E Units

E.1 SI UNITS

The International System of Units defines seven units of measures as a basic set from which all other SI units can be derived. The base units include measures of length, time, electric current, temperature, luminous intensity, and amount of substance. New definitions of basic units, introduced in May 2019, are provided in Subsection E.1.1. The names and symbols of SI base units are written in lower case, except for symbols derived from person names. For example, the meter has the symbol m, whereas the kelvin has the symbol K, since it is named after Lord Kelvin. In the same way the unit of the electric current is ampere with symbol A, as it is named after André-Marie Ampère. The derived SI units are given in Table E.2.

E.1.1 BASE SI UNITS

The names of the base SI units and the corresponding symbols are shown in Table E.1. Since 20 May 2019, some of the base units (kilogram, ampere and kelvin) received new definitions. The new SI and the dependence of base unit definitions on physical constants with fixed numerical values (see Table E.1) are illustrated in Fig. E.1.

Second

The second (s) is the unit of time and it is defined by taking the fixed numerical value of the caesium frequency $\Delta\nu_{Cs}$, the unperturbed ground-state hyperfine transition frequency of the caesium-133 atom, to be 9 192 631 770 when expressed in the unit Hz, which is equal to s^{-1}.

Meter

The meter (m) is the SI unit of length. It is defined by taking the fixed numerical value of the speed of light in vacuum c to be 299 792 458 when expressed in the unit $m{\cdot}s^{-1}$, where the second is defined as described above.

Kilogram

The kilogram (kg) is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant h to be $6.626\ 070\ 15{\times}10^{-34}$ when expressed in the unit J·s, which is equal to

Table E.1
Base SI Units

Physical Quantity	Unit Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

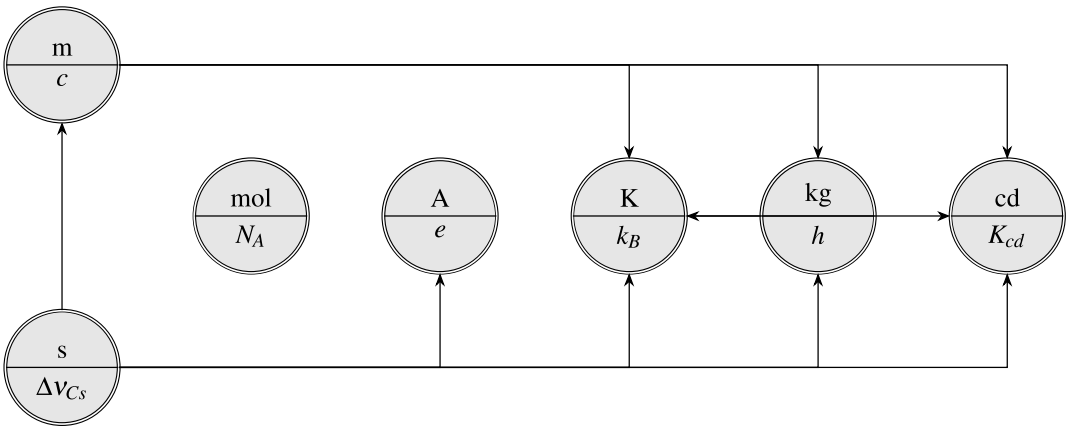

Figure E.1 Base unit relations in the new SI (since May 2019). For each base unit, the lower symbol represents the defining universal constant and arrows show dependency on other base units.

$kg{\cdot}m^2{\cdot}s^{-1}$, where the meter and the second are defined as described above.

Ampere

The ampere (A) is the SI unit of electric current. It is defined by taking the fixed numerical value of the elementary charge e to be $1.602\ 176\ 634{\times}10^{-19}$ when expressed in the unit C, which is equal to A·s, where the second is defined as described above.

