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## The Resource Handbook of

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# The Resource Handbook of

Jerry C. Whitaker Technical Press Morgan Hill, California



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## **Preface**

The hallmark of the CRC Press "Electronics Engineering Series" of books is their depth of coverage on targeted subjects. Even the more general-interest publication of the series—*The Electronics Handbook*—covers the entire realm of electronics in exceptional detail.

This book is a departure from those that have gone before it. *The Resource Handbook of Electronics* is intended to provide quick access to basic information, mostly through figures and tables. For each of the 20-plus chapters, a broad-brush overview is given, followed in most cases by extensive tabular data. *The Resource Handbook of Electronics* is intended for readers who need specific data at their fingertips, accessible in a convenient format.

This book is intended for engineers, technicians, operators, and technical managers involved in the specification, design, installation, operation, maintenance, and management of electronics facilities. The book is designed to be a hands-on pocket guide that holds solutions to specific problems. In this regard, it is a companion publication to *The Electronics Handbook* and the other books in the series. For readers who need extensive background on a given subject, *The Electronics Handbook* and its related works provide the necessary level of detail. For readers who need a broad overview of the subject and essential data relating to it, *The Resource Handbook of Electronics* is the ideal publication.

This book is organized in a logical sequence that begins with fundamental electrical properties and builds to higher levels of sophistication from one chapter to the next. Chapters are devoted to all of the most common components and devices, in addition to higher-level applications of those components.

Among the extensive data contained in The Resource Handbook of Electronics are

- Frequency assignments—A complete and up-to-date listing of frequencies used by various services in the U.S. and elsewhere
- Glossary of terms—An extensive dictionary of electronic terms, including abbreviations and acronyms
- Conversion factors—Detailed tables covering all types of conversion requirements in the field of electronics

*The Resource Handbook of Electronics* is the most detailed publication of its kind. I trust you will find it useful on the job, day in and day out.

*Jerry C. Whitaker* Morgan Hill, California

For updated information on this and other engineering books, visit the author's Internet site www.technicalpress.com

## **About the Author**

**Jerry Whitaker** is a technical writer based in Morgan Hill, California, where he operates the consulting firm *Technical Press*. Mr. Whitaker has been involved in various aspects of the communications industry for more than 25 years. He is a Fellow of the Society of Broadcast Engineers and an SBE-certified Professional Broadcast Engineer. He is also a member and Fellow of the Society of Motion Picture and Television Engineers, and a member of the Institute of Electrical and Electronics Engineers. Mr. Whitaker has written and lectured extensively on the topic of electronic systems installation and maintenance.

Mr. Whitaker is the former editorial director and associate publisher of *Broadcast Engineering* and *Video Systems* magazines. He is also a former radio station chief engineer and TV news producer.

Mr. Whitaker is the author of a number of books, including:

- The Communications Facility Design Handbook, CRC Press, 2000.
- Power Vacuum Tubes Handbook, 2nd edition, CRC Press, 1999.
- AC Power Systems, 2nd edition, CRC Press, 1998.
- DTV: The Revolution in Electronic Imaging, 2nd edition, McGraw-Hill, 1999.
- Editor-in-Chief, NAB Engineering Handbook, 9th edition, National Association of Broadcasters, 1999.
- Editor-in-Chief, The Electronics Handbook, CRC Press, 1996.
- Coauthor, Communications Receivers: Principles and Design, 2nd edition, McGraw-Hill, 1996.
- Electronic Displays: Technology, Design, and Applications, McGraw-Hill, 1994.
- Coeditor, Standard Handbook of Video and Television Engineering, 3rd edition, McGraw-Hill, 2000.
- Coeditor, Information Age Dictionary, Intertec/Bellcore, 1992.
- Maintaining Electronic Systems, CRC Press, 1991.
- Radio Frequency Transmission Systems: Design and Operation, McGraw-Hill, 1990.

Mr. Whitaker has twice received a Jesse H. Neal Award *Certificate of Merit* from the Association of Business Publishers for editorial excellence. He also has been recognized as *Educator of the Year* by the Society of Broadcast Engineers.

#### Acknowledgment

The author wishes to express appreciation to the following contributors for their assistance in the preparation of this book.

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#### 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.

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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.)

