2(g)$	−212.55	−198.32	309.66
$SOCl_2(l)$	−245.6	—	—
$SO_2Cl_2(l)$	−394.1	—	—
$SO_2Cl_2(g)$	−354.80	−310.45	311.83
tin			

Substance	ΔH_f° **(kJ mol⁻)**	ΔG_f° **(kJ mol^{-1})**	S_{298}° **(J K^{-1} mol^{-1})**
Sn(*s*)	0	0	51.2
Sn(*g*)	301.2	266.2	168.5
SnO(*s*)	−285.8	−256.9	56.5
SnO_2(*s*)	−577.6	−515.8	49.0
$SnCl_4$(*l*)	−511.3	−440.1	258.6
$SnCl_4$(*g*)	−471.5	−432.2	365.8
titanium			
Ti(*s*)	0	0	30.7
Ti(*g*)	473.0	428.4	180.3
TiO_2(*s*)	−944.0	−888.8	50.6
$TiCl_4$(*l*)	−804.2	−737.2	252.4
$TiCl_4$(*g*)	−763.2	−726.3	353.2
tungsten			
W(*s*)	0	0	32.6
W(*g*)	849.4	807.1	174.0
WO_3(*s*)	−842.9	−764.0	75.9
zinc			
Zn(*s*)	0	0	41.6
Zn(*g*)	130.73	95.14	160.98
Zn^{2+}(*aq*)	−153.9	−147.1	−112.1
ZnO(*s*)	−350.5	−320.5	43.7
$ZnCl_2$(*s*)	−415.1	−369.43	111.5
ZnS(*s*)	−206.0	−201.3	57.7
$ZnSO_4$(*s*)	−982.8	−871.5	110.5
$ZnCO_3$(*s*)	−812.78	−731.57	82.42
complexes			
$[Co(NH_3)_4(NO_2)_2]NO_3$, *cis*	−898.7	—	—
$[Co(NH_3)_4(NO_2)_2]NO_3$, *trans*	−896.2	—	—
$NH_4[Co(NH_3)_2(NO_2)_4]$	−837.6	—	—
$[Co(NH_3)_6][Co(NH_3)_2(NO_2)_4]_3$	−2733.0	—	—

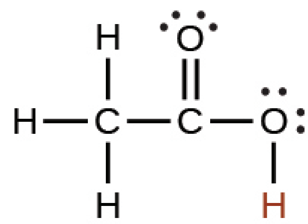
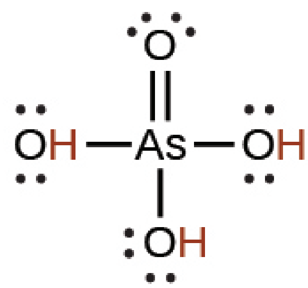
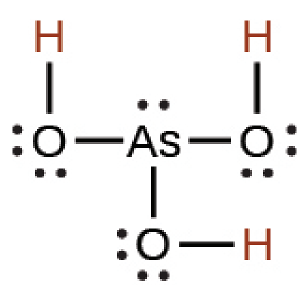
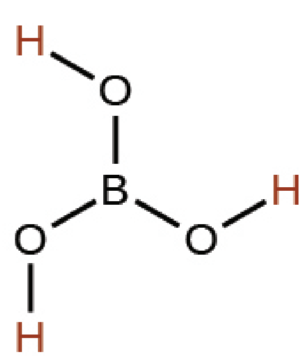
Substance	ΔH_f° (kJ mol^{-})	ΔG_f° (kJ mol^{-1})	S_{298}° (J K^{-1} mol^{-1})
$[Co(NH_3)_4Cl_2]Cl$, *cis*	–874.9	—	—
$[Co(NH_3)_4Cl_2]Cl$, *trans*	–877.4	—	—
$[Co(en)_2(NO_2)_2]NO_3$, *cis*	–689.5	—	—
$[Co(en)_2Cl_2]Cl$, *cis*	–681.2	—	—
$[Co(en)_2Cl_2]Cl$, *trans*	–677.4	—	—
$[Co(en)_3](ClO_4)_3$	–762.7	—	—
$[Co(en)_3]Br_2$	–595.8	—	—
$[Co(en)_3]I_2$	–475.3	—	—
$[Co(en)_3]I_3$	–519.2	—	—
$[Co(NH_3)_6](ClO_4)_3$	–1034.7	–221.1	615
$[Co(NH_3)_5NO_2](NO_3)_2$	–1088.7	–412.9	331
$[Co(NH_3)_6](NO_3)_3$	–1282.0	–524.5	448
$[Co(NH_3)_5Cl]Cl_2$	–1017.1	–582.5	366.1
$[Pt(NH_3)_4]Cl_2$	–725.5	—	—
$[Ni(NH_3)_6]Cl_2$	–994.1	—	—
$[Ni(NH_3)_6]Br_2$	–923.8	—	—
$[Ni(NH_3)_6]I_2$	–808.3	—	—

