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THE CALIBRATION OF SMALL VOLUMETRIC LABORATORY GLASSWARE

Josephine Lembeck

Institute for Basic Standards
National Bureau of Standards
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by

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1. INTRODUCTION

This article describes an acceptable procedure for calibrating burets, pipets and volumetric flasks of the types shown in figure 1. The physical characteristics of these items are indicated in Interim Federal Specifications NNN-B-00789a (GSA-FSS), NNN-P-00395a (GSA-FSS), NNN-F-00289a (GSA-FSS), and NBS Handbook 105-2.

The general procedure is based upon a determination of the volume of water either contained in or delivered by the vessel. This volume of water is based upon knowledge of its measured mass and its tabulated density. Inasmuch as these calibration volumes, especially the delivery volume, may be altered by the manner in which the vessels are used, it is imperative that the user of the vessel employ the same techniques as those employed during calibration. The techniques of importance here are:

    1.   reading and adjusting meniscus

    2.   filling the vessel

    3.   draining the vessel.

These three topics will be covered in detail.

2. CLEANING PROCEDURES

It is important that glassware be thoroughly cleaned before being tested or used. Apparatus must be sufficiently clean 'to permit uniform wetting of the surface. When clean, the walls will be uniformly wetted and the water will adhere to the glass surface in a continuous film. Imperfect wetting causes irregularities in capacity by distorting the meniscus and allowing nonuniform wetting of the interior surfaces to occur.

The liquids usually used for cleaning glassware are sodium dichromate sulphuric acid cleaning solution (commercially available from laboratory supply houses), nitric acid, fuming sulphuric acid, alcohol and water. The choice of cleaning agent to be used depends on the nature of the contaminant. After cleaning with the cleaning solution and thoroughly rinsing with tap water, the vessel should be rinsed with distilled water. If

the vessel is marked "TO CONTAIN", it should additionally be rinsed with ethyl alcohol and dried with clean air at room temperature. NBS uses bottled breathing air and a drying rack shown in figure 2. It is not necessary to dry any vessel marked "TO DELIVER". When cleaning small articles such as pipets, it is usually easier to fill them with cleaning solution by suction, vacuum, if available, or a small rubber bulb, but never by mouth. The solution should be sucked through the pipet several times until the entire inside surface is evenly coated. Rinse thoroughly with tap water and then with distilled water.

For cleaning flasks, pour in enough cleaning solution while rotating so that a film of solution will cover the entire interior surface. A break in the film indicates a contaminated area. For filling a buret with cleaning solution, it should be held in a vertical position and filled by pouring into the top. Open the stopcock to drain. Regardless of the type of vessel, always rinse thoroughly, first with tap water and then with distilled water.

3. FILLING AND DRAINING THE VESSEL

Pipets, burets and flasks have at least one index mark engraved on their glass bodies which serves to define their reference volume. Calibration consists of determining the volume of water required to fill the vessel to the index mark (containment volume), or the volume of water which can be drained from the vessel under specified conditions after filling (delivery volume).

The difference between containment volume and delivery volume is significant. Since these volumes are determined in weighing experiments, it is essential to avoid splashing droplets of water on to supposedly dry surfaces and it is equally important to assure that a surface is uniformly wetted when required by the procedure.

In all cases, it is necessary to fill the reference volume of the test vessel with water. This involves adjusting the height of the liquid surface to coincidence with the horizontal plane through the defining index mark.

This surface, or meniscus, is not flat; it is concave-- that is, its lowest point is in the center of the surface as shown in figure 3. There are several criteria for deciding when coincidence is achieved. Inasmuch as differing criteria result in different surface heights, it is important that the same criteria be employed during use of the vessel as was employed during calibration. Experience has shown that the following generally used technique is easy to apply and adequately

reproducible. In this procedure, the lowest point in the meniscus is brought to the same horizontal level as the horizontal plane through the engraved index line on the glass vessel.

In order to observe the lowest point, it is necessary to place a shade of some dark material immediately below the meniscus. This renders its profile dark and clearly visible against a light background. A method or device for this purpose is a collar-shaped section of thick black rubber tubing, cut open at one side and of such size as to clasp the tube firmly, as shown in figures 4 and 4A. The position of the lowest point of the meniscus with reference to the graduation line is such that it is in the plane of the middle of the graduation line. This position of the meniscus is obtained by making the setting in the center of the ellipse formed by the graduation line on the front and the back of the tube, as observed by having the eye slightly below the plane of the graduation line. The setting, the procedures for which will be discussed later, is accurate if, as the eye is raised and the ellipse narrows, the lowest point of the meniscus remains midway between the front and rear portions of the graduation line. By this method, it is possible to observe the approach of the meniscus from either above or below the line to its proper setting.

The foregoing procedure applies when the index line runs completely around the neck of the vessel. On some vessels, such as measuring flasks, figure 1, some of the lines go only one-half way around the neck. Under these conditions the operator has only one-half of an ellipse to assist him in defining the horizontal plane through the index line. Experience has shown that, although the 360° index line is most convenient for the operator, there is insignificant difference between the achievable reproducibility from this complete index, and one which extends only 180° around the neck.

On some graduated neck vessels the lines are very short indeed, extending less than one-fourth the way around the neck. Under these circumstances, there is no reference line behind the meniscus to help the operator in estimating the vertical position of the horizontal index plane. When faced with this problem, it is necessary for the operator to place his eye in his best estimate of the horizontal index plane while observing the meniscus. With experience, an operator should be able to judge the position of this plane to within one or two centimeters. The operator's eye will be (perhaps) twenty-five centimeters in front of the short index line while the center of the meniscus will be only one centimeter behind this line (for a two centimeter neck on the vessel). The geometry of this situation dictates that the vertical position error of the meniscus will be only one twenty-

fifth of the operator's error in estimating the position of the horizontal index plane. Although an optical system (e.g. a bubble level cathetometer) could reduce this error to insignificance, there is little point to such a calibration procedure unless a similar system were employed by the user of the vessel.

Having filled the reference volume of the test vessel using the meniscus observation technique procedure described above, the problem is to determine the volume of water contained, or the volume which can be drained out under specified conditions. This volume is calculated from the density of the water from table 2 and its measured mass.

In the case of a flask "to contain," this mass is the difference between the mass of the empty flask and its mass after filling as described above. For the flask "to deliver" it is the difference between the mass of the filled flask and the mass after the specified drainage period, 30 seconds, has occurred but before the walls have had a chance to become dry.

It is not necessary to weigh burets and pipets because they are "delivery" instruments. Under these circumstances their delivery volume is drained into a weighing flask. Weighing this flask, before and after loading, provides the mass of water delivered by the buret or pipet.

The detailed procedures in use at NBS for filling and draining the various test vessels are given in the following paragraphs.

A. BURETS

Clamp the buret vertically on a support stand; also clamp a plain glass tube, large enough to hold a thermometer, near the buret if the buret is of such a size that is not large enough to insert a thermometer in the top for observing the temperature of the water. A typical setup is shown in figure 5. Fill the buret from the top to the zero mark with distilled water from a reservoir or storage bottle. Drain and record the delivery time. Delivery time is determined by the unrestricted outflow of the water from the zero mark to the lowest graduation mark with the stopcock fully open. Refill the buret to approximately 1 cm above the zero mark and fill the plain glass tube that holds the thermometer; record the temperature. Set a meniscus on the zero mark using the buret stopcock to lower the liquid level and touch the tip with the wetted wall of a beaker to remove any excess water. A weighing flask which has been lightly stoppered and weighed empty is placed with the inside of the neck in contact with the tip of the buret (the flask will be at a slight angle). The stopcock must be fully open until the water is only a few

millimeters above the line being tested and then slowed so as to make an accurate setting. When the setting has been completed, move the flask horizontally, breaking contact with the buret. The flask is then stoppered and weighed a second time, after which the thermometer tube is refilled and the next interval tested in the same manner as the first one - from the zero mark to the next interval needed.

B. PIPETS

Fill pipet with distilled water by suction to the index mark and measure delivery time with the tip in contact with the glass surface or the internal side of a beaker as shown in figure 6. Refill by suction slightly above index line. Record the temperature of the distilled water in the beaker from which the pipet is filled. Any water on the outside of the tip is removed with filter paper after the filling is completed. The meniscus is then slowly lowered to the index using either the stopcock or hose clamp for "fine control." The tip must be in contact with the wet wall of a beaker while the setting is made on the index line. Any water remaining on the tip at this time is not removed. The pipet is held in a vertical position while water is delivered into a previously weighed weighing flask with the tip in contact with the inside wall of the neck of the flask as indicated in the figure 6A. Contact is broken immediately after outflow ceases. The flask is now stoppered and weighed with its contained load.

C. FLASKS (TO CONTAIN)

After cleaning and drying, weigh the empty flask including the stopper. Place an appropriate sized funnel in the flask to discharge the water below the stopper. Fill from beaker or supply line to a point slightly below the graduation line, maneuvering the funnel so as to wet the entire neck below the stopper. Let stand for about two minutes to allow the walls to drain. Place the flask under the buret and complete filling and setting the meniscus and place stopper in neck to lessen evaporation and weigh. A pipet or dropper with a finely drawn tip may be used instead of the buret. Determine the temperature by placing a thermometer in the filling beaker or in one which has been filled from the supply line. The temperature may be taken after final weighing by placing a thermometer directly in the flask, provided the flask is of sufficient size to accommodate it.

D. FLASKS (TO DELIVER)

Flasks calibrated to deliver are not dried prior to the test. Fill slightly below the index line and empty in 30 seconds by gradually inclining the flask so as to avoid splashing of the

walls as much as possible. When the main drainage stream has
ceased, the flask will be nearly vertical. Hold in this position
another 30 seconds and touch off the drop of water adhering to
the top of the flask. Place a stopper, or cap, on the flask to
reduce evaporation and weigh immediately. Take water temperature
and fill the flask, and make the meniscus setting on the index
line. Place a cap, or stopper, on the filled flask and weigh.

4. WEIGHING PROCEDURE AND CALCULATIONS

Most laboratories employ single-pan direct-reading balances for
their weighing work. Although the manufacturers' instructions
for use differ in minor detail from brand-to-brand, the major
operating features are essentially the same. Most instruments
are equipped with a screen upon which an image is projected of a
small reticle attached to the beam. Under ordinary
circumstances, a slight "zero" adjustment is made to the screen
reading with the balance pan empty. When the pan is loaded by
the unknown object, the operator manipulates dials which
mechanically add or remove built-in weights from the internal
balance structure. On some balances, the screen readings will be
"off-scale," either high or low, depending upon whether the
operator should increase or decrease the dial-operated load.
When the screen is "on-scale" the balance is ready to read. Some
balances have colored lights to indicate whether an increase or
decrease of built-in load is called for. The more sensitive
direct-reading balances are constrained from swinging freely
until the proper dial-operated load is in place. This condition
is called "partial arrestment." On the other hand, the
relatively insensitive top-loading balances (used when the
physical size of the weighing flask is large) are never arrested
except when the balance is being moved.