$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Name	Symbol	Definition	SI unit
reduced mass $\mu$ $\mu = m_1m_2/(m_1 + m_2)$ kg m <sup>-3</sup> density, mass density $\rho$ $\rho = m/V$ kg m <sup>-3</sup> relative density $d$ $d = \rho/\rho^6$ 1 surface density $\rho_A, \rho_S$ $\rho_A = m/A$ kg m <sup>-2</sup> specific volume $v$ $v = V/M = 1/\rho$ m <sup>3</sup> kg <sup>-1</sup> momentum $P$ $p = mv$ kg m <sup>-1</sup> angular momentum, action $L$ $L = r \times p$ Js moment of inertia $I, J$ $I = \sum m_i r_i^2$ kg m <sup>2</sup> force $F$ $F$ $F = dp/dt = ma$ N torque, moment of a force $T, (M)$ $T = r \times F$ N m energy $E$ J potential energy $E_s, V, \Phi$ $E_p = -\int F \cdot ds$ J kinetic energy $E_s, V, \Phi$ $E_s = (1/2)mv^2$ J work $W, w$ $W = \int F \cdot ds$ J largrange function $H$ $H(q, \rho)$ J ressure $p, P$ $p = F/A$ $Pa, N m^{-2}$ surface tension $\gamma, \sigma$ $\gamma = dW/AA$ $N m^{-1}, J m^{-2}$ weight $G, (W, P)$ $G = mg$ N gravitational constant $G$ $F = Gm_1m_2/r^2$ N m <sup>2</sup> kg <sup>-2</sup> normal stress $\sigma$ $\sigma = F/A$ Pa shear stress $\tau$ $\tau = F/A$ Pa linear strain, $\varepsilon, e$ $\varepsilon = \Delta L/l$ 1 linear strain, $\varepsilon, e = \delta - \Delta L/l$ 1 shear strain $\Theta$ $H = \frac{1}{2} m_i (dy_i / D)$ J invelative elongation modulus of elasticity, $E$ $K = K = -\delta L/l$ 1 bulk modulus, $K$ $K = -V_0 (dp/dV)$ Pa compression modulus $\eta, \mu$ $\tau_{x,z} = n/(dx_d/2)$ Pa shear strain $\Theta$ $\Theta = 1/\eta$ m $kg^{-1}s$ induction $\pi^2 s^{-1}$ friction coefficient $\mu, (f)$ $F_{frict} = \mu F_{norm}$ 1 bulk modulus, $K$ $K = N_0 (dy_d/V)$ Pa compression modulus $\eta, \mu$ $\tau_{x,z} = n/(dx_d/2)$ Pa s viscosity dynamic viscosity friction coefficient $\mu, (f)$ $F_{frict} = \mu F_{norm}$ 1 power $P$ $P = dW/dt$ $W$ sound energy flux $P, P_a$ $P = dE/dt$ $W$ acoustic factors $\tau$ $\tau = F_t/P_0$ 1 dissipation factor $\tau$ $\tau$ $\tau = F_t/P_0$ 1	mass	m		kg
$\begin{array}{llllllllllllllllllllllllllllllllllll$	reduced mass	$\mu$	$\mu = m_1 m_2 / (m_1 + m_2)$	kg
relative density $d$ $d = \rho/\rho^{\theta}$ 1 surface density $\rho_A, \rho_S$ $\rho_A = m/A$ $\lg m^{-2}$ specific volume $v$ $v = V/M = 1/\rho$ $m^3 kg^{-1}$ momentum $p$ $p = mv$ $kg ms^{-1}$ angular momentum, action $L$ $L = r \times p$ $J_S$ 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 $E$ $J$ potential energy $E_p, V, \Phi$ $E_p = -\int F \cdot ds$ $J$ kinetic energy $E_k, T, K$ $E_k = (1/2)mv^2$ $J$ work $W, w$ $W = \int F \cdot ds$ $J$ Hamilton function $H$ $H(q, p)$ $J$ = T(q, p) + V(q) Lagrange function $L$ $L(q, \dot{q})$ $J$ $= T(q, \rho) - V(q)$ pressure $\rho, P$ $p = F/A$ $Pa, Nm^{-2}$ surface tension $\gamma, \sigma$ $\gamma = dW/dA$ $Nm^{-1}, Jm^{-2}$ weight $G, (W, P)$ $G = mg$ $N$ gravitational constant $G$ $F = Gm_im_2/r^2$ $Nm^2 kg^{-2}$ normal stress $\sigma$ $\sigma = F/A$ $Pa$ shear stress $\tau$ $\tau = F/A$ $Pa$ shear stress $\tau$ $\tau = F/A$ $Pa$ shear stress $\tau$ $\tau = F/A$ $Pa$ shear stress $\tau$ $r = r/A$ $Pa$ shear stress $r = 0$ $P = m/A$ $Pa$ $Pa$ shear stress $r = 0$ $Pa = 0$ $Pa$ $Pa$ $Pa$ $Toug's modulus G H = 0 AV/V_0 1bulk modulus, R K K = -V_0(dp/dV) Pacompression modulus \eta, \mu \tau_{x,c} = \eta(dv_x/dc) Pa sradius relative isosity v v = \eta/\rho m^2 s^{-1}friction coefficient \mu, (f) First = \mu F_norm 1power P P = dW/dt Wsound energy flux P, P_a Pa = dE/dt Wsound energy flux P, P_a Pa = dE/dt Wradius factor \tau \tau r = P_r/P_0 1ransmission factor \tau \tau r = P_r/P_0 1ransmission factor \tau \tau r = P_r/P_0 1$	density, mass density	ρ	$\rho = m/V$	$kg m^{-3}$
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	relative density	d	$d = \rho / \rho^{\theta}$	1
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	surface density	QA, QS	$\rho_A = m/A$	$kg m^{-2}$
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	specific volume	v	$v = V/M = 1/\rho$	$m^3 kg^{-1}$
angular momentum, actionL $L = r \times p$ J smoment of inertia $I, J$ $I = \sum m_i r_1^2$ kg m²force $F$ $F = dp/dt = ma$ Ntorque, moment of a force $T, (M)$ $T = r \times F$ N menergy $E$ Jpotential energy $E_p, V, \Phi$ $E_p = -\int F \cdot ds$ Jkinetic energy $E_k, T, K$ $E_I = (1/2)mv^2$ Jwork $W, w$ $W = \int F \cdot ds$ JHamilton functionH $H(q, p)$ Jagrange functionL $L(q, \dot{q})$ Jressure $p, P$ $p = F/A$ Pa, N m <sup>-2</sup> surface tension $\gamma, \sigma$ $\gamma = dW/dA$ N m <sup>-1</sup> , J m <sup>-2</sup> weight $G, (W, P)$ $G = mg$ Ngravitational constant $G$ $F = Gm_im_2/r^2$ N m² kg^{-2}normal stress $\sigma$ $\sigma = F/A$ Painear strain, $\varepsilon, e$ $\varepsilon = \Delta L/l$ 1relative elongation $W$ $Y = \Delta x/d$ 1modulus of elasticity, $E$ $E = \sigma/\varepsilon$ Pashear strain $\gamma, \mu$ $\gamma = \Delta x/d$ 1balar modulus $G$ $G = T/\gamma$ Pa sviscosity $\psi$ $\psi = 1/\eta$ $mkg^{-1}s$ fiction coefficient $\mu, (f)$ $Fright = \mu F_{norm}$ 1power $P$ $P = dW/dt$ Wsouth short fiction factor $\rho$ $\rho = P_r/P_0$ 1acoustic factors $r$ $r = P_r/P_0$ 1isispation factor $\delta$ $\sigma = a_n - \tau$	momentum	p	p = mv	kg ms <sup>-1</sup>
$\begin{array}{llllllllllllllllllllllllllllllllllll$	angular momentum, action	L	$L = r \times p$	Js
forceF $F = dp/dt = ma$ Ntorque, moment of a forceT, (M) $T = r \times F$ N menergyEJpotential energyE <sub>p</sub> , V, Φ $E_p = -\int F \cdot ds$ Jkinetic energyE <sub>k</sub> , T, K $E_k = (1/2)mv^2$ JworkW, w $W = \int F \cdot ds$ JHamilton functionH $H(q, p)$ JLagrange functionL $L(q, \dot{q})$ Jpressurep, Pp = F/APa, N m <sup>-2</sup> surface tension $\gamma, \sigma$ $\gamma = dW/dA$ N m <sup>-1</sup> , J m <sup>-2</sup> weightG, (W, P)G = mgNgravitational constantGF = $Gm_1m_2/r^2$ N m <sup>2</sup> kg <sup>-2</sup> normal stress $\sigma$ $\sigma = F/A$ Painear strain, $\varepsilon, e$ $\varepsilon = \Delta l/l$ 1relative elongationGG = $\tau/\gamma$ Pamodulus of elasticity,EE = $\sigma/\varepsilon$ Pavolume strain, bulk strain $\theta$ $\theta = \Delta V/V_0$ 1balar modulusGG = $\tau/\gamma$ Pa sviscosity, dynamic viscosity $\psi$ $\psi$ $\psi = 1/\eta$ m kg <sup>-1</sup> sfluidity $\phi$ $\phi = 1/\eta$ m kg <sup>-1</sup> sshear strain $\gamma, P, P_a$ $P = dE/dt$ Wsocutic factorsreflection factor $\rho$ $\rho = P_r/P_0$ 1docustic factorsreflection factor $\sigma_{a_1}(\alpha)$ $\alpha_a = 1 - \rho$ 1tirtamsmission factor $\delta$ $\delta = \alpha_a - \tau$ 1	moment of inertia	I, J	$I = \sum m_i r_i^2$	kg m <sup>2</sup>
torque, moment of a force T, (M) T = r × F N m energy E J potential energy E $p, V, \Phi$ $E_p = -\int F \cdot ds$ J istnetic energy $E_k, T, K$ $E_k = (1/2)mv^2$ J work W, W W = $\int F \cdot ds$ J Hamilton function H $H(q, p)$ J Lagrange function L $L(q, \dot{q})$ J pressure $p, P$ $p = F/A$ $Pa, N m^{-2}$ surface tension $\gamma, \sigma$ $\gamma = dW/dA$ $N m^{-1}, J m^{-2}$ weight G, (W, P) G = mg N gravitational constant G $F = Gm_1m_2/r^2$ $N m^2 kg^{-2}$ normal stress $\sigma$ $\sigma = F/A$ $Pa$ linear strain, $\varepsilon, e$ $\varepsilon - \Delta I/I$ 1 relative elongation modulus of elasticity, E $E = \sigma/\varepsilon$ $Pa$ Young's modulus shear strain $\gamma$ $\gamma = \frac{\Delta x/d}{I}$ 1 shear modulus, $K$ $K = -V_0(dp/dV)$ $Pa$ viscosity, dynamic viscosity fluidity $\psi$ $\psi = 1/\eta$ $m kg^{-1}s$ kinematic viscosity $v$ $v = \eta/\rho$ $m^2 s^{-1}$ fluidity $\psi$ $p = A = M/dt$ W sound energy flux $P, P_a$ $P = dE/dt$ W sound energy flux $P, P_a$ $P = dE/dt$ W acoustic factors $\tau$ $\tau = P_r/P_0$ 1 tansmission factor $\delta$ $\delta = \alpha_a - \tau$ 1	force	F	F = dp/dt = ma	Ň
energy $E$ $F_{p}, V, \Phi$ $E_{p} = -\int F \cdot ds$ J potential energy $E_{k}, T, K$ $E_{k} = (1/2)mv^{2}$ J work $W, w$ $W = \int F \cdot ds$ J Hamilton function $H$ $H(q, p)$ J = T(q, p) + V(q) Lagrange function $L$ $L(q, \dot{q})$ $J$ pressure $p, P$ $p = F/A$ $Pa, N m^{-2}$ surface tension $\gamma, \sigma$ $\gamma = dW/dA$ $N m^{-1}, J m^{-2}$ weight $G, (W, P)$ $G = mg$ $N$ gravitational constant $G$ $F = Gm_{1}m_{2}/r^{2}$ $N m^{2} kg^{-2}$ normal stress $\sigma$ $\sigma = F/A$ $Pa$ shear stress $\tau$ $\tau = F/A$ $Pa$ hinear strain, $\varepsilon, e$ $\varepsilon - \Delta I/I$ 1 relative elongation $H$ $\varepsilon, e = \sigma/\varepsilon$ $Pa$ Young's modulus shear strain $\gamma$ $\gamma$ $\gamma = \Delta x/d$ 1 shear modulus $G$ $G = \tau/\gamma$ $Pa$ viscosity, dynamic viscosity $\eta, \mu$ $\tau_{x,z} = \eta(dv_{x}/dz)$ $Pa$ s $r_{x,z} = \eta(dv_{x}/dz)$ $Pa$ s $r_{x,z} = n(dv_{x}/dz)$	torque, moment of a force	T, (M)	$T = r \times F$	N m
$\begin{array}{llllllllllllllllllllllllllllllllllll$	energy	Ε		I
kinetic energy $E_k, T, K$ $E_k = (1/2)mv^2$ ] work $W, w$ $W = \int F \cdot ds$ ] Hamilton function $H$ $H(q, p)$ ] Lagrange function $L$ $L(q, \dot{q})$ J = T(q, p) + V(q) Lagrange function $L$ $L(q, \dot{q})$ J $= T(q, \dot{q}) - V(q)$ pressure $p, P$ $p = F/A$ $Pa, Nm^{-2}$ surface tension $\gamma, \sigma$ $\gamma = dW/dA$ $Nm^{-1}, Jm^{-2}$ weight $G, (W, P)$ $G = mg$ N gravitational constant $G$ $F = Gm_1m_2/r^2$ $Nm^2 kg^{-2}$ normal stress $\sigma$ $\sigma = F/A$ $Pa$ linear stress $\tau$ $\tau = F/A$ $Pa$ linear strain, $\varepsilon, e$ $\varepsilon = \Delta l/l$ 1 relative elongation modulus of elasticity, $E$ $E = \sigma/\varepsilon$ $Pa$ Young's modulus shear modulus $G$ $G = \tau/\gamma$ $Pa$ shear strain $\theta$ $\theta = \Delta V/V_0$ 1 bulk modulus, $K$ $K = -V_0(dp/dV)$ $Pa$ compression modulus $\eta, \mu$ $\tau_{x,z} = \eta(dv_x/dz)$ $Pa$ s viscosity, dynamic viscosity fluidity $\phi$ $\phi = 1/\eta$ $m kg^{-1}s$ kinematic viscosity $v$ $v = \eta/\rho$ $m^2 s^{-1}$ friction coefficient $\mu, (f)$ $F_{\rm frict} = \mu F_{\rm norm}$ 1 power $P$ $P = dE/dt$ $W$ acoustic factors reflection factor $\alpha_a, (\alpha)$ $\alpha_a = 1 - \rho$ 1 transmission factor $\tau$ $\tau$ $\tau = P_{\rm tr}/P_0$ 1 dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	potential energy	$E_n, V, \mathbf{\Phi}$	$E_n = -\int \mathbf{F} \cdot d\mathbf{s}$	Ĭ
work $W, w$ $W = \int F \cdot ds$ J Hamilton function $H$ $H(q, p)$ J = T(q, p) + V(q) Lagrange function $L$ $L(q, \dot{q})$ J $= T(q, \dot{q}) - V(q)$ pressure $p, P$ $p = F/A$ $Pa, N m^{-2}$ surface tension $\gamma, \sigma$ $\gamma = dW/dA$ $N m^{-1}, J m^{-2}$ weight $G, (W, P)$ $G = mg$ $N$ gravitational constant $G$ $F = Gm_1m_2/r^2$ $N m^2 kg^{-2}$ normal stress $\sigma$ $\sigma = F/A$ $Pa$ linear strain, $\varepsilon, e$ $\varepsilon - \Delta l/l$ 1 relative elongation modulus of elasticity, $E$ $E = \sigma/\varepsilon$ $Pa$ Young's modulus shear strain $\gamma$ $\gamma = \Delta x/d$ 1 shear modulus $G$ $G = \tau/\gamma$ $Pa$ volume strain, $\theta$ $\theta = \Delta V/V_0$ 1 bulk modulus, $K$ $K = K = -V_0(dp/dV)$ Pa compression modulus $\eta, \mu$ $\tau_{x,z} = \eta(dv_x/dz)$ Pa s viscosity, dynamic viscosity fluidity $\psi$ $\phi$ $\phi = 1/\eta$ $m kg^{-1}s$ kinematic viscosity $v$ $v = \eta/\rho$ $m^2 s^{-1}$ friction coefficient $\mu, (f)$ $F_{\rm frict} = \mu F_{\rm norm}$ 1 power $P$ $P = dW/dt$ $W$ acoustic factors reflection factor $\sigma_a, (\alpha)$ $\sigma_a = 1 - \rho$ 1 transmission factor $\tau$ $\tau$ $\tau = P_{\rm tr}/P_0$ 1 dissipation factor $\delta$ $\delta = \sigma_a - \tau$ 1	kinetic energy	$E_{k}$ , T, K	$E_{k}^{P} = (1/2)mv^{2}$	Í
Hamilton functionH $H(q, p)$ JLagrange functionL $L(q, \dot{q})$ J $= T(q, p) + V(q)$ $= T(q, \dot{q}) - V(q)$ Jpressure $p, P$ $p = F/A$ Pa, N m <sup>-2</sup> surface tension $\gamma, \sigma$ $\gamma = dW/dA$ N m <sup>-1</sup> , J m <sup>-2</sup> weight $G, (W, P)$ $G = mg$ Ngravitational constant $G$ $F = Gm_1m_2/r^2$ N m <sup>2</sup> kg <sup>-2</sup> normal stress $\sigma$ $\sigma = F/A$ Pablinear strain, $\varepsilon, e$ $\varepsilon = \Delta l/l$ 1relative elongationmodulus $\sigma$ $\sigma = \pi/\gamma$ modulus of elasticity, $E$ $E = \sigma/\varepsilon$ PaYoung's modulus $G$ $G = \tau/\gamma$ Pashear strain $\gamma$ $\gamma = \Delta x/d$ 1shear strain $\beta, \mu, \mu$ $\tau_{x,z} = \eta(dv_x/dz)$ Pa svolume strain, bulk strain $\theta$ $\theta = \Delta V/V_0$ 1bulk modulus, $K$ $K = -V_0(dp/dV)$ Pa sviscosity, dynamic viscosity $\psi$ $\psi = \eta/\rho$ $m^2 s^{-1}$ friction coefficient $\mu, (f)$ $F_{frict} = \mu F_{norm}$ 1power $P$ $P = dW/dt$ $W$ acoustic factors $r$ $r = P_t/P_0$ 1acoustic factors $r$ $r = P_t/P_0$ 1dissipation factor $\delta$ $\omega = \alpha_a - \tau$ 1	work	W, w	$W = \int F \cdot ds$	I
Lagrange function L $T (q, p) + V(q)$ Lagrange function $L$ $L(q, \dot{q})$ $T (q, \dot{p}) - V(q)$ $T = T(q, \dot{q}) - T(q)$ $T $	Hamilton function	H	H(a, p)	, I
Lagrange functionL $L(q, \dot{q}) - V(q)$ Jpressure $p, P$ $p = F/A$ $Pa, N m^{-2}$ surface tension $\gamma, \sigma$ $\gamma = dW/dA$ $N m^{-1}, J m^{-2}$ weight $G, (W, P)$ $G = mg$ Ngravitational constant $G$ $F = Gm_1m_2/r^2$ $N m^2 kg^{-2}$ normal stress $\sigma$ $\sigma = F/A$ $Pa$ shear stress $\tau$ $\tau = F/A$ $Pa$ linear strain, $\varepsilon, e$ $\varepsilon - \Delta l/l$ 1relative elongationmodulus of elasticity, $E$ $E = \sigma/\varepsilon$ shear strain $\gamma$ $\gamma = \Delta x/d$ 1shear strain $\theta$ $\theta = \Delta V/V_0$ 1bulk modulus, $K$ $K = -V_0(dp/dV)$ $Pa$ socosity, dynamic viscosity $v$ $v = \eta/\rho$ $m^2 s^{-1}$ fluidity $\phi$ $\phi = 1/\eta$ $m kg^{-1}s$ $power$ $P$ $P = dW/dt$ $W$ sound energy flux $P, P_a$ $P = dE/dt$ $value energy fluxP, P_aP = dE/dtvalue energy fluxP, P_aP = dF/normreflection factor\rho\rho = P_r/P_01acoustic absorption factor\sigma_a, (\alpha)\alpha_a = 1 - \rho1transmission factor\delta\delta = \alpha_a - \tau1$			= T(a, p) + V(a)	,
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Lagrange function	L	$L(a, \dot{a})$	I
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	88		$= T(a, \dot{a}) - V(a)$	)
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	pressure	n P	n = F/A	Pa N $m^{-2}$
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	surface tension	γ σ	$\gamma = dW/dA$	$Nm^{-1}$ $Im^{-2}$
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	weight	G(W P)	G = mg	N N
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	gravitational constant	G, (11, 12)	$F = Gm_1 m_2 / r^2$	$N m^2 k a^{-2}$
Interface $0$ $0$ $0$ $1/T$ $1a$ Interstation $\tau$ $\tau = F/A$ $Pa$ linear strain, $\varepsilon, e$ $\varepsilon - \Delta l/l$ 1relative elongation $\varepsilon, e$ $\varepsilon - \Delta l/l$ 1modulus of elasticity, $E$ $E = \sigma/\varepsilon$ $Pa$ Young's modulus $G$ $G = \tau/\gamma$ $Pa$ shear strain $\gamma$ $\gamma = \Delta x/d$ 1shear modulus $G$ $G = \tau/\gamma$ $Pa$ volume strain, bulk strain $\theta$ $\theta = \Delta V/V_0$ 1bulk modulus, $K$ $K = -V_0(dp/dV)$ $Pa$ compression modulus $\eta, \mu$ $\tau_{x,z} = \eta(dv_x/dz)$ $Pa$ sviscosity, dynamic viscosity $\psi$ $\psi = 1/\eta$ $m kg^{-1}s$ fluidity $\phi$ $\phi = 1/\eta$ $m kg^{-1}s$ gower $P$ $P = dW/dt$ $W$ sound energy flux $P, P_a$ $P = dE/dt$ acoustic factors $reflection factor$ $\rho$ $\rho = P_r/P_0$ 1acoustic absorption factor $\alpha_a, (\alpha)$ $\alpha_a = 1 - \rho$ 1dissipation factor $\varepsilon$ $\delta = \alpha_a - \tau$ 1	normal stress	σ	$\sigma = F/A$	Do
Intervision $c$ $l = P_1/R$ $la$ linear strain, $\varepsilon, e$ $\varepsilon - \Delta l/l$ 1relative elongation $relative elongation$ 1modulus of elasticity, $E$ $E = \sigma/\varepsilon$ PaYoung's modulus $G$ $G = \tau/\gamma$ Pashear strain $\gamma$ $\gamma = \Delta x/d$ 1shear modulus $G$ $G = \tau/\gamma$ Pavolume strain, bulk strain $\theta$ $\theta = \Delta V/V_0$ 1bulk modulus, $K$ $K = -V_0(dp/dV)$ Pacompression modulus $\eta, \mu$ $\tau_{x,z} = \eta(dv_x/dz)$ Pa sviscosity, dynamic viscosity $v$ $v = \eta/\rho$ $m^2 s^{-1}$ fluidity $\phi$ $\phi = 1/\eta$ $m kg^{-1}s$ kinematic viscosity $v$ $v = \eta/\rho$ $m^2 s^{-1}$ friction coefficient $\mu, (f)$ $F_{frict} = \mu F_{norm}$ 1power $P$ $P = dW/dt$ $W$ sound energy flux $P, P_a$ $P = dE/dt$ $W$ acoustic factors $r$ $\tau = P_t/P_0$ 1acoustic absorption factor $\alpha_a, (\alpha)$ $\alpha_a = 1 - \rho$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	shear stress	τ	$\tau = F/A$	Da
The strain strain relative elongation relative elongation modulus of elasticity, Shear strain $\gamma$ $\Sigma = \sigma/\varepsilon$ Pa Young's modulus shear strain $\gamma$ $\gamma = \Delta x/d$ 1 shear modulus shear modulus $G$ $G = \tau/\gamma$ Pa volume strain, bulk strain $\theta$ $\theta = \Delta V/V_0$ 1 bulk modulus, $K$ $K = -V_0(dp/dV)$ Pa compression modulus $\eta, \mu$ $\tau_{x,z} = \eta(dv_x/dz)$ Pa s viscosity, dynamic viscosity fluidity $\phi$ $\phi = 1/\eta$ m kg <sup>-1</sup> s kinematic viscosity $v$ $v = \eta/\rho$ m <sup>2</sup> s <sup>-1</sup> friction coefficient $\mu, (f)$ $F_{\text{frict}} = \mu F_{\text{norm}}$ 1 power $P$ $P = dW/dt$ W sound energy flux $P, P_a$ $P = dE/dt$ W acoustic factors reflection factor $\sigma_a, (\alpha)$ $\alpha_a = 1 - \rho$ 1 transmission factor $\tau$ $\tau$ $T = P_{\text{tr}}/P_0$ 1 dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	linear strain	6 0	$c = \Lambda I / I$	1
Tender CongressionE $E = \sigma/\varepsilon$ PaYoung's modulusshear strain $\gamma$ $\gamma = \Delta x/d$ 1shear strain $\gamma$ $\gamma = \Delta x/d$ 1shear modulus $G$ $G = \tau/\gamma$ Pavolume strain, bulk strain $\theta$ $\theta = \Delta V/V_0$ 1bulk modulus, $K$ $K = -V_0(dp/dV)$ Pacompression modulus $\eta, \mu$ $\tau_{x,z} = \eta(dv_x/dz)$ Pa sviscosity, dynamic viscosityfluidity $\phi$ $\phi = 1/\eta$ m kg <sup>-1</sup> sfluidity $\psi$ $v = \eta/\rho$ $m^2 s^{-1}$ friction coefficient $\mu, (f)$ $F_{frict} = \mu F_{norm}$ 1power $P$ $P = dW/dt$ Wsound energy flux $P, P_a$ $P = dE/dt$ Wacoustic factors $r$ $\tau = P_{tr}/P_0$ 1transmission factor $\tau$ $\tau = P_{tr}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	relative elongation	ε, ε	$\varepsilon = \Delta t / t$	1
Induction of clish(r), Young's modulus $L$ $L = 0/\varepsilon$ $ra$ Young's modulus $Shear strain$ $\gamma$ $\gamma = \Delta x/d$ 1shear strain $G$ $G = \tau/\gamma$ Pavolume strain, bulk strain $\theta$ $\theta = \Delta V/V_0$ 1bulk modulus, $K$ $K = -V_0(dp/dV)$ Pacompression modulus $\eta, \mu$ $\tau_{x,z} = \eta(dv_x/dz)$ Pa sviscosity, dynamic viscosity $\psi$ $\psi = 1/\eta$ $m kg^{-1}s$ fluidity $\phi$ $\phi = 1/\eta$ $m^2 s^{-1}$ friction coefficient $\mu, (f)$ $F_{frict} = \mu F_{norm}$ 1power $P$ $P = dW/dt$ $W$ sound energy flux $P, P_a$ $P = dE/dt$ $W$ acoustic factors $r$ $\tau = P_{rr}/P_0$ 1transmission factor $\tau$ $\tau = P_{tr}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	modulus of elasticity	F	$F = \sigma/c$	Da
Noting 5 modulus $\gamma$ $\gamma = \Delta x/d$ 1shear strain $G$ $G = \tau/\gamma$ Pavolume strain, bulk strain $\theta$ $\theta = \Delta V/V_0$ 1bulk modulus, $K$ $K = -V_0(dp/dV)$ Pacompression modulus $\eta, \mu$ $\tau_{x,z} = \eta(dv_x/dz)$ Pa sviscosity, dynamic viscosity $\psi$ $\psi = 1/\eta$ $m kg^{-1}s$ fluidity $\phi$ $\phi = 1/\eta$ $m^2 s^{-1}$ friction coefficient $\mu, (f)$ $F_{frict} = \mu F_{norm}$ 1power $P$ $P = dW/dt$ $W$ sound energy flux $P, P_a$ $P = dE/dt$ $W$ acoustic factors $reflection factor$ $\rho$ $\rho = P_r/P_0$ 1transmission factor $\tau$ $\tau = P_{tr}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	Young's modulus	L	$L = 0/\epsilon$	ra
Shear modulus $\gamma$ $\gamma = \Delta X/d$ $1$ shear modulus $G$ $G = \tau/\gamma$ $Pa$ volume strain, bulk strain $\theta$ $\theta = \Delta V/V_0$ $1$ bulk modulus, $K$ $K = -V_0(dp/dV)$ $Pa$ compression modulus $\eta, \mu$ $\tau_{x,z} = \eta(dv_x/dz)$ $Pa$ viscosity, dynamic viscosity $\psi$ $\psi = 1/\eta$ $m kg^{-1}s$ fluidity $\phi$ $\phi = 1/\eta$ $m kg^{-1}s$ kinematic viscosity $v$ $v = \eta/\rho$ $m^2 s^{-1}$ friction coefficient $\mu, (f)$ $F_{frict} = \mu F_{norm}$ $1$ power $P$ $P = dW/dt$ $W$ acoustic factors $reflection factor$ $\rho$ $\rho = P_r/P_0$ $1$ acoustic absorption factor $\alpha_a, (\alpha)$ $\alpha_a = 1 - \rho$ $1$ dissipation factor $\delta$ $\delta = \alpha_a - \tau$ $1$	shear strain	27	$y = \Delta r/d$	1
and in hourds $0$ $0$ $0$ $0$ $1$ volume strain, bulk strain $\theta$ $\theta = \Delta V/V_0$ 1bulk modulus, $K$ $K = -V_0(dp/dV)$ Pacompression modulus $\eta, \mu$ $\tau_{x,z} = \eta(dv_x/dz)$ Pa sviscosity, dynamic viscosity $\psi$ $\phi = 1/\eta$ m kg <sup>-1</sup> sfluidity $\phi$ $\phi = 1/\eta$ m kg <sup>-1</sup> skinematic viscosity $v$ $v = \eta/\rho$ m <sup>2</sup> s <sup>-1</sup> friction coefficient $\mu, (f)$ $F_{\text{frict}} = \mu F_{\text{norm}}$ 1power $P$ $P = dW/dt$ Wsound energy flux $P, P_a$ $P = dE/dt$ Wacoustic factors $reflection factor$ $\rho$ $\rho = P_r/P_0$ 1transmission factor $\tau$ $\tau = P_{\text{tr}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	shear modulus	Y C	$\gamma = \Delta x/a$	I De
Volume strain0001bulk modulus,K $K = -V_0(dp/dV)$ Pacompression modulus $\eta, \mu$ $\tau_{x,z} = \eta(dv_x/dz)$ Pa sviscosity, dynamic viscosity $\psi$ $\phi = 1/\eta$ m kg <sup>-1</sup> sfluidity $\phi$ $\phi = 1/\eta$ m kg <sup>-1</sup> skinematic viscosity $v$ $v = \eta/\rho$ m <sup>2</sup> s <sup>-1</sup> friction coefficient $\mu, (f)$ $F_{\text{frict}} = \mu F_{\text{norm}}$ 1powerP $P = dW/dt$ Wsound energy flux $P, P_a$ $P = dE/dt$ Wacoustic factors $reflection factor$ $\rho$ $\rho = P_r/P_0$ 1acoustic absorption factor $\alpha_a, (\alpha)$ $\alpha_a = 1 - \rho$ 1transmission factor $\tau$ $\tau = P_{\text{tr}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	volume strain, bulk strain	0 A	$\theta = \lambda V / V$	Fa 1
built modulus, compression modulusR $K = -v_0(dp/dv)$ Pacompression modulus $\eta, \mu$ $\tau_{x,z} = \eta(dv_x/dz)$ Pa sviscosity, dynamic viscosity $\phi$ $\phi = 1/\eta$ m kg <sup>-1</sup> sfluidity $\phi$ $\phi = 1/\eta$ m kg <sup>-1</sup> skinematic viscosity $v$ $v = \eta/\rho$ m <sup>2</sup> s <sup>-1</sup> friction coefficient $\mu, (f)$ $F_{\text{frict}} = \mu F_{\text{norm}}$ 1power $P$ $P = dW/dt$ Wsound energy flux $P, P_a$ $P = dE/dt$ Wacoustic factors $reflection factor$ $\rho$ $\rho = P_r/P_0$ 1acoustic absorption factor $\alpha_a, (\alpha)$ $\alpha_a = 1 - \rho$ 1transmission factor $\delta$ $\delta = \alpha_a - \tau$ 1	bulk modulus	v	$0 = \Delta V / V_0$	1 D-
viscosity $\phi$ $\phi = 1/\eta$ $m kg^{-1}s$ fluidity $\phi$ $\phi = 1/\eta$ $m kg^{-1}s$ kinematic viscosity $v$ $v = \eta/\rho$ $m^2 s^{-1}$ friction coefficient $\mu, (f)$ $F_{frict} = \mu F_{norm}$ 1power $P$ $P = dW/dt$ $W$ sound energy flux $P, P_a$ $P = dE/dt$ $W$ acoustic factors $reflection factor$ $\rho$ $\rho = P_r/P_0$ 1acoustic absorption factor $\alpha_a, (\alpha)$ $\alpha_a = 1 - \rho$ 1transmission factor $\tau$ $\tau = P_{tr}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	compression modulus	<b>κ</b> η, μ	$\begin{aligned} \kappa &= -v_0 (ap/av) \\ \tau_{x,z} &= \eta (dv_x/dz) \end{aligned}$	Pa Pa s
fluidity $\phi$ $\phi = 1/\eta$ m kg <sup>-1</sup> skinematic viscosity $v$ $v = \eta/\rho$ m <sup>2</sup> s <sup>-1</sup> friction coefficient $\mu$ , $(f)$ $F_{\text{frict}} = \mu F_{\text{norm}}$ 1power $P$ $P = dW/dt$ Wsound energy flux $P$ , $P_a$ $P = dE/dt$ Wacoustic factors $r$ $r$ $r = P_r/P_0$ 1acoustic absorption factor $\alpha_a$ , $(\alpha)$ $\alpha_a = 1 - \rho$ 1transmission factor $\tau$ $\tau = P_{\text{tr}}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	viscosity, dynamic viscosity			
kinematic viscosity $v$ $v = \eta/\rho$ $m^2 s^{-1}$ friction coefficient $\mu$ , $(f)$ $F_{\text{frict}} = \mu F_{\text{norm}}$ 1power $P$ $P = dW/dt$ $W$ sound energy flux $P, P_a$ $P = dE/dt$ $W$ acoustic factors $reflection factor$ $\rho$ $\rho = P_r/P_0$ 1acoustic absorption factor $\alpha_a, (\alpha)$ $\alpha_a = 1 - \rho$ 1transmission factor $\tau$ $\tau = P_{\text{tr}}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	fluidity	$\phi$	$\phi = 1/\eta$	m kg <sup>-1</sup> s
friction coefficient $\mu$ , $(f)$ $F_{\text{frict}} = \mu F_{\text{norm}}$ 1power $P$ $P = dW/dt$ $W$ sound energy flux $P, P_a$ $P = dE/dt$ $W$ acoustic factors $reflection factor$ $\rho$ $\rho = P_r/P_0$ 1acoustic absorption factor $\alpha_a, (\alpha)$ $\alpha_a = 1 - \rho$ 1transmission factor $\tau$ $\tau = P_{\text{tr}}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	kinematic viscosity	υ	$v = \eta / \rho$	$m^2 s^{-1}$
powerP $P = dW/dt$ Wsound energy flux $P, P_a$ $P = dE/dt$ Wacoustic factors $reflection factor$ $\rho$ $\rho = P_r/P_0$ 1acoustic absorption factor $\alpha_a, (\alpha)$ $\alpha_a = 1 - \rho$ 1transmission factor $\tau$ $\tau = P_{tr}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	friction coefficient	$\mu,(f)$	$F_{\rm frict} = \mu F_{\rm norm}$	1
sound energy flux $P, P_a$ $P = dE/dt$ Wacoustic factors $\rho$ $\rho = P_r/P_0$ 1reflection factor $\rho_a$ $\alpha_a, (\alpha)$ $\alpha_a = 1 - \rho$ 1acoustic absorption factor $\tau$ $\tau = P_{tr}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	power	Р	P = dW/dt	W
acoustic factors $\rho$ $\rho = P_r/P_0$ 1reflection factor $\alpha_a, (\alpha)$ $\alpha_a = 1 - \rho$ 1acoustic absorption factor $\tau$ $\tau = P_{tr}/P_0$ 1transmission factor $\delta$ $\delta = \alpha_a - \tau$ 1	sound energy flux	$P, P_a$	P = dE/dt	W
reflection factor $\rho$ $\rho = P_r/P_0$ 1acoustic absorption factor $\alpha_a, (\alpha)$ $\alpha_a = 1 - \rho$ 1transmission factor $\tau$ $\tau = P_{tr}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	acoustic factors		,	
acoustic absorption factor $\alpha_a$ , $(\alpha)$ $\alpha_a = 1 - \rho$ 1transmission factor $\tau$ $\tau = P_{tr}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	reflection factor	ρ	$\rho = P_r/P_0$	1
transmission factor $\tau$ $\tau = P_{tr}/P_0$ 1dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	acoustic absorption factor	$\alpha_{a}, (\alpha)$	$\alpha_a = 1 - \rho$	1
dissipation factor $\delta$ $\delta = \alpha_a - \tau$ 1	transmission factor	τ	$\tau = P_{\rm tr}/P_0$	1
	dissipation factor	δ	$\delta = \alpha_a - \tau$	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	Vø	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	$\mathbf{F} = \int \mathbf{D} \cdot \mathbf{u} \mathbf{A}$	$Cm^{-2}$
	D	$D = \varepsilon E$	$E C V^{-1}$
	C	C = Q/U	r, C v Em <sup>-1</sup>
permittivity	ε	$D = \varepsilon E$	rm -
permittivity of vacuum	$\varepsilon_0$	$\varepsilon_0 = \mu_0 c_0^{-1}$	Fm -
relative permittivity	ε <sub>r</sub>	$\varepsilon_r = \varepsilon/\varepsilon_0$	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	<b>p</b> , 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	$\Phi$	$\mathbf{\Phi} = \int \mathbf{B} \cdot d\mathbf{A}$	Wb
magnetic field strength	H	$B = \mu H$	$A M^{-1}$
permeability	$\mu$	$B = \mu H$	$N A^{-2}, H m^{-1}$
permeability of vacuum	$\mu_0$		$\mathrm{H}\mathrm{m}^{-1}$
relative permeability	$\mu_r$	$\mu_r = \mu/\mu_0$	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 <sup>3</sup> mol <sup>-1</sup>
magnetic dipole moment	$m, \mu$	$E_p = -\boldsymbol{m} \cdot \boldsymbol{B}$	A m <sup>2</sup> , J T <sup>-1</sup>
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	$\rho = E/j$	$\Omega$ 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	$S = E \times H$	$W m^{-2}$