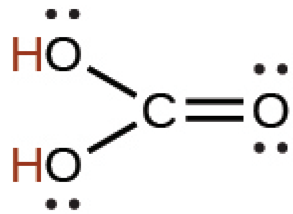
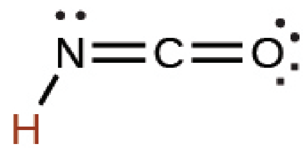
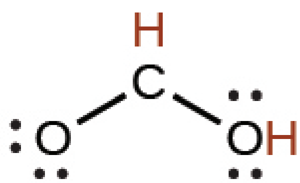
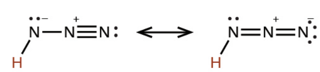
Attribution & References

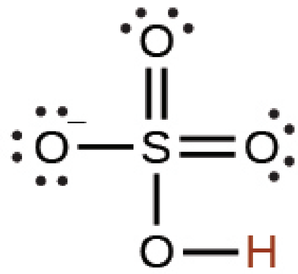
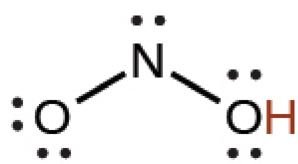
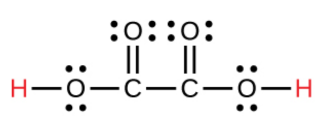
APPENDIX I: IONIZATION CONSTANTS OF WEAK ACIDS

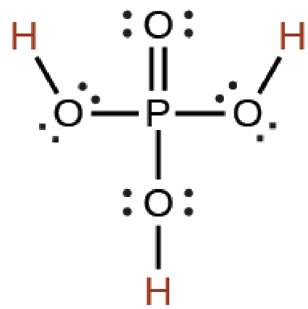
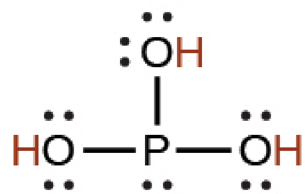
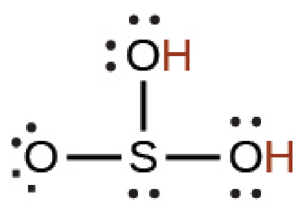
Ionization Constants of Weak Acids

Table I.1: Ionization Constants of Weak Acids

Acid	Formula	K_a at 25 °C	Lewis Structure
acetic	$CH_3CO_2\mathbf{H}$	1.8×10^{-5}	
arsenic	$\mathbf{H_3}AsO_4$	5.5×10^{-3}	
	$H_2AsO_4^{-}$	1.7×10^{-7}	
	$HAsO_4^{2-}$	5.1×10^{-12}	
arsenous	$\mathbf{H_3}AsO_3$	5.1×10^{-10}	
boric	$\mathbf{H_3}BO_3$	5.4×10^{-10}	

Acid	Formula	K_a at 25 °C	Lewis Structure
carbonic	$\mathbf{H}_2\mathrm{CO}_3$	4.3×10^{-7}	
	$\mathbf{H}\mathrm{CO}_3^-$	5.6×10^{-11}	
cyanic	$\mathbf{H}\mathrm{CNO}$	2×10^{-4}	
formic	$\mathrm{HCO}_2\mathbf{H}$	1.8×10^{-4}	
hydrazoic	$\mathbf{H}\mathrm{N}_3$	2.5×10^{-5}	
hydrocyanic	$\mathbf{H}\mathrm{CN}$	4.9×10^{-10}	
hydrofluoric	$\mathbf{H}\mathrm{F}$	3.5×10^{-4}	
hydrogen peroxide	$\mathbf{H}_2\mathrm{O}_2$	2.4×10^{-12}	
hydrogen selenide	$\mathbf{H}_2\mathrm{Se}$	1.29×10^{-4}	
	$\mathbf{H}\mathrm{Se}^-$	1×10^{-12}	

Acid	Formula	K_a at 25 °C	Lewis Structure
hydrogen sulfate ion	HSO_4^-	1.2×10^{-2}	
hydrogen sulfide	H_2S	8.9×10^{-8}	
	HS^-	1.0×10^{-19}	
hydrogen telluride	H_2Te	2.3×10^{-3}	
	HTe^-	1.6×10^{-11}	
hypobromous	$HBrO$	2.8×10^{-9}	
hypochlorous	$HClO$	2.9×10^{-8}	
nitrous	HNO_2	4.6×10^{-4}	
oxalic	$H_2C_2O_4$	6.0×10^{-2}	
	$HC_2O_4^-$	6.1×10^{-5}	

