Chapter

Fundamental Electrical Properties

1.1 Introduction

The atomic theory of matter specifies that each of the many chemical elements is composed of unique and identifiable particles called atoms. In ancient times only 10 were known in their pure, uncombined form; these were carbon, sulfur, copper, antimony, iron, tin, gold, silver, mercury, and lead. Of the several hundred now identified, less than 50 are found in an uncombined, or chemically free, form on earth.

Each atom consists of a compact nucleus of positively and negatively charged particles (protons and electrons, respectively). Additional electrons travel in well-defined orbits around the nucleus. The electron orbits are grouped in regions called *shells*, and the number of electrons in each orbit increases with the increase in orbit diameter in accordance with quantum-theory laws of physics. The diameter of the outer orbiting path of electrons in an atom is in the order of one-millionth (10^{-6}) millimeter, and the nucleus, one-millionth of that. These typical figures emphasize the minute size of the atom.

1.2 Electrical Fundamentals

The nucleus and the free electrons for an iron atom are shown in the schematic diagram in Figure 1.1. Note that the electrons are spinning in different directions. This rotation creates a magnetic field surrounding each electron. If the number of electrons with positive spins is equal to the number with negative spins, then the net field is zero and the atom exhibits no magnetic field.

In the diagram, although the electrons in the first, second, and fourth shells balance each other, in the third shell five electrons have clockwise positive spins, and one a counterclockwise negative spin, which gives the iron atom in this particular electron configuration a cumulative *magnetic effect*.

The parallel alignment of the electron spins over regions, known as *domains*, containing a large number of atoms. When a magnetic material is in a demagnetized state, the direction of magnetization in the domain is in a random order. Magnetization by an



Figure 1.1 Schematic of the iron (Fe) atom.

external field takes place by a change or displacement in the isolation of the domains, with the result that a large number of the atoms are aligned with their charged electrons in parallel.

1.2.1 Conductors and Insulators

In some elements, such as copper, the electrons in the outer shells of the atom are so weakly bound to the nucleus that they can be released by a small electrical force, or voltage. A voltage applied between two points on a length of a metallic conductor produces the flow of an electric current, and an electric field is established around the conductor. The conductivity is a constant for each metal that is unaffected by the current through or the intensity of any external electric field.

In some nonmetallic materials, the free electrons are so tightly bound by forces in the atom that, upon the application of an external voltage, they will not separate from their atom except by an electrical force strong enough to destroy the insulating properties of the material. However, the charges will realign within the structure of their atom. This condition occurs in the insulating material (dielectric) of a capacitor when a voltage is applied to the two conductors encasing the dielectric.

Semiconductors are electronic conducting materials wherein the conductivity is dependent primarily upon impurities in the material. In addition to negative mobile charges of electrons, positive mobile charges are present. These positive charges are called *holes* because each exists as an absence of electrons. Holes (+) and electrons (–),

because they are oppositely charged, move in opposite directions in an electric field. The conductivity of semiconductors is highly sensitive to, and increases with, temperature.

1.2.2 Direct Current (dc)

Direct current is defined as a unidirectional current in which there are no significant changes in the current flow. In practice, the term frequently is used to identify a voltage source, in which case variations in the load can result in fluctuations in the current but not in the direction.

Direct current was used in the first systems to distribute electricity for household and industrial power. For safety reasons, and the voltage requirements of lamps and motors, distribution was at the low nominal voltage of 110. The losses in distribution circuits at this voltage seriously restricted the length of transmission lines and the size of the areas that could be covered. Consequently, only a relatively small area could be served by a single generating plant. It was not until the development of alternating-current systems and the voltage transformer that it was feasible to transport high levels of power at relatively low current over long distances for subsequent low-voltage distribution to consumers.

1.2.3 Alternating Current (ac)

Alternating current is defined as a current that reverses direction at a periodic rate. The average value of alternating current over a period of one cycle is equal to zero. The effective value of an alternating current in the supply of energy is measured in terms of the root mean square (rms) value. The rms is the square root of the square of all the values, positive and negative, during a complete cycle, usually a sine wave. Because rms values cannot be added directly, it is necessary to perform an rms addition as shown in the equation:

$$V_{rms \ total} = \sqrt{V_{rms \ 1}^{2} + V_{rms \ 2}^{2} + L \ V_{rms \ n}^{2}}$$
(1.1)

As in the definition of direct current, in practice the term frequently is used to identify a voltage source.

The level of a sine-wave alternating current or voltage can be specified by two other methods of measurement in addition to rms. These are *average* and *peak*. A sine-wave signal and the rms and average levels are shown in Figure 1.2. The levels of complex, symmetrical ac signals are specified as the peak level from the axis, as shown in the figure.

1.2.4 Static Electricity

The phenomenon of static electricity and related potential differences concerns configurations of conductors and insulators where no current flows and all electrical



Figure 1.2 Root mean square (rms) measurements. The relationship of rms and average values is shown.

forces are unchanging; hence the term *static*. Nevertheless, static forces are present because of the number of excess electrons or protons in an object. A static charge can be induced by the application of a voltage to an object. A flow of current to or from the object can result from either a breakdown of the surrounding nonconducting material or by the connection of a conductor to the object.

Two basic laws regarding electrons and protons are:

- Like charges exert a repelling force on each other; electrons repel other electrons and protons repel other protons
- Opposite charges attract each other; electrons and protons are attracted to each other

Therefore, if two objects each contain exactly as many electrons as protons in each atom, there is no electrostatic force between the two. On the other hand, if one object is charged with an excess of protons (deficiency of electrons) and the other an excess of electrons, there will be a relatively weak attraction that diminishes rapidly with distance. An attraction also will occur between a neutral and a charged object.

Another fundamental law, developed by Faraday, governing static electricity is that all of the charge of any conductor not carrying a current lies in the surface of the conductor. Thus, any electric fields external to a completely enclosed metal box will not penetrate beyond the surface. Conversely, fields within the box will not exert any force on objects outside the box. The box need not be a solid surface; a conduction cage or grid will suffice. This type of isolation frequently is referred to as a *Faraday shield*.

1.2.5 Noise in Electronic Circuits

Noise has become the standard term for signals that are random and that are combined with the circuit signal to affect the overall performance of a system. As the study of noise has progressed, engineers have come to realize that there are many sources of noise in circuits. The following definitions are commonly used in discussions of circuit noise:

- *White noise*: a signal that has its energy evenly distributed over the entire frequency spectrum, within the frequency range of interest (typically below frequencies in the infrared range). Because *white noise* is totally random, it may seem inappropriate to refer to its frequency range, because it is not really periodic in the ordinary sense. Nevertheless, by examining an oscilloscope trace of white noise, it can be verified that every trace is different, as the noise never repeats itself, and yet each trace looks the same. There is a strong theoretical foundation to represent the frequency content of such signals as covering the frequency spectrum evenly. In this way the impact on other periodic signals can be analyzed. The term white noise arises from the fact that, similar to white light, which has equal amounts of all light frequencies, white noise has equal amounts of noise at all frequencies within circuit operating ranges.
- *Interference*: the name given to any predictable, periodic signal that occurs in an electronic circuit in addition to the signal the circuit is designed to process. This is distinguished from a noise signal by the fact that it occupies a relatively small frequency range, and because it is predictable it can often be filtered out. Usually, interference comes from another electronic system such as an interfering radio source.
- *Thermal noise*: any noise that is generated within a circuit and is temperature-dependent. This signal usually is the result of the influence of temperature directly on the operating characteristics of circuit components, which because of the random motion of molecules as a result of temperature, in turn creates a random fluctuation of the signal being processed.
- Shot noise: a type of circuit noise that is not temperature-dependent, and is not white noise in the sense that it tends to diminish at higher frequencies. This noise usually occurs in components whose operation depends on a mean *particle residence time* for the active electrons within the device. The *cutoff frequency* above which noise disappears is closely related to the inverse of this characteristic particle residence time.

1.3 References

1. Whitaker, Jerry C. (ed.), *The Electronics Handbook*, CRC Press, Boca Raton, FL, 1996.

1.4 Bibliography

Benson, K. Blair, and Jerry C. Whitaker, *Television and Audio Handbook for Technicians and Engineers*, McGraw-Hill, New York, NY, 1990.

