Part I
Opening the Geologist's Tool Kit

Every profession has a specialized vocabulary. An accountant, for example, may speak of a "leveraged" deal on the stock market or declare that a "low-income family" qualifies for the government's "earned income credit." All three terms have specific, defined meanings. Similarly, an accountant uses specific tools to do her job. She may perform financial analysis with a balance sheet or computer spreadsheet. The point: to understand what any professional does, you must learn their *vocabulary* and understand their *tools*.

The same is true in science. That's why you will learn new vocabulary in this course and discover special tools for analyzing the world around us. It's easiest to learn the vocabulary and tools by doing small problems and experiments. Like learning to ride a bicycle, once you get the hang of it, you won't forget what you have mastered.

Part I of this lab manual contains Units 1 and 2, which summarize analytical methods. These methods are the basic tools of the trade in scientific work. You may have used some of them in high school, but revisiting them here will refresh your memory and improve your understanding. These units let you practice basic scientific skills before you jump into the specifics of geology.

Understanding the tools in this unit will lay a firm foundation for the rest of your geology course. *So please do all the work assigned in these units with great care, because you need to master these skills before continuing.* Ask for help if you have difficulty!

Unit 1
Paper-and-Pencil Tools

This unit presents paper-and-pencil tools used by geologists and other scientists. We offer examples and problems in unit conversion (like meters to feet), unit analysis of formulas, constructing graphs, and constructing histograms (bar graphs). We also offer problems in applying the Le Châtelier principle: a system at equilibrium responds to any change by working to minimize the change.

Tool 1.1 Unit Conversion

One of arithmetic's most useful tools is unit conversion–converting from inches to feet, liters to gallons, miles to kilometers, and so on. The key to unit conversion is that you can multiply any number by 1 without changing the value of the original number. For example,

$$5 \times 1 = 5$$
$$31 \times 1 = 31$$
$$py^3 \times 1 = py^3$$

Also, when you divide anything by itself, like $7 \div 7$, the result is 1. All such expressions are equal in value to the number 1. For example:

$$27 \div 27 = 1$$
$$\frac{168}{168} = 1$$
$$843/843 = 1$$

Further, you can multiply any number by a fraction like 1/1, abc/abc, or 62/62 without changing the value of the original number. This little trick allows us to change *units* to more useful forms without altering *value* in any way. As a first step toward converting units, we can write:

$$\frac{12 \text{ inches}}{1 \text{ foot}} = 1$$

This equality is true because the upper and lower numbers in the fraction have the same equivalent value expressed in different form. Similarly,

$$\frac{\$1}{100 \text{ cents}} = 1$$

In the preceding examples, the fractions contain mixed units in the numerator and denominator. Nevertheless, you know they equal 1, because the top and bottom are actually the same (that is, 12 inches = 1 foot and $1 = 100 cents).

This gives us an easy way to convert measurements. For example, if we want to convert a value expressed in feet into a value expressed in inches, we can easily do so and be right every time. For example:

How many inches are in 3.5 feet? We can write:

$$3.5 \text{ feet} \times \frac{12 \text{ inches}}{1 \text{ foot}} = ?$$

$$3.5 \cancel{\text{feet}} \times \frac{12 \text{ inches}}{1 \cancel{\text{foot}}} = ?$$

$$3.5 \times \frac{12 \text{ inches}}{1} = 42 \text{ inches}$$

That's the basic idea behind unit conversion. And, by the same reasoning, you can multiply a number by several fractions to achieve multiple conversions, as long as each fraction equals 1. This technique is simple and useful because it allows us to *manipulate* numbers, putting them in different form for convenience without really changing them. It's like pouring 12 ounces of beverage from a can into a glass: you change the shape of the drink, but it's still the same amount.

Example: Converting Square Feet to Square Yards. Suppose that you measure your studio apartment with a tape measure and find that it is 21 feet long and 15 feet wide. You want to buy carpet for the room and, armed with your measurements, you figure that you need

21 feet × 15 feet = 315 square feet of carpet (also written as 315 ft.^{2})

At the store, however, you find that carpet is priced in square *yards*, not square feet. So, in the store's terms, how many square yards of carpet do you need? Your first thought might be to divide 315 by 3, but oops—wrong! Play it safe and write out a unit-conversion equation, converting square feet to square yards:

$$315 \text{ ft.}^2 = 315 \cancel{\text{feet}} \times \cancel{\text{feet}} \times \frac{1 \text{ yard}}{3 \cancel{\text{feet}}} \times \frac{1 \text{ yard}}{3 \cancel{\text{feet}}} = \frac{315 \text{ yards} \times \text{yard}}{3 \times 3} = 35 \text{ yd.}^2$$

Geologists often use unit conversion. The problems in this book assume that you can convert units using this method. You can convert units not only within the English system (like feet to yards or feet to inches) but from English units to metric ones (like feet to meters or gallons to liters) and vice versa.

The table on the inside front cover provides equivalent values for conversions. Each pair of numbers in this table, when written as a fraction, equals 1. Use these pairs to convert any units you encounter in this book.

Example: Converting Miles per Hour to Kilometers per Hour. Over-the-road truck drivers in the United States often cover 700 miles per day. Imagine that your cousin from England, where metric measures are used, moves to Louisiana and finds work as a truck driver. Using the method of unit conversion and the table on the inside front cover, help him to express 60 miles per hour, a common speed limit, in kilometers per hour.

$$\frac{60 \cancel{\text{miles}}}{\text{hour}} \times \frac{1.609 \text{ km}}{\cancel{\text{mile}}} = \frac{96.5 \text{ km}}{\text{hour}}$$

Over a 14-hour workday, your cousin averages 52 miles per hour. How many kilometers has he traveled by the end of the day?

Start with what you know: 14 hours of travel. Then use cancellation of units to get the units you want: kilometers.

$$14 \cancel{\text{hours}} \times \frac{52 \cancel{\text{miles}}}{\cancel{\text{hour}}} \times \frac{1.609 \text{ kilometer}}{\cancel{\text{mile}}} = 1171 \text{ kilometers}$$

Example: Converting Square Feet per Quart to Square Meters per Liter. Imagine that you have been working as a house painter for most of the summer. Your favorite brand of high-quality paint claims that it will cover 150 square feet per quart. One of your cousins, who sells paint in Canada, tells you that he can get you a better paint at the same price in U.S. dollars. "How much does a can cover?" you ask. He looks at his can's label and says, "11 square meters per liter." Which paint claims to cover more area, yours or his? Try converting the units on your brand.

$$\frac{150 \cancel{\text{foot} \times \text{foot}}}{\cancel{\text{quart}}} \times \frac{0.3048 \text{ meter}}{\cancel{\text{foot}}} \times \frac{0.3048 \text{ meter}}{\cancel{\text{foot}}} \times \frac{1.057 \cancel{\text{quart}}}{\text{liter}} = 14.73 \text{ m}^2/\text{L}$$

Your paint appears to cover more area than your cousin's Canadian paint. Make sure that you see how the units cancel correctly—drawing lines through them is the best way, as shown—and make sure to rub in the answer at the next family reunion!

