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ABSTRACT

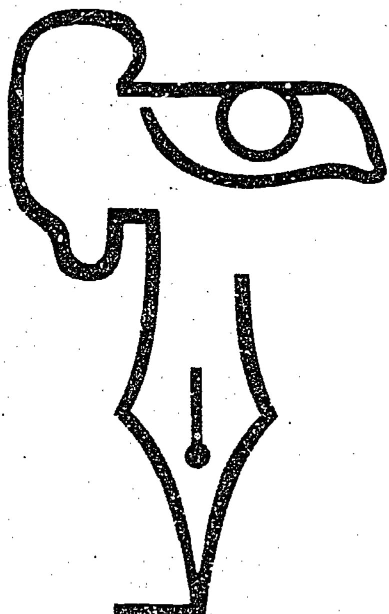
Designed to help secondary school students understand and become able to use the "language" of the scientist, which the author defines as including both vocabulary and thought processes and laboratory procedures, this book attempts to show that the reporting of scientific investigations has both a manageable pattern and a structure. Scientific language in general is considered and then specifically, the languages of the individual sciences, the language of mathematics in science, and the language of the laboratory. Also explicitly dealt with are science investigations for students themselves. Each of the early chapters has a section of questions, problems, and suggestions for building vocabulary. Chapter titles are Language and Communication; The Language of the Sciences: Biology, Chemistry, Physics, Earth and Space Sciences; The Language of the Laboratory; The Language of Mathematics in Science; and Practicing the Language of Science. Two appendices are also included: Greek Alphabet, Terms, Units of Measure, Chi-Square; and Answers to Problems and Questions. (PEB)

[illegible]
Alkaline solutions
Amino acids
Ammonia water
[illegible]
Asteroids
Astronomy
Atom
Benthic zone
Biologists
Boyle's law
Cambrian
Carbohydrates
Central tendency
Cenozoic
Chi-square
Classes, taxonomic
Compounds
Computational skills
Constellations
Continental shelf
Chemical

The Language of Science

ALAN MANDELL

NATIONAL SCIENCE TEACHERS ASSOCIATION



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The Language of Science

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Philosophy is written in that great book which ever lies before our eyes—I mean the universe—but we cannot understand it if we do not first learn the language and grasp the symbols in which it is written . . .

Galileo, *Il Saggiatore*, 1623

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Contents

Preface

To the student

The basic purpose of this book is to help you understand and be able to use the "language" of the scientist—not merely the vocabulary of science, but also the thought processes and laboratory procedures of the scientist. As you read the chapters and deal with the questions and problems provided, keep in mind that you are, in a sense, attempting to master a new language, to become fluent in its use.

If you were to visit another country, you would like to be able to speak and understand its language in order to get to know the people and in order that they might get to know you. If you could not speak their language, you would feel like an outsider, unaware of most of what was happening. In the same way, the language of science is like any other language. If you can speak and understand it, you will feel at ease with other people who are talking or writing about science and understand what is happening. Moreover, just as knowing the language of a country helps you to understand the culture of the country, so knowing the language of science helps you to understand the concepts of science. We say helps because terminology, vocabulary, and language itself are only tools; we use them to help us communicate the concepts of science. Understanding the language of science can make you a better science student, and it will make learning science more enjoyable.

Like other languages, the language of science has its structure, its rules and exceptions, and its easy and difficult areas. This book will try to clarify this structure and to give you a start in learning some of its important components. And, like any newly learned language, the language of science must be practiced and used constantly.

You will have many occasions to meet and use the language of science. Two obvious places are in the classroom as you study the various sciences and in the laboratory as you develop some of the scientist's skills.

In addition, much of the vocabulary of science can be heard in general conversation. In a simple discussion of film sizes we hear terms such as 8-millimeter movie film and 35-millimeter color slides. More sophisticated conversations may be sprinkled with **dichotomize** (to cut into two), **insecticides** (cide = to kill), and **ecology** (ecos = house or home + ology = the study of, thus the study of organisms and their homes or environment).[1] In these examples, the layman is using the language of science. As you become more familiar with the language, you can sharpen up your own conversational skills. Even as you prepare papers for other school courses, the skills and vocabulary that you develop in your study of science can be of benefit. Extend your science vocabulary into your creative writing assignments and your daily conversations whenever you can call upon an especially expressive scientific term or comparison.

Use your newly developed communication skills as you study your science courses, do your laboratory experiments, and undertake science projects. As you use this book and practice some of the techniques suggested in it, read or glance through scientific journals and texts to see how you are progressing in learning this new language. Keep a mental record of your own progress in extending your vocabulary and in using ever more precise terminology.

To the teacher

This book has been written for the science student—to help him comprehend the language of science and to gain confidence in its use in the conduct of scientific investigations. From his first introduction to the sciences in the junior high school or even earlier in the elementary school to the more in-depth studies at the college level, the student may be awed and confused by a seeming flood of new terms and concepts. This book attempts to reveal that this flood has a manageable pattern and structure. To aid him in using the language as quickly and easily as possible, the book considers scientific language in general and then, more specifically, the languages of the individual sciences, the language of mathematics in science, and the language of the

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[1] Throughout the book, we will indicate the meanings of words by breaking them into their components. The section on word-attack schemes in Chapter 1 explains the usefulness of this procedure.

laboratory. Here, the book also deals explicitly with science investigations for students themselves. In addition, each of these early chapters has, at its end, a series of questions, problems, and suggestions for building vocabulary.

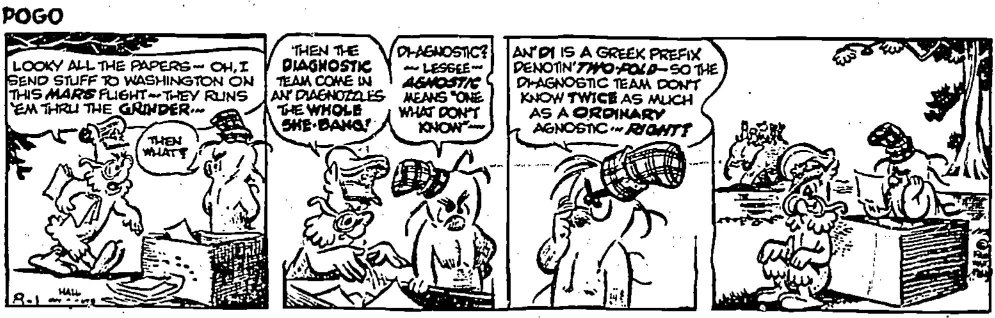
Because much of instruction in today's secondary schools has become fairly quantitative in its orientation, an important section is devoted to the application of basic statistical techniques to science problems.

The final step, then, is to practice the language of science, and a concluding chapter suggests some of the ways that students can go ahead on their own to develop skill in communication and in the laboratory.

The most useful application of this book should be as an additional reference book and as an aid to the student. Many of the modern high school science curricula either assume that the student has already learned the vocabulary of science or treat it incidentally in their text materials. All too often the student becomes lost or fails to make good progress because he lacks a good grasp of the concepts and an understanding of the terminology used.

The other purpose of this book is to encourage the student to carry out scientific activities. He should not only learn the language of science but be prepared to use it on his own in the scientific environment. Science project activity can and should have positive value in a well-organized science program. The suggestions in this book should help students realize these values.

Alan Mandell



CHAPTER 1

Language and Communication

One of the characteristics that distinguishes man from the other animals in his highly developed ability to communicate—that is, to transfer ideas from one individual to another through abstract visual or oral symbols and, especially, to record these symbols so that he can communicate with individuals far away in place or time. Many of the other animals also communicate with each other in a less complex but nevertheless interesting fashion. Some birds have a repertoire of calls, each of which appears to have a significant meaning to other birds. Worker bees have a sign system (described by Von Frisch [9][1]), by which they inform other bees in the hive of the direction and distance to a food supply. Some animals communicate by using a chemical language; the odors they produce may attract or repel other animals. Still others project messages by gestures, facial expressions, or body attitudes.

Communication by use of a language composed of abstract symbols—particularly recorded symbols—appears to be confined to man. To assure that this communicative process is successful, the individuals involved must have common agreement on and understanding of the meanings of the written and spoken symbols used in the language. A particular fruit is an "apple" only because you and I and the rest of the English-speaking world have agreed to call it that. A Spaniard calls that fruit "manzana" and might not connect the term "apple" with the red, tasty fruit we know. The Greeks call this fruit *μῆλον* ; the Russians, яблоко; and the Japanese 林檎 . Here, even the letters themselves are different. Obviously, communication requires an agreement on the symbols as well as on the arrangement of the symbols to indicate a certain concept. Understanding the mean-

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[1] References cited in the chapter will be found at the end of the chapter.

ings of symbols used in communication is of primary importance, whether it be in a foreign language, one's own native tongue, or a specialized part of a language.

Fortunately, the language of science is cosmopolitan. That is, it is used by all nations and draws upon many of them for its vocabulary. Scientific terms and symbols come from Greek, Latin, Arabic, and many other languages. Historically, Greek and Latin were the languages of the learned world, so it is not surprising that much scientific terminology derives from word roots of these languages. Some scientific terms (for example, tetravalent) have mixed Greek and Latin roots.

Pictorial symbols, too, are used in the language of science. You probably recognize ♂ as the symbol for male and ♀ as the symbol for female, though they have also been used as symbols for the planets Mars and Venus, respectively. Letters of the alphabet may also be used as symbols in the sciences to provide a kind of shorthand. However, like words themselves, symbols must have agreed-upon meanings, or communication is impossible. If there is any question in the writer's mind that the symbols he is using may not be clear to his readers, he should provide a list of the symbols and their meanings or write out each term in full when it is first used and indicate the symbol (or abbreviation) in parentheses immediately following the term. This establishes the meaning of each symbol in the context in which the author, or a speaker, is using it.

Appendix A contains a table which shows the Greek alphabet and some of the many meanings for which its letters are used in the sciences.

Word-attack schemes

To unlock the meanings of complex words, such as **infraphotodensitometer** and **bathythermograph,** or even to learn to spell them correctly, may appear to be a nearly impossible task. Yet, using some of the clues and word-attack skills discussed below, you should be able to conquer words such as these and most of the other scientific words you encounter.

You are familiar with root words, prefixes, and suffixes from your language studies. Most science terms are compound words composed of a root word and prefixes or suffixes or both. Consider the word **photosynthesis.** Here the root "photo," meaning light, and the root "synthesis," meaning to put together are combined to produce a term which signifies "putting together through the use of light." You probably know photosynthesis as a term which describes the processes by which green plants make food materials in the presence of light. If you didn't know that, the word itself, thus analyzed, would give you a clue to its meaning.

Think of some other "photo" words. **Photograph** implies writing (graphein = to write) by light; add an "er," and we have **photographer. Photometer** suggests a device to measure (meter = measure) light. Indeed, a photometer is used by photographers (people who write or record with light) to determine the amount of light available in order to take a good picture. Going back to **infraphotodensitometer,** we identify "infra" as near the limits of the light spectrum (i.e., infrared) and "density" as referring to the thickness or denseness of a material. Our word then becomes an understandable term which describes a device that measures the density of a material to infrared light energy. When we look again at **bathythermograph,** we get a clue to "thermo" from the word **thermometer,** which we know is a temperature-measuring instrument. Knowing that "bathy" refers to depths under water, we can see that bathythermograph signifies a device that records (writes) the temperature in deep waters.

From the above discussion, it should be apparent that knowing the meanings and uses of some of the more commonly used scientific root words, prefixes, and suffixes is of primary importance in becoming adept with the scientific vocabulary. Table 1 lists some common combining terms, their meanings and uses.

The arrangement of the parts of a compound word is often an important clue to its meaning. Consider, for example, **photomicrography** and **microphotography.** Knowing the meanings of "photo" and "graphy" and adding that "micro" pertains to very small objects, we can see that both terms are concerned with written records of light energy on a very small scale. Word analysis, using the relative positions of the parts of the compound word, suggests that microphotography means "small, light-written, recording." It is the process of making extremely small photographic records (on microfilm) of normal-size materials. Photomicrography, on the other hand, indicates "light-written records of tiny materials" and is used generally to describe taking pictures through the microscope.

Other words that can be analyzed in this way are given at the end of the chapter in Problems and Questions.

TABLE 1. Some Common Combining Terms Used in Science

Term[a]	Meaning	Example of Use
alb	white	albino
anti	against	antitoxin (opposes poisons)
anthrop	human being, man	anthropology (study of man)
aqua	water	aqueous (watery)
archeo	ancient	archaeology (study of ancient remains)
bar	weight, heaviness	barometer (measures weight of atmosphere)
bio	life	biology
centr	center	centrifuge
claus	an enclosed place	claustrophobia (fear of being confined)
dem	people	demography (study of human populations)
derm	skin	ectodermis
ect	outer	ectodermis (outer skin layer)
end	inner	endodermis (inner skin layer)
ep	upon, atop	epicenter (above the center)
gene	birth, descent	genealogy
ge	earth	geography (mapping of the earth)
graph	write	geography
hydr	water	hydrometer (water meter)
is	equal	isotope (same place in atomic table)
log	study of	biology, anthropology
lun	moon	lunar (pertaining to the moon)
mes	middle	mesodermis (middle skin layer)
meter	measure	metrology (study of measurement)
muta	change	mutate, mutation
morph	shape, form	morphology (study of form and structure)
nym	name	pseudonym (false name)
omni	all, total	omniscient (all-knowing)
phil	love	aquaphila (love of water)
phob	fear	claustrophobia (fear of being confined)
phon	sound	phonograph
phot	light	photograph

Term	Meaning	Example of Use
phyt	plant	epiphyte (a plant growing upon another)
pod	foot	pseudopodium ("false foot" of single-celled animal)
prot	early, first	protozoa (first animals)
pseud	false	pseudonym
scien	knowledge	science, omniscient
therm	heat	thermometer
top	place	topography
tox	poison	toxic, poisonous
zo	animal	zoology

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[a] In forming words from these terms, connecting vowels are often used, as will be clear from the examples given. Dictionaries and various authorities may give slightly different forms for terms or roots. For the sake of consistency in this publication, so far as possible we have followed the forms used in *Dictionary of Word Roots and Combining Forms* [2].

TABLE 2. Numerical Prefixes Used in Measurements

Name	Symbol[a]	Meaning	Unit Multiplier
tera-	T	trillion	10^{12}
giga-	G	billion	10^{9}
mega-	M	million	10^{6}
kilo-	k	thousand	10^{3}
hecto-	h	hundred	10^{2}
deka-	da	ten	10^{1}
deci-	d	one-tenth	10^{-1}
centi-	c	one-hundredth	10^{-2}
milli-	m	one-thousandth	10^{-3}
micro-	μ	one-millionth	10^{-6}
nano-	n	one-billionth	10^{-9}
pico-	p	one-trillionth	10^{-12}
femto-	f	one-quadrillionth	10^{-15}
atto-	a	one-quintillionth	10^{-18}

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[a] *Le Système International d'Unités (SI), International System of Units*

TABLE 3. Quantitative Prefixes

Prefix	Meaning	Example of Use
mon	one	monotone (single tone or key) monoxide (contains one oxygen atom per molecule)
un	one	unicellular (one-celled) unilateral (one-sided)
bi	two, twice, double	bicycle (two wheels) bifurcate (two branches, forked)
di		dimorphic (in two forms)
du		duplex (double, twofold)
ter	three	tertiary (third rank or stage)
tri		tripod (three-footed stand) tritium (hydrogen isotope with 3 nuclear particles)
tetr	four	tetrachloride (four chlorine atoms) tetrahedron (solid with four faces)
quadr		quadruped (four-footed animal)
a	without, lacking	abiotic (without living organisms)
an		anarchy (without government)
heter	mixed	heterogeneous (a mixture of kinds) heteromorph (exhibiting diversity of form)
hom	similar throughout	homogenized milk homograft (tissue from a similar type)
hyper	above, over, excessive	hypertoxic (excessively poisonous) hyperesthesia (unusually high sensitivity)
hypo	less than, below, deficient	hypodermic (below the skin) hypothyroid (thyroid insufficiency)
is	equal, same	isosceles triangle (equal sides, equal angles) isomorphs (same shapes or forms) isothermal (equal temperatures)
micr	small	microscope (view of small things) microbiology (study of tiny living things)
poly	many, much	polychrome (many-colored) polynuclear (having many nuclei)
tel	distant, far	telescope (distant view) television (seeing at a distance)

Numerical prefixes

Scientific terms often include prefixes that have a quantitative or numerical basis. These give us a better description of the item under consideration. Table 2 lists numerical prefixes used in measurements, symbols, and mathematical expressions. Table 3 lists some of the more commonly employed quantitative prefixes and some common and scientific terms containing them.

Fun with scientific word forms

To become more familiar with some of the terms shown in Tables 1 and 3, let us compose some silly compound words using some of these terms. The mental processes we go through in developing these words are the same as those used by the scientist as he attempts to provide a term which will make clear the idea he had in mind.

A bald-headed man could be called **asetate** (a = without, seta = hair), or perhaps **hyposetate** (lacking or deficient in hair). In any event, we all occasionally must undergo a **cephalosetectomy** (head hair removal = haircut). A very fast runner might be described as having **pteropoda** (winged feet). An ecological community containing only a single species of animals might be called **monozoic.**[2] The usual ecological community with a variety of plant and animal species could be called **polybiotic.** How would you describe your classroom (or home) aquarium in this respect? Compose terms to describe scientifically the following: (a) a midget, (b) a device to measure people's feet, (c) rock and roll music.

Problems and questions

1. What might these make-believe scientific terms mean?
   a. thermophobia b. aqualuna c. baropodate
2. What about these more truly scientific terms?
   a. demophile b. polymorphic c. pseudopodia
3. Watch your dog or cat and make a list of its communication

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[2] Actually, an excellent term in wide usage in modern experimental biology with exactly the meaning described here is **axenic** (a = without, xen = stranger or foreigner).

processes. List items of its vocabulary. Can you establish a dictionary for a dog's tail communication patterns?

Are dogs generally successful in communicating with other dogs? With cats? With other animals? How about cats in these respects?

Has your pet learned to understand your communications? Does he understand the words you use or the tone of your voice?

4. Look up the language called Interlingua. What kind of international problems could such a language help solve?
5. Suppose you were one of the first persons to meet an intelligent extraterrestrial being. How would you begin to communicate with him (it)? There have been several interesting science fiction stories written on this particular question.
6. Worthwhile science projects can be done on animal communication patterns. Suggest some questions to be investigated.
7. Try writing a theme for an English assignment in which you point out how the language of specific groups of people cuts them off from other people. Sports, economics, and dress styles are infamous for their own unique lingo.

References and Further Reading

1. Bonner, J. T. "How Slime Molds Communicate." *Scientific American*, August 1963. Reprint No. 164.
2. Borror, Donald J. *Dictionary of Word Roots and Combining Forms*. National Press Books. Palo Alto, California. 1960. (Tenth Printing, 1970).
3. Esch, Harold, "The Evolution of Bee Language." *Scientific American*. April 1967. Reprint No. 1071.
4. Hogben, Lancelot. *The Vocabulary of Science*. Stein & Day Publishers, New York. 1970.
5. Krogh, August. "The Language of the Bees." *Scientific American*. August 1948. Reprint No. 22.
6. Pei, Mario. Editor. *Language of the Specialists: A Communications Guide To Twenty Different Fields*. Funk & Wagnalls, New York. 1966.
7. Thorpe, W. H. "The Language of Birds." *Scientific American*. October 1956. Reprint No. 145.
8. Von Frisch, Karl. *Bees, Their Vision, Chemical Senses and Language*. Cornell University Press, Ithaca, New York. 1971.
9. ———. "Dialects in the Language of the Bees." *Scientific American*. August 1962.
10. Wenner, A. M. "Sound Communication in Honey Bees." *Scientific American*. April 1964. Reprint No. 181.

CHAPTER 2

The Language of the Sciences Biology

Biologists might be accused of manufacturing the greatest number of new terms for their own special vocabulary. But when you consider that biologists are trying to describe precisely all the different kinds of plants and animals, as well as their varied structures and living processes, you can understand the need for an immense number of terms.

Taxonomic terms

One of the earliest problems biologists faced was that of assigning scientific names to living organisms. You and I may agree that the four-legged animal that gives us milk will be called "a cow," but a Spaniard will call her "una vaca." The international language of biologists suggests that we all use a scientific (genus) name of *Bos*. If we do so, people of all nationalities will know which type of animal we are discussing.

Biologists have developed a scheme of classification for all organisms, living or extinct. This system of **taxonomy** (tax = arrangement, - nomy = the science of: thus, the science of arrangement) attempts to arrange the great variety of living things into organized and logical categories. Important for classification are the structure, function, development, and evolutionary history of the organism.

The early Greeks named some animals, and other later scientists revised and added to this taxonomy. Linnaeus, 1707-1778, a Swedish botanist, devised the basic system of taxonomy still in use throughout the world. (2) It consists of a hierarchy of taxonomic ranks: the first ranks contain large groups of organisms with many general, shared characteristics. Each rank and its subgroups are more discriminating than the preceding rank so that as we progress down through the ranks, we find the organisms included in each becoming more and more similar. This kind of classification tells us a great deal about the characteristics of the organism and its interrelations with other organisms.

Since the time of Darwin, the theory of evolution has become an important influence in classifying organisms with regard to their common ancestry.

The first step in the Linnaean scheme was to divide all living things into two kingdoms: plants and animals. However, as you study biology, you may be surprised to find that there are some organisms that are difficult to identify as either truly plants or truly animals. Some taxonomists have proposed a third kingdom of living things called the Protista, but generally we still use the two kingdoms. Each of the two kingdoms is divided into major groups. For animals the major groups are called **phyla** (singular, phylum; from phyl, a Greek word meaning tribe). The equivalent botanical category is the division. Phyla and divisions are subdivided into classes, classes into orders, orders into families, families into genera (singular, genus), and genera into species. (See Figure 1.)

FIGURE 1. The Ranking of Major Taxonomic Categories

Kingdom

Animal	Plant
Phylum	Division
Class	Class
Order	Order
Family	Family
Genus	Genus
Species	Species

Note: Although there are only two kingdoms, there are many phyla, classes, and other subdivisions.

As we progress from kingdom to genus and species, each succeeding rank becomes more specific in its description of the organism. The kingdom will include *all* animals; a phylum will include a very large group of animals that all have some common distinguishing characteristic; each class will include one subdivision of the phylum; and so on until we come to genus and species. Through the use of a **binomial** (bi =two, nom = name) arrangement of genus and species, each organism can be given a distinctive scientific name that designates it specifically. Here it is important to remember that species is not a name in itself and cannot be used alone. It is a specific **epithet** (epi = upon, thet = theme; characterizing term) used to further distinguish the organism of a genus.

If you study any particular group of organisms in great detail, you may find additional taxonomic levels, such as subfamilies or superclasses. However, it is the genus-and-species label that describes the particular type of organism. Thus, the common house cat is *Felis domesticus*, and the red maple tree is *Acer rubrum*. The genus name may be abbreviated as (*F. domesticus* or *A. rubrum*) if the meaning will still be clear. Notice that the generic name comes first and is capitalized; the specific epithet is not capitalized; and both words are underlined in a manuscript and printed in italics. This is the standard way to write scientific names. The names in classifications above genus—family, order, etc.—are also capitalized.

As Linnaeus and other scientists composed names to designate the various levels or ranks of taxonomy, they often used descriptive prefixes, suffixes, and root words. A good example of the descriptive power of nomenclature (nomen = name; calare = to call) is shown in Table 4, the hierarchy or classification scheme of names of the Virginia pine. Notice how the term for each rank describes the organisms in that group.[1]

The names tell us that the Virginia pine is a cone-bearing, seed-producing plant, with naked seeds.

TABLE 4. Taxonomy of the Virginia Pine

Category in order of descending rank	Name
Kingdom	Plantae (plant = plant)
Division	Spermatophyta (sperm = seed, phyt = plant)
Class	Gymnospermae (gym = naked)
Order	Coniferales (conifer = cone-bearing)
Family	Pinaceae (pine family—assigned by Linnaeus)
Genus	*Pinus* (pin = pine)
Species	*Pinus virginiana* (place of common occurrence)

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[1] Note that taxonomy and nomenclature are two separate processes. Taxonomy is the (theoretical) study of classification. Nomenclature is simply the process of naming things and is essentially a legal process, based on rules of nomenclature.

Sometimes an investigator will discover a new organism which he thinks no one has described before. It must be placed in the correct relationship to the known plants or animals, and it must be named according to nomenclatural rules.

There are very specific rules for this process. In the case of the plant kingdom these rules are to be found in the *International Code of Botanical Nomenclature*. [4] Some of the important rules for the investigator to keep in mind as he attempts to name his newly discovered plant appropriately are the following:

1. The scientific name of any plant has two parts: the genus, or generic name, and the specific epithet (species). (For example, the red spruce is *Picea rubra*.)
2. The generic name is always a noun, in the singular, nominative case, and is always written with a capital letter. It may be descriptive of some characteristic prominent in the included specimens such as *Xanthoxylum* (yellow wood) or may follow the early original name given to plants of its type, such as Quercus, the Greek name for oaks. In the case of an entirely new generic group, the name of a person may be used, such as *Jeffersonia* (after Thomas Jefferson) for a genus of herbs.
3. The specific epithet may be:
    a. an adjective indicating a distinguishing trait of the species, such as *rubra* (red) or *americana* (an American species), or
    b. a noun, such as a person's name (for example, *andersonii*), usually to honor a scholar in that branch of botany.
4. The family name is formed by adding *aceae* to the stem of the generic name. Thus, Pinaceae.
5. The order name is formed by adding *ales* to the stem of the generic name, thus Pinales from *Pinus*, Liliales from *Lilium*.

In the early history of biological taxonomy one animal might be given several different names, having been discovered and described by more than one scientist. One such organism was a freshwater amoeba which had several different names in the scientific literature.

It is reported, perhaps with tongue in cheek, that one biologist, in an attempt to straighten it all out, gave the amoeba a name still sometimes used for it. The terms he chose may have reflected the problems he encountered in the process—*Chaos chaos*—or do they refer to the large **vacuoles** (vacu = empty) characteristic of this organism (chaos = empty space)?

The taxonomy of animals also has its procedures for nomenclature. These are found in the *International Code of Zoological Nomenclature*. [1] Table 5 shows how an animal may be described in the various levels of classification from kingdom to species.

TABLE 5. Taxonomy of the Common Housefly

Category in order of descending rank	Name
Kingdom	Animalia (animal = animal)
Phylum	Arthropoda (arthr = joint, pod = foot)
Class	Insecta (insect = cut into; this refers to the divided nature of the body)
Order	Diptera (di = two, pter = wings)
Family	Muscidae (assigned by Linnaeus)
Genus	*Musca* (Latin name for fly)
Species	*Musca domestica* (domestic = around the house)

This hierarchial classification scheme shows us that the common housefly is an animal with jointed feet, a divided body, and two wings, and is a fly around the house. The word Hexapoda has also been used as the name of this class of arthropods, referring to the fact that insects typically have three pairs of legs (hex = six).

It should come as no surprise to you that biology as a science is changing every day as new information is discovered. Consequently, some biologists spend their research hours trying to improve and make more precise the taxonomic system. In addition, some authorities prefer to group certain organisms in a single category, while others consider that these organisms are sufficiently distinct to merit separate categories. Hence, we find a variation in numbers of phyla and other groups listed in reference works.

Table 6 is a list of many of the terms used in taxonomy, with an explanation of their meanings. Using this table may help you to figure out some things about an organism from its names.

TABLE 6. Some Taxonomic Terms for Higher Levels of Plants and Animals

Term	Analysis	Examples
Plant Kingdom		
Thallophyta	thall = immature plant body phyt = plant	algae, fungi
Mycophyta	myc = fungus	fungus or mold plants
Bryophyta	bryo = moss	moss plants
Pteridophyta	pteri = fern	fern plants
Spermatophyta	sperm = seed	seed plants
Animal Kingdom		
Protozoa	proto = first, early zo = animal	one-celled animals
Porifera	por = pore fer = to bear	sponges
Coelenterata	coel = hollow cavity enter = intestine	hydra and jellyfish
Platyhelminthes	plat = flat helmin = worm	flatworms, flukes
Nemathelminthes	nem = thread-like	round worms
Annelida	annel = a ring	earthworms
Mollusca	mollusc = soft	shellfish
Echinodermata	echin = spiny derm = skin	starfish
Arthropoda	arthr = jointed pod = foot	insects, spiders, crustaceans, etc.
Chordata	chord = cord	animals with notochords

Descriptive terminology

As you might expect, taxonomic terminology has frequent need for terms that describe colors. Table 7 lists some of the more commonly used terms and their color implications.

TABLE 7. Terms Describing Colors

- White
  - alb-
  - albi-
  - candi-
  - eburne- (ivory)
  - lact- (milky)
  - leuc-
- Black
  - ebon
  - nigricans
- Yellows
  - aur- (golden)
  - chrys- (golden)
  - flav- (yellow)
  - lut- (yellow)
  - auranti- (orange-red)
- Reds
  - rubr-
  - sangui-
  - ruf-
- Blues
  - cyan- (blue)
  - purpur- (purple)
- Silver
  - argyr-
- Brown
  - brunne-
- Green
  - chlor-
- Mixed
  - vari
  - versi

Terminology of processes

Terminology guides us not only to recognition of particular plants and animals but helps us to understand the stages and processes being experienced by the organism. Consider, for example, the process called **mitosis** (mit = thread, -osis = condition or state)—the nuclear changes usually accompanying cell division, which result in each daughter cell receiving identical **chromosomal** (chrom = colored, soma = body or structure) complements. This process of nuclear change is really a continuous process, but biologists have identified recognizable stages or phases that occur as the chromosomal "threads" participate in the process. The names given to the stages, once analyzed, give us clues to what is occurring at that stage.

Prior to mitosis, the cell is said to be in **interphase.** "Inter" implies between (i.e., interval), and the interphase is the stage between cell divisions—that is, the normal metabolic condition of living cells.

As mitosis begins, the nucleus is said to be in **prophase.** "Pro" is a prefix meaning in front of or before; therefore, prophase is the first stage, the beginning stage, which precedes the others.

The second stage of the mitotic process, called **metaphase**, is easy to identify under the microscope because the chromosomes are arranged across the middle portion of the cell. "Meta" implies between or midway. In this stage of mitosis the chromosomes are indeed midway between the "poles" of the cell, and each chromosome is separating, lengthwise, into two identical halves.

During the third stage these halves, or separate sets of chromosomes, move outward from the center area of the cell toward the outer areas or poles. This stage is called **anaphase**, and, as you might guess, one of the meanings of the prefix "ana" is upward or outward.

The final stage, which results in the formation of two new nuclei that are small duplicates of the original, is called **telophase**. "Telo" is a prefix which implies the end or final. Notice that this is different from the prefix "tele," which implies distance.

Thus we have a bifurcate (two-forked) attack on understanding the process of mitosis. If we analyze and understand the meanings of the words which are used to label the stages, we have clues to the processes occurring during each stage. On the other hand, if we understand the process and the sequence of events that occur in the cell, we can often recognize the words that are used to describe the activities taking place.

