THE VERNIER CALIPER

OBJECT: To study the vernier scale principle and to learn the use of vernier calipers for the accurate measurement of length.

METHOD: Several simple length measurements are made, first with a meter stick. Then a vernier caliper is studied, its least count is determined, and the length measurements are repeated. The improved accuracy of the measurements is noted. The vernier caliper principle is further studied by the use of various instruments provided with vernier scales.

THEORY: Physics, the most exact of the experimental sciences, owes much of its development to the fact that careful quantitative measurements can be made of the phenomena being studied. The measurement of length is basic to many of the experiments performed by physicists.

Measurements with Rulers: A simple and satisfactory way of measuring length for most purposes is by the use of an ordinary ruler, such as a meter stick, Fig. 1. Readings on this

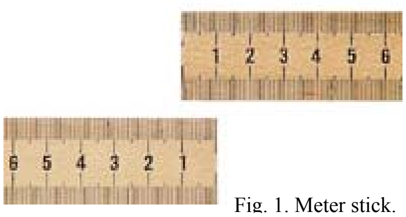

Fig. 1. Meter stick.

scale usually can be estimated to a fraction of a millimeter. By observing certain simple precautions one can materially improve the precision of his readings with a ruler, as shown in Fig. 2. If the numbers on the rule represent centimeters, the observed reading is 3.56cm, and the length should be recorded as 2.56cm. Unless one has good reason to the contrary, a meter stick reading should usually be made to fractions of a millimeter.

The Vernier Principle: More accurate measurements of fractional parts of the smallest divisions on a scale can be made by the use of a *vernier scale*, invented by Pierre Vernier in 1631. A caliper provided with a vernier scale is known as a *vernier caliper*. (Note the fact that one should not refer to this device as "a vernier".)
A vernier scale is an auxiliary scale that slides along the main scale. The graduations on the vernier scale are different in length from those on the main scale. In the most familiar type of vernier caliper *n* divisions on the main scale correspond in length to *n* - 1 divisions on the vernier scale.

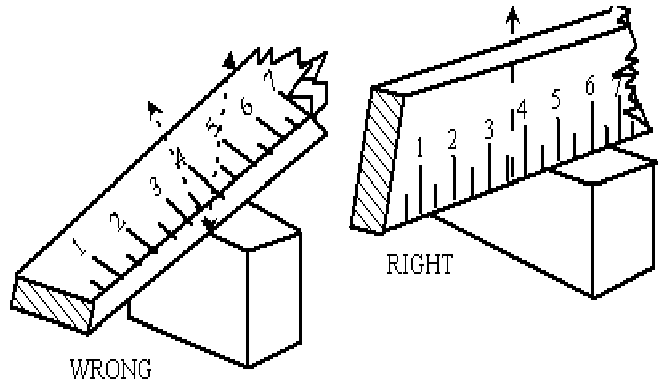

Fig. 2. Precautions in the use of rulers.

For example, the vernier scale of Fig, 3 has 10 divisions that correspond in length to 9 divisions on the main scale. Each vernier division is therefore shorter than a main-scale division by 1/10 of a main-scale division. In Fig. 3 the zero mark of the vernier scale coincides with the zero mark of the main scale.

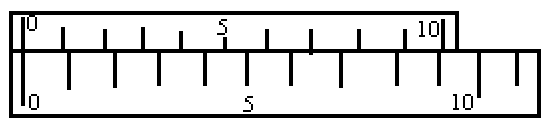

Fig. 3. Main and vernier scales.

