Introduction

This book, a companion to the textbook, *Understanding Physics*, is your guide to observations and explorations in the world of physics. Prepare for challenging work, fun, and some surprises. One of the best ways to learn physics is by *doing* physics, in the laboratory and everywhere. One cannot rely on reading and class work alone. The explorations in this book are your opportunity to gain some actual, hands-on experience with physics. Many of these explorations will assist you to design your own experiments and to discover many of the important ideas of science yourself.

As you will see from the Contents, this *Student Guide* provides a variety of potentially helpful materials. Following the Introduction is a review of units, mathematics, and scientific notation, and a list of suggested further reading and Web Sites. However, a large portion of the *Student Guide* contains further materials relating to many of the textbook chapters, as well as to laboratory explorations. In the section containing "Further Chapter Materials" you will find elaborations on topics in many of the chapters, as well as derivations of important equations. A complete list of the suggested mini- and major-laboratory explorations is also given in the Contents. Each exploration is keyed to specific portions of the textbook, and lists are also provided of the explorations pertaining to each part of the text.

There are actually three types of laboratory explorations in this book: "mini-laboratories," "major laboratories," and some suggested "laboratory activities." The mini-laboratories are hands-on experiences and demonstrations that enable you to observe and study an event in nature, either in class or in a laboratory. The major laboratories are designed for more in-depth exploration. Finally, the laboratory activities provide ideas for ways in which you might design your own investigations. All three types of explorations are closely tied to the material in the book.

The textbook material and the laboratory explorations go hand-in-hand. You will get the most out of them by working on both together. All of the laboratories are deliberately designed to be as "low tech" as possible in order to provide you with as direct an experience as possible with the material and with the analysis of the data. As you become more familiar with the material, your instructor may introduce computer and other technological enhancements.

Scientific research is often performed in groups, and no research results are accepted in science until they have been reviewed and discussed by others. Your class may also work in pairs or in groups. This is a wonderful way to learn, as long as everyone does his or her best to contribute to the work. Group work is also a model used in many careers, and it is essential in nearly every career to be able to get along with your colleagues. Communicating your results to others in written and oral form is also important.

In studying the text and engaging in these laboratory explorations, we suggest that you keep a notebook or a journal of your work. This notebook should include your notes from reading the text, your answers to the questions at the end of each chapter, your questions on any of the material in this course, the results of your group discussions, and your work in the laboratory. You will notice that the laboratory explorations in this guide do not contain any tables for plugging in your data results. Part of the research experience will be to understand the data to such an extent that you can construct your own tables to organize and present the data in the way that you think it can be done most clearly—exactly as research scientists do.

A journal will also help you to keep all of your work together, enabling you to compare what you learn in the laboratory with what you find in the text, and it will help you in preparing for examinations. It will also provide

a record of your progress in the course. When you look back in the end, you will be amazed how far you have progressed.

Physics is not an easy subject, but it is no more difficult than most other academic subjects. Like other subjects, studying physics requires a certain amount of dedication, but the rewards are well worth the effort! Studying physics may give you an entirely new perspective on your world. It will help prepare you for the scientific age in which we live, and enhance your abilities in any career that you choose.

A Word to Future and Current Teachers

Understanding Physics is an introductory course designed for non-science majors in general, and for future and current teachers, including those in K–12 classrooms, as well as in college. One aim of this course is to bring all undergraduate students at least to the level of science literacy in physics outlined in the recent national initiatives for the introductory physics course. These initiatives have been very influential in recent years at State level. Many States have been issuing more stringent education standards in science, and they are introducing new teacher certification examinations in line with these new standards. At present, the two most prominent national initiatives are:

- National Research Council. *National Science Education Standards* (Washington, DC: National Academy Press, 1996).
  Online text: http://www.nap.edu/readingroom/books/nses/html/
- Project 2061 (American Association for the Advancement of Science). *Benchmarks for Science Literacy* (New York: Oxford University Press, 1993).
  Online text: http://www.project2061.org/tools/benchol/bolframe.html/

In keeping with these developments, a second, related aim of this course is to equip future and in-service teachers with the knowledge and ability to teach the basic physical science recommended in these two national initiatives at different grade levels. In many instances you will find the same or very similar recommendations in your State standards for science education, and many of the concepts here will appear on teacher certification examinations.