Health and medical terms

There are many scientific terms that are basically medical terms. You will encounter many of these when you study health or human biology. Again, the ability to analyze the words into their component parts will enable you to understand the meanings and applications of the terms. For example, "cyto-" and "-cyte" are prefix and suffix which are used to denote cell. Thus, **cytology** is the study of cells. Consider the names given to many of the body cell types. **Neurocytes** are nerve cells (neur = nerve). **Osteocytes** are bone cells (ost = bone). **Hematocytes** and **leucocytes** are red and white blood cells, respectively (hem = blood, leuc = white).

The three suffixes "-itis," "-ectomy," and "-otomy" are commonly attached to root words to describe the conditions that exist. Thus appendic*itis* is an infection or inflammation of the appendix; appendec*tomy* refers to the removal of the appendix, and tracheo*tomy* refers to opening the trachea (usually to aid breathing). Each of the suffixes has the meanings implied in the description of the conditions above.

Certain root words are used to describe areas or specific organs of the body. Thus "gastro" refers to the digestive area or, more specifically, the stomach; "hepato" to liver, and "cerebro" to the central nervous system or more specifically, the brain. An unfortunate person who had gastr*itis*, hepat*itis*, and cerebrospinal mening*itis* would be suffering from infections of the stomach, liver, and spinal-cord tissues.

In 1822 the American physician William Beaumont treated Alexis St. Martin, a trapper who had received serious gunshot damage. Both the stomach and body wall were opened by the blast. St. Martin recovered, though the edges of the wounds joined each other, leaving an opening from the outside into St. Martin's stomach. Beaumont and St. Martin cooperated in a series of scientific observations. Could you consider the original wound a *gastrotomy*?

As you meet new words in health and anatomy, use the glossary or a dictionary, not only to find the meaning of the whole word, but also of its component parts. This will add new prefixes, suffixes, and root words to your useful vocabulary.

As you can see, the biologist has a large, rich, and varied vocabulary at his command. Someone has said that the biology student has to learn more new words than the first-year Spanish student! But as you learn even a small part of the language, you will not only be gaining the facility to communicate in this science but you will also expand your recognition and enrich your appreciation of plants and animals in everyday life.

Problems and questions

1. What might these imaginary scientific terms mean?

a. biarthrose b. gymnopoda c. neuroectomy

2. What about these more truly scientific terms?
    - a. *Canis familiaris* b. *protophyte* c. *dermatitis*
    - d. Gastropoda e. Bryozoa f. spermatozoa
    - g. arthritis
3. Look up the scientific name of the silver maple tree and the names of the higher taxonomic ranks to which it belongs. Construct a taxonomic classification scheme for it as in Table 4.
   How does this agree with and differ from the scheme for the red maple?
4. According to taxonomic groupings, which are more closely related, the maple trees and the elm trees or the maple trees and the pine trees?
5. Could an animal with jointed feet, three pairs of legs, and one pair of wings be placed in the family Muscidae?
   Why or why not?
6. According to taxonomic groupings, which are more closely related, the true flies and the fleas, or the true flies (i.e., houseflies) and the gnats?

References and Further Reading

The following books deal with nomenclature and the great biologists and their lives.

1. *International Code of Zoological Nomenclature*. First Edition, 1961. Slightly revised edition, 1964. International Trust for Zoological Nomenclature. 14 Belgrave Square, London, S.W. 1; England.
2. Jaeger, Edmund, C. *Source-Book of Biological Names and Terms*. Third Edition, C.C Thomas, Publisher. Springfield, Illinois. 1972.
3. Johnson, M. L. *A Dictionary of Biology*. Paperback. Penguin Books, Inc. Baltimore, Maryland, 1954.
4. Lanjouw, J., *et al. International Code of Botanical Nomenclature. Adopted by the Tenth International Botanical Congress*. S-H Service Agency. New York. 1966.
5. Mayr, Ernst. *Principles of Systematic Zoology*. McGraw-Hill Book Company, Inc. New York. 1969.
6. Peattie, Donald C. *Green Laurels: The Lives and Achievements of the Great Naturalists*. Simon & Schuster, Inc. New York. 1936.
7. Savory, Theodore. *Naming the Living World*. John Wiley & Sons, Inc. New York. 1963.
8. Simpson, G. G. *Principles of Animal Taxonomy*. Columbia University Press. New York. 1961.

Chemistry

The word chemistry comes from the Middle East; long ago the sacred name for Egypt was "Chemia," which means black and probably referred to the fertile black soil of the Nile valley. In those ancient times almost any kind of change was mysterious, such as the change of wood to ash when it burns, or the transformation of sand into glass. Men who understood how to make some things change were considered to be magicians [at least we might call them that today]. From their mysterious abilities to cause changes the word for the study of change was derived.

The language of chemistry has a long history of pictorial and abbreviated symbols. The early chemists—or alchemists—used pictorial symbols to stand for the chemicals with which they worked. Following are some of these early chemical symbols, many of which turn up here and there even today.

FIGURE 2. Early Chemical Symbols

Lead ♄ Tin ♃ Iron ♂ Gold ☉ Copper ♀ Mercury ☿ Silver ☽

Like biologists, chemists have developed a special nomenclature so that they can be precise when they communicate with each other or describe their work to other scientists. Today the language of chemistry has become a very elegant kind of "shorthand notation" of great clarity and precision. It begins with the names of the elements and symbols for them.

Table 8 lists alphabetically the names and the symbols for the elements. You can see that in most cases the symbol is closely related to the English name of the element, either one capital letter or one capital and one small letter. Where the symbol for an element does not correspond to the English name, it corresponds to the name of the element in some other language. Thus, C = carbon, Ca = calcium, Cd = cadmium, Ce = cerium, Cu [cuprum, Latin] = copper, Au [aurum, Latin] = gold, Fe [ferrum, Latin] = iron, and Na [Natrium, German] = sodium.

Most of the names of elements were determined on rather dry, scientific bases, but the story of the naming of antimony, if true, is a humorous one.

"It is related that an early Christian monk who was also interested in alchemy, discovered a new white powdery compound, which could be separated into a brittle silvery metal not yet known to science. Being a frugal monk, he had the practice of throwing the wastes from his various experiments to the hogs, the care of which was also his assignment in the monastery. Being scientifically observant, he noted that the hogs grew fat and healthy on the residues of his experiments which contained the new white powder. A certain humanistic concern for the welfare of his fellow monks, who were lean and thin from the rather frugal diet of the monastery, prompted him to sprinkle small portions of the white powder on the thin gruel of his fellows. He was at first pleased to note a definite improvement in their general health and well-being. Shortly after the new addition to their diet, however, most of the monks became sick, suffering severe gastrointestinal disorders of great magnitude. He reluctantly decided that his new compound was not good for monks and named its silvery metal component Antimony (anti = against, mony from the Latin for monk). It had indeed worked against the best interests of his fellow monks." (Anon.)

Whether the story is true, I shall leave to the reader to decide. A bit of damaging evidence to consider is the fact that the chemical symbol for antimony is Sb from the word stibium, which doesn't seem to pertain to the word monk.

Interesting projects can be built around research into the derivation of the names of the elements. Some references are provided at the end of the chapter.

There are some 103 known and named chemical elements, with at least two more that have been claimed to have been produced. Fortunately for our purposes in studying chemistry, we need not know all the 103 names and symbols. There are only about twenty elements that we need to keep in mind at the start. These are the elements which appear in the compounds that compose most of the common substances of concern in introductory chemistry courses and in our daily life.

Each element is composed of atoms. For a particular element, the atoms of that element are all alike (except for slight variations in mass which will be discussed later). Hydrogen has only hydrogen atoms; and the symbol H denotes hydrogen. In

TABLE 8. The Chemical Elements

Element	Symbol	Atomic Number	Atomic Mass	Element	Symbol	Atomic Number	Atomic Mass
Actinium	Ac	89	(227)	Mercury	Hg	80	200.6
Aluminum	Al	13	27.0	Molybdenum	Mo	42	95.9
Americium	Am	95	(243)	Neodymium	Nd	60	144.2
Antimony	Sb	51	121.8	Neon	Ne	10	20.2
Argon	Ar	18	39.9	Neptunium	Np	93	237.0
Arsenic	As	33	74.9	Nickel	Ni	28	58.7
Astatine	At	85	(210)	Niobium	Nb	41	92.9
Barium	Ba	56	137.3	Nitrogen	N	7	14.0
Berkelium	Bk	97	(245)	Nobelium	No	102	(254)
Beryllium	Be	4	9.01	Osmium	Os	76	190.2
Bismuth	Bi	83	209.0	Oxygen	O	8	16.0
Boron	B	5	10.8	Palladium	Pd	46	106.4
Bromine	Br	35	79.9	Phosphorus	P	15	31.0
Cadmium	Cd	48	112.4	Platinum	Pt	78	195.1
Calcium	Ca	20	40.1	Plutonium	Pu	94	(242)
Californium	Cf	98	(251)	Polonium	Po	84	(210)
Carbon	C	6	12.0	Potassium	K	19	39.1
Cerium	Ce	58	140.1	Praseodymium	Pr	59	140.9
Cesium	Cs	55	132.9	Promethium	Pm	61	(145)
Chlorine	Cl	17	35.5	Protactinium	Pa	91	231.0
Chromium	Cr	24	52.0	Radium	Ra	88	226.0
Cobalt	Co	27	58.9	Radon	Rn	86	(222)
Copper	Cu	29	63.5	Rhenium	Re	75	186.2
Curium	Cm	96	(245)	Rhodium	Rh	45	102.9
Dysprosium	Dy	66	162.5	Rubidium	Rb	37	85.5
Einsteinium	Es	99	(254)	Ruthenium	Ru	44	101.1
Erbium	Er	68	167.3	Samarium	Sm	62	150.4
Europium	Eu	63	152.0	Scandium	Sc	21	45.0
Fermium	Fm	100	(254)	Selenium	Se	34	79.0
Fluorine	F	9	19.0	Silicon	Si	14	28.1
Francium	Fr	87	(223)	Silver	Ag	47	107.9
Gadolinium	Gd	64	157.3	Sodium	Na	11	23.0
Gallium	Ga	31	69.7	Strontium	Sr	38	87.6
Germanium	Ge	32	72.6	Sulfur	S	16	32.1
Gold	Au	79	197.0	Tantalum	Ta	73	180.9
Hafnium	Hf	72	178.5	Technetium	Tc	43	98.9
Helium	He	2	4.00	Tellurium	Te	52	127.6
Holmium	Ho	67	164.9	Terbium	Tb	65	158.9
Hydrogen	H	1	1.008	Thallium	Tl	81	204.4
Indium	In	49	114.8	Thorium	Th	90	232.0
Iodine	I	53	126.9	Thulium	Tm	69	168.9
Iridium	Ir	77	192.2	Tin	Sn	50	118.7
Iron	Fe	26	55.8	Titanium	Ti	22	47.9
Krypton	Kr	36	83.8	Tungsten	W	74	183.8
Lanthanum	La	57	138.9	Uranium	U	92	238.0
Lawrencium	Lr	103	(257)	Vanadium	V	23	50.9
Lead	Pb	82	207.2	Xenon	Xe	54	131.3
Lithium	Li	3	6.94	Ytterbium	Yb	70	173.0
Lutetium	Lu	71	175.0	Yttrium	Y	39	88.9
Magnesium	Mg	12	24.3	Zinc	Zn	30	65.4
Manganese	Mn	25	54.9	Zirconium	Zr	40	91.2
Mendelevium	Md	101	(256)				

Numbers in parentheses give the mass number of the most stable isotope.

From Huheey, James. *Diversity and Periodicity, Interdisciplinary Approaches to Chemistry.* Harper & Row, Publishers, New York 1973. Page 111 a symbol H can represent one atom of hydrogen. Compounds are composed of two or more atoms of different elements. Water is composed of atoms of hydrogen (two) and oxygen (one). The formula for water is H_2O. It tells us that there are two hydrogen atoms (indicated by the subscript 2) combined with one oxygen atom. (We omit the subscript for one since the symbol alone indicates one atom.) We say that these atoms form a **molecule** (mole = mass; cule = little) of water. A molecule, thus, is composed of two or more atoms that may be either alike or different. In air we may have pairs of oxygen atoms in molecules, O_2, and carbon dioxide molecules, CO_2, which have one atom of carbon and two of oxygen.

The periodic table

What Linnaeus did for biology, the Russian Dmitri Mendeleev did for chemistry. In the 1860's he organized the known elements into a table and formulated a periodic law: "The properties of the elements and their compounds are periodic functions of the atomic weights of the elements." That is, certain characteristics occur at regular or predictable intervals in the sequence of elements. In Mendeleev's table the elements having similar properties fall in the same column or near each other. The periodic table is shown on page 27. Generally speaking, the elements in any vertical (up and down) column, called groups, are more or less similar. For example, you will find copper, silver, and gold, (Cu, Ag, and Au) in the same vertical column or group. These are the elements that have traditionally been used for coins. Sometimes the elements in a column are similar enough to have the same family name. For example, fluorine, chlorine, bromine, iodine, and astatine (F, Cl, Br, I, and At) are called the **halogens** (hal = salt; gen = form) or salt-formers. The best known salt is ordinary table salt, sodium chloride with the formula NaCl.

Each of the vertical columns is identified by a roman numeral or a roman numeral and a letter. This is the "group number." The group number for the halogens is VIIA. Fluorine, chlorine, bromine, etc. are sometimes called "Group VIIA elements" instead of "halogens."

The Group VIA elements—oxygen, sulfur, selenium, tellurium, and polonium—are sometimes called **chalcogens,** (chal = earthy; gen = form). In the earth's crust, many of the other ele-

PERIODIC TABLE OF THE ELEMENTS

200.6 — atomic mass
Hg — symbol
Mercury — name
80 — atomic number

IA	IIA	IIIB	IVB	VB	VIB	VIIB	← VIIIB →			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1.008 **H** Hydrogen 1																	4.00 **He** Helium 2
6.94 **Li** Lithium 3	9.01 **Be** Beryllium 4											10.8 **B** Boron 5	12.0 **C** Carbon 6	14.0 **N** Nitrogen 7	16.0 **O** Oxygen 8	19.0 **F** Fluorine 9	20.2 **Ne** Neon 10
23.0 **Na** Sodium 11	24.3 **Mg** Magnesium 12											27.0 **Al** Aluminum 13	28.1 **Si** Silicon 14	31.0 **P** Phosphorus 15	32.1 **S** Sulfur 16	35.5 **Cl** Chlorine 17	39.9 **Ar** Argon 18
39.1 **K** Potassium 19	40.1 **Ca** Calcium 20	45.0 **Sc** Scandium 21	47.9 **Ti** Titanium 22	50.9 **V** Vanadium 23	52.0 **Cr** Chromium 24	54.9 **Mn** Manganese 25	55.8 **Fe** Iron 26	58.9 **Co** Cobalt 27	58.7 **Ni** Nickel 28	63.5 **Cu** Copper 29	65.4 **Zn** Zinc 30	69.7 **Ga** Gallium 31	72.6 **Ge** Germanium 32	74.9 **As** Arsenic 33	79.0 **Se** Selenium 34	79.9 **Br** Bromine 35	83.8 **Kr** Krypton 36
85.5 **Rb** Rubidium 37	87.6 **Sr** Strontium 38	88.9 **Y** Yttrium 39	91.2 **Zr** Zirconium 40	92.9 **Nb** Niobium 41	95.9 **Mo** Molybdenum 42	98.9 **Tc** Technetium 43	101.1 **Ru** Ruthenium 44	102.9 **Rh** Rhodium 45	106.4 **Pd** Palladium 46	107.9 **Ag** Silver 47	112.4 **Cd** Cadmium 48	114.8 **In** Indium 49	118.7 **Sn** Tin 50	121.8 **Sb** Antimony 51	127.6 **Te** Tellurium 52	126.9 **I** Iodine 53	131.3 **Xe** Xenon 54
132.9 **Cs** Cesium 55	137.3 **Ba** Barium 56	138.9 **La*** Lanthanum 57	178.5 **Hf** Hafnium 72	180.9 **Ta** Tantalum 73	183.8 **W** Tungsten 74	186.2 **Re** Rhenium 75	190.2 **Os** Osmium 76	192.2 **Ir** Iridium 77	195.1 **Pt** Platinum 78	197.0 **Au** Gold 79	200.6 **Hg** Mercury 80	204.4 **Tl** Thallium 81	207.2 **Pb** Lead 82	209.0 **Bi** Bismuth 83	(210) **Po** Polonium 84	(210) **At** Astatine 85	(222) **Rn** Radon 86
(223) **Fr** Francium 87	226.0 **Ra** Radium 88	(227) **Ac†** Actinium 89	**#** 104	**#** 105													

*	140.1 **Ce** Cerium 58	140.9 **Pr** Praseodymium 59	144.2 **Nd** Neodymium 60	(145) **Pm** Promethium 61	150.4 **Sm** Samarium 62	152.0 **Eu** Europium 63	157.3 **Gd** Gadolinium 64	158.9 **Tb** Terbium 65	162.5 **Dy** Dysprosium 66	164.9 **Ho** Holmium 67	167.3 **Er** Erbium 68	168.9 **Tm** Thulium 69	173.0 **Yb** Ytterbium 70	175.0 **Lu** Lutetium 71
†	232.0 **Th** Thorium 90	231.0 **Pa** Protactinium 91	238.0 **U** Uranium 92	237.0 **Np** Neptunium 93	(242) **Pu** Plutonium 94	(243) **Am** Americium 95	(245) **Cm** Curium 96	(245) **Bk** Berkelium 97	(251) **Cf** Californium 98	(254) **Es** Einsteinium 99	(254) **Fm** Fermium 100	(256) **Md** Mendelevium 101	(254) **No** Nobelium 102	(257) **Lr** Lawrencium 103

The most stable known isotopes are shown in parentheses

The discovery of elements 104 and 105 has been claimed by both American and Russian scientists The Americans have suggested the names *rutherfordium* and *hahnium*, the Russians have suggested the names *kurchatovium* and *nielsbohrium*

From Huheey, James. *Diversity and Periodicity, Interdisciplinary Approaches to Chemistry.* Harper & Row, Publishers, New York 1973. Page 29 ments are found combined with one of the chalcogens, such as iron oxide, or iron ore; silicon dioxide, or sand or quartz. The formulas are Fe_2O_3 for iron oxide, and SiO_2 for silicon dioxide.

The Group IA elements are called alkali metals, and the Group IIA elements are called alkaline earths. These names come from the fact that some of the compounds of the Group IA and IIA elements form alkaline solutions in water. An alkaline solution feels slippery when rubbed between the finger and thumb because the solution will react with the fatty tissue just under your skin, causing a chemical change producing soap and glycerine from the fat. Soapy solutions feel slippery.

The periodic table also lists the atomic mass of the elements, shown above the symbol for the element in the table. A glance at the table shows the comparative mass of the elements. Look at several elements that you know—for example, aluminum, tin, and iron. As you would expect, aluminum is the least massive, with an atomic mass of 27.0. You can see that an atom of tin is more than four times as massive as an atom of aluminum. An iron atom is close to being twice as massive as an atom of aluminum.

For most of the elements, atoms may vary slightly in mass. For example, there are 9 slightly different tin atoms, identical for all practical purposes except for their slightly different masses. These atoms are called **isotopes** of the element (iso = equal; topos = place).

Notice also that for each element in the periodic table, there is an atomic number, in order, 1, 2, 3, and so on beginning with hydrogen, H, atomic number 1; then helium, He, atomic number 2; and so on. The atomic number is the number of protons in the nucleus of each atom of the element. A **proton** (protos = first) is a so-called heavy particle with one positive charge. For example, the atomic number of iron is 26, so you can tell that for each isotope of iron, no matter what its mass, there are 26 protons in the nucleus of the atom.

The study of change

As we said before, chemists study change to learn why and how things change. (Why do the leaves change color in the fall; why does iron rust?) By intelligent and imaginative guesses about the reasons for change, man learns about the material which changes. He can then apply this knowledge in a myriad ways—some beneficial, some foolish or even harmful. Perhaps if we knew more about changes, we could apply our knowledge with more wisdom.

Yes, chemistry is the study of change—but not all kinds of change, of course. Chemistry is not concerned with a change of opinion, or a change of time (from daylight saving to standard), or a change of position. Chemistry is concerned with changes in substances or matter. The substance, wood, becomes another substance, ash (and smoke and carbon dioxide and water vapor), when it burns. Burning is a chemical change. Iron changes to iron rust. Rusting is a chemical change because the substance, iron (an element), is different from the substance iron rust (a compound).

In chemical changes or reactions, new arrangements and new combinations of atoms form; the substance looks different; it behaves differently; it has different properties; it must have a different name. Chemists are still developing their theories as to how these changes or reactions occur and are constantly trying to discover more about how and under what circumstances atoms combine to form compounds.

Certain components of the atoms themselves influence the manner in which atoms join (or bond) with other atoms. Each atom has protons, which we have already mentioned, **neutrons** (neutr = neither; not plus, not minus), and **electrons** (electr = electricity). The electrons carry a negative charge, which is balanced by the positive charge of the protons. An atom in its normal state, therefore, has a balanced electric charge. So long as it hasn't lost or gained any electrons, it is neutral electrically.

MAJOR COMPONENTS OF AN ATOM

nucleus	electrons
protons	−charge
+ charge	number = number of protons, in a neutral atom
number = atomic number	
neutron	
no charge	

The electrons are presently thought to be in "a region outside" the nucleus.

In chemical reactions, atoms may capture electrons from other atoms, or they may share the electrons of a nearby atom. Obviously an atom which has acquired extra electrons (with their negative charges) will then have a negative charge. An atom which has lost electrons will have a positive charge. These atoms no longer have a balanced electric charge. Combinations of atoms, as well as individual atoms, can gain or lose electric charges. We call atoms or groups of atoms with unbalanced electric charges, **ions** (ienai = to go; in solutions, ions move about).

An ion, then, is an atom or group of atoms with a positive or negative electric charge. Some ions are two or three or more atoms combined, and the whole assembly has a positive or negative charge. If the ion has only one atom, it is called a **monatomic** (mono = one; atom), ion; if it has more than one atom, it is called a **polyatomic** (poly = many; atom), ion. Positively charged ions are called cations (pronounced căt' ī ons), and negatively charged ions are called anions (ăn' ī ons).

Some well-known monatomic ions are the Na^+ and Cl^- present in a solution of NaCl or the Cu^{2+} ion in solution in the refining of copper. Two well-known polyatomic ions are the ammonium ion in household ammonia water and the acetate ion in vinegar.

Ammonium ions, NH_4^+, are each composed of one atom of nitrogen and four of hydrogen, and the assembly has one net positive charge. Acetate ions, written CH_3COO^-, are composed of two carbon atoms, three hydrogen, and two oxygen atoms, and have one net negative charge.

Electronegativity

The tendency of an atom to lose or gain electrons (and consequently electric charges) has a great deal to do both with chemical changes and with the formation and naming of compounds. If we look back at the periodic table, we will find an interesting pattern of electronegativity of the elements. You might not guess it from the word-attack that you might make, but electronegativity means the attraction an atom has for an electron.

Fluorine, in the upper right corner (not counting the noble gases, Group VIIIA) is the most electronegative element. Francium in the lower left corner, is the least electronegative element. As you proceed from francium up, or to the right, or at an angle both up and to the right, the electronegativity of the elements increases. That is, the elements tend to gain electrons and to become negative ions, compared to those to the left, or below.

Consider what would happen between fluorine atoms and cesium atoms. Comparatively, cesium doesn't really have much tendency to attract electrons, and fluorine has a big tendency to attract electrons. A fluorine atom may take (practically without sharing it at all) an electron from cesium. This will happen with all of the atoms present, if there is an equal number of fluorine and cesium atoms. Fluorine atoms have 9 electrons which are balanced by the charge on the 9 protons of the atom. If the fluorine atom takes one electron from cesium, then the fluorine atom becomes a negative ion (fluorine anion), and the cesium atom also becomes a positive ion (cesium cation).

This reaction is a chemical reaction: a change in substance. What were atoms of cesium and fluorine are now a mixture of ions of cesium and fluorine, in a compound called cesium fluoride, CsF. When this chemical change takes place, heat energy is evolved. We can describe this reaction in symbols with an equation:

$$\mathrm{Cs} + \mathrm{F} \rightarrow \mathrm{CsF} + \text{heat}$$

The first + sign, on the left, signifies "and"; the arrow signifies "produce"; CsF signifies "cesium fluoride"; the other + sign means "and"; and you already know what heat is. There are other ways to read the symbols, as you might have guessed. Here are three ways:

1. Cesium and fluorine produce cesium fluoride and heat.
2. Cesium reacts with fluorine to produce cesium fluoride and heat.
3.

One mole of cesium atoms	reacts with	one mole of fluorine atoms	to form	one mole of cesium fluoride	and heat

To a chemist the word mole (used in the statement above) signifies the amount of substance; specifically, the mass of 6.02×10^{23} atoms. (See also the definition of a mole on page 137.) The number 6.02×10^{23} is called Avogadro's number after Amedeo Avogadro, an Italian scientist who first suggested that atoms and molecules, though too small to see, could somehow be counted. It was later determined that 12 grams of carbon (the atomic mass of carbon) contains 6.02×10^{23} atoms of carbon. Today we recognize that this number of the atoms of any element has a mass equal to the atomic mass of the element.

The mole of cesium atoms represented by Cs in the equation, signifies 6.02×10^{23} atoms of cesium, or its atomic mass of 140.1 grams. Similarly the mole of F in the equation signifies 19.0 grams of fluorine atoms (6.02×10^{23} fluorine atoms have a mass of 19.0 grams, the atomic mass of fluorine).

One other very useful grouping that turns up on the periodic table is that the nonmetals are in the upper right of the table, and the metals are in the remaining part of the table. Since neighbors on the table have similar properties, we can deduce characteristics of many of the elements from our knowledge of the characteristics of another element in the same group in the table. We have already mentioned the similarities of copper, silver, and gold as **malleable** (malle = hammer; can be hammered) metals used in coins and jewelry. Helium, neon, argon, krypton, and xenon all show little tendency to react chemically and have long been called the "noble" gases. Sodium and potassium, neighbors at the other side of the table, are both extremely active chemically and must be handled with great care.

So far we have learned about a few elements and a few compounds, the periodic table and electronegativity, and several related ideas, such as that of the mole as a special unit of amount of substance, and the idea that atoms can attract electrons from or share electrons with other atoms. Let us look at some of the formulas before continuing: The correct formula for cesium fluoride is CsF, not FCs. The correct formula for iron oxide is Fe_2O_3, not O_3Fe_2. How do we know which element to mention first in the formula? To figure out the correct formula, if we know everything else we need to know, such as 2 iron atoms together with 3 oxygen atoms, we use our knowledge of electronegativity. After we find O and Fe in the periodic table, notice that O is above and to the right of Fe. From this we can tell that O atoms are more electronegative than are the Fe atoms. We almost always put the more electronegative of the two elements on the right and the less electronegative on the left in the formula. For cesium fluoride, then, it would be CsF, because fluorine is more electronegative than cesium. Notice that we followed the same rule for carbon dioxide CO_2, and for water H_2O. (The ammonium ion, NH_4^+, is one of the few exceptions; some years ago a few chemists tried to get other chemists to follow the rule and write H_4N^+, but it didn't catch on.)

Oxidation state

Another characteristic of elements which affects their reacting with other elements is called their oxidation state. In an oversimplified definition, oxidation state is the combining capacity of the atom. Many of these oxidation states can be "read" from the periodic table, as follows:

1^+	2^+	3^+	2^-	1^-	0
IA	IIA	IIIA	VIA	VIIA	VIIIA

However, some elements will have more than one oxidation state as we shall see shortly.

We make use of the oxidation state in figuring out formulas and also in the names of compounds. Notice Table 9, **a** and **b.** Elements listed in **a** form compounds with elements listed in **b.** Lithium, for example, will form a compound with bromine. The name of the compound is lithium bromide. To figure out the formula, notice the 1^+ oxidation state for lithium and the 1^- oxidation state for bromine. Now, in the formula for molecules of a compound the sum of the oxidation states must equal zero. So, one 1^+ (for lithium) and one 1^- (for bromine) equal zero. Thus, the formula is LiBr. Try another combination for cesium ($1+$ oxidation state) and oxygen (2^- oxidation state). To add to zero we need 2 cesiums (two 1^+'s) and 1 oxygen (2^-); so the formula is Cs_2O. The name is cesium oxide. You would think that the name would be cesium oxygen, but "oxygen" is changed to "oxide" because it sounds better.

Once more, for aluminum and sulfur. On the periodic table we see that aluminum is farther to the left than sulfur; consequently Al will appear first in the name of the compound. The oxidation state for aluminum is 3^+ and for sulfur is 2^-. To get these to equal zero we can multiply the aluminum by 2 (two 3^+'s, for 6^+) and multiply the sulfur by 3 (three 2^-'s, for 6^-). Thus the formula is Al_2S_3; the name is aluminum sulfide. Here, too, we use "-ide" rather than the full name of the element sulfur.

Notice that in this scheme, it comes out that we put the element with the negative oxidation state on the right in the formula. As we become familiar with oxidation states, we can use this information instead of referring to the periodic table when we are writing formulas.

Table 9. Some Elements and Their Oxidation States

a. Fixed, positive oxidation state

Symbol	Name	Oxidation State
H	hydrogen	1+
Li	lithium	1+
Na	sodium	1+
K	potassium	1+
Rb	rubidium	1+
Cs	cesium	1+
Be	beryllium	2+
Mg	magnesium	2+
Ca	calcium	2+
Sr	strontium	2+
Ba	barium	2+
B	boron	3+
Al	aluminum	3+
Ga	gallium	3+

b. Fixed, negative oxidation state

Symbol	Name	Oxidation State	Name in Compounds
F	fluorine	1-	fluoride
Cl	chlorine	1-	chloride
Br	bromine	1-	bromide
I	iodine	1-	iodide
O	oxygen	2-	oxide
S	sulfur	2-	sulfide

c. Variable, positive, oxidation states

Symbol	Name	Oxidation States
Cu	copper	1+, 2+
Hg	mercury	1+, 2+
Fe	iron	2+, 3+
Pb	lead	2+, 4+
Ti	titanium	3+, 4+
Cr	chromium	3+, 6+

Next for more compounds we will use **a** and **c** in Table 9. That is, some elements have changeable oxidation states; a few of these are listed in the table. Let us try the compounds involving copper and oxygen. We can pick either the 1^+ or the 2^+ oxidation state for copper. Pick the 1^+. Since the oxidation state for oxygen is 2^-, and we must get a zero sum, we need two copper atoms for each oxygen atom (two 1^+'s for 2^+). The formula is Cu_2O. We can call this compound copper oxide, but we need to be more specific about the oxidation state of the copper. We want to know which oxidation state was involved. In the nomenclature for such compounds we follow a system proposed by a British chemist Alfred E. Stock. In this widely used system we indicate the oxidation state by a roman numeral immediately after the name of the metallic or least electronegative element. The name of Cu_2O then becomes copper(I) oxide. If we use the 2^+ oxidation state for copper and 2^- for oxygen, the formula then becomes CuO and the name is copper(II) oxide. These two compounds of copper and oxygen are quite different. One is reddish colored, one is jet black.

