CENCO Physics

Selective Experiments In Physics

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

SURFACE TENSION – PULL ON HORIZONTAL RING

OBJECT: To determine the value of the surface tension of a liquid from the downward pull on a horizontal ring.

METHOD: A horizontal ring is dipped into a liquid and a calibrated spring balance used to determine the force required to pull the ring out of the surface. From the pull on the ring and its mean circumference, the surface tension of the liquid is computed.

THEORY: The fact that molecules cling together to form a liquid indicates that between the molecules there must be attractive forces. When two molecules are close together the attractive force is considerable, but when separated by a distance equal to a very few times the diameter of a molecule the force becomes negligible. For many types of phenomena in physics the force between two particles varies inversely as the square of the distance. There is plenty of evidence, however, that the inverse square law does not apply to these intermolecular forces but that the force decreases as some higher power of the distance. The nature and causes of these forces are not completely known but it is probable that they are the same kind of forces as those involved in chemical bonds. A molecule in the interior of a liquid, A in Fig. 1, is attracted equally in all directions by the neighboring molecules and the vector sum of all these forces

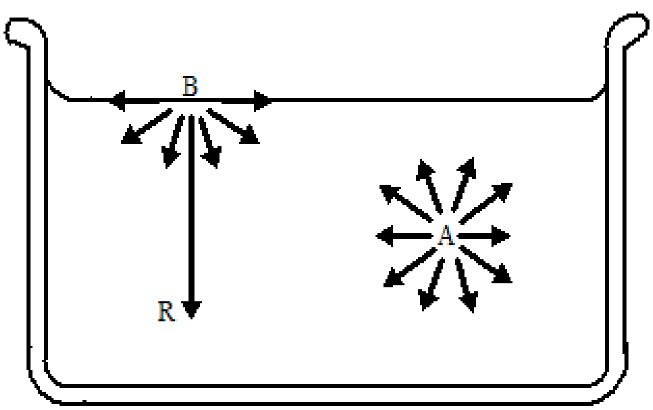

Fig. 1. A molecule on a surface is acted upon by an inward force R perpendicular to the surface.

is zero. For a molecule at B on the surface, however, this is not true. Since there are relatively few molecules in the vapor above the surface the resultant is an inward force R perpendicular to the surface. Each molecule transferred from the interior to the surface must be moved against this force. Since this requires that work be done on it, a molecule in the surface layer has more energy than a molecule in the interior. The excess free surface energy per unit area of surface is called the surface tension *T* of the liquid and may be expressed in ergs per square centimeter. This surface layer is only a few molecules thick. The shaded portion of Fig. 2 represents a liquid surface between the U-shaped frame, width *l*, and the movable rod. If the rod is moved to

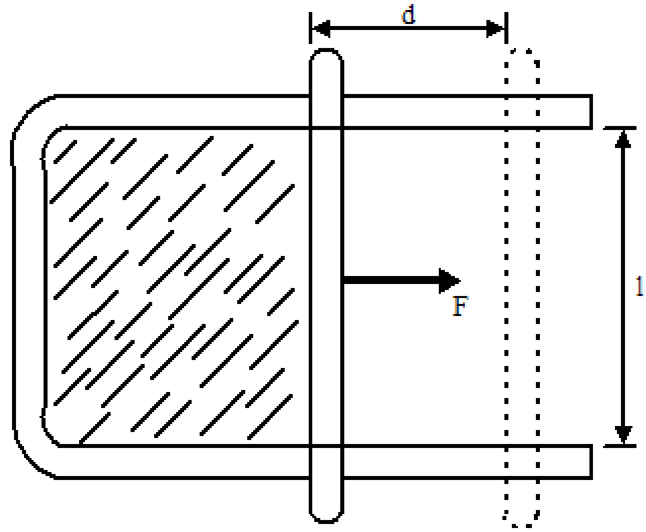

Fig. 2. Work is required to expand the surface of a liquid.

the right a distance *d* the area of the liquid surface is increased by an amount *ld* and, since *T* ergs of energy reside in each square centimeter of surface, the increase in free surface energy is *Tld*. The source of this energy is the work *Fd* done by the force *F* in moving the rod a distance *d*. Equating the work done by the force *F* and the increase in free surface energy gives

$$Fd = Tld \qquad (1)$$

from which it follows that

$$T = F/l \qquad (2)$$

This indicates that surface tension which has been expressed in ergs per square centimeter may be (and usually is) expressed in dynes per centimeter. Not only are these two methods of expressing surface tension numerically the same but they have the same physical dimensions. From the above discussion it is evident that the result is the same as if the surface of the liquid were covered with an elastic membrane under a tension of T dynes per centimeter. For this reason some authors define surface tension as the force with which molecules on one side of a one-centimeter line on the surface attract the molecules on the other side of the line. This definition is unsatisfactory since it gives a false picture of the cause of surface tension. It is true that the molecules on one side of a line attract the molecules on the other side but this is not strictly a surface phenomenon for it would also be true for the interior of the liquid.

