1.2 Laboratory and Reporting Skills

Warm Up

Classify the following observations as *quantitative* or *qualitative* by placing a checkmark in the correct column. Hint: Look each syllable of those words: *quantitative* and *qualitative*. What do they seem to mean?

Observation	Quantitative	Qualitative
The melting point of paradichlorobenzene is 53.5°C.		
Mercury(II) oxide is a deep red powder.		
The density of scandium metal is 2.989 g/cm^3.		
Copper metal may be pulled into a wire. (It is ductile.)		
Silver metal forms a black layer of tarnish over time.		
Zinc has a specific heat capacity of 388 J/(kg·K).		
Oxygen gas supports combustion.		

The Scientific Method

How do you approach the problems you encounter in everyday life? Think about beginning class at the start of the school year, for example. The first few days you make observations ar data. You might not think of it this way, but in fact, when you observe your classmates, the c and your instructor, you actually are making observations and collecting data. This process v inevitably lead you to make some decisions as you consider the best way to interact with th environment. Who would you like for a partner in this class? Where do you want to sit? Are y to interact well with this particular teacher? You are drawing conclusions. This tried and true of solving problems is called the **scientific method**.

Robert Boyle pioneered the use of the scientific method (Figure 1.2.1). He was born ir a wealthy family in Ireland in 1627. He attended Eton College of England where he perform controlled experiments. He recorded his work with detailed explanations of the procedure a apparatus used and carefully wrote out tabular records of his observations. His records allow to repeat his experiments to test the theories he developed using his scientific method. In a to receiving credit for pioneering the scientific method, Boyle is remembered for publishing called the *Sceptical Chymist*. The book put forth a new definition of the term, *element* and cl the theories of alchemists such as Aristotle and Paracelsus.

Figure 1.2.1 *Robert Boyle*

Different groups of scientists outline the parts of the scientific method in different w one example, illustrating its steps.

Steps of the Scientific Method

1. **Observation:** Involves collecting data. **Quantitative** has numbers or quantities associated with it. **Qualitative** data describes qualities or changes in the quality of matter including a substance's colour, odour, or physical state. Observations may also be categorized as **physical**, related to the colour, the temperature at which the substance changes state or the density. Or they may be **chemical**, related to the substance's chemical reactivity or its behaviour during a chemical change.
2. **Statement of a hypothesis:** The formulation of a statement in an "if…then…" format that explains the observations.
3. **Experimentation**: After making a set of observations and formulating a hypothesis, scientists devise an experiment to determine whether the hypothesis accurately explains the observations. Depending on the results, the hypothesis may be adjusted and experiments repeated collecting new observations a multitude of times.
   Frequently the results of an experiment differ from what was expected. There are a variety of reasons this might happen. Things that contribute to such differences are called **sources of error**. Sources of error are different from mistakes. Rather, they are things we have *no control over*.
4. **Statement of a Theory:** Once enough information has been collected from a series of experiments, a coherent set of explanations called a theory may be deduced. This theory may lead to a **model** that helps us explain a collection of observations. (Sometimes the scientific method leads to a **law**, which is a general statement of *fact*, without an accompanied set of explanations.)

Quick Check

1. What is the difference between a law and a theory?

   ____

2. What are the fundamental steps of the scientific method?

   ____

   ____

   ____

   ____

3. Place a checkmark in the appropriate column to indicate whether each of the reasons for determining an incorrect mass is a mistake or a source of error.

Event	Mistake	Source of Error
The balance used to weigh the product was not zeroed.		
The product being weighed was damp.		
The balance used to weigh the product only reads to the nearest centigram.		
Your partner read the value for a mass incorrectly.		
You made a subtraction error when determining the mass.		

Using Scientific Notation

Because it deals with atoms, and they are so incredibly small, the study of chemistry is notorious for using very large and very tiny numbers. For example, if you determine the total number of atoms in a sample of matter, the value will be very large. If, on the other hand, you determine an atom's diameter or the mass of an atom, the value will be extremely small. The method of reporting an ordinary, expanded number in scientific notation is very handy for both of these things.