Problem 1.1. Volume of Spilled Oil. In 1989, an oil tanker in Prince William Sound, Alaska, hit a reef. In a matter of hours, about 10 million gallons of oil spilled into the water. This was the worst oil spill in U.S. history.

Q1.1. What volume of oil was released, expressed in liters? (Use the unit-conversion method taught in this book. Record your answers to all questions on the Answer Sheet at the end of this unit.)

Problem 1.2. Weight of Spilled Oil. Water weighs about 1 kilogram per liter. Ocean water is a bit heavier (denser) because of the salt dissolved in it. Oil, of course, is less dense than water, which is why it floats atop water, creating oil slicks and the rainbow effect you see in oily puddles along the street. Now, suppose that the crude oil spilled from the ruptured tanker in Alaska weighed 0.91 kg/L.

Q1.2. How many metric tons of oil were spilled (1 metric ton = 1000 kilograms)? (Use the unit-conversion method.)

Problem 1.3. Converting Metric Tons to Pounds and Cents to Dollars. Imagine that you are an international copper broker. Copper's price is 88 cents per pound. You have an overseas dealer who wants to sell 1488 metric tons of copper (1 metric ton = 1000 kilograms).

Q1.3. How much is the copper worth right now in U.S. dollars? (Use unit conversion.)

Problem 1.4. Converting Cubic Meters to Cubic Feet. Imagine that a geologist digs a hole where she is prospecting, removing 1 cubic meter of soil.

Q1.4. How much soil is that in cubic feet? (Use unit conversion.)

Problem 1.5. Converting Grams to Troy Ounces to Dollars. A geologist is hiking along a creek and discovers a nugget of pure gold. At her office, she weighs the nugget on the only scale available, which reads in grams. The nugget weighs 388 grams.

Q1.5. If gold is priced at $345 per troy ounce in U.S. dollars, what is the nugget worth in dollars today? (Use unit conversion: 20 troy oz. = 1 lb.)

Tool 1.2 Unit Analysis of Formulas

Unit analysis is an easy concept. It helps you think through the problem you are trying to solve and understand the units you are dealing with. When you write a formula, either from memory or from a reference, pause to check the units in the equation. The units must make sense for the formula to work! For example, consider this simple equation:

$$\text{rate} = \frac{\text{distance}}{\text{time}}$$

It makes sense as far as its units are concerned, for *rate* means a *distance traveled over time.*

To double-check, plug in some familiar units that you know well:

$$\text{miles per hour } [\text{rate}] = \frac{\text{miles traveled } [\text{distance}]}{\text{hours of travel } [\text{time}]}$$

You can see that this will work. This little trick of checking the units for reasonableness and plugging in familiar examples as a quick test will help you with all equations you encounter in all your classes—geology, math, chemistry, psychology, and so on. If you have any fear of math, this technique really helps!

Example: Unit Analysis of Formula: Area of a Circle. Imagine that you are taking a standardized test, perhaps for placement in the armed forces or admission to a professional school. This first problem asks you to find the area of a circle having a radius of *r*. You aren't quite sure you remember the formula for the area of a circle, but you make an attempt:

$\text{area} = 2\pi r$
(area = 2 × pi × the radius of the circle)

Can this formula be correct? Substitute some units to see if your equation makes sense. For example:

$$\text{area} = 2 \times \text{p} \times \text{length units}$$

Or you might try specifics:

$$\text{in.}^2\ [\text{area}] = 2 \times \text{p} \times \text{inches}$$

In either case, you see that the formula cannot be correct because it equates (makes equal) a squared length unit (area) and a plain-and-simple length unit. In fact, what you remembered was the formula for the circumference of a circle. The formula for area is

$$\text{area} = \pi r^2$$

Here you can see that the units make sense, because the formula says that area—which will be a unit of length squared—equals a length measurement (radius) squared.

For the following problems, record your answers on the Answer Sheet at the end of the unit.

Problem 1.6. Unit Analysis of Formula for Area of a Triangle. Imagine that you are taking one of those long, tedious standardized exams. After studying one problem, you decide you need the formula to find the area of a triangle. You recall something like

$$\text{area} = \tfrac{1}{2}\,\text{base} \times \text{height}$$

Q1.6. In terms of unit analysis, does the formula make sense?

Problem 1.7. Unit Analysis of Formula for Porosity. A sponge has many holes or spaces within it, a property called *porosity*. For geologists, porosity is a measure of exactly how much pore space is present in a rock or soil. You will encounter *porosity* in your geology course when you study *sandstones*, which usually are filled with tiny pores. You also will see an example of extreme porosity in *pumice*, a volcanic rock that has so many open spaces that it actually floats.

Suppose your geology teacher displays the formula for porosity:

$$\text{porosity} = \frac{\text{volume of pore space Acm}^3\text{ or in.}^3\text{Bin a rock sample}}{\text{volume of rock sample Acm}^3\text{ or in.}^3\text{B}}$$

Q1.7. What is the unit for porosity? (***Hint:*** You may be surprised by the answer.)

Tool 1.3 Constructing Graphs

Graphs—scientists often call them **plots**—are useful for analyzing measurements of natural processes. The most common plot is the ***x-y* graph** (the horizontal axis is for *x* values; the vertical axis represents *y* values). You already are familiar with this concept, for *x-y* graphs are commonplace on TV and in newspapers and magazines.

As an example, the business pages of a newspaper might use an *x-y* plot to show the trend in wheat prices over several days (Figure 1.1).

In a more geological vein, consider an *x-y* graph of the *depth* of a river at a given time versus the river's *velocity* at that time. For example, let's use the depth and velocity of the Mississippi River at St. Louis (Figure 1.2). In this type of graph, you may see **error bars,** either generalized ones for all the data or bars that are assigned to specific data points. The point represents the measurement, and the error bar indicates the range of possible values for each variable. The figure indicates that the possible error involved in measuring the velocity of the river is large compared to the possible error in measuring river depth.

Note that the figure is not just a presentation of data points with their associated possible errors. The author of the graph also has used a statistical procedure to "fit" a curve through the data. Both curves and straight lines can be constructed for data using most business and scientific calculators.

Example: Exponential Equation, Logarithmic Graph, Semilogarithmic Graph. As it happens, in natural systems like our Earth and the life forms that inhabit it, many processes are governed by **exponential equations.** Such equations involve a variable that is raised to a power (exponent), like 2^x or e^x. Don't panic over such expressions. Just understand that these processes are often easiest to represent on a **logarithmic graph.**

You'll see that this is simple if we use a concrete example. Imagine that you live on a small, grassy island that has very few animal species. Someone from the mainland releases five pairs of rabbits on your island.

