Dimensions and Units for Environmental Quantities

Three fundamental dimensions of measurement, mass [M], length [L], and time [T], form the basis for most environmental quantities. A good understanding of these dimensions and of the way in which they are combined to form various units of measurement clarifies many problems of chemical fate and transport.

A.1 FUNDAMENTAL DIMENSIONS AND COMMON UNITS OF MEASUREMENT

Mass

Mass refers to an amount of substance such as a kilogram of soil, a ton of road salt, or a microgram of soot particles. The gram (g) or the kilogram (kg) are commonly used units of mass in the Système International (SI) measurement system. Mass is frequently determined by measuring the force exerted on it by a gravitational field (i.e., weighing it), but it also can be determined on the basis of its inertia. In the English measurement system, the unit of the

TABLE A-1 C[illegible]n Mass Units and Interconversion Factors[a]

	Gram	Kilogram	Pound[b]	Slug	Ton (short)[b]	Ton (metric)
Gram	1	10^{-3}	2.205×10^{-3}	6.852×10^{-5}	1.102×10^{-6}	10^{-6}
Kilogram	1000	1	2.205	6.852×10^{-2}	1.102×10^{-3}	0.001
Pound[b]	453.6	0.4536	1	3.108×10^{-2}	5×10^{-4}	4.536×10^{-4}
Slug	1.459×10^{4}	14.59	32.17	1	1.609×10^{-2}	14.59×10^{-3}
Ton (short)[b]	9.072×10^{5}	907.2	2000	62.16	1	0.9072
Ton (metric)	10^{6}	1000	2204	68.50	1.102	1

[a]Weast, R. C. (Ed.) (1990). *CRC Handbook of Chemistry and Physics*. CRC Press, Boca Raton, FL.
[b]Really a unit of force—the amount of mass that weighs 1 lb or 1 short ton.

pound (lb), often loosely used to refer to mass, is actually a unit of force, as described in the next section; a pound of soil is that amount of soil on which Earth's gravity exerts 1 lb of force. See Table A-1 for common units of mass and interconversion factors for both the SI and English systems.

Length

In the SI system, the meter (m) and the centimeter (cm) are common units of length. An English unit, the foot (ft), still is used to some extent in fields such as hydrology and meteorology. Table A-2 gives common units of length and interconversion factors. Table A-3 presents multiplier prefixes for use with SI units.

Time

The SI base unit for time is the second (sec). Often it is convenient to use units considerably longer than the second, such as hours (hr), days, and years. Because these units of time are not decimally related, one must be prepared to make unit interconversions with a hand calculator.

TABLE A-2 Common Length Units and Interconversion Factors[a]

	Centimeter	Foot	Inch	Kilometer	Meter	Mile
Centimeter	1	0.03281	0.3937	10^{-5}	10^{-2}	6.214×10^{-6}
Foot	30.48	1	12	3.048×10^{-4}	0.3048	1.894×10^{-4}
Inch	2.54	0.08333	1	2.54×10^{-5}	2.54×10^{-2}	1.578×10^{-5}
Kilometer	10^{5}	3281	39,370	1	1000	0.6214
Meter	10^{2}	3.281	39.37	10^{-3}	1	6.214×10^{-4}
Mile	1.609×10^{5}	5280	63,360	1.609	1609	1

[a]Weast (1990).

TABLE A-3 Multiplier Prefixes for Use with SI Units[a]

10^{-18}	atto-	a
10^{-15}	femto-	f
10^{-12}	pico-	p
10^{-9}	nano-	n
10^{-6}	micro-	μ
10^{-3}	milli-	m
10^{-2}	centi-	c
10^{-1}	deci-	d
10^{1}	deca-	da
10^{2}	hecto-	h
10^{3}	kilo-	k
10^{6}	mega-	M
10^{9}	giga-	G
10^{12}	tera-	T
10^{15}	peta-	P
10^{18}	exa-	E

[a]Weast (1990).

A.2 DERIVED DIMENSIONS AND COMMON UNITS

Area and Volume

Among the simplest derived dimensions are area $[L^2]$ and volume $[L^3]$. While the square meter (m^2) is a common SI unit of area, numerous other units [e.g., square foot (ft^2), acre, hectare (ha), and square mile (mi^2)] are in use, as shown in Table A-4. A common SI unit of volume is the cubic meter (m^3), although for environmental chemical problems the liter is often used. Note that liter is spelled out throughout this book, whereas [L] refers to the dimension length. Table A-5 presents common volume units and interconversion factors.