Kelvin

The kelvin (K) is the SI unit of thermodynamic temperature. It is defined by taking the fixed numerical value of the Boltzmann constant k to be $1.380\ 649{\times}10^{-23}$ when expressed in the unit $J{\cdot}K^{-1}$, which is equal to $kg{\cdot}m^2{\cdot}s^{-2}{\cdot}K^{-1}$, where the kilogram, meter and second are defined as described above.

Mole

The mole (mol) is the SI unit of amount of substance. One mole contains exactly $6.022\ 140\ 76{\times}10^{23}$ elementary entities. This number is the fixed numerical value of the Avogadro constant, N_A, when expressed in the unit mol^{-1} and is called the Avogadro number. The amount of substance, symbol n, of a system is a measure of the number of specified elementary entities. An elementary entity may be an atom, a molecule, an ion, an electron, or any other particle or specified group of particles.

Candela

The candela (cd) is the SI unit of luminous intensity in a given direction. It is defined by taking the fixed numerical value of the luminous efficacy (a measure of how well a light source produces visible light) of monochromatic radiation of frequency $540{\times}10^{12}$ Hz, K_{cd}, to be 683, when expressed in the unit $lm{\cdot}W^{-1}$, which is equal to $cd{\cdot}sr{\cdot}W^{-1}$, or $cd{\cdot}sr{\cdot}kg^{-1}{\cdot}m^{-2}{\cdot}s^3$, where the kilogram, meter and second are defined as described above.

E.1.2 DERIVED, SUPPLEMENTARY, AND TEMPORARY SI UNITS

Units of measure which are defined in terms of the seven base units specified by the International System of Units are called the derived SI units. The SI has special names for 22 of these derived

Table E.2
Physical Quantities Expressed with Derived SI Units

Physical Quantity	Unit Name	Symbol	In SI Units
Planar angle	radian	rad	m/m
Solid angle	steradian	sr	m^2/m^2
Frequency	hertz	Hz	s^{-1}
Force	newton	N	kg m s^{-2}
Pressure, stress	pascal	Pa = N m^{-2}	kg m^{-1} s^{-2}
Work, energy, quantity of heat	joule	J = N m	kg m^2 s^{-2}
Power	watt	W = J s^{-1}	kg m^2 s^{-3}
Electric potential difference	volt	V = W A^{-1}	kg m^2 s^{-3} A^{-1}
Electric charge	coulomb	C	A s
Capacitance	farad	F = C V^{-1}	kg^{-1} m^{-2} s^4 A^2
Electric resistance	ohm	Ω = V A^{-1}	kg m^2 s^{-3} A^{-2}
Electric conductance	siemens	S = $Ω^{-1}$	kg^{-1} m^{-2} s^3 A^2
Magnetic flux	weber	Wb = V s	V s
Magnetic flux density	tesla	T = Wb m^{-2}	kg s^{-2} A^{-1}
Inductance	henry	H = Wb A^{-1}	kg m^2 s^{-2} A^{-2}
Temperature (with zero at 273.15 K)	degree Celsius	°C	K
Luminous flux	lumen	lm	cd sr
Illuminance	lux	lx = lm m^{-2}	cd m^{-2}
Radioactive decay rate	beckerel	Bq	s^{-1}
Absorbed dose	gray	Gr = J kg^{-1}	m^2 s^{-2}
Equivalent dose	sievert	Sv = J kg^{-1}	m^2 s^{-2}

units. Selected derived SI units are shown in Table E.2. Selected accepted non-SI units are shown in Table E.3.

E.2 SI PREFIXES AND CONVERSION FACTORS

To express very small and very large quantities, the SI units are scaled by using the prefixes given in Table E.4. Most common conversion factors for various units of length, area, volume, mass, energy and power are given in Tables E.5 through E.14. Length unit conversion factors are given in Tables E.5 and E.6 for micro-to-meso and meso-to macro scales, respectively. Area unit conversion factors are given in Tables E.7 and E.8 for micro-to-meso and meso-to macro scales, respectively. Volume unit conversion factors are given in Table E.9 and mass unit conversion factors are given in Table E.10. There are several units that are used to express amounts of energy and power levels. The unit conversion factors for energy in micro and meso-scales are given in Table E.11, whereas Table E.12 shows the factors for energy in mesoscales to describe energy content in various fuels and energy carriers. Macroscale energy conversion factors, useful to describe global energy amounts, are given in Table E.13. The most common power conversion factors are provided in Table E.14. For conversion of other units, very comprehensive unit conversion tools can be found on the Internet[1].

