Name ______________________ Period ________ Date __________

PHYSICS SKILL

Use with Chapter 2

Factor-Label Method for Converting Units

A very useful method of converting one unit to an equivalent unit is called the factor-label method of unit conversion. You may be given the speed of an object as 25 km/h and wish to express it in m/s. To make this conversion, you must change km to m and h to s. In algebra, you learned that if a quantity is multiplied by 1, its value does not change. But 1 is just a quantity divided by its equivalent. Since 1000 m = 1 km and 60 s = 1 min and 60 min = 1 h,

$$\frac{1000\ \text{m}}{1\ \text{km}} = 1 \qquad \frac{1\ \text{min}}{60\ \text{s}} = 1 \qquad \frac{1\ \text{h}}{60\ \text{min}} = 1$$

To change 25 km/h to m/s, you must multiply by a series of factors so that the units you do not want will cancel out and the units you want will remain.

$$\frac{25\ \cancel{\text{km}}}{1\ \cancel{\text{h}}} \cdot \frac{1000\ \text{m}}{1\ \cancel{\text{km}}} \cdot \frac{1\ \cancel{\text{h}}}{60\ \cancel{\text{min}}} \cdot \frac{1\ \cancel{\text{min}}}{60\ \text{s}} = 69\ \text{m/s}$$

To convert 80 milliliters to liters, first choose the factor. Since 1 L = 1000 mL,

$$\frac{1\ \text{L}}{1000\ \text{mL}} = 1$$

Use this factor for your conversion as follows.

$$80\ \cancel{\text{mL}} \cdot \frac{1\ \text{L}}{1000\ \cancel{\text{mL}}} = 0.08\ \text{L}$$

Problems

Carry out the following conversions using the factor-label method.

1. How many seconds are in a year?

2. Convert 28 km to cm.

3. Convert 50 g to kg.

4. Convert 45 kg to mg.

5. Convert 450 m/s to m/h.

6. Convert 50 liters to mL.

7. Convert 85 cm/min to m/s.

8. Convert the speed of light, 3.0×10^8 m/s, to km/day.

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PHYSICS SKILL

Use with Chapter 2

Dimensional Analysis

Quantities such as length, speed, and area are called *dimensional quantities*. A measured dimensional quantity has a numerical value that depends upon the system of units used. For example, a given area can be stated as either 1 square meter or 10 000 square centimeters. When making a measurement, the most convenient unit is used.

When substituting values into an equation in physics, you must state the units as well as the numerical values. Including units in your calculations helps you keep units consistent throughout and assures you that your answer will be dimensionally correct.

You may also use the units or dimensions of your measurements to check the correctness of your equation.

Example

Dimensionally Incorrect Equation

velocity $\stackrel{?}{=}$ (distance) (time)

$$\frac{\text{m}}{\text{s}} \stackrel{?}{=} \text{m} \,|\, \text{s}$$

$$\frac{\text{m}}{\text{s}} \neq \text{m}\cdot\text{s}$$

Note that the final units on the right do not equal those on the left. By inspecting the dimensions, you should be immediately aware that the equation is not correctly written.

Example

Dimensionally Correct Equation

mass $\stackrel{?}{=}$ (density) (volume)

$$\text{kg} \stackrel{?}{=} \frac{\text{kg}}{\text{m}^3} \,\Big|\, \text{m}^3$$

$$\text{kg} = \text{kg}$$

Note that some of the units on the right side of the equation cancel out. The final dimensions on both sides are the same. The equation is dimensionally correct.

Problems

Use the method described above to determine if the following equations are correctly written. The proper units for the variables are listed below.

d (distance)–meters

t (time)–seconds

v (velocity)–meters/second

a (acceleration)–meters/(second)^2

v_i = initial velocity; v_f = final velocity; $\bar{v}$ = average velocity

1. $v_f \stackrel{?}{=} v_i t + a$

2. $\bar{v} \stackrel{?}{=} \dfrac{v_i + v_f}{2}$

3. $d \stackrel{?}{=} \sqrt{v_i t^2 + \frac{1}{2} a t}$

4. $v_f \stackrel{?}{=} v_i^2 + 2ad^2$

5. $d \stackrel{?}{=} \frac{1}{2} v_i t + at$

6. If r is in meters
g is in meters/s^2
x is in kg/meters^3
n is in kg/meter s

does $v = \dfrac{2\, r^2\, g\, x}{9\pi n}$?

