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BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

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THE TESTING OF HYDROMETERS

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THE TESTING OF HYDROMETERS

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I. INTRODUCTION

The object of this circular is to present to manufacturers and others the information necessary to make possible the construction and verification of hydrometers on a uniform basis, to indicate the facilities now available at the Bureau of Standards for their verification, and to anticipate the adoption by the Bureau of more comprehensive specification for hydrometers.

These specifications define the requisite qualifications for hydrometers in order that they may be accepted for official verification or test, and are provisional in that they are subject to such revision as may render them better adapted to the requirements of hydrometer users or to the facilities of the makers and of the testing laboratory.

There are in present use hydrometers for many different purposes, and moreover for the same purpose there are in use various hydrometer scales, some imperfectly defined, but retained to avoid changes in established practice. In considering hydrometer scales the testing of which shall be undertaken the Bureau has largely been guided by the present practice. In the selection of the scales for definition as standards, suitability to secure uniformity and easy realization of such definitions has also been considered.

In cases where the standard scales chosen differ from those frequently used with respect to the standard temperature selected, temperature correction tables, and, where possible, conversion tables to permit intercomparisons between the standard scales and other scales, have been prepared. These tables are published in Circular No. 19.

As in the preparation of specifications for glass volumetric apparatus, the regulations[1] of the Kaiserliche Normal-Eichungs-Kommission have been freely drawn upon.

II. SPECIFICATIONS FOR HYDROMETERS

NOTE. In order to avoid confusion and misunderstanding the American Petroleum Institute, the Bureau of Mines, and the Bureau of Standards have agreed that a scale based on the modulus 141.5 shall be used in the United States petroleum industry and shall be known as the A. P. I. scale.

The formula for converting specific gravity to A. P. I. is as follows:

$$\text{Degrees A. P. I.} = \frac{141.5}{\text{Sp. gr. } 60^\circ/60^\circ \text{ F}} - 131.5$$

The United States Baumé scale based on the modulus 140 will continue to be used for other liquids lighter than water.

Two types of hydrometers are comprised in these specifications, namely, *hydrometers* proper, and hydrometers which are combined with thermometers, called *thermo-hydrometers*.

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[1] Mitteilungen Der Kaiserlichen Normal-Eichungs-Kommission. Series 2, No. 22; Mar. 9, 1907. Article 6, Regulations for Hydrometers.

1. CLASSES OF HYDROMETERS

With reference to indication the following classes of hydrometers are included:

(*a*) **Density Hydrometers,** indicating density of a specified liquid, at a specified temperature, in specified units.

(*b*) **Specific Gravity Hydrometers,** indicating the specific gravity or relative density of a specified liquid, at a specified temperature, in terms of water at a specified temperature as unity.

(*c*) **Per Cent Hydrometers,** indicating, at a specified temperature, the percentage of a substance in a mixture or solution with water (saccharometers, alcoholometers, etc.).

(*d*) **Arbitrary Scale Hydrometers,** indicating concentration or strength of a specified liquid referred to an arbitrarily defined scale at a specified temperature (Baumé hydrometers, etc.).

2. GENERAL SPECIFICATIONS

(*a*) **Standard Temperature.**—The specified temperature for use of hydrometers or the standard temperature should be 20° C, except as indicated under special requirements.

(*b*) **Material, Construction, etc.**—Hydrometers should be made of smooth, transparent glass without bubbles, striæ, or other imperfections. White-black capillary tubes should not be used in thermo-hydrometers.

The glass should be of a kind which adequately resists the action of chemical reagents and also possesses suitable thermal qualities, such as would adapt it to use for thermometers.

The section perpendicular to the axis should be everywhere circular, except as elsewhere provided. The stems should be uniform in cross section and no irregularities should be perceptible. The outer surface must be symmetrical about a vertical axis. There should be no unnecessary thickening of the glass walls, and no abrupt constrictions which would hinder convenient cleaning. The capillary stem of a thermo-hydrometer should be parallel to the axis and should extend at least 10 mm above the scale. It should contain an enlargement which will permit heating to 120° C.

Before graduation and adjustment all hydrometers should be thoroughly annealed.

