South Central interior Distance Education School

Student Name ________________________________ ***Date Submitted*** _____________________

PHYSICS 12 (v3)

Section 1.0 Send-In

Complete this send-in as part of your course enrollment. This will be your first mark entered for the course. When this assignment has been received by SCIDES, your course materials will be sent to you.

This send-in consists of:

• Physics 12 Course Planner	______/ 5 marks
• Activity 1A	______/17 marks
• Activity 1B (1)	______/13 marks

TOTAL: ______/ 35 marks ______%

Mail:

1) This **Cover Sheet**
2) **Return Address** (page 2 or Comment Sheet) – Fill out with your complete name and address.
3) **Send-In Assignments** – Completed above noted assignments.

Be sure to put proper ***postage*** *on the envelope (if necessary) and add your* ***return address****.*

replaced March 2010

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You are REQUIRED to fill out your return address on this page if you DOWNLOADED this Assignment. [If the Assignment was mailed to you, please fill out the back of the white page of the 3 part District Education Comment Sheet.]

Please Print Clearly

NAME

ADDRESS

CITY / TOWN

PROVINCE / COUNTRY

POSTAL CODE

Is this a change of address? ☐ **Yes** ☐ **No**

Complete your MAILING address.

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Name: ______________________________

___ / 5 marks

COURSE NAME Course Planner

Complete **<u>all</u>** **the following contact information that applies to you and check the one that is the best way to contact you during the day**:

☐ Home Phone: ______________________ ☐ Work Phone: _____________________ ☐ Cell: ______________________

☐ Email: ____

☐ other way to contact you (explain) ____

When is the best time for your teacher or tutor/marker to contact you? ___:_____ AM PM

Check your Grade: ☐ Grade 10 ☐ Grade 11 ☐ Grade 12 ☐ Graduated

Timetable Options/Course Plan

One of the keys to being successful in anything that you do is to take the time to plan carefully. The objective of this section is to help you create a timetable for managing your schoolwork and enable you to set goals for finishing all of your courses by your desired completion date. **Most full-time students complete 3 to 5 assignments each week.**

The flexibility of our distributed learning program offers you many choices but a plan for completion is essential to success. Most full-time students complete 8 courses in a school year (10 months). The most common timetables are "semestered" (4 courses at a time) or "linear" (8 courses at a time).

What is your planned schedule? ☐ Semester System (22 weeks) ☐ Linear System (44 weeks)

☐ other: *(explain)* ____

What is your intended **start** date for this course? ☐ Now ☐ Other date: _________________________

What is your intended **completion** date for this course? _____ (month) ______ (year)

How many courses are you taking with us this year? ____ How many with other schools/programs? ______

Physics 12 consists of 17 more send-in assignments and 3 tests. How many assignments/tests per week must you do to complete this course as planned? _______

- *Mark target submission dates on a calendar.*
- *Add this same information from other courses to help you create a schedule for completion.*
- *Record the actual dates you submit work so you can track your progress.*

Delivery Method

Physics 12 is offered as a print course only. You will receive workbooks in print form and will be submitting your assignments through the regular mail.

If you have access to the Internet, you will find some great online resources to support your learning by searching for key words in the assignments.

Anything else?

Is there anything else you would like us to know about you or your education plans that will help us provide you with better service?

Section 1 Lesson A

REVIEW OF ONE-DIMENSIONAL KINEMATICS

An understanding of the nature of motion is essential to an understanding of physics. What follows is a quick review of the graphical analysis of linear motion; for example, the motion of a cart, a puck, or a car travelling in a straight line. The motion of objects that circle, twist, or vibrate is equally important, but is more complicated and will be studied later in this course or in later courses.

1. **Position** The position of an object describes where it is in relation to a given reference point. Position is represented by P. For example, if a runner is 25 m from the starting point on a straight track, his or her position can be stated as P = $^{+}$25 m. If the starting gun is 1.0 m behind the starting point, its position can be stated as P = $^{-}$1.0 m.

2. **Displacement** The displacement of an object is the change in its position. It is represented by d. For example, if a runner moves from a position of $^{-}$2.0 m to a position of $^{+}$3.5 m, the displacement is d = ($^{+}$3.5 m) – ($^{-}$2.0 m) = 5.5 m.

3. **Velocity** An object's velocity is its displacement per unit of time. It is represented by v. For example, to say that your car is travelling at a velocity of 36 km/h means that if you maintain this velocity for one hour, you will be displaced by (that is, you will travel) 36 km. Alternatively, you will travel 36 km/h × 1000 m/km × 1.0 h/3600 s = 10 m/s. In other words, a velocity of 36 km/h is equal to a velocity of 10 m/s.

   An object's velocity can be positive or negative, depending on the direction in which the object is being displaced. For example, if a runner changes position from $^{+}$4.2 m to $^{-}$3.5 m in one second, then his displacement d = ($^{-}$3.5 m) – ($^{+}$4.2 m) = $^{-}$7.7 m. Since his displacement is negative, his velocity is negative also.

   Instantaneous Velocity An object's instantaneous velocity is its velocity at a given instant of time. It may change from instant to instant, as when you speed up as you leave a stop sign.

Average Velocity The average velocity of an object between two instants of time is calculated by dividing the object's displacement between these two instants by the length of the time interval taken for the displacement.

$$\text{average velocity} = \frac{\text{displacement}}{\text{time}}$$

$$\bar{v} = \frac{d}{\Delta t}$$

Speed An object's speed at a given instant always has the same magnitude as its velocity, but it is not concerned with the direction in which the object is travelling. Velocity can be positive or negative, but speed is always positive.

Now turn to ***Physics*** by Giancoli, page 19, Section 2-1, *Speed.* You are responsible for the contents of this section.

Standards and Units

In this course you will use the International System of Units or **Systeme International d'Unites**, commonly called the SI system or metric system, for all measurements. You may ignore any examples in Giancoli that use other systems of units.

Now turn to ***Physics*** by Giancoli, page 9, Section 1-5, *Units, Standards and the SI System.* Also read page 1038, A-3, *Powers of 10, or Exponential Notation.*

Solving Problems

The following are general rules for solving numerical problems. Not only will they assist you, but also, if you follow them when you do the send-in activities, they will make it easier for your instructor to help you by illustrating how you have attempted to solve the problem.

1. Write down the data you are given using the standard variables.
2. Write down the variable you are asked to find with a question mark after it.
3. Choose a formula
    (a) which contains the variable you are asked to find, and
    (b) in which you know the values of all the other variables.
4. Solve the formula for the variable you are asked to find, if necessary.
5. Substitute the values of the other variables. (Remember that each piece of data may have a unit.) Then calculate the value of the variable you are asked for, rounding it off to the correct number of significant figures. Even in a two-step problem, try not to do any calculations until the end of the problem.
6. Check to make sure that these units combine algebraically to give the appropriate unit for your answer. To be correct, your answer must contain this unit.

The following examples are intended to show you how your work should be laid out.

Example 1A1

How long does it take a car whose velocity is 13.9 m/s to travel 191 m?

Solution

$v = 13.9\ \mathrm{m/s}$ (See rule 1.)
$d = 191\ \mathrm{m}$
$t = ?$ (See rule 2.)

$v = d/t$ (See rule 3.)
$t = d/v$ (See rule 4.)

$t = (191\ \mathrm{m})/(13.9\ \mathrm{m/s})$ (See rule 5.)

$t = 13.7\ \mathrm{s}$ (See rule 6: $\mathrm{m/(m/s) = s}$.)