Scientific notation refers to the method of representing numbers in *exponential form.* Exponential numbers have two parts. Consider the following example:

24 500 becomes 2.45×10^4 in scientific notation

Convention states that the first portion of a value in scientific notation should always be expressed as a number **between 1 and 10**. This portion is called the **mantissa** or the **decimal portion**. The second portion is the base 10 raised to some power. It is called the **ordinate** or the **exponential portion**.

mantissa $\rightarrow \underline{2.45} \times 10^4$ and $2.45 \times \underline{10^4} \leftarrow$ ordinate

A positive exponent in the ordinate indicates a *large number* in scientific notation, while a negative exponent indicates a *small number*. In fact the exponent indicates the number of 10s that must be multiplied together to arrive at the number represented by the scientific notation. If the exponents are negative, the exponent indicates the number of tenths that must be multiplied together to arrive at the number. In other words, the exponent indicates the number of places the decimal in the mantissa must be moved to correctly arrive at the **expanded notation** (also called standard notation) version of the number.

A *positive exponent* indicates the number of *places* the decimal must be moved to the *right*, while a *negative exponent* indicates the number of *places* the decimal must be moved to the *left*.

Quick Check

1. Change the following numbers from scientific notation to expanded notation.
   (a) 2.75×10^3 = ______________

   (b) 5.143×10^{-2} = ______________

2. Change the following numbers from expanded notation to scientific notation.
   (a) 69 547 = ______________

   (b) 0.001 68 = ______________

Multiplication and Division in Scientific Notation

To *multiply* two numbers in scientific notation, we *multiply the mantissas* and state their product multiplied by 10, raised to a power that is the *sum of the exponents*.

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

To *divide* two numbers in scientific notation, we divide one mantissa by the other and state their quotient multiplied by 10, raised to a power that is the *difference* between the exponents.

$$(A \times 10^a) \div (B \times 10^b) = (A \div B) \times 10^{(a-b)}$$

Sample Problems — Multiplication and Division Using Scientific Notation

Solve the following problems, expressing the answer in scientific notation.

1. $(2.5 \times 10^3) \times (3.2 \times 10^6) =$
2. $(9.4 \times 10^{-4}) \div (10^{-6}) =$

What to Think about	How to Do It
Question 1 1. Find the product of the mantissas.	$2.5 \times 3.2 = 8.0$ (the new mantissa)
2. Raise 10 to the sum of the exponents to determine the ordinate.	$10^{(3+6)} = \underline{10^9}$ (the new ordinate)
3. State the answer as the product of the new mantissa and ordinate.	$(2.5 \times 10^3) \times (3.2 \times 10^6) = 8.0 \times 10^9$
Question 2 1. Find the quotient of the mantissas. When no mantissa is shown, it is assumed that the mantissa is 1.	$9.4 \div 1 = \underline{9.4}$ (the new mantissa)
2. Raise 10 to the difference of the exponents to determine the ordinate.	$10^{(-4-(-6))} = \underline{10^2}$ (the new ordinate)
3. State the answer as the product of the mantissa and ordinate.	$(9.4 \times 10^{-4}) \div (10^{-6}) = 9.4 \times 10^2$

Practice Problems — Multiplication and Division Using Scientific Notation

Solve the following problems, expressing the answer in scientific notation, *without* using a calculator. Repeat the questions using a calculator and compare your answers. Compare your method of solving with a calculator with that of another student.