An older naming scheme used "ic and ous" endings. You can still find an old bottle of copper(II) oxide with the label name "cupric oxide," or an old bottle of iron(III) oxide with its label "ferric oxide." In fact, this is why the old scheme was discarded; "ic" for copper meant the 2^+ oxidation state, but it meant the 3^+ oxidation state for iron. This confused even the chemists. The Stock system is much better and is preferred by today's chemists.

Next, we can proceed to the polyatomic cations. There is only one polyatomic cation of interest to us, so it has the whole of Table 10 (such as it is) all to itself. The rule used is the same.

Table 10. One Cation Composed of More Than One Atom

Formula	Name (in compounds)	Oxidation State
NH_4^+	ammonium	1^+

Use Table 10 and Table 9,**b** (or you could use Table 10 and Table 11, jumping ahead of our story a little). Try ammomium ion and bromine. We get NH_4Br; a 1^+ and a 1^-, one of each. Try a polyatomic cation and a polyatomic anion, Tables 10 and 11, ammonium ion and sulfate ion. The oxidation state for the ammonium ion is 1^+ (so we need two) because the oxidation state for the sulfate ion is 2^-. The formula is 2 ammoniums and 1 sulfate.

Table 11. Some Anions Composed of More Than One Atom

Formula	Name (in compounds)	Oxidation State
OH^-	hydroxide	1^-
CN^-	cyanide	1^-
$C_2H_3O_2^-$	acetate	1^-
ClO_3^-	chlorate	1^-
ClO_4^-	perchlorate	1^-
NO_2^-	nitrite	1^-
NO_3^-	nitrate	1^-
HCO_3^-	hydrogen carbonate	1^-
SO_3^{2-}	sulfite	2^-
SO_4^{2-}	sulfate	2^-
CO_3^{2-}	carbonate	2^-
CrO_4^{2-}	chromate	2^-
$Cr_2O_7^{2-}$	dichromate	2^-
PO_4^{3-}	phosphate	3^-

We place a parenthesis around the ammonium ion and write the "2" subscript outside the parenthesis: $(NH_4)^2SO_4$. The name of this compound is ammonium sulfate.

We have been speaking here of the compounds formed by the attraction of electrons—the combinations of ions—in what we call ionic bonding. Generally, this type of bonding occurs when metals combine with nonmetals. When bonds form because of *shared* electrons, the process is called **covalent** bonding (co = with; valent =combination). Covalent bonds occur when nonmetals combine with nonmetals; or when the electronegativity of the two atoms is not too different. The bonded atoms seem to share certain electrons.

Rules for naming the covalent compounds are the same as those for naming the ionic compounds. The element at the left in the periodic table will be named first: NCl_3, nitrogen trichloride, for example.

Classes of compounds

Most of the compounds mentioned so far are called inorganic compounds. There is another very large class of compounds called organic compounds. Actually, for each inorganic compound known to man, there are probably more than one thousand organic compounds known. We say "probably," because no one has ever taken the trouble to count the millions of known compounds. More are being discovered and synthesized every day.

A good definition of organic compounds is not possible, if we mean a definition all chemists would agree with. Most chemists would more or less agree that all organic compounds contain carbon atoms, usually more than one carbon atom per molecule, and mostly those two or more carbon atoms would be attached to each other, and to still different atoms.

All organic compounds contain carbon atoms, but not all that contain carbon atoms are organic. Sodium carbonate, Na_2CO_3, is not an organic compound; and some chemists would say neither is potassium acetate, with the formula $KC_2H_3O_2$. Organic compounds include compounds of biological interest, such as fats, proteins, carbohydrates, vitamins, hormones, DNA, RNA, most drugs, as well as nonbiological materials such as plastics, synthetic polymers (Nylon, Teflon), etc. Once it was thought that organic compounds could only be produced by living tissue (plant or animal), but this is no longer accepted.

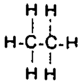
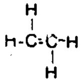
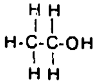
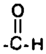
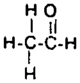
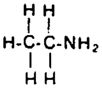
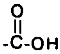
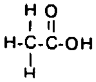
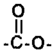
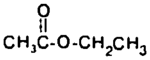
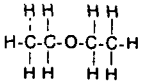
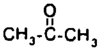
The structural clues and structural formulas for the various families of organic compounds are shown in Table 12. The first three are hydrocarbons (hydrogen + carbon).

Organic compounds include gasoline, and we can start our short excursion in the naming of organic compounds with gasoline. Ordinary unleaded gasoline contains heptane, octane, nonane, decane, and other -anes. You can probably guess, from Table 13, that heptane has 7 carbon atoms per molecule, octane has 8 carbon atoms, nonane, 9 carbon atoms, and decane, 10.

The ending "-ane" means count the carbons, multiply by two, and add two more to get the number of hydrogens. For example, what is the formula for octane? Count the carbons: 8 (octo). Double 8 to get 16 and add 2 to get 18 for the hydrogen. The formula for octane is C_8H_{18}. What is the formula for methane? Easy: One carbon; twice one is 2 plus 2 more is 4 for hydrogen; CH_4 is the formula for methane.

We can write a general formula letting *n* be any number. For the alkane family the general formula then is C_nH_{2n+2} By applying this general formula for alkanes—C_nH_{2n+2}—we can write the chemical formulas. If we know the chemical formula, we can name most of the compounds—all of them if we refer to the international systematic nomenclature adopted by the International Union of Pure and Applied Chemistry.

TABLE 12: Organic Families

Type of Compound	Structural Clue	Example of Structural Formula	General Formula	Chemical Formula Name
alkane	-C-C-	 $\mathrm{H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H}$	C_nH_{2n+2}	C_2H_6 ethane[a]
alkene	-C=C-	 $\mathrm{H-\overset{H}{C}=\underset{H}{C}-H}$	C_nH_{2n}	C_2H_4 ethene[a] (ethylene, commonly)
alkyne	-C≡C-	H-C≡C-H	C_nH_{2n-2}	C_2H_2 ethyne[a] (acetylene, commonly)
alcohol (alkanols)	-OH	 $\mathrm{H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-OH}$	$C_nH_{2n+1}+OH$	C_2H_5OH ethanol[a] (ethyl alcohol, commonly)
aldehyde	 $\mathrm{-\overset{O}{\overset{\|}{C}}-H}$	 $\mathrm{H-\underset{H}{\overset{H}{C}}-\overset{O}{\overset{\|}{C}}-H}$		C_2H_4O ethanal[a] (acetaldehyde, commonly)
amine	$-NH_2$	 $\mathrm{H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-NH_2}$		$C_2H_5NH_2$ ethanamine (ethylamine, commonly)
carboxylic acid	 $\mathrm{-\overset{O}{\overset{\|}{C}}-OH}$	 $\mathrm{H-\underset{H}{\overset{H}{C}}-\overset{O}{\overset{\|}{C}}-OH}$		CH_3COOH ethanoic acid (acetic acid, commonly)
ester	 $\mathrm{-\overset{O}{\overset{\|}{C}}-O-}$	 $\mathrm{CH_3\overset{O}{\overset{\|}{C}}-O-CH_2CH_3}$		$CH_3COOC_2H_5$ ethyl acetate[a]
ether	-O-	 $\mathrm{H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-O-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H}$		$(C_2H_5)_2O$ diethyl ether (ethyl ether, commonly)
ketone	 $\mathrm{-\overset{O}{\overset{\|}{C}}-}$	 $\mathrm{CH_3-\overset{O}{\overset{\|}{C}}-CH_3}$		$(CH_3)_2CO$ dimethyl ketone or 2-propanone[a] (acetone, commonly)

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[a] International Union of Pure and Applied Chemistry

TABLE 13. Carbon Atom Counting, Organic Compounds

Counting prefix	Number
Meth-	1
Eth-	2
Prop-	3
But-	4
Pent-	5
Hex-	6
Hept-	7
Oct-	8
Non-	9
Dec-	10

The ending "-anol" (for the alkanol or alcohol family) means count the carbons; double the number and add one for the number of hydrogens; then add an OH to finish it. The general formula in which n is any number is CnH_{2n+1} OH. Try ethanol. Eth- means 2 carbons. Double is 4 plus 1 makes 5 for the hydrogen; and add the OH. The formula for ethanol is C_2H_5OH. Ethanol is the intoxicating substance present in beer, wine, and liquors.

How about methanol? Meth- is one carbon; twice, plus 1 gives 3 for the hydrogen; remember the OH; CH_3OH is the formula for methanol. The common name for methanol is wood alcohol because when wood is heated, especially in the absence of air, so it won't burn, one of the resulting liquids is methanol. Methanol is also an intoxicating, and very poisonous, liquid. A few drops cause blindness, a few more cause death. It was formerly used as an antifreeze.

Rules for the naming of compounds have been developed and agreed upon by chemists throughout the world as the result of the work of international committees on chemical nomenclature. [1,4-6] All newly discovered or described compounds are named according to these rules, and many of the compounds named prior to the establishment of the rules have been renamed. One should keep in mind, however, that there are still many commonly used names that do not follow the rules and that there are some exceptions to the general rules. The references list nomenclature rules of the International Union of Pure and Applied Chemistry and of the American Chemical Society.

Solutions

Chemists often work with special mixtures called **solutions** (solvare = loosen). Every solution has at least two components, a solute and a solvent. The solvent may be water, and the solute may be sugar, or salt. Generally speaking, we call the substance present in largest amount the solvent and the substance present in least amount the solute. If we dissolved both sugar and salt in a large amount of water we would have a solution containing two solutes (the sugar and the salt) and one solvent (the water). Try this with lemonade, stir in a *little* salt; it will taste sweeter! (This works for grapefruit and apple pie, too.)

All true solutions are **homogeneous** (homo = same; gen = form). For example consider coffee; is it a solution? If we examine coffee closely, we would note that it is slightly cloudy, not clear. In coffee there are very tiny solid particles, suspended in the liquid. Coffee is **heterogeneous** (hetero = different; gen = form), not homogeneous; coffee is not a true solution.

Concentration means how much of one thing we have mixed in with one or more other things. For example, if we think of people at a dance, where everyone has a partner, the concentration of boys would be 50% and the concentration of girls would be 50%. No matter what the total number of people, half would be boys and the other half girls.

When chemists use the idea of concentration, they find it useful to modify their thinking a little. That is, they express concentration as how much of one thing is dissolved in a special amount, not just any amount, of solution.

They may express concentration in terms of the mass of the solute per unit mass of the solvent, or in percentage weights, or in the number of moles of solute per liter of solution. Concentrations of the solution affect certain characteristics of the solution, such as its freezing or boiling point. A very concentrated solution of salt, for example, freezes at a lower temperature than a slightly concentrated (dilute) solution.

We have touched on only a few of the many changes that occur as the chemical elements react, combine, recombine, in their never-ending changes. No wonder chemists find this such a fascinating field of study.

Problems and questions

1. Describe another kind of chemical change, in addition to wood burning or the rusting of iron.
2. The formula for baking soda is $NaHCO_3$. What is the meaning of the subscript below and to the right of the "O"? Why are there no subscripts for the other three symbols?
3. Write a definition for atomic mass and a definition for atomic number; be sure that your definitions show that these two terms are different.
4. Tell what you think the periodic table is; imagine that your answer is part of a letter you are writing to a friend who has asked about things you are learning in chemistry.
5. In a letter to the same, or another friend, how would you describe a chemical equation?
6. Use Tables 9,**a** and 9,**b** to work out the formulas and the names of compounds formed with the following pairs of elements (if no compound is possible, indicate that conclusion) (a) strontium and oxygen; (b) aluminum and bromine; (c) sodium and fluorine; (d) gallium and sulfur.
7. Use Tables 9,**b** and 9,**c** to work out the formulas and the names of all possible compounds formed with the following pairs of elements (use the Stock system for the names): (a) coper and sulfur; (b) chromium and iodine; (c) titanium and oxygen.
8. Use Tables 9,**c**, 10, and 11 to work out the formulas and names of at least six different compounds.
9. Write the formulas for heptanol and for propane.

References and Further Reading

1. Association for Science Education. *Chemical Nomenclature, Symbols and Terminology*. College Lane, Hatfield, Herts., England. 1972.
2. Benfey, O.T. *The Names and Structures of Organic Compounds*. John Wiley, New York. 1966, A programmed text.
3. Cahn, R.S. *An Introduction to Chemical Nomenclature*. Third edition. Plenum Publishing Corporation, New York. 1968.
4. Dinga, G.P. "The Elements and the Derivation of Their Names and Symbols." *Chemistry* 41 (2): 20-22; 1968.

5. IUPAC (International Union of Pure and Applied Chemistry). "Nomenclature of Inorganic Chemistry," *Journal of the American Chemical Society* 82:5523; 1960. [1]

6. IUPAC (International Union of Pure and Applied Chemistry). "Nomenclature of Organic Chemistry, Section C-Characteristic Groups." *Pure and Applied Chemistry* 11 (1-2): 1-260; 1965. [1]

7. IUPAC (International Union of Pure Organic Chemistry). "Manual of Symbols and Terminology for Physicochemical Quantities and Units." Pure and Applied Chemistry 21 (1): 1-44; 1970. [1]

8. Loening. K.L. "International Cooperation on Scientific Nomenclature." *Journal of Chemical Documentation* 10: 231-6; 1970.

9. Quagliano. J.V.. and L.M. Vallarino. *Chemistry*. Third Edition. Chapters 4 and 5. "Symbols. Formulas. Equations. and Calculations" and "Valence. Oxidation Number. and Nomenclature." Prentice-Hall, Englewood Cliffs. New Jersey. 1969.

10. Szokefalvi-Nagy. Z. "How and Why of Chemical Symbols." *Chemistry* 40:21; 1967.

11. Traynham, J.G. *Organic Nomenclature: A Programmed Introduction*. Prentice-Hall, Englewood Cliffs, New Jersey. 1966.

12. Young. J.A. *Chemical Concepts*. Prentice-Hall. Englewood Cliffs. New Jersey. 1963. A programmed text.

[1] Also available in book form from Butterworths. London.

Physics

Physics is concerned with the study of matter and energy and with the relationships between them. Traditionally it has functioned as a quantitative and inductive science. Physicists have gathered quantitative data about the natural world and, from these data, have made generalizations or laws. To obtain quantitative data requires measuring something. Consequently, the language of physics is closely tied to the language of measurement. This is one of its distinguishing features. Another is related to the inductive nature of physics. Inductive reasoning is a human function. Human minds "process" the quantitative data and propose the generalization or law which explains the phenomenon. Other minds constantly challenge, test, and extend the generalizations until they can indeed be considered laws of nature.

Many of these laws have become known by the names of the men who successfully formulated them. Hence, the language of physics is rich with names of great physicists and with terminology adapted from their names. We speak of Charles's law, Boyle's law, the Doppler effect, joules, coulombs, etc.[1] Behind each of these lies a fascinating human story, as well as a law of nature.

The quantitative-inductive process

An interesting example of the quantitative-inductive process from our own time is the discovery and naming of the Van Allen radiation belts in space. The Explorer I and III and Sputnik III satellites (1958) recorded atomic particle data that were unexpected from what was previously known about radiation at high altitudes. Physicist James Van Allen studied these data, made new tests using lead-shielded instruments on later satellites,

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[1] *See Appendix A - Some Scientific Terms Derived from the Names of Famous Scientists*

and from the new data concluded that bands or belts of radiation encircle the earth.

Thus physics extends its frontiers, with each step open to challenge, competing theories, and extension of knowledge.

Science and technology

It is obvious, too, that physics is very closely related to technology and instrumentation and that engineering is largely based on the concepts of physics. To communicate accurately about science, one must understand clearly the distinction between science and technology. Science is concerned with knowledge and with seeking out knowledge. Technology is the application of knowledge in devices and in the ways we organize to utilize our applications of knowledge. Yet neither science nor technology could get very far alone. One could imagine a scientific society in which many persons were studying the physical world and carrying on experiments to seek out new knowledge. However, without technology this would remain a very primitive kind of science, limited entirely to what man could experience within the range of his own senses. With the technology of microscopes and telescopes, for example, man extends his scientific capability enormously; with the applications of the concepts of energy exchanges, technology converts energy into power that can be harnessed to do work and provide heat, in thousands of ways. Thus, science and technology are very closely linked, but remember that they are not the same.

The language of measurement

When we measure something we compare one or more of its properties to a standard. We can measure the length and width and even the thickness of this page by determining how these characteristics compare to a standard, such as a centimeter, a millimeter, or an inch. Basic to any language of measurement are the agreed-upon standards. They must be easily manageable, reproducible, and accepted by the entire community of persons who expect to communicate about the measured quantities.

What size is the tire?

How much milk in a gallon or liter?

How many kilometers to Paris?

Our daily conversations are filled with such quantitative questions that can be answered only if we know the standard of measure.

Science as an international language generally recognizes the standards included in the metric system as being the most coherent and the most universal. A few words about its history indicate the usefulness of this system.

The first metric system came into being in 1790 in France as an effort to do away with the proliferation of systems that had grown up in various countries and that were hampering trade, particularly. This new, metric, system was a decimal system—that is, each subdivision and each multiple of the base unit followed a progression of 10. The original metric system had two base units, meter for length and kilogram for mass, and it was a coherent system in that the quantity chosen for the standard and its derived units were generally whole figures. Moreover, some value that existed in nature as a constant (the freezing point of water, for example) was sought for the standard. Prototypes were then made and placed on deposit at the International Bureau of Weights and Measures at Sèvres, near Paris, France. Copies are on deposit at other national centers, such as at the U.S. Bureau of Standards. The metric system has been a legal system of measurements in the United States since 1866. Our customary pound-yard-second system standards are defined by a ratio to the metric standards. Bills are now (1974) before the Congress to change to the metric system for our customary measurement system.

Since 1790 almost all of the nations of the world have adopted the metric standards, and an international treaty organization, the General Conference of Weights and Measures (CGPM), has expanded, developed, and refined the system. The modern metric system is known as *Le Système International d'Unités*, [International System of Units] (SI). This is the system that we shall discuss here and which it is proposed that the United States also follow. [2, 3]

The SI units are divided into three classes: base units, derived units, and supplementary units. The seven base units are shown in Table 14.

Six of the units are defined in terms of natural quantities; the seventh, the kilogram, is the mass of a cylinder of platinum-iridium alloy kept at the International Bureau of Weights and Measures. The official definitions are given in Appendix A.

TABLE 14. International System (SI) Base Units

Quantity	Unit	SI Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K (degrees Celsius may also be used)
amount of substance	mole	mol
luminous intensity	candela	cd

The vocabulary of metric measurement is a very simple and logical one. For categories of measurements, subdivisions and multiples of the base unit are denoted by the same prefixes and are always either 1/10 or 10 times the next quantity in the progression.

For example:

deci-	1/10th	deka-	10 times
centi-	1/100th	hecto-	100 times
milli-	1/1000th	kilo-	1,000 times
micro-	1/1,000,000	mega-	1,000,000 times

Refer to Table 2, Chapter 1 for additional prefixes for much smaller and much larger measurements.

The International Committee on Weights and Measures (CIPM) recognizes that users of SI will also wish to employ certain units which, although not part of SI, are in widespread use. These units, given in Table 15, play such an important part that they are retained for general use with the International System of Units.

Tables 16 and 17 show the most commonly used derived units in SI metric measurements. How derived units are obtained is discussed in the following section.

Derived units

All units other than the seven basic ones given above are *derived* units. Consider linear measurement as an example. Starting with

TABLE 15. Units in Use with the International System

Name	Symbol	Value in SI Unit
minute	min	1 min = 60 s
hour[a]	h	1 h = 60 min = 3 600 s
day	d	1 d = 24 h =86 400 s
degree	°	$1^\circ = (\pi/180)$ rad
minute	′	$1' = (1/60)^\circ = (\pi/10\,800)$ rad
second	″	$1'' = (1/60)' = (\pi/648\,000)$ rad
litre[a]	l	$1\ \text{l} = 1\ \text{dm}^3 = 10^{-3}\ \text{m}^3$
tonne[a]	t	$1\ \text{t} = 10^3$ kg

[a] The symbol of this unit is included in Resolution 7 of the 9th CGPM (1948). The litre [liter] is defined in Resolution 6 of the 12th CGPM (1964).

From *The International System of Units (SI)*, NBS Special Publication 330, U.S. Department of Commerce, National Bureau of Standards, Washington, D.C. 1972. P. 13.

the basic unit, length, we can describe the linear distance between two points as a certain number of millimeters, centimeters, decimeters, meters, dekameters, hectameters, or kilometers (or of any other units of length, such as inches or feet).

Now, if we measure linear distance in two dimensions, we can derive a unit for describing area, the square centimeter (cm^2) or the square meter (m^2). The relationship between these units is: One square meter equals 10^4 square centimeters (100cm × 100cm).[2]

If we measure the linear distance in three dimensions, we can derive a unit for describing volume, the cubic centimeter (cm^3) or the cubic meter (m^3). The relationship between these units is: One cubic meter equals 10^6 cubic centimeters (100cm × 100cm × 100cm). Another unit for volume in the metric system is the **liter** (Greek for "weight," since formerly a liter was defined in terms of weight). The word liter is now employed as a special name for the cubic decimeter. [3, p.30]

This brings us to our second basic unit, *mass*. Mass is an unchanging property of a body and is more or less its "amount." Combined with gravitational attraction, mass gives an object its "weight." The measured weight of an object when on the moon

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[2] For a discussion of exponents, see Chapter 4.

TABLE 16. SI Derived Units Expressed in Terms of Base Units

	SI Unit		
Quantity	Name	Symbol	Expression in terms of SI base units
area	square meter	m^2	
volume	cubic meter	m^3	
speed, velocity	meter per second	m/s	
acceleration	meter per second squared	m/s^2	
wave number	1 per meter	m^{-1}	
density, mass density	kilogram per cubic meter	kg/m^3	
concentration (of amount of substance)	mole per cubic meter	mol/m^3	
activity (radioactive)	1 per second	s^{-1}	
specific volume	cubic meter per kilogram	m^3/kg	
luminance	candela per square meter	cd/m^2	
heat capacity, entropy	joule per kelvin	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$
thermal conductivity	watt per meter kelvin	$W/(m \cdot K)$	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
molar energy	joule per mole	J/mol	$m^2 \cdot kg \cdot s^{-2} \cdot mol^{-1}$
electric charge density	coulomb per cubic meter	C/m^3	$m^{-3} \cdot s \cdot A$
electric field strength	volt per meter	V/m	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$

From *The International System of Units (SI)*, NBS Special Publication 330, U.S. Department of Commerce, National Bureau of Standards, Washington, D.C. 1972. Pp. 7, 9.

will differ from that as measured on earth, though the mass remains unaltered. Therefore, if you are on a diet, you might prefer to be weighed on the moon. There is, incidentally, for each object, a center of gravity and a center of mass. We tend to speak of the center of gravity when endeavoring to balance things. The center of mass is not often heard colloquially, but

TABLE 17. SI Derived Units with Special Names[a]

Quantity	SI Unit			
	Name	Symbol	Expression in terms of other units	Expression in terms of SI base units
frequency	hertz	Hz		s^{-1}
force	newton	N		$m\cdot kg\cdot s^{-2}$
pressure	pascal	Pa	N/m^2	$m^{-1}\cdot kg\cdot s^{-2}$
energy, work, quantity of heat	joule	J	$N\cdot m$	$m^2\cdot kg\cdot s^{-2}$
power, radiant flux	watt	W	J/s	$m^2\cdot kg\cdot s^{-3}$
quantity of electricity, electric charge	coulomb	C	$A\cdot s$	$s\cdot A$
electric potential, potential difference, electromotive force	volt	V	W/A	$m^2\cdot kg\cdot s^{-3}\cdot A^{-1}$
capacitance	farad	F	C/V	$m^{-2}\cdot kg^{-1}\cdot s^4\cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2\cdot kg\cdot s^{-3}\cdot A^{-2}$
conductance	siemens	S	A/V	$m^{-2}\cdot kg^{-1}\cdot s^3\cdot A^2$
magnetic flux	weber	Wb	$V\cdot s$	$m^2\cdot kg\cdot s^{-2}\cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg\cdot s^{-2}\cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2\cdot kg\cdot s^{-2}\cdot A^{-2}$
luminous flux	lumen	lm		$cd\cdot sr$[b]
illuminance	lux	lx		$m^{-2}\cdot cd\cdot sr$[b]

[a] See also Appendix A—Some Scientific Terms Derived from the Names of Famous Scientists.

[b] In this expression the steradian (sr) is treated as a base unit.

From *The International System of Units (SI)*, NBS Special Publication 330, U.S. Department of Commerce, National Bureau of Standards, Washington, D.C. 1972. P. 8.

the first American astronauts to land on the moon mentioned it to the TV audience. Their weight had changed but not their center of mass, and they had to be careful not to lose their balance and fall over while enjoying their new lightness.

Using our linear units and our second basic unit, the kilogram (mass), we can derive another useful unit. This is **density** (dens = thick), the ratio of the mass of a substance to its volume. We can express this in such terms as kilograms per cubic meter or grams per cubic centimeter. An understanding of the concept of density can help clarify the "why" of such well-known phenomena as wood and oil or alcohol floating on water. Water has a density of about one kilogram per cubic decimeter. Ethanol (ethyl alcohol) has a density of about .789 grams per cm^3 at $20^{0}C$. The alcohol is lighter than water and therefore floats on it.

If we now bring time into consideration, we can derive some concepts and measurement units concerned with motion, namely constant velocity and acceleration.

Scientists have given the name newton (N) (after the British physicist Sir Isaac Newton) to the unit of force which gives a mass of one kilogram an acceleration of one meter per second squared (m/s^2). This means that the object was increasing its velocity by one meter per second every second. Thus, starting from rest, the object was traveling at the rate of one meter per second at the end of the first second, two meters per second at the end of the next second, and so on.

We are now in a position to consider the amount of work done when a force of one newton acts over a distance of one meter. This is called one joule (J) (after the English physicist and brewer James P. Joule), and it represents the units of newtons·meters (N·m). If you move an object 20 meters while pushing in that direction with a force of one newton, you do 20 joules of work.

If we wish to work with smaller masses and distances, we might use grams and centimeters. The unit of measurement would be termed the **dyne** (dyn = power), which is defined as the force which gives a mass of one gram an acceleration of one centimeter per second squared (cm/s^2). Its value in SI units is 10^{-5}N.[3]

From force and distance we can speak of work (a term that is related to the Greek erg, which means work). Work can be defined as a force acting over a distance.[3] The value of 1 erg in SI units is 10^{-7}J.

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[3] Dyne and erg are units from the CGS (centimeter-gram-second) system.

The inductive process

Once physicists have established measurement standards and the instruments necessary to measure and record data from their observations, they turn to inductive reasoning to try to discover patterns and meaning and to build larger concepts from their observations. Some of the techniques used in this process are mentioned in the following paragraphs and in the chapters on Mathematics and Statistics.

Formulas

Like chemists, physicists have their own shorthand ways of recording and communicating their observations and the relations between them. Like the chemists, too, physicists use many well-established and accepted symbols in their shorthand language of formulas. For example, take this simple example of describing speed:

The word formula is: Average speed $= \frac{\text{distance traveled}}{\text{elapsed time}}$.

In symbols, the formula is $v_{\text{av}} = \frac{\Delta d}{\Delta t}$. v is an accepted symbol for speed. av, of course, is an abbreviation for average. Δ is the Greek letter delta which means "the change in . . ." when it precedes another symbol. Δd means the change in position (or displacement) Δt is the time elapsed.

If we are interested in the change in speed, which is called acceleration, the formula for this becomes $a_{\text{av}} = \frac{\Delta v}{\Delta t}$.

Symbols and formulas are like the vocabulary of a foreign language. One learns and practices the terms that are most frequently used and looks up the others as needed.

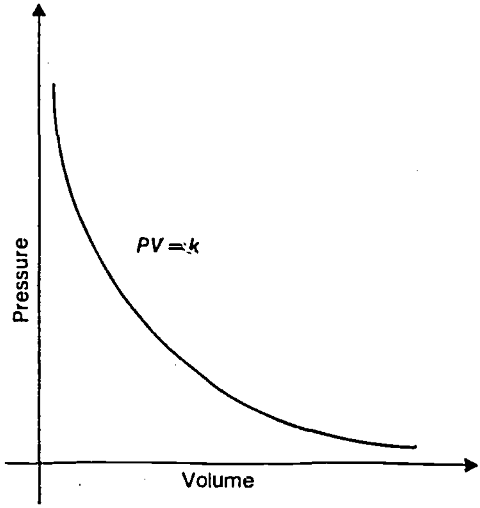
See also Appendix A, "The Greek Alphabet and Some Uses of Greek Letters in the Science Vocabulary."

Graphs and curves

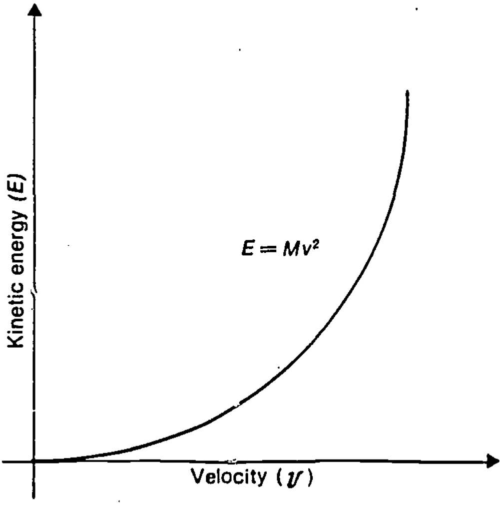
Another much-used means of communicating relationships in physics is through graphs or curves. Certain relationships will always produce a curve of a certain type. Vice versa, certain types of curves can always be interpreted into a formula for a certain kind of relationship.

Figure 3 shows two examples of formulas and the resulting curves.

FIGURE 3. Graphs of Relationships



Pressure-volume relation of a gas under constant temperature.



Kinetic energy varies directly as the square of the velocity.

From Schaaf, William L, *Basic Concepts of Elementary Mathematics*. John Wiley & Sons, Inc. New York 1965. Pp. 258,259

Card file of physics terms

A good technique to help you become familiar with the terms used in physics is the development of a card file. Using cards and the outline suggested below, you can begin to collect a useful file of study and review information and a permanent reference file.

Sample card for filing physics terms

Name of term - watt (a derived unit of the International System) *Symbol or abbreviation* W

Area of use, category, or physical quantity measured Power

Definition - Watt is the power which gives rise to the production of energy at the rate of one joule per second.

Conversion to other units -

Applicable formulas - W = J/s (joule per second)
Thermal conductivity = watt per meter-Kelvin (W/m· K)

Problems and questions

1. Starting with the basic units of mass, linear distance, and time, derive the units necessary for using Ohm's law.
2. A common phenomenon pertaining to several types of energy propagation is the fact that their intensity (or strength) diminishes in a particular way with respect to distance from the source. See how many of these different cases you can identify, and develop a mathematical statement for the relationship involved.
3. The phenomenon of resonance is another example of commonality of action among different types of energies. See how many different cases you can identify and investigate the devices which use this phenomenon for practical purposes.
4. According to one expression, "A pint's a pound the world around." How much does a pint of water weigh in grams, and under what conditions?