Both of the above online sites may be accessed through the *Understanding Physics* Web site at: http://www.springer-ny.com/. At these sites you will find specific learning goals in science for different grade levels. You will also find links to cognitive research for each grade level, bibliographic references, and many other helpful materials.

Reviewing Units, Mathematics, and Scientific Notation

UNITS

Every measurement in science is made in the units of a standard measure appropriate for the property that is being measured. For example, length might be 3 m, or 2 in, or 8 cm. (It can never be just 3 or 2 or 8). Other measurements might be 8 s, 5 g, 16 l, 46°C, and so on.

Standard units in the sciences are those defined, accepted, and used by the scientific community. For instance, the standard unit of mass in the metric system is the kilogram (about 2.2 lb). The kilogram has been defined as the mass of a platinum–iridium cylinder kept by the International Bureau of Weights and Measures in Paris, with a duplicate in the United States in the National Institute of Standards and Technology (formerly the Bureau of Standards) in Washington, DC.

In the United States, two systems of units are often encountered: the *English* system and the *metric* system. The *English* system arose through common practice in the marketplace and most of it is ill-suited for used in the laboratory. It uses the following standard measures:

Distance:	inch (in), foot (ft), yard (yd), rod, furlong (fur), mile (mi) (statute and nautical).
Time:	second (s), minute (min), hour (hr), year (yr).
Mass:	ounce (oz), pound (lb).
Force:	ounce (oz), pound (lb), ton (t).
Volume:	ounce (oz), cup, pint (pt), quart (qt), gallon (gal).
Temperature:	degree Fahrenheit (°F).
Energy:	foot-pound (ft-lb), British thermal unit (Btu), calorie (cal).

As you can see, these units can be confusing—for instance, "ounce" may refer to volume, mass, or force. Notice also how difficult it is to convert smaller units to larger ones (feet to miles, ounces to quarts, rods to furlongs, etc.). In addition, the definitions of some units, such as gallons, differ from country to country. The British, Canadian, American, and Australian gallons are all different.

Because of these problems, the English system is avoided in scientific research. Instead, the metric system, based on units of ten, is used. In this system, the prefixes of the measures tell you the relationship to the standard measure. For instance, "milli" stands for 1/1000, "centi" stands for 1/100, and "kilo" stands for 1000.

The *metric* system uses the following standard measures:

Distance:	millimeter (mm), centimeter (cm), meter (m), kilometer (km).
Time:	second (s).
Mass:	milligram (mg), gram (g), kilogram (kg).
Force:	newton (1 kg-m/s^2) (N) or dyne (1 g-cm/s^2) (dyn).
Volume:	milliliter (ml), liter (l).
Temperature:	degree Celsius (centigrade) (°C) or absolute temperature (Kelvin) (K).
Energy:	erg (1 dyne-cm), joule (1 n-m) (J), calorie (cal)

When substituting actual measurements into an equation, always be careful to retain the units along with the numbers, since they provide the units of your final answer and serve as a check on your calculation. Generally you should convert all similar types of measurements to the same units. In multiplication and division, the units are treated like numbers, while in addition and subtraction the units are simply carried through.

▼ Examples

$$5 \text{ m} + 30 \text{ cm} = 5 \text{ m} + 0.3 \text{ m} = 5.3 \text{ m},$$
$$16 \text{ kg} \times 4 \text{ m/s}^2 = 64 \text{ kg-m/s}^2 = 64 \text{ N}.$$

During this course, when you need to convert from English to metric units or vice versa, you will be able to use the following (approximate) relations. (There is no need to memorize these.)

