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Standard Test Methods for Measuring Surface Atmospheric Pressure[1]

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1. Scope

1.1 These methods cover the measurement of atmospheric pressure with two types of barometers: the Fortin-type mercurial barometer and the aneroid barometer.

1.2 In the absence of abnormal perturbations, atmospheric pressure measured by these methods at a point is valid everywhere within a horizontal distance of 100 m and a vertical distance of 0.5 m of the point.

1.3 Atmospheric pressure decreases with increasing height and varies with horizontal distance by 1 Pa/100 m or less except in the event of catastrophic phenomena (for example, tornadoes). Therefore, extension of a known barometric pressure to another site beyond the spatial limits stated in 1.2 can be accomplished by correction for height difference if the following criteria are met:

1.3.1 The new site is within 2000 m laterally and 500 m vertically.

1.3.2 The change of pressure during the previous 10 min has been less than 20 Pa.

The pressure, P_2 at Site 2 is a function of the known pressure P_1 at Site 1, the algebraic difference in height above sea level, $h_1 - h_2$, and the average absolute temperature in the space between. The functional relationship between P_1 and P_2 is shown in 10.2. The difference between P_1 and P_2 for each 1 m of difference between h_1 and h_2 is given in Table 1 and 10.4 for selected values of P_1 and average temperature.

1.4 Atmospheric pressure varies with time. These methods provide instantaneous values only.

1.5 The values stated in SI units are to be regarded as the standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific safety precautionary statements are given in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres[2]

D 3249 Practice for General Ambient Air Analyzer Procedures[2]

IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): The Modern Metric System[3]

3. Terminology

3.1 Pressure for meteorological use has been expressed in a number of unit systems including inches of mercury, millimetres of mercury, millibars, and others less popular. These methods will use only the International System of Units (SI), as described in IEEE/ASTM SI 10.

3.1.1 Much of the apparatus in use and being sold reads in other than SI units, so for the convenience of the user the following conversion factors and error equivalents are given.

3.1.1.1 The standard for pressure (force per unit area) is the pascal (Pa).

3.1.1.2 One standard atmosphere at standard gravity (9.80665 m/s^2) is a pressure equivalent to:

29.9213 in. Hg at 273.15 K
760.000 mm Hg at 273.15 K
1013.25 millibars
14.6959 $lbf/in.^2$
101325 Pa or 101.325 kPa

3.1.1.3 1 Pa is equivalent to:

0.000295300 in. Hg at 273.15 K
0.00750062 mm Hg at 273.15 K
0.01000000 millibars
0.000145037 $lbf/in.^2$
0.000009869 standard atmospheres

3.2 *standard gravity*—as adopted by the International Committee on Weights and Measures, an acceleration of 9.80665 m/s^2 (see 10.1.3).

3.3 The definitions of all other terms used in these methods can be found in Terminology D 1356 and Practice D 3249.

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[1] These test methods are under the jurisdiction of ASTM Committee D22 on Sampling and Analysis of Atmospheres and are the direct responsibility of Subcommittee D22.11 on Meteorological Measurements.

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[2] *Annual Book of ASTM Standards*, Vol 11.03.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

TABLE 1 Selected Values

Average Temperature, $\frac{T_1 + T_2}{2}$	Pressure P_1, Pa				
	110 000	100 000	90 000	80 000	70 000
	Correction to P_1, Pa/m, positive if $h_1 > h$, negative if $h_1 < h_2$				
230	16	15	13	12	10
240	16	14	13	11	10
250	15	14	12	11	10
260	14	13	12	11	9
270	14	13	11	10	9
280	13	12	11	10	9
290	13	12	11	9	8
300	13	11	10	9	8
310	12	11	10	9	8

4. Summary of Methods

4.1 The instantaneous atmospheric pressure is measured with two types of barometers.

4.2 Method A utilizes a Fortin mercurial barometer. The mercury barometer has the advantage of being fundamental in concept and direct in response. The disadvantages of the mercury barometer are the more laborious reading procedure than the aneroid barometer, and the need for temperature correction.

4.3 Method B utilizes an aneroid barometer. The aneroid barometer has the advantages of simplicity of reading, absence of mercury, no need for temperature compensation by the observer, and easy detection of trend of change. The main disadvantages of the aneroid barometer are that it is not fundamental in concept as the mercury barometer, and it requires calibration periodically against a mercury barometer.

