

Zumberge's  
**Laboratory Manual**  
*for Physical Geology*

SIXTEENTH EDITION

Robert H. Rutherford • James L. Carter



ZUMBERGE'S LABORATORY MANUAL FOR

# Physical Geology



ZUMBERGE'S LABORATORY MANUAL FOR PHYSICAL GEOLOGY, SIXTEENTH EDITION

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# Physical Geology

SIXTEENTH EDITION

Robert H. Rutherford

*The University of Texas at Dallas*

James L. Carter

*The University of Texas at Dallas*

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Education

Dedicated to the memory of

## James H. Zumberge

whose dedication to his students and commitment to the geosciences  
live on.

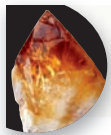
Jim was born and raised in Minneapolis, Minnesota, and received his university degrees from the University of Minnesota. He started his teaching career at the University of Michigan, and it was there that the first edition of this laboratory manual was written and published by Wm. C. Brown in 1951.

At both the national and international levels, Jim was active in polar science research and policy matters, serving on numerous government boards and as president of an international organization. He had a distinguished career in higher education administration, serving as president or chancellor of three universities.

He was a dedicated teacher with a love for geology. His enthusiasm for whatever he was involved in was contagious, and his students and colleagues were caught up in his view of the future. It is in recognition of his excellence that this manual carries his name.

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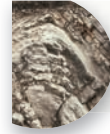


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# NOTES TO USERS OF THIS MANUAL

In previous editions this section has been titled "Materials Needed by Students Using This Manual." Reviewers of the manual have suggested that we use this page to offer some advice and help as you begin your geology laboratory experience.

In the course of the laboratory exercises, you will be using a number of items that require some care. They are not "dangerous," but you should handle them with some caution until you are comfortable with their use. Some of the laboratory experiments included in this text may be hazardous if materials are handled improperly or if procedures are conducted incorrectly. Safety precautions are necessary when you are working with chemicals, glass test tubes, hot water baths, sharp instruments, and the like, or for any procedures that generally require caution. Your school may have set regulations regarding safety procedures that your instructor will explain to you. Should you have any problems with materials or procedures, please ask your instructor for help.

In the study of minerals, your laboratory instructor will provide you with a small bottle of dilute hydrochloric acid. Although this is a very weak acid, you should take care to keep it away from your eyes and from making contact with your clothes. In the event that you do spill, wash the affected area in water immediately and advise your instructor of the problem.

You also will be provided with a glass plate for hardness testing and a piece of unglazed porcelain to use as a streak plate. When using the glass plate and the porcelain streak plate, hold them flat on the table top, not in your hand.

Following is a list of materials that will be useful for completing the exercises in this manual. For example, the hand lens should be available for the identification of the

minerals in rocks. Other materials will be required to complete the exercises dealing with maps or photos. Since the authors do not know which of the exercises you will be assigned, we urge you to ask your instructor about the exact materials that you will need during the semester.

1. 10x hand lens
2. Scale ("ruler") in metric and English units
3. Colored pencils (red, blue, and assorted other colors)
4. Felt-tip pens ( $\frac{1}{8}$ "  $\times$   $\frac{1}{4}$ " tip, three assorted colors).
5. Several medium to medium-soft pencils (2H or No. 2)
6. Small magnifying glass (optional) for map reading
7. 8  $\frac{1}{2}$ "  $\times$  11" tracing paper
8. Eraser (art gum or equivalent)
9. Inexpensive pencil sharpener
10. Inexpensive compass, for drawing circles
11. Dividers (optional), for measuring distances on maps

Finally, a word about units of measure. While the United States has "officially" adopted the metric system, the truth is that we continue to use both metric and English (US) units of measure in this country. Therefore, we have made a conscious decision to use both in this manual in the hope that you will become more comfortable with the conversion of feet and miles into meters and kilometers and the reverse. Most of the maps used in the United States are in English units. On the inside front cover you will find a conversion table for reference as you make the conversions required in the various exercises.



The geologic sciences continue to undergo remarkable changes. Those changes that have endured over time have been incorporated into each edition of this manual since the first edition was published in 1951. Although the subject matter has changed and expanded in scope, the number of laboratory sessions in a given academic quarter or semester has not increased. Because the time available in a quarter or semester cannot be expanded without disrupting the class schedule for the entire college or university, the problem of too much material for too little time poses a dilemma for authors, instructors, and students.

## Approach

On the assumption that the subject matter to be covered in any course is the prerogative of the instructor and not the authors, we have written a manual that contains more material than can be covered in a single laboratory course, thereby leaving the selection of individual exercises to the instructor. While we believe the overall scope of this manual is in keeping with the general subject material covered in a beginning laboratory course, we think the instructors should determine the specific exercises that are in keeping with their own ideas of how to organize and present subject material.

