Brief Contents

Preface iii

1. Measurement Systems, Units, and Standards 1
2. Measurement Errors 16
3. Classical Electromechanical Instruments 35
4. Electromechanical Ammeters, Voltmeters, and Ohmmeters 73
5. Analog Electronic Instruments 106
7. Digital Voltmeters, Multimeters, and Frequency Meters 162
8. Low, High, and Precise Resistance Measurements 183
9. Inductance and Capacitance Measurements 215
10. Classical AC Bridge Methods 230
11. Analog Oscilloscopes 261
12. Special Oscilloscopes 313
13. Signal Generators 339
15. Miscellaneous Instruments 397
16. Power and Energy Measurement 426
17. Magnetic Measurement 454
18. Introduction to Transducers 473
19. Telemetry 510

Appendix 1: Unit Conversion Factor 552
Appendix 2: Answers for Odd-numbered Problems 555
Index 559
Detailed Contents

Preface iii

1. Measurement Systems, Units, and Standards 1

1-1 Unit Systems 1
  CGS and MKS System 1
  The SI System 2

1-2 Scientific Notation and Metric Prefixes 3
  Scientific Notation 3
  Metric Prefixes 3
  Engineering Notation 4

1-3 The SI Mechanical Units 4
  Fundamental Mechanical Units 4
  Unit of Force 5
  Work 5
  Power 5
  Energy 6

1-4 The SI Electrical Units 7
  Units of Current and Charge 7
  Emf, Potential Difference, and Voltage 7
  Resistance and Conductance 8
  Magnetic Flux and Flux Density 8
  Inductance 8
  Capacitance 8

1-5 Temperature Units 9
  Temperature Scales 9
  Joules Equivalent 10

1-6 Dimensions 10

1-7 Measurement Standards 12
  Standard Classifications 12
  IEEE Standards 12

2. Measurement Errors 16

2-1 Error Classifications 16
  Gross and Systematic Errors 16
  Absolute and Relative Errors 18

2-2 Accuracy, Precision, Resolution, and Significant Figures 20
  Instrument Accuracy 20
Detailed Contents

Accuracy and Precision 20
Resolution 21
Significant Figures 22

2-3 Measurement Error Combinations 24
Sum of Quantities 24
Difference of Quantities 25
Product of Quantities 25
Quotient of Quantities 26
Quantity Raised to a Power 26

2-4 Basics of Statistical Analysis 27
Arithmetic Mean Value 27
Deviation 28
Standard Deviation 29
Probable Error 29
Gaussian Distribution 29
Sample Standard Deviation 31

3. Classical Electromechanical Instruments 35

3-1 Measuring Instrument Classifications 35
Instrument Types 35
Absolute and Secondary Instruments 36
Instrument Grades 36
Comparison Instruments 36

3-2 Deflection Instrument Fundamentals 37
Operating Forces 37
Suspension 38
Reading Errors 40

3-3 Permanent Magnet Moving-Coil Instrument 41
Construction and Operation 41
Torque Equation and Scale 42
Advantages of PMMC Instruments 44
Disadvantages of PMMC Instruments 44

3-4 Electrodynamic Instrument 45
Construction and Operation 45
AC Operation 45
Electrodynamic Voltmeter and Ammeter 47
Deflecting Torque 48
Advantages of Electrodynamic Instruments 49
Disadvantages of Electrodynamic Instruments 49

3-5 Moving-Iron Instruments 49
Attraction-type Moving-iron Instrument 49
Concentric-vane Moving-iron Instrument 51
Torque Equation 51
Advantages of Moving-iron Instruments 52
Disadvantages of Moving-iron Instruments 52

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3-6 Electrostatic Instruments
  Attraction-type Electrostatic Voltmeter 53
  Quadrant-type Electrostatic Voltmeter 53
  Torque Equation 54
  Advantages of Electrostatic Instruments 56
  Disadvantages of Electrostatic Instruments 56

3-7 Thermal-type Instrument
  Hot-wire Instrument 57
  Thermocouples 57
  Thermocouple Ammeters and Voltmeters 59
  Thermocouple Bridge 60
  Advantages of Thermocouple Instruments 61
  Disadvantages of Thermocouple Instruments 61

3-8 Galvanometer
  Galvanometer Operation 62
  Moving System Equation 63
  Damping 64
  Ballistic Galvanometer 65
  Null Detector 67

4. Electromechanical Ammeters, Voltmeters, and Ohmmeters 73

4-1 DC Ammeter
  Ammeter Circuit 73
  Ammeter Scale 75
  Shunt Resistance 75
  Swamping Resistance 76
  Burden Voltage 76
  Multirange Ammeters 77

4-2 DC Voltmeter
  Voltmeter Circuit 79
  Swamping Resistance 80
  Voltmeter Sensitivity 81
  Loading Effect 81
  Multirange Voltmeter 81

4-3 Rectifier Voltmeter
  PMMC Instrument on AC 83
  Full-wave Rectifier Voltmeter 84
  Half-wave Rectifier Voltmeter 86
  Half-bridge Full-wave Rectifier Voltmeter 87

4-4 Rectifier Ammeter

4-5 Series Ohmmeter
  Basic Ohmmeter Circuit 90
  Ohmmeter with Zero Adjust 92

4-6 Shunt Ohmmeter
  Shunt Ohmmeter Circuit 95
6. Digital Instrument Basics

6-1 Digital Representation of an Analog Quantity
   Resolution 138
   Analog-to-digital Conversion 139
   LSB and MSB 140
   Digital-to-analog Conversion 140

6-2 Basic Logic Circuits
   AND Gate 141
   OR Gate 142
   NAND and NOR Gates 143
   Flip-flops 143
   Flip-flop Triggering 145
   Flip-flop Logic Symbols 145

6-3 Digital Displays
   Light-emitting Diode Displays 146
   Liquid Crystal Displays 147

6-4 Digital Counting
   Scale-of-16 Counter 148
   Decade Counter 149
   Scale-of-2000 Counter 149
   Frequency Division 151

6-5 Analog-to-digital Converter
   Linear-ramp ADC 153
   Digital-ramp ADC 154
   Successive Approximation ADC 156

6-6 Digital-to-analog Converter 156

7. Digital Voltmeters, Multimeters, and Frequency Meters 162

7-1 Digital Voltmeter Systems
   Ramp-generator-type Digital Voltmeter 162
   Dual-slope-integrator DVM 164
   Range Changing 166

7-2 Digital Multimeters
   Basic Hand-held Digital Multimeter 167
   Accuracy 169
   High-performance Hand-held DMMs 169
   Bench-type DMM 169
   Additional Features 169
   Comparison of Digital and Analog Multimeters 170

