

ISA RP2.1-1985

Recommended Practice

Manometer Tables

Instrument Society of America



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FOREWORD

This Recommended Practice has been prepared as a part of the service of the Instrument Society of America toward a goal of uniformity in the field of instrumentation. To be of real value this report should not be static, but should be subjected to periodic review. Toward this end the Society welcomes all comments and criticisms, and asks that they be addressed to the Standards and Practices Board Secretary, Instrument Society of America, 67 Alexander Drive, P.O. Box 12277, Research Triangle Park, North Carolina 27709.

This report was prepared and revised by the 8D-RP2 Committee of the Production Processes Standards Division on Manometer Tables, chaired by W. G. Brombacher, Consultant, National Bureau of Standards, Washington, D.C.

The assistance of those who aided in the preparation of this Recommended Practice by answering questionnaires, offering suggestions, and in other ways is gratefully acknowledged.

The following reviewed the original practice and served as a Board of Review:

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This Recommended Practice was approved for publication by the Recommended Practices Committee on September 6, 1952, and approved for revision by the Standards & Practices Board in 1962.

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This Revision, under the direction of W. G. Brombacher, 8D-RP2 Committee Chairman, has been prepared to include changes by the National Bureau of Standards since the date of last publication (1952).

ISBN 0-87664-325-X

ISA-RP2.1 Manometer Tables

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INSTRUMENT SOCIETY OF AMERICA
67 Alexander Drive
P.O. Box 12277
Research Triangle Park, NC 27709

SCOPE

1.1 This report presents abbreviations and fundamental conversion factors commonly used in manometry, recommended definitions of pressure in terms of a column of mercury and water, and for a large number of liquids, tables of pressures indicated by, or equivalent to, heights of columns at various temperatures. These data have the object of facilitating and standardizing the use of manometers and U-tubes as direct pressure indicating instruments or in the calibration of pressure recorders and controllers.

1.2 A discussion is included of the more frequent or more important sources of error in manometric measurements, together with correction tables for mercury and water columns. To conform to general practice in this country, English units of measurements are largely used (i.e., pounds, inches, etc.) and with several exceptions, decimals are used to denote parts of units, rather than octonary fractions.

1.3 In particular, it will be seen that conversion factors for kerosine, gage oil, alcohol, dibromobenzene, dibromoethane, and acetylene tetrabromide are given only to obtain equivalent water columns at 60 F. Further, no conversion data are presented for benzol, butyl collosolve, carbitol, nbutyl phthalate, or halowax oil. The filling in of these omissions will have to await demonstrated need.

MANOMETER TABLES

DISCUSSION OF STANDARDS OF MANOMETERS

For a more complete discussion on mercury manometers, see "Mercury barometers and manometers," Nat. Bur. of Standards Monograph No. 8, 1960.

Standards. The pressure in terms of height of a column of liquid is given by the fundamental relation

$$P = Dhg \quad (1)$$

where P is the pressure in absolute units, as dynes/sq cm or pounds/sq in.

D is the density of the liquid in grams/cu cm or lb/cu in.

h is the height of the column from horizontal surface to horizontal surface of the menisci in cm or in.

g is the acceleration of gravity in cm/sec² or in./sec²

P/g is the pressure in grams/sq cm or psi

If the height of the column of a liquid is used as a unit of pressure,

$$h = \frac{P}{Dg} \quad (2)$$

from which it is evident that some value of the density of the liquid and of gravity must be selected as standard for greater convenience, preferably the same by everyone. The standard density will be considered only for water and mercury, and is more conveniently set in terms of the temperature of the liquid, rather than in terms of density.

At its meeting of September 7, 1947, the Recommended Practices Committee approved as a recommended practice the following standards:

- (a) Standard conditions for a mercury column used as unit of pressure:

Gravity: $980.665 \text{ cm/sec}^2 = 32.1740 \text{ ft/sec}^2$

Temperature: 0°C (32°F)

760 mm of mercury (=29.9213 in. of mercury)

= a pressure of one atmosphere

- (b) Standard conditions for a water column used as a unit of pressure:

Gravity: $980.655 \text{ cm/sec}^2 = 32.1740 \text{ ft/sec}^2$

Temperature: 20°C (68°F)

407.513 in. of water (= 1035.08 cm of water)

= a pressure of one atmosphere

The value of standard gravity given above is an international standard accepted in engineering and physics and therefore is applicable for all columns of all liquids in addition to water and mercury if used as a pressure unit. It should be noted that meteorologists in 1953 adopted internationally this value, previously having used the value 980.62 cm/sec^2 .