We are aware that some instructors will wish to introduce plate tectonics early in the course. Part VI, Plate Tectonics and Related Geologic Phenomena, is written so that it stands alone and can be used at any time. At The University of Texas at Dallas the physical geology lecture and laboratory courses are taught by two professors, one who opens the course with plate tectonics, the other who closes with it. In Parts IV and V the majority of the exercises also are self-contained so that instructors may use them in the order they prefer.

In addition to the variety of laboratory exercises offered, we also provide you with background material for each exercise. By allowing you to review the important concepts and geologic terms you will encounter in the laboratory, we hope to enhance your chance for a successful completion of the exercises. According to reviewers and users of past editions, the supplemental material provided is particularly useful in those instances when you do not routinely bring your textbooks to class or when you are not concurrently enrolled in the lecture class. To supplement this background material,

we include a *Glossary* (pp. 281–288) as an integral part of the manual.

The sixteenth edition follows the same overall organization of past editions. You will note that we provide answer sheets for all of the exercises. At the request of many users, we have provided tearout worksheets for mineral and rock identification.

## New to This Edition

This edition of Zumberge's *Laboratory Manual for Physical Geology* reflects the continued effort by the authors and publisher to improve the quality of the figures and tables. Consistent colors and symbols for the various rock types are used, the sharpness and detail of the photos have been increased, and efforts have been made to make this edition more user-friendly.

This manual has also been updated in other ways, including:

### Part I:

- Revision of exercise format, revision of some tables, deletion of others for clarity
- Addition of illustration

### Part II:

- Considerable rewrite of text and addition of text materials
- Refinement of line drawings
- Additional materials in section on correlation and fossils
- Complete rewrite of Exercise 7 dealing with radiometric dating and geologic ages
- Updated exercises—Exercise 7 now in two parts. 7a and 7b.

### Part III:

- Minor changes to both text and illustrations for clarity and consistency
- Updated exercises

### Part IV:

- New and revised figures
- Updated information and photo of South Cascade Glacier
- Updated information on Lake Michigan water levels

### Part V:

- Revision of illustrations and text for clarity and consistency
- Addition of text dealing with earthquake sizes including a new figure on the comparison of Richter and Mercalli scales

### Part VI:

- Revision of illustrations and text for clarity and consistency
- New materials on recent earthquake in Japan
- Revised figure on earthquake magnitude and energy (box 6.1, fig. 3)
- Updated exercises

The cover of this edition is a photo of a most interesting star dune in the Empty Quarter, Saudi Arabia. A description of star dune is provided on the outside back cover.

## Website

[www.mhhe.com/zumberge16e](http://www.mhhe.com/zumberge16e)

This text-specific site gives you the opportunity to further explore topics presented in the book using the Internet. Students will find flashcards, animations, additional photos, and all of the weblinks listed in the lab manual. Included in the password-protected Instructor's Edition is an Instructor's Manual and a list of slides that accompany the sixteenth edition.

## Personalize Your Lab

Craft your teaching resources to match the way you teach! With McGraw-Hill Create, [www.mcgrawhillcreate.com](http://www.mcgrawhillcreate.com), you can easily rearrange chapters, combine material from other content sources, and quickly upload content you have written like your course syllabus or teaching notes. Find the content you need in Create by searching through thousands of leading McGraw-Hill textbooks. Arrange your book to fit your teaching style. Create even allows you to personalize your book's appearance by selecting the cover and adding your name, school, and course information. Order a Create book and you'll receive a complimentary print review copy in 3–5 business days or a complimentary electronic review copy (eComp) via email in about one hour. Go to [www.mcgrawhillcreate.com](http://www.mcgrawhillcreate.com) today and register. Experience how McGraw-Hill Create empowers you to teach *your* students *your way*.

## Acknowledgments

We acknowledge with special thanks the contributions of the graduate teaching assistants who have assisted during the revisions of this manual. The advice and counsel of our faculty and staff colleagues at The University of Texas at Dallas are also greatly appreciated.

To those who reviewed this and past editions, we express our thanks and appreciation for their critical comments and suggestions for improvement. These include:

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As authors we accept the full responsibility for any inadvertent errors that have crept into these pages, and we welcome comments from users if they discover such errors. We also hope that users will make suggestions to us that will assist in the continued improvement of this manual in the future.

Finally, we extend our gratitude to the professional men and women of McGraw-Hill for their design of the format and expert help in transforming our manuscript into a final product.

## About the Authors

### Robert H. Rutford

Bob Rutford, Excellence in Education Foundation Chaired Professor in Geosciences Emeritus and President Emeritus of The University of Texas at Dallas, was born and raised in Minnesota, where he attended the University of Minnesota, graduating with a BA in geography in 1954.

Bob was commissioned a Second Lieutenant in the US Army and spent a year in Greenland. He returned to the University of Minnesota as a graduate student in geography, completing his MA in 1963.

In 1959 he made the first of numerous trips to Antarctica. He changed his major to geology and received his PhD in 1969. His dissertation dealt with the glacial geology and geomorphology of the Ellsworth Mountains, Antarctica.