7-3 Digital Frequency Meter
   Frequency Meter System 171
9. Inductance and Capacitance Measurements 215
   9-1 RC and RL Equivalent Circuits 215
       Capacitor Equivalent Circuits 215
       Inductor Equivalent Circuits 217
       Q Factor of an Inductor 218
       D Factor of a Capacitor 219
   9-2 Digital RCL Meters 220
       Portable and Bench Instruments 220
       Component Equivalent Circuit Determination 221
       Terminals 221
       Test Frequency 222
       Bias Voltage or Current 222
   9-3 Q Meter 223
       Q-Meter Operation 223
       Q-Meter Controls 224
       Residuals 225
       Commercial Q Meter 226
       Medium-range Inductance Measurement Procedure (Direct Connection) 226
       High-impedance Measurement Procedure (Parallel Connection) 227
       Low-impedance Measurements Procedure (Series Connection) 228

10. Classical AC Bridge Methods 230
    10-1 AC Bridge Theory 231
        Circuit and Balance Equations 231
        Balance Procedure 232
        AC Bridge Sensitivity 233
    10-2 Series and Parallel RC Bridges 233
        Simple Capacitance Bridge 233
        Series-resistance Capacitance Bridge 234
        Parallel-resistance Capacitance Bridge 236
    10-3 Schering and Wien Bridges 239
        Schering Bridge 239
        Wien Bridge 242
    10-4 Inductance Bridges 243
        Inductance Comparison Bridge 243
        Maxwell Bridge (for Measuring L in terms of C) 244
        Hay Inductance Bridge (for High-Q Coils) 246
        Anderson Bridge 248
        Owen Bridge 249
    10-5 Mutual Inductance Bridges 250
        Heaviside Bridge 250
        Campbell’s Modification 251
11. Analog Oscilloscopes

11-1 Cathode-ray Tube
Construction 262
Triode Section 262
Focusing Section 263
Deflection Section 264
Screen 265
Display Brightness 265

11-2 Deflection Amplifier 266
11-3 Waveform Display 268
11-4 Oscilloscope Time Base
   Horizontal Sweep Generator 271
   Automatic Time Base 274
11-5 Dual-trace Oscilloscopes 279
   Dual-beam CRT 279
   Switched Channel Method 280
11-6 Oscilloscope Controls 282
11-7 Measurement of Voltage, Frequency, and Phase
   Peak-to-peak Voltage Measurement 285
   Frequency Determination 286
   Phase Measurement 286
11-8 Pulse Measurements 288
   Pulse Amplitude, Pulse Width, and Space Width 288
   Rise Time, Fall Time, and Delay Time 289
   Pulse Distortion 290
11-9 Oscilloscope Probes 292
   1:1 Probes 292
   Attenuator Probes 294
   Probe Calibration 297
   Active Probes 297
11-10 Display of Device Characteristics 298
11-11 X-Y and Z Displays 300
11-12 Oscilloscope Specifications and Performance
   Sensitivity 303
   Voltage Measurement Accuracy 303
   Frequency Response 304
12. Special Oscilloscopes 313
12-1 Delayed-time-base Oscilloscopes 314
   Need for a Time Delay 314
   Delayed-time-base System 315
12-2 Analog Storage Oscilloscope 317
   Need for Signal Storage 317
   Bistable Storage CRT 317
   Variable-persistence Storage CRT 319
12-3 Sampling Oscilloscopes 320
   Waveform Sampling 320
   System Operation 321
   Expanded Mode Operation 323
12-4 Digital Storage Oscilloscopes 324
   Digital Sampling 324
   Basic DSO Operation 325
   Flat Screen Display 326
   Digital Memory and Resolution 328
   Interpolation 329
   Sampling Rate and Bandwidth 329
   Pulse Rise Time and Sampling Rate 331
12-5 DSO Applications 332
   Autoset 332
   Multichannel Displays 332
   Waveform Processing 332
   Pre-triggering and Post-triggering 333
   Zoom and Restart 334
   Glitch and Runt Catching 334
   Baby-sitting Mode 335
   Roll Mode 336
   Documentation and Analysis 336
13. Signal Generators 339
13-1 Low-frequency Signal Generators 340
   Wein Bridge Oscillator 340
   Frequency Range Changing 342
   Square-wave Conversion 343
   Output Controls 343
   Block Diagram 344
   Application 344
13-2 Function Generators 345
   Basic Circuit 345
   Sine-wave Conversion 348
xvi Detailed Contents

Function Generator Block Diagram 350
Function Generator Performance 350

13-3 Pulse Generators 351
Block Diagram 351
Astable Multivibrator as Square-wave Generator 351
Monostable Multivibrator 353
Output Attenuator 355
Pulse Shaping 356
Pulse Generator Performance 357

13-4 RF Signal Generators 357
Basic Block Diagram 357
Oscillator Circuits 358
Modulation 359
Detailed Block Diagram 360
Application 361
RF Signal Generator Performance 362

13-5 Sweep Frequency Generators 362
Basic Block Diagram 362
More-detailed Block Diagram 363
Performance 364

13-6 Frequency Synthesizer 364
Phase-locked Loop 364
Phase Detector 366
VCO 366

13-7 Arbitrary Waveform Generator 367


14-1 Comparison Methods 372
Absolute and Secondary Instruments 372
DC Voltmeter Calibration 373
DC Ammeter Calibration 374
AC Instrument Calibration 375
Ohmmeter Calibration 375
Wattmeter Calibration 375

14-2 Digital Multimeters as Standard Instruments 377
Accuracy Comparison 377
Calibration Instrument 378

14-3 DC Potentiometer 379
Basic DC Potentiometer 379
DC Potentiometer with Switched Resistors 380

14-4 Classical DC Potentiometer Calibration Methods 383
DC Ammeter Calibration by Potentiometer 383
DC Voltmeter Calibration by Potentiometer 384
Kelvin–Varley Voltage Divider 387
14-5 AC Potentiometers
  Use of DC Potentiometer for AC Measurements 389
  Polar AC Potentiometer 391
  Co-ordinate AC Potentiometer 392

15. Miscellaneous Instruments 397
  15-1 Strip-chart Recorders 398
    Galvanometric Strip-chart Recorder 398
    Potentiometric Strip-chart Recorder 399
    Representative Strip-chart Recorder 402
  15-2 X-Y Recorders and Plotters 402
    X-Y Recorders 402
    Representative X-Y Recorders 404
    Plotters 405
  15-3 Plotting Device Characteristics on an X-Y Recorder 406
    Diode Characteristics 406
    Zener Diode Characteristics 407
    Transistor Characteristics 407
  15-4 Distortion Meter 408
    Harmonic Distortion 408
    Rejection Amplifier 408
    Distortion Meter Block Diagram and Controls 409
  15-5 Spectrum Analyzers 411
    Swept TRF Spectrum Analyzer 411
    Swept Superheterodyne Spectrum Analyzer 413
    Spectrum Analyzer Controls and Specifications 415
    Digital Spectrum Analyzers 416
  15-6 True RMS Meters 417
    Disadvantage of Average-responding Instruments 417
    Waveform Crest Factor 418
    TRMS Meter Using Nonlinear Circuit 418
    Waveforms with a DC Component 419
    Thermocouple-type TRMS Meter 419
    Representative TRMS Meter 420
  15-7 Low-Level Voltmeter 420
    Low-level Voltage Measurements 420
    Chopper-stabilized Amplifier 421
    Guard Terminal 421
    Representative Low-level Voltmeter 423