Benson, K. Blair, Audio Engineering Handbook, McGraw-Hill, New York, NY, 1988.

Whitaker, Jerry C., *Television Engineers' Field Manual*, McGraw-Hill, New York, NY, 2000.

1.5 Tabular Data

Table 1.1 Symbols and Terminology for Physical and Chemical Quantities: Classical Mechanics (*From* [1]. Used with permission.)

Name	Symbol	Definition	SI unit
mass	m		kg
reduced mass	μ	$\mu = m_1 m_2 / (m_1 + m_2)$	kg
density, mass density	ρ	$\rho = m/V$	$kg m^{-3}$
relative density	d	$d = \rho / \rho^{\theta}$	1
surface density	PA. PS	$\rho_A = m/A$	$kg m^{-2}$
specific volume	υ	$v = V/M = 1/\rho$	$m^3 kg^{-1}$
momentum	P	p = mv	kg ms ⁻¹
angular momentum, action	L	$L = r \times p$	Js
moment of inertia	I, J	$I = \sum m_i r_i^2$	kg m ²
force	F	F = dp/dt = ma	N
torque, moment of a force	T, (M)	$T = r \times F$	N m
energy	Ε		I
potential energy	$E_n, V, \mathbf{\Phi}$	$E_n = -\int \mathbf{F} \cdot d\mathbf{s}$	ŗ
kinetic energy	E_{k} , T, K	$E_{k} = (1/2)mv^{2}$	j
work	W, w	$W = \int F \cdot ds$	I
Hamilton function	н, ш Н	H(a, n)	Ţ
	**	T(q, p) = T(q, p) + V(q))
Lagrange function	I	= I(q, p) + V(q)	T
bagrange function	L	L(q, q) $= T(q, \dot{q}) V(q)$)
Dreccure	n P	= I(q,q) - V(q)	D. N2
surface tension	p, r	p = r/A	Pa, Nm $-$
weight	γ, σ	$\gamma = a w / a A$	Nm ⁻ ,Jm ⁻
	G,(W,P)	G = mg	N
	6	$F = Gm_1m_2/r^2$	N m² kg ²
normal stress	σ	$\sigma = F/A$	Pa
snear stress	τ	$\tau = F/A$	Pa
linear strain,	Е, е	$\varepsilon - \Delta l/l$	1
relative elongation	_		
Young's modulus	E	$E = \sigma/\varepsilon$	Pa
shear strain	1/	$y = \Delta r/d$	1
shear modulus	G	G = T/v	Pa
volume strain bulk strain	A	$\theta = \Delta V / V_{e}$	1
bulk modulus	K	$V = \Delta V / V_0$ $K = -V_0 (dn/dV)$	I Do
compression modulus	η, μ	$\tau_{x,z} = \eta (dv_x/dz)$	Pa s
viscosity, dynamic viscosity			
fluidity	ϕ	$\phi = 1/\eta$	m kg ⁻¹ s
kinematic viscosity	v	$v = \eta / \rho$	$m^2 s^{-1}$
friction coefficient	μ , (f)	$F_{\rm frict} = \mu F_{\rm norm}$	1
power	Р	P = dW/dt	W
sound energy flux	P, P_a	P = dE/dt	W
acoustic factors			
reflection factor	ρ	$\rho = P_r / P_0$	1
acoustic absorption factor	$\alpha_{\rm a},(\alpha)$	$\alpha_a = 1 - \rho$	1
transmission factor	τ	$ au = P_{ m tr}/P_0$	1
dissipation factor	δ	$\delta = lpha_{a} - au$	1

Name	Symbol	Definition	SI unit
quantity of electricity,	Q		С
charge density	0	$\rho = O/V$	$C m^{-3}$
surface charge density	σ	$\rho = Q/\tau$ $\sigma = Q/A$	$C m^{-2}$
electric potential	VA	V = dW/dQ	$V I C^{-1}$
electric potential difference	ν,φ ΠΑΝΑΦ	V = u W / u Q	V
electromotive force	$U, \Delta V, \Delta \psi$ F	$E = \int (E/Q) \cdot ds$	v
electric field strength	F	$E = f(P,Q) \cdot us$ $E = E/Q = -\operatorname{grad} V$	$V m^{-1}$
electric flux	L M	E = F/Q = -grav v	C III
electric displacement	¥ D	$\mathbf{F} = \int \mathbf{D} \cdot \mathbf{u} \mathbf{A}$	$C m^{-2}$
	D	$D = \varepsilon E$	$E C V^{-1}$
	C	C = Q/U	r, C v Em ⁻¹
permittivity	ε	$D = \varepsilon E$	rm -
permittivity of vacuum	ε_0	$\varepsilon_0 = \mu_0 c_0^{-1}$	Fm -
relative permittivity	ε _r	$\varepsilon_r = \varepsilon/\varepsilon_0$	1
dielectric polarization (dipole moment per volume)	Р	$P=D-\varepsilon_0 E$	$C m^{-2}$
electric susceptibility	Xe	$\chi_e = \varepsilon_r - 1$	1
electric dipole moment	p , µ	p = Qr	Cm
electric current	Ι	I = dQ/dt	А
electric current density	j, J	$I = \int \boldsymbol{j} \cdot d\boldsymbol{A}$	$A m^{-2}$
magnetic flux density,	В	$F = Qv \times B$	Т
magnetic induction			
magnetic flux	Φ	$\mathbf{\Phi} = \int \mathbf{B} \cdot d\mathbf{A}$	Wb
magnetic field strength	H	$B = \mu H$	$A M^{-1}$
permeability	μ	$B = \mu H$	$N A^{-2}, H m^{-1}$
permeability of vacuum	μ_0		$\mathrm{H}\mathrm{m}^{-1}$
relative permeability	μ_r	$\mu_r = \mu/\mu_0$	1
magnetization (magnetic dipole moment per volume)	М	$M = B/\mu_0 - H$	$A m^{-1}$
magnetic susceptibility	$\chi, \kappa, (\chi_m)$	$\chi = \mu_r - 1$	1
molar magnetic susceptibility	Xm	$\chi_m = V_m \chi$	m ³ mol ⁻¹
magnetic dipole moment	m, μ	$E_p = -\boldsymbol{m} \cdot \boldsymbol{B}$	A m ² , J T ⁻¹
electrical resistance	R	$\dot{R} = U/I$	Ω
conductance	G	G = 1/R	S
loss angle	δ	$\delta = (\pi/2) + \phi_I - \phi_U$	1, rad
reactance	X	$X = (U/I) \sin \delta$	Ω
impedance	Ζ	Z = R + iX	Ω
(complex impedance)			
admittance	Y	Y = 1/Z	S
(complex admittance)			
susceptance	В	Y = G + iB	S
resistivity	ρ	$\rho = E/j$	Ω m
conductivity	κ, γ, σ	$\kappa = 1/ ho$	$\mathrm{S}~\mathrm{m}^{-1}$
self-inductance	L	E = -L(dI/dt)	Н
mutual inductance	M, L_{12}	$E_1 = L_{12}(dI_2/dt)$	Н
magnetic vector potential	Α	$B = \mathbf{\nabla} \times A$	$\mathrm{Wb}~\mathrm{m}^{-1}$
Poynting vector	\$	$S = E \times H$	$W m^{-2}$

Table 1.2 Symbols and Terminology for Physical and Chemical Quantities: Electricity and Magnetism (*From* [1]. Used with permission.)