5. Significance and Use

5.1 Atmospheric pressure is one of the basic variables used by meteorologists to describe the state of the atmosphere.

5.2 The measurement of atmospheric pressure is needed when differences from "standard" pressure conditions must be accounted for in some scientific and engineering applications involving pressure dependent variables.

5.3 These methods provide a means of measuring atmospheric pressure with the accuracy and precision comparable to the accuracy and precision of measurements made by governmental meteorological agencies.

6. Apparatus

6.1 *Fortin Barometer*, which is a mercurial barometer consisting of a glass tube containing mercury with an adjustable cistern and an index pointer projecting downward from the roof of the cistern. The mercury level may be raised or lowered by turning an adjustment screw beneath the cistern.

6.1.1 To provide acceptable measurements, the specifications of 6.1.2-6.1.11 must be met.

6.1.2 Maximum error at 100 000 Pa ± 30 Pa.

6.1.2.1 Maximum error at any other pressure for a barometer whose range: (*a*) does not extend below 80 000 Pa ± 50 Pa (*b*) extends below 80 000 Pa ± 80 Pa.

6.1.2.2 For a marine application the error at a point must not exceed ± 50 Pa.

6.1.3 Difference between errors over an interval of 10 000 Pa or less ± 30 Pa.

6.1.4 Accuracy must not deteriorate by more than ± 50 Pa over a period of a year.

6.1.5 It must be transportable without loss of accuracy.

6.1.6 A mercurial barometer must be able to operate at ambient temperatures ranging from 253 to 333 K (−20 to 60°C) and must not be exposed to temperatures below 253 K (−38°C). It must be able to operate over ambient relative humidities ranging from 0 to 100 %.

6.1.7 A thermometer with a resolution of 0.11 K and a precision and accuracy of 0.05 K must be attached to the barrel of the barometer.

6.1.8 The actual temperature for which the scale of a mercury barometer is designed to give true readings (at standard gravity) must be engraved on the barometer.

6.1.9 If the evacuated volume above the mercury column can be pumped, the head vacuum must be measured with a gage such as a McLeod gage or a thermocouple gage and reduced to 10 Pa or less.

6.1.10 The meniscus of a mercurial barometer must not be flat.

6.1.11 The axis of the tube must be vertical (that is, aligned with the local gravity vector).

6.2 *Precision aneroid barometer*, consisting of an evacuated elastic capsule coupled through mechanical, electrical, or optical linkage to an indicator.

6.2.1 To provide acceptable measurements, an aneroid barometer must meet the specifications of 6.2.2-6.2.7.

6.2.2 Resolution of 50 Pa or less.

6.2.3 Precision of ± 50 Pa.

6.2.4 Accuracy of ± 50 Pa root mean square error with a maximum observed error not to exceed 150 Pa throughout the calibration against a basic standard.

6.2.5 Temperature compensation must be included to prevent a change in reading of more than 50 Pa for a change of temperature of 30 K.

6.2.6 The accuracy must not deteriorate by more than ± 100 Pa over a period of a year.

6.2.7 The hysteresis must be sufficiently small to ensure that the difference in reading before a 5000-Pa pressure change and after return to the original value does not exceed 50 Pa.

6.3 *Static Pressure Head*—Atmospheric pressure-measuring instruments may be installed inside an enclosed space. The pressure in the space must, however, be directly coupled to the pressure of the free atmosphere and not artificially affected by heating, ventilating, or air-conditioning equipment, or by the dynamic effects of wind passage.

6.3.1 The *Manual of Barometry* **(1)**[4] describes these effects. For barometers with a static port they can be overcome with a static pressure vent, such as that described by Gill **(2)**, mounted outside and beyond the influence of the building. It is practical to consider an external static vent installation if and only if the pressure in the building differs by more than 30 Pa from true pressure. The pressure difference due to a ventilating or air conditioning system, or both can be determined from pressure readings taken with a precision aneroid barometer inside and

[4] Boldface numbers in parentheses refer to references at the end of these methods.

outside the building on calm days when the ventilating and air conditioning system is in operation. The existence of pressure errors due to the dynamic effects of wind on the building can often be diagnosed by careful observation of a fast response barometer in the building during periods of gusty winds.