The pressure of one atmosphere internationally defined for fixed points on the International Temperature scale is 1013.250 millibars. This value has been rather universally accepted. This pressure is equivalent to that exerted by a column of mercury 760 mm high, having a density of $13.5951 \text{ grams/cm}^3$ and subjected to a gravitational acceleration of 980.665 cm/sec^2 . A mm or cm or inch of mercury of differential or absolute pressure is defined as a submultiple of the atmosphere above defined. However, at high pressures correction for compressibility may have to be applied.

For convenience, mercury manometers are often calibrated to indicate the height of the mercury column in terms of mercury at 0°C when the manometer is at another temperature.

The definition of a unit height of a water column at 20°C as a unit of pressure is a recommended practice, made in an effort to eventually obtain national standardization. It is obviously worth while to standardize on a single pressure unit, but it is realized that changes from other units now used may cause serious inconvenience. Use of the proposed unit is advocated in fields where no standard has been defined. Three manometer temperatures, 15°C (59°F), 60°F (15.56°C), and 20°C (68°F), are now used on a national scale to

define the unit of pressure as the height of a water column. In aeronautics, 15°C is used; The American Gas Association, and perhaps other societies, uses 60°F; and in orifice flowmeter work, 20°C is commonly used. The temperature used to define the pressure does not affect other conditions desired as standard, as for example, volume of gas flow measured in terms of the gas at 60°F and 29.92 inches of mercury. Some have suggested the maximum density of water (3.98°C) as the unit. This temperature is far from normal laboratory temperatures and will require the application of temperature corrections in many cases where none would be necessary with 20°C as the standard. The proposal is attractive, however.

It is intended that the definition apply to distilled water, free from absorbed gases. It is easier to eliminate absorbed gases than to determine the amount present. In mercury, absorbed gases give no trouble. Lack of purity fouls the mercury meniscus long before there is a significant change in density.

No action on standards for liquids other than water and mercury was taken, since these other liquids are not often used as standards of pressure.

ERRORS OF LIQUID COLUMN MANOMETERS

3.1 The errors in the indications of manometers are (a) scale errors, (b) temperature errors, (c) gravity errors, (d) capillary errors, (e) compressibility, and (f) effect of absorbed gases. Of these, corrections are ordinarily applied only for the scale, temperature, and gravity errors. The other errors are corrected for only precise work or under special conditions of use.

3.2 Scale Errors. After a manometer reading has been corrected for temperature and gravity error, and for such of the other errors as are warranted, there usually remains a residual error which may be called the scale error. This can be determined only by calibration against a standard instrument. If corrections are made only for the temperature and gravity errors, the scale error will include (a) errors in graduating the scale, and (b) the effect of capillarity, and perhaps of compressibility and of absorbed gases. Under (a) will be included to a high degree of accuracy the error introduced when the scale is graduated true at one temperature and is assumed correct at another temperature. Further, when the effects under (b) are included under the scale error, only the variation in these effects need to be accounted for.

In general, the procedure of calibrating manometers is such that correction for scale error should be applied first in applying corrections to a manometer reading.

3.3 Temperature Errors. Since the densities of liquids vary with temperature, any deviation in manometer temperature from that selected as standard for the pressure unit will introduce an error in the manometer indication. Further, since the scale expands or contracts with changes in its temperature, an additional error is introduced. An expansion of the scale reduces

the reading of the manometer held at constant pressure and conversely an expansion of the liquid increases the reading; the two expansions tend to balance one another, but the effect of the expansion of the liquid is usually much larger.

Temperature corrections are given by the following relations:

$$H_o = H_t + C \quad (3)$$

$$C = \frac{s(t-t_o)-m(t-t_o)}{1+m(t-t_o)} H_t \quad (4)$$

where H_o is the height of the liquid column at the standard temperature

H_t is the indicated height of the liquid column at temperature t , corrected for scale errors

C is the temperature correction

s is the coefficient of linear expansion of the scale

m is the coefficient of cubical expansion of the liquid

t is the manometer temperature

t_o is the temperature at which the scale indicates the true height

t_o is the standard temperature at which the height of the liquid column is in terms of a pressure unit.