When the manual adjustment of the dial-operated load is complete,
the numerical balance indication should be observed in accordance
with the manufacturer's instructions. The coarse decades are
usually observed on the weight manipulation dials, and the last
two (or three) decades are projected on the screen. There are
two such indications, I_E referring to the empty vessel, and I_L,
the loaded vessel. The indication referring to the water is
obtained by subtraction:

$$I_w = I_L - I_E$$

If I_E and I_L are observed under the same conditions the zero
adjustment, called for in the operating instructions, may be
eliminated.

These numerical indications are normally not the mass of the
unknown. They are a measure on an arbitrary scale called

Apparent Mass (see appendix) of the load of built-in weights which exert the same force on the balance as the unknown load under the ambient conditions existing at the instant of the weighing. We can write an equation indicating the equality of the forces exerted on the balance by the water and the built-in weights associated with I_w. After eliminating "g" from both sides, we have

$$M_w \left[1 - \frac{\rho_A}{\rho_w} \right] = M_B \left[1 - \frac{\rho_A}{\rho_B} \right] \qquad (1)$$

where M_B and ρ_B are the mass and density of the built-in weights, M_w the mass of water, and ρ_A the air density at the instant of measurement. If we rearrange terms and divide both sides by the density of water, we obtain an expression for the sought after volume of water, V.

$$V = M_B \left[\frac{1}{\rho_w - \rho_A} \right] \left[1 - \frac{\rho_A}{\rho_B} \right] \qquad (2)$$

Although the volume, V, in equation (2) is the volume of water in the weighing flask at the instant of the weighing, it is also the calibrated volume of the vessel under test at temperature, T. To obtain this volume at 20 °C (the usual reference temperature) requires multiplication by the thermal expansion factor, K, which involves the test temperature, T, and the temperature coefficient of cubical expansion, α, of the material from which the vessel is made, thus,

$$K = 1 - \alpha(T-20)$$

and

$$V_{20} = M_B \left[\frac{1}{\rho_w - \rho_A} \right] \left[1 - \frac{\rho_A}{\rho_B} \right] \left[K \right] \qquad (3)$$

As explained in the appendix, the mass of the balance weights, M_B, which exert the same force as the water is given by the product of the balance indication for the water, I_w, and the apparent mass conversion factor, Q, where

$$I_w = I_L - I_E$$

$$Q = \frac{\rho_B D_{20} - .0012 \rho_B}{\rho_B D_{20} - .0012 D_{20}}$$

and

$$V_{20} = \left[I_L - I_E \right] \left[Q \right] \left[\frac{1}{\rho_w - \rho_A} \right] \left[1 - \frac{\rho_A}{\rho_B} \right] \left[K \right] \qquad (4)$$

Equation (4) shows the numerical value of the calibration, V_{20}, to be the product of five easily evaluated terms.

TERM 1

$$\left[I_L - I_E \right]$$

is the difference obtained by subtracting the balance indication in grams associated with the empty weighing flask from that associated with the loaded flask.

TERM 2

$$\left[Q \right]$$

is the apparent mass conversion factor. An acceptable value may be found in table 3 based upon the density of the balance weights, ρ_B, and the apparent mass scale to which they are adjusted, D_{20}. Both ρ_B and D_{20} may be obtained from the manufacturer of the balance if the information is not on the name plate. This value need be calculated only once for each balance.

TERM 3

$$\left[\frac{1}{\rho_w - \rho_A} \right]$$

TERM 4

$$\left[1 - \frac{\rho_A}{\rho_B} \right]$$

There are two density terms which require knowledge of air density, ρ_A, water density, ρ_w, and the density of the balance weights, ρ_B. Air density may be adequately estimated by table 1. Water density is obtained from table 2. The density of the balance weights, ρ_B, is obtained from the balance maker. His quoted value will be the density at 20°C. Inasmuch as the test temperature, T, will be near 20° and the coefficient of expansion is small the quoted value is adequate for this work.

TERM 5

$$\left[K \right]$$

The thermal expansion factor is obtainable from table 4 based upon water temperature, T_w, assumed equal to test temperature, T, and the coefficient of expansion of the vessel, α.

A sample calculation based on typical data is shown on the flow diagram, figure 7.

Examination of these numerical values shows that the value of V_{20}, equation 4, is primarily dependent upon the term showing the two balance indications, $I_L - I_E$. The other four terms, all near unity, are corrections to the balance term for the various factors mentioned above. For calibration work which is satisfied by an uncertainty of a percent or so, these four terms may be ignored.

Use of this complete format is a tedious task which requires the use of four tables and the performance of a five-multiplier product. This is because the format is designed to accommodate a very wide range of input data. However, this format offers a number of advantages:

a. It satisfies the requirements for the calibration of fused silica vessels of enormous thermal stability as well as plastic vessels of extreme thermal sensitivity.

b. It accepts data from the rather old direct-reading balances which were equipped with brass weights as well as the modern instruments with steel weights.

c. It is adaptable to balances having built-in weights adjusted to the old apparent mass vs 8.3909 scale and the new apparent mass vs 8.0 scale.

There are few, if any, calibration laboratories which work on such a wide variety of vessels with so many types of instruments. The data reduction may be grossly simplified to one table and the performance of one multiplication by restricting its applicability to the work most frequently performed.

For example, the vast majority of vessels which are submitted to NBS for calibration are made of borosilicate glass so we may eliminate α as a variable and assign to it a constant value of 0.000 010/°C so that K becomes a single-valued function of temperature,

$$K = 1 - 0.000\ 010\ (T-20).$$

Additionally, all balances in the glassware calibration laboratory have built-in weights whose densities at 20 °C are very nearly 7.78 g/cm^3, so we may eliminate ρ_B as a variable, assigning to it the constant value

$$\rho_B = 7.78\ \text{g/cm}^3.$$

The built-in weights of these balances have all been adjusted to apparent mass vs 8.3909, so that we may eliminate Q as a variable, assigning to it a constant value of

$$Q = 1.000\ 011\ 2.$$

Without significant error we may assign values for the density of air and of water of

$$\rho_A = \frac{0.464554B - 40(.00252T - 0.020582)}{1000(T + 273.16)}$$

where B = barometric pressure in millimeters of mercury and the value of relative humidity is assumed to be 40%. [1]*

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* Numbers in brackets refer to similarly numbered references at the end of this paper.

$$\rho_w = \left[1 - \frac{(T - 3.9863)^2}{508929.2} \times \frac{T + 288.9414}{T + 68.12963}\right](0.999973)$$

which is the Tilton-Taylor formula [2] expressed in g/cm^3.

The four correction terms given in equation 4 are now reduced to experimental constants or quantities which may be expressed in terms of measured barometric pressure, B, and/or measured temperature, T. If Z is the product of these four terms

$$Z = \left[1.000\ 011\ 2\right]\left[\frac{1}{\rho_w - \rho_A}\right]\left[1 - \frac{\rho_A}{7.78}\right]\left[1 - 0.000\ 010(T-20)\right] \tag{5}$$

The right member of equation 5 may be put into the form of a numerical table entered with measured values of temperature and pressure from which a value of Z may be selected, then

$$V_{20} = \left[I_L - I_E\right]Z \tag{6}$$

The table of values of Z must necessarily span the temperature range found in the calibration laboratory. Table 5 is an abbreviated form of the table used in NBS glassware calibration. For the restricted conditions mentioned above (i.e. borosilicate glass vessels calibrated by balances with weights of 7.78 g/cm^3 density adjusted to apparent mass vs. 8.3909) table 5 and equation 6 may be used with no loss of accuracy.

5. THE USE OF EQUAL-ARM BALANCES

Laboratories which employ equal-arm balances in the calibration of glassware may find adequate procedures in NBS Circular 602 "Testing of Glass Volumetric Apparatus" by J.C. Hughes.*

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* This publication is out-of-print but is available for loan at most Government Depository Libraries throughout the country.

Appendix 1. Apparent Mass

Apparent mass scales (there are two in current use) are attempts to simplify the calibration and use of weights. They are discussed in detail by Pontius [3]. Their background is of no interest here but the concept should be understood because the built-in weights of direct-reading balances are adjusted to nominal values of apparent mass. If water volumes are to be calculated from knowledge of density and the results of weighing tests, the weighing results must be in mass, not apparent mass.

The observed numerical indication, I, obtained from a measurement on a direct-reading balance is the apparent mass of the <u>effective</u> dial-operated load pertaining to that measurement. The effective load is the <u>sum</u> of the active built-in weights plus a small additional amount observed on the screen. It is necessary to convert observed values of I from units of apparent mass into units of mass. This conversion follows directly from the definition of apparent mass.

> <u>DEFINITION</u>: When, under specified ambient conditions, an unknown object exerts the same force on a balance as mass, M, of a specified hypothetical reference material, the object is said to have an <u>apparent</u> <u>mass</u> <u>versus</u> <u>the</u> <u>reference</u> <u>material</u> equal to M*, where M* is numerically equal to M. The specified ambient conditions are (1) temperature $= 20°C$, (2) air density $= 0.0012$ g/cm^3. The hypothetical reference material is completely specified by its density at 20°C. For the older apparent mass scale, this specified density at 20°C, D_{20}, is 8.3909 g/cm^3, and for the more recent scale, 8.0.

By convention M* is used when the apparent mass scale is referred to density 8.3909 material, and M** when referred to 8.0 density material.

In the conversion procedure, the "unknown object" referred to in the definition is the effective dial-operated load whose mass, M, is to be calculated. The defining equality between the forces exerted by the effective dial-operated load and by the mass, I, of the hypothetical reference material is

$$M \left[1 - \frac{.0012}{\rho_B} \right] = I \left[1 - \frac{.0012}{D_{20}} \right]$$

where ρ_B is the density of the built-in weights. The 0.0012 is the specified air density which must exist during the defining equality. The mass of the effective dial-operated load is then

$$M = I \left[\frac{\rho_B D_{20} - .0012 \rho_B}{\rho_B D_{20} - .0012 D_{20}} \right]$$

Values of ρ_B and D_{20}, if not shown in the balance instruction book, are available from the manufacturer.

If
$$Q = \left[\frac{\rho_B D_{20} - .0012 \rho_B}{\rho_B D_w - .0012 D_{20}} \right]$$

then
$$M = IQ$$

Values of Q for various values of ρ_B and D_{20} are given in table 3.

