CENCO Physics Selective Experiments In Physics

• C.J. Overbeck Northwestern University • R.R. Palmer Beloit College • Marsh W. White The Pennsylvania State University

DENSITY OF A SOLID

OBJECT: To determine from the dimensions and the mass of a: cylinder the density of the material of which the cylinder is composed.

METHOD: Using a micrometer caliper, a number of observations are made of the diameter and of the height of a cylinder. From the average value obtained for each of these dimensions the volume of the cylinder is computed. The mass of the cylinder is determined by weighing it on a balance. The ratio of the mass of the cylinder to its volume is the density of the material.

THEORY: The volume of a body depends upon the pressure, the temperature and the treatment it has received. The weight of a body is the force with which it is attracted by the earth, and this force varies somewhat depending upon the place where the weighing is done. Since changing any of these conditions does not change the amount of matter in the body, it follows that neither volume nor weight can be used to measure the amount of matter. The inertia of a body (the resistance the body offers to change in velocity) is changed only by adding or removing matter and is used, therefore, to measure the quantity of material. The measure of inertia is mass.

The chief feature of the usual laboratory balance is a beam by which the body to be weighed and a standard mass are supported. Weighing consists in comparing the weight of this body with the weight of the standard mass. It should be remembered, however, that with this type of balance it is the mass of the body, rather than its weight that is determined. Suppose, for example, that the two weights are balanced at a point on the earth's surface and the system is moved to a high altitude where the weight of each body is considerably less. Since the weight of each body is decreased by the same fraction, the balance is still in adjustment. If two bodies have the same weight at the same place, their masses are equal. Obviously a calibrated spring balance gives the weight of a body rather than its mass.

The density *D* of a body, which measures the concentration of matter in the body, is defined as the ratio of the mass *M* to the volume *V* or the mass* per unit volume. Stated algebraically

$$D = M/V \tag{1}$$

*Occasionally, particularly in the British engineering system, the equation $p = hD$ is used to compute the pressure *p* due to a depth *h* of a liquid whose density is *D*. In this particular equation it is necessary to consider the density *D* as the weight per unit volume. In scientific work, however, the pressure should be computed from the equation $p = hDg$. In this equation *g* is the acceleration due to gravity and the density *D* is mass per unit volume.

APPARATUS: A micrometer caliper, a metal cylinder and a balance are required.

A micrometer caliper is shown in Fig. 1. On one end of the heavy frame F is mounted the anvil A and on the other end the cylindrical sleeve S. On the inside wall of S an accurate screw thread has been cut. The corresponding screw thread has been cut on the outside wall of the rod R and this rod is rigidly attached to the thimble T. As R and T are rotated, they advance (or recede) a distance equal to the pitch of the screw for each revolution The total number of revolutions is indicated by the S scale (the scale on S) and the additional

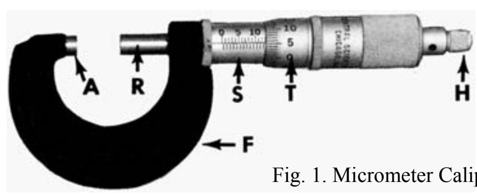

Fig. 1. Micrometer Caliper

fraction of a revolution by the T scale. In using the micrometer the body to be measured is held *lightly* clamped between the anvil A and the rod R. To make sure that the pressure exerted on the body is the same for each reading and to prevent injury to the accurately cut screw threads, R should always be turned by means of the friction head H. As R approaches its final position, H should be turned slowly until the ratchet between H and T clicks once.

The pitch of the screw for most metric micrometer calipers is ½mm and the numbers on the S scale represent the number of millimeters (not the number of revolutions). Since there are 50 divisions on the T scale, each one of these divisions represents 1/50 of a revolution or an advance of R amounting to 0.01mm. Since the T scale should be read to tenths of a division, lengths are measured to thousandths of a millimeter.

Various methods are used in marking the S scale. There may be twenty identical divisions per centimeter, Fig. 2 (a), in which case each division represents 1/2mm or one revolution; for easy identification, the half-millimeter marks may be staggered, Fig. 2 (b); or made somewhat shorter, Fig. 2(c); or the half-millimeter marks may be omitted entirely, Fig. 2 (d), in which case the observer must decide from an inspection of the two scales whether or not the half-millimeter point has been passed.

Referring to anyone of the diagrams in Fig. 2, it is seen that the S scale reading is 6.5mm and the T scale reading is 48.4

hundredths of a millimeter. The complete reading is, therefore, 6.5mm + 0.484mm or 6.984mm.
If the micrometer does not read zero when the gap between R and A is closed, it is said to have a *zero error* and the reading thus taken is called the *zero reading*. The zero reading should be subtracted *algebraically* from all readings taken with the micrometer. Since it gives exactly the same result and saves considerable time, the zero reading should be subtracted from the average of a set of "readings rather than from each individual reading.