[1]For example, `www.unit-conversion.info`

Table E.3
Physical Quantities Expressed with Accepted Non-SI Units

Physical Quantity	Unit Name	Symbol	Value in SI Units
Time	minute	min	1 min = 60 s
	hour	h	1 h = 60 min = 3 600 s
	day	d	1 d = 24 h = 86 400 s
Length	astronomical unit[a]	au	1 au = 149 597 870 700 m
Volume	litre	l, L	$1\ l = 1\ L = 10^{-3}\ m^3$
Mass	tonne (metric ton)	t	1 t = 1 000 kg
	amu[b]	u	$1\ u = 1.660\ 539\ 066\ 60(50) \times 10^{-27}$ kg
Energy	electron volt	eV	$1\ eV = 1.602\ 176\ 634 \times 10^{-19}$ J
	Temporary Units[c]		
Length	nautical mile		1 nautical mile = 1852 m
	ångström	Å	$1\ Å = 0.1\ nm = 10^{-10}$ m
Area	are	a	$1\ a = 100\ m^2$
	hectare	ha	$1\ ha = 10^4\ m^2$
	barn	b	$1\ b = 10^{-28}\ m^2$
Pressure	bar	bar	$1\ bar = 0.1\ MPa = 10^5$ Pa
Radioactive decay rate	curie	Ci	$1\ Ci = 3.7 \times 10^{10}$ Bq
Radiation exposure	röntgen	R	$1\ R = 2.58 \times 10^{-4}\ C\ kg^{-1}$
Absorbed radiation dose	rad	rad	$1\ rad = 10^{-2}$ Gy
Radiation dose equivalent	rem	rem	$1\ rem = 10^{-2}$ Sv

[a] The astronomical unit of length was redefined by the XXVIII General Assembly of the International Astronomical Union (Resolution B2, 2012) and has an exact value as given in the table.
[b] The unified atomic mass unit (amu) is equal to 1/12 of the mass of an unbound atom of the nuclide ^{12}C, at rest and in its ground state. The value must be obtained experimentally and is thus not known exactly.
[c] Other units outside the SI that are currently accepted for use with the SI, subject to further review.

Table E.4
SI Prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	μ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	hecto	h	10^{-21}	zepto	z
10^{1}	deca	da	10^{-24}	yocto	y

Note: Specific rules for using prefixes should be followed, such as:

- Never use double prefixes, such as $\mu\mu$g; use pg.
- Put prefix in numerator; thus km/s, not m/ms.
- When spelling prefixes with unit names that begin with vowel, suppress the ending vowel on the prefix; thus megohm and kilohm, not megaohm and kiloohm.
- Never use a hyphen with a prefix; thus microgram, not micro-gram.

Table E.5
Length Conversion Factors at Micro- and Mesoscale

$\downarrow \times \searrow = \rightarrow$[a]	m	yd	ft	in	Å
meter (m)	1	1.0936	3.2808	39.37	1×10^{10}
yard (yd)	0.9144	1	3	36	9.144×10^{9}
foot (ft)	0.3048	0.3333	1	12	3.048×10^{9}
inch (in)	0.0254	0.02778	0.08333	1	2.54×10^{8}
ångström (Å)	1×10^{-10}	1.0936×10^{-10}	3.281×10^{-10}	3.937×10^{-9}	1

[a] These symbols mean: "take a quantity in any unit shown in the first column, multiply by a factor in the same row in the table and obtain the quantity in units shown in the first row of the corresponding column".

