STATICS AND MECHANICS OF MATERIALS

Sixth Edition

R. C. HIBBELER

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SIXTH EDITION

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To the Student

With the hope that this work will stimulate
an interest in Engineering Mechanics and
Mechanics of Materials and provide
an acceptable guide to its understanding.

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PREFACE

This book represents a combined abridged version of two of the author's books, namely *Engineering Mechanics: Statics, Fifteenth Edition and Mechanics of Materials, Eleventh Edition*. It provides a clear and thorough presentation of both the theory and application of the important fundamental topics of these subjects, that are often used in many engineering disciplines. The development emphasizes the importance of satisfying equilibrium, compatibility of deformation, and material behavior requirements. The hallmark of the book, however, remains the same as the author's unabridged versions, and that is, strong emphasis is placed on drawing a free-body diagram, and the importance of selecting an appropriate coordinate system and an associated sign convention whenever the equations of mechanics are applied. Throughout the book, many analysis and design applications are presented, which involve mechanical elements and structural members often encountered in engineering practice.

New to this Edition

- **Expanded Answer Section.** The answer section in the back of the book now includes additional information related to the solution of select Fundamental Problems in order to offer the student some guidance in solving the problems.

- **Re-writing of Text Material.** Further clarification of some concepts has been included in this edition, and throughout the book the accuracy has been enhanced, and important definitions are now in boldface throughout the book to highlight their importance.

- **New Photos.** The relevance of knowing the subject matter is reflected by the real-world applications depicted in the many new or updated photos placed throughout the book. These photos generally are used to explain how the relevant principles apply to real-world situations and how materials behave under load.

- **New Problems.** There are approximately 30% new problems that have been added to this edition, which involve applications to many different fields of engineering.

- **New Videos.** Three types of videos are available that are designed to enhance the most important material in the book. Lecture videos serve to test the student's ability to understand the concepts. Example problem videos are intended to review these problems, and fundamental problem videos guide the student in solving these problems that are in the book.

Hallmark Features

Besides the new features just mentioned, other outstanding features that define the contents of the text include the following.

Organization and Approach. Each chapter is organized into well-defined sections that contain an explanation of specific topics, illustrative example problems, and a set of homework problems. The topics within each section are placed into subgroups defined by boldface titles. The purpose of this is to present a structured method for introducing each new definition or concept and to make the book convenient for later reference and review.

Chapter Contents. Each chapter begins with a photo demonstrating a broad-range application of the material within the chapter. A bulleted list of the chapter contents is provided to give a general overview of the material that will be covered.

Emphasis on Free-Body Diagrams. Drawing a free-body diagram is particularly important when solving problems, and for this reason, this step is strongly emphasized throughout the book. In particular, within the statics coverage some sections are devoted to show how to draw free-body diagrams. Specific homework problems have also been added to develop this practice.

Procedures for Analysis. A general procedure for analyzing any mechanics problem is presented at the end of the first chapter. Then this procedure is customized to relate to specific types of problems that are covered throughout the book. This unique feature provides the student with a logical and orderly method to follow when applying the theory. The example problems are solved using this outlined method in order to clarify its numerical application. Realize, however, that once the relevant principles have been mastered and enough confidence and judgment have been obtained, the student can then develop his or her own procedures for solving problems.

Important Points. This feature provides a review or summary of the most important concepts in a section and highlights the most significant points that should be realized when applying the theory to solve problems.

Conceptual Understanding. Through the use of photographs placed throughout the book, the theory is applied in a simplified way in order to illustrate some of its more important conceptual features and instill the physical meaning of many of the terms used in the equations. These simplified applications increase interest in the subject matter and better prepare the student to understand the examples and solve problems.

Fundamental Problems. These problems may be considered as extended examples, since the key equations and answers are all listed in the back of the book. Additionally, when assigned, these problems offer students an excellent means of preparing for exams, and they can be used at a later time as a review when studying for the Fundamentals of Engineering Exam.