Material used for ballast should be confined to the bottom of the instrument, and no loose material of any sort should be inside a hydrometer. The disposition of the weight should be such that the hydrometer will always float with its axis vertical. Shot is permitted only in hydrometers without

thermometers and should be contained in a bulb of suitable size. Bulbs containing shot may be flattened, but in all cases the shot must be confined in the bottom either by a partition or a cement which does not soften at usual temperatures.

Only mercury is permitted for ballast in thermo-hydrometers except those having one bulb, in which the final adjustment may be made by securely attaching small strips of paper or other suitable material inside the scale.

Only the best quality of paper should be used for scales and designating labels. The paper usually known as first-class ledger paper is suitable for this purpose. The scales and labels should be securely fastened in place by some material which does not soften at the highest temperature to which the instrument will be exposed in use and which does not deteriorate with time.

The scale should be straight and without twist.

The instrument should be perfectly dry on the inside when sealed. Thermometer bulbs and capillary tubes should be free from air.

The hydrometer stem should extend above the top of the scale at least 2 cm and below the scale must continue cylindrical for at least 3 mm. The thermometer scale should not extend beyond the cylindrical portion of the containing tube nor beyond the straight portion of the capillary. If within the stem, it must be above the hydrometer scale.

It is desirable that the thermometer scale should include the ice point (0° C).

The total length of any hydrometer should not exceed 45 cm and should generally be much less than this for the sake of convenience.

The top of the stem should be neatly rounded, but not unnecessarily thickened.

The graduation and inscriptions should be in permanent black ink, such as india ink. They should be clear and distinct.

The length of the smallest subdivisions of the scales should not, in general, be less than 1 mm. In certain cases the subdivisions on the hydrometer scale may be less, but never less than 0.5 mm. The smallest subdivisions should never exceed 2 mm in length.

The division lines must be perpendicular to the axis of the hydrometer; that is, horizontal when the instrument is floating.

The lengths of division and subdivision lines both on hydrometer and thermometer scales should be so chosen as to facilitate readings. Sufficient lines should be numbered to clearly indicate the reading at any point. The numbers at the ends of the scale intervals should be complete, but those intermediate may be abbreviated.

The division lines of the hydrometer scale should extend at least one-fourth around the circumference of the stem and be adjacent to or intersect a line parallel to the axis indicating the front of the scale. The division lines of the thermometer scale should extend behind and on both sides of the capillary.

To facilitate readings near the end of the hydrometer scale the graduations should be continued a few divisions beyond the ends of the principal interval.

The hydrometer scale for density indications should be divided in 0.001, 0.0005, 0.0002, or 0.0001 units of the density. For per cent or degree indications the hydrometer scale should be divided into whole, half, fifth, or tenth per cents or degrees (never to fourths).

The thermometer scale should be divided into whole or half degrees.

No hydrometer should have more than one hydrometer scale or more than one thermometer scale, and no secondary or auxiliary graduations should be on either.

(*c*) **Inscriptions.**—The hydrometer scale or a suitable special label should bear an inscription which indicates unequivocally the purpose of the instrument. This inscription should denote the liquid for which the instrument is intended, the temperature at which it is to be used, and the character of the indication, including definition of any arbitrary scale employed.

The maker's name or trade-mark, date of manufacture, and an identification number should be inscribed upon the hydrometer scale or label.

The designation of standard temperature and reference temperature may be abbreviated, as, for example, Sp. Gr. $\frac{15^\circ}{15^\circ}$C, meaning that the hydrometer indicates at 15° C the specific gravity of the liquid referred to water at 15° C as unity.

(*d*) **Tolerances.**—The greatest error of the hydrometer scale should not exceed the following:

Smallest subdivision of hydrometer scale	Limit of error
Whole or half per cents or degrees	One-half smallest division
Fifth or tenth per cents or degrees or any density subdivision	One smallest division

The greatest error of thermometer scales in thermohydrometers should not exceed the following:

Smallest division of thermometer scale	Limit of error
1°.0 C	0°.4 C
0°.5 C	0°.25 C

There should be no apparent irregularities in either the hydrometer scale or the thermometer scale.

3. SPECIAL REQUIREMENTS

The tables chosen for use as basis for standardization of hydrometers by this Bureau are contained in Bureau Circular No. 19 (6th ed.), and are referred to below by numbers used in that circular.