Velocity and Acceleration

Velocity, V or v, conveys both the speed at which something is traveling and the direction in which it is moving; it has dimensions of [L/T]. Common units include m/sec and cm/sec. Acceleration, a, is the rate at which velocity changes with time. Like velocity, it has both a magnitude and a direction. The

TABLE A-4 Common Area Units and Interconversion Factors[a]

	Acre	Hectare	Square foot	Square kilometer	Square meter	Square mile
Acre	1	0.4047	43,560	4.047×10^{-3}	4047	1.563×10^{-3}
Hectare	2.471	1	1.076×10^{5}	0.01	10^{4}	3.861×10^{-3}
Square foot	2.296×10^{-5}	9.290×10^{-6}	1	9.290×10^{-8}	0.0929	3.587×10^{-8}
Square kilometer	247.1	100	1.076×10^{7}	1	10^{6}	0.386
Square meter	2.471×10^{-4}	10^{-4}	10.764	10^{-6}	1	3.861×10^{-7}
Square mile	640	259	2.788×10^{7}	2.590	2.590×10^{6}	1

[a]Weast (1990).

fundamental dimensions of acceleration are [L/T²]; acceleration may be expressed, for example, as (cm/sec)/sec or cm/sec². Note that these units for velocity and acceleration convey only the speed or magnitude aspect. In most places in this text, the directional aspect of a problem is conveyed with a diagram or figure. In situations where the geometry of a problem is complex, the directional aspect of acceleration or velocity may be more conveniently expressed by the use of vector notation.

Force

Force, F, is defined with the help of Newton's laws of motion. Force has fundamental dimensions of [ML/T²]. These dimensions result from taking the product of mass (m) and acceleration (a):

$$F = m \cdot a.$$

A dyne (dyn) is the amount of force that gives a gram of mass an acceleration

TABLE A-5 Common Volume Units and Interconversion Factors[a]

	Acre-foot	Cubic foot	Cubic inch	Cubic meter	Liter	U.S. gallon
Acre-foot	1	43,560	7.53×10^{7}	1233	1.233×10^{6}	3.26×10^{5}
Cubic foot	2.30×10^{-5}	1	1728	0.0283	28.3	7.48
Cubic inch	1.33×10^{-8}	5.79×10^{-4}	1	1.64×10^{-5}	1.64×10^{-2}	4.33×10^{-3}
Cubic meter	8.11×10^{-4}	35.3	61,000	1	1000	264
Liter	8.11×10^{-7}	0.0353	61	10^{-3}	1	0.264
U.S. gallon	3.07×10^{-6}	0.134	231	3.79×10^{-3}	3.79	1

[a]Linsley, R. K., Jr., Kohler, M. A., and Paulhus, J. L. H. (1982). *Hydrology for Engineers*. McGraw-Hill, New York.

TABLE A-6 Common Force Units and Interconversion Factors[a]

	Dyne	Kilogram-force	Newton	Pound
Dyne	1	1.020×10^{-6}	1×10^{-5}	2.248×10^{-6}
Kilogram-force	9.807×10^{5}	1	9.807	2.205
Newton	10^{5}	0.102	1	0.225
Pound	4.448×10^{5}	0.454	4.448	1

[a]Weast (1990).

of 1 cm/sec²; thus, it has units of g · cm/sec². The unit of force required to accelerate a kilogram at a rate of 1 m/sec² is called a newton (N). A kilogram-force is 9.8 N, the weight of a mass of 1 kg at Earth's surface. See Table A-6 for common units of force and interconversion factors for both the SI and English measurement systems.

Pressure

Pressure is force per unit area and has dimensions of [M/LT²]. Pressure is an important measurement in many fields of science, and each field has different traditional units. The SI unit, the pascal [N/m² or kg/(m · sec²)], is commonly used, along with the dyn/cm². Other pressure units frequently encountered include the millimeter of mercury (mm Hg), the atmosphere (atm), the bar (10^6 dyn/cm²), and the pound per square inch (psi). The origin of some of these units is implicit in their names; the millimeter of mercury (also called a torr) is the amount of pressure that causes the mercury in a manometer to rise by 1 mm—an easy unit of measure for the laboratory experimentalist to use. Many of the common units of pressure and their interconversion factors are shown in Table A-7.

TABLE A-7 Common Pressure Units and Interconversion Factors[a]

	Atmosphere	Bar	Kilopascal	Millimeter of Hg	Psi
Atmosphere	1	1.013	101.3	760	14.7
Bar	0.987	1	100	750	14.5
Kilopascal	9.87×10^{-3}	1×10^{-2}	1	7.50	0.145
Millimeter of Hg	1.32×10^{-3}	1.33×10^{-3}	0.133	1	1.93×10^{-2}
Psi	0.0680	0.0689	6.89	51.7	1

[a]Weast (1990).