The first vernier division is 1/10 main scale division short of a mark on the main scale, the second division is 2/10 short of the next mark on the main scale, and so on until the tenth vernier division is 10/10, or a whole division, short of a mark on the main scale. It therefore coincides with a mark on the main scale. If the vernier scale is moved to the right until one mark, say the sixth as in Fig. 4, coincides with some mark of the main scale, the number

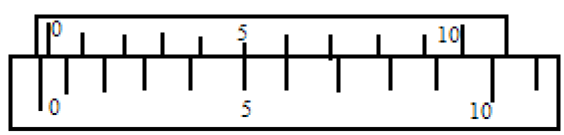

Fig. 4. Main scale with attached vernier scale, reading 0.6.

of tenths of a main-scale division that the vernier scale is moved is the number of the vernier division that coincides with any main-scale division. (It does not matter with which main-scale mark it coincides.) The sixth vernier division coincides with a main-scale mark in Fig. 4, therefore the vernier scale has moved 6/10 of a main-scale division to the right of its zero position. The vernier scale thus tells the fraction of a main-scale division that the zero of the vernier scale has moved beyond any main-scale mark. In Fig. 5 the zero is to the right of the second mark on the main scale and

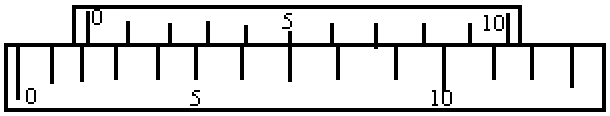

Fig. 5. Main scales with attached vernier scale, 2.4.

the fourth mark of the vernier scale coincides with a main-scale mark. The reading is 2.0 divisions (obtained from the main scale up to the vernier zero) and 0.4 division (obtained from the vernier coincidence), or 2.4 divisions.

Instruments are manufactured with many different vernier scale to main-scale ratios. The essential principle of all vernier scales is, however, the same, and the student who masters the fundamental idea can easily learn by himself to read any special type.

In brief, the general principle of the vernier scale is that a certain number n of divisions on the vernier scale is equal in length to a different number (usually one less) of main-scale divisions. In symbols

$$nV = (n-1)S \qquad (1)$$

where *n* is the number of divisions on the vernier scale, *V* is the length of one division on the vernier scale, and *S* is the length of the smallest main-scale division.

The term *least count* is applied to the smallest value that can be read directly by use of a vernier scale. It is equal to the difference between a main-scale and a vernier division. It can be expressed by rearranging Eq. (1), thus

$$\text{Least count} = S - V = \frac{1}{n}S \qquad (2)$$

When you have occasion to use anew type of vernier scale, first determine the least count of the instrument. In order to make a measurement with the instrument, read the number of divisions on the main scale before the zero of the vernier scale and note which vernier division coincides with a mark of the main scale. Multiply the number of the coinciding vernier mark by the least count to obtain the fractional part of a main-scale division to be added to the main-scale reading.

The Vernier Caliper: A widely used type of vernier caliper is shown schematically in Fig. 6. The instrument has both British and metric scales and is provided with devices to measure internal depths and both inside and outside diameters. The jaws *c* and *d* are arranged to measure an outside diameter, jaws *e* and *f* to measure an inside diameter, and the blade *g* to measure an internal depth. The knurled wheel *W* is used for convenient adjustment of the movable jaw and the latch *L* to lock the jaw in position.

APPARATUS: Solid metal cylinders; meter stick; vernier caliper; cylindrical cup; various instruments having vernier scales, such as a barometer, cathetometer, spectrometer, torsion apparatus, sextant, etc.

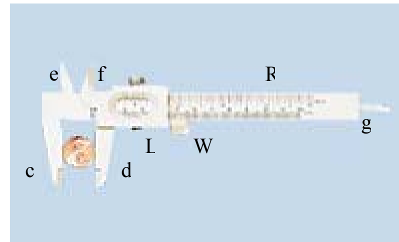

Fig. 6. Vernier caliper.