Example 1A2

What is the average velocity of a man who walks for 2.0 h at 1.8 m/s and then another 35 min at 2.1 m/s?

Solution

First 2.0 h:

$$t_1 = 2.0\ \text{h}$$
$$v_1 = 1.8\ \text{m/s}$$
$$d_1 = ?$$

$$v_1 = d_1/t_1$$
$$d_1 = v_1 t_1$$

Second 35 min:

$$t_2 = 35\ \text{min}$$
$$v_2 = 2.1\ \text{m/s}$$
$$d_2 = ?$$

$$v_2 = d_2/t_2$$
$$d_2 = v_2 t_2$$

Entire trip:

$$d = d_1 + d_2$$
$$t = t_1 + t_2$$
$$v = ?$$

$$\begin{aligned} v &= d/t \\ &= (d_1 + d_2)/(t_1 + t_2) \\ &= [(1.8\ \text{m/s})(2.0\ \text{h})(3600\ \text{s/n}) + (2.1\ \text{m/s})(35\ \text{min})(60\ \text{s/min})]/ \\ &\quad [(2.0\ \text{h})(3600\ \text{s/h}) + (35\ \text{min})(60\ \text{s/min})] \end{aligned}$$

[On your calculator, $(1.8 \times 2 \times 3600 + 2.1 \times 35 \times 60) \div$
$(2 \times 3600 + 35 \times 60) =$]
$= 1.9\ \text{m/s}$

You are expected to be able to solve a formula for any of the variables it contains. If you have trouble doing this, or if you did not follow the algebra in the two examples above, read the explanation which follows.

Remember that by definition

$$\bar{v} = d/t \qquad \text{(I)}$$

This formula states that the average velocity = distance travelled / time taken. Multiply both sides of formula (I) by t as follows:

$$\bar{v}t = d/t \times t$$
$$\bar{v}t = d$$
$$d = \bar{v}t \qquad \text{(II)}$$

This formula states that distance travelled = average velocity multiplied by time taken.

Divide both sides of formula (II) by $\bar{v}$ as follows:

$$d/\bar{v} = \bar{v}t/\bar{v}$$
$$d/\bar{v} = t$$
$$t = d/\bar{v} \qquad \text{(III)}$$

This states that time taken = distance travelled / average velocity.

When you have mastered this lesson please turn to Activity 1 A.

Activity 1 A

Answer the following questions on **your *own* ruled paper.** File your answers for future review.

1. What must be included in the measurement of an object's velocity that is not included in the measurement of its speed?
2. What must be included in the measurement of an object's displacement that is not included in the measurement of the distance it has travelled?
3. State the general rule for the use of significant figures in calculations.
4. One car travels due east at 40 km/h, and a second car travels north at 40 km/h. Are their velocities equal?
5. What must your average speed be in order to travel 680 km in 8.0 h?
6. At an average speed of 18 km/h, how far will a bicyclist travel in 3.5 h?
7. A bird can fly 30 km/h. How long does it take to fly 235 km?
8. If you are driving 90 km/h and you look to the side for 2.0 s, how far do you travel during this inattentive period?
9. A rabbit travels 4.0 k in 3.5 h. What is it's average speed in m/s ? (2 marks)
10. A rock thrown horizontally at a large bell 50m away is heard to hit the bell 4.5 s later If the speed of sound is 330 m/s, what was the speed of the rock? (Disregard the effect of gravity.) [Hint: If it requires a time of t for the sound to return, then it requires (4.5 s-t) for the stone to reach the bell.] (3 marks)
11. An airplane travels 1800 km at a speed of 1000 km/h. It then encounters a headwind that slows it to 850 km/h for the next 2300 km. What was the average speed of the plane for this trip? (2 marks)
12. A race car driver must average 180 km/h for 4 laps to qualify for a race. Because of engine trouble, the car averages only 150 km/h over the first 2 laps. What speed must be maintained for the last 2 laps? (2 marks)

__________ marks out of a possible 17

Section 1 Lesson B

REVIEW OF ONE-DIMENSIONAL KINEMATICS (CONT.)

1. **Acceleration** The acceleration of an object is the change in its velocity per second, represented by the symbol a. A car whose velocity is changing is accelerating. A drag race could be called an "acceleration" race; it is a competition to see who can achieve the greatest change in velocity in one second.

   If a car travelling at 11.0 m/s increased its velocity to 15.5 m/s in 3.0 s, its average acceleration would be (15.5 m/s - 11.0 m/s)/3.0 s or 1.5 m/s/s; that is, 1.5 m/s per second. This is often written 1.5 m/s^2. If a car travelling at 15.5 m/s slowed down to 11.0 m/s in 3.0 s, its acceleration would be $^{-}1.5$ m/s/s or $^{-}1.5$ m/s^2. With the velocity stated in km/h, this car would be slowing down from 55.8 km/h to 39.6 km/h in 3.0 s; its acceleration could be stated as $^{-}5.4$ km/h/s.

Now turn to ***Physics*** by Giancoli, page 24, Section 2.4 *Acceleration.* You are responsible for the contents of this section.

Summary

To describe fully the motion of an object you must know its

1. **position (or displacement from a reference point)**—the position of an object relative to a reference point.
2. **velocity**—rate at which the object's position is changing.
3. **acceleration**—rate at which the object's velocity is changing.

When you have mastered this part of the lesson please turn to Activity 1 B (1).

Activity 1 B (1)

Answer the following questions and solve the following problems on your own ruled paper. File your answers for future review.

1. Can the velocity of an object be zero at the same instant its acceleration is not zero? Give an example.
2. If an object has a greater speed, does it necessarily have a greater acceleration? Explain, using examples.
3. Compare the acceleration of a motorcycle that accelerates from 80 km/h to 90 km/h with a bicycle that accelerates from rest to 10 km/h in the same time.
4. Can you conclude that a car is not accelerating if its speedometer indicates a steady 60 km/h?
5. A car rounds a curve a steady 50 km/h. If it rounds the same curve at a steady 70 km/h, will its acceleration be any different? Explain.
6. Will the acceleration of a car be the same if it travels around a sharp curve at 60 km/h as when it travels around a gentle curve at the same speed? Explain.
7. Does the odometer of a car measure a scalar or a vector quantity? What about the speedometer?
8. A dolphin accelerates from 1.0 m/s to 7.6 m/s in 5.5 s. What was its acceleration? (2 marks)
9. A car accelerates from rest to 100 km/h in 7.0 s. What is its acceleration in m/s? (2 marks)
10. At high speeds, a particular automobile is capable of an acceleration of about 0.50 m/s^2. At this rate how long does it take to accelerate from 90 km/h to 100 km/h? (2 marks)

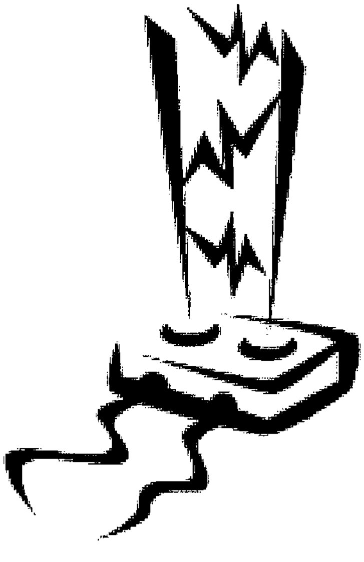
________ **marks out of a possible 13**

Physics 12 (v3)

Section Assignment #1.0

Resource Pages

Attached are the pages from the Physics 12 Resources that you need to complete this Section 1.0 Send-In Assignment.