The nominal values of the reference volumes of vessels are etched on the glass walls, and may be in units of milliliters or cubic centimeters. While, strictly speaking, milliliters are no longer an acceptable unit, for the purposes of this report, they will be considered as identical to cubic centimeters. The basic SI unit of volume is the cubic meter, M^3. Due to its large size, it is rarely employed in glassware calibration work.

Experience has shown that a competent operator should repeat volumetric calibrations within the limits indicated below.

VESSEL	NOMINAL SIZE	REPRODUCIBILITY*
Transfer Pipet	1 cm^3	0.002 cm^3
	2	.002
	5	.002
	10	.003
	15	.005
	25	.005
	50	.007
	100	.010
Flasks	10 cm^3	0.005 cm^3
	25	.005
	50	.007
	100	.011
	200	.014
	250	.017
	500	.021
	1000	.042
Burets	10 cm^3	0.003 cm^3
	25	.005
	50	.007
	100	.012

* The term "reproducibility" means the maximum deviation expected between two independent determinations of the volume. To determine the reproducibility of one's process one should recalibrate one of his own vessels periodically (e.g. once a month) to obtain a sequence of values V_1, V_2, V_3,.....V_n. From these values one can compute an average $\overline{V}$ and a standard deviation s.d. $= \sqrt{\Sigma(V-\overline{V})^2/(n-1)}$ and use the quantity $3(\sqrt{2})(s.d.)$ as the reproducibility of his process. It is essential that the recalibration be done far enough apart in time to be truly independent and representative of the process and the random errors which affect it.

The volumetric error associated with a faulty meniscus observation is a function of the magnitude of the observation error and the cross section area of the vessel's neck.

Some typical values are given below.

Error in Meniscus Position	Typical Neck Diameters			
	0.5 cm	1 cm	2 cm	3 cm
0.005 cm	0.001 cm^3	.004 cm^3	.016 cm^3	.035 cm^3
0.01 "	.002 "	.008 "	.031 "	.071 "
0.05 "	.010 "	.039 "	.157 "	.353 "
0.10 "	.020 "	.078 "	.314 "	.707 "
0.20 "	.039 "	.157 "	.628 "	1.414 "

REFERENCES

[1] Bowman, H.A. and Schoonover, R.M., Procedure for High Precision Density Determinations by Hydrostatic Weighing, J. Res. Nat. Bur. Stand. (U.S.), 71C (Eng. and Instr.), No. 3, pp. 179-198, (July-Aug. 1967).

[2] Tilton, L.W. and Taylor, J.K., Accurate Representation of the Refractivity and Density of Distilled Water as a Function of Temperature, J. Res. Nat. Bur. Stand. (U.S.), 18, RP971, pp. 205-213 (Feb. 1937).

[3] Pontius, P.E., Mass and Mass Values, Nat. Bur. Stand. (U.S.) Monogr. 133, 33 pages (1974).

TABLE 1

Air Density

TABLE 1A.

Listed below in table 1A are the approximate average Winter (January) and Summer (June-July) air densities for a group of selected cities throughout the continental United States. These densities are for an assumed temperature of 23°C and are based on information about the barometric pressure and relative humidity supplied by the Weather Bureau.

It should be remembered that these are average air densities and that the actual air density at a given time and place may differ from that given by as much as 3 percent in either direction, which may result in errors in V_{20} of 0.05%.

This data may be used as a guide in estimating values of ρ_A required for the calculation of V_{20}, equation 4.

NOTE CAREFULLY

ρ_A in equation 4 must be expressed in g/cm^3 and the values tabulated below are in mg/cm^3. Therefore, tabulated values must be multiplied by 0.001 (1.18 mg/cm^3 becomes 0.00118 g/cm^3).

This table is taken from Appendix 1 in NBS Monograph 133, Mass and Mass Values, by Paul E. Pontius.

TABLE 1B.

This table provides values of air density calculated from temperature, barometric pressure and assumed relative humidity of 40%. Errors in V_{20} which result from use of this table are insignificant.

TABLE 1A

Place		Air density		Place		Air density	
State	City	Winter	Summer	State	City	Winter	Summer
		(mg/cm³)	(mg/cm³)			(mg/cm³)	(mg/cm³)
Alabama	Birmingham	1.16	1.16	Nebraska	Lincoln	1.14	1.14
	Montgomery	1.18	1.18		North Platte	1.07	1.07
Arizona	Flagstaff	0.92	0.91	Nevada	Ely	0.95	0.96
	Phoenix	1.15	1.14		Las Vegas	1.11	1.11
	Tucson	1.08	1.08	New Hampshire	Concord	1.17	1.17
	Yuma	1.19	1.18	New Jersey	Newark	1.19	1.19
Arkansas	Little Rock	1.18	1.18	New Mexico	Albuquerque	1.00	1.00
California	Los Angeles	1.17	1.16	New York	Albany	1.18	1.18
	Oakland	1.19	1.16		Buffalo	1.16	1.15
	San Diego	1.18	1.18	North Carolina	Hatteras	1.18	1.17
	San Francisco	1.18	1.18		Raleigh	1.18	1.17
Colorado	Denver	0.98	0.98	North Dakota	Bismarck	1.11	1.11
	Grand Junction	1.00	1.00		Devils Lake	1.12	1.12
	Pueblo	1.00	1.00		Fargo	1.15	1.15
Connecticut	Hartford	1.18	1.18		Williston	1.11	1.11
District of Columbia	Washington	1.19	1.18	Ohio	Cincinnati	1.16	1.16
					Dayton	1.15	1.15
Florida	Jacksonville	1.19	1.18		Cleveland	1.15	1.15
	Key West	1.19	1.18	Oklahoma	Oklahoma City	1.14	1.14
	Miami	1.19	1.18	Oregon	Baker	1.04	1.04
	Tampa	1.19	1.18		Medford	1.13	1.14
Georgia	Atlanta	1.15	1.14		Portland	1.18	1.19
	Augusta (Aiken, S C.)	1.18	1.18		Roseburg	1.17	1.17
	Savannah	1.19	1.18	Pennsylvania	Philadelphia	1.18	1.18
Idaho	Boise	1.07	1.07	Rhode Island	Providence	1.18	1.18
Illinois	Cairo	1.18	1.17	South Carolina	Charleston	1.19	1.18
	Chicago	1.16	1.16		Columbia	1.18	1.17
	Moline	1.17	1.17	South Dakota	Huron	1.14	1.13
	Springfield	1.16	1.16		Rapid City	1.05	1.06
Indiana	Fort Wayne	1.15	1.15	Tennessee	Knoxville (Oak Ridge)	1.16	1.15
	Indianapolis	1.15	1.15		Memphis	1.18	1.17
Iowa	Burlington	1.16	1.15		Nashville	1.17	1.17
	Des Moines	1.15	1.15	Texas	Abilene	1.12	1.11
	Dubuque	1.16	1.15		Amarillo	1.04	1.04
	Sioux City	1.15	1.13		Austin	1.17	1.16
Kansas	Concordia	1.13	1.12		Brownsville	1.19	1.18
	Dodge City	1.08	1.08		Fort Worth	1.16	1.16
	Topeka	1.15	1.15		El Paso	1.04	1.04
	Wichita	1.14	1.13		Houston	1.18	1.18
Kentucky	Louisville	1.17	1.17		San Antonio	1.17	1.17
Louisiana	New Orleans	1.19	1.18	Utah	Salt Lake City	1.02	1.02
	Shreveport	1.18	1.18	Vermont	Burlington	1.17	1.17
Maine	Eastport	1.18	1.18	Virginia	Norfolk	1.19	1.18
Massachusetts	Boston	1.18	1.18		Richmond	1.18	1.18
Michigan	Alpena	1.16	1.16	Washington	Seattle	1.18	1.17
	Detroit	1.16	1.15		Spokane	1.19	1.18
	Grand Rapids	1.15	1.15		Walla Walla	1.15	1.13
	Marquette	1.15	1.15	West Virginia	Elkins	1.11	1.11
	Sault Ste. Marie	1.16	1.16		Parkersburg	1.16	1.16
Minnesota	Duluth	1.14	1.14	Wisconsin	Green Bay	1.16	1.16
	Minneapolis	1.15	1.15		Madison	1.15	1.15
	St. Paul (Airport)	1.15	1.15		Milwaukee	1.16	1.15
Mississippi	Vicksburg	1.18	1.18	Wyoming	Casper	0.97	0.97
Missouri	Kansas City	1.15	1.15		Cheyenne	0.96	0.96
	St. Louis	1.17	1.16		Sheridan	1.03	1.04
	Springfield	1.14	1.13				
Montana	Havre	1.08	1.08				

BAROMETRIC PRESSURE (MM OF HG)	16 °C	18 °C	20 °C	22 °C	24 °C	26 °C	28 °C
				TABLE 1B			
600	0.00096	0.00095	0.00095	0.00094	0.00093	0.00093	0.00092
605	0.00097	0.00096	0.00095	0.00095	0.00094	0.00093	0.00093
610	0.00098	0.00097	0.00096	0.00096	0.00095	0.00094	0.00093
615	0.00098	0.00098	0.00097	0.00096	0.00096	0.00095	0.00094
620	0.00099	0.00099	0.00098	0.00097	0.00096	0.00096	0.00095
625	0.00100	0.00099	0.00099	0.00098	0.00097	0.00096	0.00096
630	0.00101	0.00100	0.00099	0.00099	0.00098	0.00097	0.00097
635	0.00102	0.00101	0.00100	0.00099	0.00099	0.00098	0.00097
640	0.00102	0.00102	0.00101	0.00100	0.00100	0.00099	0.00098
645	0.00103	0.00103	0.00102	0.00101	0.00100	0.00100	0.00099
650	0.00104	0.00103	0.00103	0.00102	0.00101	0.00100	0.00100
655	0.00105	0.00104	0.00103	0.00103	0.00102	0.00101	0.00100
660	0.00106	0.00105	0.00104	0.00103	0.00103	0.00102	0.00101
665	0.00106	0.00106	0.00105	0.00104	0.00103	0.00103	0.00102
670	0.00107	0.00107	0.00106	0.00105	0.00104	0.00103	0.00103
675	0.00108	0.00107	0.00107	0.00106	0.00105	0.00104	0.00103
680	0.00109	0.00108	0.00107	0.00107	0.00106	0.00105	0.00104
685	0.00110	0.00109	0.00108	0.00107	0.00107	0.00106	0.00105
690	0.00110	0.00110	0.00109	0.00108	0.00107	0.00107	0.00106
695	0.00111	0.00110	0.00110	0.00109	0.00108	0.00107	0.00107
700	0.00112	0.00111	0.00110	0.00110	0.00109	0.00108	0.00107
705	0.00113	0.00112	0.00111	0.00110	0.00110	0.00109	0.00108
710	0.00114	0.00113	0.00112	0.00111	0.00110	0.00110	0.00109
715	0.00115	0.00114	0.00113	0.00112	0.00111	0.00110	0.00110
720	0.00115	0.00114	0.00114	0.00113	0.00112	0.00111	0.00110
725	0.00116	0.00115	0.00114	0.00114	0.00113	0.00112	0.00111
730	0.00117	0.00116	0.00115	0.00114	0.00114	0.00113	0.00112
735	0.00118	0.00117	0.00116	0.00115	0.00114	0.00114	0.00113
740	0.00119	0.00118	0.00117	0.00116	0.00115	0.00114	0.00113
745	0.00119	0.00118	0.00118	0.00117	0.00116	0.00115	0.00114
750	0.00120	0.00119	0.00118	0.00118	0.00117	0.00116	0.00115
755	0.00121	0.00120	0.00119	0.00118	0.00118	0.00117	0.00116
760	0.00122	0.00121	0.00120	0.00119	0.00118	0.00117	0.00117
765	0.00123	0.00122	0.00121	0.00120	0.00119	0.00118	0.00117
770	0.00123	0.00122	0.00122	0.00121	0.00120	0.00119	0.00118
775	0.00124	0.00123	0.00122	0.00122	0.00121	0.00120	0.00119
780	0.00125	0.00124	0.00123	0.00122	0.00121	0.00121	0.00120
785	0.00126	0.00125	0.00124	0.00123	0.00122	0.00121	0.00120
790	0.00127	0.00126	0.00125	0.00124	0.00123	0.00122	0.00121
795	0.00127	0.00126	0.00126	0.00125	0.00124	0.00123	0.00122