PROCEDURE: 1. With the millimeter scale of the ruler, measure the length and diameter of a solid metal cylinder. Observe the precautions shown in Fig. 2 and estimate fractions of millimeters in each reading. From these data compute the volume of the cylinder $(v = \pi r^2 h)$

2. Repeat the above observations with the vernier caliper, using the centimeter scale. If the vernier caliper does not read zero with the jaws tightly closed, it is said to have a zero error, and the reading thus taken is called the zero reading. If the zero reading of the caliper is not zero, this reading should be subtracted algebraically from the reading of each dimension. Compute the volume of the cylinder and compare the volume to the one obtained with the ruler. Express the difference in volume in cubic centimeters and in percent.

3. Use the vernier caliper to measure the inside diameter and depth of the cylindrical cup (Fig. 7). Compute its volume.

Fig. 7. Cylindrical cup.

Optional: Determine the mass of the empty cup and the mass when the cup is filled with water. From these masses and the density of water determine the volume of the cup. Compare this volume with the value obtained previously in Step 3.

Measure the mass of the metal solid cylinder and calculate its density (*d = m/v)*. Compare the measured density with the value obtained from tables.

Examine the British-scale vernier caliper. Determine its least count. Use this caliper to measure the length of a cylinder.

Examine a number of other instruments provided with vernier scales. Determine the least count of each of these instruments.

NOTE: For each of the measuring devices studied make a rough freehand sketch, similar to Fig. 8, to show the essential data connected with the particular setting of the instrument. (Do not draw the instrument to scale or include all the graduations.) Show merely the few lines necessary to indicate (a) the value of the main-scale division just before the zero of the vernier scale, (b) the value of the main-scale division just after the zero of the vernier scale, (c) the total number of vernier-scale divisions; (d) the number of the vernier-scale division that coincides with some main-scale mark, and (e) the observed reading (for example in Fig. 8 the reading is 6.27mm).

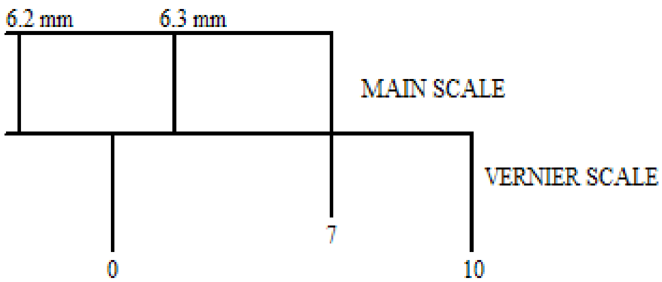

Fig. 8. Sketch of scales for recording data.

QUESTIONS: 1. In the instruction on the use of the rule it was shown that the rule should be placed on edge and that the end of the rule should not be used. Why should these precautions be taken?

2. In measuring the volume of a cylindrical body, which would produce a larger error in the results, a 1% error in the diameter or a 1% error in the length? Give reasons.

3. A *systematic error* is one that always produces an error of the same sign, as, for example, using a metal ruler that has been expanded by beat. A *random error* is one in which positive and negative errors are equally probable. State whether each of the following would produce systematic or random errors in this experiment and explain why: (a) the ends of the cylinder are slightly rounded; (b) opposite sides of the cylinder are not quite parallel; (c) the rule was not placed on edge; (d) the end of the rule was used.

4. In Table I partial information is given about five different vernier calipers. Copy the table and fill in the blank spaces.

TABLE I

Length of a Main Division	Least Count	Number of Vernier Scale Dimensions
__ in	1/128 in	16
2 1/2 mm	__ mm	10
1/2 deg	__ mm	6
1/4 in	0.01 in	___
1/4 deg	1 min	___

5. On some vernier calipers n vernier scale divisions are equal in length to $(2n-1)$ main-scale divisions. Show that the least count is one-nth of a main scale division. What advantage has such a vernier caliper over one constructed in the usual way?

6. In a few special cases it is found more convenient if the zero of the vernier scale is on the opposite end from the zero of the main scale. How does this affect the construction of the vernier scale?

7. A vernier caliper has 25 divisions on the vernier scale that correspond with 24 small divisions on the main scale. The smallest division on the main scale is 1/16 inch. What is the least count of this caliper?