1. $(4 \times 10^3) \times (2 \times 10^4) =$ ________________
2. $(9.9 \times 10^5) \div (3.3 \times 10^3) =$ ________________
3. $[(3.1 \times 10^{-4}) \times (6.0 \times 10^7)] \div (2.0 \times 10^5) =$ ________________
4. $10^9 \div (5.0 \times 10^6) =$ ________________
5. $[(4.5 \times 10^{12}) \div (1.5 \times 10^4)] \times (2.5 \times 10^{-6}) =$ ________________

Addition and Subtraction in Scientific Notation

Remember that a number in proper scientific notation will always have a mantissa between 1 and 10. Sometimes it becomes necessary to *shift* a decimal in order to express a number in proper scientific notation.

The *number of places* shifted by the decimal is indicated by an *equivalent change* in the *value of the exponent*. If the decimal is shifted *LEFT*, the *exponent* becomes *LARGER*; shifting the decimal to the *RIGHT* causes the *exponent* to become *SMALLER*.

Another way to remember this is if the *mantissa becomes smaller* following a shift, the *exponent becomes larger*. Consequently, if the *exponent becomes larger*, the *mantissa becomes smaller*. Consider AB.C × 10^x: if the decimal is shifted to change the value of the mantissa by 10^n times, the value of *x* changes $-n$ times.

For example, a number such as 18 235.0 × 10^2 (1 823 500 in standard notation) requires the decimal to be shifted 4 places to the left to give a mantissa between 1 and 10, that is 1.823 50. A LEFT shift 4 places, means the exponent in the ordinate becomes *4 numbers* LARGER (from 10^2 to 10^6). The correct way to express 18 235.0 × 10^2 in scientific notation is 1.823 50 × 10^6. Notice the new mantissa is 10^4 *smaller*, so the exponent becomes 4 numbers larger.

Quick Check

Express each of the given values in proper scientific notation in the second column. Now write each of the given values from the *first* column in expanded form in the third column. Then write each of your answers from the *second* column in expanded form. How do the expanded answers compare?

	Given Value	Proper Notation	Expanded Form	Expanded Answer
1.	6 014.51 × 10^2			
2.	0.001 6 × 10^7			
3.	38 325.3 × 10^{-6}			
4.	0.4196 × 10^{-2}			

When adding or subtracting numbers in scientific notation, it is important to realize that we add or subtract only the mantissa. *Do not add or subtract the exponents!* To begin, it is often necessary to shift the decimal to be sure the value of the exponent is the same for both numbers that will be added or subtracted. Once the arithmetic has been completed, the decimal may be shifted again if required to ensure that the mantissa is, indeed, between 1 and 10.

Shift the decimal to obtain the *same value for the exponent* in the ordinate of both numbers to be added or subtracted. Then simply *sum or take the difference of the mantissas.* Convert back to proper scientific notation when finished.

Sample Problems — Addition and Subtraction in Scientific Notation

Solve the following problems, expressing the answer in proper scientific notation.

1. $(5.19 \times 10^{3}) - (3.14 \times 10^{2}) =$
2. $(2.17 \times 10^{-3}) + (6.40 \times 10^{-5}) =$