16. Power and Energy Measurement 426
  16-1 Electrodynamic Wattmeter 427
    Electrodynamic Instrument as a Wattmeter 427
    Connection Errors 429
    Compensated Wattmeter 430
Detailed Contents

16-2 Multirange Wattmeters
- Wattmeter Voltage and Current Ranges
- Using a Multirange Wattmeter
- Use of Instrument Transformers

16-3 Power Measurement Without Wattmeters
- Three-voltmeter Method
- Three-ammeter Method

16-4 Three-phase Power Measurements
- Power in a Three-phase System
- Three-wattmeter Method
- Single-wattmeter Method
- Two-wattmeter Method
- Use of Transformers
- Three-phase Wattmeter

16-5 Three-phase Power Factor Determination

16-6 Thermocouple Wattmeter

16-7 Electromechanical Energy Meters
- Single-phase Energy Meter
- Energy Meter Error Sources and Compensation
- Energy Meter Connection Methods
- Three-phase Energy Meter

16-8 Digital Power/Energy Meter

17. Magnetic Measurement

17-1 Induction Coil and Fluxgate Magnetometers
- Induction Coil Magnetometer
- Fluxgate Magnetometer

17-2 Hall-effect Magnetometer

17-3 Flux Density Measurements by Ballistic Galvanometer

17-4 B/H Characteristic and Hysteresis Loop Determination
- Reversals Method for B/H Characteristic Determination
- Step Method for B/H Characteristic Determination
- Hysteresis Loop Determination

17-5 AC Testing of Magnetic Cores

17-6 Core Loss Measurements
- Wattmeter Measurement of Core Loss
- Separating Hysteresis and Eddy-current Losses

18. Introduction to Transducers

18-1 Resistive Transducers
- Potentiometer-type Transducer
- Strain Gauges
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-2</td>
<td>Inductive Transducers</td>
<td>478</td>
</tr>
<tr>
<td></td>
<td>Variable Reluctance Transducer</td>
<td>478</td>
</tr>
<tr>
<td></td>
<td>Linear Variable Differential Transducer (LVDT)</td>
<td>479</td>
</tr>
<tr>
<td>18-3</td>
<td>Capacitive Transducers</td>
<td>482</td>
</tr>
<tr>
<td></td>
<td>Capacitive Displacement Transducers</td>
<td>482</td>
</tr>
<tr>
<td></td>
<td>Capacitive Pressure Transducer</td>
<td>484</td>
</tr>
<tr>
<td>18-4</td>
<td>Thermal Transducers</td>
<td>485</td>
</tr>
<tr>
<td></td>
<td>Resistance Thermometer</td>
<td>485</td>
</tr>
<tr>
<td></td>
<td>Thermistor</td>
<td>488</td>
</tr>
<tr>
<td></td>
<td>Thermocouple Thermometer</td>
<td>490</td>
</tr>
<tr>
<td></td>
<td>Semiconductor Temperature Sensor</td>
<td>490</td>
</tr>
<tr>
<td>18-5</td>
<td>Optoelectronic Transducers</td>
<td>493</td>
</tr>
<tr>
<td></td>
<td>Light Units</td>
<td>493</td>
</tr>
<tr>
<td></td>
<td>Photoconductive Cell</td>
<td>494</td>
</tr>
<tr>
<td></td>
<td>Photodiodes</td>
<td>497</td>
</tr>
<tr>
<td></td>
<td>Photomultiplier</td>
<td>449</td>
</tr>
<tr>
<td>18-6</td>
<td>Piezoelectric Transducers</td>
<td>502</td>
</tr>
<tr>
<td>19.</td>
<td>Telemetry</td>
<td>510</td>
</tr>
<tr>
<td>19-1</td>
<td>Basics of an Instrumentation System</td>
<td>511</td>
</tr>
<tr>
<td>19-2</td>
<td>Instrumentation Amplifier</td>
<td>513</td>
</tr>
<tr>
<td></td>
<td>Difference Amplifier</td>
<td>513</td>
</tr>
<tr>
<td></td>
<td>Differential-input/Differential-output Amplifier</td>
<td>514</td>
</tr>
<tr>
<td></td>
<td>Complete Instrumentation Amplifier</td>
<td>515</td>
</tr>
<tr>
<td>19-3</td>
<td>Filtering</td>
<td>518</td>
</tr>
<tr>
<td></td>
<td>Basic Filter Types</td>
<td>518</td>
</tr>
<tr>
<td></td>
<td>Power Measurement in Decibels</td>
<td>519</td>
</tr>
<tr>
<td></td>
<td>Gain/Frequency Response</td>
<td>521</td>
</tr>
<tr>
<td>19-4</td>
<td>Passive Filters</td>
<td>522</td>
</tr>
<tr>
<td></td>
<td>RC Low-pass Filter Circuit</td>
<td>522</td>
</tr>
<tr>
<td></td>
<td>RC High-pass Filter Circuits</td>
<td>524</td>
</tr>
<tr>
<td></td>
<td>Band-pass Filter</td>
<td>524</td>
</tr>
<tr>
<td></td>
<td>Notch Filter</td>
<td>526</td>
</tr>
<tr>
<td></td>
<td>Resonant Filters</td>
<td>527</td>
</tr>
<tr>
<td>19-5</td>
<td>Active Filters</td>
<td>529</td>
</tr>
<tr>
<td></td>
<td>Active Filter Design Categories</td>
<td>529</td>
</tr>
<tr>
<td></td>
<td>First-order Low-pass Active Filter</td>
<td>529</td>
</tr>
<tr>
<td></td>
<td>First-order High-pass Filter</td>
<td>530</td>
</tr>
<tr>
<td></td>
<td>Second-order Low-pass Filter</td>
<td>530</td>
</tr>
<tr>
<td></td>
<td>Second-order High-pass Filter</td>
<td>532</td>
</tr>
<tr>
<td></td>
<td>Active Band-pass and Notch Filters</td>
<td>533</td>
</tr>
<tr>
<td>19-6</td>
<td>Amplitude and Frequency Modulation</td>
<td>533</td>
</tr>
<tr>
<td></td>
<td>AM and FM</td>
<td>533</td>
</tr>
</tbody>
</table>
CHAPTER 1
Measurement Systems, Units, and Standards

Objectives

After studying this chapter, you will be able to

1. Discuss CGS, MKS, and SI unit systems and explain the need for a practical units system.
2. Use scientific notation, engineering notation, and metric prefixes in stating quantities.
3. Identify the three fundamental mechanical units in the SI system, and define SI mechanical derived units.
4. Identify the fundamental electrical unit in the SI system, and define the SI derived units for various electrical and magnetic quantities.
5. Explain SI temperature scales.
6. Convert between SI and non-SI units when solving problems.
7. Determine the dimensions of all fundamental and derived units.
8. Explain the various measurement standards and their applications.