T	0.0°C	0.1°C	0.2°C	0.3°C	0.4°C	0.5°C	0.6°C	0.7°C	0.8°C	0.9°C
.0	.999840	.999846	.999853	.999859	.999865	.999871	.999877	.999883	.999888	.999893
1.0	.999899	.999903	.999908	.999913	.999917	.999921	.999925	.999929	.999933	.999937
2.0	.999940	.999943	.999946	.999949	.999952	.999954	.999956	.999959	.999961	.999963
3.0	.999964	.999966	.999967	.999968	.999969	.999970	.999971	.999971	.999972	.999972
4.0	.999972	.999972	.999972	.999971	.999971	.999970	.999969	.999968	.999967	.999965
5.0	.999964	.999962	.999960	.999958	.999956	.999954	.999951	.999949	.999946	.999943
6.0	.999940	.999937	.999933	.999930	.999926	.999922	.999918	.999914	.999910	.999906
7.0	.999901	.999896	.999892	.999887	.999881	.999876	.999871	.999865	.999860	.999854
8.0	.999848	.999842	.999835	.999829	.999822	.999816	.999809	.999802	.999795	.999787
9.0	.999780	.999773	.999765	.999757	.999749	.999741	.999733	.999725	.999716	.999707
10.0	.999699	.999690	.999681	.999672	.999662	.999653	.999643	.999634	.999624	.999614
11.0	.999604	.999594	.999583	.999573	.999562	.999552	.999541	.999530	.999519	.999507
12.0	.999496	.999485	.999473	.999461	.999449	.999437	.999425	.999413	.999401	.999388
13.0	.999376	.999363	.999350	.999337	.999324	.999311	.999297	.999284	.999270	.999256
14.0	.999243	.999229	.999215	.999200	.999186	.999172	.999157	.999142	.999128	.999113
15.0	.999098	.999083	.999067	.999052	.999036	.999021	.999005	.998989	.998973	.998957
16.0	.998941	.998925	.998908	.998892	.998875	.998858	.998841	.998824	.998807	.998790
17.0	.998773	.998755	.998738	.998720	.998702	.998684	.998666	.998648	.998630	.998612
18.0	.998593	.998575	.998556	.998537	.998519	.998500	.998480	.998461	.998442	.998422
19.0	.998403	.998383	.998364	.998344	.998324	.998304	.998284	.998263	.998243	.998222
20.0	.998202	.998181	.998160	.998139	.998118	.998097	.998076	.998055	.998033	.998012
21.0	.997990	.997968	.997947	.997925	.997903	.997881	.997858	.997836	.997814	.997791
22.0	.997768	.997746	.997723	.997700	.997677	.997654	.997630	.997607	.997584	.997560
23.0	.997536	.997513	.997489	.997465	.997441	.997417	.997392	.997368	.997344	.997319
24.0	.997294	.997270	.997245	.997220	.997195	.997170	.997145	.997119	.997094	.997068
25.0	.997043	.997017	.996991	.996966	.996940	.996913	.996887	.996861	.996835	.996808
26.0	.996782	.996755	.996728	.996702	.996675	.996648	.996621	.996593	.996566	.996539
27.0	.996511	.996484	.996456	.996428	.996401	.996373	.996345	.996316	.996288	.996260
28.0	.996232	.996203	.996175	.996146	.996117	.996088	.996060	.996031	.996001	.995972
29.0	.995943	.995914	.995884	.995855	.995825	.995795	.995765	.995736	.995706	.995676
30.0	.995645	.995615	.995585	.995554	.995524	.995493	.995463	.995432	.995401	.995370
31.0	.995339	.995308	.995277	.995246	.995214	.995183	.995151	.995120	.995088	.995056
32.0	.995024	.994992	.994960	.994928	.994896	.994864	.994831	.994799	.994766	.994734
33.0	.994701	.994668	.994635	.994602	.994569	.994536	.994503	.994470	.994436	.994403
34.0	.994369	.994336	.994302	.994268	.994234	.994201	.994167	.994132	.994098	.994064
35.0	.994030	.993995	.993961	.993926	.993891	.993857	.993822	.993787	.993752	.993717
36.0	.993682	.993647	.993611	.993576	.993541	.993505	.993469	.993434	.993398	.993362
37.0	.993326	.993290	.993254	.993218	.993182	.993146	.993109	.993073	.993036	.993000
38.0	.992963	.992926	.992889	.992852	.992815	.992778	.992741	.992704	.992667	.992629
39.0	.992592	.992554	.992517	.992479	.992442	.992404	.992366	.992328	.992290	.992252

TABLE 2: Density of Air Free Water in g/cm^3 as a Function of the Celsius
Temperature Scale, Based on the Work by H. Wagenbreth and W.
Blanke, PTB-Mitteilungen 6-71.

ρ_B	Q when $D_{20} = 8.0000$ g/cm^3	Q when $D_{20} = 8.3909$ g/cm^3
7.70	1.0000058	1.0000128
7.72	1.0000054	1.0000124
7.74	1.0000050	1.0000120
7.76	1.0000046	1.0000116
7.78	1.0000042	1.0000112
7.80	1.0000038	1.0000108
7.82	1.0000035	1.0000104
7.84	1.0000031	1.0000101
7.86	1.0000027	1.0000097
7.88	1.0000023	1.0000093
7.90	1.0000019	1.0000089
7.92	1.0000015	1.0000085
7.94	1.0000011	1.0000081
7.96	1.0000008	1.0000077
7.98	1.0000004	1.0000074
8.00	1.0000000	1.0000070
8.02	0.9999996	1.0000066
8.04	0.9999993	1.0000062
8.06	0.9999989	1.0000059
8.08	0.9999985	1.0000055
8.10	0.9999981	1.0000051
8.12	0.9999978	1.0000048
8.14	0.9999974	1.0000044
8.16	0.9999971	1.0000040
8.18	0.9999967	1.0000037
8.20	0.9999963	1.0000033
8.22	0.9999960	1.0000030
8.24	0.9999956	1.0000026
8.26	0.9999953	1.0000023
8.28	0.9999949	1.0000019
8.30	0.9999946	1.0000016
8.32	0.9999942	1.0000012
8.34	0.9999939	1.0000009
8.36	0.9999935	1.0000005
8.38	0.9999932	1.0000002
8.40	0.9999929	0.9999998

TABLE 3: Values of the apparent mass conversion factor, Q, defined in the appendix as

$$Q = \frac{\rho_B(D_{20} - .0012)}{D_{20}(\rho_B - .0012)}$$

when ρ_B is the density of the balance weights in g/cm^3, and D_{20} is the apparent mass scale to which the weights are adjusted.

Water Temp (°C)	Fused Silica (Quartz) α=1.6	Boro-Silicate Glass α=10	Soft Glass α=25	Poly-Propylene Plastic α=240	Poly-Carbonate Plastic α=450
18.0	1.000003	1.000020	1.000050	1.000480	1.000900
18.5	1.000002	1.000015	1.000038	1.000360	1.000675
19.0	1.000002	1.000010	1.000025	1.000240	1.000450
19.5	1.000001	1.000005	1.000013	1.000120	1.000225
20.0	1.000000	1.000000	1.000000	1.000000	1.000000
20.5	0.999999	0.999995	0.999988	0.999880	0.999775
21.0	0.999998	0.999990	0.999975	0.999760	0.999550
21.5	0.999998	0.999985	0.999963	0.999640	0.999325
22.0	0.999997	0.999980	0.999950	0.999520	0.999100
22.5	0.999996	0.999975	0.999938	0.999400	0.998875
23.0	0.999995	0.999970	0.999925	0.999280	0.998650
23.5	0.999994	0.999965	0.999913	0.999160	0.998425
24.0	0.999994	0.999960	0.999900	0.999040	0.998200
24.5	0.999993	0.999955	0.999888	0.998920	0.997975
25.0	0.999992	0.999950	0.999875	0.998800	0.997750
25.5	0.999991	0.999945	0.999863	0.998680	0.997525
26.0	0.999990	0.999940	0.999850	0.998560	0.997300
26.5	0.999990	0.999935	0.999838	0.998440	0.997075
27.0	0.999989	0.999930	0.999825	0.998320	0.996850
27.5	0.999988	0.999925	0.999813	0.998200	0.996625
28.0	0.999987	0.999920	0.999800	0.998080	0.996400
28.5	0.999986	0.999915	0.999788	0.997960	0.996175
29.0	0.999986	0.999910	0.999775	0.997840	0.995950
29.5	0.999985	0.999905	0.999763	0.997720	0.995725
30.0	0.999984	0.999900	0.999750	0.997600	0.995500