wavelength λ mspeed of light in vacuum c_0 ms^{-1}in a medium c $c = c_0/n$ ms^{-1}wavenumber in vacuum \bar{v} $\bar{v} = v/c_0 = 1/n\lambda$ m^{-1}wavenumber in vacuum \bar{v} $\bar{v} = v/c_0 = 1/n\lambda$ m^{-1}maxenumber in vacuum \bar{v} $\bar{v} = v/c_0 = 1/n\lambda$ m^{-1}frequency, v $v = c_c/\lambda$ Hzcircular frequency, ω $\omega = 2\pi v$ s^{-1}, rad s^{-1}pulsatancerefractive index n $n = c_0/c$ 1Planck constant h J sradiant energy $Q.W$ J J radiant energy density ρ, w $\rho = Q/V$ J practal radiant energy density ρ, w_v $\rho_v = d\rho/dv$ J in terms of requency ρ_v, w_v $\rho_v = d\rho/dv$ J matim tacked emission A_{nm} $dN_n/dt = -A_{nm}N_n$ s kg^{-1}stimulated absorption B_{mn} $dN_n/dt = \rho_v (\tilde{v}_m) B_m N_m$ s kg^{-1}stimulated emission B_{mn} $dN_n/dt = \rho_v (\tilde{v}_m) B_m N_m$ s kg^{-1}radiant torsityI $I = d\Phi/d\Omega$ W $M^{-2} K^{-4}$ radiant torsityI $I = d\Phi/d\Omega$ W $M^{-2} K^{-4}$ stimulated absorption B_{mn} $dN_n/dt = \rho_v (\tilde{v}_m) B_m N_m$ s kg^{-1}radiant energy per timeI $I = d\Phi/d\Omega$ W $M^{-2} K^{-4}$ radiant torsityI $I = d\Phi/d\Omega$ W $M^{-2} K^{-4}$ radiant tor	Name	Symbol	Definition	SI unit
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circular frequency, pulsatance ω $\omega = 2\pi v$ $s^{-1}, rad s^{-1}$ pulsatancen $n = c_0/c$ 1Planck constanth $n = c_0/c$ 1Planck constant/ 2π \tilde{n} $\tilde{n} = h/2\pi$ $J = s$ radiant energy $Q.W$ J J radiant energy density ρ, w $\rho = Q/V$ $J = s^{-1}$ in terms of frequency ρ_v, w_v $\rho_v = d\rho/dv$ $J = s^{-1}$ in terms of wavelength ρ_v, w_v $\rho_v = d\rho/dv$ $J = s^{-1}$ Einstein transition probabilitiesspontaneous emission A_{nm} $dN_n/dt = -A_{nm}N_n$ $s = s^{-1}$ simulated emission B_{nm} $dN_n/dt = -\rho_{\tilde{v}}(\tilde{v}_{nm}) \otimes B_{nm}N_n$ $s kg^{-1}$ radiant power, Φ, P $\Phi = dQ/dt$ $W = s^{-1}$ radiant intensity I $I = d\Phi/d\Omega$ $W = s^{-1}$ radiant energy per time I $I = d\Phi/d\Omega$ $W = s^{-1}$ radiant timesity I $I = d\Phi/d\Omega$ $W = s^{-1}$ (radiant flux received) $E, (I)$ $E = d\Phi/dA$ $W = s^{-1}$ emitter c $c = M/M_{bb}$ 1Stefan-Boltzman constant σ $M_{bb} = \sigma T^4$ $W = s^{-2} K^{-4}$ first radiation constant c_1 c_2 c_2 hc_0/k Kmtransmistion factor a $a = \Phi_{abs}/\Phi_0$ 1absorption factor a $a = A/1$ m^{-1} (decadic) absorbance A $A = lg(1 - \alpha_i)$ 1napierian absorbance B $B =$	frequency	υ	$v = c/\lambda$	Hz
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Planck constanthJ sPlanck constant/2 π \hbar \hbar $\hbar = h/2\pi$ J sradiant energy Q, W JJradiant energy density ρ, w $\rho = Q/V$ J m ⁻³ in terms of frequency ρ_v, w_v $\rho_v = d\rho/dv$ J m ⁻³ in terms of wavenumber ρ_v, w_v $\rho_v = d\rho/dv$ J m ⁻² in terms of wavenumber ρ_v, w_v $\rho_{\lambda} = d\rho/d\lambda$ J m ⁻⁴ Einstein transition probabilitiesspontaneous emission A_{nm} $dN_n/dt = -A_m N_n$ s^{-1}stimulated emission B_{nm} $dN_n/dt = -\rho_v(v_m) \times B_{nm}N_m$ s kg^{-1}radiant energy per timeradiant intensity V V radiant energy per time V V V radiant energy per time V $M = d\Phi/d\Omega$ W sr ⁻¹ radiant energy per time V $M = d\Phi/dA$ W m ⁻² (emitted radiant flux) V $V = T^2$ V irradiance $E, (I)$ $E = d\Phi/dA$ W m ⁻² (radiant flux received) e ε $M/M_{bb} = \sigma T^4$ W m ⁻² K ⁻⁴ first radiation constant σ $M_{bb} = \sigma T^4$ W m ⁻² K ⁻⁴ irrassiftance, τ, T $\tau = \phi_{re}/\phi_0$ 1transmission factor e $e = a/M_{bb} = 0$ 1reflection factor σ $A = lg(1 - \alpha_i)$ 1absorption factor R $A = lg(1 - \alpha_i)$ 1indiction constrat c_2 $c_2 = hc_0/k$ M (decadic) absorbance <td>refractive index</td> <td>n</td> <td>$n = c_0/c$</td> <td>1</td>	refractive index	n	$n = c_0/c$	1
Planck constant/ 2π \hbar $\hbar = h/2\pi$] s radiant energy Q, W J radiant energy density ρ, w $\rho = Q/V$ J m ⁻³ spectral radiant energy density in terms of frequency ρ_v, w_v $\rho_v = d\rho/dv$ J m ⁻³ $m^{-3}Hz^{-1}$ in terms of wavelength ρ_v, w_v $\rho_v = d\rho/dv$ J m ⁻² in terms of wavelength ρ_v, w_λ $\rho_\lambda = d\rho/d\lambda$ J m ⁻⁴ Einstein transition probabilities spontaneous emission A_{nm} $dN_n/dt = -A_{nm}N_n$ s kg ⁻¹ stimulated mission B_{nm} $dN_n/dt = \rho_{\bar{\nu}}(\bar{v}_{nm})B_{mn}N_m$ s kg ⁻¹ radiant power, Φ, P $\Phi = dQ/dt$ W radiant energy per time radiant intensity I I I = $d\Phi/d\Omega$ W sr ⁻¹ radiant furxing I I = $d\Phi/d\Lambda$ W m ⁻² (emitted radiant flux) irradiance $E, (I)$ $E = d\Phi/dA$ W m ⁻² (radiant flux received) emittance ε ε $\varepsilon = M/M_{bb}$ 1 Stefan-Boltzman constant σ $M_{bb} = \sigma T^4$ W m ⁻² K ⁻⁴ transmittance, r, T $\tau = \Phi_{tr}/\Phi_0$ 1 transmistion factor absorption coefficient (decadic) absorbance A $A = lg(1 - \alpha_i)$ 1 absorption coefficient (linear) napierian α $\alpha = B/I$ m ⁻¹ molar (decadic) ε $\varepsilon = a/c = A/cl$ m ⁻¹ molar decadic n α $\alpha = B/I$ m ⁻¹ m ⁻¹ molar decadic n α $\alpha = B/I$ m ⁻¹ m ⁻¹ molar decadic n α $\alpha = B/I$ m ⁻¹ m ⁻¹ molar decadic n α α $\alpha = B/I$ m ⁻¹ m ⁻¹ molar decadic n α α $\alpha = B/I$ m ⁻¹ m ⁻¹ molar decadic n α α $\alpha = B/I$ m ⁻¹ m ⁻¹	Planck constant	h	~,	Is
radiant energy Q, W $\rho = Q/V$ Jm^{-3} radiant energy density ρ, w $\rho = Q/V$ Jm^{-3} spectral radiant energy density ρ, w_v $\rho_v = d\rho/dv$ Jm^{-3} Hz ⁻¹ in terms of frequency $\rho_{\bar{v}}, w_{\bar{v}}$ $\rho_{\bar{v}} = d\rho/d\bar{v}$ Jm^{-2} in terms of wavenumber $\rho_{\bar{v}}, w_{\bar{v}}$ $\rho_{\bar{v}} = d\rho/d\lambda$ Jm^{-2} in terms of wavenumber $\rho_{\bar{v}}, w_{\bar{v}}$ $\rho_{\bar{\lambda}} = d\rho/d\lambda$ Jm^{-2} in terms of wavenumber $\rho_{\bar{v}}, w_{\bar{\nu}}$ $\rho_{\bar{\lambda}} = d\rho/d\lambda$ Jm^{-2} in terms of wavenumber $\rho_{\bar{v}}, w_{\bar{\nu}}$ $\rho_{\bar{\lambda}} = d\rho/d\lambda$ Jm^{-2} Einstein transition probabilities spontaneous emission A_{nm} $dN_n/dt = -A_{nm}N_n$ skg^{-1} stimulated emission B_{nm} $dN_n/dt = -\rho_{\bar{v}}(\bar{v}_{nm}) \times B_{nm}N_n$ skg^{-1} radiant opwer, Φ, P $\Phi = dQ/dt$ W W radiant energy per time radiant energy per time radiant exitance M $M = d\Phi/d\Delta$ Wm^{-2} (emitted radiant flux) irradiance ε $\varepsilon = M/M_{bb}$ 1 Stefan-Boltzman constant σ $M_{bb} = \sigma T^4$ $Wm^{-2} K^{-4}$ first radiation constant c_1 $c_1 = 2\pi hc_0^2$ Wm^2 second radiation constant c_2 $c_2 = hc_0/k$ Km transmission factor absorption factor reflection factor (decadic) absorbance A $A = lg(1 - \alpha_i)$ 1 absorption coefficient (linear) decadic a, K $a = A/l$ m^{-1} (linear) decadic a, K $a = A/l$ m^{-1} molar decadic h $k = (a/2\pi\bar{a})/4n$ m^{-1} molar decadic h $k = (a/2\pi\bar{a})/4n$ m^{-1} $molar napierian \kappa \kappa = \alpha/c = B/cl m^2 mol^{-1}absorption index k k k = \alpha/4\pi\bar{v} 1m^2mol^{-1}$	Planck constant/ 2π	ħ	$\hbar = h/2\pi$	Ís
radiant energy density ρ, w $\rho = Q/V$ J m ⁻³ spectral radiant energy density in terms of frequency ρ_v, w_v $\rho_v = d\rho/dv$ J m ⁻³ Hz ⁻¹ in terms of wavenumber $\rho_{\bar{v}}, w_{\bar{v}}$ $\rho_{\bar{v}} = d\rho/d\bar{v}$ J m ⁻² in terms of wavenumber $\rho_{\bar{v}}, w_{\bar{v}}$ $\rho_{\bar{v}} = d\rho/d\lambda$ J m ⁻⁴ Einstein transition probabilities spontaneous emission A_{nm} $dN_n/dt = -A_{nm}N_n$ s kg ⁻¹ stimulated emission B_{nm} $dN_n/dt = -\rho_{\bar{v}}(\bar{v}_{nm}) \times B_{nm}N_m$ s kg ⁻¹ radiant intergy per time radiant intensity I I I = d\Phi/d\Omega W sr ⁻¹ radiant energy per time radiant energy per time radiant flux received) emitted radiant flux irradiant flux received) emittence E, (I) E = d\Phi/dA W m ⁻² (radiant flux received) emittence ε $\varepsilon = M/M_{bb}$ 1 Stefan-Boltzman constant σ $M_{bb} = \sigma T^4$ W m ⁻² K ⁻⁴ first radiation constant c_1 $c_1 = 2\pi hc_0^2$ W m ² second radiation constant c_2 $c_2 = hc_0/k$ K m transmistion factor reflectance, ρ $\rho = \Phi_{refl}/\Phi_0$ 1 transmistion factor reflectance, β A $A = lg(1 - \alpha_i)$ 1 absorption coefficient (linear) decadic a, K $a = A/l$ m ⁻¹ (micar) mapierian α α $a = B/l$ m ⁻¹ molar (decadic) b $k = a/a = n^2 - 1$ w m ⁻² mol ⁻¹ $absorption index$ k $k = \alpha/a \pi \bar{v}$ 1 complex refractione $R = R = R = n^{2} - 1$ w m ⁻² mol ⁻¹ w m ⁻² mol ⁻¹	radiant energy	Q, W	,	Ĵ