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PHYSICS SKILL

Use with Chapter 1

Propagation of Error

Each measurement you make in an investigation has associated with it an error determined by the instrument being used. Suppose you can read a meter stick to 0.01 cm. Suppose you measure one side of a block of wood several times and get the following readings: 23.05 cm; 23.04 cm; 23.08 cm; 23.02 cm; 23.06 cm. The average of these readings is 23.05 cm. The best way to report the length of the block to indicate not only the probable length, but also the range of measurement error, is 23.05 ± 0.03 cm. The ± 0.03 cm is the difference between the average value and the highest and lowest measurement.

If you make several measurements in this fashion and add them together to calculate a new length, or multiply them to find a volume, the error in each measurement is carried along in the calculation. This accumulation of errors is called the propagation of error. The uncertainty in your final answer must reflect the errors introduced with each individual measurement.

Example

Propagation of Error in Addition and Subtraction

Suppose you measure the three sides of a triangle and want to find the perimeter. The measurements are 23.43 ± 0.2 cm, 53.46 ± 0.02 cm, and 3.25 ± 0.02 cm. Adding these values together, you get

$$23.03 \text{ cm} + 53.06 \text{ cm} + 3.25 \text{ cm} = 80.13 \text{ cm}$$

To determine what uncertainty to give your result, first find the maximum value for the perimeter by adding 0.02 cm to the average value for each measurement.

$$23.44 \text{ cm} + 53.48 \text{ cm} + 3.27 \text{ cm} = 80.19 \text{ cm}$$

Then determine the minimum value by subtracting 0.02 cm from each average value.

$$23.40 \text{ cm} + 53.44 \text{ cm} + 3.23 \text{ cm} = 80.07 \text{ cm}$$

The largest value is 0.06 cm larger than 80.13 cm, and the smallest value is 0.06 cm lower than 80.13 cm. Therefore we can write the perimeter as 80.13 ± 0.06 cm. *For addition and subtraction, the error in the result is the sum of the individual errors.* Note that in subtraction as well as addition, the individual errors are added.

Example

Propagation of Error in Multiplication and Division

The length, width, and height of a block were found to be 20.2 ± 0.2 cm, 12.4 ± 0.2 cm, and 16.3 ± 0.2 cm respectively. Calculate the volume of the block and report it with the proper error.

$$20.2 \text{ cm} \times 12.4 \text{ cm} \times 16.3 \text{ cm} = 4082.824 \text{ cm}^3$$

Following the rules for significant digits, the volume should be reported as 4080 cm^3. To determine the uncertainty, multiply the shortest lengths together.

$$20.0 \text{ cm} \times 12.2 \text{ cm} \times 16.1 \text{ cm} = 3930 \text{ cm}^3$$

Then multiply the greatest lengths.

$$20.4 \text{ cm} \times 12.6 \text{ cm} \times 16.5 \text{ cm} = 4240 \text{ cm}^3$$

$$4240 \text{ cm}^3 - 3930 \text{ cm}^3 = 311 \text{ cm}^3$$

Assume that a measurement higher than the average is just as likely as a measurement below the average; the error range is distributed equally above and below the calculated value.

$$\frac{311 \text{ cm}^3}{2} = 155 \text{ cm}^3, \text{ and the volume is } 4080 \pm 155 \text{ cm}^3.$$

However, according to the rules for significant digits, there is uncertainty in the tens place. Any number in the ones place is even more uncertain. The most correct value is

$$V = 4080 \pm 150 \text{ cm}^3$$

This notation gives the absolute error.

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An easier way to arrive at the same answer in multiplication and division is by using relative uncertainty. Using the numbers from the above example, find the percent error for each measurement.

$$l = 20.2 \pm 0.2 \text{ cm, uncertainty} = \frac{0.2}{20.2} \times 100 = 0.99\%$$

$$w = 12.4 \pm 0.2 \text{ cm, uncertainty} = \frac{0.2}{12.4} \times 100 = 1.6\%$$

$$h = 16.3 \pm 0.2 \text{ cm, uncertainty} = \frac{0.2}{16.3} \times 100 = 1.2\%$$

The sum of the percents is 3.79%. The product of the measurements was 4080 cm^3. Take 3.79% of that value and we get 150 cm^3, so the answer is 4080 ± 150 cm^3 just as before. *In multiplication and division, the relative uncertainty in the answer is equal to the sum of the percent errors of each measurement.*

Problems

1. Five students measure the mass of the same object as 7.998 g, 8.001 g, 8.001 g, 8.003 g, and 7.997 g. What would be the best way to report the mass of the object?

2. The length and width of a room were found to be 12.50 ± 0.01 m and 9.63 ± 0.01 m. Find the perimeter of the room and the uncertainty.

3. At the beginning of an investigation, a student determines that the temperature of a beaker of water is 99.8 ± 0.1°C. At the end of the investigation, the temperature is 35.5 ± 0.1 °C. What is the change in temperature?