TABLE 4: Values of the expansion factor K as a function of test temperature for various materials from which laboratory ware is made. The numerical values of α, the volumetric coefficient of thermal expansion, given in the column headings are parts per million per degree centigrade. In plastics, columns 4 and 5, this coefficient may vary from batch-to-batch, and the values stated are typical, mid-range values. In the text K is defined as

$$K = 1 - \alpha(T-20)$$

TEMP (°C)	BAROMETRIC PRESSURE (MM OF HG)				
	620	640	660	680	700
18.5	1.002390	1.002418	1.002446	1.002473	1.002501
19.0	1.002480	1.002508	1.002536	1.002564	1.002592
19.5	1.002573	1.002601	1.002629	1.002657	1.002685
20.0	1.002669	1.002697	1.002725	1.002753	1.002780
20.5	1.002768	1.002795	1.002823	1.002851	1.002879
21.0	1.002869	1.002897	1.002924	1.002952	1.002980
21.5	1.002973	1.003000	1.003028	1.003056	1.003083
22.0	1.003079	1.003107	1.003134	1.003162	1.003190
22.5	1.003188	1.003216	1.003243	1.003271	1.003298
23.0	1.003299	1.003327	1.003354	1.003382	1.003410
23.5	1.003413	1.003441	1.003468	1.003496	1.003523
24.0	1.003530	1.003557	1.003585	1.003612	1.003640
24.5	1.003649	1.003676	1.003704	1.003731	1.003758
25.0	1.003770	1.003797	1.003825	1.003852	1.003880
25.5	1.003894	1.003921	1.003949	1.003976	1.004003
26.0	1.004020	1.004047	1.004075	1.004102	1.004129
26.5	1.004149	1.004176	1.004203	1.004231	1.004258
27.0	1.004280	1.004307	1.004334	1.004361	1.004389
27.5	1.004413	1.004440	1.004467	1.004495	1.004522
28.0	1.004549	1.004576	1.004603	1.004630	1.004657

TEMP (°C)	BAROMETRIC PRESSURE (MM OF HG)				
	720	740	760	780	800
18.5	1.002529	1.002557	1.002585	1.002613	1.002641
19.0	1.002620	1.002647	1.002675	1.002703	1.002731
19.5	1.002713	1.002740	1.002768	1.002796	1.002824
20.0	1.002808	1.002836	1.002864	1.002892	1.002919
20.5	1.002906	1.002934	1.002962	1.002990	1.003017
21.0	1.003007	1.003035	1.003063	1.003091	1.003118
21.5	1.003111	1.003139	1.003166	1.003194	1.003222
22.0	1.003217	1.003245	1.003272	1.003300	1.003328
22.5	1.003326	1.003353	1.003381	1.003409	1.003436
23.0	1.003437	1.003465	1.003492	1.003520	1.003547
23.5	1.003551	1.003578	1.003606	1.003633	1.003661
24.0	1.003667	1.003695	1.003722	1.003750	1.003777
24.5	1.003786	1.003813	1.003841	1.003868	1.003896
25.0	1.003907	1.003934	1.003962	1.003989	1.004017
25.5	1.004031	1.004058	1.004085	1.004113	1.004140
26.0	1.004157	1.004184	1.004211	1.004239	1.004266
26.5	1.004285	1.004312	1.004340	1.004367	1.004394
27.0	1.004416	1.004443	1.004470	1.004498	1.004525
27.5	1.004549	1.004576	1.004603	1.004631	1.004658
28.0	1.004685	1.004712	1.004739	1.004766	1.004793

TABLE 5: Values of Z (equation 6) as Explained in the Text.

VOLUMETRIC FLASK

INDEX LINE

TO CONTAIN

NOMINAL VOLUME

TC
200 cm³
20°C

PIPET

100 cm³
20°C
45 SEC

TO DELIVER

DELIVERY TIME IN SECONDS

BURET

TD
20°C

113 SEC

MEASURING FLASK

100 ml
20°C
10 SEC
DRAIN

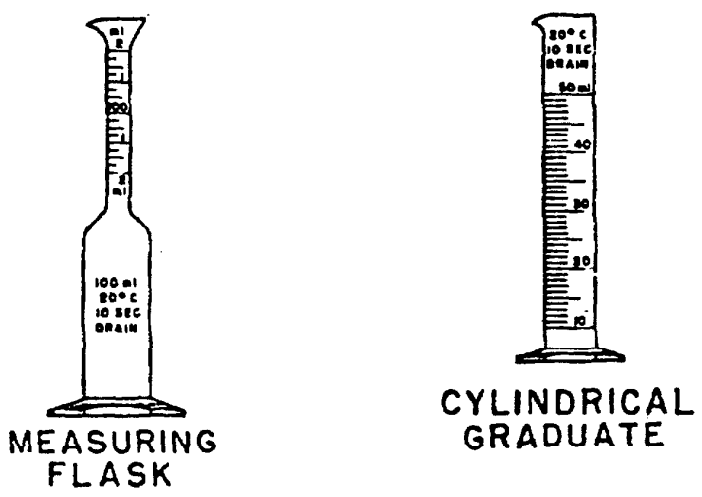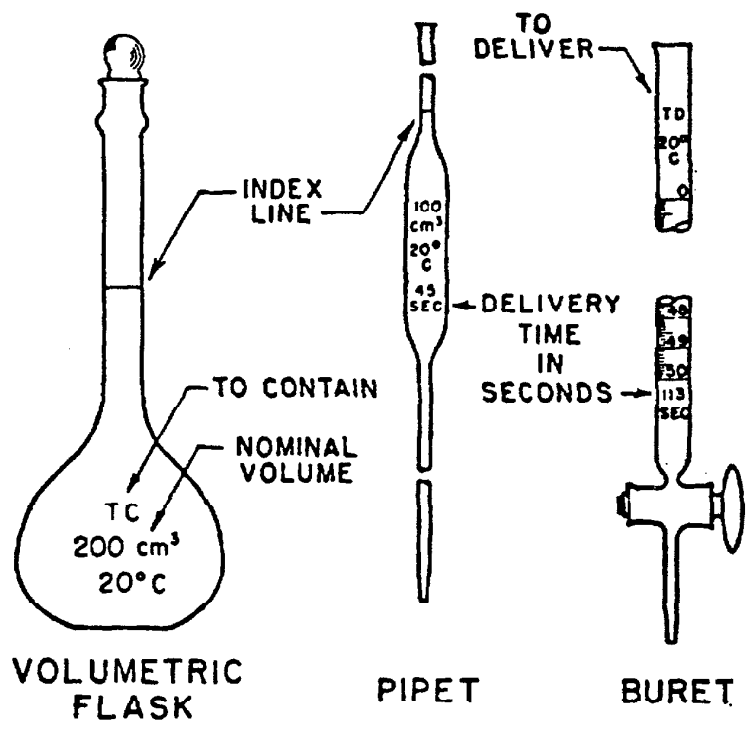**CYLINDRICAL GRADUATE**

20°C
10 SEC
DRAIN

FIGURE 1

SHOWN HERE ARE THE VARIOUS TYPES OF VOLUMETRIC APPARATUS WHICH MAY BE CALIBRATED BY THE TECHNIQUES DESCRIBED IN THIS REPORT.

FIGURE 2

DRY AIR BOTTLES AND DRYING RACK
USED TO DRY VOLUMETRIC GLASSWARE

PRESSURE IS ABOUT 1 LB PER SQ IN.
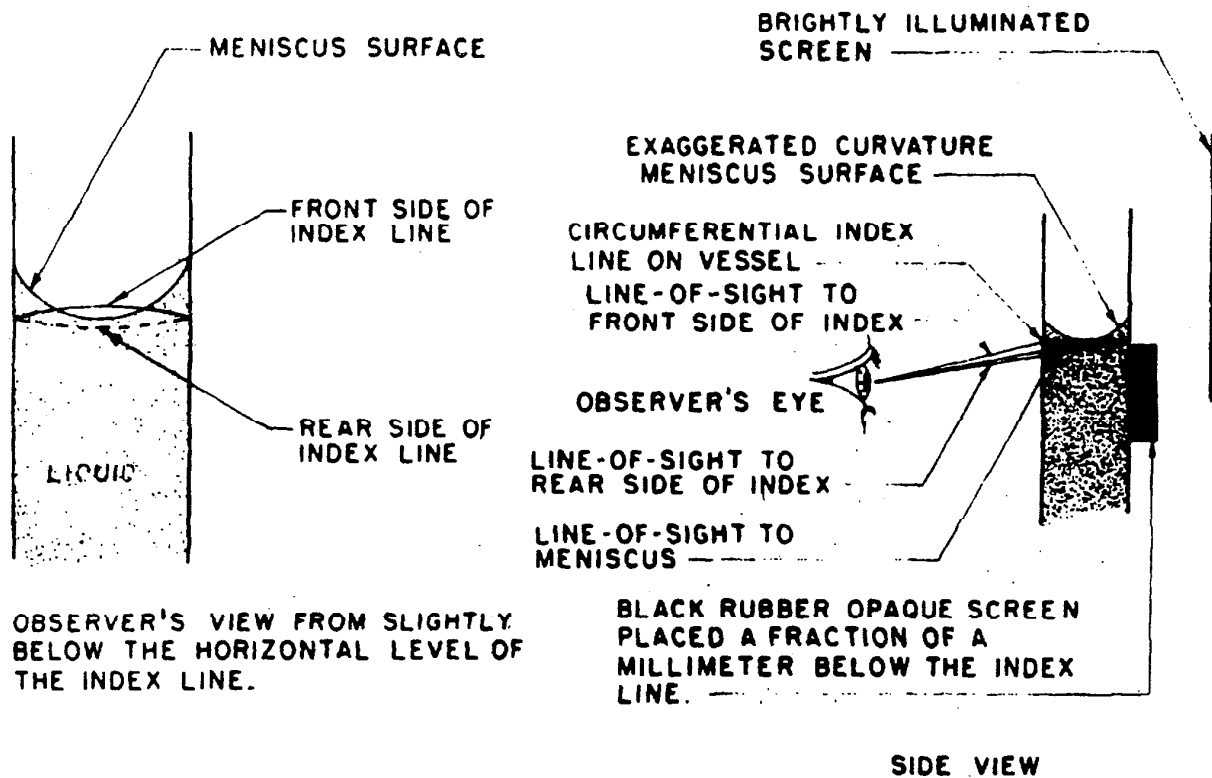
DRYING USUALLY TAKES LESS THAN 10 MINUTES

MENISCUS SURFACE

FRONT SIDE OF
INDEX LINE

REAR SIDE OF
INDEX LINE

LIQUID

OBSERVER'S VIEW FROM SLIGHTLY
BELOW THE HORIZONTAL LEVEL OF
THE INDEX LINE.

BRIGHTLY ILLUMINATED
SCREEN

EXAGGERATED CURVATURE
MENISCUS SURFACE

CIRCUMFERENTIAL INDEX
LINE ON VESSEL
LINE-OF-SIGHT TO
FRONT SIDE OF INDEX

OBSERVER'S EYE

LINE-OF-SIGHT TO
REAR SIDE OF INDEX

LINE-OF-SIGHT TO
MENISCUS

BLACK RUBBER OPAQUE SCREEN
PLACED A FRACTION OF A
MILLIMETER BELOW THE INDEX
LINE.