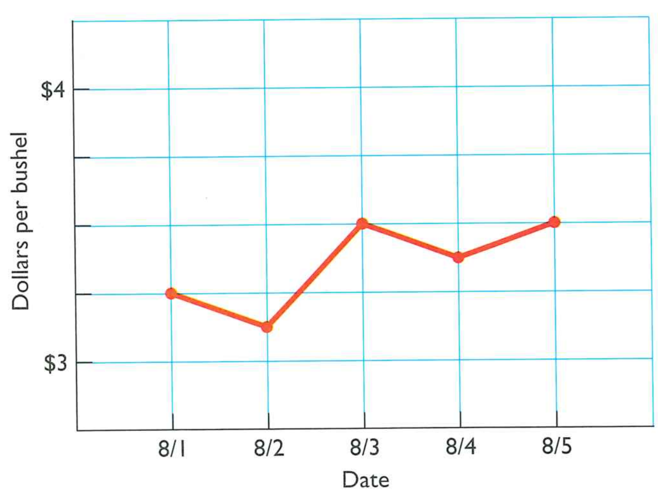


Figure 1.1 An *x-y* plot for wheat prices over several days.

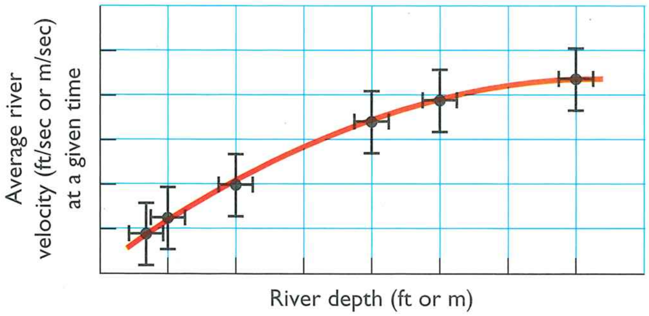


Figure 1.2 Graph (*x-y* plot) of river depth versus the river's average velocity at a certain point, for example, depth and velocity of the Mississippi River at St. Louis. The graph indicates that the deeper the river, the faster it flows. Note that the data do not lie in a straight line—they are not linear.

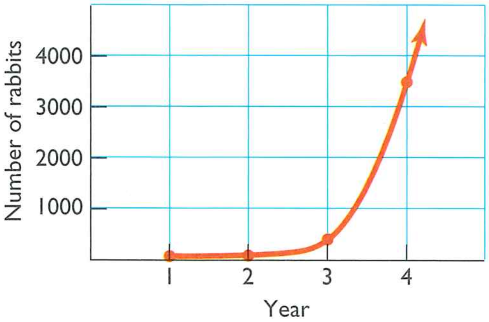


Figure 1.3 Unlimited rabbits: exponential curve. Unlimited reproduction of rabbits is represented by an exponential curve on a graph that has a linear horizontal scale and a linear vertical scale.

Because rabbits are not a native species on your island, there are no predators (coyotes, eagles, owls, and so on) to eat the rabbits. The rabbit population is free to increase at its natural rate, which is exponential.

You decide to count the rabbits and record their population. Let's assume that they all were released when young, that they will live at least four years, and that none die accidentally. If each pair of rabbits produced 12 babies per year, with the offspring evenly divided between male and female, your records would show year-by-year numbers like these:

Year 1: 5 pairs = 10 rabbits

Year 2: (5 pairs × 12 babies) + original 10 reproducing rabbits = 70 rabbits (35 pairs)

Year 3: (35 pairs × 12 babies) + 70 reproducing rabbits = 490 rabbits (245 pairs)

Year 4: (245 pairs × 12 babies) + 490 reproducing rabbits = 3430 rabbits

Summarizing:

Year 1: 10 rabbits

Year 2: 70 rabbits (7 times the original population)

Year 3: 490 rabbits (49 (or 7^2) times the original population)

Year 4: 3430 rabbits (343 (or 7^3) times the original population)

To graph this on a normal *x-y* plot, we must have a vertical (*y*) axis high enough to show 3430 (Figure 1.3). (Note that no error bars are included in this graph because they aren't needed in this make-believe example.)

Obviously, as the rabbit population continues its exponential growth, the *y* axis of the graph must grow tremendously. Scientists find it more convenient to represent this kind of information on *x-y* graphs that have one logarithmic scale. This kind of plot is called **semilogarithmic.** The rabbit example is plotted semilogarithmically in Figure 1.4.

Example: Graphing Half-life of Carbon on Linear and Semilog Plots. Carbon-14 is a form of carbon used to date recent geologic events and even artifacts from human history. The method is accurate back to about 55,000 years ago. Carbon-14 is *radioactive* because the nucleus of a carbon-14 atom is unstable. Through time, each atom "decays" by giving off energy and becomes transformed into a different element.

Scientists have measured the rate at which carbon-14 decays. Remarkably, under all known conditions of

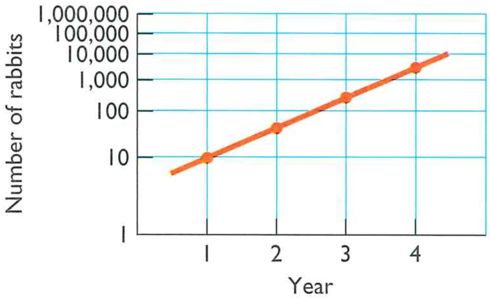


Figure 1.4 Unlimited rabbits: the same numbers on a semilogarithmic plot. Unlimited reproduction of rabbits is represented by a line on a graph that has a linear horizontal scale and a logarithmic vertical scale.

Table 1.1

How carbon-14 decays if we start with 1,000,000 atoms (half-life of carbon-14 is 5730 years)

Number of carbon-14 atoms	Time
1,000,000	0 (start)
500,000	5730 years later (1 half-life)
250,000	11,460 years after start (2 half-lives)
125,000	17,190 years after start (3 half-lives)
62,500	22,920 years after start (4 half-lives)
31,250	28,650 years after start (5 half-lives)
15,625	34,380 years after start (6 half-lives)
7,812	40,110 years after start (7 half-lives)
. . . and so on . . .	. . . and so on . . .

temperature and pressure, carbon-14 decays at a constant rate. One way of expressing this rate is to state the time required for half of a group of carbon-14 atoms to decay. This *half-life* of carbon is 5730 years. Thus, if a piece of charcoal contained 1 million atoms of carbon-14, half of them would be transformed into another element after the passage of 5730 years. From this information, we can construct Table 1.1.

Graphing these values on a regular grid gives the result shown in Figure 1.5. Because this illustrates a known principle, the graph includes no error bars. As you can imagine, for some purposes it can be useful to plot such numbers on a semilog graph (Figure 1.6).