Bob's academic career began at the University of South Dakota, then at the University of Nebraska–Lincoln and following a period at NSF in Washington, DC as Director of the Office of Polar programs, he returned to Nebraska to serve as vice chancellor. In 1982 he became the president of The University of Texas at Dallas, a position he held for

12 years. In 1994 he returned to the faculty, where he was an active teacher with classes in physical geology, global environments, glaciers, and deserts until 2007. He served as the US Delegate to the International Scientific Committee on Antarctic Research and served as president of that organization from 1998 to 2002. For several years Bob lectured on cruise ships in Antarctic water. After 2002, in recognition of his contributions to science and science policy in the Antarctic he has been honored by having two features named for him, Rutford Ice Stream and Mount Rutford, both in the vicinity of the Ellsworth Mountains, West Antarctica.

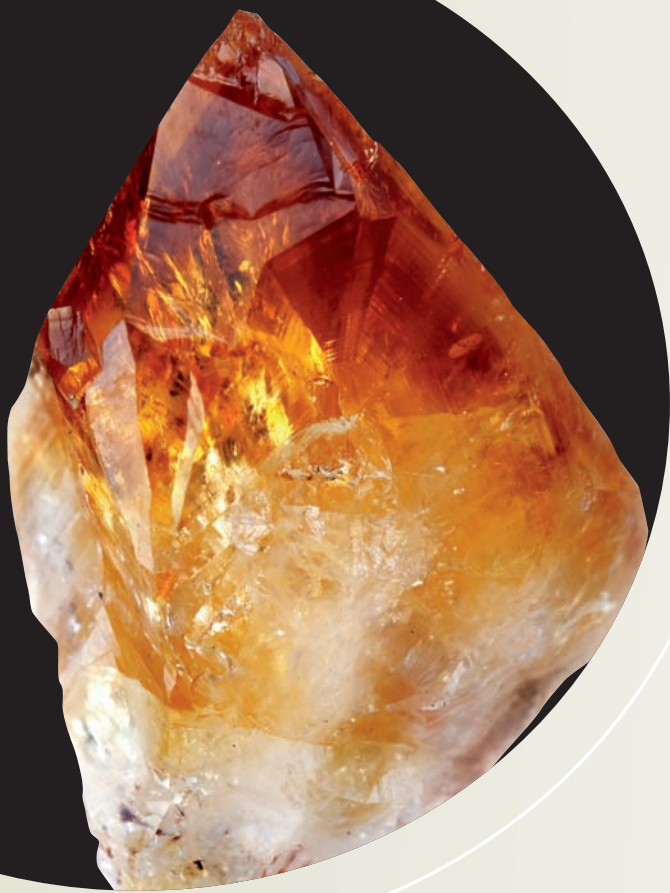
Bob became a co-author of this manual in 1979, and as the senior author since 1992, has attempted to continue Jim Zumberge's record of excellence.

### James L. Carter

James Carter, who became a co-author of this manual in 1995, spent his early years in southern Texas, where he developed his love for the outdoors. He received his BS in geological/mining engineering at Texas Western (now University of Texas at El Paso) in 1961 and a PhD from Rice University in geochemistry in 1965. His dissertation dealt with the chemistry and mineralogy of the earth's upper mantle as revealed by mantle xenoliths in basalts. His research and teaching interests are broad and include lunar studies and extraterrestrial resources, ore deposit genesis, geochemical explorations, environmental issues, and Late Cretaceous dinosaurs. He has studied ore deposits in Central America, China, India, Mexico, Chile and Peru, as well as in the United States. James was a principal investigator on the characterization of lunar regolith samples returned to earth from the six *Apollo* missions and the Russian *LUNA 20* unmanned mission. He also made the lunar regolith simulants JSC-1, JSC-1A, JSC-1A-C, JSC-1A-F, JSC-1A-VF, and JSC-1A-VFR.

Carter taught a wide range of graduate and undergraduate courses at The University of Texas at Dallas from its inception in 1969 until 2007 when he retired. In 2003 he was the recipient of the AAPG (American Association of Petroleum Geologists) Distinguished Educator Award in the Southwest Section. He is a member of the American Association of Professional Geologists.





## P A R T

# I

# Earth Materials

## Introduction

The materials that make up the crust of the earth fall into two broad categories: minerals and rocks. Minerals are elements or chemical compounds formed by a number of natural processes. Rocks are aggregates of minerals or organic substances that occur in many different architectural forms over the face of the earth, and they contain a significant part of the geologic history of the region where they occur. To identify them and understand their history, you must be able to identify the minerals that make up the rocks.

The aim of Part I is to introduce students of geology to the identification of minerals and rocks through the use of simplified identification methods and classification schemes.