English	*Metric*	*Metric*	*English*
1 inch	2.54 centimeters	1 cm	0.39 in
1 foot	0.30 meters	1 m	3.28 ft
1 mile	1.61 kilometers	1 km	0.62 mi
1 gallon	3.79 liters	1 l	0.26 gal
1 pound weight	4.45 newtons	1 N	0.22 lb
°F	°C × $\frac{9}{5}$ + 32	°C	$\frac{5}{9}$ (°F − 32)

In the metric system, if measurements of mass, distance, and time are in grams, centimeters, and seconds, this is called the *cgs system*. If the measurements are in kilograms, meters, seconds, this is called the *mks system*. The units for force and energy in the cgs system are: dyne, calorie, erg. The units for force and energy in the mks system are: newton, kilocalorie (Calorie), joule.

The cgs system is usually used in chemistry or when the amounts of material studied in the laboratory are typically small. The mks system is usually used in physics, which often concerns itself with larger objects.

The erg (in cgs) and joule (in mks) are units of mechanical energy, while the calorie (cgs) and Calorie (mks) are units of heat energy. Since they are all units of energy, but in different forms, they are all related to each other according to the following:

1 Calorie = 1000 calories = 4190 joules = 4190×10^7 ergs.

SIGNIFICANT FIGURES

The accuracy of every measurement is limited by the precision of the instrument being used. For example, if the length of a table is measured using a meter stick that is divided into centimeters and millimeters, you can measure the length to an accuracy of plus or minus 1 mm. Although it is possible to guess to a fraction of a millimeter, one cannot be more accurate than the nearest millimeter. Thus, you might measure the table to be 1.23 m long. Is it *exactly* 1.23 m long, or could it be 1.232 m or 1.229 m? One can't tell with this type of measuring instrument. A more precise instrument might yield a length of 1.23175 m. But then, could it be really 1.231749 m? It's possible, but this measurement can't tell us because, again, the instrument we are using is not that precise.

Every measuring instrument, no matter how precise, will have some imprecision. Because of the imprecision in every measurement, the last digit of a measurement is usually regarded only as an approximation. The last number is as "significant" as the other numbers in the measurement, but it is "uncertain." Thus, in the example above, for the table measured with a meter stick to be 1.23 m long, there are three significant figures, while the last figure, 3, is "uncertain." For the more precision measurement about, there are six significant figures, 1.23175, the 5 being approximate.

In calculations using measurements like the above, the answer you obtain can, of course, never be more precise than the measurements with which you started. If your answer has more digits than you started with, round off your answer to the same number of significant figures as the least number that you started with. This is especially important when you use a hand calculator, which can give eight to ten figures in an answer. For example,

$$\frac{1.23\ \text{m}}{3.69\ \text{s}} = 0.3333333\ \text{m/s} \quad \text{by using a hand calculator,}$$

but physically the answer is only 0.333 m/s.

Obviously, the original measurements were not made to the seventh decimal place. The extra decimals given by the calculator have no physical meaning, so the result has to be rounded to 0.333 m/s. Similarly,

$$\frac{18.25\ \text{m}}{6.8\ \text{s}} = 2.6838235\ \text{m/s} \quad \text{by calculator,}$$

but physically the answer is only 2.7 m/s.

If in a measurement you use all of the decimals available, you should still indicate the precision of your measurement by including zeros in your data. For instance, suppose you are using a meter stick that has centimeters and millimeters to measure the distance between two dots on a time tape. The measurement turns out to be exactly 4 cm. You may think to record 4 in your data table, but the number 4 alone does not convey the precision of your measurement. In fact, it conveys the impression that you measured only to the nearest centimeter. To indicate that you really measured to the nearest millimeter, this result should be recorded as 4.0 cm.

SCIENTIFIC NOTATION

Often when working with very large numbers or very small numbers, it is easier to express them in "scientific notation." This notation involves a decimal number, called the "argument," multiplied by 10 raised to an integer power (the exponent). The power of 10 is determined by the number of places that the decimal is moved to the left (positive) or to the right (negative).