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	radiant energy density	$\tilde{\rho}, w$	$\rho = O/V$	$J m^{-3}$
in terms of frequency ρ_v, w_v $\rho_v = d\rho/dv$ $J m^{-3}Hz^{-1}$ in terms of wavelength $\rho_{\bar{v}}, w_{\bar{v}}$ $\rho_{\bar{v}} = d\rho/d\bar{v}$ $J m^{-2}$ in terms of wavelength $\rho_{\lambda}, w_{\lambda}$ $\rho_{\lambda} = d\rho/d\bar{v}$ $J m^{-2}$ Einstein transition probabilitiesspontaneous emission A_{nm} $dN_n/dt = -A_{nm}N_n$ s^{-1} stimulated emission B_{nm} $dN_n/dt = -\rho_{\bar{v}}(\bar{v}_{nm}) \times B_{nm}N_n$ $s kg^{-1}$ stimulated absorption B_{mn} $dN_n/dt = -\rho_{\bar{v}}(\bar{v}_{nm}) \times B_{nm}N_n$ $s kg^{-1}$ radiant energy per timeradiant energy per time $W m^{-2}$ $W m^{-2}$ radiant energy per time $I = d\Phi/d\Omega$ $W sr^{-1}$ radiant energy per time $M = d\Phi/dA_{source}$ $W m^{-2}$ (emitted radiant flux) $I = 2\pi hc_0^2$ $W m^{-2} K^{-4}$ (irradiance $E, (I)$ $E = d\Phi/dA$ $W m^{-2} K^{-4}$ (radiant flux received) $e^{\pi} = \pi^{-1}$ $W m^{-2} K^{-4}$ emittance $e^{\pi} = M/M_{bb}$ 1 transmistion constant c_1 $c_1 = 2\pi hc_0^2$ second radiation constant c_1 $c_1 = 2\pi hc_0^2$ $W m^{-2} K^{-4}$ $W m^{-2} K^{-4}$ absorption factor $a^{\pi} = 4 = kg(1 - \alpha_i)$ $absorption factor$ $A = lg(1 - \alpha_i)$ 1 w^{-1} effection factor $A = A/I$ m^{-1} $(linear)$ decadic a, K $a = A/I$ m^{-1} w^{-1} molar absorbance $A = B/I$ m^{-1} w^{-1} molar absorbance $A = B/I$ m^{-1}	spectral radiant energy density	1 '	, 2,	,
in terms of wavenumber in terms of wavelength $\rho_{\bar{v}}, w_{\bar{v}}$ $\rho_{\bar{v}} = d\rho/d\bar{v}$ $J m^{-2}$ Einstein transition probabilities spontaneous emission A_{nm} $dN_n/dt = -A_{nm}N_n$ s^{-1} Sitmulated emission B_{nm} $dN_n/dt = -\rho_{\bar{v}}(\bar{v}_{nm}) \times B_{nm}N_n$ $s kg^{-1}$ stimulated emission B_{mm} $dN_n/dt = -\rho_{\bar{v}}(\bar{v}_{nm}) \times B_{nm}N_n$ $s kg^{-1}$ radiant power, radiant energy per time Φ, P $\Phi = dQ/dt$ W radiant exitance M $M = d\Phi/d\Omega$ $W sr^{-1}$ radiant exitance M $M = d\Phi/dA$ $W m^{-2}$ (emitted radiant flux)irradiance ε $\varepsilon = M/M_{bb}$ 1stean-Boltzman constant σ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ first radiation constant c_1 $c_1 = 2\pi hc_0^2$ $W m^2$ w mrassion factor a $\alpha = \Phi_{abs}/\Phi_0$ 1absorption factor B $B = ln(1 - \alpha_i)$ 1absorption coefficient a $\alpha = B/l$ m^{-1} (linear) decadic a, K $a = A/L$ m^{-1} molar decadic) ε $\varepsilon = a/c = A/cl$ $m^2 mol^{-1}$ molar apierian α $\alpha = B/l$ m^{-1} molar decadic) ε $\varepsilon = a/a = m^2 - 1$ $w^2 mol^{-1}$	in terms of frequency	ρ_n, w_n	$\rho_v = d\rho/dv$	$I m^{-3} H z^{-1}$
in terms of wavelength $\rho_{\lambda}, w_{\lambda}$ $\rho_{\lambda} = d\rho/d\lambda$ $J m^{-4}$ Einstein transition probabilitiesspontaneous emission A_{nm} $dN_n/dt = -A_{nm}N_n$ s^{-1} stimulated emission B_{nm} $dN_n/dt = -\rho_{\bar{v}}(\bar{v}_{nm}) \times B_{nm}N_n$ $s kg^{-1}$ radiant emission B_{mn} $dN_n/dt = -\rho_{\bar{v}}(\bar{v}_{nm}) \times B_{nm}N_n$ $s kg^{-1}$ radiant power, Φ, P $\Phi = dQ/dt$ W radiant energy per time I $I = d\Phi/d\Omega$ $W sr^{-1}$ radiant exitance M $M = d\Phi/dA_{source}$ $W m^{-2}$ (emitted radiant flux) V $E = d\Phi/dA$ $W m^{-2}$ irradiance ε $\varepsilon = M/M_{bb}$ 1stefan-Boltzman constant σ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ first radiation constant c_1 $c_1 = 2\pi hc_0^2$ $W m^2$ second radiation constant c_2 $c_2 = hc_0/k$ K mtransmission factor a $\alpha = \Phi_{abs}/\Phi_0$ 1absorption factor ρ $\rho = \Phi_{refl}/\Phi_0$ 1(decadic) absorbance A $A = lg(1 - \alpha_i)$ 1napierian absorbance B $B = ln(1 - \alpha_i)$ 1absorption coefficient c $\varepsilon = a/c = A/cl$ m^{-1} (linear) decadic ε $\varepsilon = a/c = B/cl$ $m^{2} mol^{-1}$ molar napierian κ $\kappa = \alpha/a \pi \tilde{v}$ 1molar napierian κ $\kappa = \alpha/c = B/cl$ $m^{2} mol^{-1}$ molar napierian κ $\kappa = \alpha/c = B/cl$ $m^{2} mol^{-1}$	in terms of wavenumber	$\rho_{\tilde{n}}, w_{\tilde{n}}$	$\rho_{\tilde{v}} = d\rho/d\tilde{v}$	$J m^{-2}$
Einstein transition probabilities spontaneous emission A_{nm} $dN_n/dt = -A_{nm}N_n$ s^{-1} stimulated emission B_{nm} $dN_n/dt = -\rho_{\bar{v}}(\bar{v}_{nm}) \times B_{nm}N_n$ $s kg^{-1}$ radiant power, Φ , P $\Phi = dQ/dt$ W radiant energy per time radiant energy per time radiant intensity I $I = d\Phi/d\Omega$ $W sr^{-1}$ radiant flux) irradiance M $M = d\Phi/dA_{source}$ $W m^{-2}$ (emitted radiant flux) irradiance E , (I) $E = d\Phi/dA$ $W m^{-2}$ (radiant flux received) emittance ε $\varepsilon = M/M_{bb}$ 1 Stefan-Boltzman constant σ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ first radiation constant c_1 $c_1 = 2\pi hc_0^2$ $W m^2$ second radiation constant c_2 $c_2 = hc_0/k$ K m transmission factor absorption factor reflection factor (decadic) absorbance B $B = ln(1 - \alpha_i)$ 1 napierian absorbance B $B = ln(1 - \alpha_i)$ 1 absorption coefficient (linear) napierian α $\alpha = B/l$ m^{-1} molar napierian κ $K = \alpha/a\pi \tilde{v}$ 1 $m^2 m c^{-1}$ M $R = R = R^{-2} - 1$ V m^{-2} m^2 molar $2\pi c^{-1}$ V	in terms of wavelength	$\rho_{\lambda}, w_{\lambda}$	$\rho_{\lambda} = d\rho/d\lambda$	$J m^{-4}$
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stimulated absorption B_{mn} $dN_n/dt = \rho_0(\bar{v}_{nm}) + v_{nm}n_n$ sk_B^{-1} radiant power, radiant energy per time Φ, P $\Phi = dQ/dt$ W radiant energy per time I $I = d\Phi/d\Omega$ $W sr^{-1}$ radiant intensity I $I = d\Phi/d\Omega$ $W sr^{-1}$ radiant exitance M $M = d\Phi/dA_{source}$ $W m^{-2}$ (emitted radiant flux) $irradiance$ $E, (I)$ $E = d\Phi/dA$ $W m^{-2}$ (radiant flux received) ε $\varepsilon = M/M_{bb}$ 1emittance ε $\varepsilon = M/M_{bb}$ 1Stefan-Boltzman constant σ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ first radiation constant c_1 $c_1 = 2\pi hc_0^2$ $W m^2$ second radiation constant c_2 $c_2 = hc_0/k$ K transmission factorabsorption factor1reflectance, neptention factor ρ $\rho = \Phi_{refl}/\Phi_0$ 1industrian absorbance B $B = \ln(1 - \alpha_i)$ 1absorption coefficient ω $\omega = B/l$ m^{-1} (linear) napierian molar (decadic) ε $\varepsilon = a/c = A/cl$ $m^2 mol^{-1}$ absorption index to coefficient k $k = \alpha/4\pi \bar{v}$ 1complex refractive index \dot{n} $\dot{n} = n + ik$ 1molar refraction \dot{n} $\dot{n} = n + ik$ 1	stimulated emission	B	$\frac{dN_n}{dt} = -\rho_{\tilde{z}}(\tilde{v}_{nm}) \times B_{nm} N_n$	s ka-1
radiant power, Φ, P $\Phi = dQ/dt$ W radiant energy per time radiant intensity I $I = d\Phi/d\Omega$ $W {\rm sr}^{-1}$ radiant energy per time radiant intensity I $I = d\Phi/d\Omega$ $W {\rm sr}^{-1}$ radiant fux received M $M = d\Phi/dA_{\rm source}$ $W {\rm m}^{-2}$ (emitted radiant flux) irradiance $E, (I)$ $E = d\Phi/dA$ $W {\rm m}^{-2}$ (radiant flux received) emittance ε $\varepsilon = M/M_{\rm bb}$ 1 Stefan-Boltzman constant σ $M_{\rm bb} = \sigma T^4$ $W {\rm m}^{-2} {\rm K}^{-4}$ first radiation constant c_1 $c_1 = 2\pi h c_0^2$ $W {\rm m}^2$ second radiation constant c_2 $c_2 = h c_0/k$ $K {\rm m}$ transmittance, τ, T $\tau = \Phi_{\rm tr}/\Phi_0$ 1 transmittance, σ Λ $\alpha = \Phi_{\rm abs}/\Phi_0$ 1 absorption factor reflectance, ρ $\rho = \Phi_{\rm refl}/\Phi_0$ 1 napierian absorbance B $B = \ln(1 - \alpha_i)$ 1 absorption coefficient (linear) napierian α $\alpha = B/l$ m^{-1} molar (decadic) ε k $k = \alpha/A \pi \tilde{v}$ 1 molar napierian k $k = \alpha/4\pi \tilde{v}$ 1 molar refraction k $k = \alpha/4\pi \tilde{v}$ 1 molar refraction k $k = \alpha/4\pi \tilde{v}$ 1 molar refraction μ $R = R$ $R = \frac{n^2 - 1}{2} V$ $m^3 m a^{-1}$	stimulated absorption	Bmm	$\frac{dN_n}{dt} = \rho_0(0,m) \times D_{nm}(n)$	s kg ⁻¹