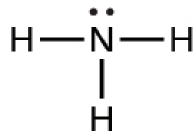
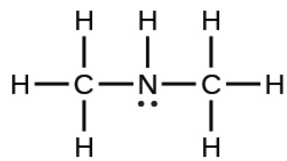
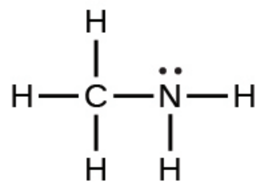
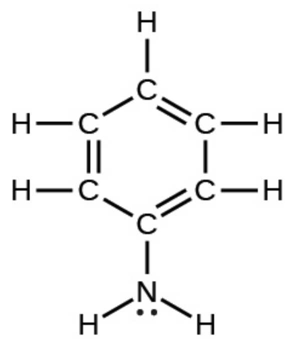
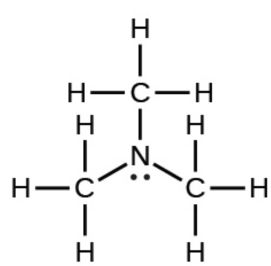
Acid	Formula	K_a at 25 °C	Lewis Structure
phosphoric	**H_3**PO_4	7.5×10^{-3}	
	$H_2PO_4^-$	6.2×10^{-8}	
	HPO_4^{2-}	4.2×10^{-13}	
phosphorous	**H_3**PO_3	5×10^{-2}	
	$H_2PO_3^-$	2.0×10^{-7}	
sulfurous	**H_2**SO_3	1.6×10^{-2}	
	HSO_3^-	6.4×10^{-8}	

Attribution & References

APPENDIX J: IONIZATION CONSTANTS OF WEAK BASES

Ionization Constants of Weak Bases

Table J.1: Ionization Constants of Weak Bases

Base	Lewis Structure	K_b at 25 °C
ammonia		1.8×10^{-5}
dimethylamine		5.9×10^{-4}
methylamine		4.4×10^{-4}
phenylamine (aniline)		4.3×10^{-10}
trimethylamine		6.3×10^{-5}

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APPENDIX K: SOLUBILITY PRODUCTS

Solubility Products

Table K.1: Solubility Products

Main Element	Substance	K_{sp} at 25 °C
aluminum	$Al(OH)_3$	2×10^{-32}
barium	$BaCO_3$	1.6×10^{-9}
barium	$BaC_2O_4 \cdot 2H_2O$	1.1×10^{-7}
barium	$BaSO_4$	2.3×10^{-8}
barium	$BaCrO_4$	8.5×10^{-11}
barium	BaF_2	2.4×10^{-5}
barium	$Ba(OH)_2 \cdot 8H_2O$	5.0×10^{-3}
barium	$Ba_3(PO_4)_2$	6×10^{-39}
barium	$Ba_3(AsO_4)_2$	1.1×10^{-13}
bismuth	$BiO(OH)$	4×10^{-10}
bismuth	$BiOCl$	1.8×10^{-31}
bismuth	Bi_2S_3	1×10^{-97}
cadmium	$Cd(OH)_2$	5.9×10^{-15}
cadmium	CdS	1.0×10^{-28}
cadmium	$CdCO_3$	5.2×10^{-12}
calcium	$Ca(OH)_2$	1.3×10^{-6}
calcium	$CaCO_3$	8.7×10^{-9}
calcium	$CaSO4 \cdot 2H_2O$	6.1×10^{-5}
calcium	$CaC_2O_4 \cdot H_2O$	1.96×10^{-8}
calcium	$Ca_3(PO_4)_2$	1.3×10^{-32}
calcium	$CaHPO_4$	7×10^{-7}
calcium	CaF_2	4.0×10^{-11}
chromium	$Cr(OH)_3$	6.7×10^{-31}
cobalt	$Co(OH)_2$	2.5×10^{-16}
cobalt	$CoS(\alpha)$	5×10^{-22}
cobalt	$CoS(\beta)$	3×10^{-26}
cobalt	$CoCO_3$	1.4×10^{-13}