Homework Problems. Apart from the Fundamental type problems mentioned previously, other types of problems contained in the book include the following:

- **General Analysis and Design Problems.** The majority of problems in the book depict realistic situations encountered in engineering practice. Some of these problems come from actual products used in industry. It is hoped that this realism will both stimulate the student's interest in engineering mechanics and provide a means for developing the skill to reduce any such problem from its physical description to a model or symbolic representation to which the principles of mechanics may be applied.

  Throughout the book, there is an approximate balance of problems using either SI or FPS units. Furthermore, in any set, an attempt has been made to arrange the problems in order of increasing difficulty, except for the end of chapter review problems, which are presented in random order. Problems that are simply indicated by a problem number have an answer given in the back of the book. However, an asterisk (*) before every fourth problem number indicates a problem without an answer.

Accuracy. As with the previous editions, apart from the author, the accuracy of the text and problem solutions has been thoroughly checked in part by Kai Beng Yap, a practicing engineer, and a team of specialists at EPAM, including Georgii Kolobov, Ekaterina Radchenko, and Artur Akberov.

Contents

The book is divided into two parts, and the material is covered in the traditional manner.

Statics. The subject of statics is presented in 6 chapters. The text begins in Chapter 1 with an introduction to mechanics and a discussion of units. The notion of a vector and the properties of a concurrent force system are introduced in Chapter 2. Chapter 3 contains a general discussion of concentrated force systems and the methods used to simplify them. The principles of rigid-body equilibrium are developed in Chapter 4 and then applied to specific problems involving the equilibrium of trusses, frames, and machines in Chapter 5. Finally, topics related to the center of gravity, centroid, and moment of inertia are treated in Chapter 6.

Mechanics of Materials. This portion of the text is covered in 10 chapters. Chapter 7 begins with a formal definition of both normal and shear stress, and a discussion of normal stress in axially loaded members and average shear stress caused by direct shear; finally, normal and shear strain are defined. In Chapter 8, a discussion of some of the important mechanical properties of materials is given. Separate treatments of axial load, torsion, bending, and transverse shear are presented in Chapters 9, 10, 11, and 12, respectively. Chapter 13 provides a partial review of the material covered in the previous chapters, in which the state of stress resulting from combined loadings is discussed. In Chapter 14, the concepts for transforming stress and strain are presented. Chapter 15 provides a means for a further summary and review of previous material by covering design of beams based on allowable stress. In Chapter 16, various methods for computing deflections of beams are presented, including the method for finding the reactions on these members if they are statically indeterminate. Lastly, Chapter 17 provides a discussion of column buckling.

Sections of the book that contain more advanced material are indicated by a star (*). Time permitting, some of these topics may be included in the course. Furthermore, this material provides a suitable reference for basic principles when it is covered in other courses, and it can be used as a basis for assigning special projects.

Alternative Method for Coverage of Mechanics of Materials. It is possible to cover many of the topics in the text in several different sequences. For example, some instructors prefer to cover stress and strain transformations *first,* before discussing specific applications of axial load, torsion, bending, and shear. One possible method for doing this would be to first cover stress and strain and its transformations, Chapter 7 and Chapter 14, then Chapters 8 through 13 can be covered with no loss in continuity.

Acknowledgments

Over the years, this text has been shaped by the suggestions and comments of many of my colleagues in the teaching profession. Their encouragement and willingness to provide constructive criticism are very much appreciated and it is hoped that they will accept this anonymous recognition. A note of thanks is also given to the reviewers of both my *Engineering Mechanics: Statics and Mechanics of Materials* texts. Their comments have guided the improvement of this book as well.

In particular, I would like to thank: S. Apple, A. Bazar, Fullerton, M. Hughes, R. Jackson, E. Tezak, H. Zhao,, K. Dennehy, A. Lutz, M. Walter, M. Zhang, A. Asgharatal, S. Ahmad, J. Aurand, D. Boyajian, J. Callahan, D. Dikin, I. Elishakoff, R. Hendricks, F. Herrera, J. Hilton, H. Kuhlman, K. Leipold, C. Roche, M. Rosengren, R. Scott, J. Tashbar, M. Bailey, B. Smith, and J. Nadeau.