Initial constructionInitial constructionInitial constructionInitial constructionradiant energy per timeI $I = d\Phi/d\Omega$ $W {\rm sr}^{-1}$ radiant energy per timeI $I = d\Phi/d\Lambda$ $W {\rm sr}^{-2}$ radiant exitanceM $M = d\Phi/dA_{\rm source}$ $W {\rm m}^{-2}$ (emitted radiant flux)irradiance $E, (I)$ $E = d\Phi/dA$ $W {\rm m}^{-2}$ (radiant flux received) ε $\varepsilon = M/M_{\rm bb}$ 1Stefan-Boltzman constant σ $M_{\rm bb} = \sigma T^4$ $W {\rm m}^{-2} {\rm K}^{-4}$ first radiation constant c_1 $c_1 = 2\pi h c_0^2$ $W {\rm m}^2$ second radiation constant c_2 $c_2 = h c_0 / k$ K mtransmittance, τ, T $\tau = \Phi_{\rm tr}/\Phi_0$ 1transmission factora $\alpha = \Phi_{\rm abs}/\Phi_0$ 1absorption factor α $\alpha = \Phi_{\rm abs}/\Phi_0$ 1reflection factorII(decadic) absorbance A $A = \lg(1 - \alpha_i)$ 1napierian absorbance B $B = \ln(1 - \alpha_i)$ 1absorption coefficient ω $\omega = \alpha = B/l$ m^{-1} (linear) napierian α $\alpha = B/l$ m^{-1} molar napierian κ $\kappa = \alpha/c = B/cl$ $m^2 {\rm mol}^{-1}$ absorption index k $k = \alpha/4\pi\bar{v}$ 1molar refraction $R = R$ $R = n^{2} - \frac{1}{N}$ $N^2 {\rm mol}^{-1}$	radiant power.	Φ P	$\Phi = dO/dt$	W
radiant intensity I $I = d\Phi/d\Omega$ $W {\rm sr}^{-1}$ radiant intensity $M = d\Phi/dA_{\rm source}$ $W {\rm m}^{-2}$ (emitted radiant flux) irradiance $E, (I)$ $E = d\Phi/dA$ $W {\rm m}^{-2}$ (radiant flux received) emittance ε $\varepsilon = M/M_{\rm bb}$ 1 Stefan-Boltzman constant σ $M_{\rm bb} = \sigma T^4$ $W {\rm m}^{-2} {\rm K}^{-4}$ first radiation constant c_1 $c_1 = 2\pi h c_0^2$ $W {\rm m}^2$ second radiation constant c_2 $c_2 = h c_0 / k$ $K {\rm m}$ transmittance, τ, T $\tau = \Phi_{\rm tr} / \Phi_0$ 1 transmission factor reflectance, ρ $\rho = \Phi_{\rm refl} / \Phi_0$ 1 reflection factor (decadic) absorbance A $A = lg(1 - \alpha_i)$ 1 napierian absorbance B $B = ln(1 - \alpha_i)$ 1 absorption coefficient (linear) napierian α $\alpha = B/l$ m^{-1} molar napierian κ $\kappa = \alpha/c = B/cl$ $m^2 {\rm mol}^{-1}$ absorption index k $k = \alpha/4\pi \bar{\nu}$ 1 remain molar (decadic) κ R $R = R = R = \frac{n^2 - 1}{2} V$ $m^3 {\rm mol}^{-1}$	radiant energy per time	- , -	r = a g/a	
radiant exitance M $M = d\Phi/dA_{source}$ $W m^{-2}$ (emitted radiant flux) irradiance $E, (I)$ $E = d\Phi/dA$ $W m^{-2}$ (radiant flux received) emittance ε $\varepsilon = M/M_{bb}$ 1 Stefan-Boltzman constant σ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ first radiation constant c_1 $c_1 = 2\pi h c_0^2$ $W m^2$ second radiation constant c_2 $c_2 = h c_0 / k$ $K m$ transmittance, τ, T $\tau = \Phi_{tr} / \Phi_0$ 1 transmission factor absorption factor reflectance, ρ $\rho = \Phi_{refl} / \Phi_0$ 1 napierian absorbance A $A = lg(1 - \alpha_i)$ 1 napierian absorbance B $B = ln(1 - \alpha_i)$ 1 absorption coefficient (linear) napierian α $\alpha = B/l$ m^{-1} molar napierian κ $\kappa = \alpha/c = B/cl$ $m^2 mol^{-1}$ absorption index k $k = \alpha/4\pi \tilde{v}$ 1 remeasurements $h = h + ik$ 1 molar refraction R R $R = R = R^{-1} - \frac{n^2 - 1}{2}$ W m^3 male π	radiant intensity	I	$I = d\Phi/d\Omega$	$W sr^{-1}$
(emitted radiant flux) $m = 0.7/0.4500000000000000000000000000000000000$	radiant exitance	M	$M = d\Phi/dA_{\text{course}}$	$W m^{-2}$
irradiance $E, (I)$ $E = d\Phi/dA$ $W m^{-2}$ (radiant flux received) emittance ε $\varepsilon = M/M_{bb}$ 1 Stefan-Boltzman constant σ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ first radiation constant c_1 $c_1 = 2\pi h c_0^2$ $W m^2$ second radiation constant c_2 $c_2 = h c_0 / k$ $K m$ transmittance, τ, T $\tau = \Phi_{tr} / \Phi_0$ 1 transmission factor absorption factor reflectance, ρ $\rho = \Phi_{refl} / \Phi_0$ 1 napierian absorbance A $A = lg(1 - \alpha_i)$ 1 napierian absorbance B $B = ln(1 - \alpha_i)$ 1 absorption coefficient (linear) napierian α $\alpha = B/l$ m^{-1} molar napierian κ $\kappa = \alpha/c = B/cl$ $m^2 mol^{-1}$ molar napierian κ $k = \alpha/4\pi \tilde{v}$ 1 complex refractive index \hat{n} R R $R = m^{2} - \frac{n^2 - 1}{2}V$ $m^3 m cl^{-1}$	(emitted radiant flux)		m – a + / a r source	** 111
Instance $E_{1}(r)$ $E = ar/an$ r m(radiant flux received) ε $\varepsilon = M/M_{bb}$ 1emittance ε $\varepsilon = M/M_{bb} = \sigma T^{4}$ $W m^{-2} K^{-4}$ first radiation constant σ $M_{bb} = \sigma T^{4}$ $W m^{-2} K^{-4}$ first radiation constant c_{1} $c_{1} = 2\pi hc_{0}^{2}$ $W m^{2}$ second radiation constant c_{2} $c_{2} = hc_{0}/k$ K mtransmittance, τ, T $\tau = \Phi_{tr}/\Phi_{0}$ 1transmission factorabsorptance, α $\alpha = \Phi_{abs}/\Phi_{0}$ 1absorption factorreflectance, ρ $\rho = \Phi_{refl}/\Phi_{0}$ 1(decadic) absorbanceA $A = \lg(1 - \alpha_{i})$ 1napierian absorbanceB $B = \ln(1 - \alpha_{i})$ 1absorption coefficient(linear) apierian α $\alpha = B/l$ m^{-1} (linear) napierian κ $\kappa = \alpha/c = A/cl$ $m^{2}mol^{-1}$ molar napierian κ $\kappa = \alpha/c = B/cl$ $m^{2}mol^{-1}$ absorption index k $k = \alpha/4\pi \tilde{v}$ 1complex refractive index \hat{n} $\hat{n} = n + ik$ 1	irradiance	F(I)	$F = d\Phi/dA$	$W m^{-2}$
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reflection factor (decadic) absorbance A $A = lg(1 - \alpha_i)$ 1 napierian absorbance B $B = ln(1 - \alpha_i)$ 1 absorption coefficient (linear) decadic a, K $a = A/l$ m^{-1} (linear) napierian α $\alpha = B/l$ m^{-1} molar (decadic) ε $\varepsilon = a/c = A/cl$ $m^2 mol^{-1}$ molar napierian κ $\kappa = \alpha/c = B/cl$ $m^2 mol^{-1}$ absorption index k $k = \alpha/4\pi\tilde{v}$ 1 complex refractive index \hat{n} $\hat{n} = n + ik$ 1 molar refraction $R = R$ $R = \frac{n^2 - 1}{2}V$ $m^3 mol^{-1}$	reflectance.	0	$\rho = \Phi_{mq} / \Phi_0$	1
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$	(decadic) absorbance	Α	$A = \lg(1 - \alpha_i)$	1
InterviewImage: Second se	napierian absorbance	B	$B = \ln(1 - \alpha_i)$	1
Interpretation a, K $a = A/l$ m^{-1} (linear) napierian α $\alpha = B/l$ m^{-1} molar (decadic) ε $\varepsilon = a/c = A/cl$ $m^2 \mod^{-1}$ molar napierian κ $\kappa = \alpha/c = B/cl$ $m^2 \mod^{-1}$ absorption index k $k = \alpha/4\pi\tilde{v}$ 1complex refractive index \hat{n} $\hat{n} = n + ik$ 1molar refraction P, P $P = \frac{n^2 - 1}{V}$ $m^3 \mod^{-1}$	absorption coefficient	-		-
(linear) napierian α $\alpha = B/l$ m^{-1} molar (decadic) ε $\varepsilon = a/c = A/cl$ $m^{2} \mod^{-1}$ molar napierian κ $\kappa = \alpha/c = B/cl$ $m^{2} \mod^{-1}$ absorption index k $k = \alpha/4\pi\tilde{v}$ 1complex refractive index \hat{n} $\hat{n} = n + ik$ 1molar refraction R $R = m^{2} - 1$ $m^{3} m a^{-1}$	(linear) decadic	a.K	a = A/l	m^{-1}
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	(linear) napierian	α, 11	$\alpha = B/I$	m^{-1}
molar napierian κ $\kappa = \alpha/c = B/cl$ $m^2 \mod^{-1}$ absorption index k $k = \alpha/4\pi\tilde{v}$ 1complex refractive index \hat{n} $\hat{n} = n + ik$ 1molar refraction R $R = m^{2} - 1$ $m^3 \mod^{-1}$	molar (decadic)	£	$\varepsilon = a/c = A/cl$	$m^2 mol^{-1}$
absorption index k $k = \alpha/4\pi\tilde{v}$ 1 complex refractive index \hat{n} $\hat{n} = n + ik$ 1 molar refraction $P = P = \frac{n^2 - 1}{2}V$ $m^3 m e^{1-1}$	molar napierian	ĸ	$\kappa = \alpha/c = B/cl$	$m^2 mol^{-1}$
complex refractive index \hat{n} $\hat{n} = n + ik$ 1 molar refraction $P_{n}P_{n} = \frac{n^{2}-1}{V}$ $m^{3} m a^{-1}$	absorption index	k	$k = \alpha/4\pi\tilde{v}$	1
molar refraction $\mathbf{P} \cdot \mathbf{P} = \frac{n^2 - 1}{V}$ $\mathbf{W} = \frac{n^2 - 1}{2}$	complex refractive index	ĥ	$\hat{n} = n + ik$	1
$K, K_m \qquad K = \frac{1}{m^2 + 2} V_m \qquad \text{III III0I}$	molar refraction	R, R_m	$R = \frac{n^2 - 1}{n^2 + 2} V_m$	m ³ mol ⁻¹
angle of optical rotation α $n^2 + 2$ 1. rad	angle of optical rotation	α	$n^{-} + 2$	1, rad