4. Measure the length and width of the cover of your physics book. Record the uncertainty of each measurement. Calculate the surface area and the absolute and relative error.

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PHYSICS SKILL

Use with Chapter 2

Graphing Techniques

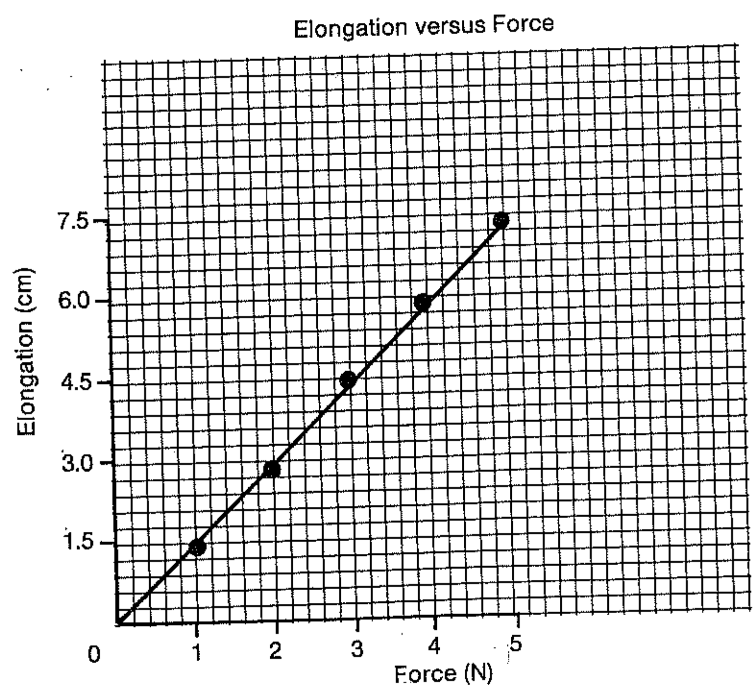
Frequently an investigation will involve finding out how changing one quantity affects the value of another. The quantity that is deliberately varied is called the *independent variable*. The quantity that changes due to the variation in the independent variable is called *dependent variable*.

More often than not the relationship between the independent and dependent variable is not obvious from simply looking at the written data. However, if one quantity is plotted against the other, the resulting graph gives evidence of what sort of relationship, if any, exists between the variables. When plotting a graph, take the following steps.

1. Identify the independent and dependent variable.
2. Choose your scale carefully. Make your graph as large as possible by spreading out the data on each axis. Let each space stand for a convenient amount. Choosing three spaces equal to 10 is not convenient because each space is an awkward fraction. Choosing five spaces equal to 10 would be better. To avoid a cluttered appearance, you do not need to number every space.
3. Plot the independent variable on the horizontal (x) axis (abscissa) and the dependent variable on the vertical (y) axis (ordinate). Plot each point as a dark dot with a small circle around it.
4. Label each axis with the name of the variable and the unit. Using a ruler, darken the lines representing the axis.
5. Title your graph. The title should clearly state the purpose of the graph and include the independent and dependent variables.
6. If the data points appear to lie roughly in a straight line, draw the best straight line you can with a ruler and sharp pencil. Have the line go through as many points as possible with approximately the same number of points above the line as below. Never "connect the dots." If the points do not form a straight line, draw the best smooth curve possible.
7. All graphs do not go through the origin (0,0). Think about your experiment and decide if the data would logically include a (0,0) point. For example, if a cart is at rest when you start the timer, then your graph of speed versus time would go through the origin. If the cart is already in motion when you start the timer, your graph will not go through the origin.

Below is a graph using good graphing techniques. Go back and check each of the items mentioned above.

Force (N)	Elongation (cm)
0	0.0
1	1.5
2	3.0
3	4.5
4	6.0
5	7.5



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Problems

Graph the following sets of data using the above techniques.

1.

Pressure (torr)	Volume (mL)
100	800
200	400
400	200
600	133
700	114
800	100
1000	80

2.

Time (s)	Distance (m)
0	0
1	5
2	20
3	45
4	80
5	125

3.