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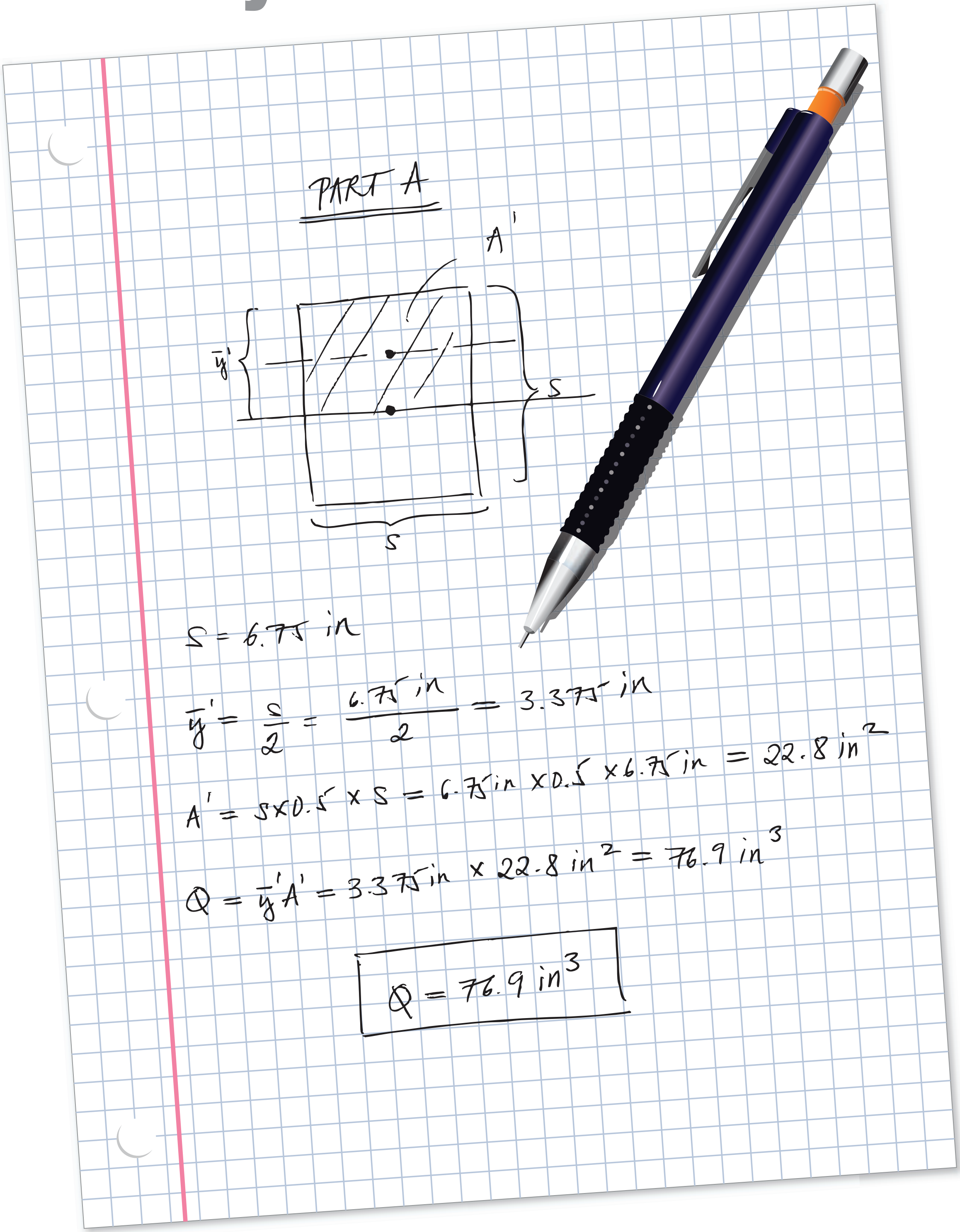
I would greatly appreciate hearing from you at any time if you have any comments or suggestions regarding the contents of this edition.

