Goals for Chapter 1

• To learn three fundamental quantities of physics and the units to measure them

• To keep track of significant figures in calculations

• To understand vectors and scalars and how to add vectors graphically

• To determine vector components and how to use them in calculations

• To understand unit vectors and how to use them with components to describe vectors

• To learn two ways of multiplying vectors
The nature of physics

• Physics is an experimental science in which physicists seek patterns that relate the phenomena of nature.

• The patterns are called physical theories.

• A very well established or widely used theory is called a physical law or principle.
Solving problems in physics

- A *problem-solving strategy* offers techniques for setting up and solving problems efficiently and accurately.

**Problem-Solving Strategy 1.1 Solving Physics Problems**

**IDENTIFY** *the relevant concepts:* Use the physical conditions stated in the problem to help you decide which physics concepts are relevant. Identify the **target variables** of the problem—that is, the quantities whose values you’re trying to find, such as the speed at which a projectile hits the ground, the intensity of a sound made by a siren, or the size of an image made by a lens. Identify the known quantities, as stated or implied in the problem. This step is essential whether the problem asks for an algebraic expression or a numerical answer.

**SET UP** *the problem:* Given the concepts you have identified and the known and target quantities, choose the equations that you’ll use to solve the problem and decide how you’ll use them. Make sure that the variables you have identified correlate exactly with those in the equations. If appropriate, draw a sketch of the situation described in the problem. (Graph paper, ruler, protractor, and compass will help you make clear, useful sketches.) As best you can, estimate what your results will be and, as appropriate, predict what the physical behavior of a system will be. The worked examples in this book include tips on how to make these kinds of estimates and predictions. If this seems challenging, don’t worry—you’ll get better with practice!

**EXECUTE** *the solution:* This is where you “do the math.” Study the worked examples to see what’s involved in this step.

**EVALUATE** *your answer:* Compare your answer with your estimates, and reconsider things if there’s a discrepancy. If your answer includes an algebraic expression, assure yourself that it represents what would happen if the variables in it were taken to extremes. For future reference, make note of any answer that represents a quantity of particular significance. Ask yourself how you might answer a more general or more difficult version of the problem you have just solved.
Standards and units

• Length, time, and mass are three fundamental quantities of physics.

• The International System (SI for Système International) is the most widely used system of units.

• In SI units, length is measured in meters, time in seconds, and mass in kilograms.
Unit prefixes

- Table 1.1 shows some larger and smaller units for the fundamental quantities.

<table>
<thead>
<tr>
<th>Table 1.1 Some Units of Length, Mass, and Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
</tr>
<tr>
<td>1 nanometer  = 1 nm  = 10^{-9} m</td>
</tr>
<tr>
<td>(a few times the size of the largest atom)</td>
</tr>
<tr>
<td>1 micrometer  = 1 μm  = 10^{-6} m</td>
</tr>
<tr>
<td>(size of some bacteria and living cells)</td>
</tr>
<tr>
<td>1 millimeter  = 1 mm  = 10^{-3} m</td>
</tr>
<tr>
<td>(diameter of the point of a ballpoint pen)</td>
</tr>
<tr>
<td>1 centimeter  = 1 cm  = 10^{-2} m</td>
</tr>
<tr>
<td>(diameter of your little finger)</td>
</tr>
<tr>
<td>1 kilometer  = 1 km  = 10^{3} m</td>
</tr>
<tr>
<td>(a 10-minute walk)</td>
</tr>
</tbody>
</table>
Unit consistency and conversions

- An equation must be *dimensionally consistent*. Terms to be added or equated must *always* have the same units. (Be sure you’re adding “apples to apples.”)
- Always carry units through calculations.
- Convert to standard units as necessary. (Follow Problem-Solving Strategy 1.2)
- Follow Examples 1.1 and 1.2.

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**Problem-Solving Strategy 1.2**  
**Solving Physics Problems**

**IDENTIFY the relevant concepts:** In most cases, it’s best to use the fundamental SI units (length in meters, masses in kilograms, and times in seconds) in every problem. If you need the answer to be in a different set of units (such as kilometers, grams, or hours), wait until the end of the problem to make the conversion.

**SET UP the problem and EXECUTE the solution:** Units are multiplied and divided just like ordinary algebraic symbols. This gives us an easy way to convert a quantity from one set of units to another: Express the same physical quantity in two different units and form an equality.