Main Element	Substance	K_{sp} at 25 °C
cobalt	$Co(OH)_3$	2.5×10^{-43}
copper	CuCl	1.2×10^{-6}
copper	CuBr	6.27×10^{-9}
copper	CuI	1.27×10^{-12}
copper	CuSCN	1.6×10^{-11}
copper	Cu_2S	2.5×10^{-48}
copper	$Cu(OH)_2$	2.2×10^{-20}
copper	CuS	8.5×10^{-45}
copper	$CuCO_3$	2.5×10^{-10}
iron	$Fe(OH)_2$	1.8×10^{-15}
iron	$FeCO_3$	2.1×10^{-11}
iron	FeS	3.7×10^{-19}
iron	$Fe(OH)_3$	4×10^{-38}
lead	$Pb(OH)_2$	1.2×10^{-15}
lead	PbF_2	4×10^{-8}
lead	$PbCl_2$	1.6×10^{-5}
lead	$PbBr_2$	4.6×10^{-6}
lead	PbI_2	1.4×10^{-8}
lead	$PbCO_3$	1.5×10^{-15}
lead	PbS	7×10^{-29}
lead	$PbCrO_4$	2×10^{-16}
lead	$PbSO_4$	1.3×10^{-8}
lead	$Pb_3(PO_4)_2$	1×10^{-54}
magnesium	$Mg(OH)_2$	8.9×10^{-12}
magnesium	$MgCO_3{\cdot}3H_2O$	*ca* 1×10^{-5}
magnesium	$MgNH_4PO_4$	3×10^{-13}
magnesium	MgF_2	6.4×10^{-9}
magnesium	MgC_2O_4	7×10^{-7}

Main Element	Substance	K_{sp} at 25 °C
manganese	$Mn(OH)_2$	2×10^{-13}
manganese	$MnCO_3$	8.8×10^{-11}
manganese	MnS	2.3×10^{-13}
mercury	$Hg_2O{\cdot}H_2O$	3.6×10^{-26}
mercury	Hg_2Cl_2	1.1×10^{-18}
mercury	Hg_2Br_2	1.3×10^{-22}
mercury	Hg_2I_2	4.5×10^{-29}
mercury	Hg_2CO_3	9×10^{-15}
mercury	Hg_2SO_4	7.4×10^{-7}
mercury	Hg_2S	1.0×10^{-47}
mercury	Hg_2CrO_4	2×10^{-9}
mercury	HgS	1.6×10^{-54}
nickel	$Ni(OH)_2$	1.6×10^{-16}
nickel	$NiCO_3$	1.4×10^{-7}
nickel	$NiS(\alpha)$	4×10^{-20}
nickel	$NiS(\beta)$	1.3×10^{-25}
potassium	$KClO_4$	1.05×10^{-2}
potassium	K_2PtCl_6	7.48×10^{-6}
potassium	$KHC_4H_4O_6$	3×10^{-4}
silver	$\frac{1}{2}Ag_2O(Ag^+ + OH^-)$	2×10^{-8}
silver	$AgCl$	1.6×10^{-10}
silver	$AgBr$	5.0×10^{-13}
silver	AgI	1.5×10^{-16}
silver	$AgCN$	1.2×10^{-16}
silver	$AgSCN$	1.0×10^{-12}
silver	Ag_2S	1.6×10^{-49}
silver	Ag_2CO_3	8.1×10^{-12}
silver	Ag_2CrO_4	9.0×10^{-12}

Main Element	Substance	K_{sp} at 25 °C
silver	$Ag_4Fe(CN)_6$	1.55×10^{-41}
silver	Ag_2SO_4	1.2×10^{-5}
silver	Ag_3PO_4	1.8×10^{-18}
strontium	$Sr(OH)_2{\cdot}8H_2O$	3.2×10^{-4}
strontium	$SrCO_3$	7×10^{-10}
strontium	$SrCrO_4$	3.6×10^{-5}
strontium	$SrSO_4$	3.2×10^{-7}
strontium	$SrC_2O_4{\cdot}H_2O$	4×10^{-7}
thallium	$TlCl$	1.7×10^{-4}
thallium	$TlSCN$	1.6×10^{-4}
thallium	Tl_2S	6×10^{-22}
thallium	$Tl(OH)_3$	6.3×10^{-46}
tin	$Sn(OH)_2$	3×10^{-27}
tin	SnS	1×10^{-26}
tin	$Sn(OH)_4$	1.0×10^{-57}
zinc	$ZnCO_3$	2×10^{-10}

