Physical Science

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Preface

This text has been written for the non-science major who has had little or no previous training in the sciences and no mathematical training beyond elementary algebra. It is an outgrowth of a year course in the physical sciences which has been developed at State University College of Education, New Paltz, New York, over a period of nearly fifteen years.

No introductory course today, whether in a single science or in a more comprehensive work in physical science, makes any pretense of "covering the field" of science; scientific knowledge is far too extensive. Rather, the attempt here is to limit the discussion to a selected few significant topics and to treat each with some thoroughness. Anecdotal and historical materials have been strategically interspersed to lend color and interest to what is frequently regarded by the student as the dull descriptive aspect of science.

It is the conviction of the authors that chemistry and physics cannot be adequately interpreted unless mathematical concepts are included. It is also their experience that students often come to college with too limited an understanding of basic mathematical concepts. These concepts have been incorporated into the text as needed, in the early chapters at a very elementary level. While the maturity of level progressively increases in later chapters, only algebraic concepts are employed. The authors anticipate that their emphasis on a gradual thorough understanding of simple arithmetic and algebraic processes will successfully lead the student into a reasonably adequate mathematical interpretation of the sciences. All too often interest is lost early in a course by plunging the student into a maze of intricate symbolism which he is ill equipped to understand. As an illustration, the solving of physics problems is little more than guesswork until the student understands the principle of consistent units. Considerable attention is given to understanding this principle.

The text has been written in two independent sections: chemistry and physics in Chapters 1-14, earth science (astronomy, meteorology, and geology) in Chapters 15-33. This should be a convenient flexible arrangement, since either section may be used first. The earth science section offers additional flexibility as it has been organized so that the astronomy, meteorology, and geology units may be taken up in any order. Furthermore, if it is necessary to shorten a course, one or more of the later chapters in geology (except Chapters 32 and 33) can be omitted or assigned to top students as independent study without seriously impairing the continuity.

Although the authors recognize the importance of integrating ideas from the different physical sciences, the integration in this text is somewhat more limited than in a number of other physical science texts. Our experience has been that a chemist will usually be willing to teach physics and a physicist chemistry. Many instructors, especially of lesser experience, hesitate to attempt to teach in more than one science outside their major area. The geologist will usually teach astronomy if at the same time he does not have to grapple with the intricacies of chemistry and physics. The experienced professor who can capably teach in all the areas of physical science will find this arrangement a convenient one in that it focuses on two sciences at a time.

The authors are indebted to many people for inspiration and assistance in bringing this book to completion. President Emeritus James B. Conant of Harvard University should receive a goodly share of credit for providing the inspiration to initiate this work. One of us (Allen) was fortunate enough to participate in a summer course at Harvard in which Dr. Conant took time out from his busy life to lend inspiration to a group of college science teachers. The influence of the Harvard case histories is obvious throughout this book. Any errors or shortcomings are obviously the responsibility of the authors.

Many others shared generously in the work of getting this book into the world. Floyd Parker and Richard Madtes have read and criticized Chapters 1-14. Betty Burns, Rosetta Einenkel, and Livia Tenedini have assisted in typing the manuscript. The photographs taken especially for this text by Neil Croom are appreciated. Special

thanks are due also to Martin Harris, Jr., and to Christoph Parade for execution of the drawings. Our wives, Kay Allen and Mary Jane Ordway, have assisted with the reading of the proof. The patience and forbearance of our families who have forgone or shortened vacations or curtailed other interesting activities so that this work might be completed are hereby gratefully acknowledged.

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CHAPTER 1

The Length and Breadth of Measurement

AT THE southeastern corner of Sicily, an island in the Mediterranean just touching the toe of Italy, lies the city of Syracuse (Fig. 1-1). Today it is a city of some 50,000 people—certainly not a great metropolitan center. Twenty-two centuries ago it was among the wealthiest and largest cities in Europe, a rival of Athens and Alexandria in the realm of the intellectual and cultural. It was founded by

Archimedes (287-212 B.C.). A modern artist pictures the moment when the aging geometrician, deep in thought in his study, is surprised by the Roman soldier who killed him. According to legend, his last words, as the intruder's footstep blurred the lines of geometric figures traced on the sanded floor, were, "Be careful! You are spoiling my figures!" The Roman victor had been delayed for months by defensive machines devised by this man of genius.

Greeks, and in it the physical sciences reached the peak of their development in Greek civilization. One of its most famous inhabitants, a man largely responsible for its pre-eminence in the physical sciences, was Archimedes (287-212 B.C.). He is probably best known to us for the role he played in solving King Hieron's problem about the honesty of the royal jeweler.

The king gave the jeweler a lump of gold and asked him to make a

Fig. 1-1.