5. Check your newspapers, popular magazines, and perhaps even TV specials to see how far the language of physics has penetrated public usage and presumed public grasp. Compare this with the use of the languages of the other sciences.

References

1. Ballentyne, D. W., and D. R. Lovett. *A Dictionary of Named Effects and Laws*. Third Edition. The Macmillan Company, New York. 1970.
2. *The International System of Units* (SI). NBS Special Publication 330. National Bureau of Standards, U.S. Department of Commerce, Washington, D.C. 20234. 1972.
3. *A Metric America—A Decision Whose Time Has Come*. National Bureau of Standards Special Publication 345. Cat. No. C 13.10:345. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. 1971.
4. *Metric Practice Guide*. ASTM Designation E380-70. American Society for Testing and Materials. Philadelphia, Pennsylvania. 1970.
5. Schaaf, William L. *Basic Concepts of Elementary Mathematics*. John Wiley & Sons, Inc., New York. 1965.
6. *Style Manual*. PUB. R-128.5. Revised Edition. American Institute of Physics, 335 East 45th Street, New York 10017. 1970.

Earth and Space Sciences

Because the earth and space sciences include astronomy, geology, meteorology, oceanography, and other related areas of science, there are "local dialects" belonging to each of the disciplines. Here we will consider chiefly the language that we use in orienting ourselves to time, to our physical location on the earth and in space, and to some of the major characteristics of the earth, atmosphere, and space.

Time and navigation

The earth is approximately a sphere; therefore, it is 360 degrees in circumference. The earth rotates on its axis once every 24 hours. That is, the sun appears over New York City and then appears again in roughly the same position 24 hours later. This means that it takes the earth one hour to rotate (with respect to the sun) 15 degrees. Consequently, if it is 12 o'clock noon in New York City, it is 11 A.M. in Chicago, which is roughly 15 degrees west of New York City. In other words, the sun will not reach its highest point above the horizon (the noon **meridian**; meridies = noon) in Chicago for another hour. This is the basis for the terms A.M. (ante meridiem = before noon) and P.M. (post meridiem = after noon).

Theoretically, if it is 12 noon in New York City and 11 A.M. in Chicago, it should be half past 11 in Cleveland, which is approximately halfway between them. You can see that this would mean that even neighboring towns might have different local times. To overcome this difficulty, standard time zones, each 15 degrees wide, have been established around the circumference of the earth.[1] (How many of these zones would there be?)

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[1] While, in principle, time zones are 15 degrees wide, in reality they vary both in size and in shape because the countries of the world establish the time zones within their boundaries; and sometimes they wish to include all or a major part of the country in a single zone. To see how this works out, refer to a large

The starting point of the zones is considered to be the "prime meridian," which passes through Greenwich, England. Because of the apparent motion of the sun around the earth, those zones to the west of the prime meridian are considered + zones, those to the east, − zones. New York City is approximately 75 degrees west of Greenwich and is in the +5 zone. One would have to add five hours to local New York time to determine the local time in Greenwich (Greenwich mean time = GMT). This concept of time zones is very helpful in locating a position on earth, as we shall see. There are some exercises at the end of the chapter dealing with time zones, but for now: Where, on the earth, do the plus and minus zones meet?

To locate a position on our planet, we need to determine the **latitude** (lat=wide) and **longitude** (long = long) of the position. (See Figure 4.) Parallels of latitude are imaginary lines encircling the earth north and south of the equator and parallel to it. Meridians of longitude are imaginary lines encircling the earth and passing through both the north and south geographical poles. These should be referred to as parallels or meridians. One possible source of confusion in dealing with these two terms is the fact that parallels of latitude, which run east and west, represent distances north or south of the **equator** (equator = equalizer), while meridians of longitude that run north and south represent distances east or west of the prime meridian. One way to clarify these relationships is to learn the navigational "address" of your own city or town. Thus, the address of Norfolk, Virginia, is approximately 37°N latitude and approximately 76°W longitude.

How then can one determine the specific coordinates for a given location on earth? Obviously, one must determine the navigational address, that is, the latitude and longitude values for that position. The process is simple in theory but more complicated in practice. From our discussion regarding time zones, do you see that you could determine your longitude with a time signal and an accurate watch? If, as a short-wave radio gave you the exact time in Greenwich, you recorded the exact local time from your watch, the difference between these two

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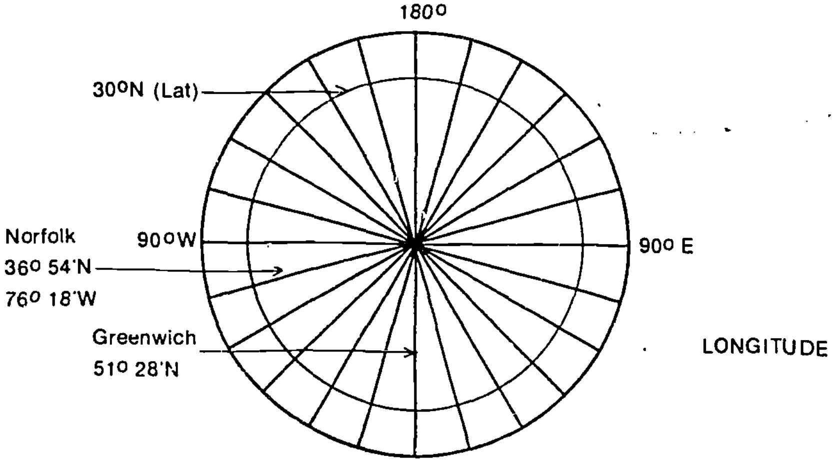
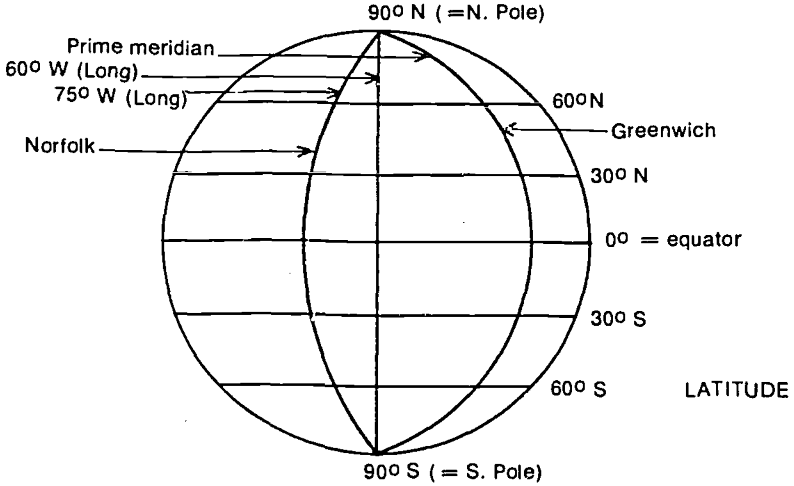
atlas, such as *The World Book Atlas*. (Field Enterprises Educational Corporation, Chicago, 1973. Pp. 226-227.)

Universal time is often used in astronomy. It is an internationally agreed-upon time that is the same as Greenwich mean time and uses a 24-hour clock, starting with 0 at midnight Greenwich mean time.

FIGURE 4. Longitude and Latitude





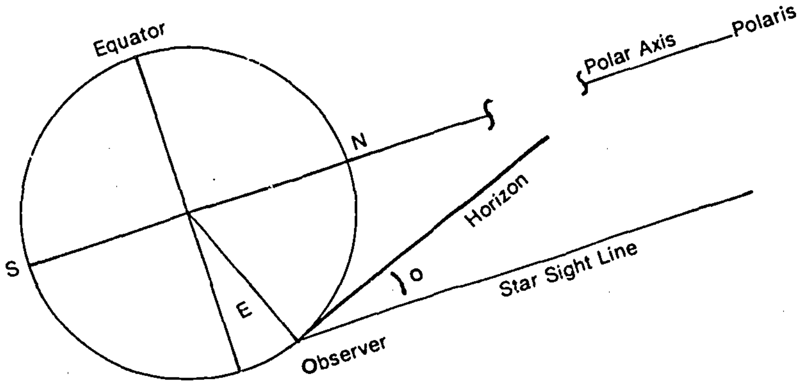
The diagram above indicates the meridians of longitude in a projection centered on the North Pole. The projection below illustrates the parallels of latitude in a sphere centered on the equator. Note that the meridians of longitude pass through both poles and that the parallels of latitude are parallel to the equator.

values would tell you how many 15-degree segments (time zones) you were from the prime meridian, or your approximate longitude. How do you decide whether your longitude is east or west? Do you see that if your local time is earlier than Greenwich time, your longitude value is west, and that if your local time is later than Greenwich time, your longitude is east? (Try to work problem 1 at the end of the chapter to see whether you understand this idea.)

How do we determine the latitude of a particular location? One method that can be used in the northern hemisphere involves finding the altitude of the north star, **Polaris** (polaris = polar). The altitude is the angle between the star and the horizon. This is usually done, for purposes of accuracy, by using a **sextant** (sextans = sixth part of a circle). However, a simple protractor can be used to roughly find the angle between the horizon and Polaris. In general the altitude of Polaris is equal to the latitude of the observer. Figure 5 is a nonscaled diagram showing the mathematical basis for this determination. Can you prove geometrically that the angle at the observer (angle O) is equal to the angle from the equator (angle E)?

As you might imagine, the more accurate the instruments used and the measurements obtained, the more precise is the

FIGURE 5. *Determining Latitude in the Northern Hemisphere*



Because of the great distance between the earth and Polaris, the star sight line and the polar axis are essentially parallel lines. Thus angle O (the altitude of Polaris) is equal to angle E (the latitude of the observer).

description of the geographical position of the particular location. Some references which discuss navigational theory in more detail are listed at the end of the chapter.

Geologic time

Having attempted to locate ourselves on the surface of the earth and in present time, we next try to locate ourselves in the sweep of geologic time. This year, this hour, this minute, are but the latest time increments that extend backward to an unknown dimension and forward to an unpredictable future. Today, the earth is thought to be at least four and one-half billion years years old. Earth scientists have developed the Geologic Time Scale as a calendar of past time and events. (See Table 18) Let us consider the language of that calendar.

TABLE 18. Geologic Time Scale

Era	Period	Epoch	Millions of Years since beginning of each (Approx.)[a]
Cenozoic (recent animal life)	Quaternary (follows Tertiary)	Recent	.01
		Pleistocene (most recent)	2
	Tertiary (Mesozoic was once named the Secondary)	Pliocene (more recent)	12[a]
		Miocene (less recent)	25
		Oligocene (scantly recent)	38
		Eocene (early recent)	55
		Paleocene (ancient recent)	65

Era	Period	Millions of Years since beginning of each (Approx.)[a]
Mesozoic (middle animal life)	Cretaceous (chalk = *creta* in Latin, cliffs of English Channel)	135
	Jurassic (Jura Mountains, Switzerland)	180
	Triassic (refers to threefold division of rocks in Germany)	225
Paleozoic (ancient animal life)	Permian (province of Perm, Russia)	275
	Carboniferous: Pennsylvanian (Pennsylvania; same as the "Coal Measures" of Britain) and Mississippian (Mississippi Valley)	350
	Devonian (South Devon, England)	413
Paleozoic	Silurian (*Silures*, Celts who ruled this part of Wales and Shropshire, England)	430
	Ordovician (*Ordovices*, ancient tribe in North Wales)	500
	Cambrian (*Cambria* = Latin for Wales)	600
Pre-Cambrian		3,000+

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[a] Dunbar, Carl O., and Karl M. Waage. *Historical Geology*. Third Edition. John Wiley & Sons, Inc., New York. 1969. P. 16.

It is fairly easy to designate a distinct point in relatively recent time. For instance, we may say that the Armistice Agreement ending World War I was signed at 11 A.M. on November 11 in the year 1918. This would seem to be a rather definite description of the time of the occurrence of the event. However, even that description is incomplete because, although it was 11 A.M. in Compiègne (France), it was 6 A.M. in New York City and 3 A.M. in San Francisco. (We just saw that the time zones cause these differing local descriptions of standard time.) We need to know the location as well as the time.

As we go back further in recorded history, the description of the time of a specific event becomes even more nebulous. The best we can say about the reign of King Tutankhamen in ancient Egypt is that it occurred in the 14th century B.C. Consider, then, the problem of accurately describing when an event took place in the long history of earth before man was present to observe or record the event. The Geologic Time Scale was developed by geologists in an attempt to define blocks of time (measured in millions of years) in which specified events or conditions occurred or were present. Thus most **paleontologists** (paleo = ancient, onto = being or thing, logy = study of: students of ancient life forms) agree that the most characteristic arthropod of the Cambrian Period was the **trilobite** (three lobes) and that this organism faded into extinction by the end of the Paleozoic Era. To read about the evidence and reasoning processes by which scientists developed and improved the Geologic Time Scale is as exciting as reading a good detective story. Some books that may get you started are listed at the end of the chapter.

As you examine the Geologic Time Scale, notice several important things about it. *Eras* are the largest divisions; then *periods*; then *epochs*. The names given to the eras are descriptive of the type of animal life (i.e., paleozoic = ancient animal life) that, in the evolutionary sense, was most common. Thus, the name of the era should suggest to you the kinds of animals present, or the kinds of animals present should suggest to you the name of the era.

The names of the geologic periods are based partly on evidence of major disturbances of the earth's crust. Usually, the name of the period reflects the name of the location where rocks deposited during a particular time interval were first described or are best displayed.

The periods of the most recent era (Cenozoic) are subdivided into epochs. The names given to the **epochs** (epoché = fixed point) were created from a Greek word meaning "recent" (the ending -cene) and the appropriate prefixes. In general usage the prefixes are treated as referring to their comparative recentness, and they are so identified in Table 18. In point of fact, however, there is an interesting bit of history here also. Four of the six names actually express the percentage of species living during those epochs which have survived into modern times. Thus **Pleisto** means "most," **Plio** means "more," **Mio** means "less," and **Oligo** means "few." Of the remaining two names, **Paleo** means "old" or "long ago" and **Eo** means "dawn," the dawn of recent living things.

With respect to remembering the names given to the epochs, the student is presented with a problem. One should know the relative sequence of the epochs so that one can recognize that something that occurred in the Eocene preceded something that occurred in the Miocene. Perhaps a practical solution is some mnemonic (memory aid) device such as: Pass Every One More Pizza Please, which helps one recall the sequence from oldest to most recent epoch and gives clues to the names. The meanings of the prefixes for the names of the epochs may also give some help in remembering their sequence in time.

Finally, the relative time of occurrence is the basic reason for the construction of the Time Scale in the first place. Hence, some understanding of the time factor is essential. There are two aspects to the time factor: (1) how long ago the particular span of time occurred (started or ended) and (2) how long the span of time lasted. Because we are dealing with rough estimates and in millions of years, the data supplied in the fourth column of Table 18 should be sufficient for most purposes.

Geologic **stratigraphy** (strat=layer, graphein=to write; the study of rock layers) and **phylogeny** (phyle = tribe, gene = procreate; the study of evolutionary development of biota) establish only relative time values (older or younger). The absolute time scale was developed by using radioactive decay and by determining the ratio of unstable and stable isotopes. This ratio changes slowly with time and depends on the half-life of the particular radioactive element that is used for the time determination.

In any event, the Geologic Time Scale represents a magnificent achievement of the minds of men as they attempted to encompass in one scale the panoramic sweep of the history of our planet and of the events and conditions that have existed on it. It is certainly one of the important pages in the dictionary of science.

Our space vehicle – the earth

When we look around at our space vehicle, we can easily recognize its three most distinctive and important regions – the solid earth, the oceans and other water surfaces, and the atmosphere. These have their own descriptive names:

Lithosphere (litho = stone; sphaer = sphere), the solid crust of the earth

Hydrosphere (hydro = water; sphaer = sphere), water- and ice-covered areas

Atmosphere (atmos = vapor; sphaer = sphere), air surrounding the earth

Now that we understand better where we are in time, it is easy to realize that many changes in the earth must have occurred over this long, long history. Let us examine our earth as it is today. Beginning with the lithosphere, let us see how earth scientists explain the physical and chemical conditions that presently exist. To do this we will need to examine some of the language of physical geology and mineralogy.

Physical geologists have identified many forces or processes which have changed the earth throughout its existence. Table 19 provides a list of some of these processes and their definitions. To study and understand the forces underlying these processes, one needs to know the language of physical geology.

Physical geologists have developed special terms for the various processes shown in Table 19. As you study in these areas, you will find that the process of word analysis which you learned in Chapter 1 on Language and Communication will be very helpful. For example, the processes of **diastrophism** (diastroph = distorted) sometimes result in the formation of **synclines** (syn = together, clin = slope), that is, layers of rocks which slope downward to form the troughs in geologic folds.

Thus the language of physical geology attempts to help us understand the physical nature of our earth -- how it acquired its present state and what it might become in the future.

The geochemist and the mineralogist help us understand the chemical nature of the earth and its storehouses of natural

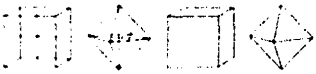
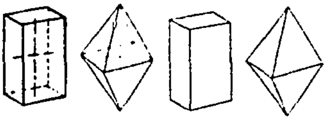
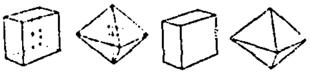
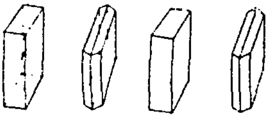
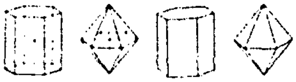
TABLE 19. Forces and Processes That Have Changed the Earth

Process	Definition or Description
Weathering	The combined and interacting effects of the chemical processes (such as dissolving, oxidation, and hydration) and physical factors (such as temperature, weather generally, and mechanical forces) which favor the disintegration of rocks near the surface.
Metamorphism	The extreme temperature and pressure effects upon rocks that cause changes in their textural, mineralogical, and structural composition.
Erosion	The wearing away of the surface of the earth through the combined effects of running waters, avalanches, landslides, ice, wind, and gravity.
Transportation	The movement of loose materials from place to place.
Deposition	The laying down of the transported materials. The term aggradation signifies the building up of the earth's surface; the term degradation implies the lowering of the surface.
Diastrophism	The movements of parts of the earth's crust through the action of internal forces, such as the lateral and vertical compressional and tensional forces which result in foldings and faultings.
Volcanism	The processes which involve volcanoes and molten rock.

resources. The geochemist is concerned with broad associations in **petrogenesis** (petro = stone, genesis = formation) and with differences in the occurrence of elements in the various depths of the earth and on the moon and other celestial bodies. Mineralogists are principally concerned with individual types of rocks and minerals. In addition, mineralogists are concerned about the shape and structure of minerals and whether they are crystalline or **amorphous** (a = without, morph = shape). Six basic crystal systems have been established and are extremely useful in identifying the nature and properties of some minerals. Table 20 describes these systems.

A knowledge of the properties of crystals, their internal structure, and the conditions affecting their development is of great economic and scientific importance. The crystal structure

TABLE 20. Crystal Systems

Crystal System	Description	Figure[a]
Isometric	(iso = equal, metr = measure) Crystal has three crystallographic axes of equal length and at right angles to each other.	
Tetragonal	(tetr = four, gon = angle) Crystal has three axes that intersect at right angles; the two horizontal axes are equal in length; the vertical one is either longer or shorter than the horizontal axes.	
Orthorhombic	(orth = straight, upright; rhomb = a parallelepiped with equal sides) Crystal has three axes, each of different length, which intersect each other at right angles.	
Monoclinic	(mon = one, clin = slope) Crystal has three axes of unequal length, one vertical, one horizontal and at right angles to the other two, and one inclined to the vertical axis.	
Triclinic	(tri = three, clin = slope) Crystal has three axes of unequal length, no two of which intersect at right angles.	
Hexagonal	(hex = six, gon = angle) Crystal has four axes, three of equal length in a horizontal plane intersecting each other at angles of 60°, the fourth at right angles to the other three.	

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[a] Illustrations reproduced with permission from *The World Book Encyclopedia*. Vol. 4. Field Enterprises Educational Corporation, Chicago. 1971. P. 930.

See also *Van Nostrand's Scientific Encyclopedia*. Fourth Edition. Van Nostrand Reinhold Company, Inc., New York. 1968. P. 466.

helps determine many of the properties of minerals and the rocks which they compose. A very interesting reference for working with and learning more about crystals is mentioned at the end of the chapter. (See reference 13.)

Meteorology

The atmosphere

As our present explorations in space and the effects of environmental pollution are both making increasingly clear, a very major and vital characteristic of the earth is its envelope of atmosphere.

Thus, while geologists help us understand the earth beneath us and the materials in it, **meteorologists** (meteor = high in the air, logy = study of) help us understand the atmosphere around and above us and its influences on our lives. Table 21 shows the major regions of the atmosphere.

TABLE 21. Regions of the Atmosphere

Kilometers above sea level [a]	Region
1,000	Exosphere (outer space)
500	Ionosphere (ionized layers)
100	
90	
80	Mesosphere (middle)
70	
60	
50	Stratosphere (upper atmosphere)
40	
30	
20	
10	
0	Troposphere (inner)

[a] The boundaries indicated are approximate and, in any event, are not sharp dividing lines but a merging of one layer into another.

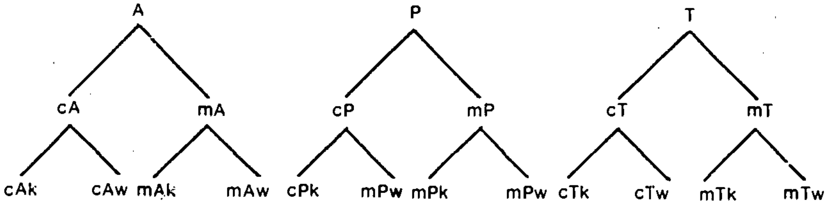
The vocabulary of weather forecasting

The language of the meteorologist is the language of the weatherman and the climatologist. Meteorologists study the weather for purposes of analysis and prediction, but the two aspects are never completely separate. Although many factors enter into weather prediction, two important concepts are the *air mass* and the *front*. An understanding of what these concepts mean and how they aid in forecasting is essential to facility in the language of atmosphere analysis and weather prediction.

An *air mass* is an "island" of air moving in the **troposphere** (trop = change, sphaer = sphere; part of the atmosphere next to the earth's surface, where most of our weather occurs). The term refers to the fact that an airstream of importance to local weather can be identified by its source region—the area where the temperature and humidity characteristics of the mass of air have been determined by its relatively long existence in a certain locality. There is a close relationship between certain types of air masses and certain types of weather.

Various systems have been proposed for the classifying of air masses, but that most commonly used is the Bergeron system. Air masses are divided first according to the thermal nature of their source regions, which are either polar (P), tropical (T), or (occasionally) arctic or antarctic (A). Then these are classified according to moisture, as continental (c) or maritime (m). Finally the mass is distinguished as to whether it is warm (w) or cold (k) as compared to the region over which it is moving.

The following diagram indicates how these symbols can be used in classifying and identifying air masses. We can see that a report reading cPk would mean that a polar air mass that developed over continental regions is moving over a place which is warmer than the air mass.



Classification of air masses. From *Van Nostrand's Scientific Encyclopedia*. Fourth Edition. Van Nostrand Reinhold Company, Inc., New York. 1968. P. 42.

The *front* concept pertains to a fairly narrow zone between two large air masses which differ in density and almost always differ in temperature, too. Sharp temperature and humidity gradients here may be accompanied by extensive clouds and rain. There is a generally predictable relationship between the type of front and ensuing weather patterns. For example, a forecaster knows that an approaching warm front (warm air replacing cold) will probably be preceded by high-level clouds and falling **barometric** (baro = pressure; meter = measure) pressures, resulting in rain and lowered cloud cover.

Obviously, fronts are not static things and are changing constantly as they move across the terrain below them. However, certain generally predictable trends characterize various types of fronts. Table 22 shows the usual observations connected with a warm front. Such characteristics are also identifiable for other types of fronts.

TABLE 22. Some General Characteristics of a Warm Front

Observations	Air Temperature	Dew Point	Pressure	Cloud Types
In cool air	Lower ahead of front	Low	Gradual, then rapid drop	Stratiform with increasing vertical development
In warm air	Higher behind front	High	Slow fall, then leveling off	Stratiform, changing to types with great vertical extent

Cloud vocabulary

Clouds are made up of condensed or frozen moisture and are useful indicators of weather conditions above the earth. Not only the amount of cloud cover (which could affect surface temperature) but the sizes and shapes of the clouds themselves provide evidence to aid the meteorologist.

Clouds may be classified in various ways—by their location in the atmosphere, as high, middle, or low clouds; or by their general appearance—and even the number of recognized classifications varies. However, a recognition of three basic cloud forms is a good beginning.

TABLE 23. Cloud Types

Height	Cloud Name	Abbreviations and Symbols	Description	Weather
Low clouds below 6,000 feet	Stratus	St 	Sheetlike, foglike layers	Precipitation rare: drizzle, overcast
(1.8 km)	Stratocumulus	Sc 	Relatively homogeneous layers, generally covering substantial portions of the sky	Associated with strong surface winds, following rains
	Nimbostratus	Ns 	Sheetlike layers of dark storm clouds	Continuous rain or sleet or snow
Middle clouds 6,000 to 18,000 feet	Altocumulus	Ac 	Round, patchy clouds in rows	Fairly stable weather
(1.8 to 55 km)	Altostratus	As 	Heavy, gray sheet of cloud	Rain or snow soon
High clouds 18,000 to 40,000 feet	Cirrus	Ci 	White, wispy semitransparent, feathery	Fair weather ice-clouds
(5.5 to 12.2 km)	Cirrocumulus	Cc 	Lumpy bands, stripes of clouds; the "Mackerel sky"	Fair weather clouds
	Cirrostratus	Cs 	Thin, transparent veils	Thickening; implies bad weather (precipitation coming)
Vertical clouds surface to 40,000 + feet	Cumulus	Cu 	Thick, willowy flat-bottomed clouds	Generally fair
(12.2 km)	Cumulonimbus	Cb 	Towering, anvil-shaped with strong shadows	Bad weather; hail, thunderstorms, gusty winds

The **cirrus** clouds (cirr = curl of hair) have a wispy, filmy appearance. They are high clouds. predominately composed of ice crystals.

The **cumulus** clouds (cumul = heap, mass) are heaps of fleecy white condensed moisture.

The **stratus** clouds (strat = layer) tend to appear as long sheets of condensed moisture, lacking distinctive shapes.

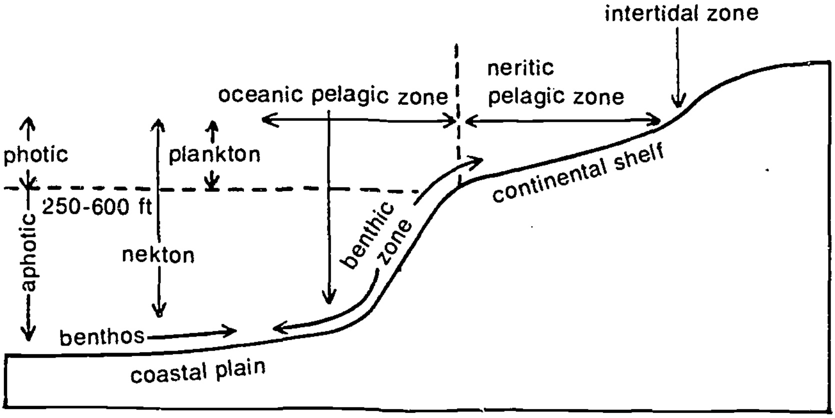
Other terms are used in describing modifications of the basic cloud types. **Alt** (= high) and **nimb** (= rain cloud) are sometimes used as prefixes to modify the basic cloud type description. Table 23 provides a list of the commonly employed cloud names, their general description, and their weather implications. From word analysis skills alone one would expect that a nimbostratus type cloud would be a dark formless cloud and an omen of bad weather. Table 23 agrees with this analysis.

The hydrosphere

The oceans cover nearly three-fourths (70.8%) of the earth's surface and have always played a major role in man's existence on the earth. The language of the oceanographer (or oceanologist) is a cosmopolitan language in that it incorporates some of the language of the biologist, the chemist, the physicist, the geologist, and the meteorologist. Water (rivers, lakes, ground water) and ice (glaciers and permanent snow on land) are the province of the hydrologist. In the oceans, and to some extent, in the other areas of the hydrosphere (rivers, lakes, glaciers, and ice caps) each of these specialists has an extensive domain of study with its own peculiarities and differences from the solid areas of the earth's surface.

In ancient times, oceans were a restricting feature for the world's people. The edge of the world lay out beyond the sea horizon. Gradually the oceans became increasingly used for transportation, and when it was established that the earth was round, the seas became even more important as links between countries, offering paths for exploration, communication, and transport. Always, the seas have been important as sources of food for coastal peoples. Today our view of the hydrosphere is greatly concerned with the resources of the oceans and the dynamic role of the oceans in water and energy exchanges on a global scale.

FIGURE 6. The Structure of an Ocean Basin



Weisz. Paul B. *The Science of Biology*. McGraw-Hill Book Company. Inc.. New York. 1963. P. 147. *Used with permission of McGraw-Hill Book Company.*

Figure 6 shows a cross section of an ocean basin as a biologist sees the ocean. His interest is in the areas and conditions that support life in the ocean. The intertidal zone—the coastal area between high and low tide—is a harsh environment because the environmental factors are so variable. Nevertheless, it does support a variety of living things. The **photic** (remember, phot = light) zone refers to the upper area of the oceans, to the depth to which sunlight can penetrate. Only in this zone will we find any plants that must depend on sunlight for photosynthesis and, of course, the animals that depend on these living plants for their food. Largely in this area, too, we find the **plankton** (plankto = wandering), all the forms of life that drift or float without power to move by themselves. They are largely microscopic forms.

The **pelagic** (pelag = the sea) zone is the water itself: the **neritic** (shallow water) zone over the continental shelf and the oceanic zone over the deep ocean floor. The continental shelf is an important life zone; much oil is found there; and the area even plays a political role in national and world affairs. The sea floor is called the **benthic** (benth = depths of the sea) zone. Benthos comprise the crawling, creeping, or **sessile** (= sitting or attached) organisms that live on the ocean bottom and on the slopes. **Nekton** (nektos = swimming) are the animals that can swim and float about in the ocean and consequently live in all of the zones.

Likewise the chemist and the physicist find in the hydrosphere many opportunities to study the composition of water, sediments, minerals, and the exchanges of matter and energy in that environment. Seawater contains some 60 chemical elements, several of them—for example, magnesium and bromine—in quantities that make it economically practical to separate them, together with sodium chloride (common salt), out of the solution. Waves, of course, are of interest to the physicist, as are studies of pressure, movements of masses of water of various densities and temperatures, travel of sound waves through water, and, of course, the tides. The interface of atmosphere and ocean is an area of constant interchange of moisture and energy and heat.

The geologist is concerned with the same questions in relation to the ocean basins as in other areas of the earth—the formation of the underlying solid earth, and the changes that have taken place over the billions of years of the earth's existence. By analyzing cores taken from the sediments and underlying rocks, scientists learn much about the history of the earth, its life forms, its mineral resources, and even ancient sea surface temperatures.