Russell Charles Hibbeler
hibbeler@bellsouth.net

your work...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Instructor's Solutions Manual This supplement provides complete solutions supported by problem statements and problem figures. The Instructor's Solutions Manual is available in PDF format on Pearson Higher Education website: www.pearson.com.

PowerPoint Slides A complete set of all the figures and tables from the textbook are available in PowerPoint format.

Resources for Students

Videos Developed by the author, three different types of videos are now available to reinforce learning the basic theory and applying the principles. The first set provides a lecture review and a self-test of the material related to the theory and concepts presented in the book. The second set provides a self-test of the example problems and the basic procedures used for their solution. And the third set provides an engagement for solving the Fundamental Problems throughout the book. For more information on how to access these videos visit www.pearson.com/hibbeler.

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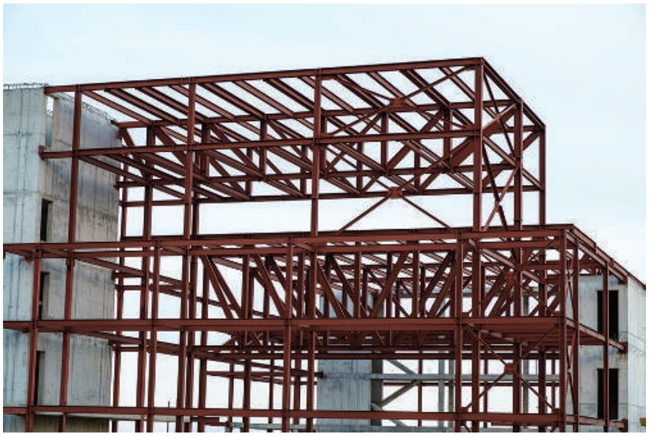

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STATICS AND MECHANICS OF MATERIALS

SIXTH EDITION

CHAPTER 1

Cranes such as this one are required to lift extremely large loads. Their design is based on the basic principles of statics and dynamics, which form the subject matter of engineering mechanics.

GENERAL PRINCIPLES

CHAPTER OBJECTIVES

- To provide an introduction to the basic quantities and idealizations of mechanics.
- To state Newton's Laws of Motion.
- To review the principles for applying the SI system of units.
- To examine the standard procedures for performing numerical calculations.
- To present a general guide for solving problems.

1.1 MECHANICS

Mechanics can be defined as that branch of the physical sciences concerned with the state of rest or motion of bodies that are subjected to the action of forces. In this book we will study two important branches of mechanics, namely, statics and mechanics of materials. These subjects form a suitable basis for the design and analysis of many types of structural, mechanical, or electrical devices encountered in engineering.

Statics deals with the equilibrium of bodies, that is, it is used to determine the forces acting either external to the body or within it that are necessary to keep the body in equilibrium. *Mechanics of materials* studies the relationships between the external loads and the distribution of internal forces acting within the body. This subject is also concerned with finding the deformations of the body, and it provides a study of the body's stability.

In this book we will first study the principles of statics, since for the design and analysis of any structural or mechanical element it is *first* necessary to determine the forces acting both on and within its various members. Once these internal forces are determined, the size of the members, their deflection, and their stability can then be determined using the fundamentals of mechanics of materials, which will be covered later.

Historical Development. The subject of statics developed very early in history because its principles can be formulated simply from measurements of geometry and force. For example, the writings of Archimedes (287–212 B.C.) deal with the principle of the lever. Studies of the pulley and inclined plane are also recorded in ancient writings—at times when the requirements for engineering were limited primarily to building construction.

