Chapter 1: The World of Energy, Review of Physics 103

Goals of Period 1

Section 1.1: To review The World of Energy, Physics 103, Part 1
Section 1.2: To review ratios
Section 1.3: To illustrate ratio reasoning
Section 1.4: To review scientific notation
Section 1.5: To review linear and exponential growth

1.1 Review of the World of Energy

The World of Energy courses, Physics 103 and 104, are a 10-credit hour, two-quarter sequence. The courses explore the basic principles of physics in the context of energy use. The courses include practical examples from everyday life to help you use energy safely and wisely. They help prepare you to make rational, informed decisions regarding energy policy, the environment, and your own place in the changing World of Energy.

Class Activities

During two, 2-hour classes per week, your instructor will explain physics concepts and introduce hands-on activities and demonstrations to illustrate these concepts. To help organize, understand, and remember the information from the demonstrations and class activities, students complete and turn in activity sheets during each class. Activity sheets are found in Part I of the *Physics 104 Activity Book*. Students must be present for the full class period to receive credit for an activity sheet, unless excused by the instructor.

Lectures

In addition to attending two 2-hour classes per week, students attend a 1-hour lecture. At most lectures, you will see a video or hear a speaker discussing energy use. These videos and lectures are an important part of the course. They explain physics principles and help relate these principles to the role of energy in everyday life. A list of questions for each video is included in Part II of the *Physics 104 Activity Book.* These questions help students identify important concepts in the videos. Answers to these video questions are not handed in. Instead, students write and turn in a summary of each lecture video of at least two paragraphs. The dates and location of the lectures are given in the course syllabus. Midterm and final exams will include questions based on the material in the lectures.

Examinations

Course examinations consist of two midterms of 30 questions each and a comprehensive final examination of 45 questions. All exam questions are multiple choice. Midterm exams are given during the lecture hour. The dates of the examinations are listed in the course syllabus. **No** make-up examinations will be given. If you have a conflict with any of the exam times, notify your instructor immediately.

Students may use calculators during exams, but may not program them or use their graphing capabilities. Exams include a sheet with useful equations and constants. Equation sheets are provided because the World of Energy emphasizes understanding concepts, rather than memorizing equations and constants. However, it is essential that students understand the meaning of the equations, their symbols, and their units. Appendix A of the *Physics 104 Textbook* lists the equations used in Physics 103. Part III of the *Physics 104 Activity Book* contains six practice exams with equation sheets. The textbook provides help in understanding equations and solving problems in the Skills and Strategies and Concept Check solutions.

How to Succeed in The World of Energy

In the World of Energy, students learn physics concepts primarily by doing activities in class, observing instructor demonstrations, and participating in class discussions. While your textbook contains important information and should be read before each class, it does not provide all the information you will need – some physics concepts have been left for you to discover in your classroom activities. *Therefore, class attendance and active participation are very important*.

In the World of Energy we will explore different forms of energy and the many ways in which energy is used to do work. We begin a review of Physics 103 by discussing some of the mathematical tools used in the course.

1.2 Ratios

To simplify comparisons among quantities, information is often presented as a ratio. A ratio is a fraction – or one quantity divided by another quantity. As was discussed in Period 1 of Physics 103, the word ***per*** means *for each* and designates a ratio.

One common use of ratios is to represent the efficiency of an energy conversion process. The efficiency of an energy conversion process is the ratio of the amount of energy of the desired type produced divided by the total amount of energy put into the conversion process. This ratio may be expressed as a fraction, as a decimal, or as a percent. Equation 1.1 below and Figure 1.1 on the next page describe this relationship.

$$\text{Efficiency} = \frac{\text{Useful Energy Out}}{\text{Total Energy In}} \qquad \textbf{(Equation 1.1)}$$

When a series of energy conversions is required to produce the desired form of energy, energy is wasted in each step of the process. The overall efficiency of a series of energy conversion processes can be quite low. The overall efficiency is the product of the efficiencies of each step in the process.