SIDE VIEW

FIGURE 3

THESE DIAGRAMS ILLUSTRATE THE PROCEDURE FOR OBSERVING
THE MENISCUS POSITION DESCRIBED IN THE TEXT.
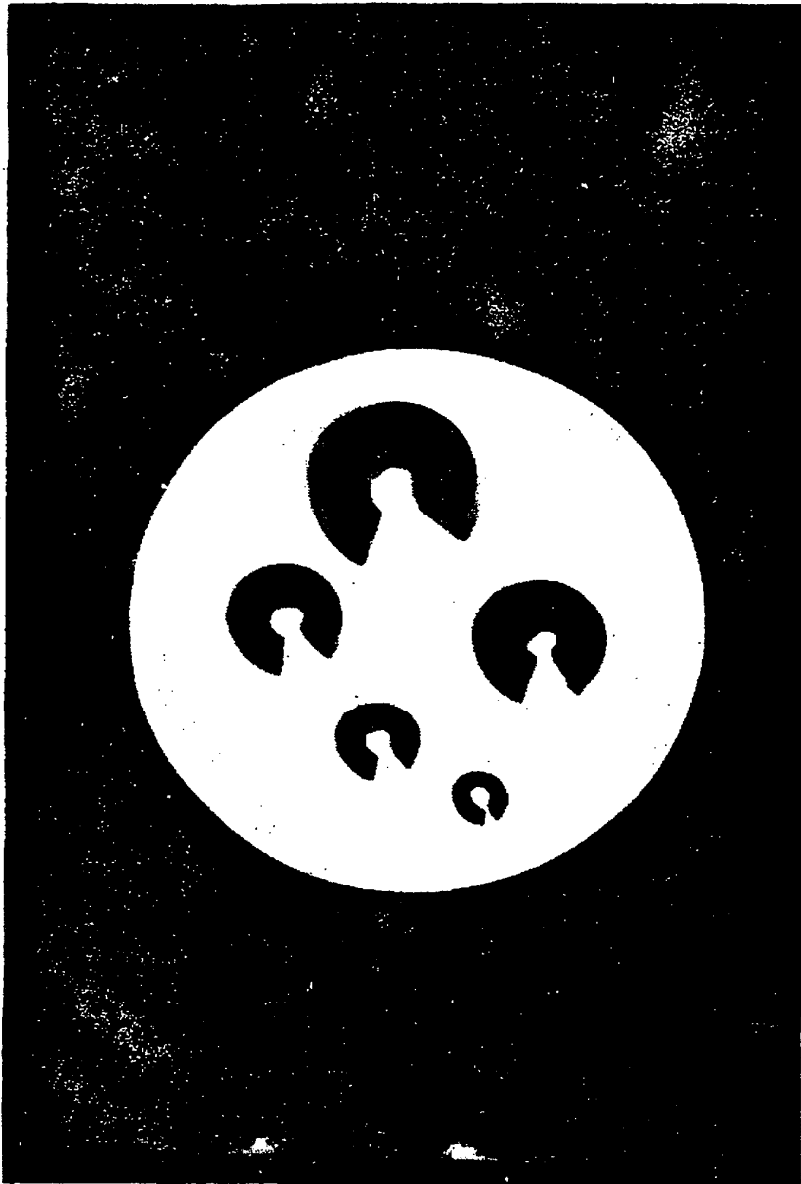
VARIOUS RUBBER COLLARS USED TO ASSIST
IN THE MENISCUS SETTING DURING THE
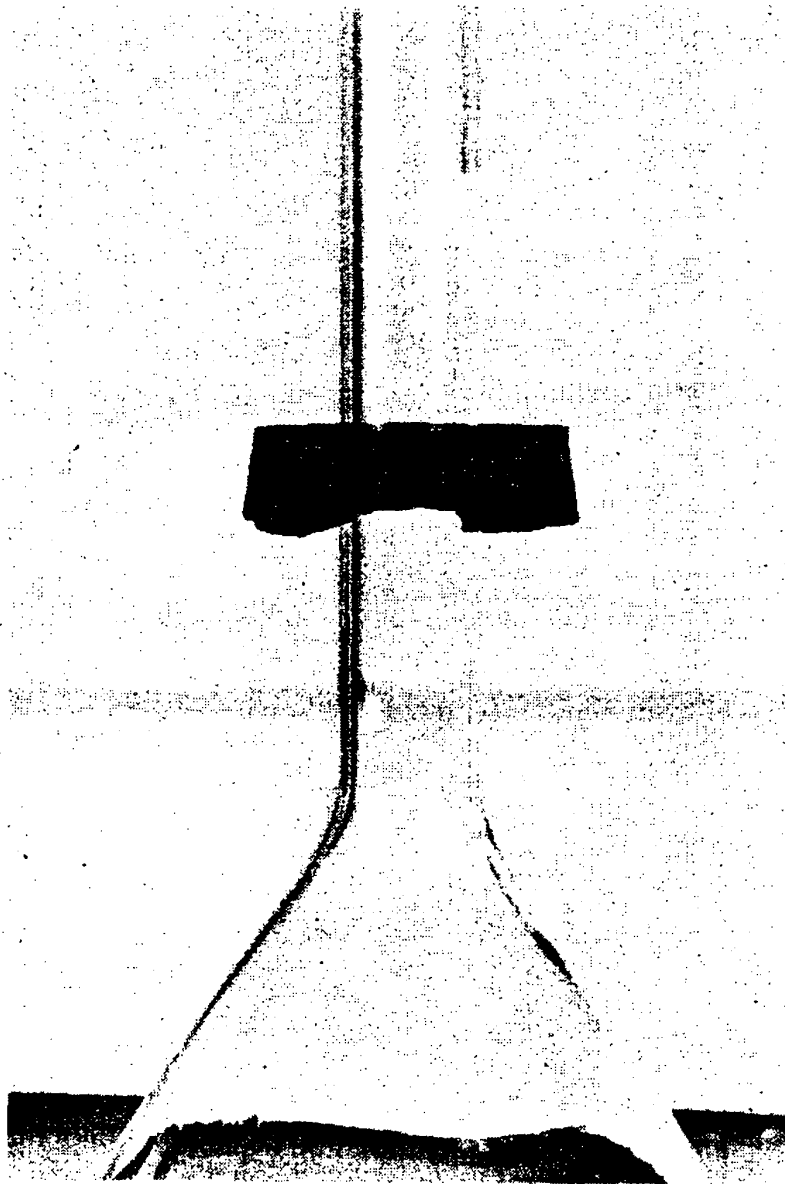CALIBRATION OF BURETS, PIPETS AND FLASKS

FIGURE 4A

A FLASK WITH A COLLAR-SHAPED PIECE OF BLACK
RUBBER TUBING IN PLACE BELOW THE INDEX LINE
WHICH   RENDERS   THE PROFILE OF THE MENISCUS
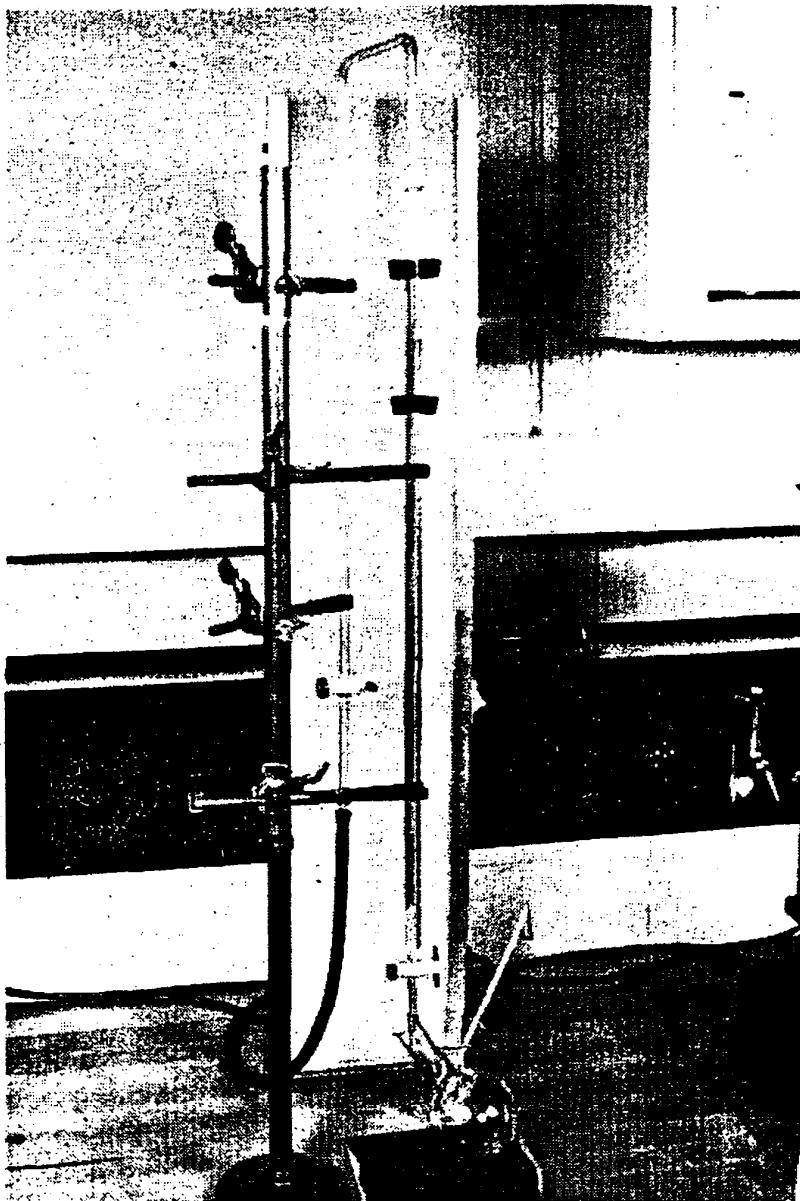CLEARLY VISIBLE AGAINST A LIGHT   BACKGROUND