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APPENDIX L: FORMATION CONSTANTS FOR COMPLEX IONS

Formation Constants – Complex Ions

Table L.1: Formation Constants for Complex Ions

Equilibrium	K_f
$Al^{3+} + 6F^- \rightleftharpoons [AlF_6]^{3-}$	7×10^{19}
$Cd^{2+} + 4NH_3 \rightleftharpoons [Cd(NH_3)_4]^{2+}$	1.3×10^{7}
$Cd^{2+} + 4CN^- \rightleftharpoons [Cd(CN)_4]^{2-}$	3×10^{18}
$Co^{2+} + 6NH_3 \rightleftharpoons [Co(NH_3)_6]^{2+}$	1.3×10^{5}
$Co^{3+} + 6NH_3 \rightleftharpoons [Co(NH_3)_6]^{3+}$	2.3×10^{33}
$Cu^{+} + 2CN \rightleftharpoons [Cu(CN)_2]^{-}$	1.0×10^{16}
$Cu^{2+} + 4NH_3 \rightleftharpoons [Cu(NH_3)_4]^{2+}$	1.7×10^{13}
$Fe^{2+} + 6CN^- \rightleftharpoons [Fe(CN)_6]^{4-}$	1.5×10^{35}
$Fe^{3+} + 6CN^- \rightleftharpoons [Fe(CN)_6]^{3-}$	2×10^{43}
$Fe^{3+} + 6SCN^- \rightleftharpoons [Fe(SCN)_6]^{3-}$	3.2×10^{3}
$Hg^{2+} + 4Cl^- \rightleftharpoons [HgCl_4]^{2-}$	1.1×10^{16}
$Ni^{2+} + 6NH_3 \rightleftharpoons [Ni(NH_3)_6]^{2+}$	2.0×10^{8}
$Ag^{+} + 2Cl^- \rightleftharpoons [AgCl_2]^{-}$	1.8×10^{5}
$Ag^{+} + 2CN^- \rightleftharpoons [Ag(CN)_2]^{-}$	1×10^{21}
$Ag^{+} + 2NH_3 \rightleftharpoons [Ag(NH_3)_2]^{+}$	1.7×10^{7}
$Zn^{2+} + 4CN^- \rightleftharpoons [Zn(CN)_4]^{2-}$	2.1×10^{19}
$Zn^{2+} + 4OH^- \rightleftharpoons [Zn(OH)_4]^{2-}$	2×10^{15}
$Fe^{3+} + SCN^- \rightleftharpoons [Fe(SCN)]^{2+}$	8.9×10^{2}
$Ag^{+} + 4SCN^- \rightleftharpoons [Ag(SCN)_4]^{3-}$	1.2×10^{10}
$Pb^{2+} + 4I^- \rightleftharpoons [PbI_4]^{2-}$	3.0×10^{4}
$Pt^{2+} + 4Cl^- \rightleftharpoons [PtCl_4]^{2-}$	1×10^{16}
$Cu^{2+} + 4CN \rightleftharpoons [Cu(CN)_4]^{2-}$	1.0×10^{25}

Equilibrium	K_f
$Co^{2+} + 4SCN^- \rightleftharpoons [Co(SCN)_4]^{2-}$	1 × 10^3

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APPENDIX M: STANDARD ELECTRODE (HALF-CELL) POTENTIALS

Standard Electrode Potentials

Table M.1: Standard Electrode (Half-Cell) Potentials

Half-Reaction	*E*° (V)
$Ag^{+} + e^{-} \longrightarrow Ag$	+0.7996
$AgCl + e^{-} \longrightarrow Ag + Cl^{-}$	+0.22233
$[Ag(CN)_2]^{-} + e^{-} \longrightarrow Ag + 2CN^{-}$	−0.31
$Ag_2CrO_4 + 2e^{-} \longrightarrow 2Ag + {CrO_4}^{2-}$	+0.45
$[Ag(NH_3)_2]^{+} + e^{-} \longrightarrow Ag + 2NH_3$	+0.373
$[Ag(S_2O_3)_2]^{3+} + e^{-} \longrightarrow Ag + 2{S_2O_3}^{2-}$	+0.017
$[AlF_6]^{3-} + 3e^{-} \longrightarrow Al + 6F^{-}$	−2.07
$Al^{3+} + 3e^{-} \longrightarrow Al$	−1.662
$Am^{3+} + 3e^{-} \longrightarrow Am$	−2.048
$Au^{3+} + 3e^{-} \longrightarrow Au$	+1.498
$Au^{+} + e^{-} \longrightarrow Au$	+1.692
$Ba^{2+} + 2e^{-} \longrightarrow Ba$	−2.912
$Be^{2+} + 2e^{-} \longrightarrow Be$	−1.847
$Br_2(aq) + 2e^{-} \longrightarrow 2Br^{-}$	+1.0873
$Ca^{2+} + 2e^{-} \longrightarrow Ca$	−2.868
$Ce^{3} + 3e^{-} \longrightarrow Ce$	−2.483
$Ce^{4+} + e^{-} \longrightarrow Ce^{3+}$	+1.61
$Cd^{2+} + 2e^{-} \longrightarrow Cd$	−0.4030
$[Cd(CN)_4]^{2-} + 2e^{-} \longrightarrow Cd + 4CN^{-}$	−1.09
$[Cd(NH_3)_4]^{2+} + 2e^{-} \longrightarrow Cd + 4NH_3$	−0.61
$CdS + 2e^{-} \longrightarrow Cd + S^{2-}$	−1.17
$Cl_2 + 2e^{-} \longrightarrow 2Cl^{-}$	+1.35827
${ClO_4}^{-} + H_2O + 2e^{-} \longrightarrow {ClO_3}^{-} + 2OH^{-}$	+0.36
${ClO_3}^{-} + H_2O + 2e^{-} \longrightarrow {ClO_2}^{-} + 2OH^{-}$	+0.33
${ClO_2}^{-} + H_2O + 2e^{-} \longrightarrow ClO^{-} + 2OH^{-}$	+0.66
$ClO^{-} + H_2O + 2e^{-} \longrightarrow Cl^{-} + 2OH^{-}$	+0.89