Students will be provided with samples of minerals and rocks in the laboratory. These samples are called **hand specimens**. Ordinarily their study does not require a microscope or any means of magnification because the naked or corrected eye is sufficient to perceive their diagnostic characteristics. A feature of a mineral or rock that can be distinguished without the aid of magnification is said to be **macroscopic** (also **megascopic**) in size. Conversely, a feature that can be identified only with the aid of magnifiers is said to be **microscopic** in size. The exercises that deal with the identification and classification of minerals and rocks in Part I are based only on macroscopic features.





# Minerals

## Definition

A **mineral** is a naturally occurring, crystalline, inorganic, homogeneous solid with a chemical composition that is either fixed or varies within certain fixed limits, and a characteristic internal structure manifested in its exterior form and physical properties.

Minerals are divided into classes based on their chemical composition (see table 1.4). The classes are based on the presence (or lack) of similar anions such as oxygen in the Oxide class. The Silicate class is the most important as it contains many of the rock forming. This class is often subdivided into mineral groups based on similar structure and chemistry.

## Mineral Identification

Common minerals are identified or recognized by testing them for general or specific physical properties. For example, the common substance table salt is actually a mineral composed of sodium chloride (NaCl) and bears the mineral name halite. The salty taste of halite is distinctive and is sufficient for identifying and distinguishing it from other substances such as sugar (not a mineral) that have a similar appearance. Chemical composition alone is not sufficient to identify minerals. The mineral graphite and the mineral diamond are both composed of a single element, carbon (C), but their physical properties are very different.

The taste test applied to halite is restrictive because it is the only mineral with the taste of common table salt. Other minerals may have a specific taste different from that of halite. Other common minerals can be tested by visual inspection for the physical properties of **crystal form**, **cleavage**, or **color**, or by using simple tools such as a knife blade or glass plate to test for the physical property of hardness.

The first step in learning how to identify common minerals is to become acquainted with the various physical properties that individually or collectively characterize a mineral specimen.

## Properties of Minerals

The physical properties of minerals are those that can be observed generally in all minerals. They include such

common features as luster, color, hardness, cleavage, streak, and specific gravity. **Special properties** are those that are found in only a few minerals. These include magnetism, double refraction, taste, odor, feel, and chemical reaction with acid. In your work in the laboratory, use the mineral hand specimens sparingly when applying tests for the various properties.

## General Physical Properties

### Luster

The appearance of a fresh mineral surface in reflected light is its **luster**. A mineral that looks like a metal is said to have a **metallic luster**. Minerals that are **nonmetallic** are described by one of the following adjectives: **vitreous** (having the luster of glass), **resinous** (having the luster of resin), **pearly**, **silky**, **dull** or **earthy** (not bright or shiny).

### Color

The color of a mineral is determined by examining a fresh surface in reflected light. Color and luster are not the same. Some minerals are clear and transparent; others are opaque. The variations in color of a mineral are called **varieties** of the mineral (fig. 1.1).



**Figure 1.1**

The specimens in this photograph are all varieties of quartz. The difference in colors is due to various impurities. Clockwise from left: smoky quartz, rock crystal, rose quartz, citrine, amethyst.

Color is not a diagnostic property for the majority of non-metallic minerals. Some nonmetallic minerals, however, have a constant color, which can be used as a diagnostic property. Examples are malachite, which is green, and azurite, which is blue. Most minerals with a metallic luster vary little in color, and color of a freshly broken surface is a diagnostic property.