What to Think about	How to Do It
Question 1	
1. Begin by shifting the decimal of one of the numbers and changing the exponent so that both numbers share the *same exponent*. For consistency, adjust one of the numbers so that *both* numbers have the *larger* of the two ordinates. The goal is for both mantissas to be multiplied by 10^{3}. This means the exponent in the second number should be increased by one. Increasing the exponent requires the decimal to shift to the left (so the mantissa becomes smaller).	3.14×10^{2} becomes 0.314×10^{3}
2. Once both ordinates are the same, the mantissas are simply subtracted.	$\begin{array}{r} 5.19 \times 10^{3} \\ \underline{-0.314 \times 10^{3}} \\ 4.876 \times 10^{3} \end{array}$
Question 1 — Another Approach	
1. It is interesting to note that we could have altered the first number instead. In that case, 5.19×10^{3} would have become 51.9×10^{2}.	$\begin{array}{r} 51.9 \times 10^{2} \\ \underline{-3.14 \times 10^{2}} \\ 48.76 \times 10^{2} \end{array}$
2. In this case, the difference results in a number that is not in proper scientific notation as the mantissa is greater than 10.	
3. Consequently, a further step is needed to convert the answer back to proper scientific notation. Shifting the decimal one place to the left (mantissa becomes smaller) requires an increase of 1 to the exponent.	48.76×10^{2} becomes 4.876×10^{3}
Question 2	
1. As with differences, begin by shifting the decimal of one of the numbers and changing the exponent so both numbers share the same ordinate. The *larger ordinate* in this case is 10^{-3}.	2.17×10^{-3} will be left as is.
2. Increasing the exponent in the second number from −5 to −3 requires the decimal to be shifted two to the left (make the mantissa smaller).	6.40×10^{-5} becomes 0.0640×10^{-3}
3. Once the exponents agree, the mantissas are simply summed.	$\begin{array}{r} 2.17 \times 10^{-3} \\ \underline{+\ 0.0640 \times 10^{-3}} \\ 2.2340 \times 10^{-3} \end{array}$
4. The alternative approach involves one extra step, but gives the same answer.	$\begin{array}{r} 217 \times 10^{-5} \\ \underline{+\ 6.40 \times 10^{-5}} \\ 223.40 \times 10^{-5} \end{array}$ becomes 2.2340×10^{-3}

Practice Problems — Addition and Subtraction in Scientific Notation

Solve the following problems, expressing the answer in scientific notation, *without* using a calculator. Repeat the questions using a calculator and compare your answers. Compare your use of the exponential function on the calculator with that of a partner.

1. 8.068×10^{8}
   -4.14×10^{7}

2. 6.228×10^{-4}
   $+4.602 \times 10^{-3}$

3. 49.001×10^{1}
   $+ \quad 10^{-1}$

Scientific Notation and Exponents

Occasionally a number in scientific notation will be raised to some power. When such a case arises, it's important to remember when one exponent is raised to the power of another, the exponents are multiplied by one another. Consider a problem like $(10^3)^2$. This is really just $(10 \times 10 \times 10)^2$ or $(10 \times 10 \times 10 \times 10 \times 10 \times 10)$. So we see this is the same as $10^{(3 \times 2)}$ or 10^6.

$$(A \times 10^a)^b = A^b \times 10^{(a \times b)}$$

Quick Check

Solve the following problems, expressing the answer in scientific notation, *without* the use of a calculator. Repeat the problems with a calculator and compare your answers.

1. $(10^3)^5$
2. $(2 \times 10^2)^3$
3. $(5 \times 10^4)^2$
4. $(3 \times 10^5)^2 \times (2 \times 10^4)^2$

Pictorial Representation of Data — Graphing

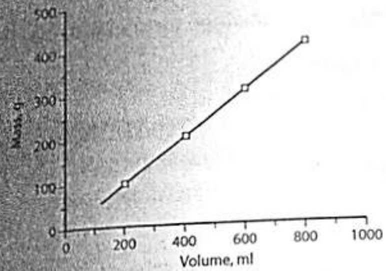
Often in scientific investigations, we are interested in measuring how the value of some property changes as we vary something that affects it. We call the value that responds to the variation the **dependent variable**, while the other value is the **independent variable**. For example, we might want to measure the extension of a spring as we attach different masses to it. In this case, the extension would be the dependent variable, and the mass would be the independent variable. Notice that the amount of extension depends on the mass loaded and not the other way around. The variable "time" is nearly always independent.

The series of paired measurements collected during such an investigation is quantitative data. It is usually arranged in a **data table**. Tables of data should indicate the *unit of measurement* at the top of each column. The information in such a table becomes even more useful if it is presented in the form of a **graph** ("graph" is the Greek word root meaning "picture"). The independent data is plotted on the *x*-axis. A graph reveals many data points not listed in a data table.

