# Chapter 1
# Units, Physical Quantities, and Vectors

## 1 The Nature of Physics

- Physics is an experimental science.
- Physicists make observations of physical phenomena.
- They try to find patterns and principles that relate to these phenomena.
- These patterns are called physical theories. And, over time, if they become well established, they are called physical laws or principles.
- The development of physical theories is a two-way process that starts and ends with observations or experiments.
- Physics is the *process* by which we arrive at general principles that describe how the physical universe behaves.
- No theory is every regarded as the final or ultimate truth. New observations may require that a theory be revised or discarded.
- ***It is in the nature of physical theory*** that we can disprove a theory by finding behavior that is inconsistent with it, but we can never prove that a theory is always correct.
- Theories typically have a ***range of validity***.

## 2 Solving Physics problems

- "You don't *know* physics unless you can *do* physics."
- Some guidelines
  1. Identify the relevant concepts
  2. Set up the problem
  3. Execute the solution (i.e., do the math)

4. Evaluate your answer (i.e., Does it make sense? Can you do a consistency check?)

### 2.1 Modeling

Sometimes, you're confronted with a problem that appears to be very complicated. "However, physicists try to reduce a problem to something that is simpler to understand!" They reduce a problem down to its bare essentials in order to identify the important components and focus on the relevant concepts.

## 3 Standards and Units

- A **physical quantity** is a number used to describe a physical phenomenon (usually a measurement).
- A physical quantity has units (e.g., mass, length, or time).
- In science, we use the SI (Système International) set of units
  1. Mass – the kilogram
  2. Length – the meter
  3. Time – the second

The kilogram, meter, and second are base units in the SI units. Combinations of these units can be used to describe other physical quantities such as velocity *(m/s)*, and acceleration $(\mathrm{m/s^2})$. Sometimes the string of units gets to be so long that we contract them into a new unit called a *derived* unit. For example,

$$\text{A unit of force has base units of} \quad kg\cdot\frac{m}{s^2} \quad \rightarrow \quad \text{newton} \quad \text{or } N$$

where the newton $(N)$ is a derived unit.

### 3.1 Physical constants

Some physical quantities in nature are "constant" and their values can be found at the NIST website. For example, the speed of light, the mass of the proton, the charge of the electron, and so on.

### 3.2 Unit Prefixes

Once we've defined a unit, it is easy to introduce larger and smaller units. For example, $1/1000^{\text{th}}$ of a meter can be abbreviated as 1 mm. A thousand meters can be abbreviated as 1 km. A complete set of prefixes can be found at the NIST web site

## 4 Unit Consistency and Conversions

An equation must always be dimensionally consistent.

$$\text{distance [meters]} = \text{velocity [meters/second]} \times \text{time [seconds]}$$

**Exercise 1.5** The most powerful engine available for the classic 1963 Chevrolet Corvette Sting Ray developed 360 horsepower and had a displacement of 327 cubic inches. Express this displacement in liters (L) by using only the conversions 1 L = 1,000 $\text{cm}^3$ and 1 in. = 2.54 cm.

## 5 Uncertainty and Significant Figures

### 5.1 Uncertainties

Whenever a physical quantity is measured, it should be quoted in the following manner:

$$\ell \;=\; (4.56 \pm 0.04)\,\text{cm} \qquad = \quad x \pm \delta x$$

where $x$ is the *mean* or "best" value that can be determined, and $\delta x$ is the *uncertainty* associated with the measurement.

The **accuracy** of a measured quantity is how close it is to the true value.

The **precision** of a measurement refers to the quality of the measurement. This is usually quoted by calculating the relative uncertainty:

$$\% \text{ relative uncertainty} \qquad \frac{\delta x}{x} \times 100\% = \frac{0.04}{4.56} \times 100\% = 0.88\%$$

**Exercise 1.16** A rectangular piece of aluminum is $5.10 \pm 0.01$ cm long and $1.90 \pm 0.01$ cm wide. a) Find the area of the rectangle and the uncertainty in the area. b) Verify that the fractional uncertainty in the area is equal to the sum of the fractional uncertainties in the length and in the width. (This is a general result; see Challenge Problem 1.98.)

The solution to this problem, as the book does it, *does not* follow the generally accepted principles of statistics, (i.e., the widely-accepted principles of data analysis). We will solve this problem using the equations derived from statistical analysis. The same techniques you learn here will also be used in the lab whenever you perform data analysis!

### 5.2 Significant Digits

Upon making a measurement, it is important to record the correct number of significant digits. Furthermore, it is important to maintain the correct number of significant digits in subsequent calculations. The number of significant digits quoted in the final answer is one of the motivating reasons for developing *scientific notation*. Here is a website describing some of the general rules for maintaining the correct number of significant digits.

Here is an applet that you can run to see if you can correctly identify the number of significant digits.