▼ Examples

$$93{,}000{,}000 = 9.3 \times 10^{7},$$
$$0.000000935 = 9.35 \times 10^{-7}.$$

When multiplying two numbers in scientific notation, first multiply the arguments, then add the exponents. Thus,

$$(6.3 \times 10^7)(1.2 \times 10^{-5}) = 7.6 \times 10^2$$

$$(9.3 \times 10^7)(8.6 \times 10^{-2}) = (9.3 \times 8.6) \times 10^5 = 79.98 \times 10^5,$$

$$= 7.998 \times 10^6.$$

When dividing two numbers, first divide the arguments, then subtract the exponent of the denominator from the exponent of the numerator. The result may be positive or negative. Thus,

$$\frac{6.3 \times 10^7}{1.2 \times 10^{-5}} = 5.3 \times 10^{12},$$

$$\frac{9.3 \times 10^7}{8.6 \times 10^{+2}} = \frac{9.3}{8.6} \times 10^5 = 1.08 \times 10^5.$$

When adding or subtracting numbers in scientific notation, first express all of the numbers in scientific notation with the same exponent, then add or subtract the arguments, maintaining the same exponent in the result. Thus,

$$(9.30 \times 10^7) + (5.80 \times 10^6) = (9.30 \times 10^7) + (0.58 \times 10^7) = 9.88 \times 10^7.$$

To square or cube a number in scientific notation, you first square or cube the “argument” then multiply the power of 10 by 2 or 3.

▼ Example

$(9.0 \times 10^7)^3 = 729 \times 10^{21} = 7.29 \times 10^{23}.$

To take the cube root of a number in scientific notation, you must first express the power of 10 in a power that is divisible by 3. Then take the cube root of the argument and divide the power of 10 by 3.

▼ Example

$(0.8 \times 10^7)^{1/3} = (8.0 \times 10^6)^{1/3} = 2.0 \times 10^2.$

▼ Exercises

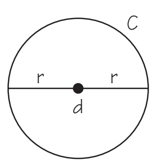
1. $(9.3 \times 10^7)(8.6 \times 10^{-2}) = ?$.
2. $(9.3 \times 10^7)/(8.6 \times 10^{-2}) = ?$.
3. $(9.3 \times 10^7) + (5.8 \times 10^6) + (1.23 \times 10^8) = ?$.
4. The speed of light is approximately 300,000 km/s. How many kilometers does light travel in 1 year? (This *distance* traveled by light in 1 year is confusingly called a "light year".)

GEOMETRY REVIEW

CIRCLES

Any line through the center of a circle and intersecting the circle is a diameter d. The center point divides the diameter into two equal halves, each of which is a radius r. The ratio of the circumference (C) of any circle to its diameter is a universal number known as pi (π):

$$\frac{C}{d} = \pi = 3.14159 \ldots .$$



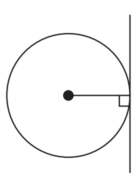
The circumference of a circle is

$$C = \pi d = 2\pi r.$$

The area of a circle is

$$A = \pi r^2.$$

The tangent to a circle at any point is perpendicular to the radius at that point.

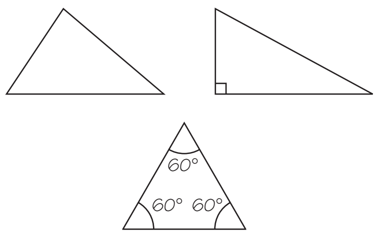


TRIANGLES

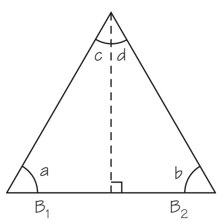
The sum of the angles of any triangle is 180°.

In a right triangle, one of the angles is 90°; while the sum of the other two angles is equal to 90°.

In an equilateral triangle, the sides are all of equal length and the three angles are each 60°.

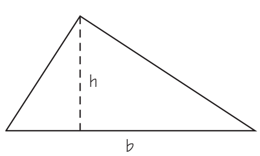


In an isosceles triangle, two of the sides are equal. The angles formed by those two sides and the third side are equal. In the triangle above, angle *a* = angle *b*. An altitude drawn from the third side to the opposite angle bisects the opposite angle, divides the third side in half, and forms a perpendicular with the third side. Thus, in the triangle above, angle *c* = angle *d*, and segment B_1 = segment B_2. The altitude thus divides an isosceles triangle into two congruent (identical) right triangles.