(*a*) **Alcoholometers.**—Alcoholometers may be graduated to indicate the percentage of ethyl alcohol, either by weight or by volume, in mixtures of ethyl alcohol and water, or they may be graduated to indicate percentages of "proof spirit" as defined by the Bureau of Internal Revenue, United States Treasury Department.

The basis for the graduation of hydrometers to indicate percentage of alcohol by weight at 20° C should be Table 2, Circular No. 19.

The basis for the graduation of hydrometers to indicate percentage of alcohol by volume at 60° F or percentage of proof spirit at 60° F should be Table 3, Circular No. 19.

Master scales for the graduation of hydrometers to indicate percentage of alcohol by weight and by volume and percentage of proof spirit are given in Tables 50 and 51, Circular No. 19.

Upon alcoholometers subdivided into fifths or tenths of per cent the length of the smallest scale intervals may be as small as 0.8 mm.

(*b*) **Saccharometers.**—Saccharometers should be graduated to indicate percentage of sugar according to weight.[2]

The basis for graduation of saccharometers, standard at 20° C, should be density at 20° C, Table 12, Circular No. 19.

Brix saccharometers should be graduated to indicate the percentage of sugar by weight at 17°.5 C and Balling saccharometers the percentage of sugar by weight at 60° F.

The smallest scale interval of saccharometers may be the same as for alcoholometers.

[2] The Bureau does not certify saccharometers on the basis of the original "Brix" and "Balling" scales; both of the terms, "Brix" and "Balling," are interpreted as meaning the percentage, by weight, of pure sucrose. The relation between percentage of sugar and density, or specific gravity, adopted by the Bureau, is that determined by Dr. F. Plato. (Wiss. Abh. der Kaiserlichen Normal-Eichungs-Kommission, 2, p. 153; 1900.)

(*c*) **Hydrometers for Sulphuric Acid.**—The basis for the graduation of hydrometers indicating per cent of sulphuric acid by weight in mixtures of acid with water should be density at 20° C, Table 13, Circular No. 19.

(*d*) **Baumé Hydrometers.**—The basis for hydrometers indicating degrees Baumé of liquids lighter than water should be the relation to specific gravity at $\frac{60°}{60°}$ F $\left(\frac{15°56}{15°56}\text{ C}\right)$ given by the formula:

$$\text{Degrees Baumé} = \frac{140}{\text{Sp. Gr.}\ \frac{60}{60}\text{F}} - 130 \quad \text{Table 21, Circular No. 19.}$$

For hydrometers indicating degrees Baumé of liquids heavier than water, the basis should be the relation to specific gravity at $\frac{60°}{60°}$ F $\left(\frac{15°56}{15°56}\text{ C}\right)$ given by the formula:

$$\text{Degrees Baumé} = 145 - \frac{145}{\text{Sp. Gr.}\ \frac{60}{60}\text{F}} \quad \text{Table 19, Circular No. 19.}$$

The liquids for standardization of Baumé hydrometers should be in general mineral oils for light liquids, and mixtures of sulphuric acid and water for heavier liquids.

(*e*) **Density and Specific Gravity Hydrometers.**—Hydrometers indicating density and specific gravity should be graduated to indicate at a standard temperature the density, in grams per milliliter or the specific gravity in terms of water, at a specified temperature of one only of the following liquids within the given range:

Liquids	Range	Liquids	Range
Mineral oil	0.62–1.00	Caustic soda	1.00–1.55
Sulphuric acid	1.00–1.85	Common salt	1.00–1.23
Nitric acid	1.00–1.55	Ammonia	0.85–1.00
Hydrochloric acid	1.00–1.25		

(*f*) **Thermohydrometers.**—Hydrometers containing thermometers should not contain temperature "correction tables," as such tables can, in general, be correct for only a very limited portion of the hydrometer scale. Accurate correction tables for the more common liquids (sugar, sulphuric acid, ethyl alcohol, and mineral oils) are given in Circulars 19 and 57.