When the correction is negative in sign, the correction is subtracted from H_t as indicated by equation (3).

The coefficient of expansion is usually available with reference to 0°C or 32°F, but no significant error is ordinarily introduced by using this value if t_o differs from 0°C. If warranted, the proper value of s can be computed.

Both the cubical and linear thermal expansions of most manometer liquids and scales are hyperbolic in character and therefore in general cannot be accurately represented by the single terms s and m used in equation (4). For the small temperature ranges over which manometers are generally used, the errors introduced are not usually significant. Consideration of this point is essential in very precise measurements.

Exceptions to the above are mercury, for which m requires no modification over the temperature range of interest, and water, for which m varies with temperature considerably and significantly for most measurements at all temperatures ordinarily of interest. Therefore, for water, equation (4) does not apply, and corrections must be applied in two parts, first for the temperature error for the scale $\{s(t-t_o)\}$ and then for the error for the liquid by a multiplier obtained from Table 12.

If t_o be substituted in equation (4) for the temperature t_o at which the scale is calibrated true and the resulting error be incorporated into the scale correction, considerable simplification in constructing tables is obtained. The error thus introduced is usually not significant. On this basis, equation (4) becomes

$$C = \frac{s(t-t_o)-m(t-t_o)}{1+m(t-t_o)} H_t = C_o H_t \quad (5)$$

For cistern manometers where the level of the liquid in the cistern shifts with change in the pressure while the scale remains fixed, equations (4) or (5) do not apply. Usually the temperature correction can be put in the form

$$C_1 = (H_t + h)C_o \quad (6)$$

where C_1 is the temperature correction, C_o is defined by equation (5), and h is an addition to the indicated column height H_t which in general must be determined by calibration tests at various temperatures of a manometer of any given design.

3.4 Gravity Errors. The effect of variation of gravity from the standard value on manometer indications is as follows:

$$P = \frac{g}{g_s} H_o \quad (7)$$

$$\text{or } P = H_o + H_o \frac{(g - g_s)}{g_s} = H_o + C \quad (8)$$

where P is the height of the liquid column subjected to standard gravity. This is the pressure if, as is common practice, no further corrections are applied.

H_o is the indicated height of the liquid column at the standard temperature

C is the correction to be applied to H_o

g is the ambient value of gravity

g_s is the standard value of gravity,
980.665 cm/sec²

The ambient value of gravity at any location can be obtained as a function of latitude from the Smithsonian Meteorological (or Physical) Tables and more accurate values for many locations from the U. S. Coast & Geodetic Survey, (Washington 25, D. C.).

In some cases the value of gravity must be obtained from the accepted relation for gravity as a function of latitude. This relation holds only for sea level. To obtain the value of gravity at a station h feet above sea level:

$$g = g_o - 0.000094h \quad (9)$$

where g is the value of gravity at the station, g_o is the value of gravity at sea level, both in cm/sec², and h is the altitude in feet. Equation (9) holds only for free air, but is sufficiently accurate for moderate elevations of terrain above sea level.

3.5 Capillary Errors. If a liquid wets the walls of the manometer tube or cistern, the center of the liquid column is elevated above the level which would obtain if the surface were infinite in extent. Conversely if the liquid does not wet the surface, of which mercury is a conspicuous example, the column level is depressed. The amount of the depression tends to vary with the direction of the change in pressure and greatly with local differences in the condition of the surface in contact with the liquid.

Correction for the capillary effect, if made at all, is normally made only for the depression of the mercury

in the tube. Part of the table given by Gould and Vickers in the Journal Scientific Instruments 29, 85, 1952, is reproduced, based on a surface tension of mercury of 450 dynes per centimeter.

DEPRESSION OF MERCURY COLUMN IN MM

Bore of tube, mm	Height of meniscus in mm				
	0.6	0.8	1.0	1.5	2.0
6	0.73	0.94	1.12	1.43	—
8	0.37	0.48	0.58	0.78	0.89
10	0.20	0.26	0.32	0.44	0.52
12	0.12	0.15	0.19	0.26	0.31
15	0.05	0.07	0.09	0.12	0.15
20	0.015	0.02	0.024	0.034	0.042

To reduce the variable effects of surface tension, certain practices may be recommended, assuming that the scale correction includes the capillary effect.