The area of a triangle is one-half of the base times the height of the triangle, or in symbols:

$$A = \tfrac{1}{2}bh.$$

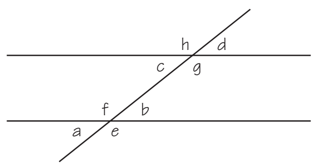


PARALLEL LINES

The following sets of angles are all equal to each other:

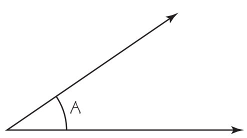
$$a = b = c = d,$$

$$e = f = g = h.$$

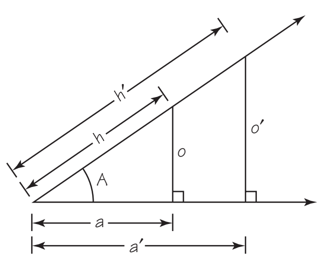


REVIEW OF BASIC TRIGONOMETRY

Two intersecting lines form an angle A, which stays constant no matter how far the two lines are extended. (This is a postulate of Euclidean geometry.)



If lines are dropped at various intervals from the upper line perpendicular to the lower line, right triangles are formed, all with the common angle A.



Since two of the angles in each of these right triangles are equal to each other (90° and angle A), the third angles are also equal. Since the sides are not equal to each other, the triangles are not congruent, but they are similar.

Because these right triangles are all similar, the ratios of their corresponding sides are all equal (although the sides themselves are all different). From this the following ratios of sides are equal to each other:

$$\frac{o}{h} = \frac{o'}{h'},$$

$$\frac{a}{h} = \frac{a'}{h'},$$

$$\frac{o}{a} = \frac{o'}{h'}.$$

The ratio of the corresponding sides of any right triangle with an angle A will be equated to one of the ratios above. These ratios are thus universal for all right triangles with the same size angles—from triangles on paper to the Earth–Sun–Moon system and beyond!

To simplify matters, these ratios are given special names. They are called the *sine* (abbreviation: sin), *cosine* (cos), and *tangent* (tan), and their values for a given angle may be found in standard tables or obtained on a pocket calculator. Referring to the first triangle formed, the definitions are

$$\sin A = \frac{o}{h},$$

$$\cos A = \frac{a}{h},$$

$$\tan A = \frac{o}{a}.$$

(The inverse ratios also have special names, but we will not consider them here.)

For example, if $A = 30°$, then o/h or o'/h', etc., will always have the ratio of 1:2 or 1/2; a/h or a'/h', etc., will be $\sqrt{3}/2$; o/a or o'/a, etc., will be $1/\sqrt{3}$.

The powerful advantage of these "trigonometric functions" is that, if you know the size of an angle in any right triangle and the length of one of the sides, you can find the other two sides simply by looking up the corresponding trigonometric functions and multiplying to obtain the unknown side. Conversely, if you know the ratio of any two sides of a right triangle, you can find the angles by finding the angle that yields the value of that trigonometric function.

An easy way to remember these functions is by remembering SOHCAHTOA. This word is made up of the first letters of: Sine is Opposite over Hypotenuse, Cosine is Adjacent over Hypotenuse, Tangent is Opposite over Adjacent.

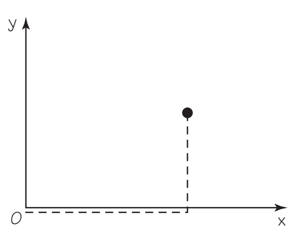
▼ Exercises

1. In a right triangle, one of the angles is 30° and the opposite side is 1 m long. Find the other angles and sides.

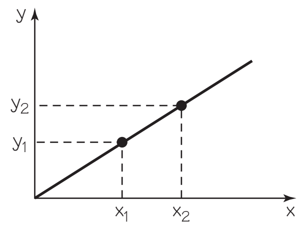
2. In an isosceles triangle, the base is 5 m long and the equal sides are each 6 m long. Find the angles and the length of the altitude from the base.