As mentioned earlier, much of present study and research involving the oceans deals with the great systems of energy and moisture exchanges. The oceans have vast expanses of surface, for the most part unbroken by the mountains and other topograph features of the continents. Also, because water is a fluid medium in contrast to the solid material of the land areas, the oceans are far more responsive to the forces of the winds, to the gravitational attraction of the moon and sun, and even to the rotation of the earth itself, than are the land areas. Great storms, such as hurricanes and typhoons, form over the oceans, and the well-known monsoons of the Asian subcontinent come about as a result of pressure differences over the land mass and the ocean. The phenomenon of tides is an excellent example of the responsiveness of the hydrosphere to physical forces and to the rhythms of the universe.

Mountain building and earthquakes

In addition to the changes in the lithosphere and the hydrosphere in response to weathering and erosion and sedimentation, cataclysmic changes have occurred during periods of mountain building through great movements beneath the earth's surface and through volcanic activity. Besides volcanoes, earthquakes are perhaps today's most noticeable evidence of this constant flux of the earth's structure. The causes of earthquakes are stresses building up in and between the blocks or plates of the earth's crust. Shifts occur along what we call faults or disruptions of portions of the earth's crust. We call these shifts **seismic** (seism = a shaking, an earthquake) disturbances. They and even weak tremors are detected by instruments called seismographs. The seismograph measures the intensity of elastic waves that travel through the earth's crust.

Earthquakes that occur under the ocean transmit their energy to the water and can cause great waves called by the Japanese term, *Tsunami*. These are seismic seawaves. It is inaccurate to call them tidal waves, because they are not related to tides.

Space

We can consider the language of space as having two major sections—the traditional language of astronomy and the language of modern space exploration and its accompanying technology.

Astronomy

Astronomy (astro = star, nomy = the science of) goes back to the earliest man. Some of our most charming examples of the picturesque imaginations of early men are still treasured in the names and descriptions given to the **constellations** (con = with, together; stella = star) and in the myths relating to the universe where a majestic hero like Atlas could hold up the sky.

The ancients developed astronomy to an amazing degree—both for its practical value in navigation and as an area of scientific study. From the early concept of an earth-centered universe, they moved to the concept of a **heliocentric** (helio = the sun, centr = the center) or sun-centered system. Gradually men have expanded their observations and speculations about the universe, helped along by the invention of the optical telescope and other technological developments, including the radio telescopes of our own time.

Today we know that we live on the fifth largest of eight **planets** (plane = wanderer) revolving around a medium-size star—our sun. This is our solar system, which is a tiny part near one edge of a galaxy we call the Milky Way. In this century, astronomers have been able to see beyond our galaxy and discover that there are many other galaxies—or universes—out in space.

Astronomy has its own language of description and measurement, based largely on light and radio waves. Distances are so great that they are measured in special units. One of these is the astronomical unit (AU), the mean distance of the earth from the sun. The value adopted for the AU in the International System is 149600 × 10^6 meters. (149,600,000 kilometers). A parsec, another unit of measurement, is the parallax of 1 second of arc with a baseline of one AU. Another special unit is the light-year—the distance traveled by light in one year, nearly 9½ trillion kilometers. Today's astronomers tell us that the *observable* universe is 10 billion light-years in radius. Any stars beyond this distance are moving away so rapidly that, because of the red shift (Doppler effect), their light can never reach us. That is, they are moving away at speeds equal to or greater than the speed of light. Thus, according to present theory, we do not know and never shall be able to know the total size of the universe. The age of the universe is estimated to be at least 5 billion years.

Much of what astronomers are learning about the universe depends on making use of electromagnetic radiation, which is also used in radio, television, and other communications technology. Figure 7 is a diagram of the spectrum of electromagnetic radiation, with major subdivisions. Note the very small segment that is visible light.

FIGURE 7. The Electromagnetic Spectrum

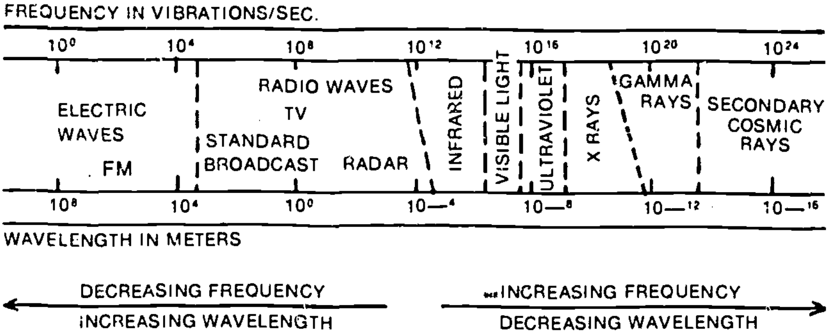


Illustration reproduced from Verwiebe, Frank L.; Van Hooft, Gordon E.; and Suchy, Robert R. *Physics: A Basic Science*. Copyright 1962, Van Nostrand Reinhold Company, Inc., New York.

"Radiation is classified by wavelength, ranging from very long radio waves (3×10^4 meters) to very short gamma waves (5×10^{-11} centimeters). The total range is called the *electromagnetic spectrum*. All of this radiation moves through space at the speed of light.

. . .

"Only a very small portion of the total electromagnetic spectrum penetrates the layer of atmosphere which surrounds earth; visible light does, of course, and so do certain portions of the radio part of the spectrum. When cosmic radiation enters our atmosphere, its character changes; so to study it properly we must study it in space.

. . .

"It is one of the fundamental phenomena of nature that any object, so long as it is not at absolute zero temperature, -273°C, emits a spectrum of electromagnetic radiations. The wavelengths in that spectrum depend only on the temperature of the object. The hotter an object is, the greater the proportion of the shorter wavelength radiation in its spectrum."[2]

. . .

By observing the predominant color in a star's spectrum or the *relative intensity* of the various colors, it is possible to estimate with fair accuracy the surface temperature of the star. In this way, we know star surfaces vary in temperature from below 2000°K (the very dull reds) to above 80,000°K (the high-luminosity blues). . . . If the light source is a luminous gas instead of an incandescent solid, we observe a radically different spectrum: a series of bright lines of color interspersed with black bands. . . . Each element has a pattern of bright-colored lines of light that is its absolute trademark. . . . Because no two elements display identical spectra, the astronomical detective now has a way of "fingerprinting." Once the spectra of the individual elements have been recorded, the composition of any mixture or compound can be determined, whether it is in our own sun, a nearby star, or a distant galaxy.

Other much-used, recent methods of studying the universe are through radio or X-ray astronomy. Large antennas collect

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[2] Hynek, J. Allen. *Challenge of the Universe*. Vistas of Science. National Science Teachers Association. Washington, D.C. Published by Scholastic Magazines, Inc., New York. 1965. Pp. 71-76.

radiation from space, and this can be analyzed by scientists. Pulsars, celestial sources of pulsating radio waves, were discovered by this technique. Earth-bound astronomers are always handicapped by the earth's atmosphere and by the gas or dust in interstellar space. We now have limited observatories in satellites (orbiting astronomical observatory, OAO; orbiting solar observatory, OSO). These and other future observatories above the earth's atmosphere do and will provide clearer views of the universe than are possible from the earth's surface.

Space science

The language of space has become familiar to all television audiences in the last 15 years. When we speak of space science today, we are thinking less of astronomy and more about the principles of gravitation, relationships between the earth and its satellite, the moon, and between the earth and neighboring planets, and the relationships with and energy from the sun. Space exploration, whether by manned or unmanned vehicles, challenges man to develop and use technology in a way that is compatible with the phenomena of the universe. **Aerodynamic** (aero = the air, atmosphere, dynam = power, energy) principles used in airplane flights must be extended to lift the spacecraft beyond the earth's atmosphere and give it sufficient velocity to orbit the earth or follow a planned trajectory toward its destination. The characteristics of space—its lack of atmosphere, for example—must be understood and constantly noted in space flight technology. Life-support systems for the astronauts .demand tremendous amounts of knowledge of and new research into the functioning of biological systems in the conditions of space travel. Investigations into the possibility of life elsewhere in the universe (exobiology) mean that we must identify the indicators of life (amino acids or even carbon) that can be detected by space probes or by manned exploration.

The language of space is a combination of very highly organized and accurate applications of physical laws on one hand and totally new experiences on the other.

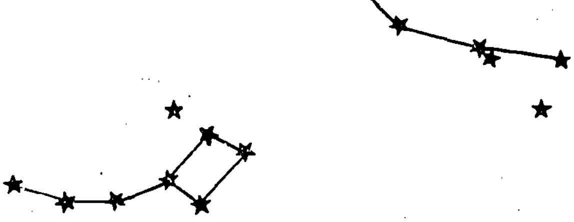
We have said nothing so far about computers, but the space explorations depend on the use of the computer in planning the entire flight and in working out solutions to complicated problems. Computers are used for simulations (models) and for handling data in all of the sciences.

Appendix A contains a selected vocabulary of space terms from the beginnings of the space age. It will continue to grow as our knowledge and capacity for research and exploration develop.

Problems and questions

1. If a man heard a radio time signal for noon in Greenwich, England, and his own watch said 10 A.M., assuming his watch to be correct for the local time, where (i.e., at what longitude) would he be?
2. Use a map to determine the approximate time in London, Tokyo, Honolulu, and Nome, Alaska, when it is 12 noon in New York.
3. A ship at sea sailing east determines the altitude of Polaris to be 36.5° as the ship's chronometer reads 2 A.M. and the Greenwich time chronometer reads 10 A.M. What port is the ship approaching?
4. If one descends to the bottom of the Grand Canyon, one encounters rock of Pre-Cambrian Age. Rocks of which other eras, periods, and epochs would you expect to find in the Canyon? Does this expectation correspond to reality? Why or why not?
5. One of the greatest treasures brought back to earth by the Apollo 15 astronauts was the so-called "genesis rock." Why was it given this name? Does it have an earth contemporary? If so, from what era, period, or epoch?
6. Make up a table (similar to Table 19), Forces and Processes That Have Changed the Moon. How does this compare with the table for the earth?
7. Look up the distinction between rocks and minerals and practice using these terms correctly.
8. Which of the following might we expect to find on the moon?
   a. Oil
   b. Fossils of the Mesozoic Era
   c. Moraines
   d. Craters
   e. Basalt
   f. Regions of troposphere and ionosphere

9. Using the Bergeron system of symbols for air masses, write the code for the classification of air masses involved in
   a. Hurricanes
   b. Snow blizzards
   c. Monsoons
   d. Bright, warm days
10. When scientists "seed" clouds with silver iodide crystals, what natural processes are they trying to replicate and why?
11. If you are traveling in a jet airplane at 30,000 feet (9km), which of the following clouds would you expect to see ahead of the plane? Which might cause the pilot to change course?
   a. Cirrocumulus
   b. Cirrostratus
   c. Nimbostratus
   d. Cumulonimbus
12. When would you expect tides to be highest: at full moon, new moon, or quarter moon? Why?
13. The highest known tidal range is in the Bay of Fundy. Look up the height of the tides there. What explanation can you give for this exceptionally great rise in the water level?
14. What names have we given to the constellations outlined below? Identify some of the key stars.



15. Make up a cloud symbol code for the following activities:
    a. Go to the beach
    b. Use snow tires (in winter)
    c. Hurry home
    d. Close windows and shutters
    e. Fly kites
    g. Go hiking

16. If someone tells you that he receives communications in waves of the following wavelengths or frequency, what kind of an instrument would you expect him to be using:
    a. .5 micron (10^{-6}m) wavelength
    b. 1 ångstrom (10^{-10}m) wavelength
    c. 1 kilocycle frequency
    d. 1,000 kilometer wavelength

References and Further Reading

1. Asimov, Isaac. *The Universe.* Walker & Company, New York. 1967.
2. Carter, Samuel. *Kingdom of the Tides.* Hawthorn Books, Inc., New York. 1966.
3. *Clouds.* Environmental Science Services Administration, U.S. Department of Commerce, Washington, D.C. 1969. (A four-color chart-folder, available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, 25 cents per copy.)
4. Corliss, William R. *Planetary Exploration: Space in the Seventies.* National Aeronautics and Space Administration, Washington, D.C. 1971.
5. Cowen, R. C. *Frontiers of the Sea.* Paperback. Bantam Books, Inc., New York. 1970.
6. Craig, R. A. *The Edge of Space.* Doubleday & Company, Inc., New York. 1968.
7. Earth Science Curriculum Project. *Investigating the Earth.* Houghton Mifflin Company, Boston, Massachusetts. 1967
8. *Exploring the Ocean World.* A History of Oceanography. C. P. Idyll, Editor. Thomas Y. Crowell Company, New York, 1969.
9. Gallant, R. A. *Exploring the Weather.* Doubleday & Company, Inc., New York. 1969.
10. Gamow, George. *Matter, Earth, and Sky.* Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 1958.

11. *Geology and Earth Sciences Sourcebook for Elementary and Secondary Schools.* Robert L. Heller, Editor. American Geological Institute. Published by Holt, Rinehart & Winston, Inc., New York. 1962.
12. *Glossary of Geology and Related Sciences: with Supplement.* American Geologic Institute, Washington, D.C. 1960.
13. Holden, A., and P. Singer. *Crystals and Crystal Growing.* Paperback. Doubleday & Company, Inc., New York. 1960.
14. Hynek, J. Allen. *Challenge of the Universe.* Vistas of Science. National Science Teachers Association. 1965. Pp. 71-76.
15. Simpson, G. G. *Life of the Past: An Introduction to Paleontology.* Yale University Press, New Haven, Connecticut. 1953.
16. Smithsonian Institution. Mimeo. SIL-470. Rev. 1/68. Department of Paleobiology, Smithsonian Institution, Washington, D.C.
17. *Space Resources for Teachers: Space Science.* National Aeronautics and Space Administration. U.S. Government Printing Office, Washington, D.C. 1969.
18. *This Island Earth.* Oran W. Nicks, Editor. National Aeronautics and Space Administration, Washington, D.C. 1970. (For sale by the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.)
19. Van Nostrand's Scientific Encyclopedia. Fourth Edition. Van Nostrand Reinhold Company, Inc., New York. 1968.
20. Zim, H. S., and P. R. Shaffer. *Rocks and Minerals.* Paperback. Golden Press, Racine, Wisconsin. 1957.

CHAPTER 3

The Language of the Laboratory

Science is often thought of in terms of laboratories. One imagines the shiny, gleaming labs of the biologists, or the psychedelic labs of the physicists with their flashing lights and intricate electronic devices, or the malodorous, smoky labs of the chemist and envisions the scientist, complete with white lab coat, delving into the secrets of nature. As romantic as this vision may be, it represents only a small portion of the actual work of many scientists and is usually a secondary outcome of previous efforts. Nonetheless, if you are studying science and wish to understand and communicate in the language of science, you must be familiar with the language of the laboratory.

Science at work is essentially a process of seeking answers to questions or solutions to problems. This is not a haphazard thrashing about for answers, but usually a carefully planned, purposeful attack. Laboratory activities are included in most science courses so that the student may practice this kind of problem solving.

Simply stated, the problem-solving process includes three phases: (1) identifying and specifying the problem, (2) gathering pertinent information to apply toward a possible solution, and (3) proposing a solution and testing its worth or accuracy. None of these is a simple task. Each involves many potential trials and tribulations. To provide the novice in science with some guidelines for attacking problems, most science textbooks discuss a procedure often called "the scientific method," though this is really a misnomer, for there is no one "method."

"The scientific method"

Scientists use many different techniques and approaches in their attempts to solve problems or find answers to their questions. The main value of studying "the scientific method" is that it does provide at least one tested and worthwhile method for attacking problems. Although it is usually discussed step by step, its application to real problems may involve repeating or omitting steps.

Obviously, we must first *identify the nature of the problem* under consideration. For example, are we trying to find out (anatomically) how crickets make their chirping sounds, or are we trying to discover whether a relationship exists between the chirp rate of the cricket and the temperature of its environment? A common difficulty at this stage of the operation is limiting or narrowing the broad problem to reasonable, smaller, and more readily investigated parts. For instance, our major concern may be to investigate possible cures for cancer, but we have several less complex aspects of the problem to consider first. We must understand the operations of "normal" cells before we can recognize "abnormalities" in cancer cells. We may have to analyze our potential test drugs to be sure we know their true and exact compositions before we test them.

A problem is usually written out in one of two forms before it is attacked. It may be stated as a specific question: "What is the melting point of this compound?" "How do birds navigate in the darkness of night?" It may also be stated as a *null hypothesis* (the hypothesis of no difference): "There is no significant relationship between the time of day and the rate of the crickets' chirping." "The compound riboflavin has no significant effect on the embryological development of amphibians."

The actual form chosen for the statement of the problem to be investigated (that is, as a question or as a null hypothesis) is dependent upon several things, including (1) the nature of the problem being investigated, (2) the degree of accuracy desired in the possible solution, and (3) the potential applications of the discovered answer or solution. Other factors are also considered in determining how to state the problem. Stating the problem as a question may be the easier way to begin solving the problem. Using the null hypothesis approach generally requires that statistical data be assembled and the actual significance (mathematical) of the obtained results be determined. Normally, this statistical approach provides results that are more valuable in the sense that they are more likely to represent "true" results rather than a chance occurrence. Many of the student science projects now entered in local, state, and national competitions have a statistical basis.

For those readers who are interested in pursuing the null hypothesis approach to problem solving, more information is available in the books listed in the references at the end of the chapter. Chapter 5 also discusses in some detail the application of several useful statistical techniques to problem-solving situations.

Assuming that we have been able to identify and state rather specifically our problem to be investigated, our next steps are to *gather information pertinent to the solution of the problem.* There are many ways in which such information can be gathered. Obviously, reading related texts, science journals, and reference books and using the other techniques of bibliographic research should be employed as needed and where possible. If someone else has solved our problem, or a closely related one, we may either want to follow his methods and recheck his findings with our materials, or we may accept his results and use them to expand the nature of the problem we are investigating.

Related to the survey of what has already been discovered is the possibility of corresponding with persons recognized as authorities in the area of our concern. But do remember that if you write such a person in the following way: "Dear Sir, I am studying about cancer for my science project. Please send me all the information you have." it is unlikely that you will get a response. Not only is such a request unreasonable, it provides the reader with no certain idea of the nature of your problem or needs. Your chances of a response are much better if your request is for specific bits of assistance and if it is countersigned by your science teacher.

Information pertinent to the problem can also be obtained through observation and cogitation. Energy applied to the thinking processes often provides much pertinent information. Scientists use several modes of thinking processes. One, the "if-then" type of reasoning, is a familiar basic approach. "*If* fiddler crabs are reacting to the physical presence of seawater, rather than to a tidal-based rhythm, *then* they would begin feeding whenever seawater was added to the environment regardless of the tidal condition." "*If* an electric current can be induced by a magnetic field, *then* maybe an electric field can produce a magnetic current." There is room for both *logical* reasoning and *creative* or *novel* thinking in this approach to gathering pertinent data.

Scientists use two main kinds of logical systems, *inductive* and *deductive* reasoning. In the inductive process we try to fit together bits and pieces of related information to develop an overall, inclusive principle, law, or statement that describes the features common to all the specific bits. Much of the paleontological evidence for evolution has been treated in this way. Isolated occurrences of marine fossils in mountainous areas were discovered and reported. Eventually someone inductively reasoned that these independent discoveries indicated that the present mountain areas at some time must have been the floor of an ocean area. This led (maybe through if-then reasoning) to the idea of earth convulsions and shifting oceans and their potential effects on living things over the eons of time.

The *deductive* process proceeds in the opposite direction. It uses the broad principles or statements to deduce specific applications or possible new examples of their application. For example, starting from Einstein's statement describing the relation between mass and energy, it was possible to deduce the idea of nuclear power as a source of energy. Very often the inductive and deductive processes are employed in a cyclic way, developing a new principle from existing examples and using the new statement to deduce novel application.

Mental models

Scientists also use a "mental model" approach to solving problems. Essentially our present concept of the structure of an atom is a mental model; no one has actually seen the structure of any atom. Yet, based upon the types of information scientists do have about atomic structure, it seems a useful and necessary concept. Sometimes to solve a particular problem the scientist constructs a mental model and then uses reasoning processes or experiments to test the correctness of the model.

One type of mental model is often called the "black box." The scientist knows that if certain treatments are applied, he can predict accurately that certain results will occur. He doesn't yet understand why, so he calls the processes not yet understood a black box. It then becomes his challenge to pry open the black box (figuratively) through reasoning, experimenting, and other means in an attempt to understand why those specific causes produce those specific results. Much of the earlier investigation into the photosynthesis process was a black-box type of research. Scientists knew what went into the process (i.e., carbon dioxide, water, and light energy) and what was produced (carbohydrates and oxygen), but until the advent of electron microscopy and radioactive tracers, how and where these events occurred were locked in the black box.

Experimental design

We have seen some examples of how scientists use their minds as laboratory tools. Wherever possible, the implications of the thought processes are checked by experiment or observation. To understand science and become proficient in the language of science, you also should practice the mental manipulations, not only in your science courses, but for other purposes as well. Problems at the end of the chapter will help you get started.

An equally important way to gather information that may be pertinent to solving a problem is through actual experimentation. This requires a careful plan or design. Designing a scientific experiment to provide meaningful data has very special requirements. Let us consider some of the language employed in the development of good laboratory experimental design and in experiments.

Basically, the scientist is concerned with manipulating *variables*. Variables are the different factors, aspects, or traits that may affect the results of the experiment. For example, in working with ideal gas problems, the physics student is concerned with at least three variables: pressure, temperature, and volume of the gas. Other related variables might include the kind of gas (active or inert) or the molecular nature of the gas.

Variables may also be classified into different types based upon their role in the experiment. For example, the *independent* or *experimental variable* is the one which is given different known values; the *dependent variables* are those values which change as the independent or experimental value changes; *irrelevant variables* are those believed to have no effect on the outcome (though a researcher usually attempts to check this assumption). In order to be able to compare the effects of certain variations of conditions with what would have happened had there been no changed or experimental condition, one uses a *control* quantity or subjects.

In designing a good experiment, we are usually concerned with controlling or equalizing all the variables except one, which is the independent or experimental variable. Suppose that we wish to study the effect of changes of pressure on the volume of a gas. Pressure then becomes the independent or experimental variable, which we give different values. The dependent variable is the volume. Since we wish to study only the effect of changing the pressure on volume, we hold the temperature constant (or try to). We keep all other factors the same by using the same kinds of devices and equipment for all of our experiments. In order to determine whether temperature and kind of gas are relevant or irrelevant variables, we would need to do our experiment with several gases and to measure the temperature. If the relationship between change in pressure and the resulting volume are always the same, we can assume that temperature and kind of gas are irrelevant in this experiment.

If we are studying the effect of a vitamin spray on the growth of plants (see Chapter 5), the applications of the spray are the experimental variable, and the amount of growth of the plant is the dependent variable. We must have control plants which are identical to the experimental plants and which are kept in the same environment in all respects except that they receive no spray.

The scientist must attempt to control all possible variables except the experimental ones. Often hidden ~~or~~ unknown variables are operating during the experiment, and this is not discovered until much later in the investigation, whereupon all earlier work must be repeated. Therefore, it is important to think through each proposed experiment before it is undertaken, trying to discover any possible weaknesses in the plans.

For example, as one part of a series of experiments in which we are attempting to investigate the effect, if any, of salinity on amphibian embryo development, we may do the following. We collect many fertilized frog eggs from an aquarium containing only one pair of adult frogs. Our purpose for this is to control the variable of genetic influences. If all the eggs used in our experiment are produced by the same pair of frogs, they are more similar genetically than eggs collected from many different pairs of frogs. We place the eggs in a bowl of fresh water.

In this part of the series of experiments, we are trying to determine at what point in its development, a frog embryo will be affected by being immersed in a saline solution. Therefore, we prepare a saline solution of known strength—to control the variable of concentration of the solution used in the experiment. We maintain our original bowl and our experiment bowls in a chamber where the temperature, the humidity, light level, oxygen tension, and other environmental factors are held constant or controlled. Each successive day of our experiment we isolate 10 eggs from the large clutch into a smaller bowl and add a measured quantity of the saline solution to the known volume of water in the small bowl. Our experimental variable here is *time*. The eggs which remain in the original container and are not exposed to the saline solution become our control set. For the remainder of our experiment we observe the development of all the eggs. When tadpoles are produced, we examine them for anatomical or physiological variations.

In this (imaginary) experiment we have many dependent variables but, we hope, only one experimental variable—time. However, we would be overlooking a hidden variable if we considered only the length of time (number of days) that the eggs were exposed to the saline solution. For time also passed (and embryological growth occurred) from the moment of fertilization to the day of the experiment. In other words, our results from the experiment could be due to the amount of time which passed before the eggs were exposed to the saline solution or to the amount of time which the eggs spent in the saline environment.

A good experiment is not only concerned with having only a single experimental variable, but also with having a large enough sample of experimental material to overcome the possible effects of chance. Suppose we had used only one frog egg each day in our experiment bowls and that the egg exposed to saline on the sixth day died within 24 hours. We might be tempted to conclude that "saline solution of a certain strength is fatal to the six-day frog embryo." However, possibly that single embryo was doomed to expire for some other unrelated (perhaps genetic) reason. Our conclusion would therefore be incorrect. With 10 eggs in each bowl and all of the six-day embryos dying within 24 hours of exposure to the saline solution, our conclusion might be more likely to be correct. If there had been 100 eggs in the bowl and all embryos died, we might feel pretty certain about our conclusion. Nevertheless, we would want to continue the experiment through subsequent days until the control eggs hatched.

Another way in which scientists try to validate their conclusions is to repeat the experiment several times, using (in our example) new eggs from other pairs of frogs. If in every case all 10 of the six-day old embryos die, we again have some certainty about our findings.

When we have gathered as much pertinent information or data as we can, our next obvious step is to *form one or more conclusions* based on these data. A conclusion is, in part, the obtained answer to our problem. Generally, a conclusion will also have certain implications which suggest ways to test the accuracy or reliableness of our obtained answer. In our previous problem assume that we did find a significant effect of that concentration of saline when it was administered to developing frog embryos at a certain point in their maturation. Our only safe conclusion based on that experiment might be the following statement: "Fertilized eggs of *Rana catesbiana*, when exposed to a 0.1N sodium chloride solution on the sixth or subsequent day of development, undergo cytolysis and disintegrate. No such effect was noted for this concentration of saline when it was administered on any day prior to the sixth day of development." We have tried to state our conclusion in such a way that it does not imply anything but what we discovered in our experiment.

Immediately, however, we can see several possible further experiments that should be conducted. Repetition of the same saline concentration with eggs from other *Rana catesbiana* parents as a check on the role of genetic makeup, if any, might be undertaken. The effect of varying the concentration of the saline solution should be investigated. Perhaps fertilized eggs from other frog species (say *Rana sylvatica*) and toad species or other amphibian eggs should also be exposed to our original concentration of saline to see whether this is a common outcome for all amphibians or peculiar to our experimental species.

From another point of view, we might wish to consider the implications of our first conclusion regarding the effect of saline pollution on natural frog breeding environments and observe the frequency of tadpoles in ponds where salinity levels exceed our critical concentration.

The previous discussion suggests one of the peculiarities of scientific research. Finding the answer to one question often provides the investigator with a group of new questions that must be investigated and answered. Perhaps you can see how a scientist might devote his entire career to trying to understand fully a small portion of science.

In retrospect, we have seen that, although we may list certain procedures as the steps of "the scientific method," the actual processes of scientific investigation are rarely that simple. Essentially, the language of the science laboratory is related to the processes involved in finding the best possible answers to problems. The discussion may also suggest why the best science projects are almost never the ones that were started a week before a deadline. Rather, the best projects are the results of student work that has incorporated the procedures and language of the scientist's laboratory.

Problems and questions

1. Assume that you have the following dry ingredients mixed together in equal small quantities in a beaker: sand, table salt, sulfur, iron filings, and moth crystals. The problem is to separate the mixture into five piles, each containing one of the substances. As an exercise in reasoning, write out how you would accomplish the separation.

2. There are many problems of the following type, which involve thinking and reasoning to solve them.
   The President, Actuary, Agency Vice-President, and Corporate Secretary of a certain insurance company are Mr. Lidstone, Mr. King, Mr. Sprague, and Mr. Watson, but not necessarily respectively. Mr. Sprague served with the President in World War II. Mr. Watson hopes to be the next President. Mr. Lidstone and the Secretary like to go to the theater together. Mr. Sprague beats the Actuary at gin rummy. Mr. Lidstone is an artistically minded young man. Mr. Watson never goes to the theater or plays cards. What are the respective names of the company's officers?

3. As an exercise in identifying problems, try listing possible problems for investigation from the broad areas of research listed below. Make your statements in the language of the laboratory.
   a. Is smoking cigarettes hazardous to human health?
   b. How can corrosion in automobiles be prevented?
   c. What is death, or why do people die at advanced ages?
   d. Is the earth's climate changing significantly over the years?
   e. How do animals communicate?

4. As an exercise in gathering pertinent information to solve a problem, select one of the specific problems you listed above and (a) describe how and where you might gather bibliographic information pertinent to it (be specific), (b) describe the design of a good experiment which might provide pertinent information.
   If you are looking for a science project idea, why not carry out your suggestions in (a) and (b) and see whether they do provide pertinent information.

5. Set up experiments in which you identify the effects of various concentrations of several chemicals (inorganic and organic) on the development of amphibian eggs, earthworm eggs, ant eggs, etc.

References

The references with Chapter 6 will be useful also for learning about the language of the laboratory.

CHAPTER 4

The Language of Mathematics in Science

Mathematics is sometimes called the "Queen of the Sciences" and is also called the "Handmaiden of the Sciences." Probably both terms reflect truisms about the relationships between mathematics and science. Mathematics provides scientists with various tools to make their findings more accurate and more reliable. It also provides scientists with a model to attempt to emulate.

Science has always been concerned with quantitative measurements. Therefore, to study and learn science, you, too, should be able to work with and think in terms of quantitative ideas. No difficult mathematical skills are generally required beyond addition, subtraction, multiplication, and division. What is involved in learning the mathematics of science is to learn what the various techniques are used for and how these techniques can help you. Now let us look at some mathematical terms and techniques.

Exponents

An *exponent* is a **superscript** (above - writing) number like the 2 in 10^2. The 10 is called the base, and the exponent 2 indicates the number of times the base is used as a factor. Thus 10^2 means two 10's are to be multiplied. This is also called raising a number to a certain power—10^2 is 10 to the second power. Table 24 shows the relationships of exponents and decimal equivalents.

Scientific notation

Because the scientist deals with extremely large numbers and extremely small numbers, he has developed a shorthand method for dealing with these types of numbers.

A common mathematical technique used in science is concerned with making these extremely large or small numbers easier to work with. It is often called "scientific *notation*" and is based upon the use of the powers of 10.