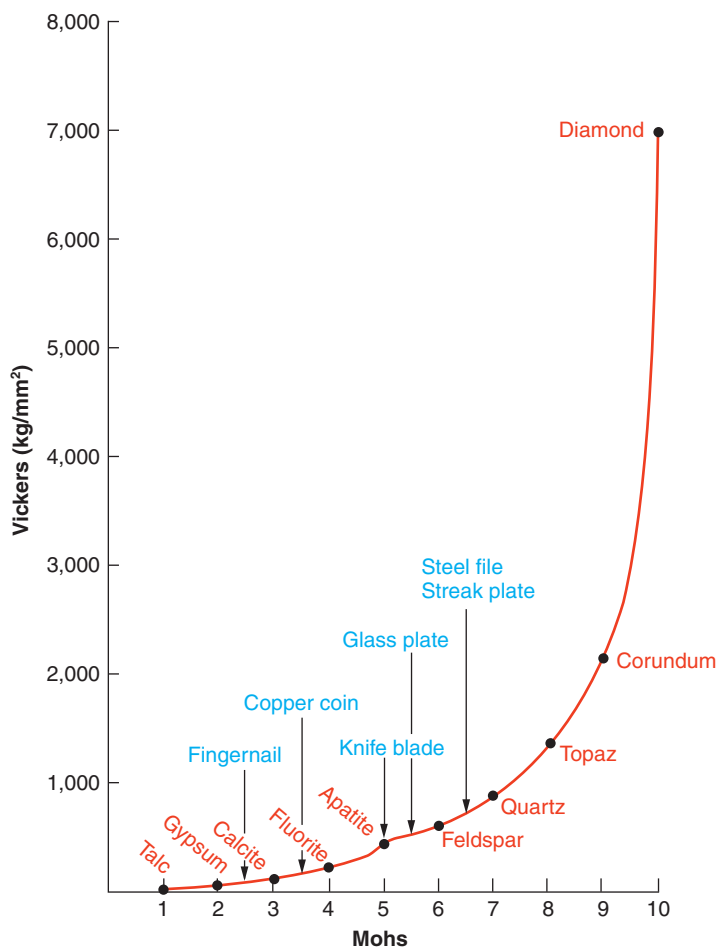
## Hardness

The **hardness** of a mineral is its resistance to abrasion (scratching). Hardness can be determined either by trying to scratch a mineral of unknown hardness with a substance of known hardness or by using the unknown mineral to scratch a substance of known hardness. Hardness is determined on a relative scale (linear scale) called the **Mohs scale of hardness**, which consists of 10 common minerals arranged in order of their increasing hardness (table 1.1). In the laboratory convenient materials other than these 10 specific minerals may be used for determining hardness.

In contrast to the Mohs scale, the Vickers scale is an example of a nonlinear scale that points out the great difference in hardness between the various minerals (fig. 1.2). Nonlinear hardness scales are used to test the hardness of materials, for example, by measuring the volume of an indentation left in the surface of the material under a known pressure.

In this manual, a mineral that scratches glass will be considered “hard,” and one that does not scratch glass will be considered “soft.” *In making hardness tests on a glass plate, do not hold the glass in your hand; keep it firmly on the table top.* If you think that you made a scratch on the glass, try to rub the scratch off. What appears to be a scratch may only be some of the mineral that has rubbed off on the glass.

Hardness	Mineral Hardness According to the Mohs Scale (A) and Some Common Materials (B)	
	A	B
1	Talc	
2	Gypsum	
2.5		Fingernail
3	Calcite	
3.5		Copper coin
4	Fluorite	
5	Apatite	
5–5.5		Knife blade
5.5		Glass plate
6	Feldspar	
6.5		Steel file, Streak plate
7	Quartz	
8	Topaz	
9	Corundum	
10	Diamond	



**Figure 1.2**

Mohs hardness scale plotted against Vickers indentation values ( $\text{kg}/\text{mm}^2$ ).

## Cleavage

**Cleavage** is the tendency of a mineral to break along definite planes of weakness that exist in the internal (atomic) structure of the mineral. Cleavage planes are related to the crystal system of the mineral and are always parallel to crystal faces or possible crystal faces. Cleavage may be conspicuous and is a characteristic physical property that is useful in mineral identification. It is almost impossible to break some minerals in such a way that cleavage planes do not develop. An example is calcite, with its rhombohedral cleavage.

**Perfect cleavage** describes cleavage planes with surfaces that are very smooth and flat and that reflect light much like a mirror. Other descriptors such as **good**, **fair**, and **poor** are used to describe cleavage surfaces that are less well defined. Some minerals exhibit excellent crystal faces but have no cleavage; quartz is such a mineral.

The cleavage surfaces of some minerals such as calcite, muscovite (fig. 1.3), halite, and fluorite are so well developed that they are easily detected. In others, the cleavage surfaces may be so discontinuous as to escape detection by casual inspection. Before deciding that a mineral has no cleavage, turn it around in a strong light and observe



**Figure 1.3**

Muscovite is a mineral with one direction of cleavage (basal cleavage).

whether there is some position in which the surface of the specimen reflects the light as if it were the reflecting surface of a dull mirror. If so, the mineral has cleavage, but the cleavage surface consists of several discontinuous parallel planes minutely separated, and rather than perfect cleavage, it has good, fair, or poor cleavage. As will be noted in the discussion of crystal form, it is important to differentiate between cleavage surfaces and crystal faces (the actual breaking of a mineral crystal may be useful in making this differentiation).

In assigning the number of cleavage planes to a specimen, do not make the mistake of calling two parallel planes bounding the opposite sides of a specimen two cleavage planes. In this case the specimen has two cleavage surfaces but only one plane of cleavage, that is, one direction of cleavage (fig. 1.3 and fig. 1.4 example 1). Halite has cubic cleavage, thus six sides, but only three planes of cleavage because the six sides are made up of three parallel pairs of cleavage surfaces.

The angle at which two cleavage planes intersect is diagnostic. This angle can be determined by inspection. In most cases, you will need to know whether the angle is 90 degrees, almost 90 degrees, or more or less than 90 degrees. The cleavage relationships that you will encounter during the course of your study of common minerals are tabulated for convenience in figure 1.4.

### Parting

Minerals may exhibit the characteristic of **parting**, sometimes called false cleavage. Parting occurs along planes of weakness in the mineral, but usually the planes are more widely separated and often are due to twinning deformation or inclusions. Parting is not present in all specimens of a given mineral.