REVIEWING GRAPHS

A flat plane, such as a table top, has two dimensions, length and width, which can be labeled y and x. A point on the table or plane can be identified if we define a corner of the plane as the "origin," that is, the place from which we start measuring length and width, y and x. In this case, if the origin is defined as $x = 0$ and $y = 0$, any point on the plane can be designated simply by giving the values of x and y that one must move away from the origin to reach the designated point.



In graph 1 on the next page, a series of points were designated such that, as the value of the x coordinate increased by the same amount each time, the value of the y coordinate also increased each time by the same amount (not necessarily the amount that x increased). When this occurs, the points lie on a straight line, which is shown in graph 1.

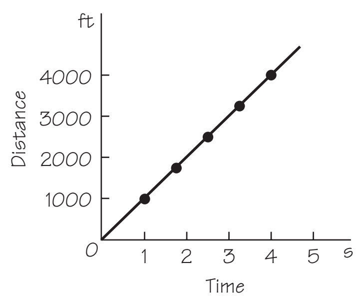


(1)

Here is an example: Measured from the origin, a plane has traveled a total distance of 1000 m in 1 s, 2000 m in 2 s, 3000 m in 3 s, and 4000 m in 4 s. These data can be placed in a table:

Time (s)	*Total distance (m)*
1	1000
2	2000
3	3000
4	4000

In graph 2 below, we plotted the position of the plane, which is the distance traveled (*d*), on the *y*-axis and the time (*t*) on the *x*-axis. Notice that each interval on the *t*-axis and on the *d*-axis of our graph has the exact same value: 1 s each for the time axis and 1000 m for each interval on the distance axis. Also, we set up the axes so that all of the data fit on the graph without going over the top or without being "scrunched" into the corner. We were also careful to label the units of each axis, seconds and feet.



(2)

The resulting data points produced a straight-line graph, as you might expect, since as time increased by 1 s at each point, the plane's position increased by 1000 m.

When the *y* and *x* variables increase or decrease together in this fashion, we say that *variable* y *is proportional to variable* x. This phrase may be written in symbols

$$y \propto x \quad \text{or in this case} \quad d \propto t.$$

Whenever two variables are proportional to each other, we can replace the proportional sign, $\propto$, by an equal sign, $=$, *if* we include a constant, which is called "the constant of proportionality." Usually this constant is given the symbol m.

$$y = mx \quad \text{where } m \text{ is a proportionality constant.}$$

It is important to note that two variables are proportional only if the points on a graph form a *straight line*. Otherwise, the variables are not proportional.

In the example of the airplane (graph 2), the straight line produced would indicate that $d \propto t$, or that $d = mt$.

How do we obtain the constant of proportionality, m? If the graph of y versus x does form a straight line, the line has a constant "slope." The slope is different for different lines, depending upon how fast or how slow the y variable changes compared to the change in the x variable. For instance, the line on a graph for a plane that travels 2000 m more every second, would have a steeper slope than for a plane that flew only 1000 m every second.

The ratio of the changes in the two variables gives the slope. More precisely, the ratio of the change in y between any two points on the line, $y_2 - y_1$, over the change in x between those same two points, $x_2 - x_1$, is the slope. For a straight line, this ratio is the same no matter which two points you choose. This constant value of the slope of the line is equal to the constant of proportionality, m in the equation $y = mx$.

$$m = \frac{y_2 - y_1}{x_2 - x_1}.$$

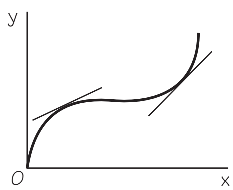
In the example of the first plane, the slope of the line measured between the first and last points is

$$m = \frac{4000 \text{ ft} - 1000 \text{ ft}}{4 \text{ s} - 1 \text{ s}} = \frac{3000 \text{ ft}}{3 \text{ s}} = 1000 \text{ ft/s}.$$

This is just the (constant) speed of the plane. So, in this case, the slope of the distance–time graph of an object moving at constant speed is the speed, v. So we can write

$$d = mt = vt.$$

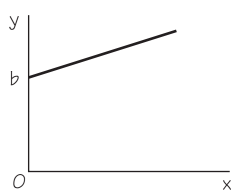
One can also find the slope of any portion of a graph that is linear over a small distance, as indicated in graph 3. In fact, a tangent can be drawn to a curve at any desired point on the curve, and the slope of the tangent can be found in the same way. This gives you a value for the slope at that point alone.