Table E.6
Length Conversion Factors at Macroscale

$\downarrow \times \searrow = \rightarrow$[a]	m	mi	naut. mile	au	parsec
meter (m)	1	6.214×10^{-4}	5.400×10^{-4}	6.685×10^{-12}	3.241×10^{-17}
mile (mi)	1609	1	0.8690	1.076×10^{-8}	5.216×10^{-14}
nautical mile[b]	1852	1.151	1	1.238×10^{-8}	6.002×10^{-14}
astronomical unit[c] (au)	1.496×10^{11}	9.296×10^{7}	8.078×10^{7}	1	4.848×10^{-6}
parsec[d]	3.086×10^{16}	1.917×10^{13}	1.666×10^{13}	2.063×10^{5}	1

[a] See Table E.5 for explanation.
[b] Defined as exactly 1852 m. Historically it was defined as one minute of latitude along any line of longitude.
[c] Defined as the average distance from the Earth to the Sun.
[d] Defined as the distance at which one astronomical unit subtends an angle of one arcsecond, i.e. $1/3600^{th}$ of a degree.

Table E.7
Area Conversion Factors at Micro- and Mesoscale

$\downarrow \times \searrow = \rightarrow$[a]	**m^2**	**yd^2**	**ft^2**	**in^2**	**b**
sq. meter (m^2)	1	1.196	10.76	1550	1×10^{28}
sq. yard (yd^2)	0.8361	1	9	1296	8.361×10^{27}
sq. foot (ft^2)	0.0929	0.1111	1	144	9.290×10^{26}
sq. inch (in^2)	6.452×10^{-4}	7.716×10^{-4}	6.944×10^{-3}	1	6.452×10^{24}
barn (b)[b]	1×10^{-28}	1.196×10^{-28}	1.0764×10^{-27}	1.550×10^{-25}	1

[a] See Table E.5 for explanation.
[b] A unit of the microscopic cross cross section.

Table E.8
Area Conversion Factors at Macroscale

$\downarrow \times \searrow = \rightarrow$[a]	m^2	are	acre	ha	sq. mile
sq. meter (m^2)	1	0.01	2.471×10^{-4}	0.0001	3.863×10^{-7}
are	100	1	0.02471	0.01	3.863×10^{-5}
acre	4047	40.47	1	0.4047	1.563×10^{-3}
hectare (ha)	10000	100	2.471	1	3.863×10^{-3}
square mile	2.589×10^{6}	2.589×10^{4}	640	258.9	1

[a] See Table E.5 for explanation.

Table E.9
Volume Conversion Factors

$\downarrow \times \searrow = \rightarrow$[a]	m^3	fl oz	gal	ft^3	bbl
cubic meter (m^3)	1	3.381×10^{4}	264.2	35.31	6.2898
fluid ounce (fl oz)	2.957×10^{-5}	1	7.813×10^{-3}	1.044×10^{-3}	1.860×10^{-4}
US gallon (gal)	3.785×10^{-3}	128	1	0.1337	2.381×10^{-2}
cubic foot (ft^3)	2.832×10^{-2}	957.5	7.481	1	0.1781
barrel petroleum (bbl)	0.1590	5376	42	5.615	1

[a] See Table E.5 for explanation.

Table E.10
Mass Conversion Factors

$\downarrow \times \searrow = \rightarrow$[a]	kg	t	lt	st	lb
kilogram (kg)	1	0.001	9.842×10^{-4}	1.102×10^{-3}	2.205
tonne (t)	1000	1	0.9842	1.102	2.205×10^{3}
long ton (lt)	1016	1.016	1	1.120	2.240×10^{3}
short ton (st)	907.2	0.9072	0.8929	1	2000
pound (lb)	0.4536	4.536×10^{-4}	4.464×10^{-4}	5×10^{-4}	1

[a] See Table E.5 for explanation.