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

wavelength $\lambda$ 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, $\omega$ $\omega = 2\pi v$ 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 $\rho, w$ $\rho = Q/V$ $J$ practal radiant energy density $\rho, w_v$ $\rho_v = d\rho/dv$ $J$ in terms of requency $\rho_v, w_v$ $\rho_v = d\rho/dv$ $J$ matim tacked emission $A_{nm}$ $dN_n/dt = -A_{nm}N_n$ s kg^{-1}stimulated absorption $B_{mn}$ $dN_n/dt = a_v(\tilde{v}_{mn})B_{mn}N_m$ s kg^{-1}stimulated emission $B_{mn}$ $dN_n/dt = \rho_v(\tilde{v}_{mn})B_{mn}N_m$ s kg^{-1}radiant torestryI $I = d\Phi/d\Omega$ $W$ $M^{-2} C^{-4}$ radiant torestryI $I = d\Phi/d\Omega$ $W$ $M^{-2} C^{-4}$ stimulated absorption $B_{mn}$ $dN_n/dt = \rho_v(\tilde{v}_{mn})B_{mn}N_m$ s kg^{-1}radiant energy pertimeI $I = d\Phi/d\Omega$ $W$ $M^{-2} C^{-4}$ radiant torestryII $I = d\Phi/d\Lambda$ $W$ $M^{-2} C^{-4}$ <th>Name</th> <th>Symbol</th> <th>Definition</th> <th>SI unit</th>	Name	Symbol	Definition	SI unit
	wavelength	λ		m
in a mediumc $c = c_0/n$ $m s^{-1}$ wavenumber in vacuum $\tilde{v}$ $\tilde{v} = v/c_0 = 1/n\lambda$ $m^{-1}$ frequency $v$ $v = c/\lambda$ $Hz$ circular frequency, $w$ $w = 2\pi v$ $s^{-1}$ , rad $s^{-1}$ pulsatance $w = 2\pi v$ $s^{-1}$ , rad $s^{-1}$ pulsatance $w = 2\pi v$ $s^{-1}$ , rad $s^{-1}$ planck constant $h$ $h$ $s$ Planck constant/ $2\pi$ $\hat{n}$ $\hat{n} = h/2\pi$ $J s$ radiant energy $Q$ , $W$ $J$ $J$ radiant energy density $\rho$ , $w$ $\rho = Q/V$ $J m^{-3}$ in terms of frequency $\rho_v$ , $w_v$ $\rho_e = d\rho/dv$ $J m^{-3}$ spectral radiant energy density $\rho_i$ , $w_z$ $\rho_e = d\rho/dv$ $J m^{-3}$ in terms of requency $\rho_v$ , $w_v$ $\rho_e = d\rho/dv$ $J m^{-4}$ Einstein transition probabilitiesspontancous emission $S_{nm}$ $dN_n/dt = -A_{nm}N_n$ $s^{-1}$ simulated absorption $B_{mn}$ $dN_n/dt = -\Delta_{lo}(\bar{v}_{mn}) \times B_{mn}N_n$ $s kg^{-1}$ radiant energy per time $I$ $I = d\Phi/d\Omega$ $W m^{-2}$ radiant intensity $I$ $I = d\Phi/dA$ $W m^{-2}$ (mitted radiant flux) $i$ $i = d\Phi/d\Lambda$ $W m^{-2}$ irradiance $M$ $M = d\Phi/dA_{source}$ $W m^{-2}$ (radiant flux received) $v$ $\pi^{-1}$ $M m^{-2} K^{-4}$ emittace $\alpha$ $\alpha = \Delta d_{abn}/\Phi_0$ 1transmission factor $a$ $\alpha = \Delta d_{abn}/\Phi_0$ 1abs	speed of light in vacuum	$c_0$		m s <sup>-1</sup>
wavenumber in vacuum $\tilde{v}$ $\tilde{v} = v/c_0 = 1/n\lambda$ m <sup>-1</sup> wavenumber (in a medium) $\sigma$ $\sigma = 1/\lambda$ m <sup>-1</sup> frequency $v$ $v = c/\lambda$ Hz circular frequency, $\omega$ $\omega = 2\pi v$ s <sup>-1</sup> , rad s <sup>-1</sup> pulsatance effractive index n $n = c_0/c$ 1 Planck constant h Is Planck constant $n$ $h = b/2\pi$ Js radiant energy $Q, W$ J radiant energy density $\rho, w$ $\rho = Q/V$ Jm <sup>-3</sup> spectral radiant energy density $\rho_i, w_i$ $\rho_v = d\rho/dv$ Jm <sup>-3</sup> Hz <sup>-1</sup> in terms of frequency $\rho_v, w_v$ $\rho_v = d\rho/dv$ Jm <sup>-3</sup> Hz <sup>-1</sup> in terms of frequency $\rho_v, w_v$ $\rho_v = d\rho/dv$ Jm <sup>-3</sup> Hz <sup>-1</sup> in terms of wavelength $\rho_\lambda, w_\lambda$ $\rho_\lambda = d\rho/d\lambda$ Jm <sup>-2</sup> in terms of wavelength $\rho_\lambda, w_\lambda$ $\rho_\lambda = d\rho/d\lambda$ Jm <sup>-2</sup> in terms of wavelength $\rho_\lambda, w_\lambda$ $\rho_\lambda = d\rho/d\lambda$ Jm <sup>-2</sup> radiant energy perime radiant energy perime radiant energy perime radiant energy perime radiant existion probabilities spontaneous emission $A_{nm}$ $dN_n/dt = -\rho_k(\delta_{nm}) \times B_{nm}N_n$ skg <sup>-1</sup> stimulated absorption $B_{mn}$ $dN_n/dt = -\rho_k(\delta_{nm}) \times B_{mn}N_n$ skg <sup>-1</sup> radiant exitance $M$ $M = d\Phi/d\Omega$ Wsr <sup>-1</sup> radiant existing $I$ $I = d\Phi/d\Omega$ Wsr <sup>-1</sup> radiant existing $I$ $I = d\Phi/d\Omega$ Wsr <sup>-2</sup> (emitted radiant flux) irradiance $\mathcal{E}$ , $(I)$ $\mathcal{E} = d\Phi/dA$ Wm <sup>-2</sup> (radiant flux received) emittance $\varepsilon$ $\varepsilon = M/M_{bb}$ 1 transmission factor absorption factor reflectance, $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 1 transmission factor absorption factor reflectance, $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 1 napierian absorbance $A$ $A = lg(1 - \alpha_i)$ 1 napierian absorbance $B$ $B = ln(1 - \alpha_i)$ 1 napierian absorbance $A$ $A = lg(1 - \alpha_i)$ 1 absorption factor reflection factor reflectance, $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 1 transmission factor $A_n = A/I$ m <sup>-1</sup> (linear) hereficient (linear) decadic $a, K$ $a = A/I$ m <sup>-1</sup> molar apierian $\alpha$ $\alpha = B_l I$ m <sup>-1</sup> molar apierian $\alpha$ $\alpha = R = R = R^{-2} - I/V$ m <sup>-3</sup> mol <sup>-1</sup>	in a medium	с	$c = c_0/n$	${ m m~s^{-1}}$
wavenumber (in a medium) $\sigma$ $\sigma = 1/\lambda$ m <sup>-1</sup> frequency $v$ $v = c/\lambda$ Hz m <sup>-1</sup> tradiant energy $v = c/\lambda$ $w = 2\pi v$ $s^{-1}$ , rad $s^{-1}$ pulsatance $w = 2\pi v$ $s^{-1}$ , rad $s^{-1}$ pulsatance $n$ $n = c_0/c$ 1 Planck constant $h$ Js Planck constant $h$ Js radiant energy $Q$ , $W$ J m <sup>-3</sup> radiant energy density $\rho$ , $w$ $\rho = Q/V$ J m <sup>-3</sup> spectral radiant energy density $\rho$ , $w$ $\rho_v = d\rho/dv$ J m <sup>-3</sup> Hz <sup>-1</sup> in terms of frequency $\rho_v$ , $w_v$ $\rho_v = d\rho/dv$ J m <sup>-3</sup> Hz <sup>-1</sup> in terms of wavenumber $\rho_{\bar{v}}$ , $w_{\bar{v}}$ $\rho_{\bar{v}} = d\rho/d\lambda$ J m <sup>-2</sup> in terms of wavenumber $\rho_{\bar{v}}$ , $w_{\bar{v}}$ $\rho_{\bar{v}} = d\rho/d\lambda$ J m <sup>-4</sup> Einstein transition probabilities spontaneous emission $A_{nm}$ $dN_n/dt = -\rho_{\bar{v}}(\bar{v}_m) \times B_{nm} N_n$ $s^{kg^{-1}}$ stimulated emission $B_{nm}$ $dN_n/dt = -\rho_{\bar{v}}(\bar{v}_m) \times B_{nm} N_m$ $s^{kg^{-1}}$ radiant energy per time radiant intensity I I I = d\Phi/d\Omega W sr <sup>-1</sup> radiant tenergy per time radiant intensity I I I = d\Phi/d\Omega W sr <sup>-1</sup> radiant tenergy per time radiant intensity I I I = d\Phi/d\Lambda W m <sup>-2</sup> (mitted radiant flux) irradiance $\varepsilon$ $\varepsilon = M/M_{bb}$ 1 Stefan-Boltzman constant $\sigma$ $M_{bb} = \sigma T^4$ W m <sup>-2</sup> K <sup>-4</sup> first radiation constant $c_1$ $c_1 = 2\pi hc_0^2$ W m <sup>2</sup> second radiation constant $c_2$ $c_2 = hc_0/k$ K m transmission factor reflectance, $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 1 transmission factor reflectance, $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 1 absorption factor reflectance, $\alpha$ $\alpha = \Phi_{bbs}/\Phi_0$ 1 absorption factor reflectance, $\alpha$ $\alpha = B/l$ m <sup>-1</sup> molar apierian absorbance $A$ $A = lg(1 - \alpha_l)$ 1 absorption factor reflectance, $k$ $k = a/2\pi v^2$ mol <sup>-1</sup> absorption index $k$ $k = k/2\pi v^2$ land $m^{-1}$ molar apierian $\alpha$ $\alpha = B/l$ m <sup>-1</sup> molar apierian $\alpha$ $\alpha = B/l$ m <sup>-1</sup> $\alpha$ molar apierian $\alpha$ $\alpha = B/l$ m <sup>-1</sup> $\alpha$ molar apierian $\alpha$ $\alpha = B/l$ m <sup>-1</sup> $\alpha$ m <sup>-1</sup> $\alpha$ molar apierian $\alpha$ $\alpha = B/l$ m <sup>-1</sup> $\alpha$ m <sup>-1</sup> $\alpha$ molar apierian $\alpha$ $\alpha$ $\alpha$ $\alpha$ $\beta = m^{-1} - 1$ $V$ molar apierian $\beta$ m <sup>-1</sup>	wavenumber in vacuum	$\tilde{v}$	$\tilde{v} = v/c_0 = 1/n\lambda$	$m^{-1}$
frequency $v$ $v = c/\lambda$ Hz circular frequency, $\omega = 2\pi v$ $w = 2\pi v$ $s^{-1}$ , rad $s^{-1}$ pulsatance refractive index $n$ $n = c_0/c$ 1 Planck constant $h$ $J$ is radiant energy $Q, W$ $p$ radiant energy density $\rho, w$ $\rho = Q/V$ $J$ $m^{-3}$ spectral radiant energy density $\rho, w$ $\rho_v = d\rho/dv$ $J$ $m^{-3}$ Hz <sup>-1</sup> in terms of frequency $\rho_v, w_v$ $\rho_v = d\rho/dv$ $J$ $m^{-3}$ Hz <sup>-1</sup> in terms of wavelength $\rho_v, w_v$ $\rho_v = d\rho/dv$ $J$ $m^{-3}$ simulated emission $B_{nm}$ $dN_n/dt = -A_{nm}N_n$ $s^{-1}$ stimulated emission $B_{nm}$ $dN_n/dt = -\rho_{\bar{v}}(\bar{v}_m) \times B_{nm}N_m$ $s^{kg^{-1}}$ stimulated emission $B_{nm}$ $dN_n/dt = \rho_{\bar{v}}(\bar{v}_m) \times B_{nm}N_m$ $s^{kg^{-1}}$ radiant intensity $I$ $I = d\Phi/d\Omega$ $W$ $sr^{-1}$ radiant intensity $I$ $I = d\Phi/d\Lambda$ $W$ $m^{-2}$ (emitted radiant flux) irradiant energy density $I$ $I = d\Phi/d\Lambda$ $W$ $m^{-2}$ (adiant flux) irradiant constant $\sigma$ $M_{bb} = \sigma T^4$ $W$ $m^{-2}$ K <sup>-4</sup> first radiation constant $\sigma$ $M_{bb} = \sigma T^4$ $W$ $m^{-2}$ K <sup>-4</sup> first radiation constant $\sigma$ $\Lambda = \Phi_{abs}/\Phi_0$ 1 transmission factor absorption factor reflectance, $\rho$ $\rho = \phi - efn/\Phi_0$ 1 transmission factor $mather density = R$ $R = R^{-1}/V$ $m^{-1}$ $m^{-1}$ molar adjords $R = R$ $R = R^{-1}/V$ $m^{-2}$ molar $m^{-1}$ molar adjords $R = R$ $R = R^{-1}/V$	wavenumber (in a medium)	σ	$\sigma = 1/\lambda$	$m^{-1}$
circular frequency, pulsatance $\omega$ $\omega = 2\pi v$ $s^{-1}, rad s^{-1}$ pulsatancen $n = c_0/c$ 1Planck constanth $n = c_0/c$ 1Planck constant/ $2\pi$ $\tilde{n}$ $\tilde{n} = h/2\pi$ $J = s$ radiant energy $Q.W$ $J$ $J$ radiant energy density $\rho, w$ $\rho = Q/V$ $J = s^{-1}$ in terms of frequency $\rho_v, w_v$ $\rho_v = d\rho/dv$ $J = s^{-1}$ in terms of wavelength $\rho_v, w_v$ $\rho_v = d\rho/dv$ $J = s^{-1}$ 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, $\Phi, P$ $\Phi = dQ/dt$ $W = s^{-1}$ 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 tintensity $I$ $I = d\Phi/d\Omega$ $W = s^{-1}$ (radiant flux) $I$ $I = d\Phi/dA$ $W = s^{-1}$ irradiant constant $\sigma$ $M_{bb} = \sigma T^4$ $W = s^{-1}$ (radiant flux received) $\varepsilon$ $\varepsilon = M/M_{bb}$ 1emittace $\kappa$ $\varepsilon = dh/dh$ $W = s^{-1}$ $\sigma$ $M_{bb} = \sigma T^4$ $W = s^{-1} W$ $T$ $\sigma$ $M_{bb} = \sigma T^4$ $W = s^{-1} W$ $T$ $\sigma$ $M_{bb} = \sigma T^4$ $W = s^{-1} W$ $T$ $\sigma$ $\sigma = dh/dh_0$ 1 $T$ $T$ $\sigma$ $\sigma = dh/$	frequency	υ	$v = c/\lambda$	Hz
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	circular frequency, pulsatance	ω	$\omega = 2\pi v$	$s^{-1}$ , rad $s^{-1}$
Planck constanthJ sPlanck constant/2 $\pi$ $\hbar$ $\hbar$ $\hbar = h/2\pi$ J sradiant energy $Q, W$ JJradiant energy density $\rho, w$ $\rho = Q/V$ J m <sup>-3</sup> in terms of frequency $\rho_v, w_v$ $\rho_v = d\rho/dv$ J m <sup>-3</sup> in terms of wavenumber $\rho_v, w_v$ $\rho_v = d\rho/dv$ J m <sup>-2</sup> in terms of wavenumber $\rho_v, w_v$ $\rho_{\lambda} = d\rho/d\lambda$ J m <sup>-4</sup> Einstein transition probabilitiesspontaneous emission $A_{nm}$ $dN_n/dt = -A_m N_n$ s^{-1}stimulated emission $B_{nm}$ $dN_n/dt = -\rho_0(\tilde{v}_{nm}) \times B_{nm} N_n$ s kg <sup>-1</sup> 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 <sup>-1</sup> radiant energy per time $V$ $M = d\Phi/dA$ $W$ m <sup>-2</sup> (emitted radiant flux) $V$ $V = T^2$ $V$ irradiance $E, (I)$ $E = d\Phi/dA$ $W$ m <sup>-2</sup> (radiant flux received) $e$ $\varepsilon$ $M/M_{bb} = \sigma T^4$ $W$ m <sup>-2</sup> K <sup>-4</sup> first radiation constant $\sigma$ $M_{bb} = \sigma T^4$ $W$ m <sup>-2</sup> K <sup>-4</sup> transmission factor $\sigma$ $A = lg(1 - \alpha_i)$ 1transmission factor $\sigma$ $A = lg(1 - \alpha_i)$ 1reflection factor $\sigma$ $A = lg(1 - \alpha_i)$ 1indiction constant $\sigma_i$ $K = aA/l$ $m^{-1}$ absorption coefficient $W$ $W^{-1} = h^2 - l/V$ $W^{-1} = 0^2 - l^2 - l/V$	refractive index	n	$n = c_0/c$	1
Planck constant/ $2\pi$ $\hbar$ $\hbar = h/2\pi$ $J$ sradiant energy $Q, W$ $J$ radiant energy density $\rho, w$ $\rho = Q/V$ $J$ in terms of frequency $\rho_v, w_v$ $\rho_v = d\rho/dv$ $J$ $m terms of wavelength\rho_v, w_v\rho_v = d\rho/dvJm terms of wavelength\rho_v, w_v\rho_v = d\rho/dvJm terms of wavelength\rho_v, w_v\rho_v = d\rho/dvJm terms of wavelength\rho_v, w_v\rho_v = d\rho/d\lambdaJm terms of wavelength\rho_w, w_v\rho_v = d\rho/d\lambdaJm terms of wavelength\rho_w, w_v\rho_v = d\rho/d\lambdaJm terms of wavelengthA_{mm}dN_n/dt = -A_{mm}N_ns kg^{-1}stimulated absorptionB_{mm}dN_n/dt = \rho_v (v_m) B_{mm}N_ms kg^{-1}m terms of requenceMM = d\Phi/d\OmegaWm^{-2}(m term terms of the model of the m$	Planck constant	h	•,	Js
radiant energy $Q, W$ $\rho = Q/V$ $Jm^{-3}$ radiant energy density $\rho, w$ $\rho = Q/V$ $Jm^{-3}$ spectral radiant energy density $\rho, w_v$ $\rho_v = d\rho/dv$ $Jm^{-3}$ Hz <sup>-1</sup> 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, $\Phi, P$ $\Phi = dQ/dt$ $W$ $W$ radiant energy per time radiant energy per time radiant exitance $M$ $M = d\Phi/d\Delta$ $Wm^{-2}$ (emitted radiant flux) irradiance $\varepsilon$ $\varepsilon = M/M_{bb}$ 1 Stefan-Boltzman constant $\sigma$ $M_{bb} = \sigma T^4$ $Wm^{-2} K^{-4}$ 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 $h$ $k = (a/2\pi\bar{a})/4n$ 1 $m^2mol^{-1}$ absorption index $k$ $k = (a/2\pi\bar{a})/4n$ 1 $m^2mol^{-1}$ $molar napierian \kappa \kappa = \alpha/c = B/cl m^2 mol^{-1}$	Planck constant/ $2\pi$	ħ	$\hbar = h/2\pi$	Ís
radiant energy density $\rho, w$ $\rho = Q/V$ J m <sup>-3</sup> spectral radiant energy density in terms of frequency $\rho_v, w_v$ $\rho_v = d\rho/dv$ J m <sup>-3</sup> Hz <sup>-1</sup> in terms of wavenumber $\rho_{\bar{v}}, w_{\bar{v}}$ $\rho_{\bar{v}} = d\rho/d\bar{v}$ J m <sup>-2</sup> in terms of wavenumber $\rho_{\bar{v}}, w_{\bar{v}}$ $\rho_{\bar{v}} = d\rho/d\lambda$ J m <sup>-4</sup> Einstein transition probabilities spontaneous emission $A_{nm}$ $dN_n/dt = -A_{nm}N_n$ s kg <sup>-1</sup> stimulated emission $B_{nm}$ $dN_n/dt = -\rho_{\bar{v}}(\bar{v}_{nm}) \times B_{nm}N_m$ s kg <sup>-1</sup> radiant intergy per time radiant intensity I I I = d\Phi/d\Omega W sr <sup>-1</sup> 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 <sup>-2</sup> (radiant flux received) emittence $\varepsilon$ $\varepsilon = M/M_{bb}$ 1 Stefan-Boltzman constant $\sigma$ $M_{bb} = \sigma T^4$ W m <sup>-2</sup> K <sup>-4</sup> first radiation constant $c_1$ $c_1 = 2\pi hc_0^2$ W m <sup>2</sup> second radiation constant $c_2$ $c_2 = hc_0/k$ K m transmistion factor reflectance, $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 1 transmistion factor reflectance, $\beta$ $A$ $A = lg(1 - \alpha_i)$ 1 napierian absorbance $B$ $B = ln(1 - \alpha_i)$ 1 absorption coefficient (linear) decadic $a, K$ $a = A/l$ $m^{-1}$ (molar apierian $\alpha$ $\alpha$ $a = B/l$ $m^{-1}$ molar (decadic) $k$ $k = \alpha/4\pi\bar{v}$ 1 complex refractione $R$ $R$ $R$ $R$ $R = n^{2} - 1$ $V$ $m^{-2}$ matrix	radiant energy	Q, W	,	Ĵ
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	radiant energy density	$\tilde{\rho}, w$	$\rho = O/V$	$J m^{-3}$
in terms of frequency $\rho_v, w_v$ $\rho_v = d\rho/dv$ $J m^{-3}Hz^{-1}$ 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 $e^{\pi} = M/M_{bb}$ $1$ stefan-Boltzman constant $c_1$ $c_1 = 2\pi hc_0^2$ w m^2 $a^{\pi} = a \phi_{abs}/\Phi_0$ $1$ transmistion factor $a^{\pi} = a \phi_{abs}/\Phi_0$ $1$ absorption factor $a^{\pi} = a e^{\pi} = J m^{-1}$ $m^{-1}$ (linear) decadic $a, K$ $a = A/l$ $m^{-1}$ (linear) napierian $\alpha$ $\alpha = B/l$ $m^{-1}$ molar (decadic) $e^{\pi} = a e^{\pi} = R/e^{\pi}$ $1$ complex refraction $R = R$ $R = n^{2} - 1$ $m^{2} mol^{-1}$ <td>spectral radiant energy density</td> <td>1 '</td> <td>, 2,</td> <td>,</td>	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 $\Phi, P$ $\Phi = dQ/dt$ $W$ 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 $\varepsilon$ $\varepsilon = M/M_{bb}$ 1stean-Boltzman constant $\sigma$ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ 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) $\varepsilon$ $\varepsilon = a/c = A/cl$ $m^2 mol^{-1}$ molar apierian $\alpha$ $\alpha = B/l$ $m^{-1}$ molar decadic) $\varepsilon$ $\varepsilon = a/a = m^2 - 1$ $w^2 mol^{-1}$	in terms of frequency	$\rho_n, w_n$	$\rho_v = d\rho/dv$	$I m^{-3} H z^{-1}$