The origin of mechanics of materials dates back to the beginning of the seventeenth century, when Galileo performed experiments to study the effects of loads on rods and beams made of various materials. However, at the beginning of the eighteenth century, experimental methods for testing materials were vastly improved, and at that time many experimental and theoretical studies in this subject were undertaken primarily in France, by such notables as Saint-Venant, Poisson, Lamé, and Navier.

Over the years, after many of the fundamental problems of mechanics of materials had been solved, it became necessary to use advanced mathematical and computer techniques to solve more complex problems. As a result, this subject has expanded into other areas of mechanics, such as the *theory of elasticity* and the *theory of plasticity*. Research in these fields is ongoing, in order to meet the demands for solving more advanced problems in engineering.

1.2 FUNDAMENTAL CONCEPTS

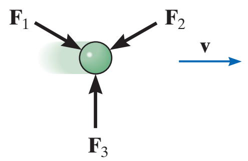
Before we begin our study, it is important to understand the definitions of certain fundamental concepts and principles.

Mass. ***Mass*** is a measure of a *quantity of matter* that is used to compare the action of one body with that of another. This property provides a measure of the resistance of matter to a change in velocity.

Force. In general, ***force*** is considered as a "push" or "pull" exerted by one body on another. This interaction can occur when there is direct contact between the bodies, such as a person pushing on a wall, or it can occur through a distance when the bodies are physically separated. Examples of the latter type include gravitational, electrical, and magnetic forces. In any case, a force is completely characterized by its magnitude, direction, and point of application.

Newton's Three Laws of Motion. Engineering mechanics is formulated on the basis of Newton's three laws of motion, the validity of which is based on experimental observation. These laws apply to the motion of a particle as measured from a *nonaccelerating* reference frame. They may be briefly stated as follows.

First Law. A particle originally at rest, or moving in a straight line with constant velocity, tends to remain in this equilibrium state provided the particle is *not* subjected to an unbalanced force, Fig. 1–1*a*.

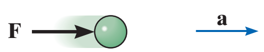


Equilibrium

(a)

Second Law. A particle acted upon by an *unbalanced force* **F** experiences an acceleration **a** that has the same direction as the force and a magnitude that is directly proportional to the force, Fig. 1–1*b*.* If the particle has a mass *m*, this law may be expressed mathematically as

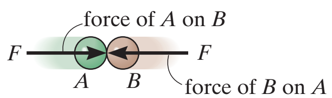
$$\mathbf{F} = m\mathbf{a} \tag{1–1}$$



Accelerated motion

(b)

Third Law. The mutual forces of action and reaction between two particles are equal, opposite, and collinear, Fig. 1–1*c*.



Action–reaction

(c)

Fig. 1–1

*Stated another way, the unbalanced force acting on the particle is proportional to the time rate of change of the particle's linear momentum.

Newton's Law of Gravitational Attraction. Shortly after formulating his three laws of motion, Newton postulated a law governing the gravitational attraction between any two particles. Stated mathematically,

$$F = G\frac{m_1 m_2}{r^2} \tag{1–2}$$

where

F = force of gravitation between the two particles

G = universal constant of gravitation; according to experimental evidence, $G = 66.73\left(10^{-12}\right)\ \mathrm{m}^3/\left(\mathrm{kg}\cdot\mathrm{s}^2\right)$

m_1, m_2 = mass of each of the two particles

r = distance between the two particles

The astronaut's weight is diminished since she is far removed from the gravitational field of the earth.

Weight. According to Eq. 1–2, any two particles or bodies have a mutual attractive (gravitational) force acting between them. In the case of a particle located at or near the surface of the earth, however, the only gravitational force having any sizable magnitude is that between the earth, because of its very large mass, and the particle. Consequently, this force, called the ***weight***, will be the only gravitational force we will consider.