6.3.2 The significant pressure field near a building in wind can extend to a height of 2.5 times the height of the building and to a horizontal distance up to 10 times the height of the building to the leeward. It may be impractical to locate a static vent beyond this field but the following considerations must be made:

6.3.2.1 The static vent must *not* be located on a side of the building;

6.3.2.2 The distance from the building must be as large as practical;

6.3.2.3 The length of the tube connecting the vent to the barometer must be minimized;

6.3.2.4 To avoid blockages, a vertical run of connecting tube is preferable to a horizontal run; and

6.3.2.5 The connecting tube system must include moisture traps and drainage slopes on horizontal runs.

6.3.3 The tubing used to connect the vent to the barometer has a minimum allowable internal diameter that is a function of the ambient static pressure, the volume of the air chambers associated with the instrument making the pressure measurement, the length of the tube between the static head and the barometer, the viscosity of the air in the tubing and connected equipment. The time lag constant must not exceed 1 s so that for pressure and temperature of the zero pressure altitude in the standard atmosphere, the inside diameter d of the tubing connecting the static pressure head with the barometer must be such that

$$d > (7.21 \times 10m^{-9}\ LV)^{1/4} \quad (1)$$

where:

L = length of the tube, m,
V = volume of the air capacity of the pressure responsive instrument and any connected air chambers within the system together with one half the volume of the tubing, m^3, and
d = inside diameter of the tubing, m.

When this calculation is made the minimum allowable inside diameter will frequently be 5 mm or less. It is often more convenient to use tubing larger than this size, and use of such larger tubing enhances the value of the static head and makes it applicable to a wider range of temperatures and pressures.

7. Safety Precautions

7.1 **Warning**: Mercury is a hazardous substance that can cause illness and death. Inhalation of mercury vapor is a health hazard, even in small quantities. Prolonged exposure can produce serious mental and physical impairment. Mercury can also be absorbed through the skin, so avoid direct contact. The effects are cumulative.

7.2 Store mercury in closed, shatter-proof non-metallic containers to control its evaporation.

7.3 Do not store or attempt to operate a mercurial barometer at temperatures below 235 K (-38°C), the freezing point of mercury.

7.4 Work with mercury only in well-ventilated spaces, preferably under a fume hood or similar device. Use non-permeable rubber gloves at all times and wash hands immediately after any operation involving mercury. Exercise extreme care to avoid spilling mercury. Minimize the effect of spills by working above a large shallow pan.

7.5 Mercurial barometers should be installed only where there is adequate ventilation. The floor beneath a mercurial barometer should be impermeable.

7.6 In a mercurial barometer, a broken tube, cistern, or bag will release mercury. Immediately clean up any spills using procedures recommended explicitly for mercury. Carefully collect, place, and seal all spilled mercury in an appropriate container. Do not re-use; dispose of spilled mercury and mercury contaminated materials in a safe, environmentally acceptable manner.

8. Calibration and Standardization

8.1 A barometer is calibrated by comparing it with a secondary standard traceable to one of the primary standards at locations listed in Table 2.

8.2 For the United States this standard is maintained by the National Institute of Standards and Technology, Gaithersburg, MD 20899.

8.3 Except in the case of catastrophic phenomena (for example, tornadoes) the horizontal pressure gradient at the earth's surface is less than 1 Pa/100 m so that the pressure at two instruments within 100 m of each other horizontally will not differ by an amount large enough to measure with instruments suggested for this method. Instruments separated by a vertical distance of less than 0.5 m may be compared without correcting for height difference.

8.3.1 Calibration of one or more barometers that do not produce mutual interference with the standard or each other can be accomplished by simple comparison with traveling or fixed standards by methods described in Refs **(1)**, **(4)**, and **(5)**. If the instruments used can cause mutual interference (for

TABLE 2 Regional Standard Barometers

Region	Location	Category
I	Pretoria, South Africa	A_r
II	Calcutta, India	B_r
III	Rio de Janeiro, Brazil	A_r
	Buenos Aires, Argentina	B_r
	Maracay, Venezuela	B_r
IV	Washington, DC, (Gaithersburg, Md.), USA	A_r
V	Melbourne, Australia	A_r
VI	London, United Kingdom	A_r
	Leningrad, U.S.S.R.	A_r
	Paris, France	A_r
	Hamburg, Federal Republic of Germany	A_r

A_r—A barometer that has been selected by regional agreement as a reference standard for barometers of that region and is capable of independent determination of pressure to an accuracy of ±5 Pa.

B_r—A working standard barometer with known errors established by comparison with a primary or secondary standard. Such barometers are used in a region where the National meteorological services of the region agree to use them as the standard barometer for the region in the event that a barometer of category A_r is unavailable.

Taken from Annex 3, of *Guide to Meteorological Instruments and Observing Practice, World Meteorological Organization.*

example, electronic instruments) use isolation barriers that freely transmit atmospheric pressure.