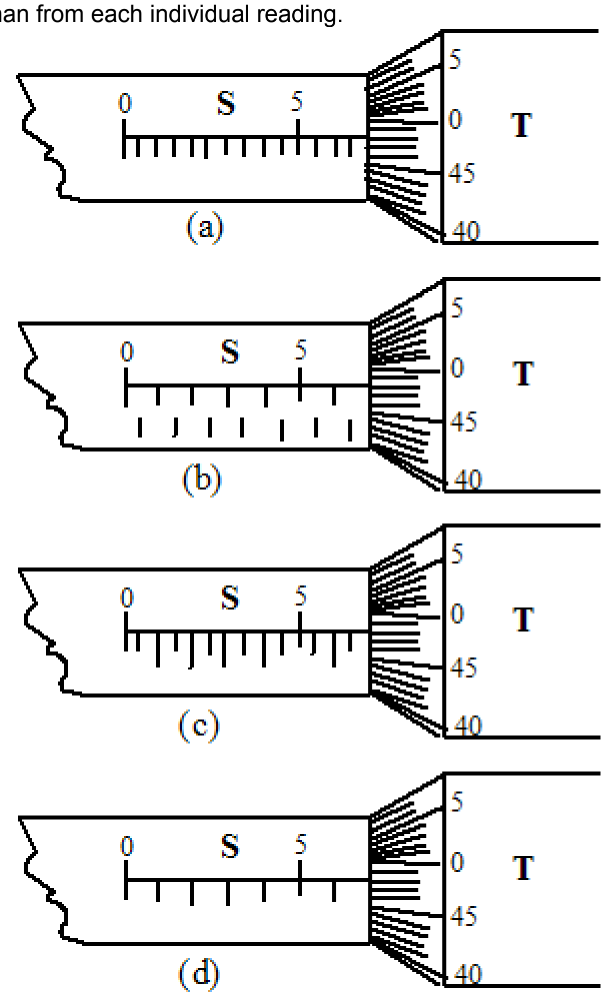

Fig. 2. Four methods of marking the micrometer scale.

A common form of laboratory balance, known as a triple beam balance, is shown in Fig. 3. The beam N is supported at point O on agate bearings. The body being weighed is placed in the pan P, and the counterclockwise torque which its weight exerts on the beam is balanced by the clockwise torque's of the movable weights I, J and H. Since the torqueses due to these weights are proportional to their respective distances from the fulcrum at O, the beams may be calibrated to read directly in grams.
With the pan empty and the weights I, J and H on the notches at the extreme left, the knob K which operates an eccentric is turned to the left so that the beam rests on its bearing and swings freely. The index on the right-hand end of the beam should vibrate about the mid-point of the scale z. If it does not do so, the balance should be adjusted by changing the position of the counterpoise weight M. Having made sure that the balance is in adjustment, the body to be weighed is placed in pan p and balance is obtained by adjusting the positions of I, J and H.

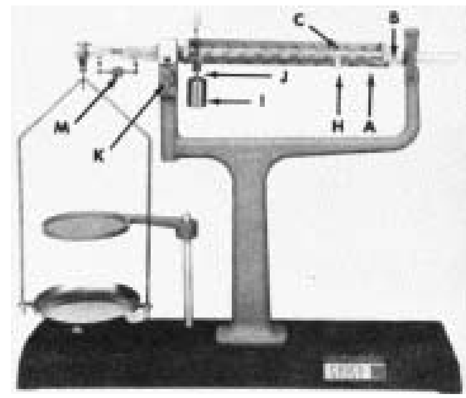

Fig. 3. Triple Beam Balance

PROCEDURE: 1. Take five observations of the zero reading of the micrometer caliper, closing the jaws each time with the ratchet.

2. Take ten observations each of the diameter and height of the cylinder. Record each observation just as it is read from the micrometer, determine the average of each set of observations, and subtract algebraically the zero reading from each of these averages.

3. Weigh (determine the mass of) the cylinder.

4. Determine the volume of the cylinder and the density of the material, being careful to express both results with the correct number of significant figures.

Optional: Use a micrometer caliper calibrated in inches to measure the diameter of a sample of wire. Referring to a wire gage table, determine the gage number of the wire.

QUESTIONS: 1. State whether each of the following would be likely to produce systematic or random errors in this experiment and explain why: (a) the micrometer is closed by twisting the thimble T rather than the friction head H; (b) the faces of the anvil A and the rod Rare not parallel; (c) the corners of the cylinder are slightly rounded; (d) the end faces of the cylinder are parallel to each other but are not quite perpendicular to the side.

2. What effect does arise in temperature have on the density of a solid?

3. Explain why it is not necessary for the zero marks on the beam of the balance (Fig. 3) to coincide with the point of support O. This is most easily explained with the help of an algebraic equation.

4. Using a meter stick to measure roughly the balance arms, estimate the mass of rider I.

5. What percentage error in the determination of the density in this experiment would each of the following produce: (a) an error of 0.01gm in the mass? (b) an error of 0.01mm in the height of the cylinder? (c) an error of 0.01mm in the diameter of the cylinder?