- In the design of the manometer, large bore tubes greatly reduce the change in capillary depression (or elevation) with meniscus height. For mercury manometers the minimum bore should be about 10 mm (0.4 in.); there is little overall advantage in bores exceeding 15 to 20 mm (0.6 to 0.8 in.). The above recommended minimum and maximum bores apply equally well to water manometers and probably also to those with other liquids. Equal size of bore is obviously indicated for U-tube manometers.
- Cistern manometers should also have the recommended tube bores. The capillary effect in the cistern is minimized by making the area of the cistern large. In mercury manometers of this type especially, it is necessary to tap or vibrate the cistern vigorously in order to reduce scatter in the readings at a constant pressure. It also helps to vibrate the tube, but not to the same degree.
- The gradual accumulation of corrosion products and dirt at mercury surfaces changes the capillary correction. This change is larger in its effect on the reading the smaller the bore of the tube or of the cistern. Corrosion seems easier to prevent with other liquids.
- After a pressure change, drainage of liquids which wet the surface of tubes is a source of error, particularly in manometers in which the measured pressure depends upon the indication of one surface level only, as in the case of most cistern manometers. In effect a time lag in reading occurs while drainage takes place. The effect reduces with increase in the bore of the manometer tubes.
- The addition of a few drops of a wetting agent, such as Aerosol OT100, or Dreen, to the water helps greatly in obtaining a symmetrical meniscus in water manometers. This decreases the difficulty in making readings and also eliminates in large measure the effect of films of foreign material on the glass.

3.6 Compressibility Effects. The absolute pressure acting on a liquid compresses it and thereby changes its density. It is of importance for manometers only in the cases where the difference between two high pressures is measured.

The compressibility coefficient C , or change in volume per-unit pressure, is defined as follows:

$$C = \frac{1}{V_0} \frac{dV}{dP} \quad (10)$$

where V_0 is the volume at pressure P or more practically is the volume at the lowest pressure
 dV/dP is the rate of change of volume with pressure normally negative since the volume usually decreases with the application of pressure

A few values of the coefficient are given in the table for water, mercury, and ethyl alcohol. The pressures are absolute values. The values for water were obtained from "Properties of Ordinary Water Substance" by E. N. Dörsey; those on mercury from the "Smithsonian Physical Tables"; and those on ethyl alcohol from the "Handbook of Chemistry and Physics."

COMPRESSIBILITY OF LIQUIDS

Liquid	Temp. deg C	*Coefficient	Pressure Range, Atmospheres
Water	10	48.0	1-25
	20	47.2	1-25
	10	49.2	25-50
	20	47.6	25-50
	10	46.0	100-200
	20	44.2	100-200
	50	42.8	100-200
	20	37.4	500-1000
	20	32.6	1000-1500
	20	29.2	1500-2000
	20	25.9	2000-2500
	20	23.6	2500-3000
Mercury	20	3.95	300
	22	3.97	500
	22	3.91	1000
Ethyl Alcohol	20	112	1-50
	28	86	150-200
	28	81	150-400

Petroleum oils with a specific gravity 60/60°F between 0.80 and 0.90 have a compressibility coefficient of approximately 70×10^{-5} at 20°C (68°F) for a gage pressure change from 0 to 50 atmospheres. Reference: R. S. Jessup, BS Jnl. of Research, Vol. 5, 1930, p985; RP 244. Most organic liquids have compressibilities of the same order as that of oil.

As a consequence of compressibility it requires 4×10^{-6} more pressure to obtain a change in indication of one mm of mercury at an absolute pressure of 760 mm than it does at one mm of mercury. This difference is 12 times as great for water and 38 times as

great for ethyl alcohol. Thus the unit of pressure defined in terms of a liquid column is also a function of pressure, but the effect in manometers as ordinarily used to measure low gage pressures is less than 0.001 per cent.

3.7 Effect of Absorbed Gases. Air absorbed in water decreases the density, contrary to what might be expected. At 100°C the decrease of water density presumably fully saturated with air is 1.6, and at 20°C, 0.4 parts per million. The weight of absorbed air is 27 at 10°C and 22 parts per million at 20°C. The effect is quite variable and requires consideration for each gas in contact with a particular liquid.