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, $\Phi, P$ $\Phi = dQ/dt$ $W$ 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 $\varepsilon$ $\varepsilon = M/M_{bb}$ 1stefan-Boltzman constant $\sigma$ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ 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 $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 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 $\varepsilon$ $\varepsilon = a/c = B/cl$ $m^{2} mol^{-1}$ molar napierian $\kappa$ $\kappa = \alpha/a \pi \bar{v}$ 1molar napierian $\kappa$ $\kappa = \alpha/c = B/cl$ $m^{2} mol^{-1}$ molar napierian $\kappa$ $\kappa = \alpha/c = B/cl$ $m^{2} mol^{-1}$	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, $\Phi$ , $P$ $\Phi = dQ/dt$ $W$ 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 $\varepsilon$ $\varepsilon = M/M_{bb}$ 1 Stefan-Boltzman constant $\sigma$ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ 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 $\alpha$ $\alpha = B/l$ $m^{-1}$ molar napierian $\kappa$ $K = \alpha/a\pi \tilde{v}$ $1$ $m^2 m c^{-1}$ $V$ $m^2 m c^{-1}$ $m^2 m c^{-1}$ $m^2 m c^{-1}$ $molar napierian \kappa k = \alpha/4\pi \tilde{v} 1m^2 m c^{-1} m^2 m c^{-1}molar napierian \kappa k = \alpha/4\pi \tilde{v} 1m^{-1} m complex refractive index k k = \alpha/4\pi \tilde{v} 1m^{-1} m complex refractive index k k = \alpha/4\pi \tilde{v} 1m^{-1} m complex refractive index k R = R = R^{-2} - 1 V m^{-2} m^{-1} R^{-2}$	in terms of wavelength	$\rho_{\lambda}, w_{\lambda}$	$\rho_{\lambda} = d\rho/d\lambda$	$J m^{-4}$
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, $\Phi$ , $P$ $\Phi = dQ/dt$ $W$ radiant energy per time radiant itensity $I$ $I = d\Phi/d\Omega$ $W sr^{-1}$ 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 fux received) emittance $\varepsilon$ $\varepsilon = M/M_{bb}$ 1 Stefan-Boltzman constant $\sigma$ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ first radiation constant $c_1$ $c_1 = 2\pi h c_0^2$ $W m^2$ second radiation constant $c_2$ $c_2 = hc_0/k$ $K m$ transmission factor absorption factor reflectance, $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 1 neflection factor (decadic) absorbance $B$ $B = ln(1 - \alpha_i)$ 1 absorption coefficient (linear) decadic $\varepsilon$ $\varepsilon$ $k = a/kI$ $m^{-1}$ molar napierian $\kappa$ $K = \alpha/a\pi \tilde{w}$ 1 nolar napierian $\kappa$ $K = \alpha/a\pi \tilde{w}$ 1 molar radiation $R$ $R$ $R$ $R = R = R^{-2} - 1$ $V$ $m^{-2}$ $m^{-2}$	Einstein transition probabilities	FX,X		,
stimulated emission $B_{nm}$ $dN_n/dt = -\rho_{\bar{p}}(\bar{v}_{nm}) \times B_{nm}N_n$ $s kg^{-1}$ stimulated absorption $B_{mn}$ $dN_n/dt = -\rho_{\bar{p}}(\bar{v}_{nm})B_{mn}N_m$ $s kg^{-1}$ radiant power, $\Phi, P$ $\Phi = dQ/dt$ $W$ 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) $I$ $E = d\Phi/dA$ $W m^{-2}$ irradiance $E, (I)$ $E = d\Phi/dA$ $W m^{-2}$ (radiant flux received) $\varepsilon$ $\varepsilon = M/M_{bb}$ $I$ stefan-Boltzman constant $\sigma$ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ first radiation constant $c_1$ $c_1 = 2\pi hc_0^2$ $W m^2$ second radiation constant $c_2$ $c_2 = hc_0/k$ $K m$ transmistor, factor $a$ $\alpha = \Phi_{abs}/\Phi_0$ $1$ absorption factor $a$ $\alpha = \Phi_{abs}/\Phi_0$ $1$ absorption factor $B$ $B = ln(1 - \alpha_i)$ $1$ absorption coefficient $\alpha$ $\alpha = B/l$ $m^{-1}$ (linear) napierian $\alpha$ $\alpha = B/l$ $m^{-1}$ molar napierian $\kappa$ $\kappa = \alpha/c = B/cl$ $m^2 mol^{-1}$ absorption index $k$ $k = \alpha/4\pi \tilde{v}$ $1$	spontaneous emission	Anm	$dN_{\rm m}/dt = -A_{\rm mm}N_{\rm m}$	s <sup>-1</sup>
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 $\Phi, P$ $\Phi = dQ/dt$ $W$ 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) $\varepsilon$ $\varepsilon = M/M_{bb}$ 1emittance $\varepsilon$ $\varepsilon = M/M_{bb}$ 1Stefan-Boltzman constant $\sigma$ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ 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 $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 1industright decadic $a, K$ $a = A/l$ $m^{-1}$ (linear) napierian molar (decadic) $\varepsilon$ $\varepsilon = a/c = A/cl$ $m^2 mol^{-1}$ absorption index $k$ $k$ $k = \alpha/4\pi \bar{v}$ 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, $\Phi, P$ $\Phi = dQ/dt$ $W$ 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 $\varepsilon$ $\varepsilon = M/M_{\rm bb}$ 1 Stefan-Boltzman constant $\sigma$ $M_{\rm bb} = \sigma T^4$ $W  {\rm m}^{-2}  {\rm K}^{-4}$ 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, $\tau, T$ $\tau = \Phi_{\rm tr}/\Phi_0$ 1 transmittance, $\sigma$ $\Lambda$ $\alpha = \Phi_{\rm abs}/\Phi_0$ 1 absorption factor reflectance, $\rho$ $\rho = \Phi_{\rm refl}/\Phi_0$ 1 napierian absorbance $B$ $B = \ln(1 - \alpha_i)$ 1 absorption coefficient (linear) napierian $\alpha$ $\alpha = B/l$ $m^{-1}$ molar (decadic) $\varepsilon$ $k$ $k = \alpha/A \pi \tilde{v}$ 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 $\mu$ $R = R$ $R = \frac{n^2 - 1}{2} V$ $m^3 m a^{-1}$	stimulated absorption	Bmm	$\frac{dN_{n}}{dt} = \rho_{0}(\tilde{v}_{nm}) \times D_{nm} v_{n}$	s kg <sup>-1</sup>
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) $\varepsilon$ $\varepsilon = M/M_{\rm bb}$ 1Stefan-Boltzman constant $\sigma$ $M_{\rm bb} = \sigma T^4$ $W  {\rm m}^{-2}  {\rm K}^{-4}$ 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, $\tau, T$ $\tau = \Phi_{\rm tr}/\Phi_0$ 1transmission factora $\alpha = \Phi_{\rm abs}/\Phi_0$ 1absorption factor $\alpha$ $\alpha = \Phi_{\rm abs}/\Phi_0$ 1reflection factorII(decadic) absorbance $A$ $A = \lg(1 - \alpha_i)$ 1napierian absorbance $B$ $B = \ln(1 - \alpha_i)$ 1absorption coefficient $\omega$ $\omega = \alpha = B/l$ $m^{-1}$ (linear) napierian $\alpha$ $\alpha = B/l$ $m^{-1}$ molar napierian $\kappa$ $\kappa = \alpha/c = B/cl$ $m^2  {\rm mol}^{-1}$ 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.	$\Phi$ 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 $\varepsilon$ $\varepsilon = M/M_{\rm bb}$ 1 Stefan-Boltzman constant $\sigma$ $M_{\rm bb} = \sigma T^4$ $W  {\rm m}^{-2}  {\rm K}^{-4}$ 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, $\tau, T$ $\tau = \Phi_{\rm tr} / \Phi_0$ 1 transmission factor reflectance, $\rho$ $\rho = \Phi_{\rm refl} / \Phi_0$ 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 $\alpha$ $\alpha = B/l$ $m^{-1}$ molar napierian $\kappa$ $\kappa = \alpha/c = B/cl$ $m^2  {\rm mol}^{-1}$ absorption index $k$ $k = \alpha/4\pi \bar{\nu}$ 1 remain molar (decadic) $\kappa$ $R$ $R = R = R = \frac{n^2 - 1}{2}  V$ $m^3  {\rm mol}^{-1}$	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 $\varepsilon$ $\varepsilon = M/M_{bb}$ 1 Stefan-Boltzman constant $\sigma$ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ 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, $\tau, T$ $\tau = \Phi_{tr} / \Phi_0$ 1 transmission factor absorption factor reflectance, $\rho$ $\rho = \Phi_{refl} / \Phi_0$ 1 napierian absorbance $A$ $A = lg(1 - \alpha_i)$ 1 napierian absorbance $B$ $B = ln(1 - \alpha_i)$ 1 absorption coefficient (linear) napierian $\alpha$ $\alpha = B/l$ $m^{-1}$ molar napierian $\kappa$ $\kappa = \alpha/c = B/cl$ $m^2 mol^{-1}$ absorption index $k$ $k = \alpha/4\pi \tilde{v}$ 1 remeasurements $h = h + ik$ 1 molar refraction $R$ $R$ $R = R = R^{-1} - \frac{n^2 - 1}{2}$ $W$ $m^3$ mal^{-1}	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 $\varepsilon$ $\varepsilon = M/M_{bb}$ 1 Stefan-Boltzman constant $\sigma$ $M_{bb} = \sigma T^4$ $W m^{-2} K^{-4}$ 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, $\tau, T$ $\tau = \Phi_{tr} / \Phi_0$ 1 transmission factor absorption factor reflectance, $\rho$ $\rho = \Phi_{refl} / \Phi_0$ 1 napierian absorbance $A$ $A = lg(1 - \alpha_i)$ 1 napierian absorbance $B$ $B = ln(1 - \alpha_i)$ 1 absorption coefficient (linear) napierian $\alpha$ $\alpha = B/l$ $m^{-1}$ molar napierian $\kappa$ $\kappa = \alpha/c = B/cl$ $m^2 mol^{-1}$ molar napierian $\kappa$ $k = \alpha/4\pi \tilde{v}$ 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) $\varepsilon$ $\varepsilon = M/M_{bb}$ 1emittance $\varepsilon$ $\varepsilon = M/M_{bb} = \sigma T^{4}$ $W m^{-2} K^{-4}$ first radiation constant $\sigma$ $M_{bb} = \sigma T^{4}$ $W m^{-2} K^{-4}$ 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, $\tau, T$ $\tau = \Phi_{tr}/\Phi_{0}$ 1transmission factorabsorptance, $\alpha$ $\alpha = \Phi_{abs}/\Phi_{0}$ 1absorption factorreflectance, $\rho$ $\rho = \Phi_{refl}/\Phi_{0}$ 1(decadic) absorbanceA $A = \lg(1 - \alpha_{i})$ 1napierian absorbanceB $B = \ln(1 - \alpha_{i})$ 1absorption coefficient(linear) apierian $\alpha$ $\alpha = B/l$ $m^{-1}$ (linear) napierian $\kappa$ $\kappa = \alpha/c = A/cl$ $m^{2}mol^{-1}$ molar napierian $\kappa$ $\kappa = \alpha/c = B/cl$ $m^{2}mol^{-1}$ 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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Animate $\alpha$ $M_{bb}$ $\sigma T^4$ $W m^{-2} K^{-4}$ 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, $\tau, T$ $\tau = \Phi_{tr} / \Phi_0$ 1transmission factor $\alpha$ $\alpha = \Phi_{abs} / \Phi_0$ 1absorption factor $reflectance,$ $\rho$ $\rho = \Phi_{refl} / \Phi_0$ 1reflectance, $\rho$ $\rho = \Phi_{refl} / \Phi_0$ 1napierian absorbance $A$ $A = \lg(1 - \alpha_i)$ 1napierian absorbance $B$ $B = \ln(1 - \alpha_i)$ 1absorption coefficient $\alpha$ $\alpha = B / l$ $m^{-1}$ (linear) napierian $\alpha$ $\alpha = B / l$ $m^{-1}$ molar (decadic) $\varepsilon$ $\varepsilon = a/c = A/cl$ $m^2 mol^{-1}$ absorption index $k$ $k = \alpha/4\pi\tilde{v}$ 1	emittance	£	$\varepsilon = M/M_{\rm bb}$	1
first radiation constant $c_1$ $c_1 = 2\pi hc_0^2$ W m²second radiation constant $c_2$ $c_2 = hc_0/k$ K mtransmittance, $\tau, T$ $\tau = \Phi_{tr}/\Phi_0$ 1transmission factorabsorption factor1reflectance, $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 1napierian absorbanceA $A = \lg(1 - \alpha_i)$ 1napierian absorbanceB $B = \ln(1 - \alpha_i)$ 1absorption (decadic) $\alpha$ $\alpha = B/l$ $m^{-1}$ (linear) decadic $a, K$ $a = A/cl$ $m^{-1}$ molar (decadic) $\varepsilon$ $\varepsilon = a/c = A/cl$ $m^2 \mod^{-1}$ absorption index $k$ $k = \alpha/4\pi\tilde{v}$ 1	Stefan-Boltzman constant	σ	$M_{\rm hb} = \sigma T^4$	$W m^{-2} K^{-4}$
The formation constant $c_2$ $c_2 = hc_0/k$ K m transmittance, $\tau, T$ $\tau = \Phi_{tr}/\Phi_0$ 1 transmission factor absorption factor reflectance, $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 1 reflectance, $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 1 reflectance, $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 1 napierian absorbance A $A = \lg(1 - \alpha_i)$ 1 napierian absorbance B $B = \ln(1 - \alpha_i)$ 1 absorption coefficient (linear) decadic a, K $a = A/l$ $m^{-1}$ (linear) decadic $\varepsilon$ $\varepsilon$ $\varepsilon = a/c = A/cl$ $m^2 mol^{-1}$ molar (decadic) index $k$ $k = \alpha/4\pi\tilde{v}$ 1 complex refraction $R = R = \frac{n^2 - 1}{r}V$ $m^3 mol^{-1}$	first radiation constant	C1	$c_1 = 2\pi h c_1^2$	$W m^2$
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absorption factor $\alpha$ $\alpha = \Phi_{abs}/\Phi_0$ 1absorption factorreflectance, $\rho$ $\rho = \Phi_{refl}/\Phi_0$ 1reflection factor(decadic) absorbance $A$ $A = \lg(1 - \alpha_i)$ 1napierian absorbance $B$ $B = \ln(1 - \alpha_i)$ 1absorption coefficient(linear) decadic $a, K$ $a = A/l$ $m^{-1}$ (linear) napierian $\alpha$ $\alpha = B/l$ $m^{-1}$ molar (decadic) $\varepsilon$ $\varepsilon = a/c = A/cl$ $m^2 \mod^{-1}$ molar napierian $\kappa$ $\kappa = \alpha/a = B/cl$ $m^2 \mod^{-1}$ absorption index $k$ $k = \alpha/4\pi\tilde{v}$ 1complex refractive index $\hat{n}$ $\hat{n} = n + ik$ 1	transmission factor	•, •	· · · · · · · · · · · · · · · · · · ·	1
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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 $\alpha$ $\alpha = B/l$ $m^{-1}$ molar (decadic) $\varepsilon$ $\varepsilon = a/c = A/cl$ $m^2 mol^{-1}$ molar napierian $\kappa$ $\kappa = \alpha/c = B/cl$ $m^2 mol^{-1}$ 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
(decadic) absorbanceA $A = \lg(1 - \alpha_i)$ 1napierian absorbanceB $B = \ln(1 - \alpha_i)$ 1absorption coefficient(linear) decadic $a, K$ $a = A/l$ $m^{-1}$ (linear) napierian $\alpha$ $\alpha = B/l$ $m^{-1}$ molar (decadic) $\varepsilon$ $\varepsilon = a/c = A/cl$ $m^2 \mod^{-1}$ molar napierian $\kappa$ $\kappa = \alpha/c = B/cl$ $m^2 \mod^{-1}$ absorption index $k$ $k = \alpha/4\pi\tilde{v}$ 1complex refractive index $\hat{n}$ $\hat{n} = n + ik$ 1	reflection factor	P	p = ren / r o	1
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	(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 $\alpha$ $\alpha = B/l$ $m^{-1}$ molar (decadic) $\varepsilon$ $\varepsilon = a/c = A/cl$ $m^2 \mod^{-1}$ molar napierian $\kappa$ $\kappa = \alpha/c = B/cl$ $m^2 \mod^{-1}$ 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 $\alpha$ $\alpha = B/l$ $m^{-1}$ molar (decadic) $\varepsilon$ $\varepsilon = a/c = A/cl$ $m^{2} \mod^{-1}$ molar napierian $\kappa$ $\kappa = \alpha/c = B/cl$ $m^{2} \mod^{-1}$ 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 $\kappa$ $\kappa = \alpha/c = B/cl$ $m^2 \mod^{-1}$ 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 <sup>3</sup> mol <sup>-1</sup>
angle of optical rotation $\alpha$ $n^2 + 2$ 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	<b>R</b> , <b>R</b> <sub>0</sub>		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	$\theta$	$n\lambda = 2d\sin\theta$	1, rad
order of reflection	n		1
order parameters			
short range	σ		1
long range	S		1
Burgers vector	b		m
particle position vector	<b>r</b> , <b>R</b> <sub>j</sub>		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 <sup>-1</sup>
Debye circular frequency	$\omega_D$		s <sup>-1</sup>
Grüneisen parameter	γ, Γ	$\gamma = \alpha V / \kappa C_V$	1
Madelung constant	$\alpha, \mathcal{M}$	$E_{\text{coul}} = \frac{\alpha N_A z_+ z e^2}{2}$	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	$N_{\omega}, g$	$N_{\omega} = dN(\omega)/d\omega$	s m -
vibrational modes	<u>.</u>	F = c i	0 m
and unitivity tensor	$\rho_{ik}$	$E = \rho \cdot f$	52 m
thermal conductivity tensor	O <sub>ik</sub>	$o \equiv \rho$	$3 \text{ m}^{-1} \text{ V}^{-1}$
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 $L = l/\sigma T$	$V^{2} K^{-2}$
Hall coefficient		$E = \lambda / \delta I$ $E = \alpha \cdot i + R \cdot (R \times i)$	$m^3 C^{-1}$
thermoelectric force	F AH, NH	$E = p \cdot j + K_H (\mathbf{b} \times \mathbf{j})$	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 <sup>-3</sup>
number concentration	n,(p)		111
and anorgy	F		т
donor ionization energy			J
acceptor ionization energy			J
Earmi anargy			J
circular wave vector	LF, CF	$k = 2\pi/3$	$m^{-1}$
propagation vector	n, 9	$\kappa = 2\pi/\kappa$	
Bloch function	11. ( <b>*</b> )	$u_{k}(\mathbf{r}) = u_{k}(\mathbf{r})\exp(i\mathbf{k}\cdot\mathbf{r})$	$m^{-3/2}$
charge density of electrons	$u_k(r)$	$\varphi(\mathbf{r}) = u_k(\mathbf{r})\exp(i\mathbf{k}\cdot\mathbf{r})$	$Cm^{-3}$
effective mass	р m*	$p(t) = -\epsilon \psi(t) \psi(t)$	ko
mobility		$u = v_{\text{ALLE}}/F$	$m^2 V^{-1} e^{-1}$
mobility ratio	μ h	$\mu = v_{driff}/E$ $h = \mu_{c}/\mu_{c}$	1
diffusion coefficient	D D	dN/dt = DA(dn/dr)	$m^{2} c^{-1}$
diffusion length	I I	$I = \sqrt{D\tau}$	m
characteristic (Waiss)	L	$L = \sqrt{D} \iota$	III V
temperature	$\varphi, \varphi_W$		K
Curie temperature	Tc		к
Néel temperature			K
i teor temperature	* /N		IX.