Problem 1.8. Gold Nuggets—Size versus Silver Content. A geologist studies gold nuggets found by prospectors in Canada's Yukon Territory. He finds that each nugget contains at least some silver. He wonders if any systematic relationship exists between nugget size and silver percentage. The easiest way to find out is to plot the two variables. You can do so using the geologist's analytical results, shown in Table 1.2.

Q1.8. In Figure 1.12 on your Answer Sheet, plot the nugget weight versus the silver percentage. Decide how to mark the x axis (the horizontal axis) to accommodate the data.

Q1.9. Looking at your plot, would you say that there is a relationship (even a rough one) between nugget size and proportion of silver in the gold?

Problem 1.9. Exponential Growth of Dalmation Dog Population. Dalmatian dogs (age 3 years), one male and one female, are released on a huge tropical island where they find plenty to eat and no animals prey on them or their offspring. If the female comes into heat twice a

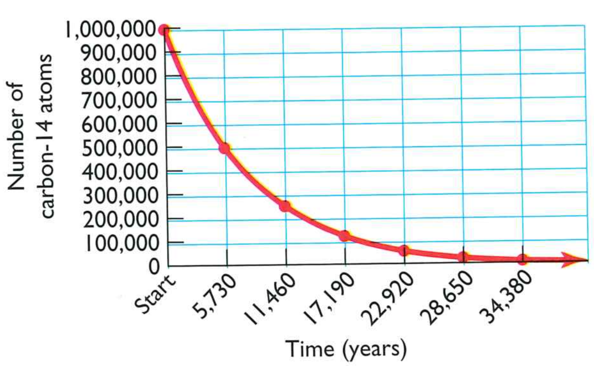


Figure 1.5 Half-life of carbon-14: linear graph. Both scales are linear.

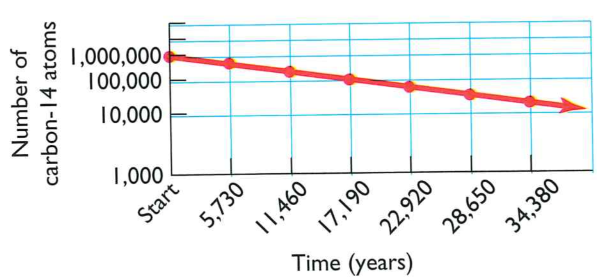


Figure 1.6 Half-life of carbon-14: semilogarithmic graph. The horizontal scale is linear; the vertical axis is a logarithmic scale.

Table 1.2

Gold nuggets found by prospectors in Canada's Yukon Territory

Nugget number	Weight of nugget (grams)	Percent of silver in the gold	Nugget number	Weight of nugget (grams)	Percent of silver in the gold
1	17.2	33	11	15.0	30
2	8.0	17	12	9.1	18
3	1.1	2	13	2.0	4
4	1.9	3	14	0.6	1
5	0.9	2	15	0.9	2
6	8.3	15	16	1.4	3
7	0.8	2	17	2.1	4
8	1.1	3	18	1.3	2
9	1.7	4	19	1.1	2
10	2.1	4	20	11.7	21

year and has 8 viable puppies in each litter, and if each pup is fertile by age 6 months, how many Dalmatians will there be on the island at the end of $2\frac{1}{2}$ years? (Assume that 50% of all puppies are female and that adult Dalmatians live for 12 years.) To help you with this problem, start by completing Table 1.3.

Q1.10. Plot your results on the normal (linear) grid in Figure 1.13 on your Answer Sheet. Determine how to mark the *y* axis to accommodate all the Dalmatians. When you have plotted your dots, connect them with your best hand-drawn curve.

Q1.11. Plot your results on the semilog graph paper in Figure 1.14 on your Answer Sheet. The plot has been started for you. When you have plotted all the dots, connect them with a line.

Q1.12. Describe the curve in Figure 1.13 in your own words.

Problem 1.10. Graphing the Decay of an Isotope (Focus on the Parent Element). Uranium-235 has a half-life of 704 million years. Imagine that a certain mineral (for example, zircon) contains 1024 atoms of uranium-235.

Table 1.3

Exponential growth of Dalmatian dog population

Time	Number of adult Dalmatians	Number of puppies	Total number of Dalmatians
Dogs released	2 (1 female)	0	2
$\frac{1}{2}$ year later	2 (1 female)	8 (4 females)	10
Full year later	10 (5 females)	40 (20 females)	50
$1\frac{1}{2}$ years later	50 (25 females)		
2 years later			
$2\frac{1}{2}$ years later			

Q1.13. On each of the two graphs in Figures 1.15 and 1.16 on your Answer Sheet, construct a curve to indicate the decreasing number of atoms of uranium-235 in the mineral over time. Both x and y axes have been clearly labeled for you on the linear graph paper (Figure 1.15) and the semilogarithmic graph paper (Figure 1.16).

Tool 1.4 Constructing Histograms

Another valuable graphical tool to geologists is the **histogram,** a type of plot that shows the *frequency distribution of a measurement.* You are probably familiar with histograms that show the distribution of class grades. In a class of 12 students, for example, the grade distribution might look like Figure 1.7.

From this histogram, you know instantly that more students (4 of them) earned a C than any other grade. One student flunked, two earned an A, and so on. Also, you can see that more students earned grades above C than below C. Thus, the distribution is not uniform but is skewed slightly. Still, for a small class, the grade distribution is close to a **normal curve** (also called a **bell curve** for its bell shape). An even more strongly skewed distribution of grades is shown in Figure 1.8.

Occasionally, a group of students ends up with quite a few high grades and quite a few low ones but few in the middle. Figure 1.9 is a histogram of such a **bimodal distribution,** that is, a distribution that has two distinct peaks.

Example: Histogram Showing Distribution of Sand Dune Grain Size. Geologists who study sand dunes use histograms to plot the distribution of sand grain sizes in a dune. Studying samples from one dune might yield a histogram that looks like Figure 1.10.

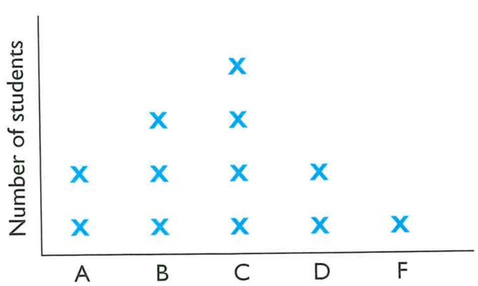


Figure 1.7 Histogram of grade distribution among 12 students. Each X represents a student.

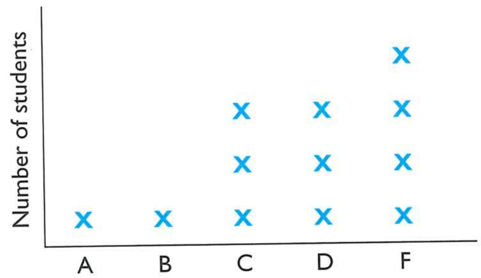


Figure 1.8 Histogram of skewed grade distribution among 12 students. Each X represents a student.