TABLE 24. Exponents and Decimal Equivalents

Base and Exponent		Decimal Equivalent
$10^1 = 10$	=	10.
$10^2 = 10 \times 10$	=	100.
$10^3 = 10 \times 10 \times 10$	=	1000.
$10^{-1} = 1/10$	=	0.1
$10^{-2} = 1/\ (10 \times 10)$	=	0.01
$10^{-3} = 1/\ (10 \times 10 \times 10)$	=	0.001
$10^0 = 1$	=	1.

Any number (except zero itself) raised to the zero exponent is equal to one.

To make a very large number more manageable, we factor the number into a product $m \times 10^k$, where m is a whole number between 1 and 9, inclusive; and k is an integer. Thus: $7{,}000 = 7 \times 10^3$; $7{,}523 = 7.523 \times 10^3$. In both instances we divide by 10 to the third power (1,000), but drop the zeros in the first number, rather than show them as decimals.

To make a very small number, such as a decimal fraction, more manageable, we use a similar procedure but multiply by the power of 10 and then show 10 to that minus power when we write the formula. For example: $.0007 = 7 \times 10^{-4}$; $.7523 = 7.523 \times 10^{-1}$. Note that the exponent on 10 is the same as the number of places we moved the decimal point to the right for the minus power and to the left for the positive power.

Significant digits

The problem of significant digits brings us to the question of accuracy and to the refinement used in our measurements. Any measurement can be made with only a certain degree of accuracy. Error can creep in from three sources: (1) The accuracy with which you measure. (2) The accuracy of the instrument you are using. (Think of measuring with a regular ruler which may be accurate to the nearest eighth of an inch as compared to measuring with a machinist's **micrometer** (micro = tiny; metr = measure) which may be accurate to the nearest one-thousandth of an inch). (3) Accuracy can also be affected by the thing being measured. (Think of the problem of getting an accurate weight of a live, squirming rabbit, or the effect of the temperature on the actual length of a metal rod which expands with warmth and contracts in the cold.)[1]

"Numbers may be precise to within intervals of a given size, such as to the nearest mile, the nearest tenth of a second, or the nearest ten-thousandth of a unit; or again, numbers may be accurate to a given percent or to a given number of significant digits—although this special use of words is not universally adopted."[2]

Thus we have two elements of concern here: possible error in our measurements and the degree of accuracy which we can achieve with the measuring instrument being used. Let us assume that we have a ruler which is marked to tenths of centimeters. We can measure with accuracy to a tenth of a centimeter. But with this measuring instrument, we could not determine hundredths of a centimeter. When we are measuring in tenths, the quantity to be measured may fall beyond one of the tenth marks but not reach the following one. The amount between these two tenth markers is called the *error in measurement*. This is a mathematical expression and does not mean a mistake in measurement. Obviously this amount (often called an apparent error) in measurement will always be less than a single unit in terms of which a measurement is stated. Therefore, an apparent error is assumed to be equal to and never greater than 0.5 of a unit in terms of which the measure is expressed. We measure a small card and find it to be 4.6 centimeters long and 3.4 centimeters wide. This is our most accurate measurement. The error of measurement would lie somewhere within the next tenth of a centimeter. Therefore we recognize that we are dealing with an approximate number.

We are confident of the accuracy of our measures 4.6 and 3.4. The term *significant digits* is used to indicate this confidence.

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[1] It is often difficult to decide whether to use "accuracy" or "precision" when speaking of measurements. Here are definitions that help to clarify the distinction between the meanings of these two words.

accuracy (as distinguished from precision)–the degree of conformity of a measured or calculated value to some recognized standard or specified value. This concept involves the systematic error of an operation, which is seldom negligible.

precision (as distinguished from accuracy)—the degree of mutual agreement between individual measurements, namely repeatability and reproducibility.
From *Metric Practice Guide*. American Society for Testing and Materials, Philadelphia, 1970. P.12.

2 From *Approximate Computation* by Aaron Bakst. The National Council of Teachers of Mathematics, Washington, D.C. 1966. p.v.

Here we have two significant digits, and only two. Now suppose that we wish to determine the area of our card and multiply 4.6 × 3.4. We obtain 15.64 square centimeters. This suggests greater accuracy than we were able to obtain with our measuring instrument.

Also since we can have only two significant digits, we round off our answer to 16. (Some texts may use the term significant figures and give the general rule that the significant figures are the digits which are certain and one more. For our example this would be 15.6. See *Chemistry, An Investigative Approach*. By F. Albert Cotton and Lawrence D. Lynch. Houghton Mifflin Company, Boston. 1968.)

If we had a more accurate ruler, we might obtain measurements of 4.63 and 3.47 centimeters (three significant digits) and our product for the area would be 16.0661 square centimeters. Because we have only three significant digits, we express the area as 16.1 square centimeters. Numerical results, before they are stated in final form, should be obtained with at least one more digit than the number of significant digits allowed by the approximate data. Then this last digit is rounded off. [4, p. 54]

Some general rules for determining significant digits when working with approximate numbers are:

1. A product or quotient of numbers has as many significant digits as the least accurate of the numbers.
2. A sum or difference of numbers is as accurate as the least accurate of these numbers, and the answer must have the same number of decimal places as the least accurate one. Rounding off here is done before the calculation is made.
3. In rounding off, numbers less than five are dropped. For numbers greater than five, raise the next digit to the left by one. If the number is a 5, carry it in the calculations until, and if necessary in, the final answer.

The following examples may help to clarify the general rules given above: 21.342 becomes 21.34, while 21.347 becomes 21.35, and 21.345 remains 21.345. Some textbooks (or teachers) may use slightly different methods for dealing with the problem of rounding off a number like 21.345. Be sure to check on this when the occasion requires.

The techniques of using scientific notation and significant digits are useful and applicable to most mathematical situations in science. However, as for most other skills, their effective use depends upon practice and application. Some practice problems are provided at the end of the chapter.

Now we will consider some slightly more sophisticated mathematics techniques which can help you be more successful with the mathematical language of science. They do not involve any more advanced mathematics than the previous techniques, but they do help to explain why certain procedures are employed.

Dimensional analysis

Dimension (dimensio = to measure out) as we are using it here refers to the nature of a quantity—for example 5 meters and 10 seconds indicate dimensions of length and time, respectively. In an equation the quantities on the two sides must have the same dimension. In the equation 100 centimeters = 1 meter, both have the same dimension—length.

In physics and chemistry, students sometimes have difficulties in working with mathematical problems in which several conversions must be made between units. For example, they may know the *constant* which describes the relationship between units, but are uncertain whether to multiply or divide with the constant. Here, a technique known as dimensional analysis can be very helpful. In this technique one pays equal attention to the labels or units (dimensions) under consideration and to the actual numbers involved. An example of its use should make the technique clear.

Problem:

Starting with the two facts that 1 inch equals 2.54 centimeters and 1 mile is 5,280 feet, determine how many kilometers equal one mile.

Attack:

1. List all the conversions that are needed.
   a. miles to feet
   b. feet to inches
   c. inches to centimeters
   d. centimeters to kilometers

2. Describe the conversion factors involved.
   - a. 1 mile equals 5,280 feet (5,280 ft/mi)
   - b. 1 foot equals 12 inches (12 in/ft)
   - c. 1 inch equals 2.54 centimeters (2.54 cm/in)
   - d. 100,000 centimeters equal 1 kilometer (10^5 cm/km)
3. List the required label of the answer: kilometers per mile (km/mi)
4. Write out the necessary conversion process, step by step, and cancel out any labels possible.

   $$\frac{5{,}280\,\cancel{\text{ft}}}{1\text{ mi}} \times \frac{12\,\cancel{\text{in}}}{1\,\cancel{\text{ft}}} \times \frac{2.54\text{ cm}}{1\,\cancel{\text{in}}} \times \frac{10^5\text{ cm}}{1\text{ km}}$$

5. See what labels are left for your answer to be expressed in. In this example our answer would be $\frac{\text{cm}^2}{\text{mi}\cdot\text{km}}$, which is not what we need. We saw in 3 above that our answer should be expressed in km/mi.
6. Determine which portion(s) of the conversion process statement (in 4 above) must be inverted to cancel out the undesired labels and produce the required answer labels.

   In this example we must invert the centimeter-kilometer relationship. Now our corrected statement reads:

   $$\frac{5{,}280\,\cancel{\text{ft}}}{\text{mi}} \times \frac{12\,\cancel{\text{in}}}{1\,\cancel{\text{ft}}} \times \frac{2.54\,\cancel{\text{cm}}}{1\,\cancel{\text{in}}} \times \frac{1\text{ km}}{10^5\,\cancel{\text{cm}}}$$

   This gives us the relationship we need for our answer; namely, km/mi.
7. Now solve the mathematical statement and label your answer.

   $$\frac{5{,}280 \times 12 \times 2.54}{10^5} = 1.61\text{ km/mi}$$

Let us apply the technique of dimensional analysis to an engineering problem.

Problem: A man swings a 10-pound hammer through an effective distance of 4 feet in driving a stake. How much horsepower is he producing per minute if he makes 5 swings per minute?

Attack: (The numbers below refer to the comparable steps in the preceding problem.)

1. Conversions that will be needed
   a. weight × distance equals foot-pounds (ft-lb) (work) per swing
   b. swings per minute to swings per second
   c. work per swing to work per second
   d. work divided by time equals power
   e. ft-lb per second to horsepower
2. Conversion factors and values involved
   a. weight × distance equals ft-lb
   10 lb × 4 ft equals 40 ft-lb/ swing
   b. 5 swings per min equal 5 swings per 60 sec
   c. 5 swings per 60 sec equal 200 ft-lb/60 sec
   d. 40 ft-lb/swing times 5 swings/60 sec equals power/sec
   e. horsepower = 550 ft-lb/sec
   f. 1 min = 60 sec
3. Required label:
   hp (ft-lb/min)
4. $\frac{10 \text{ lb} \times 4 \text{ ft}}{\text{swing}} \times \frac{5 \text{ swings}}{60 \text{ sec}} \times \frac{550 \text{ ft-lb/sec}}{\text{hp}}$
5. We can see that hp should not be in the denominator for our answer to be labeled correctly.
6. $\frac{40 \text{ ft-lb}}{\text{swing}} \times \frac{5 \text{ swings}}{60 \text{ sec}} \times \frac{\text{hp}}{550 \text{ ft-lb}}$
7. $\frac{40 \times 5}{60 \times 550} = .0061 \text{ hp/sec}$
8. $.0061 \text{ hp/sec} \times 60 = .366 \text{ hp}$

Some examples in which you may employ the techniques of dimensional analysis are provided at the end of the chapter.

Ratio, proportion, and equations

Many of the problems of science concern the relative proportions of variables or the writing of an equation which describes the relationships among variables. The following discussion of these mathematical techniques may assist the student in better understanding the reasoning involved in the manipulations that must be performed. Table 25 gives some of the symbols used to indicate these and other relationships.

TABLE 25. Standard Signs and Symbols[a]

+	Plus	⋜	Less than or equal to
−	Minus	≶	Less than or greater than
×	Multiplied by	⩾	Greater than or equal to
÷	Divided by	≥	Greater than or equal to
=	Equal to	≧	Greater than or equal to
±	Plus or minus	⋝	Greater than or equal to
∓	Minus or plus	≎	Equivalent to
⩲	Plus or equal	≭	Not equivalent
⧺	Double plus	⧥	Not equivalent
≏	Difference between	⊂	Included in
∹	Difference excess	⊃	Excluded from
≡	Identical with, congruent	∼	Difference
≢	Not identical with	∽	Difference
≠	Not equal to	⋕	Equal and parallel
≈	Nearly equal to	≐	Approaches a limit
≅	Equals approximately	≞	Is measured by
≌	Equals approximately	·	Multiplied by
⋝	Equal to or greater than	:	Ratio
⋜	Equal to or less than	∷	Proportion
<	Less than	′	Minute
⊐	Less than	″	Second
>	Greater than	°	Degree
⊏	Greater than	Σ	Summation of
≷	Greater than or less than	π	Pi (3.1416)
≮	Not less than	ε	Base (2.718) of natural system of logarithms
≯	Not greater than		
⩽	Less than or equal to	Δ	Delta
≤	Less than or equal to	∝	Variation
≦	Less than or equal to		

[a] *A Manual of Style*. Twelfth Edition. The University of Chicago Press, Chicago, Illinois. 1969. Pp. 312-313.

The **ratio** (rati = rate, proportion) of a number a to a second nonzero number b is the quotient a/b. (If a is 6, and b is 3, the ratio of 6 to 3 is 6/3 or 2 to 1.)

Note that if $b = 0$, the quotient a/b is undefined.

An **equation** (equa = equal) in mathematics is a statement of equality of mathematical expressions.

A **proportion** (pro = for; portio = portion) is a statement of the equality of two ratios, for example, $a/b = c/d$. This may also be written as $ad = bc$. Any part of the statement may be described in terms of the other three variables. Thus, $a = bc/d$ or $b = ad/c$. If a is 6, b is 3, c is 8, and d is 4, $6/3 = 8/4$ or $6 \times 4 = 3 \times 8$, and $6 = (3 \times 8)/4$ or $3 = (6 \times 4)/8$.

Considering the statement, $a = bc/d$, we can describe the type of variation involved between a and the other variables, b, c, and d. Thus a varies *directly* as the product of bc, or the product of b times c. (As the product bc increases, the value of a also increases.) We can also say that a varies *inversely* with respect to d. (As the value of d increases, the value of a decreases.) In general, a linear function specified by an equation of the form $y = mx$, $m \neq 0$ is called a direct variation, and a function specified by an equation of the form $xy = k \neq 0$ is called an inverse variation.

Let us suppose that we know that two variables are related directly (as one increases, so does the other) but we do not know the specific relationship between them. We can introduce a constant k (even if we don't know the value of the constant), and we have $a = bk$, or $a/k = b$. Often our problem then becomes one of substituting known or measured values of a and b to determine the value of k. Sometimes we can obtain the value of k from a reference book or table and determine unknown values of a from known values of b.

Consider the simple example that follows. "The more hours I work per week, the more money I get paid." This is a description of a direct relationship between two variables: hours and money. Now let us introduce a constant k, the hourly pay rate in dollars. Let a equal the number of dollars I am paid each week and b equal the number of hours worked per week. From the nature of the sentence we can write an equation $a = bk$. If I know the values of a and b for any one week I can determine the value of k. Suppose a is 60 dollars and b is 40 hours. The value of k is then $1.50 per hour. On the other hand, if I know *k* is \$1.50 per hour and *b* is equal to 10 hours, then I can predict *a* to be \$15.

Frequently, the problems of science are of this general type, but the simplicity of the solution is hidden in the complexity of the statement of the problem (or in the notational scheme one uses to translate the problem).

Consider a typical chemistry or physics gas-law problem. Remember that Robert Boyle showed that the volume (*V*) of a gas was inversely related to its pressure (*P*) if the temperature remained constant. Based on the discussion above write both a proportional statement and an equation to describe Boyle's statement. If you use V, P, and *k* in your statement, it should read as follows: $VP = k$. Later, J. A. C. Charles and, independently, J. L. Gay-Lussac, discovered that if the pressure of a gas remains constant, an increase in its temperature brings about an increase in its volume. Write the statement which describes this relationship. You probably wrote: $V = Tk$ which would be correct. We can combine our two sets of statements into what is called the "general gas law"; namely, $PV/T = k$, where the value of *k* depends upon the sample under consideration.

When you have some gas-law problems to work, remember the simple problem about a week's pay and apply that type of thinking to the data given. If you use the techniques of dimensional analysis (and can multiply and divide without error) you should get the correct answer every time.

Graphs

When we have a situation in which two variables are related, either directly or inversely, we can construct an equation. If we then substitute different values for one of the variables, we can determine the corresponding values for the other variable. In our problem dealing with number of hours worked and amount of money paid, we determined the value of *k* to be \$1.50 per hour. Using the equation $a = bk$, we can construct a table of values for any possible number of hours worked (*b*) and amount of money to be paid (*a*). Table 26 is such a table.

Now, if we use graph paper we can construct a graph or picture of this relationship, as is shown in Figure 8.

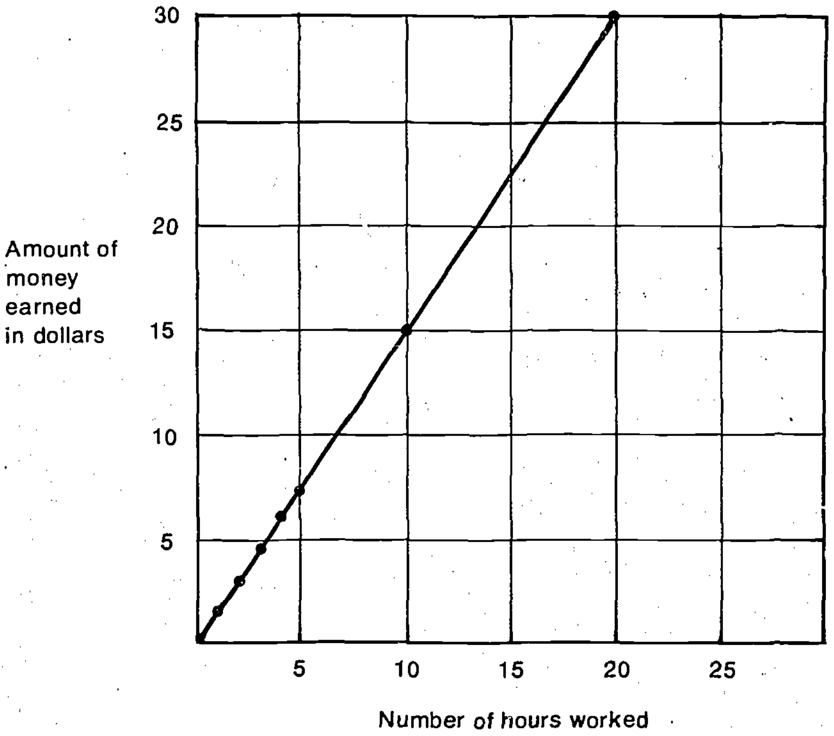
Such a graph, when carefully and correctly constructed, can be used for **interpolation** (inter = between, among; pol = an axis); that is, finding values for either of the variables within

TABLE 26. Pay Table

$a = bk$, where $k = \$1.50$/hour

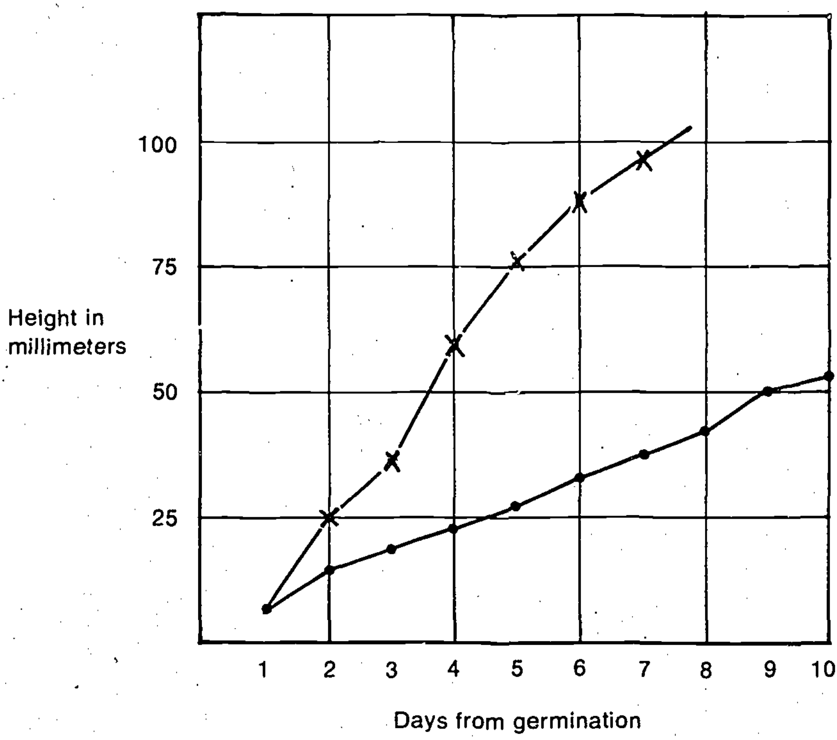
a Amount of money earned	b Number of hours worked
\$ 1.50	1
3.00	2
4.50	3
6.00	4
7.50	5
15.00	10
30.00	20

FIGURE 8. Pay Table (at rate of \$1.50 per hour)



the portion of the graph between known or plotted variables. Thus, we can determine, from the graph of the pay table, that if we work nine hours, we can expect to be paid approximately $13.50 or that in order to earn $18.00 we must work 12 hours. One must keep in mind, however, that graphical interpolation is an efficient method of estimation, but as such the answers are only approximate. This is more clearly shown in Figure 9, where we have plotted the growth patterns of plants. The graph can also be used for **extrapolation** (extra = outside, beyond; pol = an axis); that is, finding values for either variable beyond the limits of our known or plotted values. Thus, if the preceding graph line were extended to the right and our "number of hours worked" and "amount of money earned" baselines were extended, we could determine that 40 hours of work would earn us $60 or that we could earn $54 for working 36 hours.

FIGURE 9. Growth Patterns of Plants
(x - experimental ● - control)



When more than one set of data are plotted on the same graph (for example the heights of control plants and the heights of experimental plants), we can make reasonable statements about the outcomes of the experiment by looking at the graph. In Figure 9, the two graph lines represent the growth patterns of two sets of plants, an experimental set and a control set, over a period of 10 days. It is obvious from the graph that the experimental plants rapidly outgrew the control plants during the period of the experiment.

The use of graphs makes it possible for the scientist to display much of his data in a less tedious manner than in tables or narrative. The use of graphs also makes it much easier for the reader to understand and interpret the outcomes of the experiment. As you read science textbooks and articles which contain graphical representations of the data, take the time to interpret and understand what data are presented and what they mean.

Understanding the language of mathematics in science has at least two aspects of importance. The first is to know the various ways in which mathematical treatments can help you find answers to your questions. The second involves using these techniques correctly. To develop competency with both aspects of mathematics requires practice. Nothing can be more dismaying than to work through a problem in science, gather data, draw conclusions, and then make a simple computational error in your treatment of the data. As in most things, time spent in careful work and in checking results several times usually pays off in time saved over all. Computers are of tremendous help in computations and in handling data, but only to the extent that the person directing the computer understands what he wants the computer to do.

The next chapter also deals with mathematics. It will introduce you to some simple techniques of statistics and explain how these techniques can help you determine the reliability or significance of your obtained experimental results. Properly used, such techniques are a powerful ally for the scientist and an important part of the language of science.

Problems and questions

1. Express the following numbers as decimal equivalents.

a. 36.25×10^3 b. 3.625×10^3 c. 0.3625×10^3
d. 36.25×10^{-3} e. 3.625×10^{-3} f. 0.3625×10^{-3}

2. Express the following numbers in scientific notation.

   a. 2,000,000 b. 7,049 c. 2,374.65
   d. 0.186 e. 8.0 f. 0.0000437

3. Assuming the numbers involved are approximate, express the answers to the following problems.

   a. $21.35 \times 1.1 =$ b.
   $$\begin{array}{r} 3.467 \\ 12.23 \\ 0.16 \\ + \ \underline{14.543} \end{array}$$
   c. $96.0/20.5 =$

   d.
   $$\begin{array}{r} 4.35 \times 10^2 \\ \underline{\times \ 6.644 \times 10^3} \end{array}$$

4. Solve the following problem using dimensional analysis techniques. At 5 cents per kilowatt-hour, what is the cost of running an air-conditioner motor for 30 days if the motor takes 200 watts and runs a total of 10 hours each day?

References and Further Reading

A very useful book for a general understanding of the language of mathematics is the following:

1. Monroe, M. C. *The Language of Mathematics*. The University of Michigan Press, Ann Arbor, 1963.

Two books produced by the National Science Teachers Association which will be very useful for understanding more about the language of mathematics in science are:

2. Guidry, N. P., and K. B. Frye. *Graphic Communication in Science*. National Science Teachers Association, Washington, D.C. 1968.
3. Youden, W. J. *Experimentation and Measurement*. Vistas of Science series. National Science Teachers Association, Washington, D.C. 1962.

Other suggested books are:

4. Bakst, Aaron. *Approximate Computations*. Twelfth Yearbook of the National Council of Teachers of Mathematics. Washington, D.C. (See particularly Chapter V, "Approximate Computation: Approximate Numbers," and Chapter VI, "Approximate Computation: Numerical Operations.")
5. Hatcher, W. S. *Foundations of Mathematics*. W. B. Saunders Company, Philadelphia, Pennsylvania. 1968.
6. Menninger, K. W. *Mathematics in Your World*. (Grades 9-12). The Viking Press, Inc., New York. 1962.

CHAPTER 5

Statistics in the Language of Science

When scientists, or other people for that matter, enter a new area of study, they first try to get a picture of the field in general. If they have an idea of the structure or the aims of the field, they have a better idea of how the details of content or processes fit together. **Statistics,** we find, is the science dealing with the collection, organization, analysis, and interpretation of numerical data. Some of its techniques are descriptive, others are inferential and are concerned with the conclusions that can be drawn from the data.

Science is largely quantitative by the nature of its concerns. Therefore, whenever possible, the results of an investigation are expressed in numerical terms. This chapter will discuss some of the statistical techniques that you can use in handling the data from your own investigations.

Collection of data

Choice of the sample to be studied and accuracy of measurements are probably the most important aspects of the data-collection phase of a scientific investigation.

We usually speak of the group of units being studied as the *sample*. The total number of like units is called the *population*. For example, a plant population might be 500 or more—that is, there are 500 or more plants of the same kind in the area under study. From these we select a sample for our investigation.

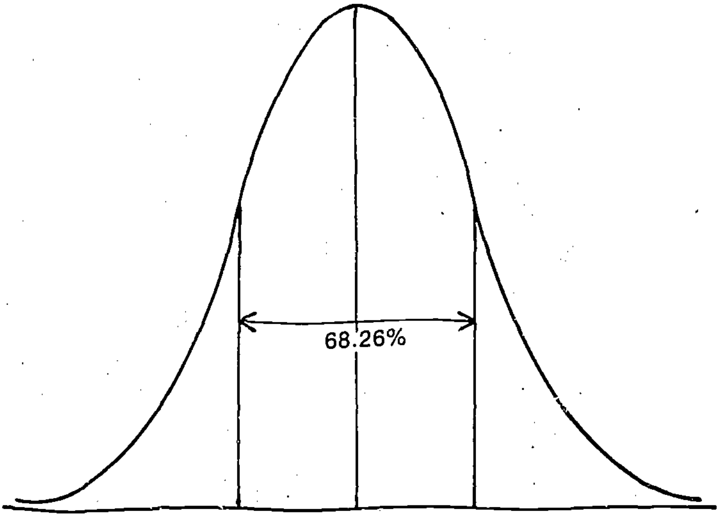
The investigator chooses a sample of the size that will provide the information he is seeking. When a sample is used, the investigator is usually interested in some characteristic(s) of the total population. But since he cannot observe every individual in the population, he selects a sample which he hopes will be representative of the total population. Being able to determine a sample of the appropriate size and makeup is in itself a very important skill in statistics.

Organization and analysis of data

Measurements of groups of units in a study show a tendency to group about a certain point, called the *central tendency*. The so-called "normal" distribution when plotted on a graph makes a symmetrical curve as shown in Figure 10. However, this is really a hypothetical curve, because it is based on the expected data for very large groups of observations, whereas most studies include relatively few observations. Nevertheless one can expect that the measurements will tend to cluster at about the midpoint of the range of measurements.

Statistics uses terms such as the *mean* and *median* to describe the central tendency or "average" measure of a sample. The arithmetic mean, or simply mean, which we often call the average, is derived by adding all of the quantities together and dividing by the number of units included. The *median* is the point at which half of the units are below and half above.

FIGURE 10. Normal Distribution



"Normal" distribution showing the percentage of the area included within one standard deviation measured both plus and minus about the arithmetic mean.

Arkin, Herbert, and Raymond R. Colton. *Statistical Methods*. Fifth Edition. Barnes & Noble, Inc., New York. 1970. P. 43.

If we are investigating plant stem elongation, we can report that the *mean* growth for the plants over a certain period of time was, for example, 12.5 mm. This would imply that some plants had grown less than this amount, and some had grown more, but the average growth was the figure given.

If we report that the *median* growth was 12.5 mm, this tells the reader that half of the plants had grown more and half had grown less than 12.5 mm. Remember that the *mean describes the average* growth, and the *median describes the point which divides the* plants *into two numerically equal groups* on the basis of amount of growth.

Measures of central tendency

We mentioned the mean and median as two examples of measures of central tendency. Let us see how these values are determined and what information they provide. Table 27 lists the heights of two sets of plants at the end of a 20-day experiment period. There were 40 germinating seeds in each of two trays—one experimental and one control—at the start of the experiment. Both trays were maintained at the same temperature, humidity, and location, and both were sprayed with equal amounts of water daily. The experimental plants had a known amount of a water-soluble vitamin dissolved in their daily spray; the control plants did not. The basic purpose of the experiment was to determine the effect, if any, of applied vitamin spray on the growth rate of this type of plant.

In Table 27 we have recorded the height of each plant in the two sets and arranged the figures in order of magnitude for each set. Then we have determined the mean and median height of each set of plants.

The mean height of the control plant distribution was found by adding up all the heights to find their sum, 11,878 mm. This sum of the heights is divided by the number of scores (40) to find the value of the mean. For the controls, the mean is 11,878 mm/40 or 296.95, which becomes 297 mm when we consider the significant digits available.[1] The mean of the experimental plants is 12,159 mm/40 or 304 mm. From this information we can see that the "average" experimental plant was taller (by 7 mm) than was the "average" control plant. The value of the median was

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[1] Refer to the discussion of significant digits in Chapter 4.

TABLE 27. Comparative Heights of Plants (in millimeters)

(20-day experiment period)

Control				Experimental			
306	302	300	298	310	306	304	302
306	302	300	298	310	306	304	302
305	302	300	298	309	306	304	302
305	302	300	297	309	306	304	301
305	301	299	297	309	305	303	301
304	301	299	296	308	305	303	300
304	301	299	294	308	305	303	298
303	301	299	250	307	305	303	298
303	301	299	250	307	305	303	295
303	300	298	250	307	304	302	290
3,044	3,013	2,993	2,828	3,084	3,053	3,033	2,989

3,044
3,013
2,993
2,828
$11{,}878 = \Sigma X$

$n = 40$
Median $= 300$
$$\text{Mean} = \frac{\Sigma X}{n} = \frac{11{,}878}{40} = 296.95 = 297$$

3,084
3,053
3,033
2,989
$12{,}159 = \Sigma X$

$n = 40$
Median $= 304$
$$\text{Mean} = \frac{\Sigma X}{n} = \frac{12{,}159}{40} = 303.975 = 304$$

The formula for determining the mean is $\Sigma X/n$. Σ (Greek letter sigma) indicates the sum of; X indicates the measurements obtained; n is the number of units in the sample.

determined by finding the point that divides the number of measurements used into two halves. For the control set the point lies between the 20th and 21st measurements from either end. Because these two measurements have the same value (300), the median height for the control plants has a value of 300 mm. In the same way, the median height of the experimental plants is found to be 304 mm.