$ClO_4{}^- + 2H_3O^+ + 2e^- \longrightarrow ClO_3{}^- + 3H_2O$	+1.189
$ClO_3{}^- + 3H_3O^+ + 2e^- \longrightarrow HClO_2 + 4H_2O$	+1.21
$HClO + H_3O^+ + 2e^- \longrightarrow Cl^- + 2H_2O$	+1.482
$HClO + H_3O^+ + e^- \longrightarrow \frac{1}{2}Cl_2 + 2H_2O$	+1.611
$HClO_2 + 2H_3O^+ + 2e^- \longrightarrow HClO + 3H_2O$	+1.628
$Co^{3+} + e^- \longrightarrow Co^{2+}$ (2mol\;//\;H_2SO_4)	+1.83
$Co^{2+} + 2e^- \longrightarrow Co$	−0.28
$[Co(NH_3)_6]^{3+} + e^- \longrightarrow [Co(NH_3)_6]^{2+}$	+0.1
$Co(OH)_3 + e^- \longrightarrow Co(OH)_2 + OH^-$	+0.17
$Cr^3 + 3e^- \longrightarrow Cr$	−0.744
$Cr^{3+} + e^- \longrightarrow Cr^{2+}$	−0.407
$Cr^{2+} + 2e^- \longrightarrow Cr$	−0.913
$[Cu(CN)_2]^- + e^- \longrightarrow Cu + 2CN^-$	−0.43
$CrO_4{}^{2-} + 4H_2O + 3e^- \longrightarrow Cr(OH)_3 + 5OH^-$	−0.13
$Cr_2O_7{}^{2-} + 14H_3O^+ + 6e^- \longrightarrow 2Cr^{3+} + 21H_2O$	+1.232
$[Cr(OH)_4]^- + 3e^- \longrightarrow Cr + 4OH^-$	−1.2
$Cr(OH)_3 + 3e^- \longrightarrow Cr + 3OH^-$	−1.48
$Cu^{2+} + e^- \longrightarrow Cu^+$	+0.153
$Cu^{2+} + 2e^- \longrightarrow Cu$	+0.34
$Cu^+ + e^- \longrightarrow Cu$	+0.521
$F_2 + 2e^- \longrightarrow 2F^-$	+2.866
$Fe^{2+} + 2e^- \longrightarrow Fe$	−0.447
$Fe^{3+} + e^- \longrightarrow Fe^{2+}$	+0.771
$[Fe(CN)_6]^{3-} + e^- \longrightarrow [Fe(CN)_6]^{4-}$	+0.36
$Fe(OH)_2 + 2e^- \longrightarrow Fe + 2OH^-$	−0.88
$FeS + 2e^- \longrightarrow Fe + S^{2-}$	−1.01
$Ga^{3+} + 3e^- \longrightarrow Ga$	−0.549
$Gd^{3+} + 3e^- \longrightarrow Gd$	−2.279

$\frac{1}{2}H_2 + e^- \longrightarrow H^-$	−2.23
$2H_2O + 2e^- \longrightarrow H_2 + 2OH^-$	−0.8277
$H_2O_2 + 2H_3O^+ + 2e^- \longrightarrow 4H_2O$	+1.776
$2H_3O^+ + 2e^- \longrightarrow H_2 + 2H_2O$	0.00
$HO_2{}^- + H_2O + 2e^- \longrightarrow 3OH^-$	+0.878
$Hf^{4+} + 4e^- \longrightarrow Hf$	−1.55
$Hg^{2+} + 2e^- \longrightarrow Hg$	+0.851
$2Hg^{2+} + 2e^- \longrightarrow Hg_2{}^{2+}$	+0.92
$Hg_2{}^{2+} + 2e^- \longrightarrow 2Hg$	+0.7973
$[HgBr_4]^{2-} + 2e^- \longrightarrow Hg + 4Br^-$	+0.21
$Hg_2Cl_2 + 2e^- \longrightarrow 2Hg + 2Cl^-$	+0.26808
$[Hg(CN)_4]^{2-} + 2e^- \longrightarrow Hg + 4CN^-$	−0.37
$[HgI_4]^{2-} + 2e^- \longrightarrow Hg + 4I^-$	−0.04
$HgS + 2e^- \longrightarrow Hg + S^{2-}$	−0.70
$I_2 + 2e^- \longrightarrow 2I^-$	+0.5355
$In^{3+} + 3e^- \longrightarrow In$	−0.3382
$K^+ + e^- \longrightarrow K$	−2.931
$La^{3+} + 3e^- \longrightarrow La$	−2.52
$Li^+ + e^- \longrightarrow Li$	−3.04
$Lu^{3+} + 3e^- \longrightarrow Lu$	−2.28
$Mg^{2+} + 2e^- \longrightarrow Mg$	−2.372
$Mn^{2+} + 2e^- \longrightarrow Mn$	−1.185
$MnO_2 + 2H_2O + 2e^- \longrightarrow Mn(OH)_2 + 2OH^-$	−0.05
$MnO_4{}^- + 2H_2O + 3e^- \longrightarrow MnO_2 + 4OH^-$	+0.558
$MnO_2 + 4H^+ + 2e^- \longrightarrow Mn^{2+} + 2H_2O$	+1.23
$MnO_4{}^- + 8H^+ + 5e^- \longrightarrow Mn^{2+} + 4H_2O$	+1.507
$Na^+ + e^- \longrightarrow Na$	−2.71