A geologist interpreting this histogram would reason as follows:

- The wind blew grains of sand around, perhaps blowing a lot of sand across many miles.
- Where this particular dune sits, the grains deposited measure mostly 1/8 to 1/16 inch.
- Smaller grains, being lighter, were carried onward to another location.
- Larger grains, being heavier, settled out sometime earlier at another location.

A histogram from a sand dune in another area might be quite different. By studying distributions of sand grain sizes, geologists have learned a great deal about how the wind moves particles. Work on many topics in other branches of geology has been aided by constructing histograms.

Problem 1.11. Grade Distribution in Percent. In a freshman geology class of 200 students, grades at semester's end are as shown in Table 1.4.

Q1.14. Convert the number of students who received each grade into a percentage of the whole group. Then draw a histogram for the grade

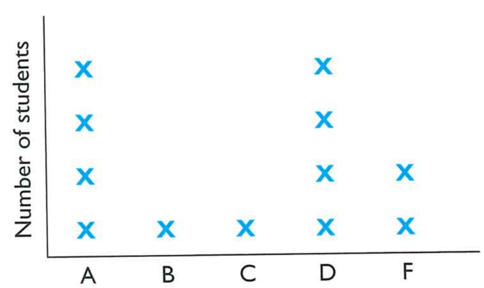


Figure 1.9 Histogram showing bimodal distribution of grades among 12 students. Each X represents a student.

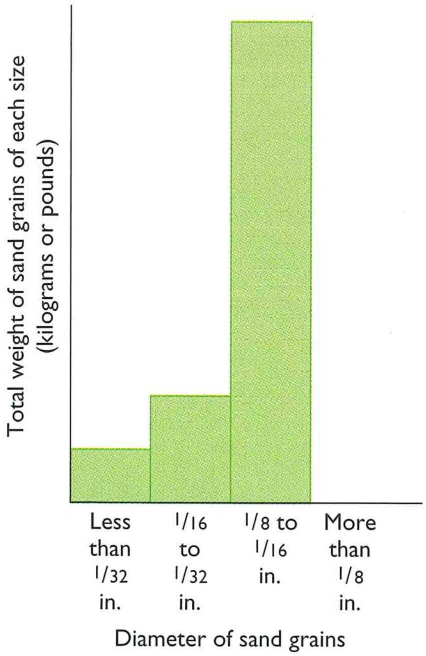


Figure 1.10 Histogram showing distribution of sand grain sizes in a sand sample from a dune, by weight.

distribution of the class on the grid in Figure 1.17 on your Answer Sheet.

Q1.15. What is the name for this type of distribution?

Problem 1.12. Gold in Parts per Million from 18 Samples in a Mine. Deep underground in a gold mine, a geologist takes 18 samples of rock. He sends the samples to an assay lab, and the lab returns the results shown in Table 1.5.

The term *ppm* means parts per million by weight. This means that for every weight unit of gold in the rock, there are 1 million weight units of rock (for example, 1 pound of gold in 1 million pounds of rock). The term ppm is common in the gold industry. Rocks that contain at least 1 ppm gold generally are worth mining. Another way to say this: the value of gold is high compared to lots of other Earth materials.

Q1.16. Using an **X** for each rock sample, construct a histogram of the geologist's results in Figure 1.18 on your Answer Sheet. If you find a value that has a second or third sample for it, simply stack the **X**s atop one another.

Table 1.4

Grade distribution for 200 students

A+ 4 students	B+ 6 students	C+ 10 students	D+ 30 students
A 24 students	B 5 students	C 18 students	D 10 students
A− 46 students	B− 5 students	C− 22 students	D− 15 students
			F 5 students

Table 1.5

Gold content in 18 samples from a mine

Rock sample	Gold content (ppm)	Rock sample	Gold content (ppm)	Rock sample	Gold content (ppm)
1	1.1	7	0.6	13	0.7
2	1.2	8	0.9	14	1.3
3	0.9	9	1.1	15	1.4
4	1.3	10	1.2	16	1.1
5	1.1	11	2.2	17	0.8
6	0.8	12	1.0	18	0.9

One rock sample has an unusually high gold concentration. In the science of statistics, such a misfit sample is called an **outlier,** because it lies outside the range of most other samples. Gold particles, due to their chemical nature, have a strong tendency to clump together, so such high-concentration outliers are not unusual in gold mining. This phenomenon is called the *nugget effect.*

Determining the average gold content of rock in a mine can be extraordinarily difficult, in part because of the nugget effect. To put it another way, never invest in a gold mine on the basis of just a few assay samples—many samples must be assayed to get an accurate picture of an ore!

Q1.17. In the table, which sample is the outlier, and what is its gold content in ppm?

Tool 1.5 The Le Châtelier Principle

Scientists use the term **closed system** to describe some part of the universe that is not exchanging matter with its surroundings. For example, a sugar cube sitting on a table could be considered a "closed system" because the sugar molecules are not wafting away into the air.

However, a drop of water on the same tabletop would not be a closed system. In this case, water molecules leave the drop, evaporating into the air. Note that this evaporation also absorbs a slight amount of heat from the tabletop, cooling it slightly. This is an example of an **open system,** in which both matter and energy move into or out of the system.

Scientists use the term **equilibrium** for systems in which a balance exists between forces or processes such that no net change occurs. For example, consider a cup of hot coffee. It is not at equilibrium for two reasons. Its temperature is not at equilibrium because the coffee is hotter than its surroundings—it is cooling down. Its volume is not at equilibrium because the water is evaporating. Thus, the cup of hot coffee is an open system and it is not at equilibrium because it is experiencing a net change (evaporation of water and loss of heat).

However, suppose we seal the open cup of coffee with plastic wrap. Now it will reach an equilibrium with respect to temperature and volume—eventually. The temperature will reach equilibrium with the coffee cup's surroundings as the coffee cools and the surroundings warm ever so slightly. The volume will reach equilibrium when the rate of evaporation of the coffee equals the rate of condensation dripping from the plastic wrap. Under equilibrium conditions, the temperature and volume of coffee do not change even though individual water molecules in the coffee are not at rest.

A French chemist named Henry-Louis Le Châtelier developed a valuable concept in the 1800s. It states: "A system at equilibrium will respond to any new change applied to it in such a way as to lessen (minimize) the effect of the change." This is called the **Le Châtelier principle.**

Example: Equilibrium of Water Molecules in the Oceans and Atmosphere. Generally speaking, water neither leaves planet Earth nor is added in significant quantities to our planet from space, so we say that Earth is a closed system for water. Within this closed system, vast volumes of water exist as liquid in the oceans and as water vapor in the atmosphere. The oceans and the atmosphere are in constant contact, so water molecules are free to travel between the two. In one direction, water evaporates from the ocean into the atmosphere, whereas in the other direction, water from the atmosphere falls as rain and snow into the ocean. This exchange of water occurs constantly worldwide.