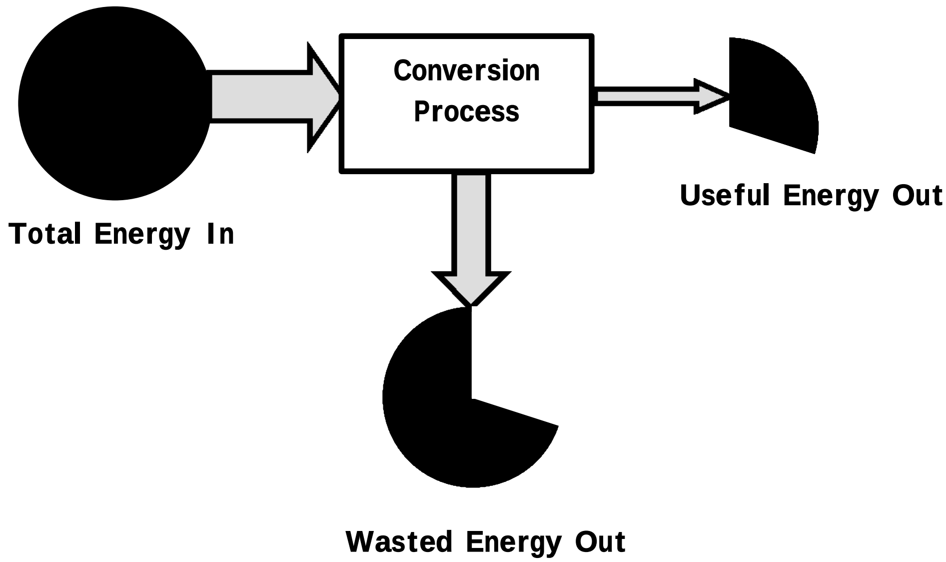
Overall Efficiency = (Efficiency of step 1) x (Efficiency of step 2) x (Efficiency of step 3) x ...

or

$$\text{Overall Efficiency} = = \text{Efficiency}_1 \times \text{Efficiency}_2 \times \text{Efficiency}_3 \times \ldots..$$

Efficiencies given as a percent must be converted to a decimal before performing the multiplication indicated above.

Fig. 1.1 Efficiency of an Energy Conversion



Total Energy In = Useful Energy Out + Wasted Energy Out

Another important use of ratios is for converting a quantity from one unit into another. Ratios formed from any two equivalent quantities, such as 60 min = 1 hour or 365 days = 1 year are just another way of writing unity, or one, and can be used to convert units. Multiplying a quantity by such a ratio does not change the value of the quantity, but merely changes the units in which that value is expressed. For example, to convert from hours to minutes, use a ratio to cancel the unit you wish to eliminate.

$$3\ \cancel{\text{hours}} \times \frac{60\text{ min}}{1\ \cancel{\text{hour}}} = 180\text{ min}$$

(Example 1.1)

There are 1,609 meters per 1 mile. Use ratios to convert 60 miles per hour into meters per second.

$$\frac{60\ \cancel{\text{mile}}\text{s}}{1\ \cancel{\text{hour}}} \times \frac{1{,}609\ \text{meters}}{\cancel{1\ \text{mile}}} \times \frac{1\ \cancel{\text{hour}}}{60\ \cancel{\text{min}}} \times \frac{1\ \cancel{\text{min}}}{60\text{ sec}} = \frac{27\text{ meters}}{1\text{ sec}} = 27\ \text{meters/sec}$$

1.3 Ratio Reasoning

Ratio reasoning is a powerful mathematical tool that allows you to write equations using ratios to solve everyday problems by making the equation yourself. To use ratios in this way, units must be included with each quantity.