The "Handbook of Chemistry and Physics" and the "International Critical Tables" contain data on the solubility of many gases in a number of liquids. These references, however, contain relatively little information on the effect of solubility on the density of those liquids that are used in manometers.

Mercury is an exception in that small amounts of gases go into solution. No data were found, but no sensible outgassing is evident when mercury is subject to a sudden decrease in pressure, as is the case with most other manometric liquids.

Since there is considerable time lag in both outgassing and in the dissolving of gases in liquids, considerable uncertainty usually exists as to the precise amount of gas in solution. For this reason, densities used in computing pressures should be for gas-free liquids if available, and when necessary, corrections made for the change in density due to the gas in solution. The correction is rarely made except in precise work or under unusual conditions of measurement

BASIS, DESCRIPTION AND USE OF TABLES

4.1 Table 1. Abbreviations. Abbreviations used are those proposed by the American Standards Association (Z10.1-1941).

4.2 Table 2. Fundamental Constants and Common Factors. As indicated in the table the values are largely taken from "Units of Weight and Measure," NBS M233, although the number of digits in the values is far in excess of that needed in manometry. The conversion factors are primarily from metric to English units and vice versa.

4.3)

4.4) - Tables 3, 4, and 5. No comment is required.

4.5)

4.6 Table 6. Density of Mercury. The values of the density of mercury given here are based on the mean value of the thermal coefficient of volume expansion. Accurate (not mean) values of the coefficient of cubical thermal expansion of mercury are given by Beattie, Blaisdell, Kaye, Gerry and Johnson, Proc. Am. Acad. Arts and Sciences, 74, 370, 1941. The two values of the density do not differ more than one part in 100000. At 0°C, the density is generally considered accurate to one part in 100,000 for virgin natural mercury. There is no great difficulty in purifying mercury to the

degree necessary to realize the densities given; even minute impurities of the base metals make the mercury unusable in a manometer.

The density at 0°C is the standard used at present in defining pressure in terms of the height of a mercury column.

4.7 Table 7. Density of Water. The values given here differ slightly from those given by various experimenters. The data for temperatures above 40°C (104°F) are less reliable than those for lower temperatures, which is indicated by dropping one digit from the values. As pointed out under "Discussion of Standards and Errors of Manometers", the density is affected somewhat by the content of absorbed air. Also, the dissolved salts will affect the density, which effect is avoided by the use of distilled water.

The unit height of a water column at either 15°C, 60°F, or 68°F is used in various fields of engineering to define a pressure. The ISA has adopted as a recommended practice 68°F (20°C) as the definition.

4.8 Tables 8A and 8B. Gravity Corrections at Sea Level at Various Latitudes or at Various Values of Gravity. In Table 8A are given the gravity corrections at sea level for a column of any liquid in any unit of height, mm, cm, in., or ft, against latitude. The values of gravity corresponding to latitude are from the formulas and tables given in the Smithsonian Meteorological Tables, 1958 edition.

Table 8B presents the gravity corrections, again for any liquid or in any unit of height, against evenly divided values of gravity. This table is convenient to use if the value of gravity for the station is known. It is preferable to base corrections on the actual value of gravity of the station, if available. The U. S. Coast and Geodetic Survey, (Washington, D. C.) has determined and can furnish values of gravity for hundreds of locations in the United States.

When Table 8A is used, an additional correction is required for the elevation of the station above sea level. The altitude correction to be applied to the value of gravity, which is strictly speaking only for free air and applies only approximately to large elevations found in mountainous areas, is as follows:

$$\text{Correction (cm/sec}^2\text{)} = -94 \times 10^{-6}h$$

where h is the elevation in feet of the manometer above sea level.

As an example of the use of the tables, assume a liquid column height of 72 inches (after application of scale correction, before or after application of the temperature correction) at latitude 38 degrees and elevation above sea level of 150 feet.

From Table 8A the value of gravity at sea level at 38 degrees latitude is 979.997 cm/sec².

The altitude correction is $-94 \times 150 \times 10^{-6}$ or -0.014 .

The value of gravity is 979.983 cm/sec².

By interpolation in Table 8B, the gravity correction is -0.048 in.

The column height corrected for gravity is 72 -0.048 or 71.952 inches.

