1.3.6 Electromagnetic radiation

Name	Symbol	Definition	SI unit	Notes
wavelength	λ		m	
speed of light				
in vacuum	c_0	$c_0 = 299\ 792\ 458$ m s^{-1}	m s^{-1}	(1)
in medium	c	$c = c_0/n$	m s^{-1}	
wavenumber in vacuum	$\tilde{v}$	$\tilde{v} = v/c_0 = 1/n\lambda$	m^{-1}	(2)
wavenumber	σ	$\sigma = 1/\lambda$	m^{-1}	
(in medium)				
frequency	v	$v = c/\lambda$	Hz	
angular frequency,	ω	$\omega = 2\pi v$	s^{-1}, rad s^{-1}	
pulsatance				
refractive index	n	$n = c_0/c$	1	
Planck constant	h		J s	
Planck constant/2π	h	$h = h/2\pi$	J s	
radiant energy	Q, W		J	(3)
radiant energy density	ρ, w	$\rho = Q/V$	J m^{-3}	(3)

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(1)   When there is no risk of ambiguity the subscript $_0$ denoting vacuum is often omitted.

(2)   The unit cm^{-1} is generally used for wavenumber in vacuum.

(3)   The symbols for the quantities *radiant energy* through *irradiance* are also used for the corresponding quantities concerning visible radiation, i.e. luminous quantities and photon quantities. Subscripts e for energetic, v for visible, and p for photon may be added whenever confusion between these quantities might otherwise occur. The units used for luminous quantities are derived from the base unit candela (cd).

Example	radiant intensity	I_e, SI unit: W sr^{-1}
	luminous intensity	I_v, SI unit: cd
	photon intensity	I_p, SI units: s^{-1} sr^{-1}

Name	Symbol	Definition	SI unit	Notes
spectral radiant energy density				(3)
in terms of frequency	ρ_v, w_v	$\rho_v = d\rho/dv$	J m^{-3}, Hz^{-1}	
in terms of wavenumber	$\rho\tilde{v}, w\tilde{v}$	$\rho = d\rho/d\tilde{v}$	J m^{-2}	
in terms of wavelength	ρ_λ, w_λ	$\rho_\lambda = d\rho/d\lambda$	J m^{-4}	
radiant power, radiant per time	Φ, P	$\Phi = dQ/dt$	W	(3)
radiant intensity	I	$I = d\Phi/d\Omega$	W sr^{-1}	(3)
radiant excitance (emitted radiant flux)	M	$M = d\Phi/dA_{source}$	W m^{-2}	(3)
radiance	L	$L = \dfrac{d^2\Phi}{d\Omega\, d A_{source}}$	W sr^{-1} m^{-2}	(3), (4)
intensity, irradiance (radiant flux received)	I, E	$I = d\Phi/dA$	W m^{-2}	(3), (5)
spectral intensity spectral irradiance	$I(\tilde{v}), E(\tilde{v})$	$I(\tilde{v}) = dI/d\tilde{v}$	W m^{-1}	(6)
fluence	$F, (H)$	$F = \int I dt = \int \dfrac{d\Phi}{dA} dt$	J m^{-2}	(7)
emittance	ε	$\varepsilon = M/M_{bb}$	1	(8)
Stefan-Boltzmann constant	σ	$M_{bb} = \sigma T^4$	W m^{-2} K^{-4}	(8)

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(4)   The radiance is a normalized measure of the brightness of a source; it is the power emitted per area of source, per solid angle of the beam from each point of the source.

(5)   The name intensity, symbol I, is usually used in discussions involving collimated beams of light, as in applications of the Lambert-Beer law for spectrometric analysis.

(6)   Spectral quantities may also be defined with respect to frequency v, or wavelength λ; see spectral radiant energy density above.

(7)   Fluence is used in photochemistry to specify the energy delivered in a given time interval (for instance by a laser pulse). This quantity may also be called radiant exposure.

(8)   The emittance of a sample is the ratio of the flux emitted by the sample to the flux emitted by a black body at the same temperature; M_{bb} is the latter quantity.

Name	Symbol	Definition	SI unit	Notes
étendue (throughput, light gathering power)	E, (e)	$E = A\Omega = \Phi/L$	m^2 sr	(9)
resolving power	R	$R = \tilde{v}/\delta\tilde{v}$	1	(10)
resolution	$\delta\tilde{v}$		m^{-1}	(10), (11)
free spectral range	$\Delta\tilde{v}$	$\Delta\tilde{v} = 1/2l$	m^{-1}	(12)
finesse	f	$f = \Delta\tilde{v}/\delta\tilde{v}$	1	(12)
quality factor	Q	$Q = 2\pi v \dfrac{W}{-\mathrm{d}W/\mathrm{d}t}$	1	(12), (13)
first radiation constant	c_1	$c_1 = 2\pi h c_0^2$	W m^2	
second radiation constant	c_2	$c_2 = hc_0/k$	K m	

(9)   Étendue is a characteristic of an optical instrument. It is a measure of the light gathering power, i.e. the power transmitted per radiance of the source. A is the area of the source (or image stop); Ω is the solid angle accepted from each point of the source by the aperture stop.

(10)   This quantity characterizes the performance of a spectrometer, or the degree to which a spectral line (or a laser beam) is monochromatic. It may also be defined using frequency v, or wavelength λ.

(11)   The precise definition of resolution depends on the lineshape, but usually resolution is taken as the full line width at half maximum intensity (FWHM) on a wavenumber, δ, or frequency, δv, scale.