From Eq. 1–2, if the particle has a mass $m_1 = m$, and we assume the earth is a nonrotating sphere of constant density and having a mass $m_2 = M_e$, then if r is the distance between the earth's center and the particle, the weight W of the particle becomes

$$W = G\frac{mM_e}{r^2}$$

If we let $g = GM_e/r^2$, we have

$$\boxed{W = mg} \tag{1–3}$$

If we allow the particle to fall downward, then neglecting air resistance, the only force acting on the particle is its weight, and so Eq. 1–1 becomes $W = ma$. Comparing this result with Eq. 1–3, we see that $a = g$. In other words, g is the acceleration due to gravity. Since it depends on r, then the weight of the particle or body is *not* an absolute quantity. Instead, its magnitude depends upon the elevation where the measurement was made. For most engineering calculations, however, g is determined at sea level and at a latitude of 45°, which is considered the "standard location."

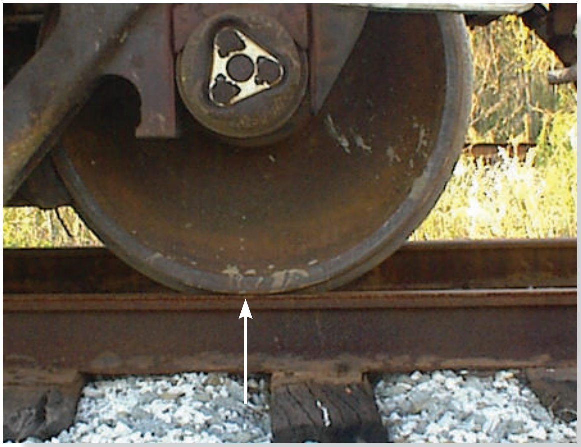
Idealizations. Models or idealizations are used in mechanics in order to simplify application of the theory. Here we will consider three important idealizations.

Particle. A ***particle*** has a mass, but a size that can be neglected. For example, the size of the earth is insignificant compared to the size of its orbit, and therefore the earth can be modeled as a particle when studying its orbital motion. When a body is idealized as a particle, the principles of mechanics reduce to a rather simplified form since the geometry of the body *will not be involved* in the analysis of the problem.

Rigid Body. A ***rigid body*** can be considered as a combination of a large number of particles in which all the particles remain at a fixed distance from one another, both before and after applying a load. This model is important because the body's shape does not change when a load is applied, and so we do not have to consider the type of material from which the body is made. In most cases the actual deformations occurring in structures, machines, mechanisms, and the like are relatively small, and the rigid-body assumption is suitable for analysis.

Concentrated Force. A ***concentrated force*** represents the effect of a loading which is assumed to act at a point on a body. We can represent a load by a concentrated force, provided the area over which the load is applied is very small compared to the overall size of the body. An example would be the contact force between a wheel and the ground.

Three forces act on the ring. Since these forces all meet at a point, then for any force analysis, we can assume the ring to be represented as a particle.



Steel is a common engineering material that does not deform very much under load. Therefore, we can consider this railroad wheel to be a rigid body acted upon by the concentrated force of the rail.

1

TABLE 1–1 SI System of Units

Name	Length	Time	Mass	Force
International System of Units	meter	second	kilogram	newton*
SI	m	s	kg	N $\left(\frac{kg \cdot m}{s^2}\right)$

*Derived unit.

1.3 THE INTERNATIONAL SYSTEM OF UNITS

The four basic quantities—length, time, mass, and force—are not all independent from one another; in fact, they are *related* by Newton's second law of motion, $\mathbf{F} = m\mathbf{a}$. Because of this, the *units* used to measure these quantities cannot *all* be selected arbitrarily. The equality $\mathbf{F} = m\mathbf{a}$ is maintained only if three of the four units, called ***base units***, are *defined* and the fourth unit is then *derived* from the equation.

For the International System of Units, abbreviated SI after the French "Système International d'Unités," length is in meters (m), time is in seconds (s), and mass is in kilograms (kg), Table 1–1. The unit of force, called a ***newton*** (N), is *derived* from $\mathbf{F} = m\mathbf{a}$. Thus, 1 newton is equal to a force required to give 1 kilogram of mass an acceleration of $1 \text{ m/s}^2 \left(\text{N} = \text{kg} \cdot \text{m/s}^2\right)$.