Neglecting the altitude correction and using Table 8A to obtain the correction, there is obtained 0.049 inch. Correcting gravity for the altitude effect introduces negligible error in this case.

4.9 Table 9. Conversion Factors for Various Pressure Units. This table was computed based largely on the data given in Tables 2, 6, and 7. The number of digits of the factors is greater than required for most manometer use. The factors were used insofar as applicable in preparing the other tables.

The factors apply only to manometer readings after all corrections have been made to obtain the pressures in the units stated.

4.10 Table 10. Properties of Manometer Liquids. This table is not complete, either in the properties of the liquids listed or in the best liquids which might be used for a particular application. Members of the ISA who have additional data are urged to furnish it so that this table can be perfected.

Water is probably the most widely used manometric liquid, being not only low in cost, readily available, and stable in nature, but also having a low factor of thermal expansion. Its major disadvantages are its limited range of utility — usually from 0.05 to 2.0 psi, and only 40°F to 100°F — and its corrosive effect on ferrous metals. One of the most desirable methods of increasing its visibility in glass tubing is by the addition of a few drops of fluorescein solution; coloring by inks or dyes is not satisfactory.

Mercury is the second most widely used manometric liquid, being quite stable and reasonably available, immiscible with other liquids, and having a low thermal expansion and low vapor pressure. It can be used over a wide range of temperature conditions — from -35°F to over 250°F , and normally in the pressure range from 0.2 psi to 20-30 psi. Many metals, such as copper, tin, silver, and zinc are soluble in mercury, so that instrument parts in contact with it should be glass, carbon steel, stainless steel or good grade iron.

The major use of kerosine as a manometric liquid is a substitute for water in locations of low temperatures; for many years steel mills and coke oven plants have used "mm of oil" as a manometric unit on exposed mains. Normal practice specifies the use of 40-41 degrees API kerosine, having a specific gravity of 0.8200-0.8204 at 60°F. It has some advantages over water in that it can be used at low temperatures, will not become discolored by rusting of iron fittings with which it is in contact, and provides slightly more accurate measurements because of its lower density. Its use provides a fire hazard, and it cannot be used at temperatures above 75-85°F because of vapor phase and meniscus effects.

Ellison gage oil is a special petroleum fraction, similar to kerosine, having a specific gravity of 0.830-0.834 designed for use in inclined gages measuring low differentials in pressure.

Alcohol, and mixtures of alcohol and ethylene glycol, are quite frequently used as substitutes for water in locations in which temperatures below 35°F are encountered. Ethyl alcohol, having a specific gravity of only 0.794, may provide a slightly more sensitive measurement of pressures, but has the drawbacks of being inconstant in density due to absorption of water vapor, becoming discolored by rusting, promoting a fire hazard, and being undesirable above 90-100°F. A mixture of 36 per cent by volume of ethyl alcohol, and 64 per cent of ethylene glycol (or Prestone) has a specific gravity at 60°F comparable to that of water, and is therefore frequently used in water manometers for below freezing temperatures. However, both alcohol and glycol have relatively large thermal expansion coefficients which, if not taken into account when these substances are used at low temperatures, may lead to serious calibration errors.

Glycerine finds some use as a manometric liquid at temperatures above those at which water or kerosene may be used from 100°F to 250°F. At ordinary temperatures it is relatively viscous and slow draining; deliquescence alters its density.

Both dibromobenzene and dibromoethane have densities approximately twice as great as that of water, and they are therefore used to obtain more accurate measurements within the range 10 to 150 in H₂O than can be obtained by use of mercury. Both have the serious drawback of being hydrolyzed by water and becoming slightly acidic; they should be used only in glass tubes or instruments with special brass chambers and fittings.

Acetylene tetrabromide, or tetrabromoethane, is another high density liquid which is used for measuring pressures greater than those that can be conveniently reached by use of water columns, i.e., equivalents of 5 to 250 in H₂O or 0.2 to 10.0 psi. In spite of a greater degree of bromination, tetrabromoethane appears to be somewhat more stable and less reactive than dibromoethane, but not sufficiently so to permit use in contact with appreciable concentrations of water vapor, nor in instruments that are not provided with special brass chambers or fittings.

Butyl phthalate has low vapor pressure and forms a satisfactory meniscus. It has a relatively low freezing point. It absorbs air readily to a degree which may be troublesome, but no quantitative data were found.