**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
Epoxy	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	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	SiO <sub>2</sub> SiO <sub>2</sub> 10 wt% Na <sub>2</sub> O	2.20 2.291	ABS Acrylic	1.05–1.07 1.17–1.19
Co	8.8	MgO	3.581	$SiO_2$ 19.35 wt% Na <sub>2</sub> O SiO <sub>2</sub> 29.20 wt% Na <sub>2</sub> 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} {\rm SiC(hex)} \\ {\rm Si}_{3}{\rm N}_{4}\left(\alpha\right) \\ {\rm Si}_{3}{\rm N}_{4}\left(\beta\right) \\ {\rm TiO}_{2}\left({\rm 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 <sub>2</sub> ZrO <sub>2</sub> (CaO) Al <sub>2</sub> O <sub>3</sub> MgO 3Al <sub>2</sub> O <sub>3</sub> 2SiO <sub>2</sub>	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/m<sup>3</sup> (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 <sup>6</sup> Hz	Dielectric strength V/mil	Volume resistivity $\Omega \cdot cm (23^{\circ}C)$	Loss factor <sup>a</sup>
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 <sup>14</sup>	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

<sup>a</sup>Power 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 <sup>a</sup>
	( 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

<sup>a</sup>Power factor  $\times$  dielectric constant equals loss factor.

		Dielectric			Dielectric
Material	Freq., Hz	constant	Material	Freq., Hz	Constant
Acetamide	$4 \times 10^8$	4.0	Phenanthrene	$4 \times 10^8$	2.80
Acetanilide	-	2.9	Phenol (10°C)	$4 \times 10^8$	4.3
Acetic acid (2°C)	$4 \times 10^8$	4.1	Phosphorus, red	10 <sup>8</sup>	4.1
Aluminum oleate	$4 \times 10^8$	2.40	Phosphorus, yellow	10 <sup>8</sup>	3.6
Ammonium bromide	10 <sup>8</sup>	7.1	Potassium aluminum		
Ammonium chloride	10 <sup>8</sup>	7.0	sulfate	10 <sup>6</sup>	3.8
Antimony trichloride	10 <sup>8</sup>	5.34	Potassium carbonate		
Apatite $\perp$ optic axis	$3 \times 10^{8}$	9.50	(15°C)	10 <sup>8</sup>	5.6
Apatite    optic axis	$3 \times 10^{8}$	7.41	Potassium chlorate	$6 \times 10^{7}$	5.1
Asphalt	$< 3 \times 10^{6}$	2.68	Potassium chloride	10 <sup>4</sup>	5.03
Barium chloride (anhyd.)	$6 \times 10^{7}$	11.4	Potassium chromate	$6 \times 10^{7}$	7.3
Barium chloride (2H <sub>2</sub> O)	$6 \times 10^{7}$	9.4	Potassium iodide	$6 \times 10^{7}$	5.6
Barium nitrate	$6 \times 10^{7}$	5.9	Potassium nitrate	$6 \times 10^{7}$	5.0
Barium sulfate(15°C)	10 <sup>8</sup>	11.4	Potassium sulfate	$6 \times 10^{7}$	5.9
Bervl $\perp$ optic axis	10 <sup>4</sup>	7.02	Ouartz $\perp$ optic axis	$3 \times 10^{7}$	4.34
Bervl    optic axis	10 <sup>4</sup>	6.08	Ouartz    optic axis	$3 \times 10^{7}$	4.27
Calcite $\perp$ optic axis	10 <sup>4</sup>	8.5	Resorcinol	$4 \times 10^{8}$	3.2
Calcite    optic axis	10 <sup>4</sup>	8.0	Ruby⊥ optic axis	10 <sup>4</sup>	13.27
Calcium carbonate	106	6.14	Ruby    optic axis	10 <sup>4</sup>	11.28
Calcium fluoride	104	7.36	Rutile $\perp$ optic axis	10 <sup>8</sup>	86
Calcium sulfate $(2H_2O)$	$10^{4}$	5.66	Rutile    optic axis	108	170
Cassiterite   optic axis	10 <sup>12</sup>	23.4	Selenium	108	6.6
Cassiterite    optic axis	10 <sup>12</sup>	24	Silver bromide	106	12.2
d-Cocaine	$5 \times 10^8$	3 10	Silver chloride	106	11.2
Cupric oleate	$4 \times 10^8$	2.80	Silver cyanide	106	5.6
Cupric oxide $(15^{\circ}C)$	108	18.1	Smithsonite   ontic	10 <sup>12</sup>	93
Suprie Oxide (15-6)	10	10.1	axis	10	
Cupric sulfate (anhyd.)	$6 \times 10^{7}$	10.3			
Cupric sulfate (5H <sub>2</sub> O)	$6 \times 10^{7}$	7.8	Smithsonite    optic	10 <sup>10</sup>	9.4
Diamond	10 <sup>8</sup>	5.5	axis		
Diphenylymethane	$4 \times 10^8$	2.7	Sodium carbonate (anhvd.)	$6 \times 10^{7}$	8.4
Dolomite $\perp$ optic axis	10 <sup>8</sup>	8.0	Sodium carbonate	$6 \times 10^{7}$	5.3
Dolomite    optic axis	10 <sup>8</sup>	6.8	(10H <sub>2</sub> O)		
Ferrous oxide (15°C)	10 <sup>8</sup>	14.2	Sodium chloride	$10^{4}$	6.12
Iodine	$10^{8}$	4	Sodium nitrate	-	5.2
Lead acetate	10 <sup>6</sup>	2.6	Sodium oleate	$4 \times 10^8$	2.75
Lead carbonate (15°C)	108	18.6	Sodium perchlorate	$6 \times 10^{7}$	5.4
Lead chloride	10 <sup>6</sup>	4.2	Sucrose (mean)	$3 \times 10^8$	3.32
Lead monoxide (15°C)	108	25.9	Sulfur (mean)	-	4.0
Lead nitrate	$6 \times 10^{7}$	37.7	Thallium chloride	106	46.9
Lead oleate	$4 \times 10^{8}$	3.27	<i>p</i> -Toluidine	$4 \times 10^8$	3.0
Lead sulfate	106	14.3	Tourmaline $\perp$ optic	$10^{4}$	7.10
Lead sulfide (15°)	10 <sup>6</sup>	17.9	axis		
Malachite (mean)	1012	7.2	Tourmaline    optic	$10^{4}$	6.3
Mercuric chloride	$10^{6}$	3.2	axis		
Mercurous chloride	10 <sup>6</sup>	9.4	Urea	$4 \times 10^8$	3.5
Naphthalene	$4 \times 10^8$	2.52	Zircon $\perp$ ,	$10^{8}$	12
1.					

**Table 1.10** Dielectric Constants of Solids in the Temperature Range 17–22°C (From [1].Used with permission.)

Whitaker, Jerry C. "International Standards and Constants" *The Resource Handbook of Electronics*. Ed. Jerry C. Whitaker Boca Raton: CRC Press LLC, ©2001

### Chapter

## 2

## International Standards and Constants

#### 2.1 Introduction

Standardization usually starts within a company as a way to reduce costs associated with parts stocking, design drawings, training, and retraining of personnel. The next level might be a cooperative agreement between firms making similar equipment to use standardized dimensions, parts, and components. Competition, trade secrets, and the *NIH factor* (not invented here) often generate an atmosphere that prevents such an understanding. Enter the professional engineering society, which promises a forum for discussion between users and engineers while downplaying the commercial and business aspects.

#### 2.2 The History of Modern Standards

In 1836, the U.S. Congress authorized the Office of Weights and Measures (OWM) for the primary purpose of ensuring uniformity in custom house dealings. The Treasury Department was charged with its operation. As advancements in science and technology fueled the industrial revolution, it was apparent that standardization of hardware and test methods was necessary to promote commercial development and to compete successfully with the rest of the world. The industrial revolution in the 1830s introduced the need for interchangeable parts and hardware. Economical manufacture of transportation equipment, tools, weapons, and other machinery was possible only with mechanical standardization.

By the late 1800s professional organizations of mechanical, electrical, chemical, and other engineers were founded with this aim in mind. The Institute of Electrical Engineers developed standards between 1890 and 1910 based on the practices of the major electrical manufacturers of the time. Such activities were not within the purview of the OWM, so there was no government involvement during this period. It took the pressures of war production in 1918 to cause the formation of the American Engineering

Standards Committee (AESC) to coordinate the activities of various industry and engineering societies. This group became the American Standards Association (ASA) in 1928.

Parallel developments would occur worldwide. The International Bureau of Weights and Measures was founded in 1875, the International Electrotechnical Commission (IEC) in 1904, and the International Federation of Standardizing Bodies (ISA) in 1926. Following World War II (1946) this group was reorganized as the International Standards Organization (ISO) comprised of the ASA and the standardizing bodies of 25 other countries. Present participation is approximately 55 countries and 145 technical committees. The stated mission of the ISO is *to facilitate the internationalization and unification of industrial standards*.

The International Telecommunications Union (ITU) was founded in 1865 for the purpose of coordinating and interfacing telegraphic communications worldwide. Today, its member countries develop regulations and voluntary recommendations, and provide coordination of telecommunications development. A sub-group, the International Radio Consultative Committee (CCIR) (which no longer exists under this name), is concerned with certain transmission standards and the compatible use of the frequency spectrum, including geostationary satellite orbit assignments. Standardized transmission formats to allow interchange of communications over national boundaries are the purview of this committee. Because these standards involve international treaties, negotiations are channeled through the U.S. State Department.

#### 2.2.1 American National Standards Institute (ANSI)

ANSI coordinates policies to promote procedures, guidelines, and the consistency of standards development. Due process procedures ensure that participation is open to all persons who are materially affected by the activities without domination by a particular group. Written procedures are available to ensure that consistent methods are used for standards developments and appeals. Today, there are more than 1000 members who support the U.S. voluntary standardization system as members of the ANSI federation. This support keeps the Institute financially sound and the system free of government control.

The functions of ANSI include: (1) serving as a clearinghouse on standards development and supplying standards-related publications and information, and (2) the following business development issues:

- Provides national and international standards information necessary to market products worldwide.
- Offers American National Standards that assist companies in reducing operating and purchasing costs, thereby assuring product quality and safety.
- Offers an opportunity to voice opinion through representation on numerous technical advisory groups, councils, and boards.
- Furnishes national and international recognition of standards for credibility and force in domestic commerce and world trade.

• Provides a path to influence and comment on the development of standards in the international arena.

Prospective standards must be submitted by an ANSI accredited standards developer. There are three methods which may be used:

- Accredited organization method. This approach is most often used by associations and societies having an interest in developing standards. Participation is open to all interested parties as well as members of the association or society. The standards developer must fashion its own operating procedures, which must meet the general requirements of the ANSI procedures.
- Accredited standards committee method. Standing committees of directly and materially affected interests develop documents and establish consensus in support of the document. This method is most often used when a standard affects a broad range of diverse interests or where multiple associations or societies with similar interests exist. These committees are administered by a *secretariat*, an organization that assumes the responsibility for providing compliance with the pertinent operating procedures. The committee can develop its own operating procedures consistent with ANSI requirements, or it can adopt standard ANSI procedures.
- Accredited canvass method. This approach is used by smaller trade associations or societies that have documented current industry practices and desire that these standards be recognized nationally. Generally, these developers are responsible for less than five standards. The developer identifies those who are directly and materially affected by the activity in question and conducts a letter ballot *canvass* of those interests to determine consensus. Developers must use standard ANSI procedures.

Note that all methods must fulfill the basic requirements of public review, voting, consideration, and disposition of all views and objections, and an appeals mechanism.

The introduction of new technologies or changes in the direction of industry groups or engineering societies may require a mediating body to assign responsibility for a developing standard to the proper group. The Joint Committee for Intersociety Coordination (JCIC) operates under ANSI to fulfill this need.

#### 2.2.2 Professional Society Engineering Committees

The engineering groups that collate and coordinate activities that are eventually presented to standardization bodies encourage participation from all concerned parties. Meetings are often scheduled in connection with technical conferences to promote greater participation. Other necessary meetings are usually scheduled in geographical locations of the greatest activity in the field. There are no charges or dues to be a member or to attend the meetings. An interest in these activities can still be served by reading the reports from these groups in the appropriate professional journals. These wheels may seem to grind exceedingly slowly at times, but the adoption of standards that may have to endure for 50 years or more should not be taken lightly.

#### 2.3 References

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

#### 2.4 Bibliography

Whitaker, Jerry C., and K. Blair Benson (eds.), *Standard Handbook of Video and Television Engineering*, McGraw-Hill, New York, NY, 2000.

#### 2.5 Tabular Data

Table 2.1 Common Standard Units

Name	Symbol	Quantity
ampere	А	electric current
ampere per meter	A/m	magnetic field strength
ampere per square meter	A/m <sup>2</sup>	current density
becquerel	Bg	activity (of a radionuclide)
candela	cd	luminous intensity
coulomb	С	electric charge
coulomb per kilogram	C/kg	exposure (x and gamma rays)
coulomb per sq. meter	C/m <sup>2</sup>	electric flux density
cubic meter	m³	volume
cubic meter per kilogram	m³/kg	specific volume
degree Celsius	°C	Celsius temperature
farad	F	capacitance
farad per meter	F/m	permittivity
henry	Н	inductance
henry per meter	H/m	permeability
hertz	Hz	frequency
joule	J	energy, work, quantity of heat
joule per cubic meter	J/m <sup>3</sup>	energy density
joule per kelvin	J/K	heat capacity
joule per kilogram K	J/(kg∙K)	specific heat capacity
joule per mole	J/mol	molar energy
kelvin	K	thermodynamic temperature
kilogram	kg	mass
kilogram per cubic meter	kg/m³	density, mass density
lumen	lm	luminous flux
lux	lx	luminance

#### Table 2.1 Common Standard Units (continued)

Name	Symbol	Quantity
meter	m	length
meter per second	m/s	speed, velocity
meter per second sq.	m/s²	acceleration
mole	mol	amount of substance
newton	Ν	force
newton per meter	N/m	surface tension
ohm	Ω	electrical resistance
pascal	Pa	pressure, stress
pascal second	Pa•s	dynamic viscosity
radian	rad	plane angle
radian per second	rad/s	angular velocity
radian per second squared	rad/s <sup>2</sup>	angular acceleration
second	S	time
siemens	S	electrical conductance
square meter	m²	area
steradian	sr	solid angle
tesla	Т	magnetic flux density
volt	V	electrical potential
volt per meter	V/m	electric field strength
watt	W	power, radiant flux
watt per meter kelvin	W/(m•K)	thermal conductivity
watt per square meter	W/m <sup>2</sup>	heat (power) flux density
weber	Wb	magnetic flux

Table 2.2 Standard Pref	lixes
-------------------------	-------

Multiple	Prefix	Symbol	
10 <sup>18</sup>	еха	E	
10 <sup>15</sup>	peta	Р	
10 <sup>12</sup>	tera	Т	
10 <sup>9</sup>	giga	G	
10 <sup>6</sup>	mega	Μ	
10 <sup>3</sup>	kilo	k	
10 <sup>2</sup>	hecto	h	
10	deka	da	
10 <sup>-1</sup>	deci	d	
10 <sup>-2</sup>	centi	С	
10 <sup>-3</sup>	milli	m	
10 <sup>-6</sup>	micro	μ	
10 <sup>-9</sup>	nano	n	
10 <sup>-12</sup>	pico	р	
10 <sup>-15</sup>	femto	f	
10 <sup>-18</sup>	atto	а	

Table 2.3 Common Standard Units for Electrical Work

\_

Unit	Symbol
centimeter	cm
cubic centimeter	cm <sup>3</sup>
cubic meter per second	m³/s
gigahertz	GHz
gram	g
kilohertz	kHz
kilohm	kΩ
kilojoule	kJ
kilometer	km
kilovolt	kV
kilovoltampere	kVA
kilowatt	kW
megahertz	MHz
megavolt	MV
megawatt	MW
megohm	MΩ
microampere	μA
microfarad	μF
microgram	μg
microhenry	μH
microsecond	μs
microwatt	μW
milliampere	mA
milligram	mg
millihenry	mH
millimeter	mm
millisecond	ms
millivolt	mV
milliwatt	mW
nanoampere	nA
nanofarad	nF
nanometer	nm
nanosecond	ns
nanowatt	nW
picoampere	pА
picofarad	pF
picosecond	ps
picowatt	pW

Table 2.4 Names and Symbols for the SI Base Units (From [1]. Used Used with permission.)