What is important to us here is that equilibrium exists in the proportion of water molecules that reside in the ocean and those that reside as water vapor in the atmosphere.

Adding heat to the oceans would increase the number of water molecules that evaporate to join the water in the atmosphere. This would disturb the equilibrium. But because the evaporation process absorbs heat energy from the ocean, it also would slightly reduce the ocean temperature, thus minimizing the effect of the change. This is an example of the Le Châtelier principle.

Example: Equilibrium of Sugar Dissolved in and Precipitated from Coffee. Considering a system closer to home, imagine that you stir a large quantity of sugar into a cup of hot coffee. You add so much sugar that not all of it can dissolve, so some accumulates on the bottom of the cup. When you are finished stirring, the sugar crystals at the bottom are in equilibrium with the sugar molecules that are dissolved in the coffee. However, as the coffee cools, it can hold fewer dissolved sugar molecules. This forces the sugar molecules in solution to precipitate, joining the sugar at the bottom of the cup. This precipitation reaction releases heat, thus lessening the effects of the cooling, another illustration of the Le Châtelier principle.

Example: Equilibrium of Solutes in Hot Springs. The situation described in the previous example also exists with dissolved salts in hot springs (Figure 1.11). Where a spring releases water at the ground surface, the hot wa-

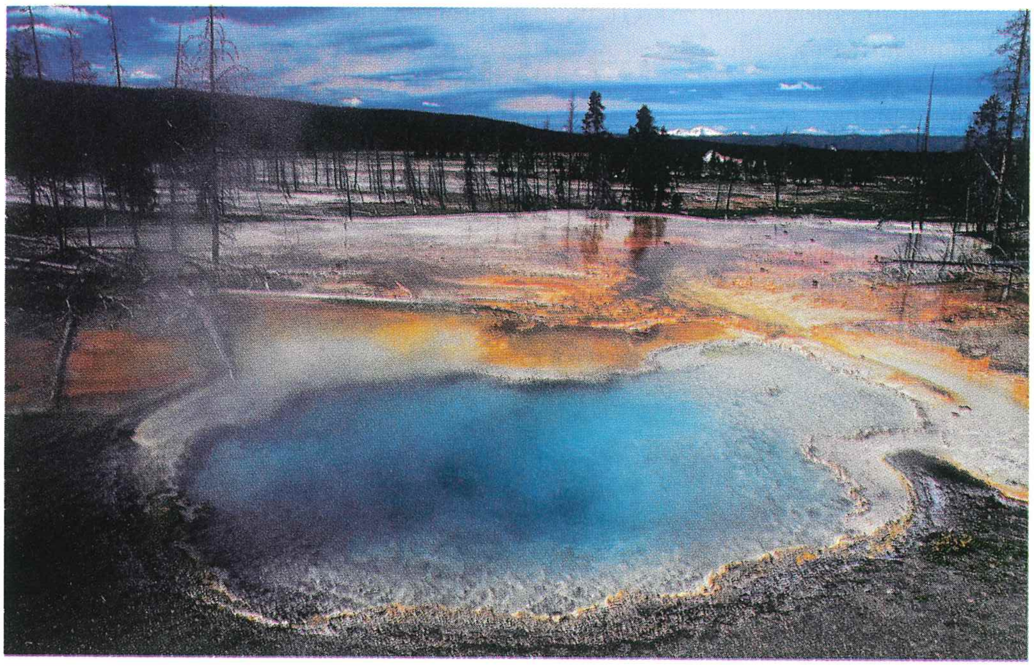


Figure 1.11 Hot spring pool with surrounding mineral precipitate, Yellowstone National Park, Wyoming. Note the minerals that have precipitated around the spring as the water cools and evaporates. (*Fritz Polking/Visuals Unlimited*)

ter spreads out. This allows the water to cool, forcing dissolved chemicals to precipitate. An example is silica (the common ingredient in opal, flint, and chert). This precipitation releases heat. It explains the buildup of silica you see around the spring in the photo.

Many precipitation reactions release heat. This makes sense, because you know that in the reverse situation, when you dissolve powdered detergent, salt, or sugar in water, adding heat to the water allows a lot more of the solid to dissolve. This implies that when detergent, salt, and sugar dissolve, they absorb heat.

Of course, other processes can be significant in the chemistry of hot springs. For example, some of the water is evaporating into the air, thus concentrating salts in the water, which also promotes precipitation.

As you will see, the Le Châtelier principle allows us to predict changes that occur when systems at equilibrium are disturbed. Note that the principle doesn't tell us how much heat will be consumed or how much solid will precipitate. It just tells us in what direction changes in the system will move.

Example: Equilibrium of Glaciers. Imagine that Switzerland experiences three unusually warm summers and winters in a row. How can the Le Châtelier principle be used to explain what will happen to Switzerland's famous glaciers? When ice melts, heat is consumed—as you know simply from holding an ice cube in your hand. The melting ice absorbs heat from your hand, leaving your skin quite frigid. Thus, if Switzerland is unusually warm for several years, the local glaciers will respond to lessen this increase in temperature. Glacier ice will melt, a process that consumes heat, and Switzerland's glaciers will shrink, "retreating" up the mountain valleys.

Problem 1.13. Le Châtelier Principle Explains Why Adding Heat Allows Saturated Saltwater to Hold More Salt. Imagine that you have a cold glass of water into which you have dissolved all the salt you can. After stirring and stirring, a thin layer of salt crystals remains on the bottom of the glass. Now imagine that you carefully immerse the glass in a large pan of hot water, thus heating your glass of saltwater. You see that as the water warms up, the salt crystals on the bottom of your glass disappear entirely, dissolving into the warmer water.

Q1.18. How does this event illustrate the Le Châtelier principle?

Problem 1.14. Le Châtelier Principle Explains Whether Diamond or Graphite Forms, Depending on Pressure. Geologists know that the element *carbon* occurs as the soft, slippery mineral *graphite* near Earth's surface, but the same element forms hard *diamonds* deep within Earth. Imagine that a geologist puts a piece of graphite into a tightly sealed cylinder that has a plunger. He then exerts enormous, constant pressure on the graphite. Eventually, he produces a cylinder of carbon that is 90% graphite and 10% diamond. No further change occurs—in other words, the system is in equilibrium under some particular constant pressure.

Q1.19. If at this point the geologist increases the pressure even more, what will happen? How does this illustrate the Le Châtelier principle? (***Hint:*** Diamond is a denser structure of carbon molecules than graphite.)