## 6 Estimates and Orders of Magnitude

Once we know the precision of the numbers we are manipulating, we can make educated guesses (or estimates) of our results. Whenever we perform multiple calculations on a calculator, we hope that our final result is *close* the our "best guess." If not, we should re-do our calculation or rethink how we came up with **order-of-magnitude estimate**.

Example: How thick are the pages in your textbook?

# 7 Vectors and Vector Addition

A **scalar** has magnitude only.

A **vector** has both magnitude and direction.

## 7.1 Definition of a Vector

The simplest vector → the **displacment vector**

Vector notation: $\vec{A}$ (with an arrow over the top) or **A** (boldface)

The **negative** of a vector

Vectors that are **parallel** or **antiparallel**

The magnitude of a vector: (Magnitude of $\vec{A}$) $=$ $A$ or $= |\vec{A}\,|$

## 7.2 Vector Addition (graphically)

Suppose a *displacement* described by $\vec{C}$ is the result of two displacement vectors, vector $\vec{A}$ followed by vector $\vec{B}$. How can we graphically represent the sum of these two vectors?

$$\vec{C} = \vec{A} + \vec{B}$$

How can we graphically represent the difference between two vectors?

$$\vec{D} = \vec{A} - \vec{B}$$

# 8 Components of Vectors–numerical addition of vectors

Any vector on the $x$-$y$ plane can be reduced to the sum of two vectors, one along the $x$ axis, and the other along the $y$ axis.

$$\vec{A} = \vec{A}_x + \vec{A}_y$$

where the magnitude of $\vec{A}_x$ is $A\cos\theta$, and the magnitude of $\vec{A}_y$ is $A\sin\theta$. This is sometimes written as

$$\text{magnitude of } \vec{A}_x = A_x = A\cos\theta$$
$$\text{magnitude of } \vec{A}_y = A_y = A\sin\theta$$

Likewise, if we know $A_x$ and $A_y$, then we can calculate the magnitude and direction of the vector from the following equations:

$$A = \sqrt{A_x^2 + A_y^2} \qquad \text{and}$$
$$\theta = \arctan\left(\frac{A_y}{A_x}\right)$$

**Exercise 30.** Hearing rattles from a snake, you make two rapid displacements of magnitude 1.8 m and 2.4 m. In sketches (roughly to scale), show how your two displacements might add up to give a resultant of magnitude a) 4.2 m; b) 0.6 m; c) 3.0 m.

## 8.1 Questions and Answers regarding vectors

# 9 Unit Vectors

## 9.1 Unit vectors in the Cartesian coordinate system

Define the unit vectors $\hat{\imath}$, $\hat{\jmath}$, and $\hat{k}$.

Now, we can write a vector $\vec{A}$ in terms of the *unit vectors*.

$$\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath}$$

**Exercise 1.41** A disoriented physics professor drives 3.25 km north, then 4.75 km west, and then 1.50 km south. Find the magnitude and direction of the resultant displacement, using the method of components. In a vector addition diagram (roughly to scale), show that the resultant displacement found from your diagram is in qualitative agreement with the result you obtained using the method of components.

# 10 Product of Vectors

When considering the product of two vectors, there are two kinds of results one can obtain, either a *scalar* or a *vector*.

## 10.1 Scalar Product

$$\vec{A} \cdot \vec{B} = A\,B\,\cos\phi \qquad \text{(scalar dot product)}$$

Do some examples.

**Exercise 1.53** For the vectors $\vec{A}$, $\vec{B}$, and $\vec{C}$ in Fig. 1.34, find the scalar products a) $\vec{A} \cdot \vec{B}$; b) $\vec{B} \cdot \vec{C}$; c) $\vec{A} \cdot \vec{C}$.

## 10.2 Vector Product

$$\vec{C} = \vec{A} \times \vec{B} \qquad \text{(vector cross product)}$$

$$\text{The magnitude of} \, \vec{C} = A\,B\,\sin\phi$$

Discuss the **right-hand rule** and **right-handed** coordinate systems.

Do some examples.

**Exercise 1.59** For the two vectors in Fig. 1.35, a) find the magnitude and direction of the vector product $\vec{A} \times \vec{B}$; b) find the magnitude and direction of $\vec{B} \times \vec{A}$.

### 10.3 Questions and Answers on Vector Products

# 11 Challenge Problem

1.101 **Navigating the Big Dipper.** All the stars of the Big Dipper (part of the constellation Ursa Major) may appear to be the same distance from the earth, but in fact they are very far from each other. One light year (ly) is $9.461 \times 10^{15}$ m.

a.) Alkaid and Merak are $25.6^\circ$ apart in the earth's sky. In a diagram, show the relative positions of Alkaid, Merak, and our sun. Find the distance in light years from Alkaid to Merak.

b.) To an inhabitant of a planet orbiting Merak, how many degrees apart in the sky would Alkaid and our sun be?

### Homework

Exercises: 4, 5, 7, 11, 12, 14, 18, 27, 30, 32, 35, 41, 51, 53, 54, 56, 59
Problems: 61, 62, 86, 90