Liquid mixtures such as alcohol-water, alcohol-glycol, and liquids which absorb water readily, such as glycol, alcohol, and glycerin do not hold their initial densities in a manometer open to the air and therefore must be used with caution.

Many organic liquids, such as the petroleum derivatives, Halowax oil and others, have densities which vary from lot to lot. The petroleum derivatives are mixtures, while the organic liquids in the technical grades contain impurities to a degree sufficient to affect the density. The densities given are therefore approximate and should be determined for each lot if pressures are to be measured accurately. Comparison of manometers containing liquids of unknown density

against a water column is a convenient method of determining their density.

4.11 Table 11. Expansion Coefficients of Scale Materials. The length of the scale is determined from the coefficients of linear expansion of scale materials by the relation

$$\begin{aligned} L &= L_0(1+at) & \text{for } t \text{ in deg C} \\ L &= L_0\{1+b(t-32)\} & \text{for } t \text{ in deg F} \end{aligned}$$

where L is the length at temperature t , L_0 is the length at 0°C or 32°F, and a and b are the expansion coefficients per C and per F respectively.

The above relation is not exact, but the error is tolerable for the small temperature ranges ordinarily experienced by manometers. In fact, if the scale length is known at some other temperature than 0°C, the above relations can be written without serious loss in accuracy as follows:

$$\begin{aligned} L &= L_1\{1+a(t-t_1)\} & \text{for } t \text{ in deg C} \\ L &= L_1\{1+b(t-t_1)\} & \text{for } t \text{ in deg F} \end{aligned}$$

where L_1 is the length measured at t_1 and the other terms are defined as above.

It is obvious for precise measurements, that the variations in the coefficients for a given material are such that the coefficient of expansion of the scale material must be measured. Knowledge of the composition of the scale material, and of the degree of cold work for metals, may often serve to pick up a reasonably accurate value from the literature on the subject.

4.12 Table 12. Conversion Factors for Water Columns at Various Temperatures. For a number of temperatures of the water column, the equivalent psi is given for one inch of water, and the equivalent height of a mercury column at 32°F and of water columns at 60°F, 68°F (20°C), and 77°F (25°C) are given for unit height of a water column in any unit as cm, in., etc. The table must be entered in all cases with the true height, that is, the indicated height must be corrected for scale errors and for the effect of temperature on the scale, and any other errors, if significant.

If psi corresponding to one cm of water are desired, multiply the given values in psi by 0.3937.

As an example, find the equivalent psi, in. of mercury and in. of water at 68°F of 35 in. of water at 75°F. Entering the table at 75°F there is obtained

$$\begin{aligned} 35 \times 0.036031 &= 1.261 \text{ psi} \\ 35 \times 0.073359 &= 2.568 \text{ in. of mercury at } 0^\circ\text{C} \\ 35 \times 0.9991 &= 34.97 \text{ in. of water at } 68^\circ\text{F} \end{aligned}$$

4.13 Tables 13 and 14. Temperature Corrections for Water Manometers with Brass Scales to Obtain Reading at 68°F (20°C) and at 60°F. These tables were constructed from the following relation:

$$\text{Correction} = \left[\frac{D-D_0}{D_0} + s(t-t_0) \right] h$$

where D is density of water at temperature t ; D_0 the density at the reference temperature t_0 which is 68°F in Table 13 and 60°F in Table 14; s is the linear coefficient of expansion of brass; and h is the indicated

height of the water column at temperature t after correction for scale error. The temperatures are in degrees Fahrenheit.

This form of the equation has to be used rather than equation (4) of the section on "Temperature Errors", because the coefficient of expansion of water varies too much with temperature to be assumed constant.

Table 11 shows that the coefficient s varies for brass. The value was taken as 10.2×10^{-6} per degree F following the usual practice in barometry. A deviation in s of 10 per cent from the value chosen will on the average affect the corrections in the order of 1 per cent. The density of water was obtained from Table 7.

Either table may be entered with the height of the column in inches or mm, or any other unit, to obtain the temperature correction in the same unit. Also, it has been assumed that the scales are graduated to indicate correctly at 68°F in Table 13, and 60°F in Table 14. The tables can be used nevertheless if the effect of deviations from this assumption can be lumped in with the scale error.