To calculate the cost of electricity from an electric bill, use ratios to cancel all units except the one you wish to use to express the result of your calculation. Remember that power is the energy or work transferred divided by the time required, as shown in Equation 1.2.

$$\boldsymbol{P = \frac{E}{t} = \frac{W}{t}} \qquad \textbf{(Equation 1.2)}$$

(Example 1.2)

Given kilowatt-hours (kWh) and cost per kilowatt-hour, find the total cost.

$$0.44\ \cancel{\text{kWh}} \times \frac{\$0.075}{\cancel{\text{kWh}}} = \$0.033$$

Given the total cost and the kilowatt-hours of use, find the cost per kWh.

$$\$0.033 \times \frac{1}{0.44\ \text{kWh}} = \frac{\$0.075}{\text{kWh}}$$

Given the total cost and the cost per kilowatt-hour, find the kilowatt-hours used.

$$\cancel{\$}\,0.033 \times \frac{\text{kWh}}{\cancel{\$}\,0.075} = 0.44\ \text{kWh}$$

Ratio reasoning can also be used to determine whether the additional cost of purchasing an energy-efficient compact fluorescent light bulb is paid back through savings in operating costs.

(Example 1.3)

A 25 watt CF bulb costs $5 to purchase and lasts for 10,000 hours. A 75 watt incandescent bulb, which produces about the same amount of light, costs $0.50 to purchase and lasts for about 750 hours. If electricity costs 8.5 cents per kilowatt-hour, what is the cost of purchasing and operating each type of bulb for 10,000 hours?

$$\text{Total Cost} = \left(\frac{\text{cost}}{\text{kWh}} \times \text{kWh used}\right) + \text{purchase price}$$

Compact Fluorescent Bulb

Operating cost of CF bulb:

$$25\ \cancel{\text{watts}} \times \frac{1\ \text{ki}\cancel{\text{lowatt}}}{1{,}000\ \cancel{\text{watts}}} \times 10{,}000\ \cancel{\text{hours}} \times \frac{\$0.085}{\cancel{\text{kilowatt hour}}} = \$21.25$$

Purchase price of CF bulb = $5.00

Total cost for 10,000 hours use of CF bulb = $21.25 + $5.00 = $26.25

Incandescent Bulb

Operating cost of incandescent bulb:

$$75\ \cancel{\text{watts}} \times \frac{1\ \text{ki}\cancel{\text{lowatt}}}{1{,}000\ \cancel{\text{watts}}} \times 10{,}000\ \cancel{\text{hours}} \times \frac{\$0.085}{\cancel{\text{kilowatt hour}}} = \$63.75$$

Number of bulbs needed:

10,000 hours x 1 bulb = 14 bulbs

Purchase price of incandescent bulbs: $14 \text{ ~~bulbs~~} \times \frac{\$0.50}{\text{~~bulb~~}} = \$7.00$

Total cost for 10,000 hours use of incandescent bulbs = \$63.75 + \$7.00 = \$70.75

Therefore, the compact fluorescent bulb saves \$70.75 - \$21.25 = \$49.50

1.4 Scientific Notation (Powers of Ten)

A number in ***scientific notation*** is written as a number with one digit to the left of the decimal point times 10 raised to an exponential power. When any number is raised to an exponential power, that number is called the base. Scientific notation uses the base 10 and is sometimes called ***powers of 10*** notation. Scientific notation is useful when considering very large or very small numbers.

Mass of the Earth = 5.98×10^{24} kg

Universal gravitational constant, G = 6.67×10^{-11} N m^2/kg^2

Radius of a proton = 7×10^{-16} m

When converting any number to scientific notation, the exponent of base 10 is found by counting the number of places the decimal point is shifted to the left for positive exponents or shifted to the right for negative exponents. A positive exponent of 10 indicates how many times the base 10 is multiplied by itself. A negative exponent indicates how many times 1 is divided by 10. Any number to the power zero equals one.