For example, when we say that $1 \text{ min} = 60 \text{ s}$, we don’t mean that the number 1 is equal to the number 60; rather, we mean that 1 min represents the same physical time interval as 60 s. For this reason, the ratio $(1 \text{ min})/(60 \text{ s})$ equals 1, as does its reciprocal $(60 \text{ s})/(1 \text{ min})$. We may multiply a quantity by either of these factors (which we call *unit multipliers*) without changing that quantity’s physical meaning. For example, to find the number of seconds in 3 min, we write

$$3 \text{ min} = (3 \text{ min}) \left( \frac{60 \text{ s}}{1 \text{ min}} \right) = 180 \text{ s}$$

**EVALUATE your answer:** If you do your unit conversions correctly, unwanted units will cancel, as in the example above. If, instead, you had multiplied 3 min by $(1 \text{ min})/(60 \text{ s})$, your result would have been the nonsensical $\frac{1}{20} \text{ min}^2/\text{s}$. To be sure you convert units properly, you must write down the units at all stages of the calculation.

Finally, check whether your answer is reasonable. For example, the result $3 \text{ min} = 180 \text{ s}$ is reasonable because the second is a smaller unit than the minute, so there are more seconds than minutes in the same time interval.
Uncertainty and significant figures—Figure 1.7

• The uncertainty of a measured quantity is indicated by its number of significant figures.

• For multiplication and division, the answer can have no more significant figures than the smallest number of significant figures in the factors.

• For addition and subtraction, the number of significant figures is determined by the term having the fewest digits to the right of the decimal point.

• Refer to Table 1.2, Figure 1.8, and Example 1.3.

• As this train mishap illustrates, even a small percent error can have spectacular results!
Estimates and orders of magnitude

• An order-of-magnitude estimate of a quantity gives a rough idea of its magnitude.

• Follow Example 1.4.
Vectors and scalars

• A scalar quantity can be described by a single number.

• A vector quantity has both a magnitude and a direction in space.

• In this book, a vector quantity is represented in boldface italic type with an arrow over it: $\vec{A}$.

• The magnitude of $\vec{A}$ is written as $A$ or $|\vec{A}|$. 
Drawing vectors—Figure 1.10

- Draw a vector as a line with an arrowhead at its tip.
- The *length* of the line shows the vector’s *magnitude*.
- The *direction* of the line shows the vector’s *direction*.
- Figure 1.10 shows equal-magnitude vectors having the same direction and opposite directions.

Displacements $\vec{A}$ and $\vec{A}'$ are equal because they have the same length and direction. Displacement $\vec{B}$ has the same magnitude as $\vec{A}$ but opposite direction; $\vec{B}$ is the negative of $\vec{A}$. 
Two vectors may be added graphically using either the parallelogram method or the head-to-tail method.

(a) We can add two vectors by placing them head to tail.

(b) Adding them in reverse order gives the same result.

(c) We can also add them by constructing a parallelogram.
• To add several vectors, use the head-to-tail method.

• The vectors can be added in any order.

(a) To find the sum of these three vectors ...

(b) we could add \( \vec{A} \) and \( \vec{B} \) to get \( \vec{D} \) and then add \( \vec{C} \) to \( \vec{D} \) to get the final sum (resultant) \( \vec{R} \), ...

(c) or we could add \( \vec{B} \) and \( \vec{C} \) to get \( \vec{E} \) and then add \( \vec{A} \) to \( \vec{E} \) to get \( \vec{R} \), ...

(d) or we could add \( \vec{A}, \vec{B}, \) and \( \vec{C} \) to get \( \vec{R} \) directly, ...

(e) or we could add \( \vec{A}, \vec{B}, \) and \( \vec{C} \) in any other order and still get \( \vec{R} \).
Figure 1.14 shows how to subtract vectors.

Subtracting $\vec{B}$ from $\vec{A}$...

...is equivalent to adding $-\vec{B}$ to $\vec{A}$.

$\vec{A} - \vec{B} = \vec{A} + (-\vec{B}) = \vec{A} - \vec{B}$

With $\vec{A}$ and $-\vec{B}$ head to tail, $\vec{A} - \vec{B}$ is the vector from the tail of $\vec{A}$ to the head of $-\vec{B}$.

With $\vec{A}$ and $\vec{B}$ head to head, $\vec{A} - \vec{B}$ is the vector from the tail of $\vec{A}$ to the tail of $\vec{B}$. 