(12)   These quantities characterize a Fabry-Perot cavity, or a laser cavity. l is the cavity spacing, and $2l$ is the round-trip path length. The free spectral range is the wavenumber interval between successive longitudinal cavity modes.

(13)   It is the energy stored in the cavity, and $-\mathrm{d}W/\mathrm{d}t$ is the rate of decay of stored energy. Q is also related to the linewidth of a single cavity mode: $Q = v/\delta v = \tilde{v}/\delta\tilde{v}$. Thus high Q cavities give narrow linewidths.

Name	Symbol	Definition	SI unit	Notes
transmittance, transmission factor	τ, T	$\tau = \Phi_{tr}/\Phi_0$ 1		(14), (15)
absorptance, absorption factor	α	$\alpha = \Phi_{abs}/\Phi_0$	1	(14), (15)
reflectance, reflection factor	ρ	$\rho = \Phi_{refl}/\Phi_0$	1	(14), (15)
(decadic) absorbance	A_{10}, A	$A_{10} = -\lg(1 - \alpha_i)$	1	(15), (16)
napierian absorbance	A_e, B	$A_e = -\ln(1 - \alpha_i)$	1	(15), (16)
absorption coefficient,				
(linear) decadic	a, K	$a = A_{10}/l$	m^{-1}	(15), (17)
(linear) napierian	α	$\alpha = A_e/l$	m^{-1}	(15), (17)
molar (decadic)	ε	$\varepsilon = a/c = A_{10}/cl$	$m^2 mol^{-1}$	(15),(17),(18),(19)
molar napierian	κ	$\kappa = \alpha/c = A_e/cl$	$m^2\,mol^{-1}$	(15),(17),(18)

(14) If scattering and luminescence can be neglected, $\tau + \alpha + \rho = 1$. In optical spectroscopy internal properties (denoted by subscript i) are defined to exclude surface effects and effects of the cuvette such as reflection losses, so that if scattering and luminescence in the sample can be neglected $\tau_i + \alpha_i = 1$. This leads to the customary form of the Lambert-Beer law, $\Phi_{tr}/\Phi_0 = I_{tr}/I_0 = \tau_i = 1 - \alpha_i = \exp(-\kappa cl)$.

(15) In spectroscopy all of these quantities are usually taken to be defined in terms of the spectral intensity, $I(\widetilde{v})$, so that they are all regarded as functions of wavenumber   (or frequency v) across the spectrum. Thus, for example, the absorption coefficient $\alpha(\widetilde{v})$ at wavenumber $\widetilde{v}$ defines the absorption spectrum of the sample; similarly $T(\widetilde{v})$ defines the transmittance spectrum.

(16) The definitions given here relate the absorbance A_{10} or A_e to the *internal* absorptance α_i; see note (14). However the subscript i on the absorptance α is often omitted.

(17) l is the absorbing path length, and c is the amount (of substance) concentration.

(18) The molar decadic absorption coefficient ε is frequently called the 'extinction coefficient' in published literature. Unfortunately numerical values of the 'extinction coefficient' are often quoted without specifying units; the absence of units usually means that the units are $mol^{-1}\,dm^3\,cm^{-1}$. The word 'extinction' should properly be reserved for the sum of the effects of absorption, scattering, and luminescence.

(19) In analytical usage l is in cm and c in $mol\,dm^{-3}$ giving $\varepsilon = dm^3 mol^{-1} cm^{-1}$. See Chapter 10, 11 and Table 10.3.

Name	Symbol	Definition	SI unit	Notes
complex refractive index	$\hat{n}$	$\hat{n} = n + ik$	1	
molar refraction	R	$R = \left(\dfrac{n^2 - 1}{n^2 + 2}\right) V_m$	$m^3\ mol^{-1}$	
angle of optical rotation	α		1, rad	(20)
specific optical rotatory power	$[\alpha]_\lambda^\theta$	$[\alpha]_\lambda^\theta = \alpha/\gamma l$	$rad\ m^2\ kg^{-1}$	(20)
molar optical rotatory power	α_m	$\alpha_m = \alpha/cl$	$rad\ m^2\ mol^{-1}$	(20)

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(20)   The sign convention for the angle of rotation is as follows: α is positive if the plane of polarization is rotated clockwise as viewed looking towards the light source. If the rotation is anticlockwise then α is negative.

The optical rotation due to a solute in solution may be specified by a statement of the type α(589.3 nm, 20 °C, sucrose, 10 g dm^{-3} in H$_2$O, 10 cm path) = +0.6647°

The same information may be conveyed by quoting either the specific optical rotatory power $\alpha/\gamma l$, or the molar optical rotatory power α/cl, where γ is the mass concentration, c is the amount (of substance) concentration, and l is the path length. Most tabulations give the specific optical rotatory power, denoted $[\alpha]$. The wavelength of light used λ (frequently the sodium D line) and the Celsius temperature θ are conventionally written as a subscript and superscript to the specific rotatory power $[\alpha]$. For pure liquids and solids $[\alpha]$ is similarly defined as $[\alpha] = \alpha/\rho l$, where ρ is the mass density.

Specific optical rotatory powers are customarily called *specific rotations*, and are unfortunately usually quoted without units. The absence of units may usually be taken to mean that the units are deg cm^3 g^{-1} dm^{-1} for pure liquids and solutions, or deg cm^3 g^{-1} mm^{-1} for solids, where deg is used as a symbol for degrees of plane angle.