If a median point falls on a measurement (which always happens with an odd number of measurements), it takes the value of that measurement. If it falls between two different measures, its value is halfway between them. For example, if the 20th measure had been 300 and the 21st had been 301, the median would have a value of 300.5 mm.

Adding up two sets of 40 measurements is fairly time consuming, even with an adding machine, but if there were a thousand measurements to work with, it could take a very appreciable amount of time. Consequently, it is often desirable to arrange our measurements in a *frequency distribution* before dealing with them. We set up such a distribution by taking the smallest and the largest measurements as the two end points and marking off equal *intervals* between them. In our measurements these points are 250 and 306 for the control and 290 and 310 for the experimental plants. There should usually be from 7 to 14 intervals in any such frequency distribution. Fewer than 7 intervals tends to lose the true emphasis that each measurement should have. Many more than 14 intervals revives the problem of time needed for calculations. Therefore, we chose 3 mm as the value of each interval. This gave us 18 intervals for the control plant data and 7 for the experimental plant data.

Table 28 shows the plant data arranged in a frequency distribution in which each interval contains three possible measurements. For instance, in the control plant data, all the plants which were 304, 305, or 306 mm tall are recorded in the frequency (*f*) column opposite the top interval of 303.5-306.5. Notice that the frequency intervals use decimals to describe the exact limits of each interval. Theoretically, a measurement of 300 mm could be as small as 299.6 mm or as large as 300.4 mm and still be recorded as 300 mm in our data. (See the discussion of significant digits, Chapter 4.) The use of .5, + and −, as the exact limits for each interval takes this fact into consideration.

In Table 28, for the controls, there is a column called *X* or midpoint. In a frequency distribution we place measures having more than one value in a single interval. For example, 304, 305, and 306 are all placed in the top interval of the control plants. We use the midpoint value, or X, of the interval as the "average" measurement for all the heights recorded there. This can produce small errors (called errors of grouping) in our computations, but usually over the total set of intervals these errors tend to cancel each other out. Notice that our obtained ΣfX (sum of frequency distributed measures or heights) of 11,873 differs from our Table 27 value of 11,878 by only 5 mm; and our two means do not differ at all when rounded off to their significant digits.

TABLE 28. Frequency Distribution of Heights of Plants (in millimeters)

Control Plants

Interval	f	X (midpoint)	fX
303.5 - 306.5	7	305	2,135
300.5 - 303.5	12	302	3,624
297.5 - 300.5	14	299	4,186
294.5 - 297.5	3	296	888
291.5 - 294.5	1	293	293
288.5 - 291.5	0	290	0
. . . . . .[a]			
250.5 - 253.5	0	252	0
247.5 - 250.5	3	249	747
	$n = 40$		$\Sigma fX = 11{,}873$

Median = 300.5
-0.214
= 300.3

$$\text{Mean} = \frac{\Sigma fX}{n} = \frac{11{,}873}{40} = 296.82 = 297$$

Experimental Plants

Interval	f	Y (midpoint)	fY
307.5 - 310.5	7	309	2,163
304.5 - 307.5	12	306	3,672
301.5 - 304.5	14	303	4,242
298.5 - 301.5	3	300	900
295.5 - 298.5	2	297	594
292.5 - 295.5	1	294	294
289.5 - 292.5	1	291	291
	$n = 40$		$\Sigma fY = 12{,}156$

Median = 304.3

Mean = 303.9 = 304

---

[a] Some intervals have been omitted.

The values in the *f*X column are obtained by multiplying the number of scores (*f*) in any interval by the midpoint value (X) of that interval. This column is then added to give us ΣfX which is divided by n to obtain the mean height of the plants. Notice also that we use the letter Y for the measurements of the experimental plants in the same way.

In the data for the control plants in Table 28 several intervals were omitted (shown by the dotted line and the asterisk). In a frequency distribution every interval between the one containing the highest measurement and the one containing the lowest measurement should be included. If there are no measures in that interval, a zero is placed in the *f* column. The reason for this requirement will become obvious when we work with finding the standard deviation statistic. Omissions should be noted as we have done here.

When scores or measurements are recorded in a frequency distribution, it may be difficult to determine the median. We are still seeking the value of the point which divides the measurements into two equal halves, but it may be "hidden" in an interval. Consider the data for the control plants in Table 28. We are looking for the point between the 20th and 21st measurements. If we count down the *f* column from the top, we have 7 plus 12 is 19 scores included in the first two intervals. The 20th and 21st are both among the 14 scored in the next interval, but where? (In a frequency distribution we don't know the actual values of those 14 scores, only that they are either 298, 299, or 300 mm.) Therefore, for the purpose of finding the median, we assume that all the scores in any interval are evenly distributed in the interval. We divide the number of additional measurements we need to reach our halfway point by the number of scores actually in that interval and multiply that result by the length of the interval. In our present example, we have 19 scores —we need 1 more; there are 14 scores in the interval, and the length of the interval is 3. Therefore, we divide 1 by 14 and multiply the answer by 3 to get .214. This tells us how far into the interval our median point is; by subtracting this value from the upper exact limit of the interval (300.5), we find the value of the median height of our control plants—300.3 mm.

Although we have used an interval of size three in our example, it is permissible to use any appropriate size. If the interval is an odd number of scores, the midpoint will be a whole number, as in our example.

What do our data tell us about our experiment? As mentioned earlier, the obtained means show us that the experimental plants average 7 mm taller than do the control plants. This is also verified by the relative size of the medians, but neither of these statistics tells us anything about the distribution of plant heights within the control or experimental groups.

Standard deviation

We turn then to another useful descriptive statistic, the **standard deviation** (de = from, out; via = road; therefore, off the road or path). The standard deviation provides information about how a sample is distributed around the mean. It is based upon the amount each separate measurement varies or deviates from that mean.

Two groups of boys might both have the same mean age, say 15 years. But one group could be made up of equal numbers of 14-year-olds and 16-year-olds, while the other group could have equal numbers of 2-year-olds and 28-year-olds. Both would have mean age values of 15 years, but they would certainly be extremely different in their ability to be a baseball team. In this example, the boys in the first group all deviate from the mean age by one year (some above and some below). In the second group the members all deviate by 13 years from the mean.

Referring to our previous example of the plants, we might report that the mean growth of the plants was 12.5 mm with a standard deviation of 3.2 mm. This tells a reader who understands statistics that about two-thirds of our plants had grown between 9.3 and 15.7 mm in height. We shall see why one can make such an assumption when we discuss the standard deviation in more detail.

Table 29 shows how we determine the standard deviation using the data of the experimental plants from Table 28. We use the frequency distribution data for our sample because usually it simplifies the calculations. However, the standard deviation can also be determined using every score. The formula for obtaining the standard deviation for grouped data is

$$s = \sqrt{\frac{\Sigma fd^2}{n-1}},$$

where Σ is the sum of the number of entries in the interval, d is

TABLE 29. Determination of Standard Deviation for Heights of Plants[a]

Interval mm	f	Y (midpoint)	d	d^2	fd^2
307.5 - 310.5	7	309	+5	25	175
304.5 - 307.5	12	306	+2	4	48
301.5 - 304.5	14	303	-1	1	14
298.5 - 301.5	3	300	-4	16	48
295.5 - 298.5	2	297	-7	49	98
292.5 - 295.5	1	294	-10	100	100
289.5 - 292.5	1	291	-13	169	169
	$n = 40$			$\Sigma fd^2 = 652$	

Mean = 304

$$s = \sqrt{\frac{\Sigma fd^2}{n\text{-}1}}$$

$$= \sqrt{\frac{652}{39}}$$

$$= \sqrt{16.7} = 4.1$$

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[a] Experimental plant data from the preceding Tables 27 and 28.

the difference between the mean and the midpoint of the interval, and n is the total number of scores. (Note we are using the symbol s for standard deviation. The small Greek letter sigma σ is also used when the total population is being considered. In that case also, one would use N instead of n-1 in the formula.)

Notice that we first find the mean height of the plants (304 mm) and then record in the d column how much the midpoint of each interval deviates from that mean. (In the case of the top interval the midpoint of 309 deviates by +5 from the mean of 304.) Each entry in this column is squared and entered in the d^2 column. Finally the frequency of scores in each interval is multiplied by its corresponding d^2 value to give us the entries in the fd^2 column. This column is totaled to find Σfd^2 which is used in the formula provided. The square root of the quantity Σfd^2 divided by the number of measurements minus one, is the standard deviation of the measurements in our sample. If the characteristic being measured is normally distributed in the sample, we can expect approximately two-thirds (actually 68.26 percent) of the plants to be within one standard deviation on either side of the mean height. (See Figure 10.) Let us check this distribution for our plants.

1. Mean ± 1 s = 304 ± 4 or 300 to 308 mm in height.
2. Two-thirds of 40 plants would be 26.6 or 27.
3. From Table 27 we can see that there are 28 plants taller than 300 mm and shorter than 308 mm, and 33 plants which are at least 301 mm but not taller than 309 mm.

We should note, however, that the distribution of a trait usually only approximates the normal distribution. If we were to measure the height of all the boys in a high school, we would expect some few to be extremely short and some few to be extremely tall, but we would expect the great majority to be spread around the "average" height of high school boys in general. On the other hand, we might not expect to find height normally distributed if we measured only the members of the basketball team. Most of them would probably be above the "average" height of high school boys.

Another way in which knowledge of the standard deviation is helpful in interpreting data is shown by the following example. Suppose we had been feeding two sets of chicks on two different diets for a period of time. We weigh all the chicks in each group and find the mean weight and standard deviation in weight for each set. Assume that our data are: Group I—mean weight 236.5 grams, standard deviation 6.3 grams; Group II—mean weight 234.7 grams, standard deviation 11.8 grams. We can see from the data that although both sets of chicks have approximately the same mean weight, the chicks in Group I all have weights relatively close to the mean weight (two-thirds of them weigh between 230.2 and 242.8 grams). The chicks in Group II appear to have more divergent weight patterns (two-thirds of them weigh between 222.9 and 246.5 grams). We might conclude that the diet of Group I was more beneficial for increasing the weight of most chicks of the type studied. The previous discussion suggests one of the reasons why most research studies provide the reader with both the mean and standard deviation values as part of the data.

Interpretation of data

From the analysis of data we move on now to the interpretation of the data or what is sometimes called inferential statistics. This area of statistics includes the tests and techniques that make it possible for us to determine how significant our results are, or what degree of confidence the reader can attach to our findings if he wishes to generalize beyond the actual subjects in the sample. The use of appropriate statistical processes makes the results of our investigation not only more readily understood but also more valuable to the person who understands the language of science.

Standard error

The standard deviation measures the scatter about the arithmetic mean or average; the standard error is the average of the deviations about the line of regression. To understand the concept and use of the standard error, let us return to our example of the two sets of plants. (Tables 27-29) You will recall that we used 40 plants in each set; therefore, the data we obtained are true only with respect to those 80 plants. It is our assumption that the data would be true of any other number of that same type of plant treated to the same conditions. Our 80 plants were only a small sample of the total population of possible plants of the same type. We would like to be able to report how closely our sample represents the results we could expect for the total population.

How close is our obtained mean height of 304 mm for the experimental plants to the true mean height we would obtain if we used all possible plants of the same type in our experimental set? It is our assumption that the value of the population mean should not be very different from our obtained sample mean, but it would be more satisfactory if we could provide statistical evidence to show the correctness of our assumption. The standard error is a statistic which does describe how accurately our sample mean describes the true population mean.

The determination of the value of the standard error of the mean (S.E. mean) is relatively simple. We divide the value of the standard deviation by the square root of the number of measurements in our sample; i.e., $\text{S.E.}_{\text{mean}} = \frac{s}{\sqrt{n}}$. For the experimental plants we find the standard error to be equal to $4.1/\sqrt{40}$ or 4.1/6.32 which is $\text{S.E.}_{\text{mean}} = .65$.

The interpretation of this obtained standard error value follows the same type of reasoning as that used with the standard deviation. We can expect that, if the trait being measured is relatively normally distributed, the true value of the population mean, for 68.26 percent of the population, would lie between the sample mean plus or minus one standard error. For the experimental plants in our example, we could expect the true population mean to lie between 304 − .65 and 304 + .65 (303.35 to 304.65 mm) in around two-thirds of the cases. Consequently, the standard error shows us, in this example, that our 40 plants were a good representative sample of the way in which the possible population of plants might have responded to the vitamin-spray treatment. In one-third of the cases, the true mean height of the population of plants might have been either less than 303.35 or greater than 304.65 mm.

A numerically small standard error suggests that our findings can be assumed to apply to the larger population of plants, whereas a numerically large value for the standard error might suggest that our results do not truly represent what might occur with a larger population of plants. In the latter case, we might be inclined to conclude that our sample of plants represents a chance occurrence for growth under the conditions described.

The standard error of the difference between means

One further statistical technique is of value for the type of experiments we have been discussing, where one set of materials is a control set and the other is an experimental set. We would like to be able to show that our obtained results do show a significant difference; that the plants sprayed with the vitamin solution did grow significantly taller, on the average, than did the control plants; or that Group I of the chicks did gain significantly more weight, on the average, than did Group II. For these types of situations we need to determine the *standard error of the difference between means*.

Table 30 deals with the data of our two sets of plants in an attempt to answer the question "Did the experimental plants have a significantly higher mean growth than had the control plants?" The method of determining this new statistic, the standard error of the difference between means, involves squaring the standard error value for each set of plants, adding

TABLE 30. Determining the Standard Error of the Difference Between Means

	Control Plants	Experimental Plants
Mean	297 mm	304 mm
Standard deviation	14.08	4.1
Standard error	2.26	.66

Standard error of the difference between means:

$$
\begin{aligned}
\text{S.E.}_{Dm} &= \sqrt{(\text{S.E. con.})^2 + (\text{S.E. exp.})^2} \\
&= \sqrt{(2.26)^2 + (.66)^2} \\
&= \sqrt{5.11 + .44} \\
&= \sqrt{5.55} \\
&= 2.36
\end{aligned}
$$

$$
\begin{aligned}
\text{Critical ratio} &= \frac{\text{actual difference between means}}{\text{S.E.}_{Dm}} \\
&= \frac{304 - 297}{2.36} \\
&= 2.97^{a}
\end{aligned}
$$

---

[a] A rule of thumb is that if the critical ratio is 2.0 or larger, there is a significant difference at the 95% level of confidence; and if the critical ratio is 3.0 or larger, there is a significant difference at the 99% level of confidence.

these, and finding the square root of their sum. For our experiment the value obtained was 2.3.

To interpret this result we set up a *critical ratio*. The critical ratio is equal to the *actual difference between means* (304 - 297] divided by the *standard error of the difference between means* (S.E.$_{Dm}$ = 2.36]. In Table 30 the obtained critical ratio has a value of 2.97, and the table shows a rule of thumb to be used in interpreting the critical ratio. If the value is 2.0 or larger, it implies that there was indeed a significant difference (a true difference] between the growth of the two sets of plants and that this much difference would occur 95 times out of a hundred for such an experiment. Only 5 times out of 100 would we predict this much difference in growth to occur merely by chance. If the critical ratio is 3.0 or larger, our rule of thumb says that this is significant at the 99 percent level of confidence. That is, only one time out of a hundred would we expect this much difference in growth to occur by chance; 99 times out of a hundred, this much difference would be expected to occur.

Do you see how the use of these statistical steps has made our experimental findings much more valuable? We have been able to say that our results with a small sample of plants are a reasonable description of what would occur with a larger population of plants. And we can say that our results would occur by chance only once in a hundred such experiments.

This first set of statistical techniques shows you how to determine the significance of your findings (confidence levels) in any experiment in which you are basically observing the effects of two different treatments on two different samples. There are other techniques for use with experiments of different design. Be careful not to apply a statistical technique in a situation where it does not belong.

Chi-square

Chi-square is a simple statistical technique which can be used to find the significance of other types of experimental outcomes. Simply stated, chi-square is a technique which attempts to answer the question: "Does our observed outcome differ significantly from an outcome which might be expected by chance alone?" The usual example used to explain chi-square involves flipping a coin. If we were to flip a "good" coin 1,000 times, we would expect there would be 500 heads occurring and 500 tails. Even if we obtained 505 heads and 495 tails we would still feel that this was a minor fluctuation due mainly to chance. But suppose an individual claimed that he could control the flip of a coin and make one side (say heads) occur more often than the other. He flipped the coin 1,000 times and obtained 550 heads and 450 tails. Was he truly affecting the outcome? Does this obtained result differ significantly from what we would expect by chance occurrence? Chi-square can help us make a decision. Our coin example is worked out in Table 31.

Our value of 10.0 for chi-square must be checked against a table of significant chi-square values. The appropriate line from such a table is shown below. A simplified chi-square table is given in Appendix A.

Degree of Freedom		Probability	
	$P = .10$	$P = .05$	$P = .01$
1	2.71	3.84	6.64

TABLE 31. Calculation of Chi-Square (χ^2)

Outcome of Toss	Expected Frequency f_e	Observed Frequency f_o	Computation $f_o - f_e$	$(f_o - f_e)^2$	$\frac{(f_o - f_e)^2}{f_e}$
Heads	500	550	50	2500	5
Tails	500	450	-50	2500	5

Calculated $\chi^2 = 10$

$$\chi^2 = \Sigma\left[\frac{(f_o - f_e)^2}{f_e}\right]$$

The value $\frac{(f_o - f_e)^2}{f_e}$ is computed for each cell of the table and the values for all cells added to yield χ^2.

Notice that our answer for chi-square (10.0) is as large as or larger than the P = .01 table value of 6.64. This result is interpreted in the following way. Our chi-square value is significant beyond the P = .01 level of confidence. This means that a difference as large as the one our subject made in the obtained head-tail pattern would happen by chance occurrence less than one time out of a hundred. It implies that something other than chance was affecting the fall of the coin. Of course, it does not prove that our subject had powers of telekinesis but rather that a non-chance series of events had occurred.

The coin example shows the procedures used to determine the value of chi-square. The expected outcomes (f_e) are recorded, and then the observed or obtained outcomes (f_o) are recorded. The difference between the f_o and f_e for each case is determined; this value is squared and divided by the appropriate f_e value. The sum of all of the cases is calculated and represents the value of chi-square for that particular problem. One must then use a table such as the one in Appendix A to determine the significance of the obtained chi-square value. The first column in such a table is labeled *d.f.* which is an abbreviation for degree of freedom. The number of degrees of freedom in a chi-square determination generally is one less than the number of variables involved in the determination. Thus, in the coin problem there were two variables (heads and tails), and the degree of freedom was consequently one. If we were to apply chi-square to the obtained and expected results from rolling one die (dice), there would be six variables (six possible numbers to be rolled) and five degrees of freedom. In this latter case we would enter the table of chi-square values in the fifth row, where *d.f.* has a value of five.

Let us apply the chi-square technique to the problem mentioned in Chapter 3 about the relationship between the time of day and the rate of crickets' chirping. We shall assume that we have trapped a certain number of crickets in a screen-wire trap. The trap was placed in the normal habitat of crickets, and we sat nearby to record the number of times the crickets chirped during *certain one-hour periods of the day. (A battery-powered tape* recorder might be useful for obtaining the data.) Our obtained counts are shown in Table 32.

TABLE 32. Data on Cricket Chirp Count

Time of Day		No. of Chirps
A.M.		
6 - 7		153
8 - 9		112
10 - 11		80
P.M.		
12 - 1		24
2 - 3		22
4 - 5		61
6 - 7		143
	Total	595

Number of hours observed, 7

Mean chirps per hour observed, 595/7 = 85.0

Thus we have our obtained data. What is our expected cricket chirp rate? If we assume that the time of day does not have an effect on cricket chirp rate, then we would expect the rate to be about the same for every hour of the day. Therefore our average or mean chirping rate for the seven hours of observation would be our best assumption for the expected rate of chirping for each hour. We record our expected and obtained data and determine the value of chi-square as in Table 33. Notice that we have seven variables (seven different times during the day), which give us six degrees of freedom.

From Appendix A we see that our value of chi-square (200.2) is markedly larger than the P = .01 level of confidence value (16.81) with 6 degrees of freedom. Consequently, we may say that the amount of difference that occurred between what we observed and what we expected, would occur by chance much less than one time in a hundred. We may conclude that the rate of crickets' chirping is probably related to the time of day. From our data we would note that the rate of chirping was higher than expected at dawn and sunset, and lower than expected during midday hours.

It is important to note here that we have not proved a cause-and-effect relationship between time of day and rate of chirping; we have shown only that the observed rate of chirping does vary significantly from an assumed "no difference in rate over daylight hours." Our data used in the problem were imaginary. What other variables might have been operating (and not controlled) in our description of this experiment? You probably listed temperature, humidity, intensity of light, physiological state of

TABLE 33. Calculation of Chi-Square (χ^2)

Time of Day	Expected Frequency f_e	Observed Frequency f_o	Computation $f_e \cdot f_o$	$(f_e \cdot f_o)^2$	$\frac{(f_e \cdot f_o)^2}{f_e}$
A.M.					
6-7	85	153	-68	4,624	54.4
8-9	85	112	-27	729	8.6
10-11	85	80	5	25	.3
P.M.					
12-1	85	24	61	3,721	43.8
2-3	85	22	63	3,969	46.7
4-5	85	61	24	576	6.8
6-7	85	143	-58	3,364	39.6

$$\chi^2 = \Sigma\left[\frac{(f_e \cdot f_o)^2}{f_e}\right] = 200.2$$

the cricket (hunger, thirst, etc.), and other noncontrolled variables. Any of these (or a combination of all of them) might be the cause of the variation in rate. In any event, they do represent a series of new experiments we would have to conduct to determine the effect of each. By using the chi-square technique in each case we could determine which of the variables were significant in affecting chirping rate and which were not.

This has been only an elementary introduction to the possible applications of the chi-square technique in testing the significance of obtained results. Several of the references at the end of the chapter will provide further understanding of the method and suggest other possible applications.

Correlation coefficients

Often the results of a research question may be used to show a relationship or correlation between an independent variable and a dependent variable. For example, one might expect that there would be a relationship between the height of a tree and its age in years or between the speed with which a rat covers a maze and the length of time since he was last fed. The first example is considered a direct or positive correlation—as one variable increases (or decreases) so does the other increase (or decrease). The second example is considered an inverse or negative correlation—as one variable increases the other decreases (or vice versa). A short time since feeding will increase the time required by the rat to complete the maze; a long fast will speed up his performance and decrease the time involved.

Numerically, correlation coefficients range between +1.00 and −1.00. The sign of the coefficient (+ or −) tells us the nature of the relationship—that is, whether it is a direct or an inverse relationship. The numerical value tells us of the importance or significance of the relationship. Thus coefficients which are near to either +1.00 or −1.00 indicate significant relationships; those which have values near to zero show relationships which are not meaningful or signify "no real relationships" between the variables.

It is also important to remember that a high correlation result does not necessarily mean that there is a cause-and-effect relationship between the variables investigated. For example, there is a high positive correlation between the number of drownings in any month and the amount of ice cream sold in that month. As you can surmise, there is no cause-and-effect relationship between drowning rate and ice cream consumption, even though there might be a high correlation. Undoubtedly, a third variable (temperature) plays an important role in producing this outcome. In warm months more ice cream is consumed, and more people go swimming, than in cold months. When you use correlation techniques on the data you obtain from experiments, remember that you must consider both the type and degree of relationship between variables. The more cases (or examples) of the relationship you can establish, the more likely that you have found a true cause-and-effect relationship.

Let us consider an example of the use of a correlational technique in an imaginary piece of research. A student was interested in finding out whether the presence of a specific moss plant (say, "pigeon-wheat" moss) was indicative of a high concentration of a specific chemical substance (say, copper ions) in the soil. He constructed a square "cookie-cutter" which was 10 centimeters on each side and collected samples 100 cm² from various locations where the moss grew. He then counted the number of moss plants per sample, weighed out a one-gram portion of soil from each sample, and determined photometrically the concentration of copper ions in these one-gram portions. He then recorded his data as shown in Table 34.

One formula for determining a correlation coefficient from such data, called the Pearson product-moment coefficient, is shown below:

$$r = \frac{(n)\ (\Sigma XY) - (\Sigma X)\ (\Sigma Y)}{\sqrt{(n)\ (\Sigma X^2) - (\Sigma X)^2} \times \sqrt{(n)\ (\Sigma Y^2) - (\Sigma Y)^2}}$$

Where n is the number of samples, X is the number of plants in 100 cm², and Y is the number of Cu^+ ions in one gram of soil. We use this formula to determine the relationship between the concentration of copper ions in the soil and the number of moss plants growing in the soil. (See Table 35.)

Notice that the number of moss plants found per 100 cm² is recorded in the X column and that the concentration of Cu^+ ion per gram of soil is recorded in the Y column. The values in the X and Y columns are squared to provide the entries under X^2 and Y^2, respectively; and the product of each X times Y is re-

TABLE 34. Data on Soil Samples Collected

Site No.	Number of Plants/100 cm^2	Concentration of Cu^{+} Ions/Gram Soil $(\times 10^{-5})$
1	60	50
2	40	30
3	130	110
4	90	75
5	100	80
6	20	15
7	110	90
8	70	60
9	80	65
10	120	100

Mean number of plants = 820/10 = 82

Mean concentration = 675/10 = 67.5×10^{-5}

corded in the XY column. Each column is totaled to get the sums which are used in the formula. Remember there is a difference between ΣX^2 and $(\Sigma X)^2$. When the computations were performed, the student found a positive .9987 correlation coefficient. This shows a very close relationship between the number of moss plants in certain samples of soil and the concentration of copper ion in the soil. Once again, this finding does not establish that copper ions are required for good heavy moss growth or that this moss is an indicator plant for high copper ion concentration soils.

If the student continually found high positive correlations for samples of soil from other locations and never any samples with heavy moss plant counts and low or limited copper ion concentrations, he might begin to feel assured that he had determined a significant relationship. If the results obtained in Table 35 had been +.35, it would have indicated that there was little relationship between the amount of copper ion in the soil and the growth habit of the moss. A negative correlation might suggest that high concentrations of copper ions may be associated with a decrease in the growth of the moss. The sign of the correlation coefficient and its magnitude provide useful information and indications for further investigations.

TABLE 35. Determination of the Pearson Product-Moment Coefficient

X	X^2	Y	Y^2	XY
60	3,600	50	2,500	3,000
40	1,600	30	900	1,200
130	16,900	110	12,100	14,300
90	8,100	75	5,625	6,750
100	10,000	80	6,400	8,000
20	400	15	225	300
110	12,100	90	8,100	9,900
70	4,900	60	3,600	4,200
80	6,400	65	4,225	5,200
120	14,400	100	10,000	12,000
820	78,400	675	53,675	64,850

Number of samples, $n = 10$

X – number of plants

$Y = \text{Cu}^{+}$ ions/gram soil

$\Sigma X = 820$

$\Sigma Y = 675$

$\Sigma X^2 = 78{,}400$

$\Sigma Y^2 = 53{,}675$

$\Sigma XY = 64{,}850$

$$r = \frac{(n)\,(\Sigma XY) - (\Sigma X)\,(\Sigma Y)}{\sqrt{(n)\,(\Sigma X^2) - (\Sigma X)^2} \times \sqrt{(n)\,(\Sigma Y^2) - (\Sigma Y)^2}}$$

$$= \frac{(10)\,(64{,}850) - (820)\,(675)}{\sqrt{(10)\,(78{,}400) - (820)^2} \times \sqrt{(10)\,(53{,}675) - (675)^2}}$$

$$= .9987$$

Thus we have seen that there are varied statistical techniques available for use by the scientist. We have been able to provide only a minimum of examples of their use. If you are considering using some of these techniques in your own work, you will want to read some of the books suggested at the end of this chapter. You will probably also want to seek the help of a mathematics teacher to check on the accuracy of your procedures and results. The primary purpose of including introductory statistics in this book is to make you aware of another aspect of the language of science and possibly to provide you with some new techniques to make your own work in science more interesting and valuable.

References and Further Reading

Very useful and easily understood books:

1. Alder, Henry L., and Edward B. Roessler. *Introduction to Probability and Statistics*. Third Edition. W. H. Freeman and Co. Publishers, San Francisco. 1964.
2. Arkin, Herbert, and Raymond R. Colton. *Statistical Methods*. Fifth Edition. College Outline Series. Barnes & Noble, Inc., New York. 1970.
3. Bancroft, H. *Introduction to Biostatistics*. Harper & Row, Publishers, New York. 1957.
4. Weaver, Warren. *Lady Luck, the Theory of Probability*. Anchor Books of Doubleday & Company, Inc., Garden City, New York. 1963.
5. Wilson, E. Bright, Jr. *An Introduction to Scientific Research*. McGraw-Hill Book Company, Inc., New York. 1952.
6. Youden, W. J. *Experimentation and Measurement*. A Vistas of Science Book. National Science Teachers Association, Washington, D.C. 1962.

An interesting book which discusses some of the ways in which statistical techniques should not be used is the following:

7. Huff, Darrell. *How To Lie With Statistics*. W. W. Norton & Company, Inc., New York. 1954.

Three introductory programmed books for self-instruction in basic statistics are:

8. McCullough, C., and L. Van Atta. *Introduction to Descriptive Statistics and Correlation*. McGraw-Hill Book Company, Inc., New York. 1965.
9. Schoer, L. A. *An Introduction to Statistics and Measurement*. Allyn & Bacon, Inc., Boston. 1966.
10. Townsend, E.A. and P.J. Burke. *Statistics for the Classroom Teacher*. The Macmillan Company, New York. 1963.

CHAPTER 6

Practicing the Language of Science

Throughout this book we have examined the ways in which scientists are involved with science. We have analyzed some of the language they use. If we stop here, however, we have probably missed the most exciting part of learning the language of science—actually practicing its use in a problem of interest to us.

You are undoubtedly familiar with many local, state, and national programs which involve students interested in science. These include science-related youth congresses, scholarship and other awards programs, seminars, and widespread science fairs. All are concerned with the science activities actually undertaken by individual students.

Students who have been involved in these programs in the past have all stressed several important aspects of their experience. First, there is the pride in having accomplished something of their own. Second, there is the satisfaction of having started with a problem or question and devised the means to find a reasonable (and defensible) answer. Third, there is the experience of meeting and discussing ideas with other students, scientists, and persons interested in science. That is, using the language of science with other people who speak and understand it. Fourth, these young people mentioned the tangible rewards, such as scholarship assistance, medals, cups, and other trophies. Some of them also realized that their participation in these science activities had provided them with an introduction to the beginning stages of the careers they wished to pursue. For many it was also an introduction to the preparation of a scientific paper, which makes its own special demands on one's ability to use the language of science.

I heartily recommend that you, too, become involved in these types of programs. It will require a great deal of work; it will take time that you might otherwise use for recreation. But the potential personal reward and satisfaction usually overcome these and other possible drawbacks.

To become involved, you must determine what you would like to undertake as an investigation. This is very often the most difficult step and the place where a great many students give up. They want to build a perpetual-motion machine, or cure cancer, or develop a new antibiotic. Their problem is, of course, how to do it. As a suggestion which has proved to be of value to other students, consider the following. Your investigation should reflect both your major area of interest and an area with which you already have some familiarity. If the project is selected from an area in which you have a reasonable degree of interest, you will be personally involved and enthusiastic about finding out more about the area through your science activity. If you are working in an area about which you already know something, and you are familiar with the types of research and findings that have been reported, you may avoid many early mistakes or false starts.