Unit 1 Paper-and-Pencil Tools

Last (Family) Name ____________________ First Name ____________________

Instructor's Name ____________________ Section ____________________ Date ____________________

Q1.1. ____________________ liters

Q1.2. ____________________ metric tons

Q1.3. US$ ____________________

Q1.4. ____________________ cubic feet

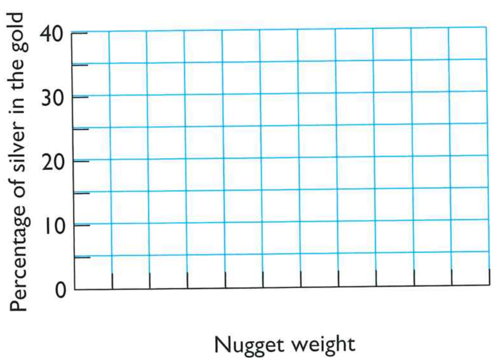
Q1.5. US$ ____________________

Q1.6. (circle one) yes no

Q1.7. porosity unit: ____________________

Q1.8.

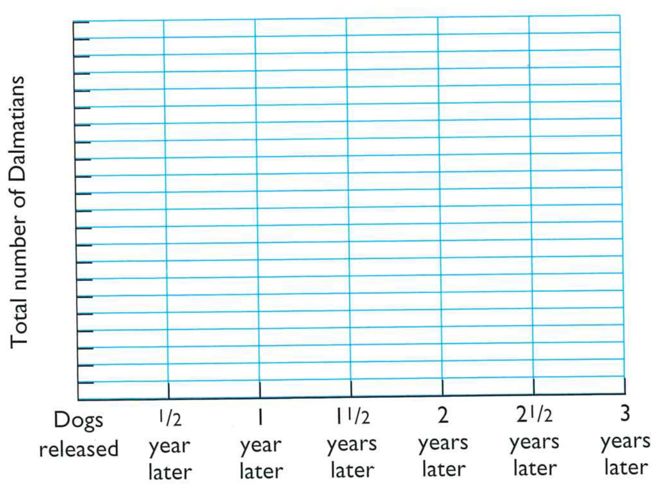
Figure 1.12 Percentage of silver in the gold nuggets.



Q1.9. (circle one) yes no

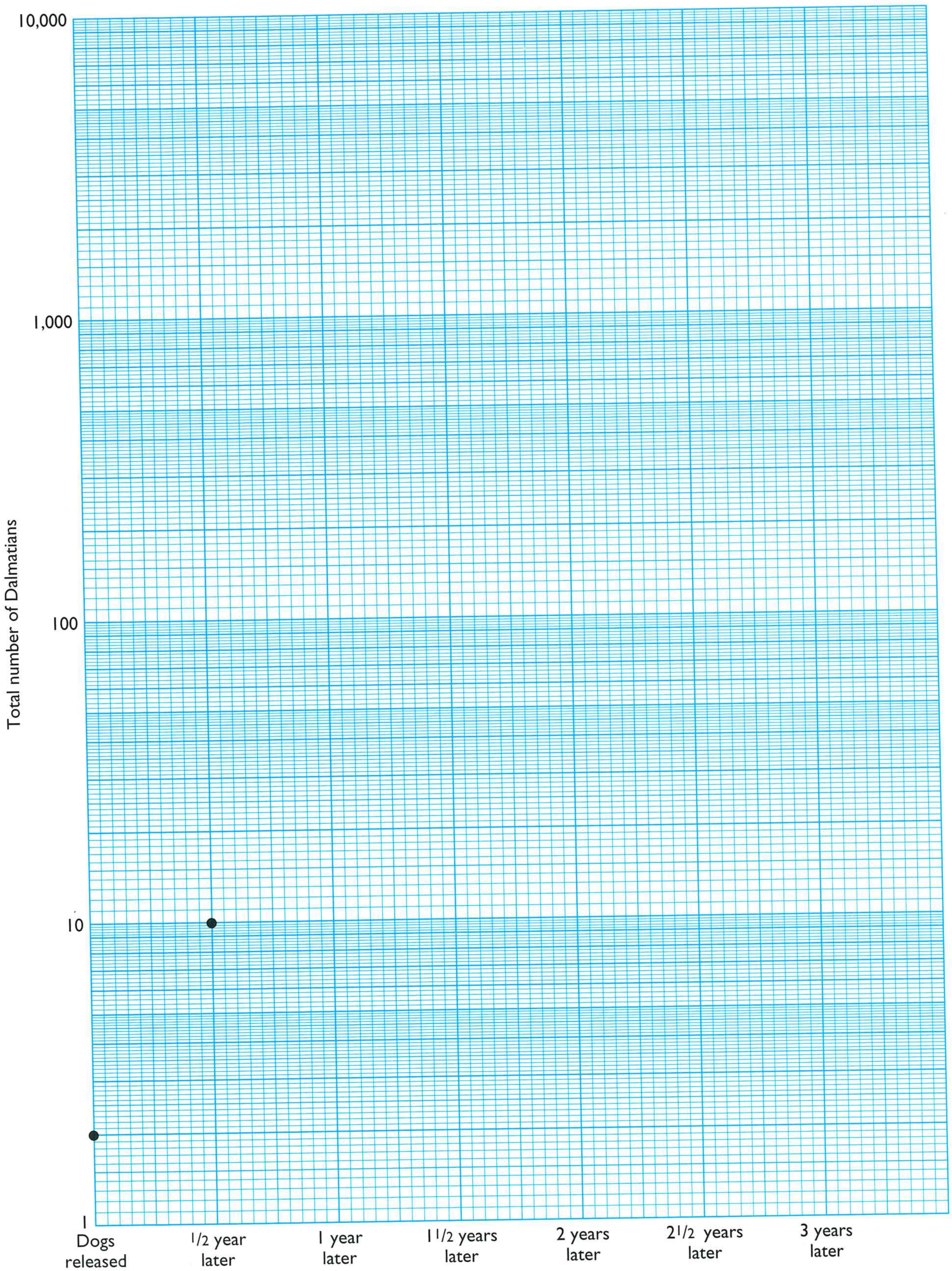
Q1.10.

Figure 1.13 Linear plot of exponential population.



Q1.11.

Figure 1.14 Semilogarithmic plot of exponential population growth of Dalmatian dogs.