The forces responsible for surface tension are normal to the surface, but these forces manifest themselves as tangential forces. Fig. 3 may help in the understanding of the nature of these forces and the way in which the normal force R, Fig. 1, manifests itself as a tangential force in Fig. 2. A paper strip passes over two fixed pulleys and supports a weight W

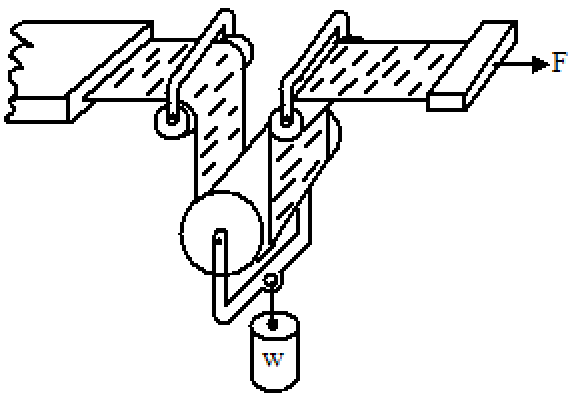

Fig. 3. The forces responsible for surface tension are normal to the surface but the measured forces are tangent to the surface.

attached to a movable pulley. Obviously, if the strip is sufficiently strong, the force F required to extend the strip to the right depends upon the magnitude of the weight W and not upon the tensile strength of the strip. This analogy is helpful but should not be pushed too far.

Although there is no elastic skin on the surface of a liquid, the results are exactly the same and in many cases the computations are more simple if surface problems are treated from the standpoint of the tension in this equivalent elastic skin rather than in terms of surface energy. This is done in the discussion that follows. The student should remember, however, that the forces responsible for surface tension are normal to the surface and that the tension in an elastic skin, while mathematically equivalent, is a convenient fiction.

In the discussion above, Fig. 2 was treated as if there were only one surface. In the case of a thin film (for example, a soap film) there are two surfaces (front and back) but an analysis of this case leads to the same conclusions as those given above.

In the development of the theory above, the work done was set equal to the change in free surface energy. Free surface energy will now be defined. When a surface contracts, the surface layer is heated slightly and this heat flows to the interior of the liquid. Therefore part of the potential energy of the surface molecules is converted into heat and the rest is available for doing work on the movable rod, Fig. 2. That part of the potential energy of the surface layer that is available for doing work is called the free surface energy.

A common form of ring for measuring surface tension is illustrated in Fig. 4. If this ring is dipped under the surface of a liquid and then withdrawn, the surface is pulled up as indicated in Fig. 5. The force required to pull the ring out of the surface is equal to the weight of t be ring W plus the downward pull F due to surface tension.

Taking account of both the inner and outer surfaces, simple theory indicates that the total downward force F due to surface tension is given by the equation

$$F = 2LT \tag{3}$$

where L is the mean (average of inside and outside) circumference. Solving this equation for T gives

$$T = F/2L \tag{4}$$

In the derivation of these equations, however, certain facts have been ignored which may lead to serious error. An inspection of Fig. 5 shows that the pull on the ring is not vertically down. Since only the vertical component of this force is measured, this would indicate that the true value of F is less than that given by Eq. (3). There is, however, another factor which tends to produce an error of the opposite sign. The pressure on the top of the ring is atmospheric whereas the pressure on the bottom of the ring is atmospheric minus hdg, where h is the vertical height of the bottom of the ring above the level part of the surface of the liquid, d is the density of the liquid, and g is the acceleration due to gravity. Obviously this factor tends to make F larger than the value given by Eq. (3).

Although these errors are opposite in sign they do not, in general, compensate each other and Eq. (4) must be changed to read

$$T = \frac{F}{2L} G \tag{5}$$

where the correction factor G depends upon the circumference of the ring, the size of the wire in the ring, the total downward pull on the ring, and the density of the liquid. In Fig. 6 the correction factor G, for a ring having a mean circumference of 4cm and made of No. 28 B & S gage wire, is plotted against the ratio of the force F to the density d of the liquid. For a ring having different dimensions the value of G may be determined from tables given by Harkins and Jordan. *

For those students who are interested in a more complete treatment of surface tension the following treatises, each of which contains an extensive bibliography, are recommended:

N. K. Adam, *The Physics and Chemistry of Surfaces*, Oxford University Press, 1938;

N. E. Dorsey, *The Investigation of Surface Tension and Associated Phenomenon*, Bulletin of the National Research Council, No.69, 1929.