(3)

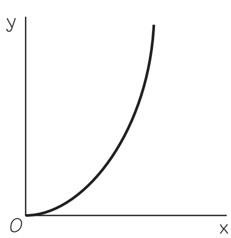
If the line does not go through the origin, as in graph 4, it will intersect the y-axis at some other point, $y = b$. In that case, the relationship between y and x for this line may be written

$$y = mx + b.$$



(4)

If a graph of a series of values for y and x does not yield a straight line, but an upward curve, as in graph 5, it may be a parabola. To see if it is, instead of graphing y versus x, try y versus x^2, that is, square each value of the x value (leaving the y values alone) and then graph those new numbers against y.



(5)

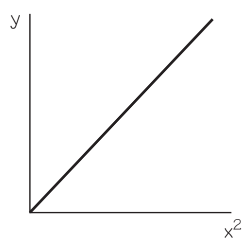
If the new graph turns out to be a straight line, then you have found a new proportionality between y and x^2, rather than between y and x. In this case

$$y \propto x^2 \qquad \text{or} \qquad y = kx^2.$$

This is the equation of a *parabola*. In this case, k is the slope of the new graph of y versus x^2.

Of course, one can substitute other variables for y and x, such as distance d and time t of a moving plane or any other object.

Although your graph does not have to start at the origin, most of the time it will. Always be sure to indicate the value of the origin variables; always indicate which variable is placed on each axis; and always clearly indicate the units for each axis.



(6)

Further Reading and Web Sites

SOME GENERAL READING

E.B. Bolles, ed., *Galileo's Commandment: 2,500 Years of Great Science Writing* (New York: Freeman, 1999).

J. Carey, ed., *Eyewitness to Science: Scientists and Writers Illuminate Natural Phenomena from Fossils to Fractals* (Cambridge, MA: Harvard University Press, 1995).

R.P. Feynman, *The Character of Physical Law* (New York: Modern Library, 1994).

M. Gardner, ed., *Great Essays in Science* (Amherst, NY: Prometheus Books, 1994).

G. Holton, *Einstein, History, and Other Passions* (Cambridge, MA: Harvard University Press, 2000).

G. Holton, *Science and Anti-Science* (Cambridge, MA: Harvard University Press, 1994).

P. Morrison, *Nothing is Too Wonderful to be True* (New York: Springer-Verlag, 1995).

R. Pool, *Beyond Engineering: How Society Shapes Technology* (New York: Oxford University Press, 1997).

C. Sagan, *Cosmos* (New York: Ballantine Books, 1993).

Plays

B. Bertolt, *Galileo* (New York: Grove Press, 1991).

F. Durrenmatt, *The Physicists* (New York: Grove Press, 1992).

M. Frayn, *Copenhagen* (London: Metheuen, 2000).

H. Kipphardt, *In the Matter of J. Robert Oppenheimer* (London: Hill and Wang, 1968).

Recent Fiction

C. Djerassi, *Cantor's Dilemma* (New York: Penguin, 1991).

C. Minichino, *The Hydrogen Murder* (New York: Thomas Bouregy, 1997).

C. Minichino, *The Helium Murder* (New York: Avalon, 1998).

C. Minichino, *The Lithium Murder* (New York: William Morrow, 1999).

D. Sobel, *Galileo's Daughter: A Historical Memoir of Science, Faith, and Love* (New York: Walker, 1999).

Poetry and Art

D.H. Levy, *More Things in Heaven and Earth: Poets and Astronomers Read the Night Sky* (Wolfville, Nova Scotia: Wombat Press, 1997).

L. Shlain, *Art and Physics: Parallel Visions in Space, Time, and Light* (New York: Morrow, 1991).

(See also the end of each chapter.)

SLOAN TECHNOLOGY BOOK SERIES ON HISTORY OF TECHNOLOGY

R. Buderi, *The Invention That Changed the World: How a Small Group of Radar Pioneers Won the Second World War and Launched a Technological Revolution* (New York: Touchstone Books, 1998).