Once a graph is drawn, it can be used to find a mathematical **relationship** (equation) that indicates how the variable quantities depend on each other. The first step to determining the relationship is to calculate the **proportionality constant** or **slope** "*m*" for the *line of best fit*. Curved graphs must be manipulated mathematically before a constant can be determined. Such manipulation is beyond the scope of this course. First, the constant is been determined by finding the change in *y* over the change in *x* ($\Delta y/\Delta x$ or the "rise over the run"). Then substitution of the *y* and *x* variable names and the calculated value for *m*, including its units, into the general equation $y = mx + b$. The result will be an equation that describes the relationship represented by our data.

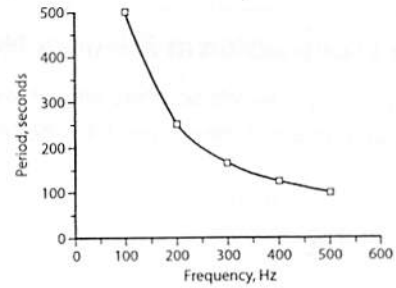
$y = mx + b$ is the general form for the equation of a *straight line relationship* where m represents the *slope, determined by* $m = \Delta y/\Delta x$. In scientific relationships, the slope includes units and represents the constant that relates two variables. For this reason, it is sometimes represented by a *K*.

The three most common types of graphic relationships are shown in Figure 1.2.2.



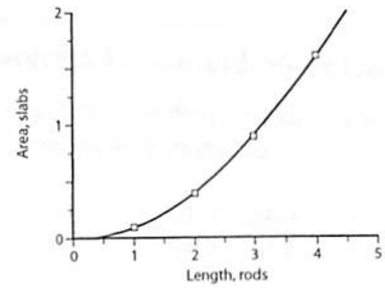
Direct: $y = Kx$

(y and x increase in direct proportion)



Inverse: $y = K/x$

(as x increases, y decreases)



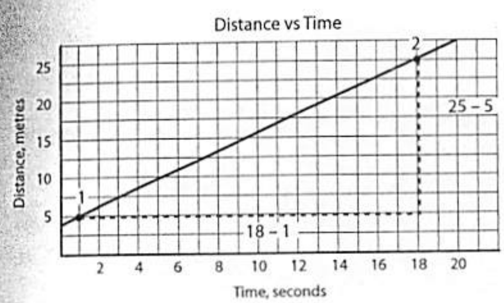
Exponential: $y = Kx^n$

(as x increases, y increases more quickly)

Figure 1.2.2 *Three common types of graphic relationships*

Sample Problem — Determination of a Relationship from Data

Find the relationship for the graphed data below:



What to Think about

1. Determine the constant of proportionality (the slope) for the straight line. To do this, select two points on the line of best fit.
   These should be points whose values are easy to determine on both axes. *Do not use data points* to determine the constant.
   Determine the change in y (Δy) and the change in x (Δx) including the units.
   The constant is $\Delta y / \Delta x$.

2. The relationship is determined by subbing in the *variable names* and the constant into the general equation, $y = Kx + b$.

   Often, a straight line graph passes through the origin, in which case, $y = Kx$.

How to Do It

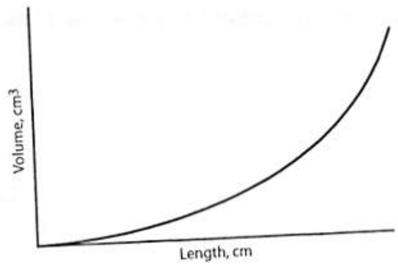
Δy is $25-5 = 20$ m
Δx is $18 - 1 = 17$ s

20 m$/17$ s $= 1.18$ m/s

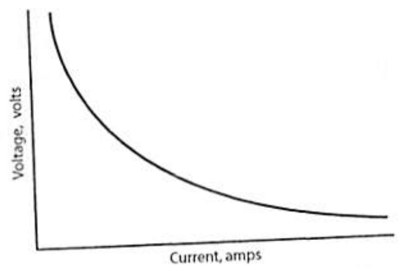
Distance = (1.18 m)Time + 4.0 m.