FIGURE 5

APPARATUS USED IN THE CALIBRATION OF A 50ML BURET. THE U-
SHAPED TUBE AT THE TOP IS CONNECTED TO A DISTILLED WATER
SUPPLY LINE USED TO FILL THE BURET. THE WEIGHING FLASK
UNDER THE BURET IS IN POSITION, WITH ITS TIP IN CONTACT
WITH THE NECK OF THE FLASK TO RECEIVE THE MEASURED VOLUME.
THE BLACK COLLARS AT THE TOP OF THE BURET ARE AN AID IN
SETTING THE MENISCUS. THE THERMOMETER IS USED TO OBTAIN A
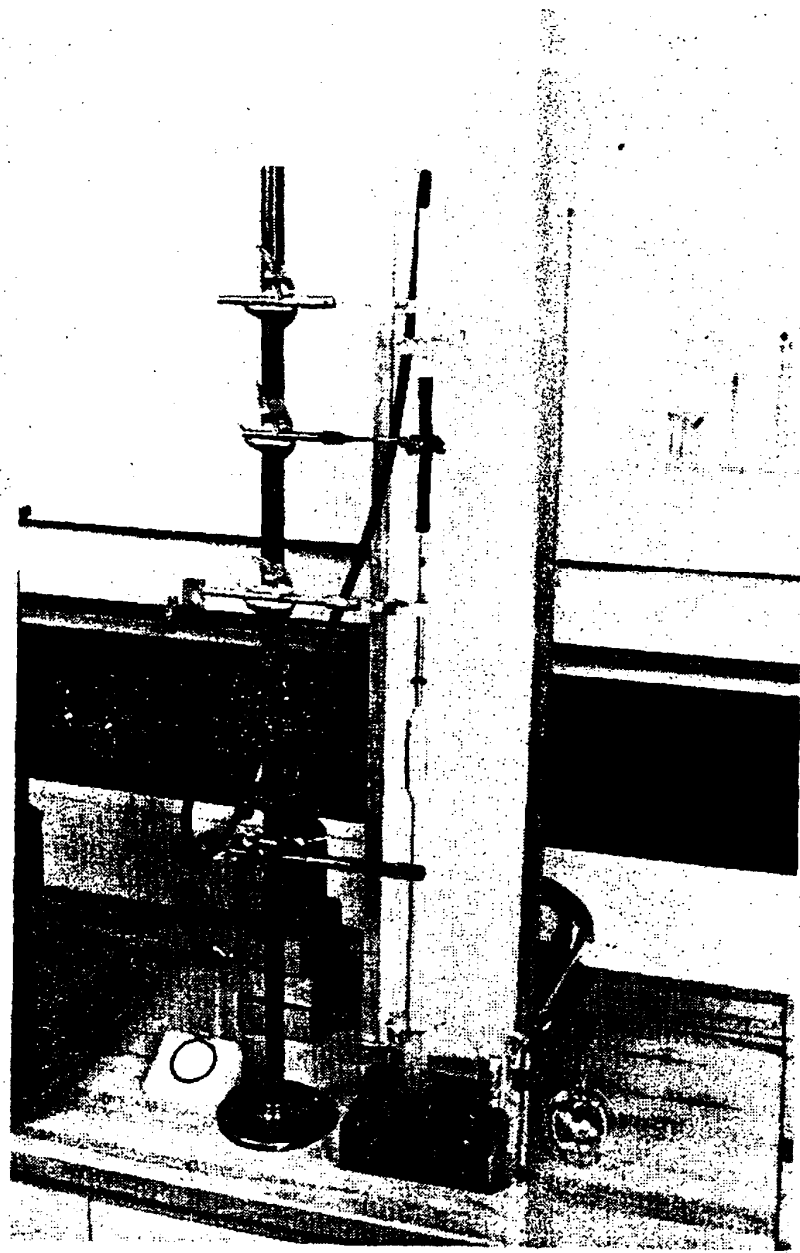MEASURE OF THE TEMPERATURE OF THE WATER IN THE BURET.

FIGURE 6

TRANSFER PIPET CLAMPED VERTICALLY ON A STAND IN FRONT OF A
FROSTED GLASS LIGHT BOX. THE TIP IS IN CONTACT WITH A PIECE
OF FROSTED GLASS WHILE THE SETTING OF THE MENISCUS IS MADE.
THE HOSE ON THE GLASS TUBE ABOVE THE STOPCOCK IS CONNECTED
TO A TRAP BOTTLE WHICH, IN TURN, IS CONNECTED TO THE VACUUM
LINE. THE HOSE CLAMP IS USED TO SLOW THE FLOW WHILE MAKING
THE MENISCUS SETTING. THE STOPWATCH IS FOR TIMING THE
DELIVERY OF THE PIPET. THE TEMPERATURE OF THE DISTILLED
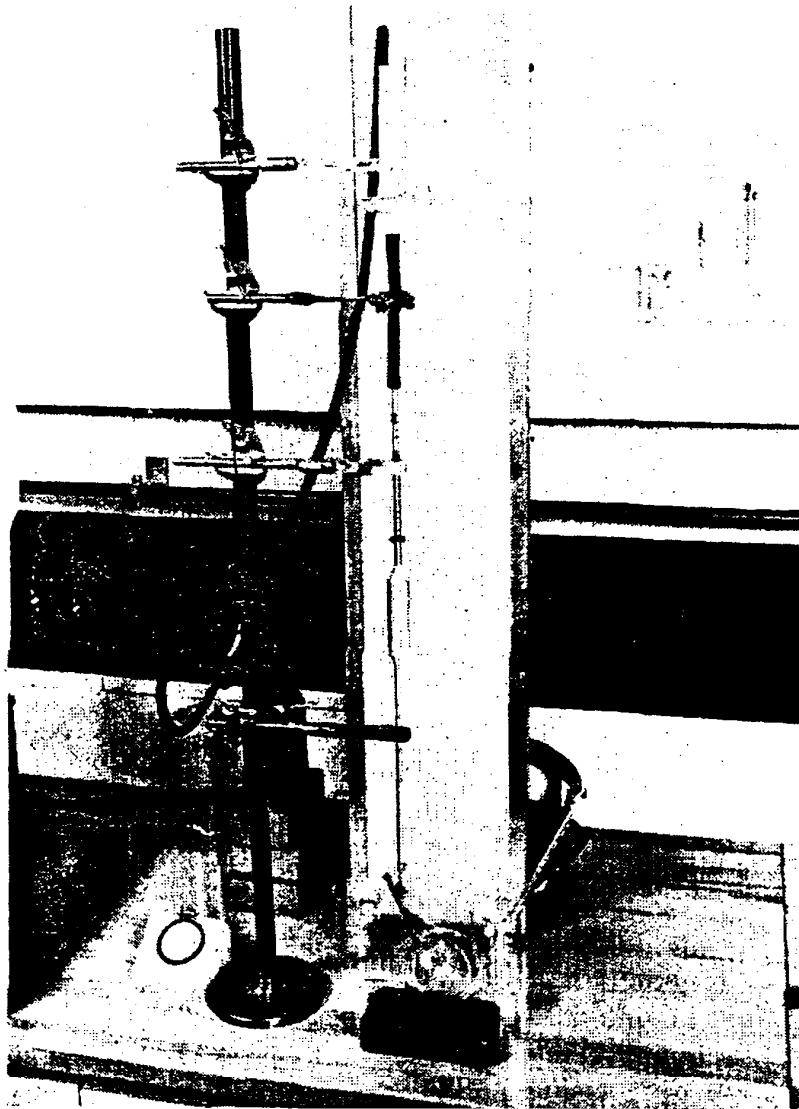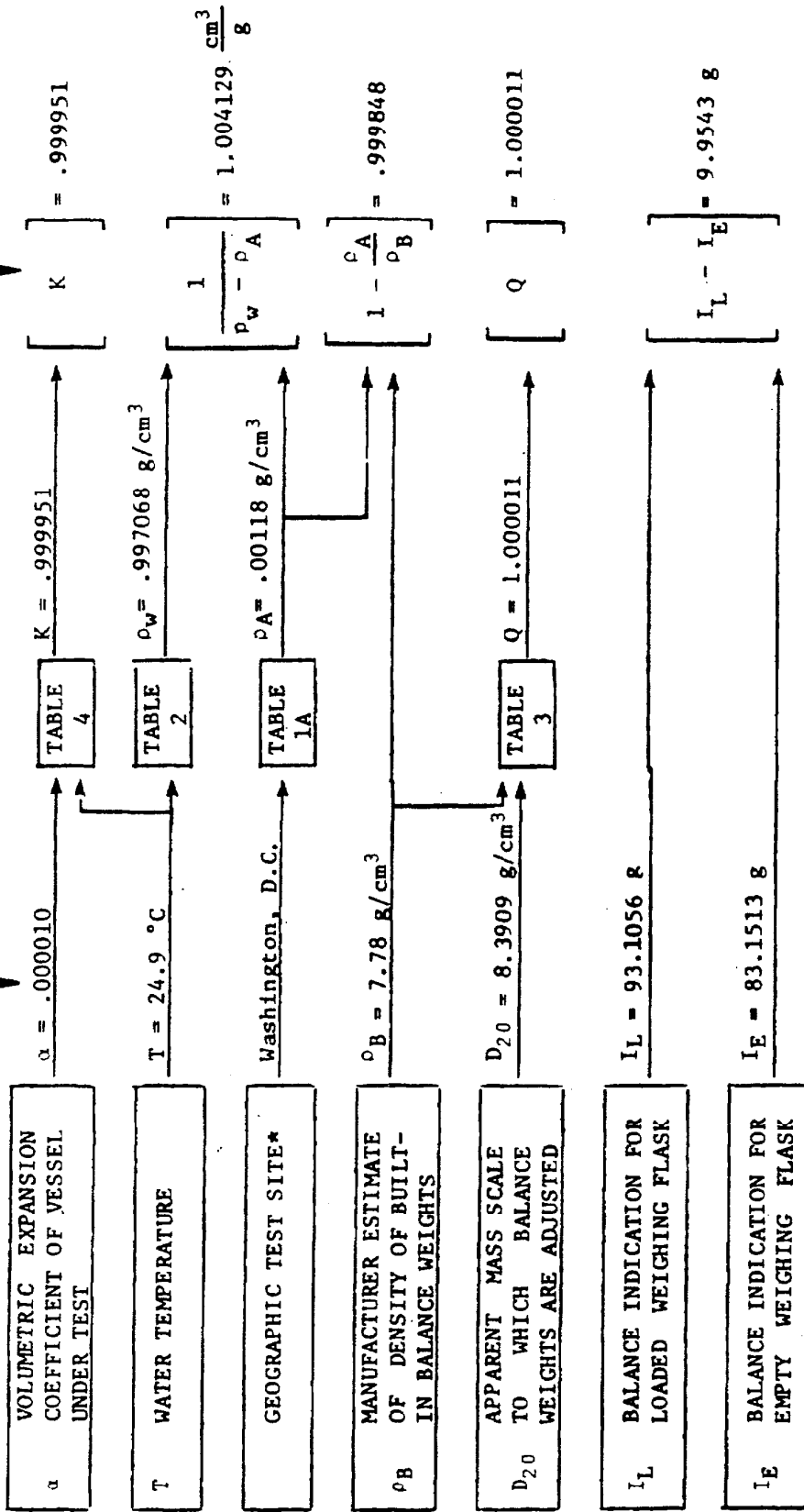WATER IS TAKEN IN THE BEAKER FROM WHICH THE PIPET IS FILLED.