Physical quantity	Name of SI unit	Symbol for SI unit
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	Α
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

**Table 2.5** Units in Use Together with the SI (These units are not part of the SI, but it is recognized that they will continue to be used in appropriate contexts. *From* [1]. *Used* with permission.)

Physical quantity	Name of unit	Symbol for unit	Value in SI units
time	minute	min	60 s
time	hour	h	3600 s
time	day	d	86 400 s
plane angle	degree	0	$(\pi/180)$ rad
plane angle	minute	/	$(\pi/10\ 800)\ rad$
plane angle	second	//	$(\pi/648\ 000)$ rad
length	ångstrom <sup>a</sup>	Å	$10^{-10}$ m
area	barn	b	$10^{-28} \text{ m}^2$
volume	litre	l, L	$dm^3 = 10^{-3}m^3$
mass	tonne	t	$Mg = 10^3 kg$
pressure	bar <sup>a</sup>	bar	$10^5 \text{ Pa} = 10^5 \text{ N m}^{-2}$
energy	electronvolt <sup>b</sup>	$eV (= e \times V)$	pprox 1.60218 $ imes$ 10 <sup>-19</sup> J
mass	unified atomic mass unit <sup>b, c</sup>	$u (= m_a ({}^{12}C)/12)$	$\approx 1.66054 \times 10^{-27}$ }

<sup>a</sup>The ångstrom and the bar are approved by CIPM for temporary use with SI units, until CIPM makes a further recommendation. However, they should not be introduced where they are not used at present.

<sup>b</sup>The values of these units in terms of the corresponding SI units are not exact, since they depend on the values of the physical constants e (for the electronvolt) and  $N_A$  (for the unified atomic mass unit), which are determined by experiment.

<sup>c</sup>The unified atomic mass unit is also sometimes called the dalton, with symbol Da, although the name and symbol have not been approved by CGPM.

Physical quantity	Name of SI unit	Symbol for SI unit	Expression in terms of SI base units
frequency <sup>a</sup>	hertz	Hz	s <sup>-1</sup>
force	newton	Ν	m kg s <sup>-2</sup>
pressure, stress	pascal	Pa	$N m^{-2} = m^{-1} kg s^{-2}$
energy, work, heat	joule	J	$N m = m^2 kg s^{-2}$
power, radiant flux	watt	W	$J s^{-1} = m^2 kg s^{-3}$
electric charge	coulomb	С	As
electric potential, electromotive force	volt	V	$J C^{-1} = m^2 kg s^{-3} A^{-1}$
electric resistance	ohm	Ω	$V A^{-1} = m^2 kg s^{-3} A^{-2}$
electric conductance	siemens	S	$\Omega^{-1} = m^{-2} kg^{-1} s^3 A^2$
electric capacitance	farad	F	$C V^{-1} = m^{-2} kg^{-1} s^4 A^2$
magnetic flux density	tesla	Т	$V s m^{-2} = kg s^{-2} A^{-1}$
magnetic flux	weber	Wb	$V s = m^2 kg s^{-2} A^{-1}$
inductance	henry	Н	$V A^{-1} s = m^2 kg s^{-2} A^{-2}$
Celsius temperature <sup>b</sup>	degree Celsius	°C	K
luminous flux	lumen	lm	cd sr
illuminance	lux	lx	cd sr m <sup>-2</sup>
activity (radioactive)	becquerel	Bq	s <sup>-1</sup>
absorbed dose (of radiation)	gray	Gy	$J kg^{-1} = m^2 s^{-2}$
dose equivalent (dose equivalent index)	sievert	Sv	$J kg^{-1} = m^2 s^{-2}$
plane angle	radian	rad	$1 = m m^{-1}$
solid angle	steradian	sr	$1 = m^2 m^{-2}$

Table 2.6 Derived Units with Special Names and Symbols (From [1]. Used with permission.)

<sup>a</sup>For radial (circular) frequency and for angular velocity the unit rad  $s^{-1}$ , or simply  $s^{-1}$ , should be used, and this may not be simplified to Hz. The unit Hz should be used only for frequency in the sense of cycles per second.

<sup>b</sup>The Celsius temperature  $\theta$  is defined by the equation:

#### $\theta/^{\circ}C = T/K - 273.15$

The SI unit of Celsius temperature interval is the degree Celsius,  $^{\circ}$ C, which is equal to the kelvin, K.  $^{\circ}$ C should be treated as a single symbol, with no space between the  $^{\circ}$  sign and the letter C. (The symbol  $^{\circ}$ K and the symbol  $^{\circ}$  should no longer be used.)

	Greek letter	Greek name	English equivalent		Greek letter	Greek name	English equivalent
Α	α	Alpha	a	N	ν	Nu	n
В	β	Beta	b	Ξ	ξ	Xi	х
Г	γ	Gamma	g	0	0	Omicron	ŏ
Δ	δ	Delta	d	П	π	Pi	р
Е	e	Epsilon	ĕ	Р	ρ	Rho	r
Z	ζ	Zeta	z	Σ	σς	Sigma	s
Н	η	Eta	ē	Т	τ	Tau	t
Θ	θθ	Theta	th	Υ	υ	Upsilon	u
I	ι	Iota	i	Φ	$\phi \phi$	Phi	ph
Κ	κ	Карра	k	Х	X	Chi	ch
Λ	λ	Lambda	1	Ψ	Ý	Psi	ps
М	μ	Mu	m	Ω	ω	Omega	ō

Table 2.7 The Greek Alphabet (From [1]. Used with permission.)

Table 2.8 Constants (From [1]. Used with permission.)

$\pi$ Constants									
$\pi = 3.1415$	9 26535	89793	23846 2	26433	83279	50288	41971	69399	37511
$1/\pi = 0.3183$	0 98861	83790	67153 7	77675	26745	02872	40689	19291	48091
$\pi^2 = 9.8690$	44010	89358	61883 4	44909	99876	15113	53136	99407	24079
$\log_e \pi = 1.1447$	2 98858	49400	17414 3	34273	51353	05871	16472	94812	91531
$\log_{10} \pi = 0.4971$	4 98726	94133	85435	12682	88290	89887	36516	78324	38044
$\log_{10}\sqrt{2}\pi = 0.3990$	8 99341	79057	52478 2	25035	91507	69595	02099	34102	92128
<b>Constants Involvir</b>	1g <i>e</i>								
e = 2.7	1828 182	84 59045	5 23536	02874	71352	66249	77572	47093	69996
1/e = 0.3	6787 944	11 71442	2 32159	55237	70161	46086	74458	11131	03177
$e^2 = 7.3$	8905 609	89 30650	) 22723	04274	60575	00781	31803	15570	55185
$M = \log_{10} e = 0.4$	3429 448	19 03251	82765	11289	18916	60508	22943	97005	80367
$1/M = \log_e 10 = 2.3$	0258 509	29 94045	68401	79914	54684	36420	76011	01488	62877
$\log_{10} M = 9.6$	3778 431	13 00536	5 78912	29674	98645	-10			
Numerical Constan	nts								
$\sqrt{2} = 1.41421$	35623 7	3095 04	880 16	887 2	4209	69807	85696	71875	37695
$\sqrt[3]{2} = 1.25992$	10498 9	4873 16	6476 72	106 0	7278	22835	05702	51464	70151
$\log_e 2 = 0.69314$	71805 5	9945 30	941 72	321 2	1458	17656	80755	00134	36026
$\log_{10} 2 = 0.30102$	99956 6	3981 19	521 37	388 9	4724	49302	67881	89881	46211
$\sqrt{3} = 1.73205$	08075 6	8877 29	352 74	463 4	1505	87236	69428	05253	81039
$\sqrt[3]{3} = 1.44224$	95703 0	7408 38	16 16	383 1	0780	10958	83918	69253	49935
$\log_e 3 = 1.09861$	22886 6	8109 69	139 52	452 3	6922	52570	46474	90557	82275
$\log_{10} 3 = 0.47712$	12547 1	9662 43	5729 50	279 0	3255	11530	92001	28864	19070

Whitaker, Jerry C. "Electromagnetic Spectrum" *The Resource Handbook of Electronics*. Ed. Jerry C. Whitaker Boca Raton: CRC Press LLC, ©2001

### Chapter

## 3

## **Electromagnetic Spectrum**

#### 3.1 Introduction

The usable spectrum of electromagnetic-radiation frequencies extends over a range from below 100 Hz for power distribution to 1020 for the shortest X-rays. The lower frequencies are used primarily for terrestrial broadcasting and communications. The higher frequencies include visible and near-visible infrared and ultraviolet light, and X-rays.

#### 3.1.1 Operating Frequency Bands

The standard frequency band designations are listed in Tables 3.1 and 3.2. Alternate and more detailed subdivision of the VHF, UHF, SHF, and EHF bands are given in Tables 3.3 and 3.4.

#### Low-End Spectrum Frequencies (1 to 1000 Hz)

Electric power is transmitted by wire but not by radiation at 50 and 60 Hz, and in some limited areas, at 25 Hz. Aircraft use 400-Hz power in order to reduce the weight of iron in generators and transformers. The restricted bandwidth that would be available for communication channels is generally inadequate for voice or data transmission, although some use has been made of communication over power distribution circuits using modulated carrier frequencies.

#### Low-End Radio Frequencies (1000 to 100 kHz)

These low frequencies are used for very long distance radio-telegraphic communication where extreme reliability is required and where high-power and long antennas can be erected. The primary bands of interest for radio communications are given in Table 3.5.

Table 3.1 Standardized Frequency Bands (From [1]. Used with permission.)

Extremely low-frequency (ELF) band:	30 Hz up to 300 Hz	(10 Mm down to 1 Mm)
Voice-frequency (VF) band:	300 Hz up to 3 kHz	(1 Mm down to 100 km)
Very low-frequency (VLF) band:	3 kHz up to 30 kHz	(100 km down to 10 km)
Low-frequency (LF) band:	30 kHz up to 300 kHz	(10 km down to 1 km)
Medium-frequency (MF) band:	300 kHz up to 3 MHz	(1 km down to 100 m)
High-frequency (HF) band:	3 MHz up to 30 MHz	(100 m down to 10 m)
Very high-frequency (VHF) band:	30 MHz up to 300 MHz	(10 m down to 1 m)
Ultra high-frequency (UHF) band:	300 MHz up to 3 GHz	(1 m down to 10 cm)
Super high-frequency (SHF) band:	3 GHz up to 30 GHz	(1 cm down to 1 cm)
Extremely high-frequency (EHF) band:	30 GHz up to 300 GHz	(1 cm down to 1 mm)

 Table 3.2 Standardized Frequency Bands at 1GHz and Above (From [1]. Used with permission.)

L band:	1 GHz up to 2 GHz	(30 cm down to 15 cm)
S band:	2 GHz up to 4 GHz	(15 cm down to 7.5 cm)
C band:	4 GHz up to 8 GHz	(7.5 cm down to 3.75 cm)
X band:	8 GHz up to 12 GHz	(3.75 cm down to 2.5 cm )
Ku band:	12 GHz up to 18 GHz	(2.5 cm down to 1.67 cm)
K band:	18 GHz up to 26.5 GHz	(1.67 cm down to 1.13 cm)
Ka band:	26.5 GHz up to 40 GHz	(1.13 cm down to 7.5 mm)
Q band:	32 GHz up to 50 GHz	(9.38 mm down to 6 mm)
U band:	40 GHz up to 60 GHz	(7.5 mm down to 5 mm)
V band:	50 GHz up to 75 GHz	(6 mm down to 4 mm)
W band:	75 GHz up to 100 GHz	(4 mm down to 3.33 mm)

#### Medium-Frequency Radio (20 kHz to 2 MHz)

The low-frequency portion of the band is used for around-the-clock communication services over moderately long distances and where adequate power is available to overcome the high level of atmospheric noise. The upper portion is used for AM radio, although the strong and quite variable *sky wave* occurring during the night results in substandard quality and severe fading at times. The greatest use is for AM broadcasting, in addition to fixed and mobile service, LORAN ship and aircraft navigation, and amateur radio communication.

#### High-Frequency Radio (2 to 30 MHz)

This band provides reliable medium-range coverage during daylight and, when the transmission path is in total darkness, worldwide long-distance service, although the

Table 3.3 Detailed Subdivision of the UHF, SHF, and EHF Bands (From [1]. Used with permission.)

L band:	1.12 GHz up to 1.7 GHz	(26.8 cm down to 17.6 cm)
LS band:	1.7 GHz up to 2.6 GHz	(17.6 cm down to 11.5 cm)
S band:	2.6 GHz up to 3.95 GHz	(11.5 cm down to 7.59 cm)
C(G) band:	3.95 GHz up to 5.85 GHz	(7.59 cm down to 5.13 cm)
XN(J, XC) band:	5.85 GHz up to 8.2 GHz	(5.13 cm down to 3.66 cm)
XB(H, BL) band:	7.05 GHz up to 10 GHz	(4.26 cm down to 3 cm)
X band:	8.2 GHz up to 12.4 GHz	(3.66 cm down to 2.42 cm)
Ku(P) band:	12.4 GHz up to 18 GHz	(2.42 cm down to 1.67 cm)
K band:	18 GHz up to 26.5 GHz	(1.67 cm down to 1.13 cm)
V(R, Ka) band:	26.5 GHz up to 40 GHz	(1.13 cm down to 7.5 mm)
Q(V) band:	33 GHz up to 50 GHz	(9.09 mm down to 6 mm)
M(W) band:	50 GHz up to 75 GHz	(6 mm down to 4 mm)
E(Y) band:	60 GHz up to 90 GHz	(5 mm down to 3.33 mm)
F(N) band:	90 GHz up to 140 GHz	(3.33 mm down to 2.14 mm)
G(A) band:	140 GHz up to 220 GHz	(2.14 mm down to 1.36 mm)
R band:	220 GHz up to 325 GHz	(1.36 mm down to 0.923 mm)

Table 3.4 Subdivision of the VHF, UHF, SHF Lower Part of the EHF Band (From [1]. Used with permission.)

A band:	100 MHz up to 250 MHz	(3 m down to 1.2 m)
B band:	250 MHz up to 500 MHz	(1.2 m down to 60 cm)
C band:	500 MHz up to 1 GHz	(60 cm down to 30 cm)
D band:	1 GHz up to 2 GHz	(30 cm down to 15 cm)
E band:	2 GHz up to 3 GHz	(15 cm down to 10 cm)
F band:	3 GHz up to 4 GHz	(10 cm down to 7.5 cm)
G band:	4 GHz up to 6 GHz	(7.5 cm down to 5 cm)
H band:	6 GHz up to 8 GHz	(5 cm down to 3.75 cm)
I band:	8 GHz up to 10 GHz	(3.75 cm down to 3 cm)
J band:	10 GHz up to 20 GHz	(3 cm down to 1.5 cm)
K band:	20 GHz up to 40 GHz	(1.5 cm down to 7.5 mm)
L band:	40 GHz up to 60 GHz	(7.5 mm down to 5 mm)
M band:	60 GHz up to 100 GHz	(5 mm down to 3 mm)

reliability and signal quality of the latter is dependent to a large degree upon ionospheric conditions and related long-term variations in sun-spot activity affecting sky-wave propagation. The primary applications include broadcasting, fixed and mobile services, telemetering, and amateur transmissions.

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Table 3.5 Radio Frequency Bands (From [1]. Used with permission.)

#### Very High and Ultrahigh Frequencies (30 MHz to 3 GHz)

VHF and UHF bands, because of the greater channel bandwidth possible, can provide transmission of a large amount of information, either as television detail or data communication. Furthermore, the shorter wavelengths permit the use of highly directional parabolic or multielement antennas. Reliable long-distance communication is provided using high-power *tropospheric scatter* techniques. The multitude of uses include, in addition to television, fixed and mobile communication services, amateur radio, radio astronomy, satellite communication, telemetering, and radar.

#### Microwaves (3 to 300 GHz)

At these frequencies, many transmission characteristics are similar to those used for shorter optical waves, which limit the distances covered to line of sight. Typical uses include television relay, satellite, radar, and wide-band information services. (See Tables 3.6 and 3.7.)

#### Infrared, Visible, and Ultraviolet Light

The portion of the spectrum visible to the eye covers the gamut of transmitted colors ranging from red, through yellow, green, cyan, and blue. It is bracketed by infrared on the low-frequency side and ultraviolet (UV) on the high side. Infrared signals are used in a variety of consumer and industrial equipments for remote controls and sensor circuits in security systems. The most common use of UV waves is for excitation of phosphors to produce visible illumination.

#### X-Rays

Medical and biological examination techniques and industrial and security inspection systems are the best-known applications of X-rays. X-rays in the higher-frequency range are classified as *hard X-rays* or *gamma rays*. Exposure to X-rays for long periods can result in serious irreversible damage to living cells or organisms.

 Table 3.6 Applications in the Microwave Bands (From [1]. Used with permission.)