III. MANIPULATION OF HYDROMETERS

Hydrometers are seldom used for the greatest accuracy, as the usual conditions under which they are used preclude such special manipulation and exact observation as are necessary to obtain high precision. It is, nevertheless, important that they be accurately graduated to avoid, as far as possible, the use of instrumental corrections, and to obtain this result it

is necessary to employ certain precautions and methods in standardizing these instruments.

The methods of manipulation described below are, in general, the ones employed at this Bureau in testing hydrometers and should be followed by the maker or user to a degree depending on the accuracy required.

1. OBSERVING

The hydrometer should be clean, dry, and at the temperature of the liquid before immersing to make a reading.

The liquid in which the observation is made should be contained in a clear, smooth glass vessel of suitable size and shape.

By means of the stirrer which reaches to the bottom of the vessel, the liquid should be thoroughly mixed.

The hydrometer is slowly immersed in the liquid slightly beyond the point where it floats naturally and then allowed to float freely.

The scale reading should not be made until the liquid and hydrometer are free from air bubbles and at rest.

In reading the hydrometer scale the eye is placed slightly below the plane of the surface of the test liquid; it is raised slowly until the surface, seen as an ellipse, becomes a straight line. The point where this line cuts the hydrometer scale should be taken as the reading of the hydrometer.

In reading the thermometer scale, errors of parallax are avoided by so placing the eye that near the end of the mercury column the portions on either side of the stem and that seen through the capillary appear to lie in a straight line. The line of sight is then normal to the stem.

2. INFLUENCE OF TEMPERATURE

In order that a hydrometer may correctly indicate the density or strength of a specified liquid, it is essential that the liquid be uniform throughout and at the standard temperature.

To insure uniformity in the liquid, stirring is required shortly before making the observation. This stirring should be complete and may be well accomplished by a perforated disk or spiral at the end of a rod long enough to reach the bottom of the vessel. Motion of this stirrer from top to bottom serves to disperse layers of the liquid of different density.

The liquid should be at nearly the temperature of the surrounding atmosphere, as otherwise its temperature will be changing during the observation, causing not only differences in density but also doubt as to the actual temperature. When the temperature at which the hydrometer