### Fracture

Some minerals have no cleavage but show **fracture** that forms a surface with no relationship to the internal structure of the mineral; that is, the break occurs in a direction other than a cleavage plane. The broken surface may exhibit **conchoidal** fracture, where the fractured surface is curved

Number of Cleavage Planes	Remarks	Examples
1	Usually called <b>basal cleavage</b> . Examples: muscovite and biotite.	
2	<b>Two at 90 degrees</b> . Examples: feldspar and pyroxene (augite) have cleavage surfaces that intersect at close to 90 degrees.	
2	<b>Two not at 90 degrees</b> . Example: amphibole (hornblende) has cleavage surfaces that intersect at angles of about 60 and 120 degrees.	
3	<b>Three at 90 degrees. Minerals with three planes of cleavage that intersect at 90 degrees are said to have cubic cleavage</b> . Examples: halite and galena.	
3	<b>Three not at 90 degrees. A mineral that breaks into a six-sided prism, with each side having the shape of a parallelogram, has rhombic cleavage</b> . Example: calcite.	
4	<b>Four sets of cleavage surfaces in the form of an octahedron produce octahedral cleavage</b> . Example: fluorite.	
6	<b>Complex geometric forms</b> . Example: sphalerite.	

**Figure 1.4**

Descriptive notes on cleavage planes.

and smooth with fine, concentric ridges (see fig. 1.9). The mineral asbestos (crysotile) is characterized by **fibrous** fracture. Other descriptive terms often used to describe fracture types include **hackly**, **uneven** (rough), **even** (smooth), and **earthy** (dull but smooth fracture surfaces common in soft mineral aggregates such as kaolinite).

## Streak

The color of a mineral's powder is its **streak**. The streak is determined by rubbing the hand specimen on a piece of unglazed porcelain (**streak plate**). Some minerals have a streak that is the same as the color of the hand specimen; others have a streak that differs in color from the hand specimen. The streak of minerals with a metallic luster is especially diagnostic.

## Specific Gravity

The **specific gravity** (G) of a mineral is a number that represents the ratio of the mineral's weight to the weight of an equal volume of water. In contrast to density, defined as mass per unit volume, specific gravity is a dimensionless number. The higher the specific gravity, the greater the density of a mineral.

For purposes of estimating the specific gravity of the minerals in the laboratory, it is sufficient to utilize a simple **heft** test; that is, to compare the relative specific gravity of one sample by lifting the sample in question in one hand while lifting a sample of a known specific gravity of similar size in the other hand. For example, compare a sample of graphite (G = 2.2) in one hand with a sample of galena (G = 7.6) in the other hand. *Take care to compare samples of similar size.* This allows you to determine the relative specific gravity of minerals. When hefted, minerals such as graphite (G = 2.2) and gypsum (G = 2.3) are relatively "light," quartz (G = 2.65) and calcite (G = 2.7) are "average," whereas corundum (G = 4.0), magnetite (G = 5.2), and galena (G = 7.6) are "heavy."

## Diaphaneity

The ability of a mineral to transmit light is its **diaphaneity**. If a mineral transmits light freely so that an object viewed through it is clearly outlined, the mineral is said to be **transparent**. If light passes through the mineral but the object viewed is not clearly outlined, the mineral is **translucent**. Some minerals are transparent in thin slices and translucent in thicker sections. If a mineral allows no light to pass through it, even in the thinnest slices, it is said to be **opaque**.

## Tenacity

**Tenacity** is an index of a mineral's resistance to being broken or bent. It is not to be confused with hardness. Some of the terms used to describe tenacity are:

**Brittle**—The mineral shatters when struck with a hammer or dropped on a hard surface.

**Elastic**—The mineral bends without breaking and returns to the original shape when stress is released.

**Flexible**—The mineral bends without breaking but does not return to its original shape when the stress is released.

## Crystal Form

A **crystal** is a solid bounded by surfaces (crystal faces) that reflect the internal (atomic) structure of the mineral. **Crystal form** refers to the assemblage of crystal faces that constitute

the exterior surface of the crystal. **Crystal symmetry** is the geometric relationship between the faces.

Symmetry in a crystal is determined by completing a few geometric operations. For example, a cube has six faces, each at right angles to the adjacent faces. A planar surface that divides the cube into portions such that the faces on one side of the plane are mirror images of the faces on the other side of the plane is called a **plane of symmetry**. A cube has nine such planes of symmetry. In the same way, imagine a line (axis) connecting the center of one face on a cube with the center of the face opposite it (see cubic model at the top left of fig. 1.5). Rotation of the cube about this axis will show that during a complete rotation a crystal face identical with the first face observed will appear in the same position four times. This is a fourfold **axis of symmetry**. Rotation of the cube around an axis connecting opposite corners will show that three times during a complete rotation an identical face appears, thus a **threefold axis of symmetry**.