Table 1.3 Symbols and Terminology for Physical and Chemical Quantities: Electromagnetic Radiation (*From* [1]. Used with permission.)

Name	Symbol	Definition	SI unit
lattice vector	R , R ₀		m
fundamental translation	$a_1; a_2; a_3,$	$R = n_1 a_1 + n_2 a_2 + n_3 a_3$	m
vectors for the crystal	a; b; c		
lattice			
(circular) reciprocal	G	$G \cdot R = 2\pi m$	m^{-1}
lattice vector			
(circular) fundamental	$b_1; b_2; b_3,$	$\boldsymbol{a}_i \cdot \boldsymbol{b}_k = 2\pi \delta_{ik}$	m^{-1}
translation vectors for	a*; b*; c*		
the reciprocal lattice			
lattice plane spacing	d		m
Bragg angle	θ	$n\lambda = 2d\sin\theta$	1, rad
order of reflection	n		1
order parameters			
short range	σ		1
long range	S		1
Burgers vector	b		m
particle position vector	r , R _j		m
equilibrium position	R_0		m
vector of an ion			
equilibrium position	R_0		m
vector of an ion			
displacement vector of an ion	и	$u=R-R_0$	m
Debye–Waller factor	B, D		1
Debye circular wavenumber	q_D		m ⁻¹
Debye circular frequency	ω_D		s ⁻¹
Grüneisen parameter	γ, Γ	$\gamma = \alpha V / \kappa C_V$	1
Madelung constant	α, \mathcal{M}	$E_{\text{coul}} = \frac{\alpha N_A z_+ z e^2}{2}$	1
A sector of states	N7	$4\pi\varepsilon_0 R_0$	r-13
density of states	IN E	$N_E = aN(E)/aE$) - m -
(spectral) density of	N_{ω}, g	$N_{\omega} = dN(\omega)/d\omega$	s m -
vibrational modes	<u>.</u>	F = c i	0 m
and unitivity tensor	ρ_{ik}	$E = \rho \cdot \mathbf{j}$	52 m
thermal conductivity tensor	O _{ik}	$b \equiv \rho$	$3 \text{ m}^{-1} \text{ V}^{-1}$
residual resistivity	Aik Or	$J_q = -\lambda \cdot \text{grad} T$	Om
relayation time	p_R	$\tau = l/m$	56 III 5
Lorenz coefficient	I	l = l/bF $I = l/\sigma T$	$V^{2} K^{-2}$
Hall coefficient		$E = A/0 I$ $E = a \cdot i + B \cdot (B \times i)$	$m^3 C^{-1}$
thermoelectric force	F AH, NH	$L = p \cdot \mathbf{j} + \mathbf{k}_H (\mathbf{b} \times \mathbf{j})$	W
Deltion coefficient			V
Thomson coefficient	11		$V V V^{-1}$
work function	$\mu, (\iota)$	$\Phi = E = E$	V K
number density	Ψ (n)	$\Psi = E_{\infty} - E_F$	m ⁻³
number concentration	n,(p)		111
number concentration	F		т
dapar ionization anarray			J
donor ionization energy	Ed F		J
Example on one of the second s			J
singular wave vector	LF, EF	$k = 2\pi ()$) m ⁻¹
circular wave vector,	к, ч	$\kappa = 2\pi/\kappa$	111
Plo ab for ation		ala (m) and (m) and (ille m)	
bloch function	$u_k(r)$	$\psi(\mathbf{r}) = u_k(\mathbf{r})\exp(i\mathbf{k}\cdot\mathbf{r})$	C = -3
effective mass	ρ_{m^*}	$\rho(r) = -e\psi(r)\psi(r)$	C m ·
mability	m	$u = v \dots / F$	Kg m ² 17−1 a−1
mobility ratio	μ	$\mu = v_{\text{drift}} / E$	111 V S
HODINY PATIO	D	$v = \mu_n / \mu_p$	$\frac{1}{m^2}$ c^{-1}
diffusion coefficient	D	$a_{IN}/at = -DA(an/dx)$	m- s -
airrusion length		$L = \sqrt{D\tau}$	m K
cnaracteristic (Weiss)	ϕ, ϕ_W		К
Curio tomporature	Τ.		V
Vial temperature			N V
iveei temperature	1 N		л