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practice to keep an extra significant figure or two throughout a calculation, and round off only in the final result. Note also that calculators sometimes give too few significant figures. For example, when you multiply 2.5 × 3.2, a calculator may give the answer as simply 8. But the answer is good to two significant figures, so the proper answer is 8.0.

Powers of ten (scientific notation)

It is common in science to write numbers in "powers of ten," or "exponential" notation—for instance 36,900 as 3.69×10^4, or 0.0021 as 2.1×10^{-3}. (For more details, see Appendices A–2 and A–3.) One advantage of exponential notation is that it allows the number of significant figures to be clearly expressed. For example, it is not clear whether 36,900 has three, four, or five significant figures. With exponential notation the ambiguity can be avoided: if the number is known to an accuracy of three significant figures, we write 3.69×10^4, but if it is known to four, we write 3.690×10^4.

CONCEPTUAL EXAMPLE 1–1 **Is the diamond yours?** A friend asks to borrow your precious diamond for a day to show her family. You are a bit worried, so you carefully have your diamond weighed on a scale which reads 8.17 grams. The scale's accuracy is claimed to be ±0.05 grams. The next day you weigh the returned diamond again, getting 8.09 grams. Is this your diamond?

RESPONSE The scale readings are measurements and do not give the actual value of the mass. Each measurement could have been high or low by up to 0.05 gram or so. The actual mass of your diamond lies most likely between 8.12 grams and 8.22 grams. The actual mass of the returned diamond is most likely between 8.04 grams and 8.14 grams. These two ranges overlap, so there is no reason to doubt that the returned diamond is yours, at least based on the scale readings. (But check the color!)

1–5 Units, Standards, and the SI System

The measurement of any quantity is made relative to a particular standard or **unit**, and this unit must be specified along with the numerical value of the quantity. For example, we can measure length in units such as inches, feet, or miles, or in the metric system in centimeters, meters, or kilometers. To specify that the length of a particular object is 18.6 is meaningless. The unit *must* be given; for clearly, 18.6 meters is very different from 18.6 inches or 18.6 millimeters.

Standard of length (meter)

The first real international standard was the **meter** (abbreviated m) established as the standard of **length** by the French Academy of Sciences in the 1790s. In a spirit of rationality, the standard meter was originally chosen to be one ten-millionth of the distance from the Earth's equator to either pole,[†] and a platinum rod to represent this length was made. (This turns out to be, very roughly, the distance from the tip of your nose to the tip of your longest finger, with arm and hand stretched out horizontally.) In 1889, the meter was defined more precisely as the distance between two finely engraved marks on a particular bar of platinum–iridium alloy. In 1960, to provide greater precision and reproducibility, the meter was redefined as 1,650,763.73 wavelengths of a particular orange light emitted by

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[†] Modern measurements of the Earth's circumference reveal that the intended length is off by about one-fiftieth of 1 percent. Not bad!

the gas krypton 86. In 1983 the meter was again redefined, this time in terms of the speed of light (whose best measured value in terms of the older definition of the meter was 299,792,458 m/s, with an uncertainty of 1 m/s). The new definition reads: "The meter is the length of path traveled by light in vacuum during a time interval of 1/299,792,458 of a second."[†]

British units of length (inch, foot, mile) are now defined in terms of the meter. The inch (in.) is defined as precisely 2.54 centimeters (cm; 1 cm = 0.01 m). Other conversion factors are given in the table on the inside of the front cover of this book.

Table 1–1 presents some characteristic lengths, from very small to very large.

Standard of time (second)

The standard unit of **time** is the **second** (s). For many years, the second was defined as 1/86,400 of a mean solar day. The standard second is now defined more precisely in terms of the frequency of radiation emit-

TABLE 1–1
Some typical Lengths or Distances (order of magnitude)

Length (or distance)	Meters (approximate)
Neutron or proton (radius)	10^{-15} m
Atom	10^{-10} m
Virus [see Fig. 1–6]	10^{-7} m
Sheet of paper (thickness)	10^{-4} m
Finger width	10^{-2} m
Football field length	10^{2} m
Mt. Everest height [see Fig. 1–6]	10^{4} m
Earth diameter	10^{7} m
Earth to Sun	10^{11} m
Nearest star, distance	10^{16} m
Nearest galaxy	10^{22} m
Farthest galaxy visible	10^{26} m

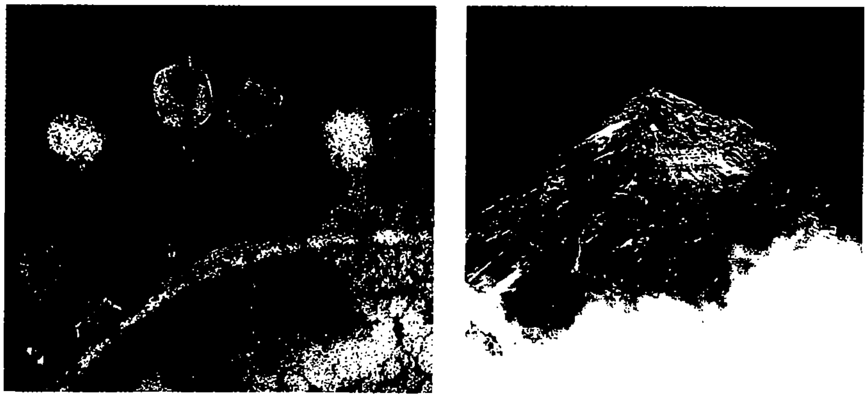

(a) (b)

FIGURE 1–6 (a) Some viruses (about 10^{-7} m long) attacking a cell. (b) Mt. Everest's height is on the order of 10^4 m (8848 m to be precise).

[†] The new definition of the meter has the effect of giving the speed of light the exact value of 299,792,458 m/s.

TABLE 1–2 Some typical Time Intervals

Time interval	Seconds (approximate)
Lifetime of very unstable particle	10^{-23} s
Lifetime of radioactive elements	10^{-22} s to 10^{28} s
Lifetime of muon	10^{-6} s
Time between human heartbeats	10^{0} s (= 1 s)
One day	10^{5} s
One year	3×10^{7} s
Human life span	2×10^{9} s
Length of recorded history	10^{11} s
Humans on Earth	10^{14} s
Life on Earth	10^{17} s
Age of Universe	10^{18} s

TABLE 1–3 Some Masses

Object	Kilograms (approx.)
Electron	10^{-30} kg
Proton, neutron	10^{-27} kg
DNA molecule	10^{-17} kg
Bacterium	10^{-15} kg
Mosquito	10^{-5} kg
Plum	10^{-1} kg
Person	10^{2} kg
Ship	10^{8} kg
Earth	6×10^{24} kg
Sun	2×10^{30} kg
Galaxy	10^{41} kg

ted by cesium atoms when they pass between two particular states. Specifically, one second is defined as the time required for 9,192,631,770 periods of this radiation. There are, of course, precisely 60 s in one minute (min) and 60 minutes in one hour (h). Note that these two factors of 60 (as well as the 2.54 cm per inch) are definitions and hence have an indefinite number of significant figures. Table 1–2 presents a range of measured time intervals.

Standard of mass (kilogram)

The standard unit of **mass** is the **kilogram** (kg). The standard mass is a particular platinum–iridium cylinder, kept at the International Bureau of Weights and Measures near Paris, France, whose mass is defined as exactly 1 kg. A range of masses is presented in Table 1–3. [For practical purposes, 1 kg weighs about 2.2 pounds.]