M. Campbell-Kelly and W. Aspray, *Computer: A History of the Information Machine* (New York: Basic Books, 1997).

C. Canine, *Dream Reaper: The Story of an Old-Fashioned Inventor in the High-Stakes World of Modern Agriculture* (Chicago: University of Chicago Press, 1997).

D.E. Fisher, and M.J. Fisher, *Tube: The Invention of Television* (New York: Harcourt Brace, 1997).

S.S. Hall, *A Commotion in the Blood: A Century of Using the Immune System to Battle Cancer and Other Diseases* (New York: Henry Holt, 1997).

J. Hect, *City of Light: The Story of Fiber Optics* (New York: Oxford University Press, 1999).

T.A. Heppenheimer, *Turbulent Skies: The History of Commercial Aviation* (New York: Wiley, 1998).

R. Kanigel, *The One Best Way: Frederick Winslow Taylor and the Enigma of Efficiency* (New York: Viking Press, 1997).

B.H. Kevles, *Naked to the Bone: Medical Imaging in the Twentieth Century*, (Piscataway, NJ: Rutgers University Press, 1997).

V. McElheny, *Insisting on the Impossible: The Life of Edwin Land, Inventor of Instant Photography* (New York: Perseus Press, 1999).

R. Pool, *Beyond Engineering: How Society Shapes Technology* (New York: Oxford University Press, 1997).

R. Rhodes, *Dark Sun: The Making of the Hydrogen Bomb* (New York: Touchstone Books, 1996).

R. Rhodes, ed., *Visions of Technology: A Century of Vital Debate about Machines, Systems and the Human World* (New York: Simon and Schuster, 2000).

M. Riordan, and L. Hoddeson, *Crystal Fire: The Birth of the Information Age* (New York: Norton, 1997).

C.H. Townes, *How the Laser Happened: Adventures of a Scientist* (New York: Oxford University Press, 1999).

Some Web Sites

Web sites come and go. Visit the course Web site for an up-to-date list, at: http://www.springer-ny.com/.

A. Einstein: http://www.aip.org/history/einstein
A. Sakharov: http://www.aip.org/history/sakharov
M. Curie: http://www.aip.org/history/Curie/contents.html
Heisenberg and the Uncertainty Principle: http://www.aip.org/history/heisenberg
The Discovery of the Electron: http://www.aip.org/history/electron
Double Slit Experiment with Electrons or Photons: http://www.inkey.com/dslit
Virtual Physics Laboratories: http://explorescience.com
Discovery of the Transistor: http://www.pbs.org/transistor
Lasers: http://www.aip.org/success/industry/index.html
Superconducting Devices: http://superconductors.org and http://www.oml.gov/reports/m/ornlm3063r1/pt4.html
Todd's Intro to Quantum Mechanics: http://www-theory.chem.washington.edu/~trstedl/quantum/quantum.html
Nobel Prize Winners: http://nobelprizes.com/nobel/nobel.html
Women in Physics: http://www.physics.ucla.edu/~cwp
L. Kristick: "Physics: An Annotated List of Key Resources on the Internet," http://www.ala.org/acrl/resmar00.html
PhysLink (information resource on all aspects of physics): http://www.physlink.com
PhysicsEd: Physics Education Resources: http://www-hpcc.astro.washington.edu/scied/physics.html. A host of resource references on curricula, video, demonstration materials, software, and more.
Physics-2000: http://www.colorado.edu/physics/2000. Many interactive virtual experiments.
NASA: http://spacelink.nasa.gov
"How Stuff Works": http://www.howstuffworks.com
Physics Web: http://physicsweb.org/tiptop/lab
"Beyond Discovery Series," National Academy of Sciences: http://www.Beyond-Discovery.org
"Physics Success Stories": http://www.aip.org/success/
"Top 20 Engineering Achievements of the Twentieth Century," National Academy of Engineering: http://greatachievements.org
Flash-Card physics: http://hyperphysics.phys-astr.gsu.edu/hphys.html