The same mineral always shows the same angular relations between crystal faces, a relationship known as the **law of constancy of interfacial angles**. The symmetric relationship of crystal faces, related to the constancy of interfacial angles, is the basis for the recognition of the six crystal systems by crystallographers, and all crystalline substances crystallize in one of the six crystal systems (fig. 1.5). Some common substances, such as glass, are often described as crystalline, but in reality they are **amorphous**—they have solidified with no fixed or regular internal atomic structure.

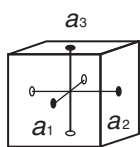

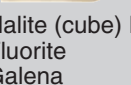





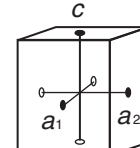


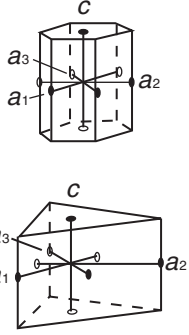








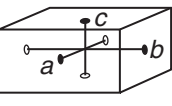


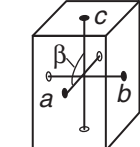




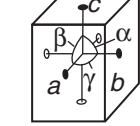

The six crystal systems can be recognized by the symmetry they display. Figure 1.5 summarizes the basic elements of symmetry for each system and shows some examples of the **crystal habit** (the crystal form commonly taken by a given mineral) of minerals you may see in the laboratory or a museum.

Perfect crystals usually form under special conditions in which there is open space for them to grow unrestricted during crystallization. In nature, they are the exception rather than the rule. Crystals are more commonly distorted, and their external form (crystal habit) is not perfectly developed. Regardless of the external form, the internal arrangement of the atoms within the crystals is fixed.

Many of the hand specimens you see in the laboratory will be made up of many minute crystals, so few crystal faces, or none, can be seen, and the specimen will appear granular. Other hand specimens may be fragments of larger crystals, so only one or two imperfect crystal faces can be recognized. Although perfect crystals are rare, most student laboratory collections contain some reasonably good crystals of quartz, calcite, gypsum, fluorite, and pyrite.

A word of caution: Cleavage fragments of minerals such as halite, calcite, and galena are often mistaken for crystals. This is because their cleavage fragments have the same geometric form as the crystal.

Two or more crystals of some minerals may be grown together in such a way that the individual parts are related through their internal structures. The external form that

CRYSTAL SYSTEM	CHARACTERISTICS	EXAMPLES*
 CUBIC (ISOMETRIC)	Three mutually perpendicular axes, all of the same length ( $a_1 = a_2 = a_3$ ). Fourfold axis of symmetry around $a_1$ , $a_2$ , and $a_3$ .	 Halite (cube)  Fluorite  Galena  Pyrite  Magnetite (octahedron)  Pyrite  Fluorite (twinned)
 TETRAGONAL	Three mutually perpendicular axes, two of the same length ( $a_1 = a_2$ ) and a third ( $c$ ) of a length not equal to the other two. Fourfold axis of symmetry around $c$ .	 Zircon  Zircon
 HEXAGONAL	Three horizontal axes of the same length ( $a_1 = a_2 = a_3$ ) and intersecting at 120 degrees. The fourth axis ( $c$ ) is perpendicular to the other three. Sixfold or threefold axis of symmetry around $c$ .	 Apatite  Apatite  Quartz  Corundum  Calcite (steep rhomb)  Calcite (flat rhomb)  Calcite (scalenoedron)  Calcite (twinned)
 ORTHORHOMBIC	Three mutually perpendicular axes of different length. ( $a \neq b \neq c$ ). Twofold axis of symmetry around $a$ , $b$ , and $c$ .	 Topaz  Staurolite** (twinned)
 MONOCLINIC	Two mutually perpendicular axes ( $b$ and $c$ ) of any length. A third axis ( $a$ ) at an oblique angle ( $\beta$ ) to the plane of the other two. Twofold axis of symmetry around $b$ .	 Orthoclase  Orthoclase (carlsbad twin)  Gypsum  Gypsum (twinned)
 TRICLINIC	Three axes at oblique angles ( $\alpha$ , $\beta$ , and $\gamma$ ), all of unequal length. No rotational symmetry.	 Plagioclase

**Figure 1.5**

Characteristics of the six crystal systems and some examples.

*Colors have been added to the original and are not accurate. They are shown for illustrative purposes only.*

*\*Most laboratory collections of minerals for individual student use do not include crystals of these minerals. The collection may, however, contain incomplete single crystals, fragments of single crystals, or aggregates of crystals of one or more minerals. The best examples of these and other crystals may be seen on display in most mineralogical museums.*

*\*\*Staurolite is actually monoclinic but is also classified as pseudo-orthorhombic. Pseudo-orthorhombic means that staurolite appears to be orthorhombic because the angle  $\beta$  in the monoclinic system (see left-hand column under monoclinic) is so close to 90 degrees that in hand specimens it is not possible to discern that the angle  $\beta$  for staurolite is actually 89 degrees, 57 minutes.*

results is manifested in a **twinned crystal**. Some twins appear to have grown side by side (plagioclase), some are reversed or are mirror images (calcite), and others appear to have penetrated one another (fluorite, orthoclase, staurolite). Recognition of twinned crystals may be useful in mineral identification.