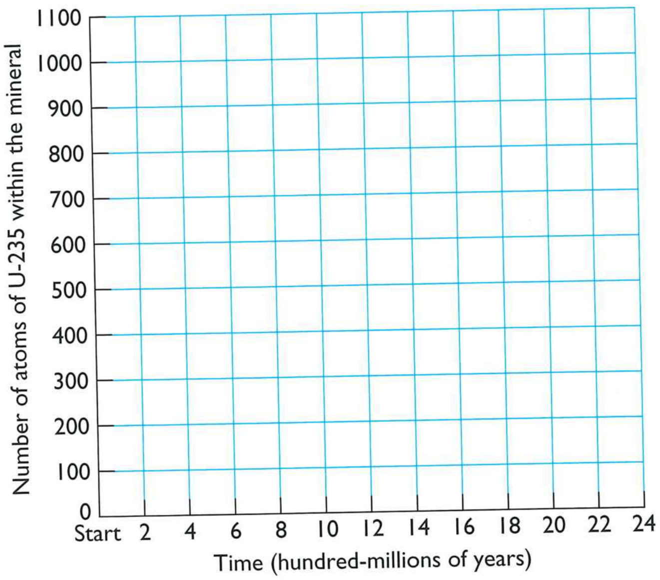


Q1.12. ______________________________

____

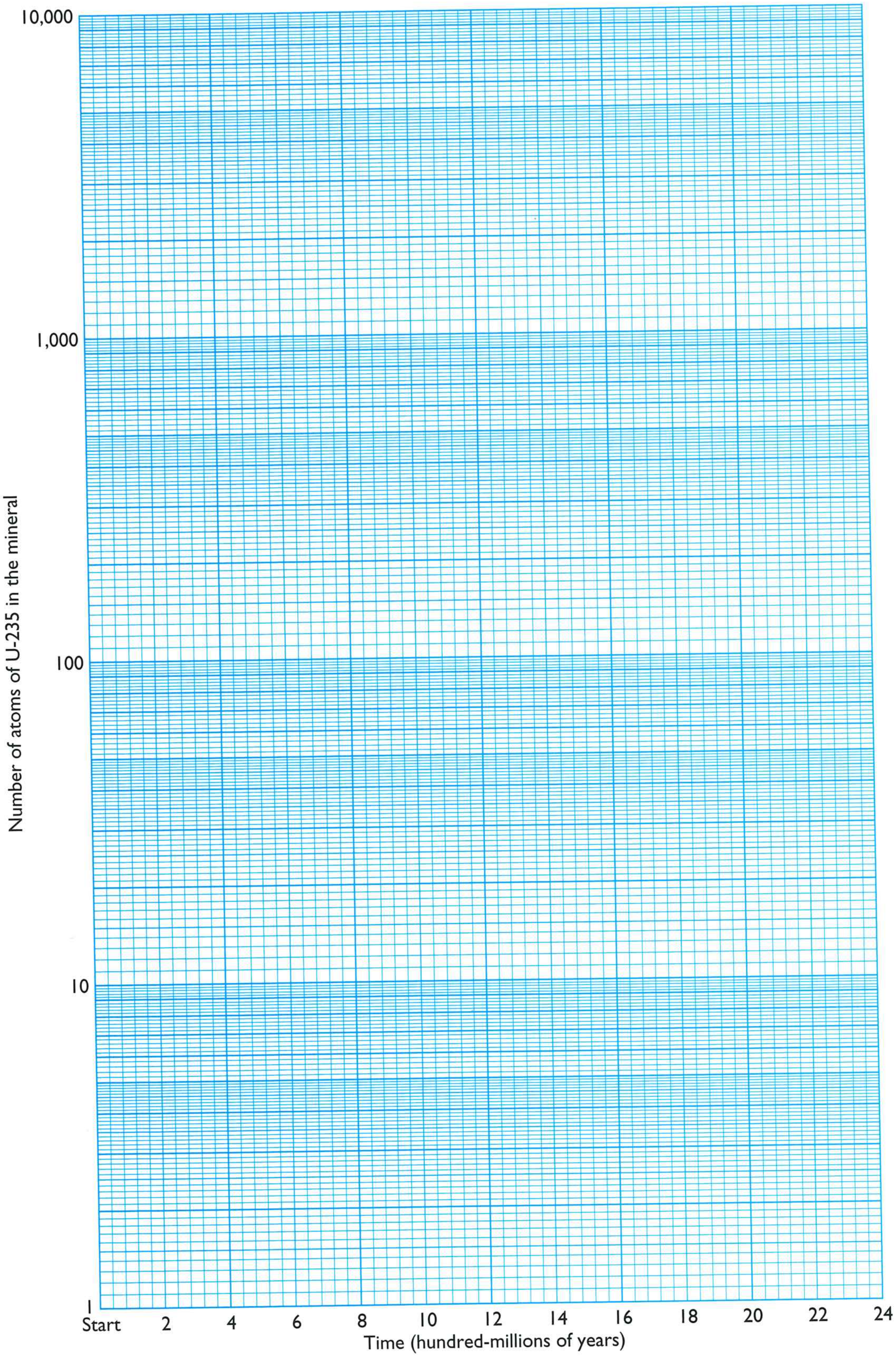
Q1.13.

Figure 1.15 **Half-life of uranium-235 shown on linear graph.**



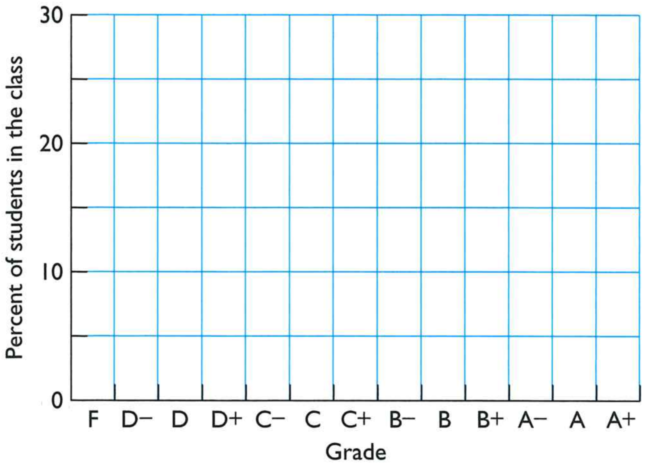
Q1.13. *(cont'd.)*

Figure 1.16 **Half-life of uranium-235 shown on semilogarithmic graph.**



Q1.14.

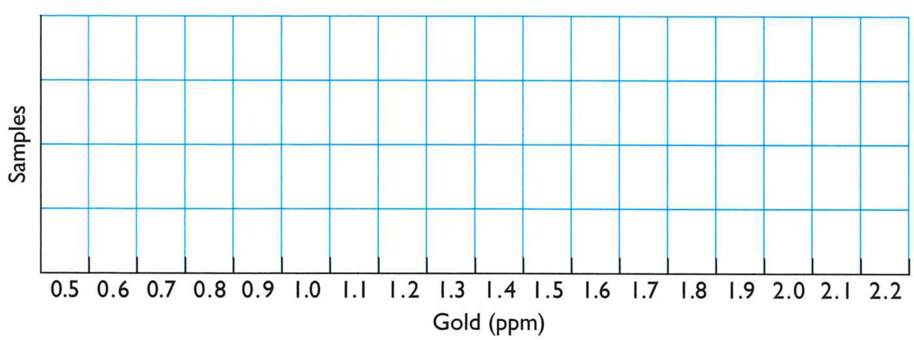
Figure 1.17 Histogram of grade distribution for the class.



Q1.15. ____________________ distribution

Q1.16.

Figure 1.18 Histogram showing distribution of gold concentration (ppm) in rock samples.



Q1.17. Sample ____________________, ____________________ ppm

Q1.18. ____

____

____

Q1.19. ____

____

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