$10^2 = 10 \times 10 = 100$

$10^1 = 10$

$10^0 = 1$

$10^{-1} = 1/10 = 0.1$

$10^{-2} = 1/(10 \times 10) = 0.01$

Rules for Using Scientific Notation

1. When multiplying powers of 10, add their exponents.

$$10^A \times 10^B = 10^{(A+B)}$$

2. When dividing powers of 10, subtract their exponents.

$$10^A / 10^B = 10^{(A-B)}$$

3. When raising a power of 10 to a power, multiply the exponents.

$$(10^A)^B = 10^{(A \times B)}$$

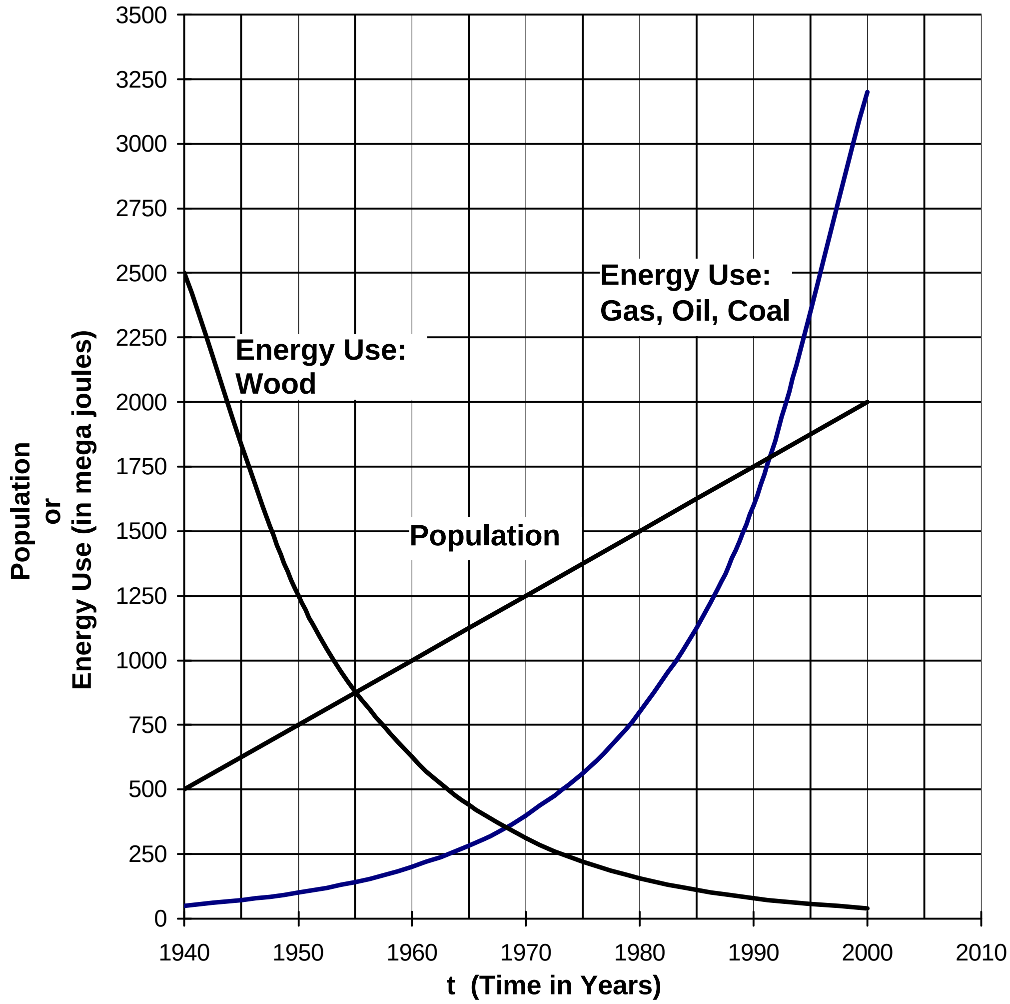
4. Any number raised to the power zero equals 1.

$$A^0 = 1 \qquad 10^0 = 1; \quad 27^0 = 1$$

1.5 Linear and Exponential Growth

A growth rate is the ratio of the amount of increase to the time elapsed. Figure 1.2 illustrates two common models for growth rates – linear growth and exponential growth. It also illustrates what happens when a quantity decreases exponentially with time – exponential decay.