This map of the Mediterranean region shows the location of Syracuse, a city founded twenty-seven centuries ago by Corinthian Greeks. When Archimedes lived there (third century B.C.) it was the greatest city of Sicily and an important center of Greek science and mathematics.

crown. When the job was finished, the king suspected that the crown did not contain all the gold he had given the jeweler; the weight of the crown was the same as that of the original lump of gold, but the king suspected that a less expensive metal had been substituted for some of it. Archimedes was brought in as a sort of scientific detective to find out if there was any reason to suppose that a substitution had been made. He was not to mar the crown in any way in his scientific sleuthing. The problem for a long time baffled even this astute mathematician. Then one day as Archimedes entered a local public bath, he watched how the water level rose higher and higher on the wall as more and more of his body became submerged.

What was unusual about such an observation? Anybody knows that the material substance of Archimedes' mortal frame could not occupy the same space as the water in the bath. Objects which are immersed in water push out of the way, or displace, an equal *volume* of water (Fig. 1-2). How could so commonplace an observation serve as the key to Archimedes' solution of so difficult a problem?

An object which is completely immersed in a liquid displaces a quantity of liquid equal to its own volume. An irregular object like a crown, whose volume could not be measured directly, is thus as easily measurable as a cube. In the kitchen the cook may use a similar method for making sure she has exactly half a cup of butter.

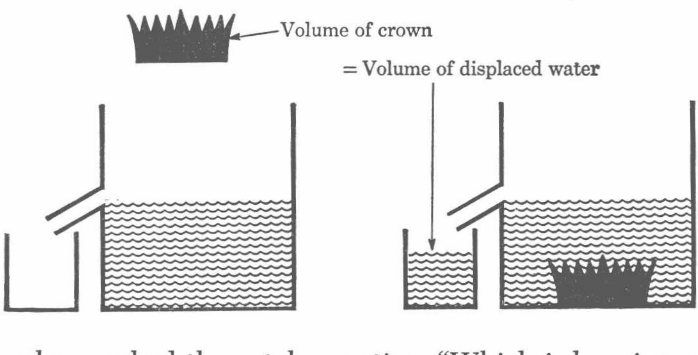


Fig. 1-2.

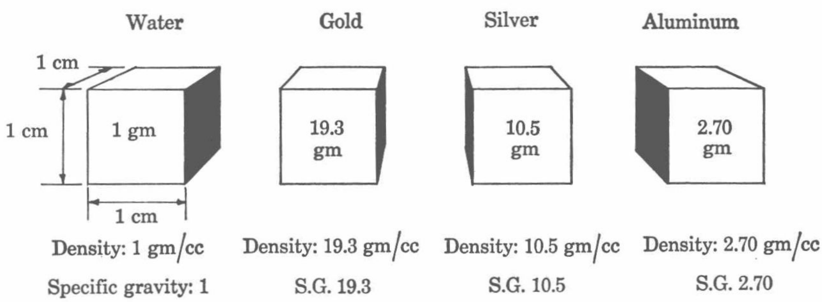
Every child has been asked the catch question, "Which is heavier, a pound of lead or a pound of cork?" Of course a pound is a pound: the difference between lead and cork is in the volume occupied, a pound of cork occupying a much larger volume than a pound of lead. In a word, lead is *denser* than cork. To understand the problem raised by the gold crown and its solution, we must first understand what is meant by density and the closely related quantity known as specific gravity.

The Concept of Density If cubes of certain metals, each 1 centimeter on a side (2.54 cm = 1 in.), are weighed, their weights will be as shown in Fig. 1-3. Density may be practically defined as *weight per unit volume.* The density of gold is 19.3 grams per cubic centimeter.* (This may also be written 19.3 gm/cm^3 or 19.3 gm/cc.) In order to calculate the density of an object, its weight must be divided by its volume. Density may also be expressed in other units of weight

Fig. 1-3.

Centimeter cubes of different metals have different weights. The weight of a unit cube is the density *of the metal. Density is formally defined as* mass *per unit volume. It is numerically the same as weight per unit volume at sea level. Weight is distinguished from mass later in this chapter (See page 10, The Standard of Mass).*

The specific gravity of a substance is the ratio of its density to the density of water. Since in the metric system the density of water is 1 gm/cc, the specific gravities of other substances are numerically the same as their densities: e.g., the density of gold being 19.3 gm/cc and the density of water 1 gm/cc, the specific gravity of gold $=$ *19.3 gm/cc* $\div$ *1 gm/cc* $=$ *19.3.*



and volume, as for example in pounds per cubic foot. Water has a density of 1 gm/cc; this is equivalent to 62.4 lb/cu ft. The numerical value of the density depends, then, on the units used.

ILLUSTRATIVE PROBLEM

Determine the density of gold if the volume occupied by 4825 gm is 250.0 cc.