Table 1.4 Symbols and Terminology for Physical and Chemical Quantities: Solid State

 (From [1]. Used with permission.)

Polymer	Elongation
ABS	5–20
Acrylic	2–7
Ероху	4.4
HDPE	700-1000
Nylon, type 6	30-100
Nylon 6/6	15-300
Phenolic	0.4–0.8
Polyacetal	25
Polycarbonate	110
Polyester	300
Polypropylene	100-600
PTFE	250-350

Table 1.5 Total Elongation at Failure of Selected Polymers (*From*[1]. Used with permission.)

Table 1.6 Tensile Strength of Selected Wrought Aluminum Alloys (From [1].	Used with
permission.)	

Alloy	Temper	r TS (MPa	
1050	0	76	
1050	H16	130	
2024	0	185	
2024	T361	495	
3003	0	110	
3003	H16	180	
5050	0	145	
5050	H34	195	
6061	0	125	
6061	T6, T651	310	
7075	0	230	
7075	T6, T651	570	

Metal		Ceramic		Glass		Polymer	
Ag Al	10.50 2.7	Al_2O_3 BN (cub)	3.97-3.986 3.49 3.01 3.03	SiO ₂ SiO ₂ 10 wt% Na ₂ O SiO ₂ 10 55 wt% Na ₂ O	2.20 2.291	ABS Acrylic Enour	1.05–1.07 1.17–1.19
Co	8.8	MgO	3.581	SiO_2 19.35 wt% Na ₂ O SiO ₂ 29.20 wt% Na ₂ O	2.383	HDPE	1.80–2.00 0.96
Cr Cu Fe Ni	7.19 8.93 7.87 8.91	$\begin{array}{l} \mathrm{SiC(hex)}\\ \mathrm{Si}_3\mathrm{N}_4\left(\alpha\right)\\ \mathrm{Si}_3\mathrm{N}_4\left(\beta\right)\\ \mathrm{TiO}_2\left(\mathrm{rutile}\right) \end{array}$	3.217 3.184 3.187 4.25	SiO_2 39.66 wt% Na_2O SiO_2 39.0 wt% CaO	2.521 2.746	Nylon, type 6 Nylon 6/6 Phenolic Polyacetal	1.12–1.14 1.13–1.15 1.32–1.46 1.425
Pb Pt Ti W	11.34 21.44 4.51 19.25	UO ₂ ZrO ₂ (CaO) Al ₂ O ₃ MgO 3Al ₂ O ₃ 2SiO ₂	10.949–10.97 5.5 3.580 2.6–3.26			Polycarbonate Polyester Polystyrene PTFE	1.2 1.31 1.04 2.1–2.3

Table 1.7 Density of Selected Materials, Mg/m³ (From [1]. Used with permission.)