INTRODUCTION

Before standard systems of measurement were invented, many approximate units were used. A long distance was often measured by the number of days it would take to ride a horse over the distance; a horse’s height was measured in hands; liquid was measured by the bucket or barrel. English-speaking peoples adopted the foot and the mile for measuring distances, the pound for mass, and the gallon for liquid. Other nations followed the lead of the French in adopting a metric system, in which large and small units are very conveniently related by a factor of 10. With the development of science and engineering, accurate units had to be devised, and several different unit systems were used before an international system was adopted.

1-1 UNIT SYSTEMS

CGS and MKS Systems

For many years, systems using the centimeter, gram, and second (CGS) as the fundamental mechanical units were employed for scientific and engineering purposes. These were termed absolute systems because all quantities could be defined in terms of the three fundamental units. There are two CGS systems: an electrostatic system of units (esu) and an electromagnetic units system (emu). In the electrostatic system, the permittivity of free space ($\varepsilon_0$) is defined as 1, and the unit of electrical charge is defined as the charge that exerts unit force on a
similar charge located at 1 cm distance. In the electromagnetic system, the *permeability of free space* \((\mu_0)\) is defined as 1, and the unit magnetic pole is defined as the pole that exerts unit force on a similar pole located at 1 cm distance.

Except in the case of electrostatic research, the electromagnetic system tended to be more convenient to use than the electrostatic system. However, some of the esu and emu units were different in magnitude, and care had to be taken in making conversions. Many CGS units were too small or too large for practical engineering applications, so a system of *practical units* was also used. Thus, there were two CGS (esu and emu) systems for use in research work, and a third (practical) system for engineering applications. Furthermore, both CGS systems were regarded as *irrational* (or *unrationalized*) because of the presence of the factor \(4\pi\) in equations where it seemed inappropriate, and its absence in other equations where it was appropriate.

These factors led to the proposed use of the practical units in an *MKS system*, using the meter \(m\), kilogram \(kg\), and second \(s\) as the fundamental units. The name *Giorgi system* is also applied to the MKS system, in reference to Italian Professor Giorgi who first suggested its use. The MKS system was also *rationalized*, to relocate the factor \(4\pi\) to appropriate equations, and (instead of 1) the permittivity and permeability of free space were redefined as: \(\varepsilon_0 = 1/(36 \pi \times 10^{-9})\) and \(\mu_0 = 4 \pi \times 10^{-7}\).

**The SI System**

To facilitate the exchange of scientific information, it was necessary to establish a single system of units of measurement that would be acceptable internationally. A metric system which uses the *meter*, *kilogram*, and *second* as fundamental mechanical units is now generally employed around the world. This was first devised in France, and it is known (from “systéme international”) as the *SI system*.

The meter, kilogram, and second are the *fundamental mechanical units* of the SI system. Other units which are defined in terms of the fundamental units are termed *derived units*; for example, the unit of area is meters squared \((m \times m = m^2)\). Thus, \(m^2\) is a derived unit. Some other derived units are those for force, work, energy, and power.

A fundamental electrical unit is required in the SI system, and this is the *ampere* \((A)\), the unit of electric current. With this addition, the MKS system became an *MKSA system*. Fundamental units are also required for temperature and illumination calculations, and these are the *kelvin* \((K)\) and the *candela* \((cd)\), respectively. The fundamental mechanical units are sometimes referred to as the *primary fundamental units*, and the units for current, temperature, and illumination are then termed *auxiliary fundamental units*.

When solving problems, it is sometimes necessary to convert between SI and other unit systems. Appendix 1 provides a list of conversion factors for this purpose.
Section Review
1-1.1 Explain the following in relationship to unit systems: CGS, MKSA, esu, emu, absolute system, practical units.

1-2 SCIENTIFIC NOTATION AND METRIC PREFIXES

Scientific Notation

Very large or very small numbers are conveniently written as a number multiplied by 10 raised to a power:

- \(100 = 1 \times 10 \times 10 = 1 \times 10^2\)
- \(10,000 = 1 \times 10 \times 10 \times 10 \times 10 = 1 \times 10^4\)
- \(0.001 = \frac{1}{10 \times 10 \times 10} = \frac{1}{10^3} = 1 \times 10^{-3}\)
- \(1500 = 1.5 \times 10^3\)
- \(0.015 = 1.5 \times 10^{-2}\)

Numbers presented in this form are said to use scientific notation. Note that in the SI system of units, spaces are used instead of commas when writing large numbers. Four-numeral numbers are an exception. One thousand is written as 1000, while ten thousand is 10 000.

Metric Prefixes

Metric prefixes and the letter symbols for the various multiples and submultiples of 10 are listed in Table 1-1, with those most commonly used with electrical units shown in bold type. The prefixes are employed to simplify the representation of very large and very small quantities. Thus, 1000 \(\Omega\) can be expressed as 1 kilohm, or 1 k\(\Omega\). Here kilo is the prefix that represents 1000, and \(k\) is the symbol for kilo. Similarly, \(1 \times 10^{-3}\) A can be written as 1 milliampere, or 1 mA.

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<tbody>
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<td>tera</td>
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<tr>
<td>1 000 000 000</td>
<td>(10^9)</td>
<td>giga</td>
<td>G</td>
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<tr>
<td>1 000 000</td>
<td>(10^6)</td>
<td>mega</td>
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<tr>
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</tbody>
</table>
Engineering Notation
As already discussed, 1 kΩ is 1 x 10^3 Ω, and 1 mA is 1 x 10^-3 A. Note also from Table 1-1 that 1 x 10^6 Ω is expressed as 1 MΩ, and 1 x 10^-6 A can be written as 1 μA. These quantities, and most of the metric prefixes in Table 1-1, involve multiples of 10^3 or 10^-3. Quantities that use 10^3 or 10^-3 are said to be written in engineering notation. A quantity such as 1 x 10^4 Ω is more conveniently expressed as 10 x 10^3 Ω, or 10 kΩ. Also, 47 x 10^-4 A is best written as 4.7 x 10^-3 A, or 4.7 mA. For electrical calculations, engineering notation is more convenient than ordinary scientific notation.

Example 1-1
Write the following quantities using (a) scientific notation, (b) engineering notation, (c) metric prefixes: 12 000 Ω, 0.000 3 V, 0.000 01 A.