TABLE A-8 mon Energy Units and Interconversion Factors[a]

	Btu[b]	Calorie	Erg	Foot-pound	Joule	Kilowatt-hour
Btu	1	251.996	1.055×10^{10}	778.169	1055.056	2.931×10^{-4}
Calorie	3.968×10^{-3}	1	4.187×10^{7}	3.088	4.187	1.163×10^{-6}
Erg	9.478×10^{-11}	2.388×10^{-8}	1	7.376×10^{-8}	10^{-7}	2.778×10^{-14}
Foot-pound	1.285×10^{-3}	0.324	1.356×10^{7}	1	1.356	3.766×10^{-7}
Joule	9.478×10^{-4}	0.239	10^{7}	0.738	1	2.778×10^{-7}
Kilowatt-hour	3412.14	8.598×10^{5}	3.6×10^{13}	2.655×10^{6}	3.6×10^{6}	1

[a]Weast (1990).
[b]British thermal unit.

Energy

Energy is the capability to perform work. Energy may occur in mechanical, thermal, chemical, nuclear, or electrical form, and has dimensions of $[ML^2/T^2]$. The basic SI energy unit, the joule (J), is equal to the energy conveyed by a force of 1 N exerted over a distance of 1 m; therefore, it has the units of kg · m²/sec². Other units of energy are the British thermal unit (Btu), calorie, erg, foot-pound, and kilowatt-hour, as shown in Table A-8.

Power

Power is the rate at which energy is transferred, and therefore it has dimensions of $[ML^2/T^3]$. One watt (W) is defined as 1 J/sec. Other common units are horsepower and Btu/hr. (Curiously, the metric cheval-vapeur is equivalent to only 735 W, slightly less than the U.S./British horsepower of 746 W.) See Table A-9 for interconversion factors for these units.

TABLE A-9 Common Power Units and Interconversion Factors[a]

	Btu per hour	Horsepower	Joule per second	Watt
Btu per hour	1	3.930×10^{-4}	0.293	0.293
Horsepower	2544.43	1	745.700	745.700
Joule per second	3.412	1.341×10^{-3}	1	1
Watt	3.412	1.341×10^{-3}	1	1

[a]Weast (1990).

TABLE A-10 Atomic Weights of Some Common Elements

Chemical	Symbol	Atomic weight (g/mol)	Chemical	Symbol	Atomic weight (g/mol)
Aluminum	Al	26.98	Mercury	Hg	200.59
Argon	Ar	39.95	Molybdenum	Mo	95.94
Arsenic	As	74.92	Neon	Ne	20.18
Barium	Ba	137.34	Nickel	Ni	58.70
Beryllium	Be	9.01	Nitrogen	N	14.01
Bromine	Br	79.90	Oxygen	O	16.00
Cadmium	Cd	112.40	Phosphorus	P	30.97
Calcium	Ca	40.08	Platinum	Pt	195.09
Carbon	C	12.01	Potassium	K	39.10
Chlorine	Cl	35.45	Radium	Ra	226.03
Chromium	Cr	52.00	Radon	Rn	222.00
Cobalt	Co	58.93	Selenium	Se	78.96
Copper	Cu	63.55	Silicon	Si	28.09
Fluorine	F	19.00	Silver	Ag	107.87
Helium	He	4.00	Sodium	Na	23.00
Hydrogen	H	1.01	Sulfur	S	32.06
Iodine	I	126.90	Tin	Sn	118.69
Iron	Fe	55.85	Titanium	Ti	47.90
Lead	Pb	207.20	Uranium	U	238.03
Magnesium	Mg	24.30	Zinc	Zn	65.38
Manganese	Mn	54.94			

Atomic and Molecular Weight

The atomic weight of an element is numerically equal to the mass, in grams, of a mole (6.023×10^{23} atoms) of the element. Molecular weight (MW) of a molecule is the sum of the atomic weights of its constituent atoms. Table A-10 gives atomic weights for many common elements.

Gas Constant

The gas constant R appears in numerous expressions, including the ideal gas law—Eq. [1-29]—and the equation relating an equilibrium constant of a reaction to its free energy—Eq. [1-12]. Equivalent values of R are

8.3145 J/(mol · K)
0.082058 (L · atm)/(mol · K)
1.9859 cal/(mol · K)
8.3145×10^7 erg/(mol · K)