Solution

$$\text{Density} = \frac{\text{weight}}{\text{volume}}$$

$$\text{Density} = \frac{4825 \text{ gm}}{250.0 \text{ cc}} = 19.30 \text{ gm/cc}$$

The weight given, 4825 gm, is that occupying 250.0 units of volume

* The milliliter is often used in expressing liquid volumes. For all but the most precise measurements the milliliter and the cubic centimeter may be considered equivalent.

(250.0 cc). Density is numerically equal to the weight of a *single unit of volume.*

Specific Gravity Specific gravity and density are closely related; in fact, the two may be identical in value. Specific gravity is defined as the ratio of the weight of an object to that of an equal volume of water:

$$\text{Specific gravity} = \frac{\text{weight of object}}{\text{weight of water, same volume as object}}$$

An overflow can filled with water (Fig. 1-2) is a very useful device for determining specific gravity because it provides a convenient means of obtaining a quantity of water whose volume is equal of that of the object.

Specific gravity may also be defined as the ratio of the density of the object to that of water.

$$\text{Specific gravity} = \frac{\text{density of object}}{\text{density of water}}$$

Specific gravity and the density are equal if the density of water is unity. Furthermore, the ratio of an object's density to that of water is equal to the weight ratio of similar unit volumes of these materials.

$$\text{Specific gravity} = \frac{\text{density of object}}{\text{density of water}} = \frac{\text{weight of 1 cc cube of object}}{\text{weight of 1 cc cube of water}}$$

$$= \frac{\text{weight of 1 cu ft of object}}{\text{weight of 1 cu ft of water}}$$

THE SOLUTION OF ARCHIMEDES' PROBLEM

In Fig. 1-3, we have taken equal units of volume of different metals and compared their weights: thus the density of gold is 19.3 gm/cc, the density of silver is 10.5 gm/cc, and the density of aluminum is 2.70 gm/cc. We might in the same way take equal units of weight of each metal and then compare their volumes: if gold weighs 19.3 gm/cc, then the volume of 1 gram of gold is

$$\text{Volume} = \frac{\text{weight}}{\text{density}} = \frac{1\ \text{gm}}{19.3\ \text{gm/cc}} = 0.0518\ \text{cc}$$

Similarly, the volume of 1 gram of aluminum is 0.370 cc. The number 0.370 is considerably larger than 0.0952, which is larger than

0.0518; thus the volume occupied by 1 gram of silver or by 1 gram of aluminum is larger than the volume occupied by 1 gram of gold. Since the crown had the same weight as the original gold, its volume must be greater if the jeweler substituted an equal weight of silver or aluminum (though he could not have done this: aluminum was not available in ancient Sicily) for the gold. What Archimedes suddenly realized as he plunged into his bath was that for a given weight, a metal of smaller specific gravity or density than gold would have a greater volume than gold and hence would displace a greater amount of water (Fig. 1-4). This gave him the solution to the king's problem,

The solution of Archimedes' problem. Equal weights of metals having different densities will displace unequal volumes of water. The greater the density, the smaller the volume displaced. The lump of pure gold balances the crown in a pair of scales, but the crown proves to be made of an alloy, for it displaces a larger volume of water than the lump.

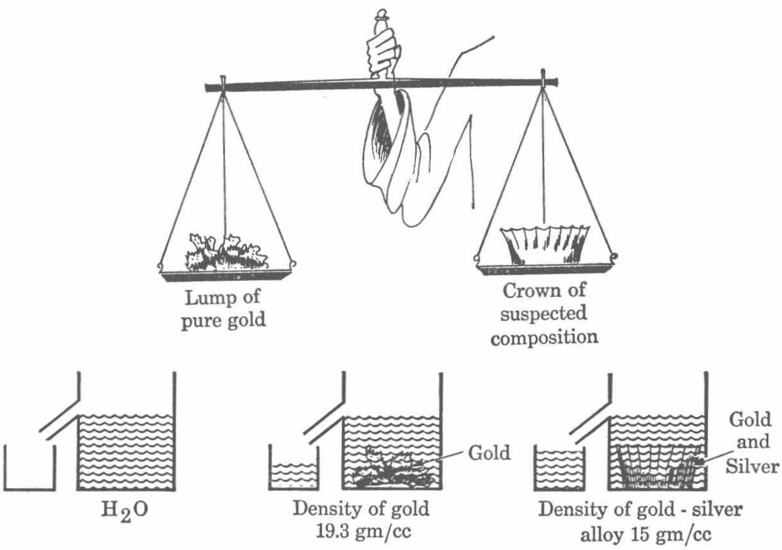


Fig. 1-4.

and this is why he raced home shouting "Eureka! Eureka!" (I have found it). Once home, he promptly filled a vessel with water to the brim, plunged the king's crown into it, and measured the overflow. Sure enough, the amount of water displaced by the crown proved to be greater than the amount displaced by a lump of pure gold that balanced the crown in a pair of scales. The king's jeweler was dealt with accordingly.