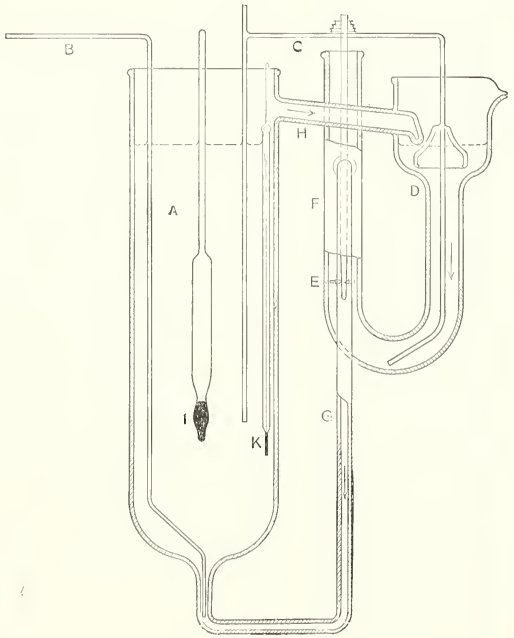

Fig. 1.—*Section of hydrometer comparator*

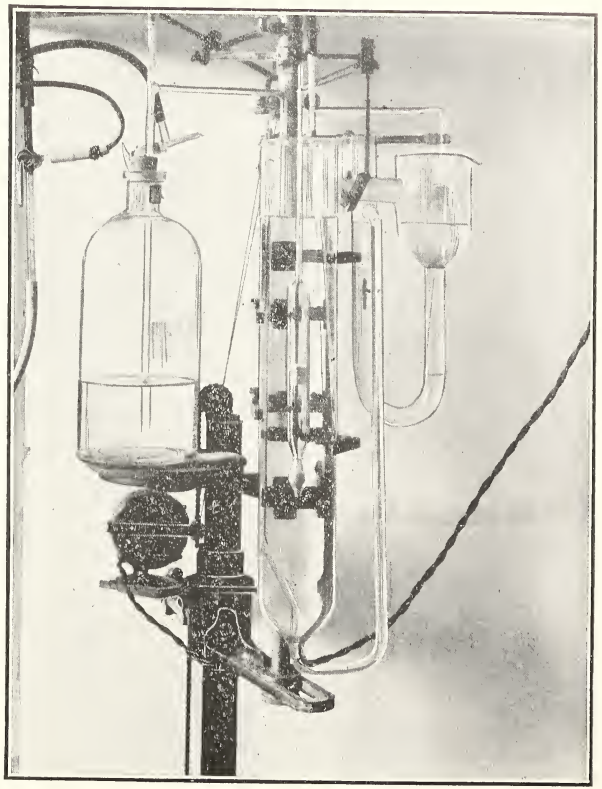

Fig. 2.—*Hydrometer comparator*

A is the cylinder containing the test liquid. B is a glass tube for filling and emptying A. C is a siphon for removing the liquid from D into A. E is a propeller which stirs the liquid and raises it in the tube F making it flow through G into A and through the cross tube H into D. I is a hydrometer. K is a thermometer.

is observed differs from the standard temperature of the instrument, the reading is not truly the density according to the basis of the instrument or the quality of the liquid according to per cent or arbitrary scale, but a figure which differs from the normal reading by an amount depending on the difference in temperature and on the relative thermal expansions of the instrument and the particular liquid.

If the latter properties are known, tables of corrections for temperature may be prepared for use with hydrometers at various temperatures. Such tables should be used with caution, and only for approximate results when the temperature differs much from the standard temperature or from the temperature of the surrounding air.

3. INFLUENCE OF SURFACE TENSION

Surface tension effects on hydrometer observations are a consequence of the downward force exerted on the stem by the curved surface or meniscus, which rises about the stem, and affects the depth of immersion and consequent scale reading.

Because a hydrometer will indicate differently in two liquids having the same density but different surface tensions, and since surface tension is a specific property of liquids, it is necessary to specify the liquid for which a hydrometer is intended.

Although hydrometers of equivalent dimensions may be compared, without error, in a liquid differing in surface tension from the specified liquid, comparisons of dissimilar instruments in such a liquid must be corrected for the effect of the surface tension.

In many liquids spontaneous changes in surface tension occur due to the formation of surface films of impurities, which may come from the apparatus, the liquid, or the air.

Errors from this cause are avoided either by the use of liquids not subject to such changes, which, however, require correction of the results by calculation, or by the purification of the surface by overflowing immediately before making the observation. This latter method is employed at this Bureau for testing hydrometers in sulphuric-acid solutions and alcohol solutions, and is accomplished by causing the liquid to overflow from the part of the apparatus in which the hydrometer is immersed by a small rapidly rotating propeller which serves also to stir the liquid. The apparatus is shown in Figs. 1 and 2.