## Special Properties

### Magnetism

The test for **magnetism**, the permanent magnetic effect of naturally magnetic rocks, requires the use of a common magnet or magnetized knife blade. Usually, magnetite is the only mineral in your collection that will be attracted by a magnet.

### Double Refraction (Birefringence)

If an object appears to be double when viewed through a transparent mineral, the mineral is said to have **double refraction**. Calcite is the best common example (see fig. 1.14).

### Taste

The distinctive saline **taste** of halite is an easy means of identifying the mineral. Few minerals are soluble enough to possess this property. (*For obvious sanitary reasons, do not use the taste test on your laboratory hand specimens.*)

### Odor

Some common minerals have a characteristic **odor** (smell) associated with them. Exhaling your breath on a kaolinite specimen will dampen the surface, causing the mineral to exude a musty or damp earthy odor. The streak of sphalerite will give off a rotten egg odor.

### Feel

The **feel** of a mineral is the impression gained by handling or rubbing it. Terms used to describe feel are common descriptive adjectives such as **soapy, greasy, smooth, or rough**.

### Chemical Reaction

Calcite will effervesce (bubble) when treated with cold dilute (1N) hydrochloric acid ( $\text{CaCO}_3 + 2\text{HCl} \leftrightarrow \text{CaCl}_2 + \text{CO}_2 \uparrow + \text{H}_2\text{O}$ ). This **chemical reaction** is one example of many that occur in nature. NOTE: Your laboratory instructor will provide the proper dilute acid if you are to use this test. ***Take care to keep acid off of your skin and clothing. In the event of a spill, wash in water quickly and notify your lab instructor.***

## Identification of Common Minerals

Your instructor will provide you with a variety of minerals to be identified and may also discuss with you a methodology to be used in the identification process. In the event that no such methodology is provided, we suggest the following as a useful identification scheme. Take time to examine the minerals and review the various physical properties described in the previous pages. Select several samples and examine them for luster, color, hardness, and streak, and compare their specific gravity (G) using the heft test.

Study table 1.2, which is divided into three groups:

- Group I, Nonmetallic luster, light-colored
- Group II, Nonmetallic luster, dark-colored
- Group III, Metallic luster

*Identification of the minerals listed in table 1.2 follows an identification scheme based on the sequential identification of luster, color, hardness, and cleavage.*

Some minerals have physical properties that make their identification relatively easy. For example, graphite is soft, feels greasy, and marks both your hands and paper. Galena is “heavy,” shiny, and has perfect cubic cleavage. Calcite has perfect rhombohedral cleavage, is easily scratched by a knife, reacts with cold dilute HCl, and in transparent specimens shows double refraction.

When you feel that you have an understanding of the various physical properties and the tests that you must apply to determine these properties, select a specimen at random from the group of minerals provided to you in the laboratory. Refer to figures 1.6 through 1.21 as an aid to identification. Be aware that your laboratory collection may contain some minerals that are not shown in the figures. Due to the normal variations within a single mineral species, some of the specimens may appear different from the same minerals shown in the figures in this manual.

Remember the warning about color variations discussed on page 3 and the exhibit of color variations shown in Figure 1.1.

*Using the worksheets for minerals provided, record your observations following the steps outlined below.*

1. Carefully examine a single mineral specimen selected at random from the group of minerals provided to you in the laboratory. Assign it a number and record in the Worksheet for Minerals.
2. Determine whether the sample has a metallic or a nonmetallic luster.
3. Then determine whether it is light- or dark-colored. (The terms *dark* and *light* are subjective. A mineral that is “dark” to one observer may be “light” to another. This possibility is anticipated in table 1.2, where mineral specimens that could fall into either the “light” or “dark” category are listed in both groups. The same is true for minerals that may exhibit either metallic or nonmetallic luster.)
- 4a. If the mineral falls into either Group I or II, proceed to test it first for hardness and then for cleavage. This will place the mineral with a small group of other minerals in table 1.2. Identification can be completed by noting other diagnostic general or specific physical properties.
- 4b. If the mineral falls into Group III (table 1.2), test it for hardness, cleavage, and streak and note general and special properties such as color until the mineral fits the description of one of those given in table 1.2 under Group III.
5. To assist you in confirming your identification, refer to the expanded mineral descriptions in table 1.3.
6. Your laboratory instructor will advise you as to the procedure to use to verify your identification.
7. Refer to table 1.3 to learn about occurrence, economic value, and uses of each mineral. The chemical groupings and composition of some of the common minerals are presented in table 1.4.

Worksheet for Minerals								
Sample #	Luster	Color Light/Dark	Hardness	Cleavage Angles	Streak	Special Properties	Mineral Name	Chemical Composition