If the weight of a body located at the "standard location" is to be determined in newtons, then Eq. 1–3 must be applied. Here measurements give $g = 9.806\,65 \text{ m/s}^2$; however, for calculations the value $g = 9.81 \text{ m/s}^2$ will be used. Thus,

$$W = mg \quad (g = 9.81 \text{ m/s}^2) \tag{1–4}$$

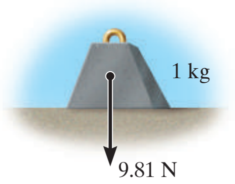


Fig. 1–1

Therefore, a body of mass 1 kg has a weight of 9.81 N, a 2-kg body weighs 19.62 N, and so on, Fig. 1–1. Perhaps it is easier to remember that a small apple weighs one newton. Also, by comparison with the U.S. Customary system of units (FPS),

$$1 \text{ pound (lb)} = 4.448 \text{ N}$$
$$1 \text{ foot (ft)} = 0.3048 \text{ m}$$

Prefixes. When a numerical quantity is either very large or very small, the units used to define its size may be modified by using a prefix. Some of the prefixes used in the SI system are shown in Table 1–2. Each represents a multiple or submultiple of a unit which, if applied successively, moves the decimal point of a numerical quantity to every third place.* For example, 4 000 000 N = 4 000 kN (kilo-newton) = 4 MN (mega-newton), or 0.005 m = 5 mm (milli-meter). Notice that the SI system does not include the multiple deca (10) or the submultiple centi (0.01), which form part of the metric system. Except for some volume and area measurements, the use of these prefixes is generally avoided in science and engineering.

TABLE 1–2 Prefixes

	Exponential Form	Prefix	SI Symbol
Multiple			
1 000 000 000	10^9	giga	G
1 000 000	10^6	mega	M
1 000	10^3	kilo	k
Submultiple			
0.001	10^{-3}	milli	m
0.000 001	10^{-6}	micro	μ
0.000 000 001	10^{-9}	nano	n

Rules for Use. Here are a few of the important rules that describe the proper use of the various SI symbols:

- Quantities defined by several units which are multiples of one another are separated by a *dot* to avoid confusion with prefix notation, as indicated by $\mathrm{N} = \mathrm{kg \cdot m/s^2} = \mathrm{kg \cdot m \cdot s^{-2}}$. Also, $\mathrm{m \cdot s}$ (meter-second), whereas ms (milli-second).
- The exponential power on a unit having a prefix refers to both the unit *and* its prefix. For example, $\mu\mathrm{N}^2 = (\mu\mathrm{N})^2 = \mu\mathrm{N} \cdot \mu\mathrm{N}$. Likewise, mm^2 represents $(\mathrm{mm})^2 = \mathrm{mm \cdot mm}$.
- With the exception of the base unit the kilogram, in general avoid the use of a prefix in the denominator of composite units. For example, do not write N/mm, but rather kN/m; also, m/mg should be written as Mm/kg.
- When performing calculations, represent the numbers in terms of their *base or derived units* by converting all prefixes to powers of 10. The final result should then be expressed using a *single prefix*. Also, after calculation, it is best to keep numerical values between 0.1 and 1000; otherwise, a suitable prefix should be chosen. For example,

$$
\begin{aligned}
(50\,\mathrm{kN})(60\,\mathrm{mm}) &= \left[50(10^3)\,\mathrm{N}\right]\left[60(10^{-9})\mathrm{m}\right] \\
&= 3000(10^{-6})\,\mathrm{N \cdot m} = 3(10^{-3})\,\mathrm{N \cdot m} = 3\,\mathrm{mN \cdot m}
\end{aligned}
$$

*The kilogram is the only base unit that is defined with a prefix.