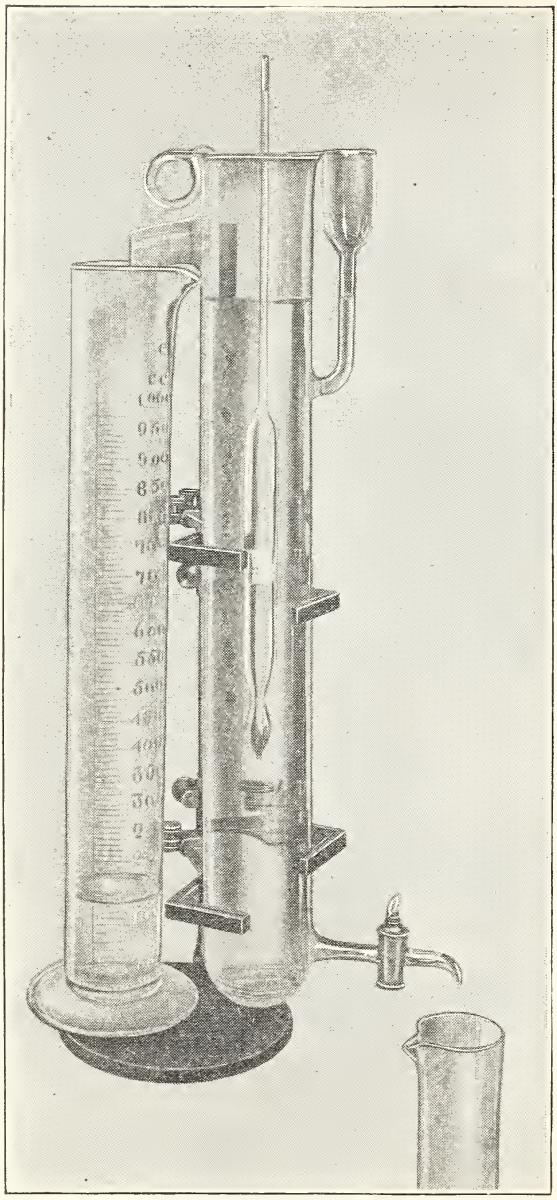

Fig. 3.—*Special hydrometer cylinder in use*

A more simple apparatus for hydrometer use, designed to permit renewal of the surface by overflowing, is shown in Fig. 3.

The manipulation is as follows: The cylinder is filled nearly to the spout by the liquid whose density is desired or in which hydrometers are to be compared. The hydrometer is then immersed in the liquid and permitted to float freely until it has assumed the temperature of the liquid. The hydrometer is raised to permit thorough stirring of the liquid. The temperature is observed if desired. From a beaker of the same liquid enough is poured into the funnel to cause the liquid to overflow and run out the spout, where it is caught in a convenient vessel.

The hydrometer is then read. The completeness of the cleansing of the surface of the liquid may be tested by repeating the operation, as the readings will approach a constant value as the surface becomes normal.

The necessity for such special manipulation is confined to the reading of hydrometers in liquids which are subject to surface contamination. Such, in general, are aqueous solutions or mixtures of

acids, alkalies, salts, sugar, and weak alcoholic mixtures. Oils, alcoholic mixtures of strength above 40 per cent by volume, and other liquids of relatively low surface tension are not, in general, liable to surface contamination sufficient to cause appreciable changes in hydrometer readings.

4. CLEANLINESS

The accuracy of hydrometer observations depends, in many cases, upon the cleanliness of the instruments and of the liquids in which the observations are made.

In order that readings shall be uniform and reproducible, the surface of the hydrometers, and especially of the stem, must be clean, so that the liquid will rise uniformly and merge into an imperceptible film on the stem.

The readiness with which this condition is fulfilled depends somewhat upon the character of the liquid, certain liquids, such as mineral oils and strong alcoholic mixtures, adhere to the stem very readily, while with weak aqueous solutions of sugar, salts, acids, and alcohol, scrupulous cleaning of the stem is required in order to secure the normal condition.

Before being tested, hydrometers are thoroughly washed in soap and water, rinsed, and dried by wiping with a clean linen cloth.

If to be used in aqueous solutions which do not adhere readily, the stems are dipped into strong alcohol and immediately wiped dry with a soft, clean, linen cloth.

IV. TESTS PERFORMED BY THE BUREAU

1. INSTRUMENTS ADMITTED FOR TEST

At present the Bureau is prepared to test hydrometers and thermo-hydrometers of the kinds indicated below, which conform to the specifications of this circular:

Alcoholometers.

Saccharometers.

Baumé hydrometers for mineral oils or for sulphuric acid.

Hydrometers indicating density or specific gravity of mineral oils or of sulphuric acid.

Hydrometers indicating per cent of sulphuric acid.

Instruments in addition to the above are later to be included in those regularly admitted for test, but until further notice instruments other than the above should not be submitted for test without previous arrangement being made.

2. CHARACTER OF TEST

Three kinds of tests are made: (*a*) Regular test for precision stamp without certificate, (*b*) certification of corrections with precision stamp, and (*c*) special certification of corrections without precision stamp.

(*a*) **The Regular Test** (viz, preliminary examination, verification of the hydrometer scale, and of the thermometer scale when this is included) determines whether the instrument is qualified to receive the precision stamp indicating an approved degree of accuracy. This test (usually performed in the order given above) is continued far enough to indicate with reasonable certainty whether the instrument complies with the specifications. Upon instruments which pass this test the precision stamp, described below, is etched. Hydrometers submitted with request simply to "*test*," or with instructions not otherwise sufficiently explicit, are tested in this manner. A fee is charged as given under schedule 28, (*a*) or (*b*), depending upon whether one or both scales are actually tested.