When dealing with atoms and molecules, the **unified atomic mass unit** (u) is usually used. In terms of the kilogram

$$1\ \text{u} = 1.6605 \times 10^{-27}\ \text{kg}.$$

The definitions of other standard units for other quantities will be given as we encounter them in later chapters.

In the metric system, the larger and smaller units are defined in multiples of 10 from the standard unit, and this makes calculation particularly easy. Thus 1 kilometer (km) is 1000 m, 1 centimeter is $\frac{1}{100}$ m, 1 millimeter (mm) is $\frac{1}{1000}$ m or $\frac{1}{10}$ cm, and so on. The prefixes "centi-," "kilo-," and others are listed in Table 1–4 and can be applied not only to units of length, but to units of volume, mass, or any other metric unit. For example, a centiliter (cL) is $\frac{1}{100}$ liter (L) and a kilogram (kg) is 1000 grams (g).

➥ **PROBLEM SOLVING**

Always use a consistent set of units

SI units

When dealing with the laws and equations of physics it is very important to use a consistent set of units. Several systems of units have been in use over the years. Today the most important is the **Système International** (French for International System), which is abbreviated SI. In SI units, the standard of length is the meter, the standard for time is the second, and the standard for mass is the kilogram. This system used to be called the MKS (meter-kilogram-second) system.

A second metric system is the **cgs system**, in which the centimeter, gram, and second are the standard units of length, mass, and time, as abbreviated in the title. The **British engineering system** takes as its standards the foot for length, the pound for force, and the second for time.

SI units are the principal ones used today in scientific work. We will therefore use SI units almost exclusively in this book, although we will give the cgs and British units for various quantities when introduced.

1–6 Converting Units

Any quantity we measure, such as a length, a speed, or an electric current, consists of a number *and* a unit. Often we are given a quantity in one set of units, but we want it expressed in another set of units. For example, suppose we measure that a table is 21.5 inches wide, and we want to express this in centimeters. We must use a **conversion factor** which in this case is

$$1\ \text{in.} = 2.54\ \text{cm}$$

or, written another way,

$$1 = 2.54\ \text{cm/in.}$$

Since multiplying by one does not change anything, the width of our table, in cm, is

$$21.5\ \text{inches} = (21.5\ \cancel{\text{in.}}) \times \left(2.54\,\frac{\text{cm}}{\cancel{\text{in.}}}\right) = 54.6\ \text{cm}$$

Note how the units (inches in this case) cancelled out. A table containing many unit conversions is found inside the front cover of this book. Let's take some Examples.

EXAMPLE 1–2 **The 100-m dash.** What is the length of the 100-m dash expressed in yards?

SOLUTION Let us assume the distance is accurately known to four significant figures, 100.0 m. One yard (yd) is precisely 3 feet (36 inches), so we can write

$$1\ \text{yd} = 3\ \text{ft} = 36\ \text{in.} = (36\ \cancel{\text{in.}})\left(2.540\,\frac{\text{cm}}{\cancel{\text{in.}}}\right) = 91.44\ \text{cm}$$

or,

$$1\ \text{yd} = 0.9144\ \text{m},$$

since 1 m = 100 cm. We can rewrite this result as

$$1\ \text{m} = \frac{1\ \text{yd}}{0.9144} = 1.094\ \text{yd}.$$

Then

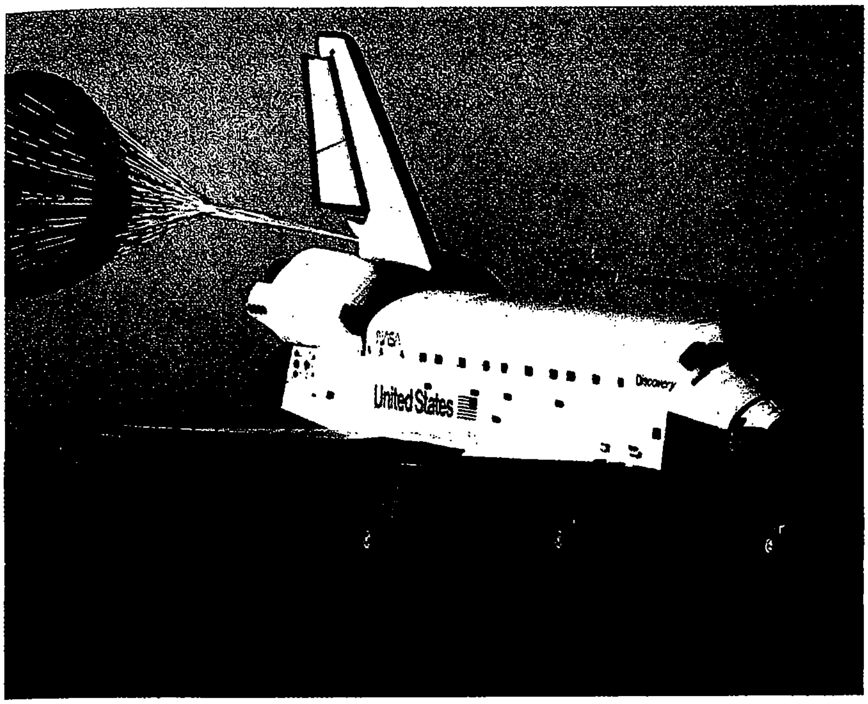
$$100\ \text{m} = (100\ \cancel{\text{m}})\left(1.094\,\frac{\text{yd}}{\cancel{\text{m}}}\right) = 109.4\ \text{yd},$$

so a 100-m dash is 9.4 yards longer than a 100-yard dash.

TABLE 1–4
Metric (SI) Prefixes

Prefix	Abbreviation	Value
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deka	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro[†]	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

[†] μ is the Greek letter "mu."



Space shuttle Discovery landing on Earth. The parachute helps it to reduce its speed quickly. The directions of Discovery's velocity and acceleration are shown by the green (**v**) and gold (**a**) arrows. Note that they (**v** and **a**) point in opposite directions.

CHAPTER 2

DESCRIBING MOTION: KINEMATICS IN ONE DIMENSION

The motion of objects—baseballs, automobiles, joggers, and even the Sun and Moon—is an obvious part of everyday life. Although the ancients acquired significant insight into motion, it was not until comparatively recently, in the sixteenth and seventeenth centuries, that our modern understanding of motion was established. Many contributed to this understanding, but, as we shall soon see, two individuals stand out above the rest: Galileo Galilei (1564–1642) and Isaac Newton (1642–1727).

The study of the motion of objects, and the related concepts of force and energy, form the field called **mechanics**. Mechanics is customarily divided into two parts: **kinematics**, which is the description of how objects move, and **dynamics**, which deals with force and why objects move as they do. This chapter and the next deal with kinematics.

We start by discussing objects that move without rotating (Fig. 2–1a). Such motion is called **translational motion**. In the present chapter we will be concerned with describing an object that moves along a straight-line path, which is one-dimensional motion. In Chapter 3 we will study how to describe translational motion in two (or three) dimensions.

(a) (b)

FIGURE 2–1 The pinecone in (a) undergoes pure translation as it falls, whereas in (b) it is rotating as well as translating.