Fig. 1.2 Sample Data on Population and Energy Use



In Figure 1.2, the graph of population is a straight line, which has a constant slope. Graphs with a constant positive slope represent ***linear growth***. Linear growth is characterized by the addition of a constant amount during a fixed time period. The equation describing linear growth is

(Equation 1.3)

$$N = A \times t + B$$

where

- N = the amount of the quantity at a given time
- A = the amount of increase per time period
- t = the number of time periods elapsed
- B = the initial amount of the quantity

Concept Check 1.1

A population of 12,500 people increases by 25 people per year. What will the population be 12 years from now?

____

The graph of energy use in Figure 1.2 illustrates ***exponential growth.*** An exponential growth graph is not a straight line because the amount of the increase per time period is not constant. Exponential growth is characterized by a doubling of the amount of the quantity during a fixed time period. The time between doublings is called the ***doubling time***. Since the amount increases by a factor of two, exponential growth is described by base 2 raised to an exponential power equal to the number of time periods elapsed. The equation describing exponential growth is

$$N = B \times 2^{t} \qquad \textbf{(Equation 1.4)}$$

where

N = the amount of the quantity at a given time

t = the number of time periods elapsed

B = the initial amount of the quantity

Concept Check 1.2

a) A town uses 7,500 MJ of energy per year. If the energy use doubles every 5 years, how much energy would the town require 20 years from now?

____

b) Another town used 40,000 MJ of energy from wood in 1950. If the amount of wood used decreases by a factor of two every 10 years, how much energy from wood did this town use in 2000?