Solution

<table>
<thead>
<tr>
<th>(a) Scientific notation</th>
<th>(b) Engineering notation</th>
<th>(c) Metric prefixes</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 000 Ω</td>
<td>12 x 10³ Ω</td>
<td>12 kΩ</td>
</tr>
<tr>
<td>0.000 3 V</td>
<td>3 x 10^-4 V</td>
<td>300 μV</td>
</tr>
<tr>
<td>0.000 01 A</td>
<td>1 x 10^-5 A</td>
<td>10 μA</td>
</tr>
</tbody>
</table>

Practice Problem
1-2.1 Express the following quantities using engineering notation: 0.005, 77700, 6 x 10^-8, 6.8 x 10^4, 5.9 x 10^7, 0.00033

1-3 THE SI MECHANICAL UNITS
Fundamental Mechanical Units
As discussed above, the three fundamental mechanical units in the SI system are:
- Unit of length: the meter (m)
- Unit of mass: the kilogram (kg)
- Unit of time: the second (s)

The meter was originally defined as one ten-millionth of a meridian passing through Paris from the North Pole to the equator. The kilogram was defined as 1000 times the mass of one cubic centimeter of distilled water. The liter is 1000 times the volume of one cubic centimeter of liquid. Consequently, one liter of water has a mass of 1 kilogram. Because of the possibility of error in the original measurement, the meter was redefined in terms of atomic radiation. Also, the kilogram is now defined as the mass of a certain platinum-iridium standard bar kept at the International Bureau of Weights and Measures in France. The second is, of course, 1/(86 400) of a mean solar day, but it is more accurately defined by atomic radiation.

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Unit of Force

The SI unit of force is the newton\(^1\) (N), defined as that force which will give a mass of 1 kilogram an acceleration of one meter per second per second.

When a body is to be accelerated or decelerated, a force must be applied proportional to the desired rate of change of velocity, that is, proportional to the acceleration (or deceleration).

\[
F = m \times \text{acceleration}
\]

Equation 1-1 gives the force in newtons when the mass is in kilograms and the acceleration is in m/s\(^2\).

If the body is to be accelerated vertically from the earth’s surface, the acceleration due to gravity \((g)\) must be overcome before any vertical motion is possible. In SI units:

\[
g = 9.81 \text{ m/s}^2
\]

Thus, a mass of 1 kg has a gravitational force of 9.81 N.

Work

When a body is moved, a force is exerted to overcome the body’s resistance to motion.

The work done in moving a body is the product of the force and the distance through which the body is moved in the direction of the force.

\[
W = F \times d
\]

The SI unit of work is the joule\(^2\) (J), defined as the amount of work done when a force of one newton acts through a distance of one meter.

Thus, the joule may also be termed a newton-meter. For the equation \(W = F \times d\), work is expressed in joules when \(F\) is in newtons and \(d\) is in meters.

Power

Power is the time rate of doing work.

If a certain amount of work \(W\) is to be done in a time \(t\), the power required is

\[
P = \frac{W}{t}
\]

The SI unit of power is the watt\(^3\) (W), defined as the power developed when one joule of work is done in one second.

For \(P = W/t\), \(P\) is in watts when \(W\) is in joules and \(t\) is in seconds.

---

\(^1\)Named for the great English philosopher and mathematician Sir Isaac Newton (1642–1727).

\(^2\)Named after the English physicist James P. Joule (1818–1899).

\(^3\)Named after the Scottish engineer and inventor James Watt (1736–1819).
Energy

Energy is defined as the capacity for doing work. Consequently, energy is measured in the same units as work.

When 1 W of power is used for one hour, the energy consumed (or work done) is one watt-hour (1 Wh). When 1 kW is used for one hour, 1 kilowatt-hour (1 kWh) of energy is consumed. Recall that power is the time rate of doing work, and that a power of 1 W represents a work rate of one joule per second (1 J/s). Therefore, when 1 W of power is dissipated for 1 s, 1 J of energy is consumed, or 1 J of work is done. Similarly, when 1 kW of power is expended for 1 minute

\[
\text{Energy consumed} = 1 \text{kW} \times 60 \text{s} = 60 \text{kJ}
\]

and when 1 kW is expended for 1 hour,

\[
\text{Energy consumed} = 1 \text{kW} \times 60 \text{s} \times 60 \text{min} = 3600 \text{kJ} = 3.6 \text{MJ}
\]

The megajoule (MJ) is the SI unit of energy consumption.

**Example 1-2**

Calculate the power required to raise a 100 kg load 100 m vertically in 30 s.

**Solution**

Eqs. 1-1 & 1-2,

\[
F = ma = 100 \text{kg} \times 9.81 \text{m/s}^2 = 981 \text{N}
\]

Eq. 1-3,

\[
W = F \times d = 981 \text{N} \times 100 \text{m} = 98100 \text{J}
\]

Eq. 1-4,

\[
P = \frac{W}{t} = \frac{98100 \text{J}}{30 \text{s}} = 3.27 \text{kW}
\]

**Section Review**

1-3.1 State the SI units for power and work, and define each unit.

**Practice Problem**

1-3.1 Determine how long it takes for an engine with a 750 W output to raise a 50 kg load vertically through 65 m.
1-4 THE SI ELECTRICAL UNITS

Units of Current and Charge

Electric current \((I)\) is a flow of charge carriers. Therefore, current could be defined in terms of the quantity of electricity \((Q)\) that passes a given point in a conductor during a time of \(1\) s.

The coulomb\(^4\) \((C)\) is the unit of electrical charge or quantity of electricity.

The coulomb was originally selected as the fundamental electrical unit from which other units were derived. However, because it is much easier to measure current accurately than it is to measure charge, the unit of current is now the fundamental electrical unit in the SI system. Consequently, the coulomb is a derived unit, defined in terms of the unit of electric current.

The ampere\(^5\) \((A)\) is the unit of electric current.

The ampere (also termed an absolute ampere) is defined as that constant current which, when flowing in each of two infinitely long parallel conductors \(1\) meter apart, exerts a force of \(2 \times 10^{-7}\) newton per meter of length on each conductor.

The coulomb is defined as that charge which passes a given point in a conductor each second, when a current of \(1\) ampere flows.

These definitions show that the coulomb could be termed an ampere-second. Conversely, the ampere can be described as a coulomb per second:

\[
\text{Amperes} = \frac{\text{coulomb}}{\text{second}} \quad (1-5)
\]

It has been established experimentally that \(1\) coulomb is equal to the total charge carried by \(6.24 \times 10^{18}\) electrons. Therefore, the charge carried by one electron is

\[
Q = \frac{1}{(6.24 \times 10^{18})} = 1.602 \times 10^{-19}\ C
\]

Emf, Potential Difference, and Voltage

The volt\(^6\) \((V)\) is the unit of electromotive force (emf) and potential difference.

The volt \((V)\) is defined as the potential difference between two points on a conductor carrying a constant current of one ampere when the power dissipated between these points is one watt.