2–1 Reference Frames and Displacement

All measurements are made relative to a frame of reference

Any measurement of position, distance, or speed must be made with respect to a **frame of reference**. For example, while you are on a train traveling at 80 km/h, you might notice a person who walks past you toward the front of the train at a speed of, say, 5 km/h (Fig. 2–2). Of course this is the person's speed with respect to the train as frame of reference. With respect to the ground that person is moving at a speed of 80 km/h + 5 km/h = 85 km/h. It is always important to specify the frame of reference when stating a speed. In everyday life, we usually mean "with respect to the Earth" without even thinking about it, but the reference frame should be specified whenever there might be confusion.

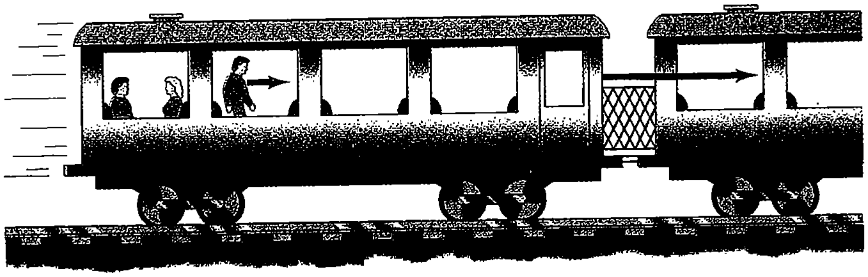


FIGURE 2–2 A person walks toward the front of a train at 5 km/h. The train is moving 80 km/h with respect to the ground, so the walking person's speed, relative to the ground, is 85 km/h.

Even distances depend on the frame of reference. For example, there is no point in telling you that Yosemite National Park is 300 km away unless I specify 300 km from where. Furthermore, when specifying the motion of an object, it is important to specify not only the speed but also the direction of motion. Often we can specify a direction by using the cardinal points, north, east, south, and west, and by "up" and "down." In physics, we often draw a set of **coordinate axes**, as shown in Fig. 2–3, to represent a frame of reference. We can always place the origin 0, and the directions of the x and y axes, as we like for convenience. Objects positioned to the right of the origin of coordinates (0) on the x axis have an x coordinate which we usually choose to be positive; then points to the left of 0 have a negative x coordinate. The position along the y axis is usually considered positive when above 0, and negative when below 0, although the reverse convention can be used if convenient. Any point on the plane can be specified by giving its x and y coordinates. In three dimensions, a z axis perpendicular to the x and y axes is also used.

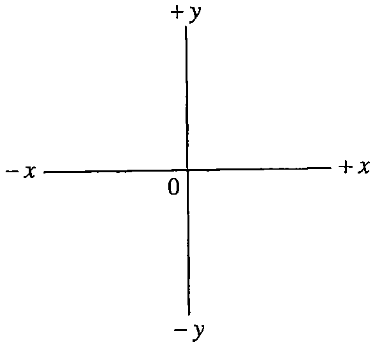


FIGURE 2–3 Standard set of xy coordinate axes.

For one-dimensional motion, we often choose the x axis as the line along which the motion takes place. Thus the position of an object at any moment is given by its x coordinate.

Displacement

We need to make a distinction between the distance an object has traveled, and its **displacement**, which is definied as the *change in position* of the object. That is, displacement is how far the object is from its starting point. To see the distinction between total distance and displacement, imagine a person walking 70 m to the east and then turning around and walking back (west) a distance of 30 m (see Fig. 2–4). The total *distance* traveled is 100 m, but the *displacement* is only 40 m since the person is now only 40 m from the starting point.

Displacement is a quantity that has both magnitude and direction. Such quantities are called **vectors**, and are represented in diagrams by arrows. For example, in Fig. 2–4, the blue arrow represents the displacement whose magnitude is 40 m and whose direction is to the right.

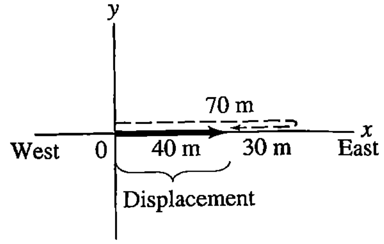


FIGURE 2–4 A person walks 70 m east, then 30 m west. The total distance traveled is 100 m (path is shown in black); but the displacement, shown as a blue arrow, is 40 m to the east.

We will deal with vectors more fully in Chapter 3. For now, we deal only with motion in one dimension, along a line, and in this case, vectors which point in one direction will have a positive sign, whereas vectors that point in the opposite direction will have a negative sign.

Let's see how this works. Consider the motion of an object over a particular time interval. Suppose that at some initial moment in time, call it t_1, the object is on the x axis at the point x_1 in the coordinate system shown in Fig. 2-5. At some later time, t_2, suppose the object is at point x_2. The displacement of our object is $x_2 - x_1$, and is represented by the arrow pointing to the right in Fig. 2–5. It is convenient to write

$$\Delta x = x_2 - x_1$$

where the symbol Δ (Greek letter delta) means "change in." Then Δx means "the change in x," which is the displacement. Note that the "change in" any quantity means the final value of that quantity, minus the initial value.

To be concrete, suppose $x_1 = 10.0\,\text{m}$ and $x_2 = 30.0\,\text{m}$. Then

$$\Delta x = x_2 - x_1 = 30.0\,\text{m} - 10.0\,\text{m} = 20.0\,\text{m}.$$

See Fig. 2–5.

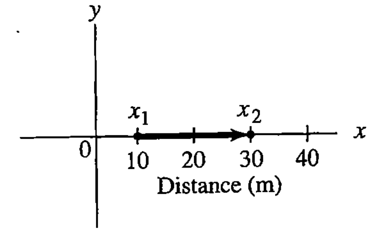


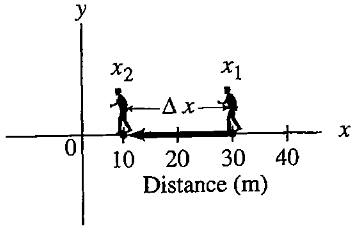
FIGURE 2–5 The arrow represents the displacement $x_2 - x_1$. Distances are in meters.

Now consider a different situation, that of an object moving to the left as shown in Fig. 2–6. Here an object, say a person, starts at $x_1 = 30.0\,\text{m}$ and walks to the left to the point $x_2 = 10.0\,\text{m}$. In this case

$$\Delta x = x_2 - x_1 = 10.0\,\text{m} - 30.0\,\text{m} = -20.0\,\text{m}$$

and the blue arrow representing the vector displacement points to the left. This Example illustrates that when dealing with one-dimensional motion, a vector pointing to the right has a positive value, whereas one pointing to the left has a negative value.

FIGURE 2–6 For the displacement $\Delta x = x_2 - x_1 = 10.0\,\text{m} - 30.0\,\text{m}$, the displacement vector points to the left.



2–2 Average Velocity

The most obvious aspect of the motion of a moving object is how fast it is moving—its speed or velocity.