Practice Problem — Determination of a Relationship from Data

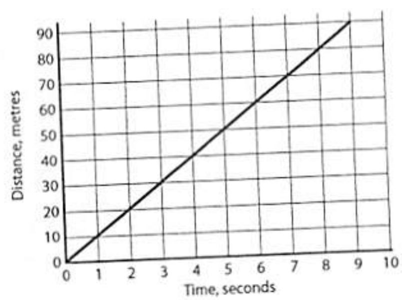
Examine the following graphs. What *type of relationship* does each represent? Give the full relationship described by graph (c).



(a)



(b)



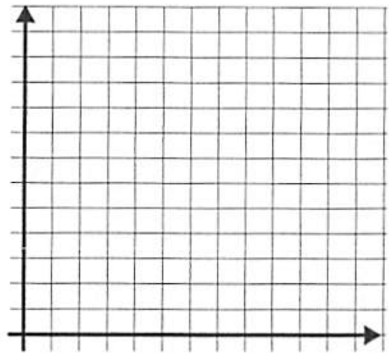
(c)

1.2 Activity: Graphing Relationships

Question
Can you produce a graph given a set of experimental data?

Background
A beaker full of water is placed on a hotplate and heated over a period of time. The temperature is recorded at regular intervals. The following data was collected.

Temperature (°C)	Time (min)
22	0
30	2
38	4
46	6
54	8
62	10
70	12



Procedure
1. Use the grid above to plot a graph of temperature against time. (Time goes on the *x*-axis.)

Results and Discussion
1. What type of relationship was studied during this investigation?

2. What is the constant (be sure to include the units)?

3. What temperature was reached at 5 minutes?

4. Use the graph to determine the relationship between temperature and time.

5. How long would it take the temperature to reach 80°C?

6. What does the *y*-intercept represent?

7. Give a source of error that might cause your graph to vary from that expected.

6.

1.2 Review Questions

1. Use the steps of the scientific method to design a test for the following hypotheses:
   (a) If a person takes vitamin C daily, then they will get fewer colds.

   (b) If cyclists ride titanium bicycles, then they will win more races.

2. Complete the following table for the listed observations by checking the appropriate columns.

Property Observed	Qualitative	Quantitative
Freezes at 52.0°C		
Dissolves in ethylene glycol		
Fractures into cubic crystals		
5.4 mol dissolve in each litre		

3. Complete the following table for the listed observations by checking the appropriate columns.

Property Observed	Qualitative	Quantitative
Attracts to a magnet		
Changes to $Br_2(l)$ at −7.2°C		
Has a density of 4.71 g/mL		
Is a bright orange solid crystal		

4. Convert the following numbers from *scientific* notation to *expanded* notation and vice versa (be sure the scientific notation is expressed correctly).

Scientific Notation	Expanded Notation
3.08×10^4	
	960
4.75×10^{-3}	
	0.000 484
0.0062×10^5	

5. Give the product or quotient of each of the following problems (express all answers in proper form scientific notation). Do **not** use a calculator.
   (a) $(8.0 \times 10^3) \times (1.5 \times 10^6) =$

   (b) $(1.5 \times 10^4) \div (2.0 \times 10^2) =$

   (c) $(3.5 \times 10^{-2}) \times (6.0 \times 10^5) =$

   (d) $(2.6 \times 10^7) \div (6.5 \times 10^{-4}) =$

6. Give the product or quotient of each of the following problems (express all answers in proper form scientific notation). Do **not** use a calculator.
(a) $(3.5 \times 10^4) \times (3.0 \times 10^5) =$
(b) $(7.0 \times 10^6) \div (1.75 \times 10^2) =$
(c) $(2.5 \times 10^{-3}) \times (8.5 \times 10^{-5}) =$
(d) $(2.6 \times 10^5) \div (6.5 \times 10^{-2}) =$

7. Solve the following problems, expressing the answer in scientific notation, *without* using a calculator. Repeat the questions using a calculator and compare your answers.