Essentially, your first step is the same as that mentioned in the scientific method; namely, identifying and making specific the problem you wish to investigate or the question you seek to answer. "Can dogs recognize color?" "Can a family of organic compounds be identified by migration rates in a chromatography system?" One possible way to develop the specific question which you will investigate is to write down the things you don't know or understand about the topic. Then read and browse in the literature related to it to see whether anybody else has found some of those answers. As you read, you will undoubtedly uncover statements like: "It is still unclear exactly why this occurs," or "The actual relationships involved in this process have not yet been identified." These are clues to possible specific question(s) you might investigate.

Suppose you really don't have any specific areas of major interest, but you would still like to undertake a worthwhile project. There are several approaches available here. Consider the field of advertising claims. Obviously all detergents cannot be "the best brightener." What is it that "brightens"? What are the results of comparison studies on various brands of detergents? Another interesting and very fertile field for possible projects involves developing productive uses for waste materials. You are aware that a major problem now facing man is the mounting quantity of waste materials he produces. Some of these used materials are already being reclaimed, recycled, and put to new uses. Any number of interesting and practical investigations could be undertaken in this area. One local student, for example, designed a process for reclaiming silver from large-scale photoprocessing tanks and used the money from the reclaimed silver to finance part of his college expenses. Another obvious area of much current concern to man is environmental pollution. Not just the fumes from automobiles and industry, or the wastes discharged into streams and rivers (although these are important), but also the pollution due to such items as the nitrogen of fertilizers, the nitrates of detergents, the residues of insecticides and herbicides. Projects which include investigating the prevention, control, or cure of these aspects of pollution are badly needed.

You can also get ideas about possible project areas by reading some of the books describing past projects or suggesting new ones. The bibiliography at the end of this chapter lists several such books.

Let us assume now that you have decided on an area of concern and have a general idea of the basic question you wish to investigate. Next, you must consider appropriate techniques for gathering information to answer the question. Certainly, you will use bibliographic techniques, gathering notes about related research, types of experiments already conducted, and findings reported. Also you will undoubtedly try to design an appropriate experiment for investigating the problem yourself. A good way to start this process is to think about it first. That is, consider such ideas as:

1. What types of materials or facilities will I need?
2. Can I get these things?
3. What variables will be operating in my experiment?
4. How can I control the nonexperimental variables?
5. How long will it take to get reasonable data?
6. Will I be able to use statistics in gathering and analyzing the data from my investigation?

A possible next step is to try the experiment, itself, mentally. Anticipate possible results and consider the implications for changes in the design. Finally, set up your experiment and begin to gather data.

The gathering and recording of data are essential to success. From the very beginning, use a notebook to record everything related to your experiment. Jot down your random thoughts, your reasoning patterns, your preliminary procedures—everything. This is your personal record of events related to your project. It is not the finished "science notebook" or "project log," but it will be the source of the material that does go into the final polished report. Jot things down as they happen; don't trust your memory. Wherever possible plan ahead and make specific tables for recording data; the table form will help assure that you record all of the important data. As you begin to interpret your data, don't stop with the first obvious conclusion. Ask yourself what else the data might imply. Your tentative conclusions may suggest ways to test your findings further (the if–then approach to obtain results).

When you are finally satisfied with your first set of results and their interpretation, write up your research. Perhaps your school has a suggested form for this purpose. Generally, what is essential in such a report is that it cover the following aspects of the research: (1) an exact description of the problem investigated, (2) a complete description of the procedures used, covering control procedures, source of materials, nature of apparatus employed, and other related information, (3) a clear display of your obtained data, sometimes in table form, sometimes in graph form, usually a combination, (4) a clear statement of your conclusions and their implications, if any, and, (5) a statement of the applications of your findings if there are any.

In preparing this report, remember that you are attempting to communicate clearly to the reader (or listener) exactly what you did, what you found, and what you think it means. Use your skills in the language of science to make your report a literate one.

I hope that this book has been of help to you—that it has made science seem more human and the language of science more understandable. I hope that some of the ideas mentioned have stimulated you to want to participate in the satisfying experience of being a scientific researcher. Even if your career plans do not include the sciences as a major interest, the opportunity provided by your science classes to practice at being a scientist is too valuable to let slip by.

References and Further Reading

An excellent book for learning more about science projects and how to conduct them is:

1. Goldstein. P. *How To Do An Experiment*. Harcourt Brace Jovanovich, Inc., New York. 1957.

Several sources of ideas for science projects follow.

2. "The Amateur Scientist," *Scientific American*. Each month this magazine has a section devoted to projects and research ideas for the amateur scientist. Also, many of these articles have been compiled in:
3. Stong, C. L. *The Scientific American Book of Projects for the Amateur Scientist*. Simon & Schuster, New York. 1960.

   For books which give suggestions as to possible problem areas needing investigation and within the capability of student science projects, see any of the following:

4. Goldstein, Philip, and Jerome Metzner. *Experiments with Microscopic Animals*. Doubleday Company Inc., New York. 1971.
5. Guidry, Nelson P., and Kenneth B. Frye. *Graphic Communication in Science: A Guide to Format, Techniques, & Tools*. National Science Teachers Association, Washington, D.C. 1968.
6. McAvoy, B., *et al. Biology Projects*. Science Publications, Normal, Illinois. 1967.
7. Moore, S., Editor. *Science Projects Handbook*. Science Service, Washington, D.C. 1960.
8. Showalter, Victor M., and Irwin L. Slesnick. *Ideas for Science Investigations*. National Science Teachers Association, Washington, D.C. 1968.
9. Turabian, Kate L. *A Manual for Writers of Term Papers, Theses, and Dissertations*. Fourth Edition. The University of Chicago Press, Chicago. 1973.
10. Wilson, E. Bright Jr. *An Introduction to Scientific Research*. McGraw-Hill Book Company, Inc., New York. 1960.

APPENDIX A

The Greek Alphabet and Some Uses of Greek Letters in the Science Vocabulary

Capital	Lowercase		
A	α	alpha	a plane angle; radiation particle composed of 2 neutrons and 2 protons; linear coefficient of thermal expansion; angular resolving power of a telescope; degree of ionization (solutions)
B	β	beta	a plane angle; radiation particle equivalent to an electron; volume coefficient of thermal expansion
Γ	γ	gamma	a plane angle; radioactive radiation similar to X-rays; specific weight of a substance; the ratio of specific heats; contrast of photographic emulsions
Δ		delta	signifies changing values; differences between two (often successive) values; optical length of a lens
	δ	delta	angle of deviation; a deviation; total thermal expansion; galvanometer deflection
E	ϵ	epsilon	average molecular kinetic energy; base of natural (Naperian) logarithms
Z	ζ	zeta	
H	η	eta	coefficient of viscosity
Θ	θ	theta	a plane angle; angle of diffraction
I	ι	iota	
K	κ	kappa	absorption index
Λ		lambda	permeance (magnetic)
	λ	lambda	wavelength; linear density
M	μ	mu	coefficient of friction; electric moment of an atom, dipole molecule, or dipole; micron
N	ν	nu	frequency (optics, quantum theory)
	ξ	xi	
O	o	omicron	
Π	π	pi	osmotic pressure; 3.1416 . . .

Ρ	ρ	rho	density; vapor density; specific resistance; absolute humidity; radius of curvature
Σ		sigma	the summation operator (meaning "add together")
	σ	sigma	surface tension; electric conductivity; molecular diameter (collision); the standard deviation
Τ	τ	tau	a vector unit tangent to the path; a time constant; mean life (radioactivity); dew-point temperature
ϒ	υ	upsilon	
Φ		phi	a plane angle; magnetic flux
	ϕ	phi	fluidity (reciprocal of viscosity); phase angle
Χ	χ	chi	specific magnetic susceptibility
Ψ		psi	total flux of electric displacement; the amplitude of a wave function
	ψ	psi	azimuth angle
Ω	ω	omega	a solid angle; resistance in ohms

References: *Handbook of Chemistry and Physics*. 45th Edition. The Chemical Rubber Company. Cleveland, Ohio. 1964. F-102, F-103.

Webster's New International Dictionary. Second Edition. G. & C. Merriam Co., Springfield, Massachusetts. 1955. P. 3009.

Some Scientific Terms Derived from the Names of Famous Scientists

1. Names of chemical elements:

Curium	Marie Curie (1867-1934), Polish chemist and physicist in France, discovered radium and polonium, Nobel Prize 1903 and 1911.
Einsteinium	Albert Einstein (1879-1955), German-American physicist, introduced the theory of relativity, Nobel Prize 1921.
Fermium	Enrico Fermi (1901-1954), Italian-American physicist, instrumental in developing the atomic bomb, Nobel Prize 1938.
Mendelevium	Dimitri Mendeleev (1834-1907), Russian chemist, developed the periodic table of the elements.

2. Selected names of basic and derived units of measurement:[a]

ampere	A	after André Marie Ampère, French physicist, (1775-1836); the unit of electric current; constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2 × 10^{-7} newton per meter of length. [1, p. 21]
celsius (degree)	°C	after Anders Celsius, (1701-1744), who made and used the celsius (centigrade) thermometer.
fahrenheit (degree)	°F	after Gabriel Daniel Fahrenheit, German instrument maker [1686-1736]; invented the Fahrenheit thermometer.
kelvin	K	after Lord Kelvin (William Thomson), English physicist (1824-1907); the absolute temperature scale.
ångström	A	after Anders Jons Ångström, Swedish physicist (1814-1874); used in measuring the length of light waves; 1A = 10^{-10} meters.

[a] For the most part these units are those used in the International System. However, there are several systems in use, and these systems are indicated where appropriate. Scientists avoid mixing the units of the various sytems.

For the sake of clarity in the definitions and to further illustrate the concept of derived units, these names have been grouped in a hierarchy as follows: first, those that are basic units; second, those that can be defined in terms of the first group units or other basic SI units; third, those that can be defined in terms of the first two units; etc.

coulomb	C	after Charles Augustin de Coulomb, French physicist (1736-1806); a unit of electrical charge; the quantity of electricity carried in one second in a current of one ampere.
curie	Ci	after Marie Curie; a unit of radioactivity; the quantity of any radioactive isotope undergoing 3.7×10^{10} disintegrations per second.
hertz	Hz	after Heinrich Rudolf Hertz, German physicist (1857-1894); a unit of electromagnetic radiation frequency; equals one cycle per second.
newton	N	after Sir Isaac Newton, English mathematician and philosopher (1642-1727); (MKS system) unit of force; force which if applied to a free body having a mass of 1 kg, would give it an acceleration of 1 meter per second per second. [2, p. 1184]
oersted		after Hans Christian Oersted, Danish physicist (1777-1851); a unit (emu system) of magnetic field strength; magnetic field produced at the center of a plane circular coil of one turn, and of radius one centimeter, which carries a current of ($\frac{1}{2}\pi$) abamperes. [2, p. 1235]
roentgen	r	after Wilhelm Konrad Roentgen, German physicist (1845-1923); the unit used in measuring radiation; a magnitude of 2.58×10^{-4} coulombs per kilogram of air. [2, p. 1544]
weber	Wb	after Wilhelm Weber, German physicist (1804-1891); the unit of magnetic flux; magnetic flux which, linking a circuit of one turn, would produce in it an electromotive force of 1 volt if it were reduced to zero at a uniform rate in 1 second. [1, p. 21]
joule	J	after James Prescott Joule, English physicist (1818-1889); a unit of work or energy (in the MKS system of units); the work done when a force of one newton produces a displacement of one meter in the direction of the force. [2, p. 963]
watt	W	after James Watt, Scottish physicist (1736-1819); a unit of power; power which in one second gives rise to energy of 1 joule. [1, p. 21]

volt	V	after Alessandro Volta, Italian physicist (1745-1827); the unit of electrical potential difference and electromotive force; difference of electric potential between two points of a conducting wire carrying a constant current of 1 ampere, when the power dissipated between these points is equal to 1 watt. [1, p. 21]
farad	F	after Michael Faraday, English chemist and physicist (1791-1867); a unit of capacitance; capacitance of a capacitor between the plates of which there appears a potential difference of 1 volt when it is charged by a quantity of electricity of 1 coulomb. (1, p. 21)
henry	H	after Joseph Henry, American physicist (1797-1878); a unit of electrical inductance; inductance of a closed circuit in which an electromotive force of 1 volt is produced when the electric current in the circuit varies uniformly at the rate of 1 ampere per second. [1, p. 21]
maxwell	Mx	after James Maxwell, Scottish physicist (1831-1879); the (cgs system) unit of magnetic flux; is the magnetic flux which, when linked with a single turn, generates an electromotive force of 1 abvolt in the turn, as it (the magnetic flux) decreases uniformly to zero in one second. [2, p. 1092]
ohm	Ω	after Georg Simon Ohm, German physicist (1787-1854); the unit of electric resistance; electric resistance between two points of a conductor when a constant potential difference of 1 volt, applied to these points, produces in the conductor a current of 1 ampere, the conductor not being the seat of any electromotive force. [1, p. 21]
gauss	Gs, G	after Karl F. Gauss, German mathematician and physicist (1777-1855); cgs (Gaussian System) electromagnetic unit of magnetic induction; equal to 1 maxwell per square centimeter.

References

1. *The International System of Units (SI).* U.S. Department of Commerce, Washington, D.C. 1972, P. 21.
2. *Van Nostrand's Scientific Encyclopedia.* Fourth Edition. Van Nostrand Reinhold Company, Inc., New York. 1968.

Definitions of the Base Units of the International System

Meter – unit of length[1]

The meter is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton-86 atom.

Kilogram – unit of mass

The kilogram is the unit of mass [and not of weight or of force]; it is equal to the mass of the international prototype of the kilogram.

This international prototype made of platinum-iridium is kept at the International Bureau of Weights and Measures (BIPM) under conditions specified by the 1st General Conference of Weights and Measures (CGPM) in 1889.

Second – unit of time

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.

Ampere – unit of electric current

The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length.

Kelvin – unit of thermodynamic temperature

The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. (Adopted in 1967 instead of degree Kelvin)

Note: In addition to the thermodynamic temperature (symbol T), expressed in kelvins, use is also made of Celsius temperature (symbol t) defined by the equation

$$t = T - T_0$$

where $T_0 = 273.15$ K by definition. The Celsius temperature is in general expressed in degrees Celsius (symbol °C). The unit "degree Celsius" is thus equal to the unit "kelvin," and an interval or a difference of Celsius temperature may also be expressed in degrees Celsius.

Mole – unit of amount of substance

The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

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[1] Note that in the SI system, numbers are written with space rather than commas between groups of three digits. The spelling of meter, rather than metre, is used here.

Note: When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

Candela – unit of luminous intensity

The candela is the luminous intensity, in the perpendicular direction, of a surface of 1/600 000 square meter of a blackbody at the temperature of freezing platinum under a pressure of 101 325 newtons per square meter.

From *The International System of Units (SI)*. National Bureau of Standards, U.S. Department of Commerce, Washington, D.C. 1972. Pp. 3-5.

Space Vocabulary Terms

These are examples of terms used in space language.

Term	Meaning
ablation ablat = removed	removal by melting (Heat shields on spacecraft are made of material that melts away, thus carrying off most of the intense heat of the reentry into the earth's atmosphere.)
apogee apo = away ge = the earth	point in an orbit that is farthest from the earth's surface; highest altitude reached by a sounding rocket
airglow	steady, visible emission from the upper atmosphere; light in the night-time sky
aphelion apo = away helio = the sun	point at which a planet or other celestial object in orbit around the sun is farthest from surface of the sun
attitude	position or orientation of aircraft or spacecraft in relation to some reference line such as the horizon
booster	the first-stage engine; also the entire launch vehicle
burn	period during which rocket engine is firing
center of mass	point at which all the mass of a body or system may be assumed to be concentrated
Coriolis effect	deflection of air masses or body in motion caused by a body's rotation; in the case of the earth, deflection is clockwise in northern hemisphere, counterclockwise in southern hemisphere

cosmic dust cosm = universe	small meteoroids of a size similar to dust; usually refers to interstellar particles
cosmic rays	extremely high energy subatomic particles which bombard the atmosphere from outer space
cosmonaut	Russian name for the persons who participate in space flights
destruct	deliberate destruction of a rocket vehicle after launching but before it has completed its course
drogue parachute	type of parachute used to slow down a body; also called deceleration parachute
escape velocity	speed which a body must attain in order to escape from the gravitational field of a planet or star (Escape velocity from earth is approximately 7 miles per second.)
exobiology exo = out, outside bio = life	study of possibility of living organisms existing on celestial bodies other than the earth
free fall	fall or drop of a body not retarded by parachute or other braking device
fuel cell	a cell which converts chemical energy directly into electrical energy
g	acceleration equal to the acceleration of gravity, approximately 32.2 feet (9.81 m) per second per second at sea level (The value of g varies over the surface of the earth.); unit of stress measurement for bodies undergoing acceleration
gyro (gyroscope) gyr = round, turning	device which utilizes angular momentum of a spinning rotor to sense angular motion of its base about one or two right angles to the spin axis
heat shield	device that protects from heat
hypersonic	noting or pertaining to speed at least five times the speed of sound in the same medium
inertial guidance	guidance by means of acceleration measured and integrated within the craft
insertion into orbit	process of putting an artificial satellite into orbit; often refers to last burn or burst of speed which gives orbital velocity
launch vehicle	any device which propels and guides a spacecraft into orbit about the earth or into a trajectory toward another celestial body

lox	liquid oxygen
Mach number	relationship of speed of an object to speed of sound in still air; Mach 1 is equal to the speed of sound
meteoroids meteor = high in air, heavenly bodies	solid objects moving in interplanetary space; smaller than an asteroid, larger than an atom or molecule
module	self-contained unit of a launch vehicle or spacecraft
orbit orbi = circle, track	the path of a body or particle under the influence of gravitation; to go around the earth or other body in an orbit
orbital velocity	velocity at which an earth satellite or other orbiting body travels around its primary body
oxidizer	substance that supports the combustion of a fuel or propellant
parallax	apparent difference between the angular directions of an object viewed from two different locations
payload	that which a launch vehicle carries
perigee peri = around ge = earth	orbital point nearest the surface of earth or body around which the orbit is being made (Technically apogee and perigee apply to points in orbits around the earth, but are also used for orbits around other bodies.)
probe	device or instrumented vehicle sent into an environment to obtain information about that environment
propellant	any agent for consumption or combustion and from which the rocket derives its thrust
radar	device for locating an object by means of ultra high frequency radio waves reflected from the object
radiation belts	areas of high amounts of radiation in space
radio telescope	device to receive and concentrate radio waves coming from space
radiosonde	balloon-borne instrument for the measurement and transmission of meteorological data
reentry window	the area at the limits of the earth's atmosphere through which a spacecraft in a given trajectory can pass to accomplish a successful reentry

remote sensors	devices to obtain data from a distance
retrorocket retr = back, backward	rocket on or in a spacecraft or satellite to produce thrust opposite to forward motion
satellite	a body that orbits around another body
selenology selen = the moon	astronomy that deals with the moon
sensible atmosphere	part of the atmosphere that offers resistance to a body passing through it
sensor	part of an instrument that converts an input signal into a quantity which is measured by another part of the instrument; sensing element
solar cell	photovoltaic device that converts sunlight directly into electrical energy
solar wind	stream of protons constantly moving outward from the sun
space station	a station sent into orbit for use as a launch site for further spacecraft or as an observatory
spectrometer	instrument which measures some characteristics of electromagnetic radiations
stationary orbit	an orbit in which the satellite revolves around the primary at the same rate as the primary rotates on its axis; hence the satellite appears to be stationary over a point on the primary; orbit must be over equator with satellite moving east
subsonic sub = under son = sound	dealing with speeds less than the speed of sound
supersonic	pertaining to speeds greater than the speed of sound; $\text{Mach} \geq \text{velocity} < \text{Mach } 5$
synchronous satellite syn = with, together chron = time	satellite orbiting the earth at an altitude of 22,300 statute miles (35,888 km), at which altitude it makes one revolution in 24 hours, synchronous with the earth's rotation; it must be over the equator moving east
telemetry tele = far metry = measurement	science of measuring quantities, transmitting the data to distant station, for recording and interpreting the data
thrust	the pushing force developed by an aircraft or rocket engine

tracking station	location for the process of following the movement of a satellite or rocket by radar, radio, and photographic observation
trajectory	path traced by a body moving as a result of externally applied forces
transonic	close to the speed of propagation of sound
traverse	a journey across a piece of terrain for the purpose of exploration; as the Apollo 15 traverses of the lunar surface
universal time	Greenwich mean time
Van Allen belts	zones where high-energy extraterrestrial particles are trapped by or contained by the geomagnetic field
weightlessness	condition in which no acceleration, whether of gravity or other force, can be detected by an observer within the system in question
zenith	point on the celestial sphere directly above the observer
zero g	complete absence of effects of gravity; weightlessness

Note: Many of the above definitions are taken from *Short Glossary of Space Terms*. National Aeronautics and Space Administration, Washington, D.C. 1962.

A Simplified Chi-Square Table of Values

d.f.	*P*=.10	*P*=.05	*P*=.01
1	2.71	3.84	6.64
2	4.60	5.99	9.21
3	6.25	7.82	11.34
4	7.78	9.49	13.28
5	9.24	11.07	15.09
6	10.64	12.59	16.81
7	12.02	14.07	18.48
8	13.36	15.51	20.09
9	14.68	16.92	21.67
10	15.99	18.31	23.21
15	22.31	25.00	30.58
20	28.41	31.41	37.57

APPENDIX B

Answers to Problems and Questions

Chapter 1

Page 11. a. A midget? how about micromorph?
- b. A device to measure people's feet? how about a podometer?
- c. Rock and roll? Some people might call it pseudophonics (false noise).

You undoubtedly thought of other equally reasonable terms to apply.

1. a. Fear of heat or hot places
   - b. Moon water (moonshine?)
   - c. Heavy footed
2. a. Lover of people, friendly?
   - b. Many shaped, rubbery?
   - c. False feet

Chapter 2

Biology

1. a. Biarthrose. How about double-jointed?
   - b. Gymnopoda. How about barefooted?
   - c. Neuroectomy. How about removal of nerve, or cowardice?
2. a. Genus and species names of the familiar (common domesticated) dog
   - b. An early plant, perhaps a predecessor of the primitive algae
   - c. Infection of the skin
   - d. Stomach-footed
   - e. Animals in mossy colors
   - f. Sperm-producing animals
   - g. Inflammation of joints
3.
4. The elms and maples are in the same class; the pines and maples are not.
5. Yes, Muscidae have one pair of wings, as do the other members of the order Diptera.
6. Flies and gnats

Chemistry

2. There are 3 oxygen atoms in the molecule. There is only 1 atom each of the other elements. Subscripts are omitted for the number 1.

6. a. SrO, strontium oxide
   b. $AlBr_3$, aluminum bromide
   c. NaF, sodium fluoride
   d. Ga_2S_3, gallium sulfide

7. a. Cu_2S, copper(I) sulfide
      CuS, copper(II) sulfide
   b. CrI_3, chromium(III) iodide
      CrI_6, chromium(VI) iodide
   c. Ti_2O_3, titanium(III) oxide
      TiO_2, titanium (IV)oxide

9. Heptanol $C_7H_{15}OH$
   Propane C_3H_8

Physics

1. In this derivation you are working toward the definition of the *ampere*, the *volt*, and the *ohm*. The ampere is the amount of current that will carry silver to a cathode at the rate of .001118 grams per second (mass and time). A volt source will give each coulomb it delivers one joule of energy. (Work backwards from the joule.) An ohm is not defined from our basic mass, length, time units but is defined arbitrarily as the resistance to an unvarying current of a column of mercury at 0°C, 106.3 centimeters long, of constant cross-sectional area, and weighing 14.4521 grams.

2. Light energy, sound energy, kinetic energy of waves (water) from a point source, and radiant energy of other types all show this phenomenon. The relationship can be expressed as $i \propto 1/d^2$; where *i* is the intensity, and *d* is the distance from the source.

3. Resonance occurs in sound energy, light energy, water waves, and other types of radiant energy. Resonance cavities have been developed to use this phenomenon for most of these energy types; for example, the laser, the cavitron tube, and even parabolic reflectors.

4. 473.2 grams of water at its maximum density 4°C (1 liter of water weighs 1,000 grams; 1 pint is 0.4732 liters).

Earth and Space Science

1. 30° West longitude.

2. London: 1700 hours or 5 *P.M.* Tokyo: 2 *A.M.* the next morning. Nome, Alaska: 6 *A.M.* Honolulu: 7 *A.M.* the same morning. In other words, while you are having lunch in New York, the Alaskan and Hawaiian are having their breakfast, the Londoner is preparing for his supper, and the people of Tokyo have already gone to bed. Were you surprised to find that Nome, Alaska, is farther west than Honolulu?

3. San Francisco.

4. One would expect to find rocks of the Paleozoic, Mesozoic, and Cenozoic eras; in fact, all eras, periods, and epochs to the present time. This is not the case, however, either because some of the more recent rocks of Mesozoic and Cenozoic age have already been removed by weathering and erosion, or because no rocks were formed during some periods and epochs.

5. It was called the "genesis rock" because the astronauts hoped that it would prove to be as old as the formation of the moon. Estimates made by scientists on the earth who dated the rock set its age as about 4.1 billion years. Earth rocks of this age would be from the Pre-Cambrian Era.

6. The table might include
    Weathering (excluding effects of wind and water)
    Metamorphism
    Erosion (excluding effects of wind and water)
    Transportation
    Diastrophism
    Volcanism
    Impact of bodies from space

7.

8. d. Craters
    e. Basalt

9. a. Hurricanes, mTw
    b. Snow blizzards, mPk
    c. Monsoons: Summer, mTk
                         Winter, cAk
    d. Bright, warm days, cPw

10. In seeding clouds, scientists are trying to promote formation of water drops that will fall as rain. Successful seeding with silver iodide requires subcooled cloud droplets (T 0°C). Silver iodide will act as a freezing nucleus, and in a mixed water-ice particle cloud the latter will grow at the expense of the former. Thus the particles become larger, fall faster, and by collision will collect more droplets and eventually grow to raindrop size.

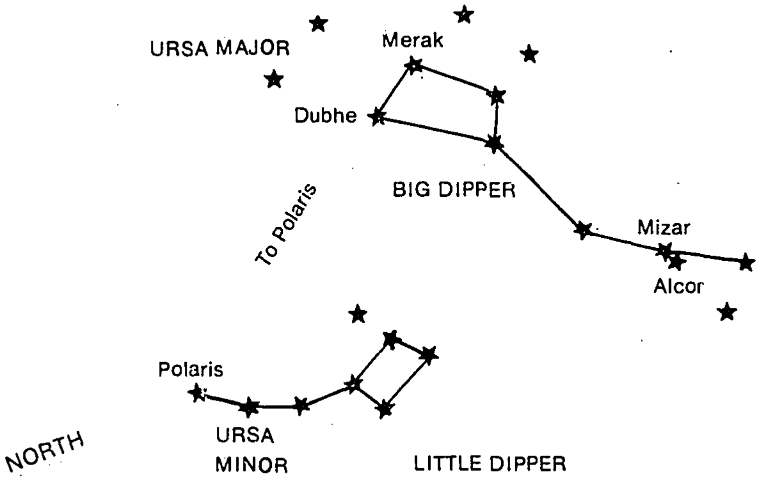
11. a. Cirrocumulus
    b. Cirrostratus

c. Cumulonimbus, which might cause the pilot to change course to avoid thunderstorms, lightning, and severe turbulence.

12. Tides are highest at full and new moon because at those periods the sun and moon are in parallel positions and their gravitational pulls are combined; at quarter moon, their forces are acting at right angles and consequently exert less combined pull.

13. Tides may exceed 50 feet in the Bay of Fundy, which is a constricted estuary.

14.



15. a. Go to the beach 
    b. Use snow tires 
    c. Hurry home 
    d. Close windows and shutters 
    e. Fly kites 
    f. Go hiking 

16. a. .5 micron—telescope, microscope, or no instrument; we see these waves as visible light
    b. 1 ångström—X-ray photography
    c. 1 kilocyle—radio receiver
    d. 1,000 kilometers—radio telescopes

Chapter 3—The Laboratory

1. One approach could be to use a magnet to extract the iron filings. Then if carbon disulfide were added, the sulfur (and only the sulfur) would dissolve; the fluid could be decanted, and the solvent

evaporated to reclaim the sulfur. In the same way water would dissolve the salt, but not the moth crystals or the sand. Finally, an organic solvent (say, alcohol) could remove the moth crystals in solution and leave the sand. Thus, all five materials could be separated into invididual piles.

It might also be *possible to centrifuge the dry* particles to separate them.

Other possible methods: using a geologist's sieve-series could also be effective. Applying heat and collecting each portion at its particular melting point would work.

There are probably other ways, too. The point is that, to solve the problem, one must call up isolated bits of information and use reasoning processes to put them together in an effective way. The problem also suggests that in problem solving, there is no one "correct" answer.

2. The easiest approach to solving this problem is a negative one. We first of all rule out all the positions a man cannot hold (from the statements given) and then use the remaining information to determine which position he does hold.

   Thus, Mr. Sprague cannot be the President if he "served with the President in the First World War," nor can he be the Actuary if he "beats him at gin rummy." If Mr. Watson never "goes to the theater nor plays cards" he cannot be the Secretary or the Actuary.

   Mr. Lidstone—Actuary
   Mr. King—President
   Mr. Sprague—Secretary
   Mr. Watson—Vice President

3. a. It would be impossible to list all of the possible problems inherent in the major area of concern, but there would be chemistry problems, such as:

   What is the chemical nature of cigarette smoke?

   Do these chemicals do damage independently or must they be in interaction with body chemicals to be harmful?

   What are harmful dosage levels?

   Is the damage cumulative?

   There could also be biological problems, such as:
   What organs (tissues, cells) are harmed?

   How are these structures harmed?

   There might be environmental studies, such as:

   What is the concentration of smoke in

   (a) a closed car with two people smoking,
   (b) the boys' restroom between classes,

(c) the student's home (if his parents smoke) over a 4-hour evening period?

In the same way one could consider problems of prevention of corrosion through physical means such as improved lubrication, plastic wrapping; through chemical means by improved paints or new substances; electrical (cathodic) protection such as is used on ships.

Mathematics

1. a. 36,250
   b. 3.625
   c. 362.5
   d. 0.03625
   e. 0.003625
   f. 0.0003625
2. a. 2×10^6
   b. 7.049×10^3
   c. 2.37465×10^3
   d. 1.86×10^{-1}
   e. 8.0×10^0
   f. 4.37×10^{-5}
3. a. 23
   b. 30.40
   c. 4.68
   d. 2.89×10^6
4. $200 \text{ watts} \times \frac{10 \text{ hours}}{\text{day}} \times 30 \text{ days} \times \frac{5 \text{ cents}}{\text{kWhr}} \times \frac{1 \text{ kW}}{1{,}000 \text{ watts}} = \$3$

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Solar system
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