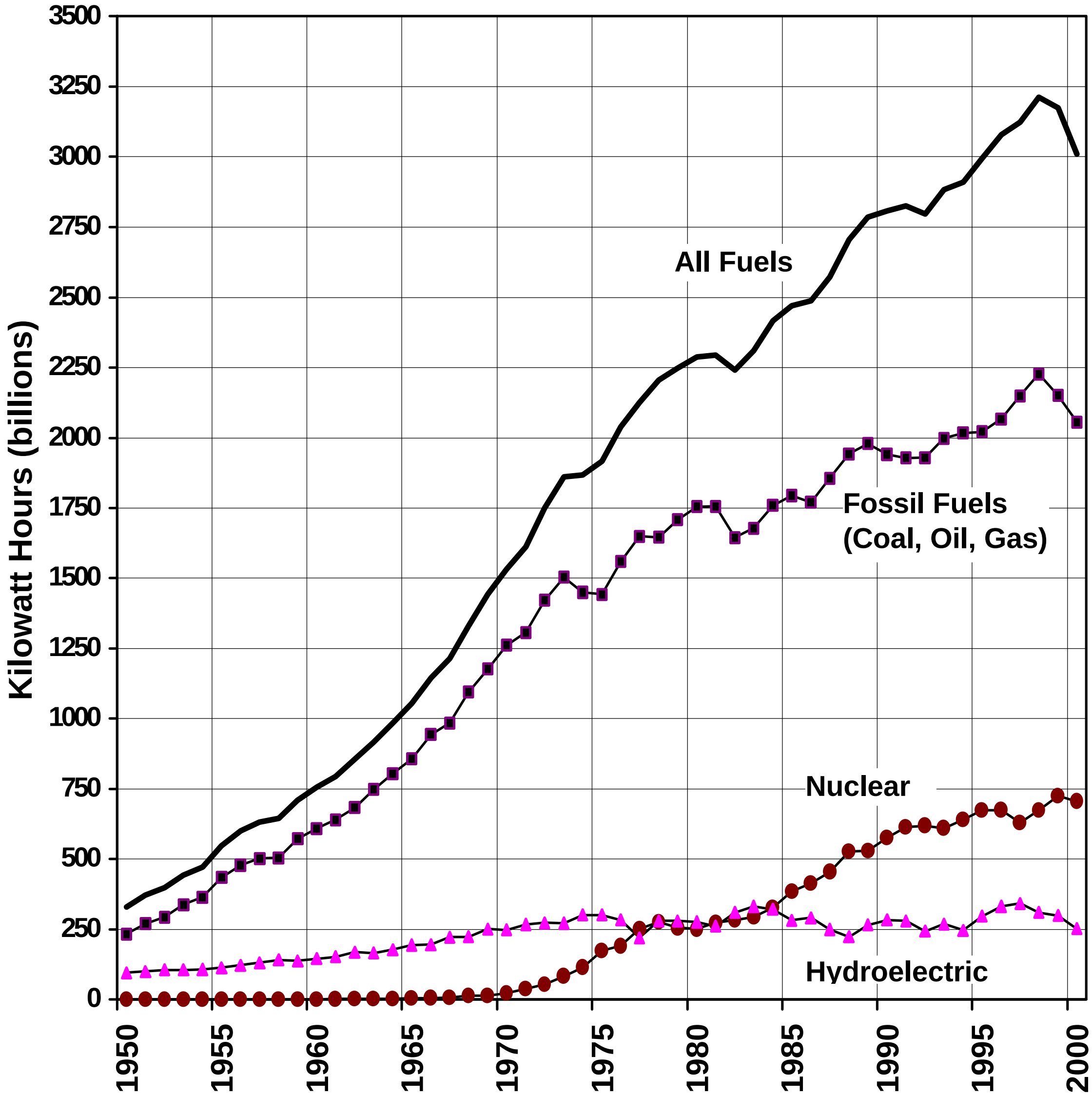
____

When carrying out the calculation in part b of Concept Check 1.2, it is necessary to count backwards in time from 1990 to 1950. When a quantity decreases exponentially with time, the variable t is a halving time instead of a doubling time. When a quantity decreases exponentially, Equation 1.4 is written with a negative exponent of t, as shown in Equation 1.5.

$$N = B \times 2^{-t} \qquad \textbf{(Equation 1.5)}$$

Dependence on particular energy sources in the U.S. has changed over the past century. Figure 1.3 on the next page illustrates the growth of electrical energy production in the U.S. from 1950 to 2000 and the energy sources for this electricity.

Figure 1.3 Annual Electricity Production in the U.S. by Type of Fuel



Concept Check 1.3

a) Between 1950 and 1970, what type of growth best represents the graph of electricity production from all fuels in Figure 1.3? ________________________

b) If this growth rate had continued, what would the energy production have been in 1980? ______________ in 1990? _________________

c) Between 1975 and 1995, what type of growth best represents the graph of electricity production from all fuels? __________________________________

d) If this growth rate continues, what would the electricity production from all fuels be in 2005? ______________ in 2015? ______________

Exponential growth and decay rates have many applications in business and finance and in physical and biological systems. The length of time for a quantity to double, the doubling time, is particularly important. Table 1.1 gives the doubling time in years for various growth rates when compounded annually.

Table 1.1: Growth Rates and Doubling Times

Annual Growth Rate (in percent)	Doubling Time (in years)		Annual Growth Rate (in percent)	Doubling Time (in years)
0	Infinite		20	3.8
1	69.7		30	2.6
2	35.0		40	2.1
3	23.4		50	1.7
4	17.7		60	1.5
5	14.2		70	1.3
6	11.9		80	1.2
7	10.2		90	1.1
8	9.0		100	1.0
9	8.0		200	0.6
10	7.3		300	0.5
12	6.1		400	0.4
14	5.3		900	0.3
16	4.7		9900	0.15
18	4.2			

Concept Check 1.4

a) If you invest $5,000 at 8% interest compounded annually, how long will it take for your money to double to $10,000? ____________________

b) If a stock doubles in value every 4.2 years, what is its rate of growth? ________

Period 1 Summary

1.1: The World of Energy presents physics concepts in the context of energy use. The hands-on format of the course makes student class participation especially important.

1.2-1.3: The concept of *per* is represented by a ratio – one quantity divided by another quantity. When converting units, use ratios that allow cancellation of the unwanted units.

The efficiency of an energy conversion process equals the amount of energy of the desired type produced per total amount of energy put into the process.

Efficiency = Useful Energy Out/Total Energy In

Ratio reasoning is a mathematical tool that allows you to solve practical problems using ratios.