Antmongetion0.30Global positioning system (GPS) down link:1.35–1.40 GHzMilitary communications (COM)/radar:1.35–1.40 GHzMiscellaneous COM/radar:1.40–1.71 GHzL-band telemetry:1.435–1.535 GHzGPS downlink:1.57 GHzMilitary COM (troposcatter/telemetry):1.71–1.85 GHzCommercial COM and private line of sight (LOS):1.85–2.20 GHzMicroware ovens:2.45 GHzCommercial COM/radar:2.50–2.69 GHzInstructional television:2.70–2.90 GHzMilitary radar (airport surveillance):2.70–2.90 GHzMiritime navigation radar:2.90–3.10 GHzMiscellaneous radars:2.90–3.70 GHzCommercial C-band satellite (SAT) COM downlink:3.70–4.20 GHzMilitary COM (troposcatter):4.40–4.99 GHzCommercial C-band satellite (SAT) COM downlink:5.25–5.92 GHzMiscellaneous radars:5.25–5.92 GHzCommercial C-band SAT COM uplink:5.25–5.92 GHzCommercial C-band SAT COM uplink:5.925–6.425 GHzCommercial C-band SAT COM uplink:7.125–7.25 GHzMilitary LOS COM:7.125–7.25 GHzMilitary LOS COM:7.25–7.75 GHzMilitary SAT COM downlink:7.90–9.20 GHzMilitary SAT COM uplink:7.90–9.20 GHzMilitary SAT COM downlink:7.90–9.20 GHzMilitary SAT COM downlink:7.90–9.20 GHzMilitary SAT COM uplink:7.90–9.20 GHzMilitary SAT COM downlink:7.90–9.20 GHzMilitary SAT COM downlink:7.90–9.20 GHzMilitary COM	Aeronavigation	0.96_1.215 GHz
Military communications (COM)/radar:       1.32-1.40 ft/z         Miscellaneous COM/radar:       1.40-1.71 GHz         L-band telemetry:       1.435-1.35 GHz         GPS downlink:       1.57 GHz         Military COM (troposcatter/telemetry):       1.71-1.85 GHz         Commercial COM and private line of sight (LOS):       1.85-2.20 GHz         Microwave ovens:       2.45 CHz         Commercial COM/radar:       2.45-2.69 GHz         Instructional television:       2.00-3.10 GHz         Miscellaneous radars:       2.90-3.10 GHz         Commercial C-band satellite (SAT) COM downlink:       3.70-4.20 GHz         Miscellaneous radars:       2.90-3.70 GHz         Commercial C-band satellite (SAT) COM downlink:       3.70-4.20 GHz         Miltary COM (troposcatter):       4.40-4.99 GHz         Commercial C-band satellite (SAT) COM downlink:       5.00-5.25 GHz         Miscellaneous radars:       5.25-5.925 GHz         Commercial C-band SAT COM uplink:       6.425-7.125 GHz         Mobile television links:       6.425-7.125 GHz         Mobile television links:       6.425-7.125 GHz         Military LOS COM:       7.125-7.25 GHz         Military SAT COM downlink:       7.25-7.75 GHz         Military SAT COM downlink:       7.00-9.90 GHz	Global positioning system (GPS) down link:	1 2276 GHz
Miscellaneous COM/radar:       1.40–1.71 GHz         L-band telemetry:       1.435–1.535 GHz         GPS downlink:       1.57 GHz         Military COM (troposcatter/telemetry):       1.71–1.85 GHz         Commercial COM and private line of sight (LOS):       1.85–2.20 GHz         Microwave ovens:       2.45 GHz         Commercial COM/radar:       2.45–2.69 GHz         Instructional television:       2.70–2.90 GHz         Military radar (airport surveillance):       2.70–2.90 GHz         Commercial C-band satellite (SAT) COM downlink:       3.70–4.20 GHz         Radar altimeter:       4.20–4.40 GHz         Military radars:       5.00–5.25 GHz         Commercial C-band satellite (SAT) COM downlink:       5.05–5.29 GHz         Miscellaneous radars:       5.25–5.29 CHz         Commercial C-band SAT COM uplink:       5.925–6.425 GHz         Commercial C-band SAT COM uplink:       6.875–7.125 GHz         Military IOS COM:       7.125–7.75 GHz         Military SAT COM downlink:       7.25–7.75 GHz         Military SAT COM downlink:       7.90–5.25 GHz         Military SAT COM uplink:       7.90–7.20 GHz         Military SAT COM uplink:       7.95–7.75 GHz         Military SAT COM uplink:       7.90–7.90 GHz         Military SAT COM	Military communications (COM)/radar:	1 35–1 40 GHz
L-band telemetry:1.435–1.535 GHzGPS downlink:1.57 GHzMilitary COM (troposcatter/telemetry):1.71–1.85 GHzCommercial COM and private line of sight (LOS):1.85–2.20 GHzMicrowave ovens:2.45 GHzCommercial COM/radar:2.50–2.69 GHzInstructional television:2.50–2.09 GHzMilitary radar (airport surveillance):2.70–2.90 GHzMiritime navigation radar:2.90–3.10 GHzMiscellaneous radars:2.90–3.70 GHzCommercial C-band satellite (SAT) COM downlink:3.70–4.20 GHzRadar altimeter:4.20–4.00 GHzMilitary COM (troposcatter):4.40–4.99 GHzCommercial C-band SAT COM uplink:5.25–5.925 GHzCommercial C-band SAT COM uplink:5.25–5.925 GHzCommercial C-band SAT COM uplink:5.925–6.425 GHzCommercial COM:6.425–7.125 GHzMilitary LOS COM:7.125–7.75 GHzMilitary SAT COM downlink:7.05–7.9 GHzMilitary SAT COM uplink:7.05–7.9 GHzMilitary SAT COM uplink:9.00–9.20 GHzX-band weather radar:8.00–10.55 GHzMilitary SAT COM uplink:7.05–7.9 GHzMilitary SAT COM uplink:10.70–11.20 GHzCommercial COM:10.70–11.20 GHzCommercial COM:10.70–11.20 GHzVaband weather radar (and maritime navigation radar):9.30–9.50 GHzPolice radar:10.70–13.25 GHzCommercial Mubile COM [LOS and electronic news gathering (ENG)]:10.50–11.70 GHzCommercial COM:10.70–13.25 GHzCommercial COM: <td>Miscellaneous COM/radar:</td> <td>1.40–1.71 GHz</td>	Miscellaneous COM/radar:	1.40–1.71 GHz
GPS downlink:       1.57 GHz         Military COM (troposcatter/telemetry):       1.71–1.85 GHz         Commercial COM and private line of sight (LOS):       1.85–2.20 GHz         Microwave ovens:       2.45 GHz         Commercial COM/radar:       2.45–2.69 GHz         Instructional television:       2.00–3.10 GHz         Microwave ovens:       2.90–3.10 GHz         Miritime navigation radar:       2.90–3.10 GHz         Miscellaneous radars:       2.90–3.70 GHz         Commercial C-band satellite (SAT) COM downlink:       3.70–4.20 GHz         Radar altimeter:       4.20–4.40 GHz         Miscellaneous radars:       5.25–5.925 GHz         Commercial C-band satellite (SAT) COM downlink:       5.25–5.925 GHz         Miscellaneous radars:       5.25–5.925 GHz         Commercial C-band SAT COM uplink:       5.925–6.425 GHz         Commercial C-band SAT COM uplink:       5.925–6.425 GHz         Commercial COM:       6.425–7.125 GHz         Military LOS COM:       7.125–7.25 GHz         Military LOS COM:       7.125–7.25 GHz         Military SAT COM downlink:       7.90–8.40 GHz         Military SAT COM uplink:       7.90–7.125 GHz         Military SAT COM uplink:       7.90–7.75 GHz         Military SAT COM uplink:       7	L-band telemetry:	1.435-1.535 GHz
Military COM (troposcatter/telemetry):1.71–1.85 GHzCommercial COM and private line of sight (LOS):1.85–2.20 GHzMicrowave ovens:2.45 GHzCommercial COM/radar:2.50–2.69 GHzInstructional television:2.70–2.90 GHzMilitary radar (airport surveillance):2.70–2.90 GHzMiritime navigation radar:2.90–3.10 GHzCommercial C-band satellite (SAT) COM downlink:3.70–4.20 GHzRadar altimeter:4.20–4.40 GHzMilitary COM (troposcatter):4.40–4.99 GHzCommercial microwave landing system:5.00–5.25 GHzCommercial C-band SAT COM uplink:5.25–5.925 GHzCommercial C-band SAT COM uplink:5.35–5.47 GHzCommercial C-band SAT COM uplink:6.875–7.125 GHzMilitary LOS COM:7.125–7.25 GHzMilitary SAT COM downlink:7.25–7.25 GHzMilitary SAT COM downlink:7.25–7.25 GHzMilitary SAT COM uplink:7.90–8.40 GHzMilitary SAT COM uplink:7.90–9.20 GHzVahan wather radar:9.00–9.20 GHzVahan wather radar (and maritime navigation radar):9.09–9.20 GHzVahan wather radar (and maritime navigation radar):9.00–9.20 GHzVahan wather radar (and maritime navigation radar):10.525 GHzCommercial COM:10.70–11.20 GHzCommercial Mubile COM [LOS and electronic news gathering (ENG)]:10.52–10.68 GHzCommercial Mubile COM [LOS and electronic news gathering (ENG)]:10.52–10.82 GHzCommercial COM:11.70–11.20 GHzCommercial Ru-band SAT COM downlink:11.70–11.20 GHz </td <td>GPS downlink:</td> <td>1.57 GHz</td>	GPS downlink:	1.57 GHz
Commercial COM and private line of sight (LOS):1.85–2.20 GHzMicrowave ovens:2.45 GHzCommercial COM/radar:2.45–2.69 GHzInstructional television:2.50–2.69 GHzMilitary radar (airport surveillance):2.70–2.90 GHzMaritime navigation radar:2.90–3.10 GHzMiscellaneous radars:2.90–3.70 GHzCommercial C-band satellite (SAT) COM downlink:3.70–4.20 GHzRadar altimeter:4.20–4.40 GHzMilitary COM (troposcatter):4.40–4.99 GHzCommercial microwave landing system:5.00–5.25 GHzCommercial microwave landing system:5.25–5.925 GHzCommercial C-band SAT COM uplink:5.925–6.425 GHzCommercial COM:6.425–7.125 GHzMilitary LOS COM:7.125–7.25 GHzMilitary SAT COM downlink:7.25–7.75 GHzMilitary SAT COM downlink:7.90–8.40 GHzMilitary SAT COM uplink:7.90–8.40 GHzMilitary SAT COM uplink:10.525 GHzCommercial mobile COM [LOS and electronic news gathering (ENG)]:10.55–10.68 GHzOntorecial mobile COM [LOS and electronic news gathering (ENG)]:10.55–10.68 GHzCommercial Mobile COM [LOS and electronic news gathering (ENG)]:10.70–11.20 GHzCommercial Ku-band SAT COM downlink:11.70–11.20 GHzCommercial Ku-band SAT COM downlink:11.70–12.20 GHzCommercial Ku-band S	Military COM (troposcatter/telemetry):	1.71–1.85 GHz
Microwave ovens:2.45 GHzCommercial COM/radar:2.45 GHzInstructional television:2.50-2.69 GHzMilitary radar (airport surveillance):2.70-2.90 GHzMaritime navigation radar:2.90-3.10 GHzMiscellaneous radars:2.90-3.70 GHzCommercial C-band satellite (SAT) COM downlink:3.70-4.20 GHzRadar altimeter:4.20-4.40 GHzMilitary COM (troposcatter):4.40-4.99 GHzCommercial microwave landing system:5.00-5.25 GHzMiscellaneous radars:5.25-5.925 GHzC-band weather radar:5.35-5.47 GHzCommercial C-band SAT COM uplink:5.925-6.425 GHzCommercial COM:6.425-7.125 GHzMilitary LOS COM:7.125-7.25 GHzMilitary SAT COM downlink:7.25-7.75 GHzMilitary SAT COM uplink:7.90-8.40 GHzMilitary SAT COM uplink:9.30-9.50 GHzPrecision approach radar:9.00-9.20 GHzVabard weather radar (and maritime navigation radar):9.30-9.50 GHzPolice radar:10.52 GHzCommercial Mobile COM [LOS and electronic news gathering (ENG)]:10.55-10.68 GHzCommercial Ru-band SAT COM downlink:11.70-11.20 GHzCommercial Ku-band SAT COM downlink:12.20-12.70 GHzCommercial Ku-band SAT COM downlink:12.20-12.70 GHzCommercial Ku-band SAT COM downlink:12.20-12.70 GHzDirect broadcast satellite (DBS) downlink and private LOS COM:12.20-12.70 GHzCommercial Ku-band SAT COM uplink:14.00-14.50 GHzMiscellaneous radars and SAT COM:13.25-14.00	Commercial COM and private line of sight (LOS):	1.85–2.20 GHz
Commercial COM/radar:2.45–2.69 GHzInstructional television:2.50–2.69 GHzMilitary radar (airport surveillance):2.70–2.90 GHzMaritime navigation radar:2.90–3.10 GHzCommercial C-band satellite (SAT) COM downlink:3.70–4.20 GHzCommercial C-band satellite (SAT) COM downlink:3.70–4.20 GHzMiscellaneous radars:2.90–3.70 GHzCommercial c-band satellite (SAT) COM downlink:3.70–4.20 GHzMiscellaneous radars:4.40–4.99 GHzCommercial microwave landing system:5.05–5.925 GHzCommercial microwave landing system:5.35–5.47 GHzCommercial C-band SAT COM uplink:5.925–6.425 GHzCommercial COM:6.425–7.125 GHzMilitary LOS COM:7.15–7.25 GHzMilitary LOS COM:7.5–7.5 GHzMilitary SAT COM downlink:7.25–7.5 GHzMilitary SAT COM uplink:7.90–8.40 GHzMilitary SAT COM uplink:9.30–9.50 GHzPrecision approach radar:9.30–9.50 GHzPolice radar:10.70–11.70 GHzCommercial COM:10.70–11.70 GHzCommercial COM:10.70–11.70 GHzCommercial COM:10.70–11.70 GHzCommercial COM:12.20–12.70 GHzCommercial COM:12.20–12.70 GHzCommercial Ku-band SAT COM downlink:12.75–13.25 GHzCommercial Ku-band SAT COM downlink:10.70–11.70 GHzCommercial Ku-band SAT COM downlink:12.75–13.25 GHzCommercial Ku-band SAT COM downlink:12.75–13.25 GHzCommercial Ku-band SAT COM downlink:12.75–13.25 GHz	Microwave ovens:	2.45 GHz
Instructional television:2.50–2.69 GHzMilitary radar (airport surveillance):2.70–2.90 GHzMaritime navigation radar:2.90–3.10 GHzMiscellaneous radars:2.90–3.70 GHzCommercial C-band satellite (SAT) COM downlink:3.70–4.20 GHzRadar altimeter:4.20–4.40 GHzMilitary COM (troposcatter):4.40–4.99 GHzCommercial microwave landing system:5.00–5.25 GHzMiscellaneous radars:5.25–5.925 GHzC-band weather radar:5.35–5.47 GHzCommercial C-band SAT COM uplink:6.425–7.125 GHzMobile television links:6.425–7.125 GHzMilitary LOS COM:7.125–7.25 GHzMilitary SAT COM downlink:7.25–7.75 GHzMilitary SAT COM downlink:7.25–7.75 GHzMilitary SAT COM uplink:9.00–9.20 GHzMiscellaneous radars:9.00–9.20 GHzV-band weather radar:9.00–9.20 GHzMilitary SAT COM uplink:9.00–9.20 GHzMiscellaneous radars:9.00–9.20 GHzV-band weather radar (and maritime navigation radar):9.30–9.50 GHzPrecision approach radar:9.30–9.50 GHzPolice radar:10.70–11.70 GHzCommercial COM:10.70–11.20 GHzCommercial COM:10.70–11.20 GHzCommercial COM:10.70–11.20 GHzCommercial COM:12.20-12.70 GHzCommercial COM:12.20-12.70 GHzCommercial COM:12.20-12.70 GHzCommercial Ku-band SAT COM downlink: and private LOS COM:12.20-12.70 GHzENG and LOS COM:12.25–14.00 GHz <trt< td=""><td>Commercial COM/radar:</td><td>2.45–2.69 GHz</td></trt<>	Commercial COM/radar:	2.45–2.69 GHz
Military radar (airport surveillance):2.70–2.90 GHzMaritime navigation radar:2.90–3.10 GHzMiscellaneous radars:2.90–3.70 GHzCommercial C-band satellite (SAT) COM downlink:3.70–4.20 GHzRadar altimeter:4.20–4.40 GHzMilitary COM (troposcatter):4.40–4.99 GHzCommercial microwave landing system:5.00–5.25 GHzCommercial microwave landing system:5.25–5.925 GHzCommercial C-band SAT COM uplink:5.25–5.925 GHzCommercial C-band SAT COM uplink:5.925–6.425 GHzCommercial COM:6.425–7.125 GHzMobile television links:6.875–7.125 GHzMilitary LOS COM:7.25–7.75 GHzMilitary LOS COM:7.25–7.75 GHzMilitary SAT COM uplink:7.90–8.40 GHzMilitary SAT COM uplink:7.90–8.40 GHzMilitary SAT COM uplink:9.00–9.20 GHzVahad weather radar:9.00–9.20 GHzVahad weather radar:9.00–9.20 GHzVahad weather radar (and maritime navigation radar):9.30–9.50 GHzPolice radar:10.70–11.70 GHzCommercial COM:10.70–11.70 GHzCommercial COM:10.70–11.22 GHzCommercial COM:10.70–11.22 GHzDirect broadcast satellite (DBS) downlink: and private LOS COM:10.70–11.20 GHzCommercial Ku-band SAT COM uplink:11.70–12.20 GHzCommercial Ku-band SAT COM uplink:11.70–12.20 GHzCommercial Ku-band SAT COM uplink:12.75–13.25 GHzCommercial Ku-band SAT COM uplink:13.25–14.00 GHzMilitary COM (LOS, mobile, and Tacti	Instructional television:	2.50–2.69 GHz
Maritime navigation radar:       2.90–3.10 GHz         Miscellaneous radars:       2.90–3.70 GHz         Commercial C-band satellite (SAT) COM downlink:       3.70–4.20 GHz         Radar altimeter:       4.20–4.40 GHz         Military COM (troposcatter):       4.40–4.99 GHz         Commercial microwave landing system:       5.00–5.25 GHz         Miscellaneous radars:       5.25–5.925 GHz         C-band weather radar:       5.35–5.47 GHz         Commercial C-band SAT COM uplink:       5.925–6.425 GHz         Commercial COM:       6.425–7.125 GHz         Mobile television links:       6.875–7.125 GHz         Military LOS COM:       7.125–7.25 GHz         Military LOS COM:       7.25–7.75 GHz         Military LOS COM:       7.75–7.9 GHz         Military SAT COM uplink:       7.90–8.40 GHz         Miscellaneous radars:       8.50–10.55 GHz         Precision approach radar:       9.00–9.20 GHz         X-band weather radar (and maritime navigation radar):       9.30–9.50 GHz         Police radar:       10.525 GHz         Commercial COM:       10.70–11.20 GHz         Commercial Mubile COM [LOS and electronic news gathering (ENG]]:       10.55–10.68 GHz         Commercial COM:       10.70–13.25 GHz         Commercial Ku-band SAT COM<	Military radar (airport surveillance):	2.70–2.90 GHz
Miscellaneous radars:       2.90–3.70 GHz         Commercial C-band satellite (SAT) COM downlink:       3.70–4.20 GHz         Radar altimeter:       4.20–4.40 GHz         Military COM (troposcatter):       4.40–4.99 GHz         Commercial microwave landing system:       5.00–5.25 GHz         Miscellaneous radars:       5.25–5.925 GHz         C-band weather radar:       5.35–5.47 GHz         Commercial C-band SAT COM uplink:       5.925–6.425 GHz         Commercial COM:       6.425–7.125 GHz         Mobile television links:       6.875–7.125 GHz         Military LOS COM:       7.125–7.25 GHz         Military LOS COM:       7.25–7.75 GHz         Military SAT COM downlink:       7.90–8.40 GHz         Military SAT COM uplink:       1.05–10.68 GHz         Va-band weather radar (and maritime navigation radar):       9.30–9.50 GHz         Police radar:       10.525 GHz         Commercial Mobile COM [LOS and electronic news gathering (ENG)]:       10.55–10.68 GHz         Commercial Mobile COM [LOS and electronic news gathering (ENG)]:       10.55–10.68 GHz         Commercial COM:       10.70–11.70 GHz </td <td>Maritime navigation radar:</td> <td>2.90–3.10 GHz</td>	Maritime navigation radar:	2.90–3.10 GHz
Commercial C-band satellite (SAT) COM downlink:3.70–4.20 GHzRadar altimeter:4.20–4.40 GHzMilitary COM (troposcatter):4.40–4.99 GHzCommercial microwave landing system:5.00–5.25 GHzCommercial microwave landing system:5.00–5.25 GHzCommercial cows radars:5.25–5.925 GHzCommercial C-band SAT COM uplink:5.925–6.425 GHzCommercial COM:6.425–7.125 GHzMobile television links:6.875–7.125 GHzMilitary LOS COM:7.125–7.25 GHzMilitary LOS COM:7.25–7.75 GHzMilitary SAT COM downlink:7.90–8.40 GHzMilitary SAT COM uplink:9.00–9.20 GHzMilitary SAT COM uplink:9.00–9.20 GHzV-band weather radar:9.00–9.20 GHzV-band weather radar (and maritime navigation radar):9.30–9.50 GHzPolice radar:10.525 GHzCommercial mobile COM [LOS and electronic news gathering (ENG)]:10.55–10.68 GHzCommercial Mobile COM [LOS and electronic news gathering (ENG)]:10.55–10.68 GHzCommercial COM:11.70–12.20 GHzCommercial COM:12.75–13.25 GHzMiscellaneous radars and SAT COM:12.20–12.70 GHzDirect broadcast satellite (DBS) downlink and private LOS COM:12.25–14.00 GHzMiscellaneous radars and SAT COM:13.25–14.00 GHzMiscellaneous radars and SAT COM:13.25–14.00 GHzMiscellaneous radars and SAT COM:14.50–15.35 GHzMiscellaneous radars and SAT COM:14.50–15.35 GHzMiscellaneous radars and SAT COM:13.25–14.00 GHzMilitary COM	Miscellaneous radars:	2.90–3.70 GHz
Radar altimeter:       4.20–4.40 GHz         Military COM (troposcatter):       4.40–4.99 GHz         Commercial microwave landing system:       5.00–5.25 GHz         Miscellaneous radars:       5.25–5.925 GHz         C-band weather radar:       5.35–5.47 GHz         Commercial C-band SAT COM uplink:       5.925–6.425 GHz         Commercial COM:       6.425–7.125 GHz         Mobile television links:       6.875–7.125 GHz         Military LOS COM:       7.125–7.25 GHz         Military SAT COM downlink:       7.25–7.75 GHz         Military SAT COM uplink:       7.90–8.40 GHz         Military SAT COM uplink:       7.90–8.40 GHz         Military SAT COM uplink:       9.00–9.20 GHz         Military SAT COM uplink:       9.00–9.20 GHz         Miscellaneous radars:       9.00–9.20 GHz         V-band weather radar (and maritime navigation radar):       9.30–9.50 GHz         Police radar:       10.525 GHz         Commercial Mobile COM [LOS and electronic news gathering (ENG)]:       10.55–10.68 GHz         Commercial Ku-band SAT COM downlink:       10.70–11.20 GHz         Direct broadcast satellite (DBS) downlink and private LOS COM:       12.20–12.70 GHz         Commercial Ku-band SAT COM:       12.25–13.25 GHz         Miscellaneous radars and SAT COM:	Commercial C-band satellite (SAT) COM downlink:	3.70–4.20 GHz
Military COM (troposcatter):       4.40–4.99 GHz         Commercial microwave landing system:       5.00–5.25 GHz         Miscellaneous radars:       5.25–5.925 GHz         C-band weather radar:       5.35–5.47 GHz         Commercial C-band SAT COM uplink:       5.925–6.425 GHz         Commercial COM:       6.425–7.125 GHz         Mobile television links:       6.875–7.125 GHz         Military LOS COM:       7.125–7.25 GHz         Military SAT COM downlink:       7.25–7.75 GHz         Military SAT COM uplink:       7.90–8.40 GHz         Military SAT COM uplink:       7.90–8.40 GHz         Miscellaneous radars:       8.50–10.55 GHz         Military SAT COM uplink:       9.00–9.20 GHz         Miscellaneous radars:       9.00–9.20 GHz         V-band weather radar (and maritime navigation radar):       9.30–9.50 GHz         Precision approach radar:       10.525 GHz         Commercial mobile COM [LOS and electronic news gathering (ENG)]:       10.55–10.68 GHz         Commercial COM:       10.70–11.20 GHz         Direct broadcast satellite (DBS) downlink: and private LOS COM:       12.20–12.70 GHz         Direct broadcast satellite (DBS) downlink: and private LOS COM:       12.20–12.70 GHz         Miscellaneous radars and SAT COM:       13.25–14.00 GHz         Misc	Radar altimeter:	4.20-4.40 GHz
Commercial microwave landing system:       5.00–5.25 GHz         Miscellaneous radars:       5.25–5.925 GHz         C-band weather radar:       5.35–5.47 GHz         Commercial C-band SAT COM uplink:       5.925–6.425 GHz         Commercial COM:       6.425–7.125 GHz         Mobile television links:       6.875–7.125 GHz         Military LOS COM:       7.125–7.25 GHz         Military SAT COM downlink:       7.25–7.75 GHz         Military SAT COM uplink:       7.90–8.40 GHz         Military SAT COM uplink:       7.90–8.40 GHz         Military SAT COM uplink:       7.90–8.40 GHz         Military SAT COM uplink:       9.00–9.20 GHz         Miscellaneous radars:       9.00–9.20 GHz         Vaband weather radar (and maritime navigation radar):       9.30–9.50 GHz         Precision approach radar:       10.525 GHz         Commercial Mobile COM [LOS and electronic news gathering (ENG]):       10.55–10.68 GHz         Commercial COM:       10.70–11.20 GHz         Commercial COM:       10.70–13.25 GHz         Commercial Ku-band SAT COM downlink:       11.70–12.20 GHz         Direct broadcast satellite (DBS) downlink and private LOS COM:       12.27–13.25 GHz         Commercial Ku-band SAT COM:       13.25–14.00 GHz         ENG and LOS COM:       13.25–14.00 GHz	Military COM (troposcatter):	4.40–4.99 GHz
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C-band weather radar:5.35–5.47 GHzCommercial C-band SAT COM uplink:5.925–6.425 GHzCommercial COM:6.425–7.125 GHzMobile television links:6.875–7.125 GHzMilitary LOS COM:7.125–7.25 GHzMilitary LOS COM:7.25–7.75 GHzMilitary LOS COM:7.75–7.9 GHzMilitary LOS COM:7.90–8.40 GHzMiscellaneous radars:8.50–10.55 GHzPrecision approach radar:9.00–9.20 GHzX-band weather radar (and maritime navigation radar):9.30–9.50 GHzPolice radar:10.525 GHzCommercial mobile COM [LOS and electronic news gathering (ENG)]:10.55–10.68 GHzCommercial COM:10.70–11.70 GHzCommercial Ku-band SAT COM downlink:11.70–12.20 GHzDirect broadcast satellite (DBS) downlink and private LOS COM:12.20–12.70 GHzENG and LOS COM:13.25–14.00 GHzMiscellaneous radars and SAT COM:13.25–14.00 GHzMiscellaneous radars and SAT COM:13.25–14.00 GHzMiscellaneous radars and SAT COM uplink:14.00–14.50 GHzMiscellaneous radars and SAT COM:13.25–14.00 GHzMiscellaneous radars and SAT COM:14.50–15.35 GHzMiscellaneous radars and SAT COM:14.50–15.35 GHzMilitary COM (LOS, mobile, and Tactical):14.50–15.35 GHzAeronavigation:15.40–15.70 GHzMilitary COM (LOS, mobile, and Tactical):15.70–17.70 GHzMiscellaneous radars:15.70–17.70 GHzMiscellaneous radars:15.70–17.70 GHzMiscellaneous radars:15.70–17.70 GHzM	Miscellaneous radars:	5.25–5.925 GHz
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Commercial COM:6.425-7.125 GHzMobile television links:6.875-7.125 GHzMilitary LOS COM:7.125-7.25 GHzMilitary SAT COM downlink:7.25-7.75 GHzMilitary LOS COM:7.75-7.9 GHzMilitary SAT COM uplink:7.90-8.40 GHzMiscellaneous radars:8.50-10.55 GHzPrecision approach radar:9.00-9.20 GHzV-band weather radar (and maritime navigation radar):9.30-9.50 GHzPolice radar:10.525 GHzCommercial mobile COM [LOS and electronic news gathering (ENG)]:10.55-10.68 GHzCommercial COM:10.70-11.70 GHzCommercial Ku-band SAT COM downlink:11.70-12.20 GHzDirect broadcast satellite (DBS) downlink and private LOS COM:12.20-12.70 GHzMiscellaneous radars and SAT COM:13.25-14.00 GHzMiscellaneous radars and SAT COM uplink:14.00-14.50 GHzMilitary COM (LOS, mobile, and Tactical):14.50-15.35 GHzAeronavigation:15.40-15.70 GHzMiscellaneous radars:15.70-17.70 GHz	Commercial C-band SAT COM uplink:	5.925–6.425 GHz
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Military SAT COM uplink:7.90–8.40 GHzMiscellaneous radars:8.50–10.55 GHzPrecision approach radar:9.00–9.20 GHzX-band weather radar (and maritime navigation radar):9.30–9.50 GHzPolice radar:10.525 GHzCommercial mobile COM [LOS and electronic news gathering (ENG)]:10.55–10.68 GHzCommercial COM:10.70–11.70 GHzCommercial COM:10.70–13.25 GHzCommercial Ku-band SAT COM downlink:11.70–12.20 GHzDirect broadcast satellite (DBS) downlink and private LOS COM:12.20–12.70 GHzENG and LOS COM:13.25–14.00 GHzMiscellaneous radars and SAT COM uplink:14.00–14.50 GHzMilitary COM (LOS, mobile, and Tactical):14.50–15.35 GHzAeronavigation:15.40–15.70 GHzMiscellaneous radars:15.70–17.70 GHzMiscellaneous radars:15.70–17.70 GHzDBS uplink:17.30–17.80 GHz	Military LOS COM:	7.75–7.9 GHz
Miscellaneous radars:8.50–10.55 GHzPrecision approach radar:9.00–9.20 GHzX-band weather radar (and maritime navigation radar):9.30–9.50 GHzPolice radar:10.525 GHzCommercial mobile COM [LOS and electronic news gathering (ENG)]:10.55–10.68 GHzCommon carrier LOS COM:10.70–11.70 GHzCommercial COM:10.70–13.25 GHzCommercial Ku-band SAT COM downlink:11.70–12.20 GHzDirect broadcast satellite (DBS) downlink and private LOS COM:12.20–12.70 GHzENG and LOS COM:13.25–14.00 GHzMiscellaneous radars and SAT COM uplink:14.00–14.50 GHzMilitary COM (LOS, mobile, and Tactical):14.50–15.35 GHzAeronavigation:15.40–15.70 GHzMiscellaneous radars:15.70–17.70 GHzDBS uplink:17.30–17.80 GHz	Military SAT COM uplink:	7.90-8.40 GHz
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X-band weather radar (and maritime navigation radar):9.30–9.50 GHzPolice radar:10.525 GHzCommercial mobile COM [LOS and electronic news gathering (ENG)]:10.55–10.68 GHzCommon carrier LOS COM:10.70–11.70 GHzCommercial COM:10.70–13.25 GHzCommercial Ku-band SAT COM downlink:11.70–12.20 GHzDirect broadcast satellite (DBS) downlink and private LOS COM:12.20–12.70 GHzENG and LOS COM:12.75–13.25 GHzMiscellaneous radars and SAT COM uplink:14.00–14.50 GHzMilitary COM (LOS, mobile, and Tactical):14.50–15.35 GHzAeronavigation:15.40–15.70 GHzMiscellaneous radars:15.70–17.70 GHzDBS uplink:17.30–17.80 GHz	Precision approach radar:	9.00–9.20 GHz
Police radar:10.525 GHzCommercial mobile COM [LOS and electronic news gathering (ENG)]:10.55–10.68 GHzCommon carrier LOS COM:10.70–11.70 GHzCommercial COM:10.70–13.25 GHzCommercial Ku-band SAT COM downlink:11.70–12.20 GHzDirect broadcast satellite (DBS) downlink and private LOS COM:12.20–12.70 GHzENG and LOS COM:12.75–13.25 GHzMiscellaneous radars and SAT COM:13.25–14.00 GHzCommercial Ku-band SAT COM uplink:14.00–14.50 GHzMilitary COM (LOS, mobile, and Tactical):14.50–15.35 GHzAeronavigation:15.40–15.70 GHzMiscellaneous radars:15.70–17.70 GHzDBS uplink:17.30–17.80 GHz	X-band weather radar (and maritime navigation radar):	9.30–9.50 GHz
Commercial mobile COM [LOS and electronic news gathering (ENG)]:10.55–10.68 GHzCommon carrier LOS COM:10.70–11.70 GHzCommercial COM:10.70–13.25 GHzCommercial Ku-band SAT COM downlink:11.70–12.20 GHzDirect broadcast satellite (DBS) downlink and private LOS COM:12.20–12.70 GHzENG and LOS COM:12.75–13.25 GHzMiscellaneous radars and SAT COM:13.25–14.00 GHzCommercial Ku-band SAT COM uplink:14.00–14.50 GHzMilitary COM (LOS, mobile, and Tactical):14.50–15.35 GHzAeronavigation:15.40–15.70 GHzMiscellaneous radars:15.70–17.70 GHzDBS uplink:17.30–17.80 GHz	Police radar:	10.525 GHz
Common carrier LOS COM:10.70–11.70 GHzCommercial COM:10.70–13.25 GHzCommercial Ku-band SAT COM downlink:11.70–12.20 GHzDirect broadcast satellite (DBS) downlink and private LOS COM:12.20–12.70 GHzENG and LOS COM:12.75–13.25 GHzMiscellaneous radars and SAT COM uplink:13.25–14.00 GHzCommercial Ku-band SAT COM uplink:14.00–14.50 GHzMilitary COM (LOS, mobile, and Tactical):14.50–15.35 GHzAeronavigation:15.40–15.70 GHzMiscellaneous radars:15.70–17.70 GHzDBS uplink:17.30–17.80 GHz	Commercial mobile COM [LOS and electronic news gathering (ENG)]:	10.55–10.68 GHz
Commercial COM:10.70–13.25 GHzCommercial Ku-band SAT COM downlink:11.70–12.20 GHzDirect broadcast satellite (DBS) downlink and private LOS COM:12.20–12.70 GHzENG and LOS COM:12.75–13.25 GHzMiscellaneous radars and SAT COM:13.25–14.00 GHzCommercial Ku-band SAT COM uplink:14.00–14.50 GHzMilitary COM (LOS, mobile, and Tactical):14.50–15.35 GHzAeronavigation:15.40–15.70 GHzMiscellaneous radars:15.70–17.70 GHzDBS uplink:17.30–17.80 GHz	Common carrier LOS COM:	10.70–11.70 GHz
Commercial Ku-band SAT COM downlink:11.70–12.20 GHzDirect broadcast satellite (DBS) downlink and private LOS COM:12.20–12.70 GHzENG and LOS COM:12.75–13.25 GHzMiscellaneous radars and SAT COM:13.25–14.00 GHzCommercial Ku-band SAT COM uplink:14.00–14.50 GHzMilitary COM (LOS, mobile, and Tactical):14.50–15.35 GHzAeronavigation:15.40–15.70 GHzMiscellaneous radars:15.70–17.70 GHzDBS uplink:17.30–17.80 GHz	Commercial COM:	10.70–13.25 GHz
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ENG and LOS COM:       12.75–13.25 GHz         Miscellaneous radars and SAT COM:       13.25–14.00 GHz         Commercial Ku-band SAT COM uplink:       14.00–14.50 GHz         Military COM (LOS, mobile, and Tactical):       14.50–15.35 GHz         Aeronavigation:       15.40–15.70 GHz         Miscellaneous radars:       15.70–17.70 GHz         DBS uplink:       17.30–17.80 GHz	Direct broadcast satellite (DBS) downlink and private LOS COM:	12.20–12.70 GHz
Miscellaneous radars and SAT COM:13.25–14.00 GHzCommercial Ku-band SAT COM uplink:14.00–14.50 GHzMilitary COM (LOS, mobile, and Tactical):14.50–15.35 GHzAeronavigation:15.40–15.70 GHzMiscellaneous radars:15.70–17.70 GHzDBS uplink:17.30–17.80 GHz	ENG and LOS COM:	12.75–13.25 GHz
Commercial Ku-band SAT COM uplink:         14.00–14.50 GHz           Military COM (LOS, mobile, and Tactical):         14.50–15.35 GHz           Aeronavigation:         15.40–15.70 GHz           Miscellaneous radars:         15.70–17.70 GHz           DBS uplink:         17.30–17.80 GHz	Miscellaneous radars and SAT COM:	13.25–14.00 GHz
Military COM (LOS, mobile, and Tactical):       14.50–15.35 GHz         Aeronavigation:       15.40–15.70 GHz         Miscellaneous radars:       15.70–17.70 GHz         DBS uplink:       17.30–17.80 GHz	Commercial Ku-band SAT COM uplink:	14.00–14.50 GHz
Aeronavigation:         15.40–15.70 GHz           Miscellaneous radars:         15.70–17.70 GHz           DBS uplink:         17.30–17.80 GHz	Military COM (LOS, mobile, and Tactical):	14.50–15.35 GHz
Miscellaneous radars:15.70–17.70 GHzDBS uplink:17.30–17.80 GHz	Aeronavigation:	15.40–15.70 GHz
DBS uplink: 17.30–17.80 GHz	Miscellaneous radars:	15.70–17.70 GHz
	DBS uplink:	17.30–17.80 GHz