As an example, assume a manometer with a brass scale to read 720 mm at a manometer temperature of 82°F, to obtain the height of the water column at 68°F. Assume the scale correction to be -1 mm when calibrated at 68°F. Applying this correction gives a reading of 719 mm. Enter Table 13 successively with 700, 100 and 900 mm, and interpolate between 80 and 85°F. The temperature correction is then, properly locating the decimal point, $1.24 + 0.02 + 0.02$ or -1.28 mm, and the reading corrected for temperature is 717.7 mm.

4.14 Tables 15A and 15B. Equivalents in psi of Water Columns at Various Temperatures in Inches and in Feet and Inches. These tables were constructed from the conversion factors given in Table 9. The tables are entered with the true height of the water column at the designated temperature, that is, entered with manometer readings corrected for all errors.

As an example of the use of Table 15B, 8 ft 11½ in. of water at 95°F = $3.447 + 0.395 + 0.018 = 3.860$ psi.

4.15 Table 16. Conversion Factors for Mercury Columns at Various Temperatures. The table presents the equivalent of one inch of mercury in psi at the designated temperature, and the factor for converting the height of a mercury column at the designated temperature to the height of a mercury column at 32°F (0°C) and to the height of a water column at any one of the three temperatures, 60, 68, or 77°F. The conversion factor can be used to convert the mercury column in any unit of height to obtain the height in the same unit of the desired liquid column. The table should be entered with the true height of the mercury column at the designated temperature.

The computations are based on the data given in Tables 6, 7, and 9.

As an example, convert 25.00 mm of mercury at 85°F to psi, to a mercury column at 32°F, and to a water column at 68°F.

- (a) $25 \times 0.48854 = 12.21$ psi
- (b) $25 \times 0.9947 = 24.87$ mm of mercury at 32°F
- (c) $25 \times 13.547 = 338.7$ mm of water at 68°F

To obtain psi for 1 mm of mercury, multiply the psi factor given in the table by 0.03937.

4.16 Tables 17 and 18. Temperature Corrections for Mercury Manometers and Barometers with Brass Scales to Obtain Readings at 0°C (32°F). The two tables are alike except that one is for deg C and the other is for deg F. The indicated column heights given in the tables were selected for convenience: if temperatures are measured in deg C, the manometer is more likely to be graduated in millimeters; in deg F, in inches. However, either table may be entered with the liquid height either in millimeters or inches, or any other unit, to obtain the temperature correction in the same unit.

The corrections were computed from equation (4) of the section on "Temperature Errors".

$$\text{Correction} = \frac{s(t-t_0) - m(t-t_0)}{1+m(t-t_0)} H_t$$

where H_t = reading of the manometer at temperature t corrected for scale error.

t = temperature of the manometer in deg C for Table 17, in deg F for Table 18.

t_0 = 0°C for Table 17, 32°F for Table 18.

m = coefficient of expansion of mercury, 0.0001818 per deg C for Table 17, 0.0001010 for Table 18.

s = linear coefficient of expansion for the brass scale, 0.0000184 for deg C for Table 17, 0.0000102 per deg F for Table 18.

It is obvious that the correction is linear with the reading and very nearly so with temperature, sufficiently for the purposes of interpolation in the tables.

Brass scales will not necessarily have the value given above for the coefficient of expansion, which is that commonly used in barometry. A deviation of as much as 10 per cent from the value used will introduce an error of about 1 per cent in the correction.

It will be noted that the brass scale has been assumed accurate at 32°F or 0°C. Such is not generally the case, but the corrections will still apply with high accuracy if the error due to this assumption is merged with the scale error. This procedure is facilitated by the common practice of calibrating a manometer against a "standard" manometer.

Table 17 for deg C is identical with the barometer temperature correction table for deg C in the Smithsonian Meteorological Tables (SMT). Table 18 for deg F differs from that in the SMT in that the brass scale is assumed calibrated correctly at 62°F (t_0 in the term $s(t-t_0)$ in the equation above equals 62°F) in SMT, instead of 32°F as here assumed. Since neither temperature is in correspondence with normal practice, it seems more practical and convenient to use 32°F.

The corrections apply only to manometers and barometers in which the scale is read at both liquid levels, or the zero of the scale and the lower liquid