As already noted, the coulomb is the charge carried by \(6.24 \times 10^{18}\) electrons. One joule of work is done when \(6.24 \times 10^{16}\) electrons are moved through a potential difference of \(1\) V. One electron carries a charge of \(1/(6.24 \times 10^{18})\) coulomb. If only one electron is moved through 1 V, the energy involved is an electron volt \((eV)\).

\[
1\ eV = \frac{1}{(6.24 \times 10^{18})}\ J \quad (1-6)
\]

\(^4\)Named after the French physicist Charles Augustin de Coulomb (1736–1806).

\(^5\)Named after the French physicist and mathematician Andre Marie Ampere (1775–1836).

\(^6\)Named in honour of the Italian physicist Count Alessandro Volta (1745–1827), inventor of the voltaic pile.
The electron-volt is frequently used in the case of the very small energy levels associated with electrons in orbit around the nucleus of an atom.

**Resistance and Conductance**

The ohm\(^7\) is the unit of resistance, and the symbol used for ohms is \(\Omega\), the Greek capital letter omega. The ohm is defined as that resistance which permits a current flow of one ampere when a potential difference of one volt is applied to the resistance.

The term conductance (\(G\)) is applied to the reciprocal of resistance. The siemens\(^8\) (S) is the unit of conductance. The unit of conductance was previously the mho (ohm spelled backwards).

**Magnetic Flux and Flux Density**

The weber\(^9\) (Wb) is the SI unit of magnetic flux.

The weber is defined as the magnetic flux which, linking a single-turn coil, produces a 1 V emf when the flux is reduced to zero at a constant rate in 1 s.

The tesla\(^10\) (T) is the SI unit of magnetic flux density.

The tesla is the flux density in a magnetic field when 1 weber of flux occurs in a plane of 1 square meter; that is, the tesla can be described as 1 Wb/m\(^2\).

**Inductance**

The SI unit of inductance is the henry\(^11\) (H).

The inductance of a circuit is 1 henry, when a 1 V emf is induced by the current changing at the rate of 1 A/s.

**Capacitance**

The farad\(^12\) (F) is the SI unit of capacitance.

The farad is the capacitance of a capacitor that contains a charge of 1 coulomb when the potential difference between its terminals is 1 volt.

**Example 1-3**

A bar magnet with a 1 inch square cross-section has 500 maxwells (see Appendix 1) total magnetic flux. Determine the flux density in teslas.

**Solution**

From Appendix 1,

\[
\Phi = (500 \text{ maxwell}) \times 10^{-8} \text{ Wb}
\]

\[
= 5 \mu\text{Wb}
\]

\(^7\)Named after the German physicist Georg Simon Ohm (1787–1854), whose investigations led to his statement of Ohm’s law of resistance.

\(^8\)Named after Sir William Siemens (1823–1883), a British engineer who was born Karl William von Siemens in Germany.

\(^9\)Named after the German physicist Wilhelm Weber (1804–1890).

\(^10\)Named for the Croatian-American researcher and inventor Nikola Tesla (1856–1943).

\(^11\)Named for the American physicist Joseph Henry (1797–1878).

\(^12\)Named for the English chemist and physicist Michael Faraday (1791–1867).
Chapter 1  Measurement Systems, Units, and Standards 9

<table>
<thead>
<tr>
<th>Area,</th>
<th>[ A = (1 \text{ in} \times 1 \text{ in}) \times (2.54 \times 10^{-2})^2 \text{ m}^2 ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flux density,</td>
<td>[ B = \frac{\Phi}{A} = \frac{5 \mu\text{Wb}}{2.54^2 \times 10^{-4}} ]</td>
</tr>
<tr>
<td></td>
<td>[ = 7.75 \text{ mT} ]</td>
</tr>
</tbody>
</table>

**Section Review**

1-4.1  State the SI units for current and charge, and define each unit.
1-4.2  State the SI units for magnetic flux and flux density, and define each unit.

**Practice Problem**

1-4.1  A bar magnet has a cross-section of 0.75 in × 0.75 in and a flux density of 1290 lines per square inch. Calculate the total flux in webers.

---

1-5 TEMPERATURE UNITS

**Temperature Scales**

There are two SI temperature scales, the **Celsius scale**\(^{13}\) and the **Kelvin scale**\(^{14}\). The Celsius scale has 100 equal divisions (or degrees) between the freezing temperature and the boiling temperature of water. At normal atmospheric pressure, water freezes at 0°C (zero degrees Celsius) and boils at 100°C.

The Kelvin temperature scale, also known as the **absolute scale**, commences at absolute zero of temperature, which corresponds to –273.15°C. Therefore, 0°C is equal to 273.15 K, and 100°C is the same temperature as 373.15 K. A temperature difference of 1 K is the same as a temperature difference of 1°C. With the (non-SI) **Fahrenheit scale**, 32°F is the freezing temperature of water and 212°F is the boiling temperature.

**Example 1-4**

The normal human body temperature is given as 98.6°F. Determine the equivalent Celsius and Kelvin scale temperatures.

**Solution**

From Appendix 1,

<table>
<thead>
<tr>
<th>Celsius temperature</th>
<th>[ = \frac{^\circ\text{F} - 32^\circ}{1.8} = \frac{98.7^\circ - 32^\circ}{1.8} = 37^\circ \text{C} ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kelvin temperature</td>
<td>[ = \frac{^\circ\text{F} - 32^\circ}{1.8} + 273.14 ]</td>
</tr>
<tr>
<td></td>
<td>[ = 310.15 \text{ K} ]</td>
</tr>
</tbody>
</table>

\(^{13}\)Invented by the Swedish astronomer and scientist Anders Celsius (1701–1744).

\(^{14}\)Named for the Irish-born scientist and mathematician William Thomson, who became Lord Kelvin (1824–1907).
Joules Equivalent

To raise a liter of water through 1 °C requires an energy input of 4187 J. This is known as Joules equivalent, or the mechanical equivalent of heat. Using Joules equivalent, the energy required to raise a quantity of water through a given temperature change can be easily calculated. When water is heated, the container must also be raised to the same temperature as the water, so each container is usually defined as having a certain water equivalent. The water equivalent is the quantity of water that would absorb the same amount of energy as the container when heated through a specified temperature change.

Practice Problem

1-5.1 Calculate the time required for a kettle with a 1500 W heating element and a 0.5 liter water equivalent to raise 2 liters of water from 24 °C to boiling point.