1.4: Powers of 10 simplify calculations with very large or small numbers.

When multiplying powers of 10, add exponents.

When dividing powers of 10, subtract exponents.

1.5: Linear growth adds a constant amount of a quantity during each time period

Linear growth is expressed by $\boldsymbol{N} = \boldsymbol{A} \times \boldsymbol{t} + \boldsymbol{B}$

Exponential growth doubles the amount of the quantity during each time period.

Exponential growth is expressed by $\boldsymbol{N} = \boldsymbol{B} \times 2^{\boldsymbol{t}}$

Exponential decay is expressed by $\boldsymbol{N} = \boldsymbol{B} \times 2^{-\boldsymbol{t}}$

where ***N*** = the amount of the quantity
A = the amount of increase per time period
B = the initial amount
t = the number of time periods elapsed

The doubling time for exponential growth is the length of time required for the amount of a quantity to double.

Growth rate tables (Table 1.1) provide an easy way to determine growth rates and doubling times.

Period 1 Exercises

E.1 How many gallons of gasoline would each vehicle require to go 245 miles?

(a) goes 50 miles on 2.25 gallons

(b) goes 50 miles on 3.5 gallons

(c) goes 50 miles on 6.5 gallons

E.2 The British thermal unit (BTU) is a common unit of measurement for thermal energy. If one gallon of gasoline contains 126,000 BTU's, what is the energy content of 15.5 gallons of gasoline?

a) 8.13×10^{3} BTU's
b) 8.13×10^{4} BTU's
c) 1.95×10^{5} BTU's
d) 1.95×10^{6} BTU's
e) 1.95×10^{7} BTU's

E.3 4.5×10^{5} divided by 1.5×10^{7} is between

a) 10^{-3} and 10^{-2}
b) 10^{-2} and 10^{-1}
c) 10^{-1} and 10^{0}
d) 10^{0} and 10^{1}
e) 10^{2} and 10^{3}

E.4 Which of the following expression(s) is/are correct?

a) $10^{A} \times 10^{B} = 10^{A \times B}$
b) $10^{A} / 10^{B} = 10^{A / B}$
c) $10^{A+B} \times 10^{C} = 10^{A + B \times C}$
d) $10^{A+B} \times 10^{C} = 10^{A+B+C}$
e) None of the expressions is correct.

E.5 What is the efficiency of an energy conversion process that requires 1,600 joules of energy and produces 400 joules of wasted energy?

a) 25%
b) 30%
c) 50%
d) 75%
e) 400%

E.6 Use the data in Table 1.1 to find when a population of 50,000 people, with an annual growth rate of 20%, will reach 1,600,000.

a) 7.6 years
b) 15.2 years
c) 19.0 years
d) 22.8 years
e) 35.0 years

E.7 The return on an investment is 9% per year. If you invested $2,000 in 2002, when will your investment reach $128,000 if the annual growth rate remains constant?

a) 2034
b) 2042
c) 2050
d) 2058
e) 2066

E.8 The population of a rural area decreases by a factor of two every 15 years. If the population was 60,000 in 2000, when will it reach 7,500, assuming that the halving time remains the same?

a) 2015
b) 2030
c) 2045
d) 2060
e) 2075

Period 1 Review Questions

R.1 When using ratio reasoning to solve a problem, how do you decide which value to put in the numerator and which in the denominator of each ratio? Explain your answer by finding the cost of operating a microwave oven for 15 minutes per day every day for a year, if electricity costs $0.10/kWh.

R.2 Explain how to tell whether a graph exhibits linear or exponential growth rates. Does every growth rate fit into one of these two types?

R.3 What determines the amount added during each time period to a quantity that is growing linearly? What determines the amount added during each time period to a quantity that is growing exponentially?

R.4 What is the doubling time of a quantity? How long will it take a stock that increases in value at a rate of 10% per year to double in value?

R.5 What is the halving time of a quantity? How long will it take a stock that decreases in value at a rate of 12% per year to reach one-half of its original value?