FIGURE 6A

THE PIPET IS DELIVERING ITS MEASURED VOLUME INTO
A WEIGHING FLASK, WITH ITS TIP IN CONTACT WITH
THE NECK OF THE FLASK. WHEN THE OUTFLOW HAS
CEASED THE FLASK IS REMOVED, STOPPERED AND WEIGHED.

THE CALIBRATION VOLUME,
V_{20}, IS THE PRODUCT OF
THESE FIVE TERMS

INPUT DATA ITEMS | TYPICAL VALUES

| α | VOLUMETRIC EXPANSION COEFFICIENT OF VESSEL UNDER TEST | $\alpha = .000010$ | → | TABLE 4 | $K = .999951$ | → | $\left[\quad K \quad \right] = .999951$ |

| T | WATER TEMPERATURE | $T = 24.9 \, °C$ | → | TABLE 2 | $\rho_W = .997068 \, g/cm^3$ | → | $\left[\dfrac{1}{\rho_W - \rho_A} \right] = 1.004129 \, \dfrac{cm^3}{g}$ |

| | GEOGRAPHIC TEST SITE* | Washington, D.C. | → | TABLE 1A | $\rho_A = .00118 \, g/cm^3$ | → | $\left[1 - \dfrac{\rho_A}{\rho_B} \right] = .999848$ |

| ρ_B | MANUFACTURER ESTIMATE OF DENSITY OF BUILT-IN BALANCE WEIGHTS | $\rho_B = 7.78 \, g/cm^3$ | | | | | |

| D_{20} | APPARENT MASS SCALE TO WHICH BALANCE WEIGHTS ARE ADJUSTED | $D_{20} = 8.3909 \, g/cm^3$ | → | TABLE 3 | $Q = 1.000011$ | → | $\left[\quad Q \quad \right] = 1.000011$ |

| I_L | BALANCE INDICATION FOR LOADED WEIGHING FLASK | $I_L = 93.1056 \, g$ | | | | | |

| I_E | BALANCE INDICATION FOR EMPTY WEIGHING FLASK | $I_E = 83.1513 \, g$ | | | | → | $\left[I_L - I_E \right] = 9.9543 \, g$ |

$$V_{20} = 9.9935 \, cm^3$$

* AIR DENSITY VALUES BASED UPON GEOGRAPHIC LOCATION ARE QUITE ADEQUATE FOR THIS WORK. FOR A BETTER VALUE, TABLE 1B PROVIDES AN ESTIMATE BASED UPON MEASURED TEMPERATURE AND BAROMETRIC PRESSURE AND ASSUMED RELATIVE HUMIDITY.
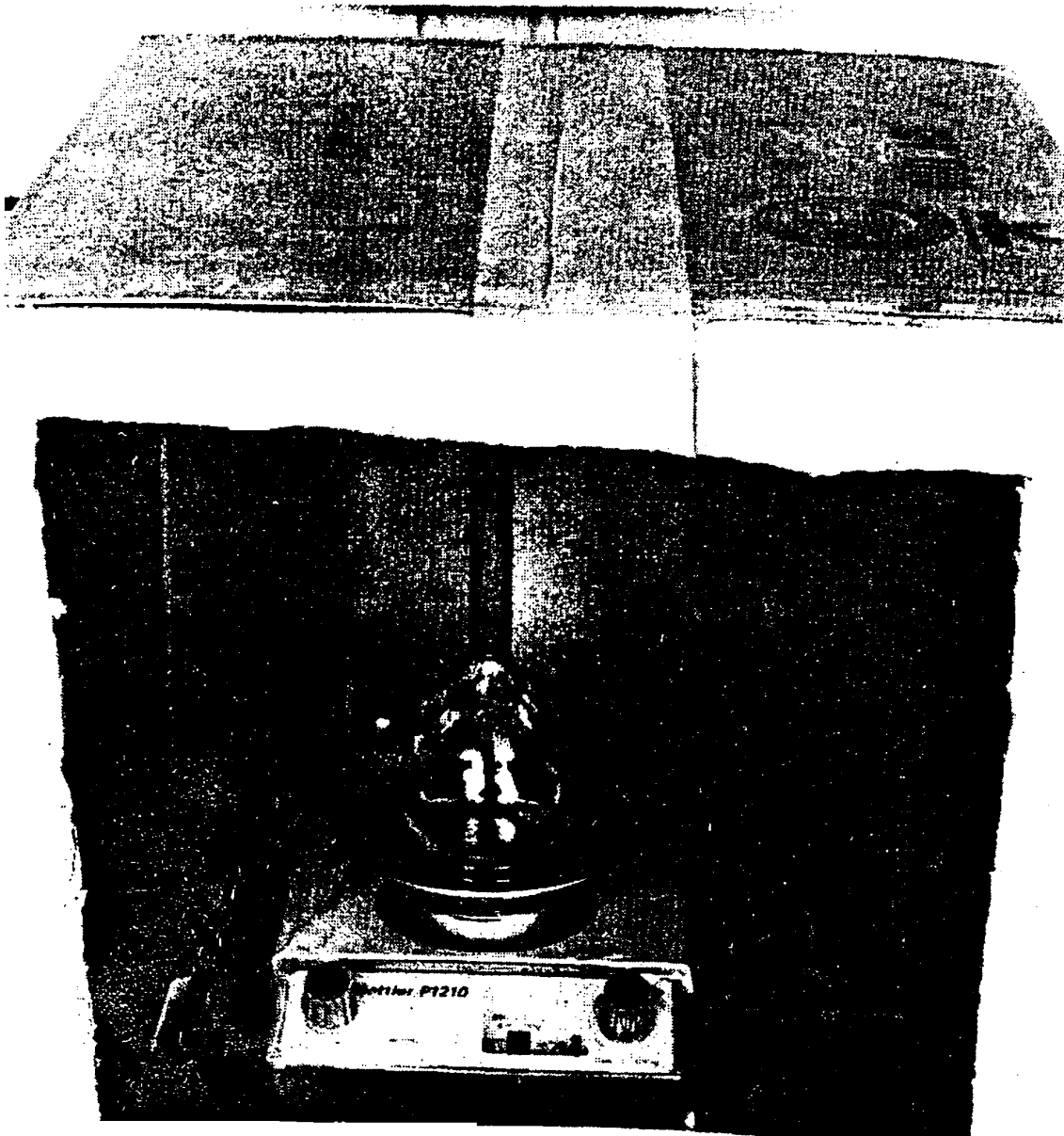
FIGURE 7

- 30 -

FIGURE 8

1200G TOP-LOADING DIRECT READING BALANCE SUITABLE FOR THE RAPID
WEIGHING OF LARGE FLASKS. IT IS SHIELDED BY A CARDBOARD BOX
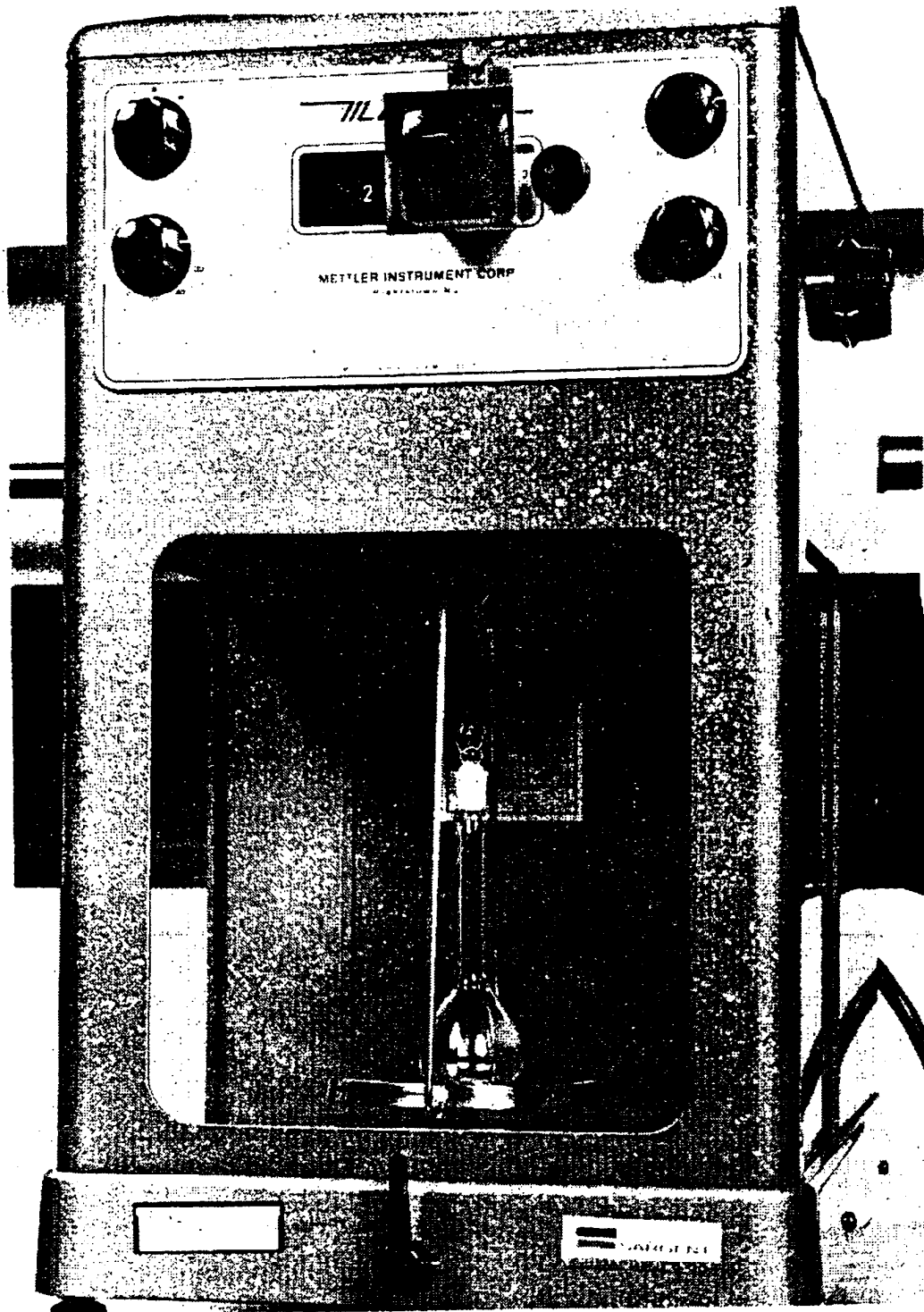TO PREVENT AIR CURRENTS FROM AFFECTING THE BALANCE READING.

FIGURE 9

100G SINGLE-PAN BALANCE USED TO
WEIGH SMALL TO CONTAIN FLASKS.