*J. Am. Chem. Sac., 52, 1751 (1930).

APPARATUS: Platinum-iridium ring equipped with stirrup, Jolly balance with adjustable platform, small dish, box of weights, weight pan, and cleaning solution are required.

The Jolly balance, equipped for measuring surface tension, is shown in Fig. 7. The upper end of the sensitive helical spring S is attached to the inner telescoping support tube C. This tube may be raised or lowered by turning the knurled wheel W at the base. The tube is graduated and its height is

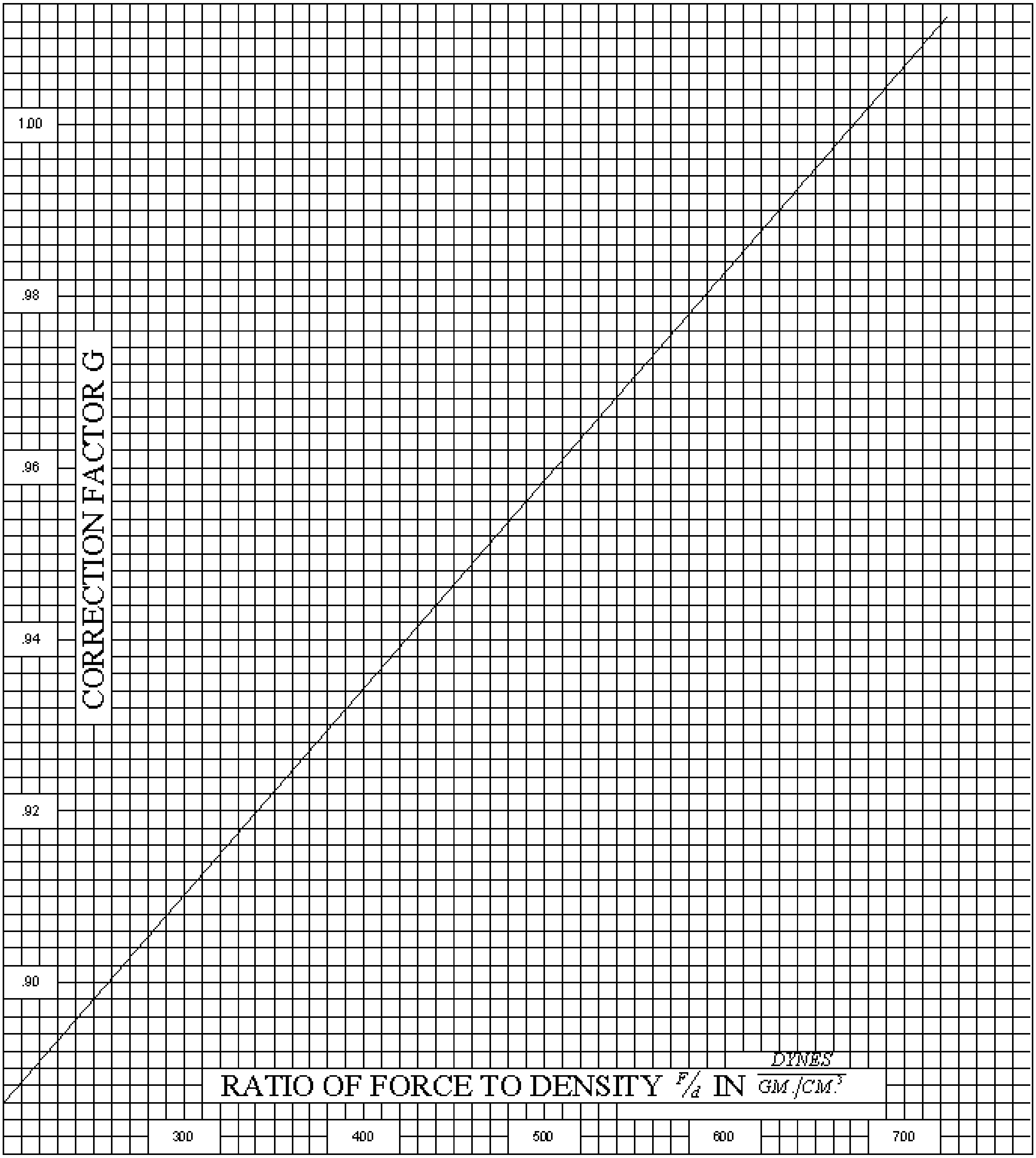

Fig. 6. Curve used to determine the correction factor. It is assumed that the ring has a mean circumference of 4 cm and is made of No. 28 gage wire.