Table 3.6 Applications in the Microwave Bands (continued)

Common carrier LOS COM:	17.70–19.70 GHz
Commercial COM (SAT COM and LOS):	17.70–20.20 GHz
Private LOS COM:	18.36–19.04 GHz
Military SAT COM:	20.20–21.20 GHz
Miscellaneous COM:	21.20–24.00 GHz
Police radar:	24.15 GHz
Navigation radar:	24.25–25.25 GHz
Military COM:	25.25–27.50 GHz
Commercial COM:	27.50–30.00 GHz
Military SAT COM:	30.00–31.00 GHz
Commercial COM:	31.00–31.20 GHz
Navigation radar:	31.80–33.40 GHz
Miscellaneous radars:	33.40–36.00 GHz
Military COM:	36.00–38.60 GHz
Commercial COM:	38.60–40.00 GHz

#### 3.2 Radio Wave Propagation

To visualize a radio wave, consider the image of a sine wave being traced across the screen of an oscilloscope [2]. As the image is traced, it sweeps across the screen at a specified rate, constantly changing amplitude and phase with relation to its starting point at the left side of the screen. Consider the left side of the screen to be the antenna, the horizontal axis to be distance instead of time, and the sweep speed to be the speed of light, or at least very close to the speed of light, and the propagation of the radio wave is visualized. To be correct, the traveling, or propagating, radio wave is really a wavefront, as it comprises an electric field component and an orthogonal magnetic field component. The distance between wave crests is defined as the *wavelength* and is calculated by,

$$\lambda = \frac{c}{f} \tag{3.1}$$

where:  $\lambda =$  wavelength, m c = the speed of light, approximately  $2.998 \times 10^8$  m/s f = frequency, Hz

At any point in space far away from the antenna, on the order of 10 wavelengths or 10 times the aperture of the antenna to avoid *near-field effects*, the electric and magnetic fields will be orthogonal and remain constant in amplitude and phase in relation to any other point in space. The polarization of the radio wave is defined by the polarization of the electric field, horizontal if parallel to the Earth's surface and vertical if perpendicu-

Band	Uplink	Downlink	Satellite Service
VHF		0.137-0.138	Mobile
VHF	0.3120-0.315	0.387-0.390	Mobile
L-Band		1.492-1.525	Mobile
	1.610-1.6138		Mobile, Radio Astronomy
	1.613.8-1.6265	1.6138-1.6265	Mobile LEO
	1.6265-1.6605	1.525-1.545	Mobile
		1.575	Global Positioning System
		1.227	GPS
S-Band	1.980-2.010	2.170-2.200	MSS. Available Jan. 1, 2000
	(1.980–1.990)		(Available in U.S. in 2005)
	2.110-2.120	2.290-2.300	Deep-space research
		2.4835-2.500	Mobile
C-Band	5.85-7.075	3.4-4.2	Fixed (FSS)
	7.250-7.300	4.5-4.8	FSS
X-Band	7.9-8.4	7.25-7.75	FSS
Ku-Band	12.75-13.25	10.7-12.2	FSS
	14.0-14.8	12.2-12.7	Direct Broadcast (BSS) (U.S.)
Ka-Band		17:3-17.7	FSS (BSS in U.S.)
			22.55–23.55 Intersatellite
			24.45–24.75 Intersatellite
			25.25–27.5 Intersatellite
	27-31	17–21	FSS
Q	42.5-43.5, 47.2-50.2	37.5-40.5	FSS, MSS
	50.4-51.4		Fixed
		40.5-42.5	Broadcast Satellite
V	54.24-58.2		Intersatellite
	59–64		Intersatellite

Table 3.7 Satellite Frequency Allocations (From [1]. Used with permission.)

*Sources*: Final Acts of the World Administrative Radio Conference (WARC-92), Malaga– Torremolinos, 1992; 1995 World Radiocommunication Conference (WRC-95). Also, see Gagliardi, R.M. 1991. *Satellite Communications*, van Nostrand Reinhold, New York. Note that allocations are not always global and may differ from region to region in all or subsets of the allocated bands.

lar to it. Typically, polarization can be determined by the orientation of the antenna radiating elements.

An *isotropic antenna* is one that radiates equally in all directions. To state this another way, it has a gain of unity.

If this isotropic antenna is located in an absolute vacuum and excited with a given amount of power at some frequency, as time progresses the radiated power must be equally distributed along the surface of an ever expanding sphere surrounding the isotropic antenna. The power density at any given point on the surface of this imaginary sphere is simply the radiated power divided by the surface area of the sphere, that is:

$$P_d = \frac{P_t}{4\pi D^2} \tag{3.2}$$

where:

 $P_d$  = power density, W/m<sup>2</sup>

D = distance from antenna, m

 $P_t$  = radiated power, W

Because power and voltage, in this case power density and electric field strength, are related by impedance, it is possible to determine the electric field strength as a function of distance given that the impedance of free space is taken to be approximately  $377 \Omega$ ,

$$E = \sqrt{Z P_d} = 5.48 \frac{\sqrt{P_t}}{D}$$
(3.3)

where E is the electric field strength in volts per meter.

Converting to units of kilowatts for power, the equation becomes

$$E = 173 \frac{\sqrt{P_{t(kW)}}}{D} \text{ V/m}$$
(3.4)

which is the form in which the equation is usually seen. Because a half-wave dipole has a gain of 2.15 dB over that of an isotropic radiator (dBi), the equation for the electric field strength from a half-wave dipole is

$$E = 222 \frac{\sqrt{P_{\iota(kW)}}}{D} \,\mathrm{V/m} \tag{3.5}$$

From these equations it is evident that, for a given radiated power, the electric field strength decreases linearly with the distance from the antenna, and power density decreases as the square of the distance from the antenna.

#### 3.2.1 Free Space Path Loss

A typical problem in the design of a radio frequency communications system requires the calculation of the power available at the output terminals of the receive antenna [2]. Although the gain or loss characteristics of the equipment at the receiver and transmitter sites can be ascertained from manufacturer's data, the effective loss between the two antennas must be stated in a way that allows for the characterization of the transmission path between the antennas. The ratio of the power radiated by the transmit antenna to the power available at the receive antenna is known as the *path loss* and is usually expressed in decibels. The minimum loss on any given path occurs between two antennas when there are no intervening obstructions and no ground