1-6 DIMENSIONS

Table 1-2 gives a list of quantities, quantity symbols, units, unit symbols, and quantity dimensions. The symbols and units are those approved for use with the SI system. To understand the dimensions column, consider the fact that the area of a rectangle is determined by multiplying the lengths of the two sides:

\[ \text{Area} = \text{length} \times \text{length} \]

The dimensions of area are \((\text{length})^2\)

or, \[ [\text{area}] = [L][L] = [L]^2 \]

Similarly, \[ [\text{velocity}] = \frac{[\text{length}]}{[\text{time}]} = \frac{[L]}{[T]} = [LT^{-1}] \]

\[ [\text{acceleration}] = \frac{[\text{velocity}]}{[\text{time}]} = \frac{[LT^{-1}]}{[T]} = [LT^{-2}] \]

\[ [\text{force}] = [\text{mass}] \times [\text{acceleration}] \]

\[ = [M][LT^{-2}] = [MLT^{-2}] \]

\[ [\text{work}] = [\text{force}] \times [\text{distance}] \]

\[ = [MLT^{-2}][L] = [ML^2T^{-2}] \]

\[ [\text{power}] = \frac{[\text{work}]}{[\text{time}]} = \frac{[ML^2T^{-2}]}{[T]} = [ML^2T^{-3}] \]

For the electrical quantities, current is another fundamental unit. So, electrical quantities can be analyzed to determine dimensions in the fundamental units of \(L\), \(M\), \(T\), and \(I\).

\[ \text{Charge} = \text{current} \times \text{time} \]

\[ [\text{charge}] = [I][T] = [IT] \]
Example 1-5
Determine the dimensions of voltage and resistance.

Solution

From,

\[ P = EI \]

voltage,

\[ [E] = \frac{[P]}{[I]} = \frac{[ML^2T^{-3}]}{[I]} = [ML^2T^{-3}I^{-1}] \]

resistance,

\[ [R] = \frac{[E]}{[I]} = \frac{[ML^2T^{-3}I^{-1}]}{[I]} = [ML^2T^{-3}I^{-2}] \]

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Unit</th>
<th>Unit symbol</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>( l )</td>
<td>meter</td>
<td>m</td>
<td>[L]</td>
</tr>
<tr>
<td>Mass</td>
<td>( m )</td>
<td>kilogram</td>
<td>kg</td>
<td>[M]</td>
</tr>
<tr>
<td>Time</td>
<td>( t )</td>
<td>second</td>
<td>s</td>
<td>[T]</td>
</tr>
<tr>
<td>Area</td>
<td>( A )</td>
<td>square meter</td>
<td>m(^2)</td>
<td>[L(^2)]</td>
</tr>
<tr>
<td>Volume</td>
<td>( V )</td>
<td>cubic meter</td>
<td>m(^3)</td>
<td>[L(^3)]</td>
</tr>
<tr>
<td>Velocity</td>
<td>( v )</td>
<td>meter per second</td>
<td>m/s</td>
<td>[LT(^{-1})]</td>
</tr>
<tr>
<td>Acceleration</td>
<td>( a )</td>
<td>meter per sec per sec</td>
<td>m/s(^2)</td>
<td>[LT(^{-2})]</td>
</tr>
<tr>
<td>Force</td>
<td>( F )</td>
<td>newton</td>
<td>N</td>
<td>[MLT(^{-2})]</td>
</tr>
<tr>
<td>Pressure</td>
<td>( p )</td>
<td>newton per square meter</td>
<td>N/m(^2)</td>
<td>[ML(^{-1})T(^{-2})]</td>
</tr>
<tr>
<td>Work</td>
<td>( W )</td>
<td>joule</td>
<td>J</td>
<td>[ML(^2)T(^{-2})]</td>
</tr>
<tr>
<td>Power</td>
<td>( P )</td>
<td>watt</td>
<td>W</td>
<td>[ML(^2)T(^{-3})]</td>
</tr>
<tr>
<td>Electric current</td>
<td>( I )</td>
<td>ampere</td>
<td>A</td>
<td>[I]</td>
</tr>
<tr>
<td>Electric charge</td>
<td>( Q )</td>
<td>coulomb</td>
<td>C</td>
<td>[IT]</td>
</tr>
<tr>
<td>Emf</td>
<td>( V )</td>
<td>volt</td>
<td>V</td>
<td>[ML(^2)T(^{-3})I(^{-1})]</td>
</tr>
<tr>
<td>Electric field strength</td>
<td>( \xi )</td>
<td>volt per meter</td>
<td>V/m</td>
<td>[MLT(^{-3})I(^{-1})]</td>
</tr>
<tr>
<td>Resistance</td>
<td>( R )</td>
<td>ohm</td>
<td>( \Omega )</td>
<td>[ML(^2)T(^{-3})I(^{-2})]</td>
</tr>
<tr>
<td>Capacitance</td>
<td>( C )</td>
<td>farad</td>
<td>F</td>
<td>[M(^{-1})L(^{-2})T(^{-4})]</td>
</tr>
<tr>
<td>Inductance</td>
<td>( L )</td>
<td>henry</td>
<td>H</td>
<td>[ML(^2)T(^{-3})I(^{-2})]</td>
</tr>
<tr>
<td>Magnetic field strength</td>
<td>( H )</td>
<td>ampere per meter</td>
<td>A/m</td>
<td>[IL(^{-1})]</td>
</tr>
<tr>
<td>Magnetic flux</td>
<td>( \Phi )</td>
<td>weber</td>
<td>Wb</td>
<td>[ML(^2)T(^{-2})I(^{-1})]</td>
</tr>
<tr>
<td>Magnetic flux density</td>
<td>( B )</td>
<td>tesla</td>
<td>T</td>
<td>[MT(^{-2})I(^{-1})]</td>
</tr>
</tbody>
</table>
Practice Problems

1-6.1 Determine the dimensions of power from \( P = I^2 R \) and from \( P = V^2 / R \).

1-6.2 The permeability of a magnetic material is \( \mu = B / H \). Determine the dimensions of \( \mu \).

1-7 MEASUREMENT STANDARDS

Standard Classifications

Electrical measurement standards are precise resistors, capacitors, inductors, voltage sources, and current sources, which can be used for comparison purposes when measuring electrical quantities. For example, resistance can be accurately measured by means of a Wheatstone bridge (see Section 8-2) which uses a standard resistor. Similarly, standard capacitors and inductors may be employed in bridge (or other) methods to accurately measure capacitance and inductance.

Measurement standards are classified in four levels: international standards, primary standards, secondary standards, and working standards.

International standards are defined by international agreements, and are maintained at the International Bureau of Weights and Measures in France. These are as accurate as it is scientifically possible to achieve. They may be used for comparison with primary standards, but are otherwise unavailable for any application.

Primary standards are maintained at institutions in various countries around the world, such as the National Bureau of Standards in Washington. They are also constructed for the greatest possible accuracy, and their main function is checking the accuracy of secondary standards.

Secondary standards are employed in industry as references for calibrating high-accuracy equipment and components, and for verifying the accuracy of working standards. Secondary standards are periodically checked at the institutions that maintain primary standards.