$Nd^{3+} + 3e^- \longrightarrow Nd$	−2.323
$Ni^{2+} + 2e^- \longrightarrow Ni$	−0.257
$[Ni(NH_3)_6]^{2+} + 2e^- \longrightarrow Ni + 6NH_3$	−0.49
$NiO_2 + 4H^+ + 2e^- \longrightarrow Ni^{2+} + 2H_2O$	+1.593
$NiO_2 + 2H_2O + 2e^- \longrightarrow Ni(OH)_2 + 2OH^-$	+0.49
$NiS + 2e^- \longrightarrow Ni + S^{2-}$	+0.76
$NO_3{}^- + 4H^+ + 3e^- \longrightarrow NO + 2H_2O$	+0.957
$NO_3{}^- + 3H^+ + 2e^- \longrightarrow HNO_2 + H_2O$	+0.92
$NO_3{}^- + H_2O + 2e^- \longrightarrow NO_2{}^- + 2OH^-$	+0.10
$Np^{3+} + 3e^- \longrightarrow Np$	−1.856
$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$	+0.401
$O_2 + 2H^+ + 2e^- \longrightarrow H_2O_2$	+0.695
$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$	+1.229
$Pb^{2+} + 2e^- \longrightarrow Pb$	−0.1262
$PbO_2 + SO_4{}^{2-} + 4H^+ + 2e^- \longrightarrow PbSO_4 + 2H_2O$	+1.69
$PbS + 2e^- \longrightarrow Pb + S^{2-}$	−0.95
$PbSO_4 + 2e^- \longrightarrow Pb + SO_4{}^{2-}$	−0.3505
$Pd^{2+} + 2e^- \longrightarrow Pd$	+0.987
$[PdCl_4]^{2-} + 2e^- \longrightarrow Pd + 4Cl^-$	+0.591
$Pt^{2+} + 2e^- \longrightarrow Pt$	+1.20
$[PtBr_4]^{2-} + 2e^- \longrightarrow Pt + 4Br^-$	+0.58
$[PtCl_4]^{2-} + 2e^- \longrightarrow Pt + 4Cl^-$	+0.755
$[PtCl_6]^{2-} + 2e^- \longrightarrow [PtCl_4]^{2-} + 2Cl^-$	+0.68
$Pu^3 + 3e^- \longrightarrow Pu$	−2.03
$Ra^{2+} + 2e^- \longrightarrow Ra$	−2.92
$Rb^+ + e^- \longrightarrow Rb$	−2.98
$[RhCl_6]^{3-} + 3e^- \longrightarrow Rh + 6Cl^-$	+0.44
$S + 2e^- \longrightarrow S^{2-}$	−0.47627