If the result of examination and test of any hydrometer or thermohydrometer indicates a satisfactory conformity to the specifications, the **official precision stamp,** consisting of the letters "U. S." and the year date, is etched as shown below:

(*b*) **Regular Certification** of corrections with precision stamp. A hydrometer qualified to receive the precision stamp as described above, if request is made when test is submitted, will be assigned a *certification number* in addition to the precision stamp, and a certificate of corrections will be furnished. If certificate is desired *only* in case the instrument receives the precision stamp, the request for test should instruct to "*certify and stamp.*" Three points will be certified unless more are requested. A fee is charged as given in schedule 28.

(*c*) **Special Certification** of corrections without precision stamp. A hydrometer not qualified to receive the precision stamp because of nonconformity with the specifications either as to construction or errors tolerated will, if found suited to the testing facilities of this Bureau and adapted to the intended purpose, be tested as a special instrument and given a certification number and certificate as described under (*a*). If certificate is desired regardless of whether the instrument receives the precision stamp the request for test should instruct to "*certify specially.*" If not thus specifically

requested, hydrometers will be certified only if they comply with the specifications, but hydrometers submitted for special certification, if found qualified, will always receive the precision stamp. Special tests are made only at the discretion of the Bureau. A fee is charged according to schedule 28.

Upon instruments for which corrections are certified a certification number is etched as shown below:

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3. CONTROL MARKS

In addition to the *certification number* on certified hydrometers and other hydrometers tested and stamped, the weight in milligrams of the instrument against brass weights in air at 760 mm pressure and 20° C will be stamped if the sender so requests.

V. DIRECTIONS FOR SUBMITTING APPARATUS FOR TEST

Application for Test.—The request for test should be made in writing and should include a complete list of the apparatus and a statement of the nature of the test desired as explained under IV, 2.

The sender should always examine apparatus carefully before submitting it for test, to ascertain if it complies with specifications, thus avoiding the loss of transportation on apparatus not qualified for the test desired.

Purchasers of apparatus to be submitted to the Bureau for test should give the dealer advance notice in order to avoid unnecessary delays and misunderstandings.

Identification Marks.—Instruments and the packages in which they are shipped should both be plainly marked to facilitate identification, preferably with the name of the manufacturer or shipper, and a special reference number should be given to each article, which should be referred to in the correspondence concerning the test. After receipt at the Bureau the B. S. test number should also be used.

Shipping Directions.—Instruments should be securely packed in cases or packages, which may be used in returning them to the owner. In all cases transportation charges are payable by the party desiring the test and should be prepaid. Apparatus must be accompanied by an itemized shipping invoice.

Breakage.—No risk of breakage will be assumed by the Bureau. All possible care will be taken in handling the apparatus submitted for test,

but a certain amount of breakage is unavoidable and must be borne by the owner.

Address.—Articles should be addressed, "Bureau of Standards, Washington, D. C."; delays incident to other forms of addresses will thus be avoided. Articles delivered in person or by messenger should be left at the shipping office of the Bureau, and should be accompanied by a written request for the verification.

Remittances.—Fees should be remitted by money order drawn to the order of the "Bureau of Standards," and should be sent with the request for test whenever practicable. Delays in forwarding fees involve corresponding delays in the return of articles tested, as the articles are held until the fees due thereon have been paid.

All communications should be addressed, "Bureau of Standards, Washington, D. C."

VI. FEES FOR TESTING HYDROMETERS

SCHEDULE 28.—HYDROMETERS AND THERMO-HYDROMETERS

(*a*)	Test of hydrometer to determine whether it complies with Bureau requirements for precision stamp	$1.00
(*b*)	Test of thermo-hydrometer, as under (*a*), including test of thermometer scale	1.75
(*c*)	Certificate of corrections at three points on either or both scales, additional fee	.50
(*d*)	For additional points certified, each extra point	.25
(*e*)	For determination of weight of instrument, additional fee	.25
(*f*)	For supplying missing identificaiion numbers, charges for each number	.20
(*g*)	For special tests not enumerated above, reasonable fees will be charged depending upon the nature of the test.	

S. W. Stratton,
Director.

Approved:
Herbert Hoover,
Secretary of Commerce.