The term "speed" refers to how far an object travels in a given time interval. If a car travels 240 kilometers (km) in 3 hours, we say its average speed was 80 km/h. In general, the **average speed** of an object is defined as *the distance traveled along its path divided by the time it takes to travel this distance:*

$$\text{average speed} = \frac{\text{distance traveled}}{\text{time elapsed}}. \qquad \textbf{(2–1)}$$

Average speed

The terms velocity and speed are often used interchangeably in ordinary language. But in physics we make a distinction between the two. Speed is simply a positive number, with units. **Velocity**, on the other hand, is used to signify both the *magnitude* (numerical value) of how fast an object is moving and the *direction* in which it is moving. (Velocity is therefore a vector.) There

Velocity

2–4 Acceleration

An object whose velocity is changing is said to be accelerating. A car whose velocity increases in magnitude from zero to 80 km/h is accelerating. If one car can accomplish this change in velocity in less time than another, it is said to undergo a greater acceleration. That is, acceleration specifies how rapidly the velocity of an object is changing. **Average acceleration** is defined as the change in velocity divided by the time taken to make this change:

$$\text{average acceleration} = \frac{\text{change of velocity}}{\text{time elapsed}}.$$

In symbols, the average acceleration, $\bar{a}$, over a time interval $\Delta t = t_2 - t_1$ during which the velocity changes by $\Delta v = v_2 - v_1$, is defined as

Average acceleration

$$\bar{a} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}. \qquad \textbf{(2–4)}$$

Acceleration is also a vector, but for one-dimensional motion, we need only use a plus or minus sign to indicate direction relative to a chosen coordinate system.

The **instantaneous acceleration,** a, can be defined in analogy to instantaneous velocity, for any specific instant:

Instantaneous acceleration

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t}. \qquad \textbf{(2–5)}$$

Here Δv represents the very small change in velocity during the very short time interval Δt.

EXAMPLE 2–3 **Average acceleration.** A car accelerates along a straight road from rest to 75 km/h in 5.0 s, Fig. 2–9. What is the magnitude of its average acceleration?

SOLUTION The car starts from rest, so $v_1 = 0$. The final velocity is $v_2 = 75$ km/h. Then from Eq. 2–4, the average acceleration is

$$\bar{a} = \frac{75\,\text{km/h} - 0\,\text{km/h}}{5.0\,\text{s}} = 15\,\frac{\text{km/h}}{\text{s}}.$$

This is read as "fifteen kilometers per hour per second" and means that, on average, the velocity changed by 15 km/h during each second. That is, assuming the acceleration was constant, during the first second the car's velocity increased from zero to 15 km/h. During the next second its velocity increased by another 15 km/h up to 30 km/h, and so on, Fig. 2–9. (Of course, if the instantaneous acceleration was not constant, these numbers could be different.)

Careful: Do not confuse velocity with acceleration

Note carefully that *acceleration tells us how fast the velocity changes,* whereas *velocity tells us how fast the position changes.* In this last Example, the calculated acceleration contained two different time units: hours and seconds. We

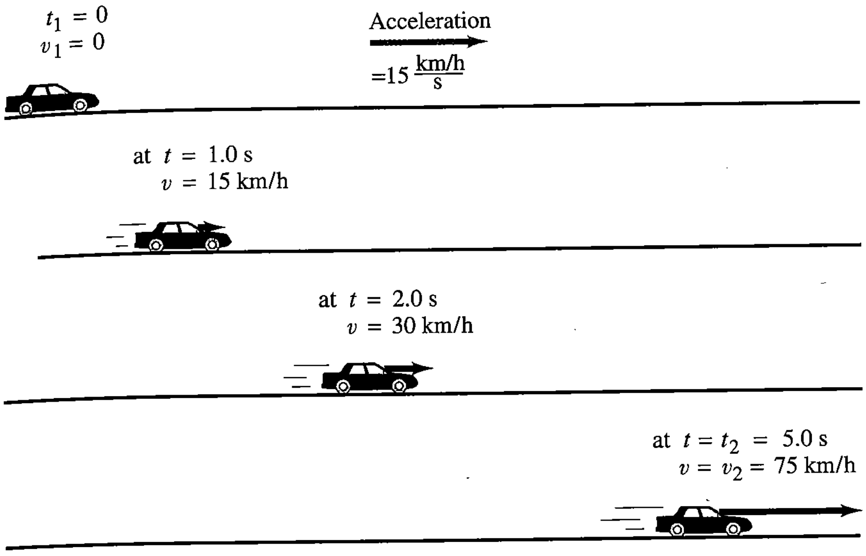


FIGURE 2–9 Example 2–3. The car is shown at the start with $v_1 = 0$ at $t_1 = 0$. It is shown three more times, at $t = 1.0$ s, $t = 2.0$ s, and $t_2 = 5.0$ s. We assume the acceleration is constant and equals 15 km/h/s. The green arrows represent the velocity vectors; the length of each represents the magnitude of the velocity at that moment. The acceleration vector is the orange arrow.

usually prefer to use only seconds. To do so we can change km/h to m/s (see Section 1–6, and Example 1–4):

$$75\text{ km/h} = \left(75\frac{\cancel{\text{km}}}{\cancel{\text{h}}}\right)\left(\frac{1000\text{ m}}{1\ \cancel{\text{km}}}\right)\left(\frac{1\ \cancel{\text{h}}}{3600\text{ s}}\right) = 21\text{ m/s}.$$

Then we get

$$\bar{a} = \frac{21\text{ m/s} - 0.0\text{ m/s}}{5.0\text{ s}} = 4.2\frac{\text{m/s}}{\text{s}} = 4.2\frac{\text{m}}{\text{s}^2}.$$

We almost always write these units as m/s^2 (meters per second squared), as done here, instead of m/s/s. This is possible because:

$$\frac{\text{m/s}}{\text{s}} = \frac{\text{m}}{\text{s}\cdot\text{s}} = \frac{\text{m}}{\text{s}^2}.$$

According to the above calculation, the velocity in Example 2–3 (Fig. 2–9) changed on the average by 4.2 m/s during each second, for a total change of 21 m/s over the 5.0 s.

CONCEPTUAL EXAMPLE 2–4 **Velocity and acceleration.** (*a*) If the velocity of an object is zero, does it mean that the acceleration is zero? (*b*) If the acceleration is zero, does it mean that the velocity is zero? Think of some examples.

RESPONSE A zero velocity does not necessarily mean that the acceleration is zero, nor does a zero acceleration mean that the velocity is zero. (*a*) For example, when you put your foot on the gas pedal of your car which is at rest, the velocity starts from zero but the acceleration is not zero since the velocity of the car changes. (How else could your car start forward if its velocity weren't changing—that is, if the acceleration were zero?) (*b*) As you cruise along a straight highway at a constant velocity of 100 km/h, your acceleration is zero.

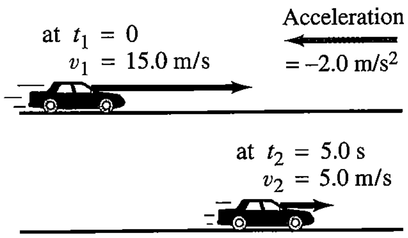


FIGURE 2–10 Example 2–5, showing the position of the car at times t_1 and t_2, as well as the car's velocity represented by the green arrows. The acceleration vector (orange) points to the left.

EXAMPLE 2–5 **Car slowing down.** An automobile is moving to the right along a straight highway, which we choose to be the positive x axis (Fig. 2–10), and the driver puts on the brakes. If the initial velocity is $v_1 = 15.0\text{ m/s}$ and it takes 5.0 s to slow down to $v_2 = 5.0\text{ m/s}$, what was the car's average acceleration?