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Table 1.8 Dielectric Constants of Ceramics (From [1]. Used with permission.)

Material	Dielectric con- stant, 10 ⁶ Hz	Dielectric strength V/mil	Volume resistivity $\Omega \cdot cm (23^{\circ}C)$	Loss factor ^a
Alumina	4.5-8.4	40-160	1011-1014	0.0002-0.01
Corderite	4.5-5.4	40-250	$10^{12} - 10^{14}$	0.004-0.012
Forsterite	6.2	240	10 ¹⁴	0.0004
Porcelain (dry process)	6.0-8.0	40-240	$10^{12} - 10^{14}$	0.0003-0.02
Porcelain (wet process)	6.0-7.0	90400	$10^{12} - 10^{14}$	0.006-0.01
Porcelain, zircon	7.1-10.5	250-400	$10^{13} - 10^{15}$	0.0002-0.008
Steatite	5.5-7.5	200-400	$10^{13} - 10^{15}$	0.0002-0.004
Titanates (Ba, Sr, Ca, Mg, and Pb)	15-12.000	50-300	$10^8 - 10^{15}$	0.0001-0.02
Titanium dioxide	14-110	100-210	$10^{13} - 10^{18}$	0.0002-0.005

^aPower factor \times dielectric constant equals loss factor.

Table 1.9 Dielectric Constants of Glass (From [1]. Used with permission.)

Type	Dielectric constant at 100 MHz (20°C)	Volume resistivity $(350^{\circ} \text{C M } \Omega \cdot \text{cm})$	Loss factor ^a
	(22	10	0.015
Corning 0010	6.32	10	0.015
Corning 0080	6.75	0.13	0.058
Corning 0120	6.65	100	0.012
Pyrex 1710	6.00	2,500	0.025
Pyrex 3320	4.71	-	0.019
Pyrex 7040	4.65	80	0.013
Pyrex 7050	4.77	16	0.017
Pyrex 7052	5.07	25	0.019
Pyrex 7060	4.70	13	0.018
Pyrex 7070	4.00	1,300	0.0048
Vycor 7230	3.83	_	0.0061
Pyrex 7720	4.50	16	0.014
Pyrex 7740	5.00	4	0.040
Pyrex 7750	4.28	50	0.011
Pyrex 7760	4.50	50	0.0081
Vycor 7900	3.9	130	0.0023
Vycor 7910	3.8	1,600	0.00091
Vycor 7911	3.8	4,000	0.00072
Corning 8870	9.5	5,000	0.0085
G.E. Clear (silica glass)	3.81	4,000-30,000	0.00038
Quartz (fused)	3.75–4.1 (1 MHz)	_	0.0002 1 M

^aPower factor \times dielectric constant equals loss factor.

		Dielectric			Dielectric
Material	Freq., Hz	constant	Material	Freq., Hz	Constant
Acetamide	4×10^8	4.0	Phenanthrene	4×10^8	2.80
Acetanilide	-	2.9	Phenol (10°C)	4×10^8	4.3
Acetic acid (2°C)	4×10^8	4.1	Phosphorus, red	10 ⁸	4.1
Aluminum oleate	4×10^8	2.40	Phosphorus, yellow	10 ⁸	3.6
Ammonium bromide	10 ⁸	7.1	Potassium aluminum		
Ammonium chloride	10 ⁸	7.0	sulfate	10 ⁶	3.8
Antimony trichloride	10 ⁸	5.34	Potassium carbonate		
Apatite \perp optic axis	3×10^{8}	9.50	(15°C)	10 ⁸	5.6
Apatite optic axis	3×10^{8}	7.41	Potassium chlorate	6×10^{7}	5.1
Asphalt	$< 3 \times 10^{6}$	2.68	Potassium chloride	10 ⁴	5.03
Barium chloride (anhyd.)	6×10^{7}	11.4	Potassium chromate	6×10^{7}	7.3
Barium chloride (2H ₂ O)	6×10^{7}	9.4	Potassium iodide	6×10^{7}	5.6
Barium nitrate	6×10^{7}	5.9	Potassium nitrate	6×10^{7}	5.0
Barium sulfate(15°C)	10 ⁸	11.4	Potassium sulfate	6×10^{7}	5.9
Bervl \perp optic axis	10 ⁴	7.02	Ouartz \perp optic axis	3×10^{7}	4.34
Bervl optic axis	10 ⁴	6.08	Ouartz optic axis	3×10^{7}	4.27
Calcite \perp optic axis	10 ⁴	8.5	Resorcinol	4×10^{8}	3.2
Calcite optic axis	10 ⁴	8.0	Ruby⊥ optic axis	10 ⁴	13.27
Calcium carbonate	106	6.14	Ruby optic axis	10 ⁴	11.28
Calcium fluoride	104	7.36	Rutile \perp optic axis	10 ⁸	86
Calcium sulfate $(2H_2O)$	10^{4}	5.66	Rutile optic axis	108	170
Cassiterite optic axis	10 ¹²	23.4	Selenium	108	6.6
Cassiterite optic axis	10 ¹²	23.1	Silver bromide	106	12.2
d-Cocaine	5×10^8	3 10	Silver chloride	106	11.2
Cupric oleate	4×10^8	2.80	Silver cyanide	106	5.6
Cupric oxide $(15^{\circ}C)$	108	18.1	Smithsonite ontic	10 ¹²	93
Suprie Oxide (15-6)	10	10.1	axis	10	
Cupric sulfate (anhyd.)	6×10^{7}	10.3			
Cupric sulfate (5H ₂ O)	6×10^{7}	7.8	Smithsonite optic	10 ¹⁰	9.4
Diamond	10 ⁸	5.5	axis		
Diphenylymethane	4×10^8	2.7	Sodium carbonate (anhvd.)	6×10^{7}	8.4
Dolomite \perp optic axis	10 ⁸	8.0	Sodium carbonate	6×10^{7}	5.3
Dolomite optic axis	10 ⁸	6.8	(10H ₂ O)		
Ferrous oxide (15°C)	108	14.2	Sodium chloride	10^{4}	6.12
Iodine	10^{8}	4	Sodium nitrate	-	5.2
Lead acetate	10 ⁶	2.6	Sodium oleate	4×10^8	2.75
Lead carbonate (15°C)	108	18.6	Sodium perchlorate	6×10^{7}	5.4
Lead chloride	10 ⁶	4.2	Sucrose (mean)	3×10^8	3.32
Lead monoxide (15°C)	108	25.9	Sulfur (mean)	-	4.0
Lead nitrate	6×10^{7}	37.7	Thallium chloride	106	46.9
Lead oleate	4×10^{8}	3.27	<i>p</i> -Toluidine	4×10^8	3.0
Lead sulfate	106	14.3	Tourmaline \perp optic	10^{4}	7.10
Lead sulfide (15°)	10 ⁶	17.9	axis		
Malachite (mean)	1012	7.2	Tourmaline optic	10^{4}	6.3
Mercuric chloride	10^{6}	3.2	axis		
Mercurous chloride	10 ⁶	9.4	Urea	4×10^8	3.5
Naphthalene	4×10^8	2.52	Zircon ⊥, ∥	10^{8}	12
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Table 1.10 Dielectric Constants of Solids in the Temperature Range 17–22°C (From [1].Used with permission.)