(a) $\begin{array}{r} 4.034 \times 10^5 \\ \underline{-2.12 \times 10^4} \end{array}$ (b) $\begin{array}{r} 3.114 \times 10^{-6} \\ \underline{+2.301 \times 10^{-5}} \end{array}$ (c) $\begin{array}{r} 26.022 \times 10^2 \\ \underline{+7.04 \times 10^{-1}} \end{array}$

8. Solve the following problems, expressing the answer in scientific notation, *without* using a calculator. Repeat the questions using a calculator and compare your answers.

(a) $\begin{array}{r} 2.115 \times 10^8 \\ \underline{-1.11 \times 10^7} \end{array}$ (b) $\begin{array}{r} 9.332 \times 10^{-3} \\ \underline{+6.903 \times 10^{-4}} \end{array}$ (c) $\begin{array}{r} 68.166 \times 10^2 \\ \underline{+ \qquad \times 10^{-1}} \end{array}$

9. Solve each of the following problems *without* a calculator. Express your answer in correct form scientific notation. Repeat the questions using a calculator and compare.
(a) $(10^{-4})^3$ (b) $(4 \times 10^5)^3$ (c) $(7 \times 10^9)^2$ d. $(10^2)^2 \times (2 \times 10)^3$

10. Solve each of the following problems *without* a calculator. Express your answer in correct form scientific notation. Repeat the questions using a calculator and compare.
(a) $(6.4 \times 10^{-6} + 2.0 \times 10^{-7}) \div (2 \times 10^6 + 3.1 \times 10^7)$

(b) $\dfrac{3.4 \times 10^{-17} \times 1.5 \times 10^4}{1.5 \times 10^{-4}}$

(c) $(2 \times 10^3)^3 \times [(6.84 \times 10^3) \div (3.42 \times 10^3)]$

(d) $\dfrac{(3 \times 10^2)^3 + (4 \times 10^3)^2}{1 \times 10^4}$

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11. Use the grid provided to plot graphs of mass against volume for a series of metal pieces with the given volumes. Plot all three graphs on the same set of axes with the independent variable (volume in this case) on the *x*-axis. Use a different colour for each graph.

Volume (mL)	Copper (g)	Aluminum (g)	Platinum (g)
2.0	17.4	5.4	42.9
8.0	71.7	21.6	171.6
12.0	107.5	32.4	257.4
15.0	134.4	40.5	321.8
19.0	170.2	51.3	407.6

(a) Determine the constant for each metal.

(b) The constant represents each metal's density. Which metal is most dense?

12. Use the grid provided to plot two separate graphs, (a) and (b), for each the following sets of data. Be sure to draw a *smooth curve* through the points. Indicate the type of relationship represented by each graph.

Initial Rate (y) (mol/L/s)	Concentration (mol/L)
0.003	0.05
0.012	0.10
0.048	0.20
0.075	0.25
0.108	0.30
0.192	0.40

Volume (y) (L)	Pressure (kPa)
5.0	454
10.0	227
15.0	151
20.0	113
25.0	91
30.0	76

13. Many science departments use a still to produce their own distilled water. Data representing the volume of distilled water produced over a particular period of time might look like the data shown in the table.

Volume of Distilled Water (L)	Distillation Time (h)
0.8	0.4
1.6	0.8
2.4	1.2
5.0	2.5
7.2	3.6
9.8	4.9

(a) Plot this data on your own piece of graph paper. Where should time be plotted?

(b) Determine the constant for your graph. Show all work on the graph.

(c) Determine the relationship between volume and time.

(d) Assume the still was left on overnight. What volume of water would be collected if a period of 14 h passed?

(e) How long would it take to produce 12.5 L of water with this still?