Working standards are the standard resistors, capacitors, and inductors usually found in a measurements laboratory. Working standard resistors are usually constructed of manganin or a similar material, which has a very low temperature coefficient. They are normally available in resistance values ranging from 0.01 \( \Omega \) to 1 M\( \Omega \), with typical accuracies of \( \pm 0.01 \% \) to \( \pm 0.1 \% \). A working standard capacitor could be air dielectric type, or it might be constructed of silvered mica. Available capacitance values are 0.001 \( F \) to 1 \( F \) with a typical accuracy of \( \pm 0.02 \% \). Working standard inductors are available in values ranging from 100 \( H \) to 10 \( H \) with typical accuracies of \( \pm 0.1 \% \). Calibrators provide standard voltages and currents for calibrating voltimeters and ammeters (see Section 14-2).

IEEE Standards

Standards published by the Institute of Electrical and Electronic Engineers (IEEE) are not the kind of measurement standards discussed above. Instead,
for example, they are standards for electrical hardware, for the controls on
instrument front panels, for test and measuring procedures, and for
electrical installations in particular situations. Standard device and logic
graphic symbols for use on schematics are also listed. For instrumentation
systems, a very important IEEE standard is standard hardware for
interfacing instruments to computers for monitoring and control purposes.
Detailed information about IEEE standards is available on the internet.

Section Review

1-7.1 List the various categories of measurement standards, and discuss
their applications.

REVIEW QUESTIONS

Section 1-1
1-1 Identify the two CGS units systems, and discuss difficulties that occur with
their use.
1-2 Briefly discuss the origins of the SI system as an MKS system, and why the
MKS system became the preferred practical units system.
1-3 Define the following in respect to a units system: Fundamental units, derived
units, primary fundamental units, auxiliary fundamental units, rationalized
system.
1-4 State the expressions for the permittivity of free space and the permeability of
free space in the CGS unit systems and in the SI system.

Section 1-2
1-5 List the names of the various metric prefixes and the corresponding symbols.
Also, list the value of each prefix in scientific notation.

Section 1-3
1-6 List the three fundamental SI mechanical units and unit symbols, and discuss
their origin.
1-7 Define the SI units for force and work.
1-8 Define \( g \), and state its numerical value in SI units.
1-9 Identify the SI units and unit symbols for energy and power. Define each unit.

Section 1-4
1-10 State the SI units and unit symbols for electric current and charge. Define each
unit.
1-11 Define the SI units for electrical resistance and conductance.
1-12 Identify the SI units and unit symbols for magnetic flux and flux density.
Define each unit.
1-13 Define the SI units for inductance and capacitance.

Section 1-5
1-14 Name the two SI temperature scales, and identify the freezing and boiling
temperatures of water for each scale.

Section 1-6
1-15 State the dimensions of the four fundamental units in the SI system, and write
the dimensions for volume, velocity, and charge.
1-16 List the various levels of measurement standards, and discuss the application of each classification.

PROBLEMS

Section 1-2

1-1 Express the following quantities using (a) scientific notation, (b) metric prefixes: 0.029 A, 13 000 Ω, 5240 V, 0.0003 H, 738 000 Ω.

1-2 Perform the following calculations to produce the answers using scientific notation: (a) 0.29 × 1300/0.006, (b) 83 400/5.13, (c) 0.4² × 300, (d) 3³₀⁹/(√169), (e) 0.005³/1200.

1-3 Express the following quantities using (a) engineering notation, (b) metric prefixes: 6800 Ω, 0.000 05 A, 0.027 H, 82 000 V, 0.0005 F.

Section 1-3

1-4 Referring to the unit conversion factors in Appendix 1, perform the following conversions: (a) 6215 miles to kilometers, (b) 50 miles per hour to kilometers per hour, and (c) 12 square feet to square centimeters.

1-5 Determine how long it takes light to travel to earth from a star 1 million miles away. The speed of light is 3 × 10⁸ m/s.

1-6 The speed of sound in air is 345 m/s. Calculate the distance in miles from a thunderstorm when the thunder is heard 5 s after the lightning flash.

1-7 A 140 lb person has a height of 5 ft 7 in. Convert these measurements into kilograms and centimeters.

1-8 Determine the force that must be exerted by a crane to lift a 20 000 kg load.

1-9 A 2000 kg automobile is accelerated to 70 km/h in a 20 s time period. Neglecting all friction effects, calculate the force exerted by the engine.

1-10 A 1000 kg elevator with a 1500 kg load is raised through a height of 60 m in 1 minute. Calculate the work done and the power involved.

1-11 One thousand liters of water is pumped through a 20 m height in a 30 minute time period. Determine the work done and the power required.

Section 1-4

1-12 A 1/4 horsepower electric motor is operated 8 hours per day for 5 days every week. Assuming 100% efficiency, calculate the amount of energy consumed in 1 year in kWh and in MJ.

1-13 Calculate the number of electrons that pass through a resistor in a 1.5 h period when a 500 mA current flows.

1-14 Determine the work done in joules when a 2 A current flows through a 12 Ω resistor for 45 minutes.

1-15 An electrical appliance consumes 1500 W of power when connected to a 115 V supply. Determine the supply current and the energy consumed in 5 h of operation.

1-16 Calculate the conductance of a lamp that dissipates 60 W when connected to a 120 V supply.

1-17 An electronic amplifier produces 12 W output to a speaker. The amplifier draws a current of 650 mA from a 25 V supply. Calculate the amplifier efficiency.
Chapter 1
Measurement Systems, Units, and Standards

1-18 A 115 V electrical appliance with 80% efficiency absorbs 3 kW from the supply. Determine the energy consumed by the appliance and the energy output from the supply over a 12 h period.

1-19 A total flux of 0.5 µWb is emitted from one pole of a bar magnet. The pole dimensions are 0.48 inches × 0.48 inches. Calculate the flux density in tesla within the metal. Also, determine the flux density at a short distance from the pole if all of the flux is contained in an area of 2 inches × 2 inches.

Section 1-5

1-20 Calculate the Celsius and Kelvin scale equivalents of 80°F.

1-21 An electric water heater takes 6 minutes to boil 1 liter of water in a pot which has a 0.2 liter water equivalent. If the element draws 11 A from the 115 V supply, calculate the efficiency of the heater.

Section 1-6

1-22 Determine the dimensions of area, volume, velocity, and acceleration.

1-23 Derive the dimensions for force, work, energy, and power.

1-24 Derive the dimensions for charge, voltage, and resistance.

1-25 Determine the dimensions of capacitance and inductance.

1-26 The balance equations for a Maxwell-Wein bridge (Section 10-4) gives \( L_2 = \frac{C_3}{R_1 R_4} \). Use dimensional analysis to show that the right side of the equation has the dimensions of inductance.

Practice Problem Answers

1-2.1 \(5 \times 10^{-3}, 77.7 \times 10^{3}, 60 \times 10^{-4}, 59 \times 10^{6}, 330 \times 10^{-6}\)

1-3.1 42.5 s

1-4.1 7 µWb

1-5.1 8.8 min

1-6.1 \([ML^2T^{-3}]\)

1-6.2 \([MLT^{-2}I^{-2}]\)