Time (s)	Speed (m/s)
0	0
1	20
2	45
3	60
4	84
5	105

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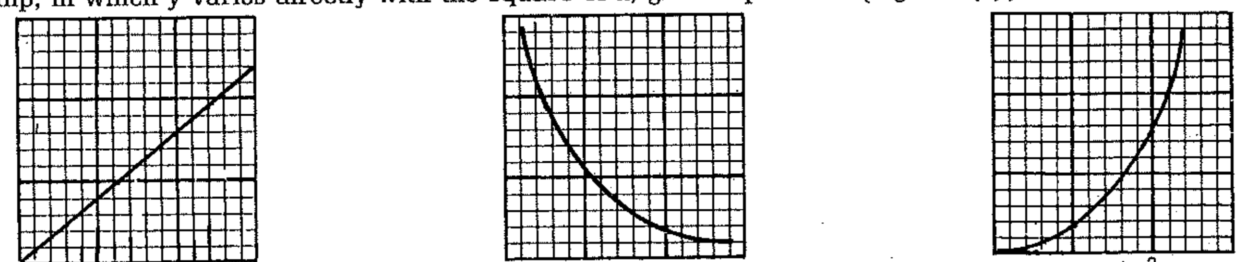
PHYSICS SKILL

Use with Chapter 2

Interpreting Graphs

In the laboratory investigations, you generally control one variable and measure the effect it has on another variable while you hold all other factors constant. For example, you might vary the force on a cart and measure its acceleration while you keep the mass of the cart constant. After the data is collected, you then make a graph of acceleration versus force using the techniques for good graphing. The graph gives you a better understanding of the relationship between the two variables.

There are three relationships that occur frequently in physical processes. If the dependent variable varies directly with the independent variable, the graph will be a straight line passing through the origin (Figure 1(a)). If y varies inversely with x, the graph will be a hyperbola as shown in Figure 1(b). The third relationship, in which y varies directly with the square of x, gives a parabola (Figure 1(c)).



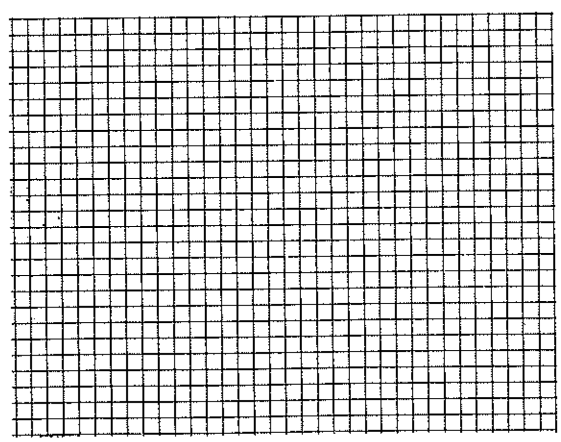
$y = kx$ $y = k/x$ $y = kx^2$

Sometimes you need information about a value that you have not determined experimentally. Reading from the graph between data points is called *interpolation.* Reading from the graph beyond the limits of your experimentally determined data points is called *extrapolation.* Extrapolation must be used with caution because you cannot be sure that the relationship between the variable remains the same beyond the limits of your investigation.

Problems

1. Suppose you recorded the following data below during your study of the relationship of force to acceleration. Plot the graph in the space provided.

Force (N)	Acceleration (m/s^2)
10	6.0
20	12.5
30	19.0
40	25.0



a. Describe the relationship between force and acceleration as shown by the graph.

____

b. Write an equation for the line. (Recall that slope $= \frac{\Delta y}{\Delta x}$.)

c. What is the slope of the graph? Remember to include units with your slope. (A newton equals $kg{\cdot}m/s^2$.)

____

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d. What physical quantity does the slope represent? ______________________

e. What is the value of the force for an acceleration of 15 m/s^2? ______________________

f. Reading between data points is called ______________________.

g. What is the acceleration when the force is 50 N? ______________________

h. Reading beyond the range of the data collected is called ______________________.

2. Consider the data below on the distance an object travels in certain time periods. Plot your data.

time (s)	distance (cm)
0	0
1	3
2	12
3	27
4	48

a. Describe the relationship between x and y and write a general equation for the curve.

____

b. Is the distance traveled greater between 0 and 1 second or 3 and 4 seconds?

____

c. Is the slope of the curve greater between seconds one and two or seconds three and four?

____

3. Answer the questions about the sets of data below. First try answering the questions by simply looking at the data. Then make a graph of each set and see if the questions are easier to answer.

A.

x	y
1	3
2	6
3	9
4	12
5	15

B.

x	y
0	0
1	2
2	8
3	18
4	32

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C.

x	y
1	80
2	40
3	27
4	20
5	16

D.

x	y
0	2
1	4
2	6
3	3
4	2

________ **a.** In which graph is *y* directly proportional to *x*?

________ **b.** In which graph does y decrease as x increases?

________ **c.** In which set of data is *y* inversely proportional to *x*?

________ **d.** Which graph does not seem to picture a simple relationship?

________ **e.** Which graph has the general equation $y = kx^2$?