read with the aid of the vernier scale V mounted on the fixed outer tube. An index hangs freely inside a glass cylinder and, when the balance is adjusted for reading, the central line on the index coincides with a line etched about the glass cylinder. With no load on the spring the wheel W is used to bring these two lines into coincidence and the scale reading is noted. In a similar manner, a reading is taken with the force (or weight) to be measured acting on the spring. Obviously, the difference between these two readings gives the elongation produced by the force and, if the constant of the spring is known, this elongation may be used to determine the magnitude of the force.

The screw with knurled head J is used to adjust the height of the movable platform P. When properly aligned the telescoping tubes are vertical and the index hangs freely, not touching the side of the glass cylinder. To facilitate this

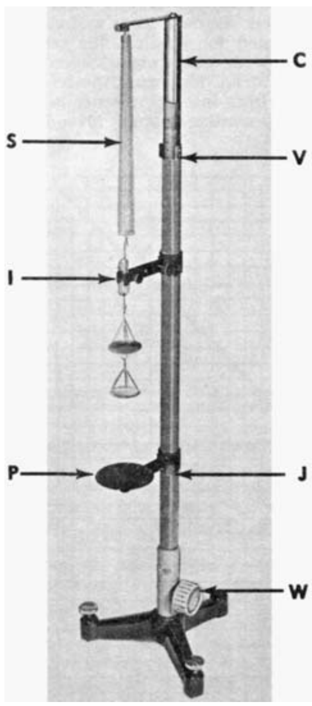

Fig. 7. Jolly Balance with ring and adjustable platform.

alignment the base of the instrument is equipped with leveling screws.

PROCEDURE: Suspend the weight pan from the spring and align the apparatus. Using the knurled wheel W, adjust the position of the spring support so that the middle line on the index coincides with the line on the glass tube. To prevent error due to parallax, care must be taken to place the eye at the same level as the index at I. Since the line etched on the glass cylinder lies in a horizontal plane, when the eye is in the correct position the line on the back surface of the cylinder is hid by the line on the front. With the weight pan in place make five independent observations of the zero reading of the balance. Also make five observations of the reading of the balance with a one-gram weight in the pan. The difference between the averages of these two sets of readings is the elongation of the spring produced by a force of one gram-weight. Assuming that the spring obeys Hooke's law, the elongation e of the spring is proportional to the stretching force *F* or

$$F = ke \tag{6}$$

where the constant of proportionality *k* is called the constant of the spring. Determine the constant of the spring, expressing it in dynes per centimeter. Having determined *k*, Eq. (6) may be used to measure unknown forces.

Care must be taken to remove all traces of grease from the ring and dish. Grease is most easily removed from the ring by heating it "red-hot" in a Bunsen burner. The dish should be cleaned with cleaning solution and rinsed in tap water.

Make five determinations of the zero reading of the balance with the ring suspended from the spring. Fill the dish with water, place it on the adjustable platform P, and raise the platform until the surface of the water touches the ring and pulls it under. Gradually raise the upper spring support by turning W until the ring is pulled from the surface. To keep the lines at I in coincidence, it will be necessary to use one hand to lower the platform while the other hand raises the spring support. Make five determinations of the balance reading when the pull of the spring is just sufficient to detach the ring. Record the temperature of the room.

Use Eq. (6) to compute the downward pull F on the ring due to surface tension. Use the graph, Fig. 6, to determine the correction factor G and Eq. (5) to compute the surface tension of water. Compute the value of the surface tension of water at 20°C. The temperature coefficient for water is -0.154 dyne per centimeter per degree centigrade; the surface tension decreases 0.154 dyne per centimeter for each degree rise in temperature. Assume that the temperature of the water is the same as the temperature of the room.

Determine the value of the surface tension, at room temperature, of other liquids designated by the instructor.

QUESTIONS: 1. If the air is removed from the region above a liquid surface there is a slight increase in surface tension. Explain why.

2. The surface tension of a liquid approaches zero as the temperature approaches the critical temperature. Explain.

3. In this experiment it is assumed that the temperature of the liquid in a shallow vessel is the same as room temperature. Discuss the possible source of error involved in this assumption.

4. A certain salt when added to water increases the surface tension. The concentration of the salt in the surface layer is less than in the interior. Explain.

5. A drop of mercury rests on a horizontal surface. What factors determine its shape?