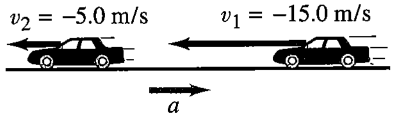
SOLUTION The average acceleration is equal to the change in velocity divided by the elapsed time, Eq. 2–4. Let us call the initial time $t_1 = 0$; then $t_2 = 5.0\text{ s}$. (Note that our choice of $t_1 = 0$ doesn't affect the calculation of $\bar{a}$ because only $\Delta t = t_2 - t_1$ appears in Eq. 2–4.) Then

$$\bar{a} = \frac{5.0\text{ m/s} - 15.0\text{ m/s}}{5.0\text{ s}} = -2.0\text{ m/s}^2.$$

The negative sign appears because the final velocity is less than the initial velocity. In this case the direction of the acceleration is to the left (in the negative x direction)—even though the velocity is always pointing to the right. We say that the acceleration is 2.0 m/s^2 to the left, and it is shown in Fig. 2–10 as an orange arrow.

FIGURE 2–11 The same car as in Example 2–5, but now moving to the left and decelerating. The acceleration is

$$a = \frac{v_2 - v_1}{\Delta t} = \frac{-5.0\text{ m/s} - (-15.0\text{ m/s})}{5.0\text{ s}} = \frac{-5.0\text{ m/s} + 15.0\text{ m/s}}{5.0\text{ s}} = +2.0\text{ m/s}.$$



When an object is slowing down, we sometimes say it is decelerating. But be careful: deceleration does *not* mean that the acceleration is necessarily negative. For an object moving to the right along the positive x axis and slowing down (as in Fig. 2–10), the acceleration *is* negative. But the same car moving to the left (decreasing x) and slowing down has positive acceleration that points to the right, as shown in Fig. 2–11. We have a deceleration whenever the velocity and acceleration point in opposite directions.

2–5 Motion at Constant Acceleration

Let a = constant

Many practical situations occur in which the acceleration is constant or close enough that we can assume it is constant. That is, the acceleration doesn't change over time. We now treat this situation when the magnitude of the acceleration is constant and the motion is in a straight line (sometimes called **uniformly accelerated motion**). In this case, the instantaneous and average accelerations are equal.

$t_1 = 0, t_2 = t$
$x_1 = x_0, x_2 = x$
$v_1 = v_0, v_2 = v$

To simplify our notation, let us take the initial time in any discussion to be zero: $t_1 = 0$. We can then let $t_2 = t$ be the elapsed time. The initial position (x_1) and initial velocity (v_1) of an object will now be represented by x_0 and v_0; and at time t the position and velocity will be called x and v (rather than x_2 and v_2). The average velocity during the time t will be (from Eq. 2–2)

$$\bar{v} = \frac{x - x_0}{t - t_0} = \frac{x - x_0}{t}$$

since $t_0 = 0$. And the acceleration, which is assumed constant in time, will be (from Eq. 2–4)

$$a = \frac{v - v_0}{t}.$$

A common problem is to determine the velocity of an object after a certain time, given its acceleration. We can solve such problems by solving

We now have four equations relating position, velocity, acceleration, and time, when the acceleration a is constant. We collect them here in one place for further reference (the tan background screen is to emphasize their usefulness):

Kinematic equations for constant acceleration (we'll use them a lot)

$$v = v_0 + at \qquad [a = \text{constant}] \qquad \textbf{(2–10a)}$$

$$x = x_0 + v_0 t + \tfrac{1}{2}at^2 \qquad [a = \text{constant}] \qquad \textbf{(2–10b)}$$

$$v^2 = v_0^2 + 2a(x - x_0) \qquad [a = \text{constant}] \qquad \textbf{(2–10c)}$$

$$\bar{v} = \frac{v + v_0}{2}. \qquad [a = \text{constant}] \qquad \textbf{(2–10d)}$$

These useful equations are not valid unless a is a constant. In many cases we can set $x_0 = 0$, and this simplifies the above equations a bit. Note that x represents position, not distance, and $x - x_0$ is the displacement.

EXAMPLE 2–6 **Runway design.** You are designing an airport for small planes. One kind of airplane that might use this airfield must reach a speed before takeoff of at least 27.8 m/s (100 km/h), and can accelerate at 2.00 m/s^2. (*a*) If the runway is 150 m long, can this airplane reach the proper speed to take off? (*b*) If not, what minimum length must the runway have?

SOLUTION (*a*) We are given the airplane's acceleration ($a = 2.00\,\text{m/s}^2$), and we know the plane can travel a distance of 150 m. We want to find its velocity, to determine if it will be at least 27.8 m/s. We want to find v when we are given:

Known	Wanted
$x_0 = 0$	v
$v_0 = 0$	
$x = 150\,\text{m}$	
$a = 2.00\,\text{m/s}^2$	

PROBLEM SOLVING

Equations 2–10 are valid only when the acceleration is constant, which we assume in this Example

Of the above four equations, Eq. 2–10c will give us v, when we know v_0, a, x, and x_0:

$$\begin{aligned} v^2 &= v_0^2 + 2a(x - x_0) \\ &= 0 + 2(2.0\,\text{m/s}^2)(150\,\text{m}) = 600\,\text{m}^2/\text{s}^2 \\ v &= \sqrt{600\,\text{m}^2/\text{s}^2} = 24.5\,\text{m/s}. \end{aligned}$$

This runway length is *not* sufficient.

(*b*) Now we want $(x - x_0)$ given $v = 27.8\,\text{m/s}$ and $a = 2.0\,\text{m/s}^2$. So we use Eq. 2–10c, rewritten as

$$(x - x_0) = \frac{v^2 - v_0^2}{2a} = \frac{(27.8\,\text{m/s})^2 - 0}{2(2.0\,\text{m/s}^2)} = 193\,\text{m}.$$

each point can be read off this figure by measuring the length of the corresponding arrow and using the scale shown (1 cm = 90 km/h).

When we write the symbol for a vector, we will always use boldface type. Thus for velocity we write **v**. (In handwritten work, the symbol for a vector can be indicated by putting an arrow over it, a $\vec{v}$ for velocity.) If we are concerned only with the magnitude of the vector, we will write simply v, in italics.

3–2 Addition of Vectors—Graphical Methods

Because vectors are quantities that have direction as well as magnitude, they must be added in a special way. In this chapter, we will deal mainly with displacement vectors (for which we now use the symbol **D**) and velocity vectors (**v**). But the results will apply for other vectors we encounter later.

We use simple arithmetic for adding scalars. Simple arithmetic can also be used for adding vectors if they are in the same direction. For example, if a person walks 8 km east one day, and 6 km east the next day, the person will be 8 km + 6 km = 14 km east of the point of origin. We say that the *net* or *resultant* displacement is 14 km to the east (Fig. 3–2a). If, on the other hand, the person walks 8 km east on the first day, and 6 km west (in the reverse direction) on the second day, then the person will end up 2 km from the origin (Fig. 3–2b), so the resultant displacement is 2 km to the east. In this case, the resultant displacement is obtained by subtraction: 8 km − 6 km = 2 km.

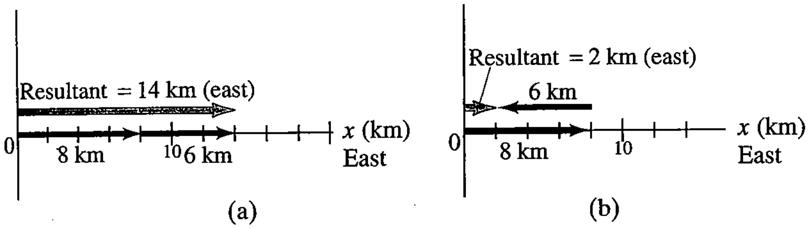


FIGURE 3–2 Combining vectors in one dimension.