$S + 2H^{+} + 2e^{-} \longrightarrow H_2S$	+0.142
$Sc^{3+} + 3e^{-} \longrightarrow Sc$	−2.09
$Se + 2H^{+} + 2e^{-} \longrightarrow H_2Se$	−0.399
$[SiF_6]^{2-} + 4e^{-} \longrightarrow Si + 6F^{-}$	−1.2
$SiO_3{}^{2-} + 3H_2O + 4e^{-} \longrightarrow Si + 6OH^{-}$	−1.697
$SiO_2 + 4H^{+} + 4e^{-} \longrightarrow Si + 2H_2O$	−0.86
$Sm^{3+} + 3e^{-} \longrightarrow Sm$	−2.304
$Sn^{4+} + 2e^{-} \longrightarrow Sn^{2+}$	+0.151
$Sn^{2+} + 2e^{-} \longrightarrow Sn$	−0.1375
$[SnF_6]^{2-} + 4e^{-} \longrightarrow Sn + 6F^{-}$	−0.25
$SnS + 2e^{-} \longrightarrow Sn + S^{2-}$	−0.94
$Sr^{2+} + 2e^{-} \longrightarrow Sr$	−2.89
$TeO_2 + 4H^{+} + 4e^{-} \longrightarrow Te + 2H_2O$	+0.593
$Th^{4+} + 4e^{-} \longrightarrow Th$	−1.90
$Ti^{2+} + 2e^{-} \longrightarrow Ti$	−1.630
$U^{3+} + 3e^{-} \longrightarrow U$	−1.79
$V^{2+} + 2e^{-} \longrightarrow V$	−1.19
$Y^{3+} + 3e^{-} \longrightarrow Y$	−2.37
$Zn^{2+} + 2e^{-} \longrightarrow Zn$	−0.7618
$[Zn(CN)_4]^{2-} + 2e^{-} \longrightarrow Zn + 4CN^{-}$	−1.26
$[Zn(NH_3)_4]^{2+} + 2e^{-} \longrightarrow Zn + 4NH_3$	−1.04
$Zn(OH)_2 + 2e^{-} \longrightarrow Zn + 2OH^{-}$	−1.245
$[Zn(OH)_4]^{2} + 2e^{-} \longrightarrow Zn + 4OH^{-}$	−1.199
$ZnS + 2e^{-} \longrightarrow Zn + S^{2-}$	−1.40
$Zr^{4} + 4e^{-} \longrightarrow Zr$	−1.539

Attribution & References

INFOGRAPHICS - TEXT VERSION

Infographics used in this book

- 2.0a Twelve Women in Chemistry
- 10.1a This Day in Chemistry May 12 – Dorothy Hodgkin

This page provides a textual summary of infographics used in the following areas of the book.

2.0a Twelve Women in Chemistry

Carolyn Bertozzi – Chemical Biologist

Bertozzi researches the role of sugars on the surface of cells in diseases such as cancer, and develops technology to advance biomedical research.

Ada Yonath – Crystallographer

Yonath's research on the structure of the ribosome, which helps cells build proteins, won her a Nobel Prize. She also worked on modes of action of antibiotics.

Susan Solomon – Atmospheric Chemist

Solomon's work helped confirm that chlorine-containing compounds deplete ozone, and explained why this depletion was focused over the Earth's poles.

Paula Hammond – Chemical Engineer

Hammond's research focuses on nanoscale polymers for drug delivery and other applications. She co-founded the MIT Institute for Soldier Nanotechnology.

Darleane Hoffman – Nuclear Chemist

Hoffman was one of the researchers who confirmed the existence of element 106, Seaborgium. She also captured and analysed elements heavier than uranium.

Carol Robinson – Physical Chemist

The first female chemistry professor at both Cambridge and Oxford University. Uses mass spectrometry to reveal the structure and reactivity of proteins.

Pratibha Gai – Materials Chemist

Gai co-invented a type of microscope that allows visualisation of reactions at the atomic scale. She chose not to patent it so it could be easily used by others.

Jacqueline Barton – Biophysical Chemist

Barton studies the chemical and physical properties of DNA and the role of charge transport chemistry in DNA repain. She has received numerous awards for her work.

Jennifer Doudna – Molecular Biochemist

Doudna was a leading figure in the development of CRISPR gene editing, a technology that could in the future lead to treatments for a range of diseases.

Tu Youyou – Pharmaceutical Chemist

Won a Nobel Prize for her discovery of artemisinin, a compound derived from the wormwood plant and used as a drug to treat malaria.

Lesley Yellowlees – Inorganic Chemist

The first female president of the Royal Society of Chemistry. Her research focuses on electron transfer reactions, solar energy and EPR spectroscopy.

Polly Arnold – Organometallic Chemist

Arnold's research focuses on synthetic chemistry and theories of bonding and reactivity, with the ai, of understanding the behaviour of nuclear waste.

10.1a This Day in Chemistry May 12 – Dorothy Hodgkin

Dorothy Hodgkin was born on May 12, 1910; died July 29, 1994. She's most famous for being one of only four women to have won a Nobel Prize in Chemistry, and the only British woman to have done so. This graphic takes a look at the work that earned her the prize:

- **Penicillin (1945):** Hodgkin confirmed the structure of penicillin – the first time the structure of a whole molecule had been calculated using X-ray data.
- **Vitamin B_{12} (1955):** Vitamin B_{12} was, at the time, the most complex molecule tackled by X-ray crystallography. Its structure took Hodgkin eight years to solve.
- **Insulin (1969):** Hodgkin first grew crystals of insulin in 1935, but it was another 34 years before she determined its three-dimensional structure.

Read more about "This Day in Chemistry May 12 – Dorothy Hodgkin" by Andy Brunning / Compound Interest, CC BY-NC-ND

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