Table E.11
Energy Conversion Factors at Micro- and Mesoscale

$\downarrow \times \searrow = \rightarrow$[a]	J	eV	cal_{th}	cal_{IT}	erg
J	1	6.24150×10^{18}	0.2390	0.2388	1×10^{7}
eV[b]	1.602×10^{-19}	1	3.829×10^{-18}	3.826×10^{-18}	1.602×10^{-12}
cal_{th}[c]	4.184	2.6114×10^{19}	1	0.9993	4.184×10^{7}
cal_{IT}[d]	4.1868	2.6132×10^{19}	1.0007	1	4.1868×10^{7}
erg[e]	1×10^{-7}	6.2415×10^{11}	2.390×10^{-8}	2.388×10^{-8}	1

[a] See Table E.5 for explanation.
[b] An electron volt (eV) is defined as 1 eV = (e/C)J = 1.602 176 634$\times 10^{-19}$ J (exact).
[c] A thermochemical calorie (cal_{th}) is defined as the amount of energy equal exactly to 4.184 J.
[d] An International Steam Table calorie (cal_{IT}) is defined as exactly 1.163 mW·h = 4.1868 J.
[e] An erg is defined as the amount of work done by a force of one dyne exerted for a distance of one centimeter.

Table E.12
Energy Conversion Factors at Mesoscale

$\downarrow \times \searrow = \rightarrow$[a]	kJ	BTU	kWh	toe	tce
kJ[b]	1	0.9478	2.778×10^{-4}	2.388×10^{-8}	3.4123×10^{-8}
BTU[c]	1.055	1	2.931×10^{-4}	2.519×10^{-8}	3.600×10^{-8}
kWh[d]	3600	3.412×10^{3}	1	8.597×10^{-5}	1.228×10^{-4}
toe[e]	4.1868×10^{7}	3.9682×10^{7}	1.163×10^{4}	1	1.429
tce[f]	2.93076×10^{7}	2.7780×10^{7}	8.141×10^{3}	0.7000	1

[a] See Table E.5 for explanation.
[b] A kilojoule (kJ) is equal to 1000 J.
[c] A British Thermal Unit (BTU) was originally defined as the amount of heat required to raise the temperature of 1 pound of liquid water by 1 degree Fahrenheit at a constant pressure of one atmosphere.
[d] A kilowatt-hour (kWh) is equal to 3.6 GJ.
[e] A ton of oil equivalent (toe) is defined by the International Energy Agency to be equal to 41.868 GJ.
[f] A ton of coal equivalent (tce) is defined by the International Energy Agency to be equal to 29.3076 GJ.

Table E.13
Energy Conversion Factors at Macroscale

$\downarrow \times \searrow = \rightarrow$[a]	TWh	EJ	Mtoe	quad	Q
TWh[b]	1	3.600×10^{-3}	8.598×10^{-2}	3.412×10^{-3}	3.412×10^{-6}
EJ[c]	277.8	1	23.89	0.9479	9.479×10^{-4}
Mtoe[d]	11.63	4.187×10^{-2}	1	0.03969	3.969×10^{-5}
quad[e]	293.1	1.055	25.20	1	0.001
Q[f]	2.931×10^{5}	1055	2.520×10^{4}	1000	1

[a] See Table E.5 for explanation.
[b] A terrawatt-hour (TWh) is equal to 10^{12} watthours.
[c] An exajoule (EJ) is equal to 10^{18} joules.
[d] 1 Mtoe is equal to 10^{6} toe.
[e] A quad is defined as equal to 10^{15} BTU.
[f] Q is defined as equal to 10^{18} BTU.

Table E.14
Power Conversion Factors

$\downarrow \times \searrow = \rightarrow$[a]	W	kW	hp	BTU/s	ft·lbf/s
watt (W)	1	0.001	1.341×10^{-3}	9.478×10^{-4}	0.7376
kilowatt (kW)	1000	1	1.341	0.9478	737.6
horsepower (hp)	745.7	0.7457	1	0.7068	550
BTU/second	1055	1.055	1.415	1	778.2
ft·lbf/s	1.356	1.356×10^{-3}	1.818×10^{-3}	1.285×10^{-3}	1

[a] See Table E.5 for explanation.