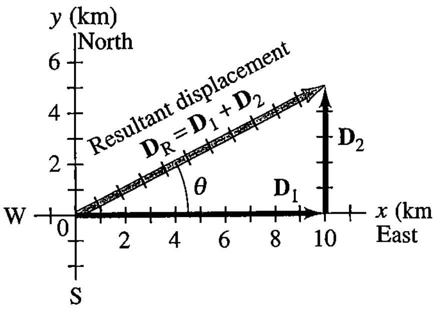
But simple arithmetic cannot be used if the two vectors are not along the same line. For example, suppose a person walks 10.0 km east and then walks 5.0 km north. These displacements can be represented on a graph in which the positive y axis points north and the positive x axis points east, Fig. 3–3. On this graph, we draw an arrow, labeled $\mathbf{D}_1$, to represent the displacement vector of the 10.0-km displacement to the east. Then we draw a second arrow, $\mathbf{D}_2$, to represent the 5.0-km displacement to the north. Both vectors are drawn to scale, as in Fig. 3–3.

After taking this walk, the person is now 10.0 km east and 5.0 km north of the point of origin. The **resultant displacement** is represented by the arrow labeled $\mathbf{D}_R$ in Fig. 3–3. Using a ruler and a protractor, you can measure on this diagram that the person is 11.2 km from the origin at an angle of 27° north of east. In other words, the resultant displacement vector has a magnitude of 11.2 km and makes an angle $\theta = 27°$ with the positive x axis. The magnitude (length) of $\mathbf{D}_R$ can also be obtained using the theorem of Pythagoras in this case, since D_1, D_2, and D_R form a right triangle with D_R as the hypotenuse. Thus

$$D_R = \sqrt{D_1^2 + D_2^2} = \sqrt{(10.0\,\text{km})^2 + (5.0\,\text{km})^2} = \sqrt{125\,\text{km}^2} = 11.2\,\text{km}.$$

You can use the Pythagorean theorem, of course, only when the vectors are *perpendicular* to each other.

FIGURE 3–3 A person walks 10.0 km east and then 5.0 km north. These two displacements are represented by the vectors $\mathbf{D}_1$ and $\mathbf{D}_2$, which are shown as arrows. The resultant displacement vector, $\mathbf{D}_R$, which is the vector sum of $\mathbf{D}_1$ and $\mathbf{D}_2$, is also shown. Measurement on the graph with ruler and protractor shows that $\mathbf{D}_R$ has a magnitude of 11.2 km and points at an angle $\theta = 27°$ north of east.



Rule A–1 gives us the same result:

$$(a^5)(a^{-3}) = a^{5-3} = a^2.$$

What does an exponent of zero mean? That is, what is a^0? Any number raised to the zeroth power is defined as being equal to 1:

$$a^0 = 1.$$

This definition is used because it follows from the rules for adding exponents. For example,

$$a^3a^{-3} = a^{3-3} = a^0 = 1.$$

But *does* a^3a^{-3} actually equal 1? Yes, because

$$a^3a^{-3} = \frac{a^3}{a^3} = 1.$$

Fractional exponents are used to represent *roots*. For example, $a^{\frac{1}{2}}$ means the square root of a; that is $a^{\frac{1}{2}} = \sqrt{a}$. Similarly, $a^{\frac{1}{3}}$ means the cube root of a, and so on. The fourth root of a means that if you multiply the fourth root of a by itself four times, you again get a:

$$(a^{\frac{1}{4}})^4 = a.$$

This is consistent with rule A–3 since $(a^{\frac{1}{4}}) = a^{\frac{4}{4}} = a^1 = a$.

A–3 Powers of 10, or Exponential Notation

Writing out very large and very small numbers such as the distance of Neptune from the Sun, 4,500,000,000 km, or the diameter of a typical atom, 0.00000001 cm, is inconvenient and prone to error. It also leaves in question (see Section 1–4) the number of significant figures. (How many of the zeros are significant in the number 4,500,000,000 km?) We therefore make use of the "powers of 10," or exponential notation. The distance from Neptune to the Sun is then expressed as 4.50×10^9 km (assuming that the value is significant to three digits) and the diameter of an atom 1.0×10^{-8} cm. This way of writing numbers is based on the use of exponents, where a^n signifies a multiplied by itself n times. For example, $10^4 = 10 \times 10 \times 10 \times 10 = 10{,}000$. Thus, $4.50 \times 10^9 = 4.50 \times 1{,}000{,}000{,}000 = 4{,}500{,}000{,}000$. Notice that the exponent (9 in this case) is just the number of places the decimal point is moved to the right to obtain the fully written out number ($\underrightarrow{4.500,000,000.}$)

When two numbers are multiplied (or divided), you first multiply (divide) the simple parts and then the powers of 10. Thus, 2.0×10^3 multiplied by 5.5×10^4 equals $(2.0 \times 5.5) \times (10^3 \times 10^4) = 11 \times 10^7$, where we have used the rule for adding exponents (Appendix A–2). Similarly, 8.2×10^5 divided by 2.0×10^2 equals

$$\frac{8.2 \times 10^5}{2.0 \times 10^2} = \frac{8.2}{2.0} \times \frac{10^5}{10^2} = 4.1 \times 10^3.$$

For numbers less than 1, say 0.01, the exponent power of 10 is written with a negative sign: $0.01 = 1/100 = 1/10^2 = 1 \times 10^{-2}$. Similarly, $0.002 = 2 \times 10^{-3}$. The decimal point has again been moved the number of places expressed in the exponent. Thus, $0.020 \times 3600 = 72$; in exponential notation $(2.0 \times 10^{-2}) \times (3.6 \times 10^3) = 7.2 \times 10^1 = 72$.

Notice also that $10^1 \times 10^{-1} = 10 \times 0.1 = 1$, and by the law of exponents, $10^1 \times 10^{-1} = 10^0$. Therefore, $10^0 = 1$.

When writing a number in exponential notation, it is usual to make the simple number be between 1 and 10. Thus it is conventional to write 4.5×10^9 rather than 45×10^8, although they are the same number.[†] This notation also allows the number of *significant figures* to be clearly expressed. We write 4.50×10^9 if this value is accurate to three significant figures, but 4.5×10^9 if it is accurate to only two.

A–4 Algebra

Physical relationships between quantities can be represented as equations involving symbols (usually letters of the alphabet) that represent the quantities. The manipulation of such equations is the field of algebra, and is used a great deal in physics. An equation involves an equals sign, which tells us that the quantities on either side of the equals sign have the same value. Examples of equations are

$$3 + 8 = 11$$

$$2x + 7 = 15$$

$$a^2b + c = 6.$$

The first equation involves only numbers, so is called an arithmetic equation. The other two equations are algebraic since they involve symbols. In the third equation, the quantity a^2b means the product of a times a times b: $a^2b = a \times a \times b$.

Solving for an Unknown

Often we wish to solve for one (or more) symbols, and we treat it as an *unknown*. For example, in the equation $2x + 7 = 15$, x is the unknown; this equation is true, however, only when $x = 4$. Determining what value (or values) the unknown(s) can have to satisfy the equation(s) is called *solving the equation*. To solve an equation, the following rule can be used:

> *An equation will remain true if any operation performed on one side is also performed on the other side:* for example, (*a*) addition or subtraction of a number or symbol; (*b*) multiplication or division by a number or symbol; (*c*) raising each side of the equation to the same power, or taking the same root (such as square root).

[†] Another convention used, particularly with computers, is that the simple number be between 0.1 and 1. Thus we could write 4,500,000,000 as 0.450×10^{10}.