Multiplying a vector by a scalar

- If \( c \) is a scalar, the product \( c\vec{A} \) has magnitude \(|c|A\).

- Figure 1.15 illustrates multiplication of a vector by a positive scalar and a negative scalar.

(a) Multiplying a vector by a positive scalar changes the magnitude (length) of the vector, but not its direction.

- \( 2\vec{A} \) is twice as long as \( \vec{A} \).

(b) Multiplying a vector by a negative scalar changes its magnitude and reverses its direction.

- \( -3\vec{A} \) is three times as long as \( \vec{A} \) and points in the opposite direction.
Addition of two vectors at right angles

- First add the vectors graphically.
- Then use trigonometry to find the magnitude and direction of the sum.
- Follow Example 1.5.
Components of a vector—Figure 1.17

- Adding vectors graphically provides limited accuracy. Vector components provide a general method for adding vectors.
- Any vector can be represented by an $x$-component $A_x$ and a $y$-component $A_y$.
- Use trigonometry to find the components of a vector: $A_x = A \cos \theta$ and $A_y = A \sin \theta$, where $\theta$ is measured from the $+x$-axis toward the $+y$-axis.

(a) The component vectors of $\vec{A}$

(b) The components of $\vec{A}$

\[ A_x = A \cos \theta \]
\[ A_y = A \sin \theta \]
• The components of a vector can be positive or negative numbers, as shown in the figure.
Finding components—Figure 1.19

- We can calculate the components of a vector from its magnitude and direction.
- Follow Example 1.6.
Calculations using components

• We can use the components of a vector to find its magnitude and direction: \[ A = \sqrt{A_x^2 + A_y^2} \] and \[ \tan \theta = \frac{A_y}{A_x} \]

• We can use the components of a set of vectors to find the components of their sum:
  \[ R_x = A_x + B_x + C_x + \cdots, \quad R_y = A_y + B_y + C_y + \cdots \]

• Refer to Problem-Solving Strategy 1.3.
Adding vectors using their components—Figure 1.22

- Follow Examples 1.7 and 1.8.
A **unit vector** has a magnitude of 1 with no units.

The unit vector \( \hat{i} \) points in the \(+x\)-direction, \( \hat{j} \) points in the \(+y\)-direction, and \( \hat{k} \) points in the \(+z\)-direction.

Any vector can be expressed in terms of its components as \( \vec{A} = A_x \hat{i} + A_y \hat{j} + A_z \hat{k} \).

Follow Example 1.9.
The scalar product—Figures 1.25–1.26

- The *scalar product* (also called the “dot product”) of two vectors is
  \[ \vec{A} \cdot \vec{B} = AB \cos \phi. \]

- Figures 1.25 and 1.26 illustrate the scalar product.
Calculating a scalar product

- In terms of components, \( \vec{A} \cdot \vec{B} = A_x B_x + A_y B_y + A_z B_z \).
- Example 1.10 shows how to calculate a scalar product in two ways.
Finding an angle using the scalar product

Example 1.11 shows how to use components to find the angle between two vectors.
The vector product—Figures 1.29–1.30

- The vector product ("cross product") of two vectors has magnitude

|\vec{A} \times \vec{B}| = AB \sin \phi

and the right-hand rule gives its direction. See Figures 1.29 and 1.30.

(a) Using the right-hand rule to find the direction of \(\vec{A} \times \vec{B}\)

1. Place \(\vec{A}\) and \(\vec{B}\) tail to tail.
2. Point fingers of right hand along \(\vec{A}\), with palm facing \(\vec{B}\).
3. Curl fingers toward \(\vec{B}\).
4. Thumb points in direction of \(\vec{A} \times \vec{B}\).

(b) \(\vec{B} \times \vec{A} = -\vec{A} \times \vec{B}\) (the vector product is anticommutative)

(Magnitude of \(\vec{A} \times \vec{B}\) equals \(A(B \sin \phi)\).
(Magnitude of \(\vec{A}\) times (Component of \(\vec{B}\) perpendicular to \(\vec{A}\))

(Magnitude of \(\vec{A} \times \vec{B}\) also equals \(B(A \sin \phi)\).
(Magnitude of \(\vec{B}\) times (Component of \(\vec{A}\) perpendicular to \(\vec{B}\))
• Use $AB\sin\phi$ to find the magnitude and the right-hand rule to find the direction.

• Refer to Example 1.12.