8.4 Calibration is done by making a number of comparisons between the instrument being calibrated and the standard under a broad range of pressures.

8.5 Calibration records include pressure readings from the barometers; temperature readings from the attached thermometers; wind speed and gustiness (observed in accordance with methods described in Refs **(4)** or **(5)**); corrections for gravity, temperature, and instrumental error; the elevation above mean sea level of the zero point of the barometers; the latitude; the longitude; the name of the place; and the dates and times of observations.

8.6 Aneroid barometers are equipped with a means of setting the mechanism during calibration and comparison.

8.7 Protect all barometers from violent mechanical shock and explosive changes in pressure. A barometer subjected to either of these must be recalibrated.

8.8 Maintain the vertical and horizontal temperature gradients across the instruments at less than 0.1 K/m. Locate the instrument so as to avoid direct sunlight, drafts, and vibration.

9. Procedures

9.1 For synoptic meteorological observations determine the latitude and longitude of the station to the nearest second of arc and the height above mean sea level to the nearest 0.03 m. A method for such determination is described in the *Manual of Barometry* **(1)**.

NOTE 1—This information is not needed for nonsynoptic purposes when pressure is being measured by Method B or by Method A when the local acceleration of gravity is known.

9.2 *Method A, Fortin Mercurial Barometer*:

NOTE 2—The method for measuring atmospheric pressure from a mercurial barometer is described in detail in 3.1.3 through 3.1.6 of the *World Meteorological Guide to Meteorological Instruments and Practices* **(4)**.

9.2.1 Read the temperature T from the thermometer attached to the barrel to the nearest 0.1 K.

9.2.2 Lower the mercury level in the cistern until it clears the index pointer. Raise the level slowly until a barely discernible dimple appears on the surface of the mercury.

9.2.3 Tap the barrel near the top of the mercury column.

9.2.4 Set the vernier so that the base just cuts off light at the highest point of the meniscus (the curved upper surface of the mercury column) and carefully avoid parallax error.

9.2.5 Read the height of the mercury Column B from the barometer in the manner appropriate to the vernier scale used to the equivalent of the nearest 10 Pa. Apply appropriate corrections as described in Section 10.

9.3 *Method B, Aneroid Barometer*:

9.3.1 Always read an aneroid barometer when it is in the same position (vertical or horizontal) as when calibrated.

9.3.2 Immediately before an aneroid barometer with mechanical linkage is read tap its case lightly to overcome bearing drag.

9.3.3 Read the aneroid barometer to the nearest equivalent of 10 Pa.

10. Calculations

10.1 For Method A using a Fortin-type barometer with brass scales, determine the temperature correction by means of the following equation or an appropriate table **(6)**:

$$C_t = (0.04452345 - 0.000163T)B \tag{2}$$

where:
T = temperature, K,
C_t = correction at temperature T, and
B = observed barometer reading at temperature T, Pa.

10.1.1 Correct the reading by applying the temperature correction and instrumental correction as follows:

$$B_1 = B + C_t + C_i \tag{3}$$

where:
B_1 = barometer reading reduced to standard temperature and corrected for instrumental errors but not reduced to standard gravity and
C_i = instrumental error determined by calibration.

10.1.2 Correct for gravity as follows:

$$B_n = B_1 \frac{g_{\phi,H}}{g_n} \tag{4}$$

where:
B_n = barometric pressure at standard gravity (g_n) and standard temperature, 288.15 K (15°C), and corrected for instrumental errors,
$g_{\phi,H}$ = local acceleration of gravity in m/s^2 at the station latitude ϕ and station elevation H above sea level, and
g_n = standard acceleration of gravity, which is 9.80665 m/s^2.

10.1.3 The local acceleration of gravity may be calculated by the method described in Section 3.8 of the *Guide to Meteorological Instruments and Observing Practices* **(4)**, Table 168 of the *Smithsonian Meteorological Tables* **(6)**, determined by direct measurement with a gravimeter or obtained from government or academic institutions. If the value is reported by the Potsdam system the value $g_{\phi,H}$ is obtained by subtracting 0.00013 m/s^2.

$g_{\phi,H}$ = local acceleration of gravity in m/s^2 at the station latitude ϕ and station elevation H above sea level to be used for meteorological purposes.
$(g_{\phi,H})_P$ = measured gravity by the Potsdam system.

10.2 If the atmospheric pressure P_1, height h_1, and atmospheric temperature T_1 at some Site 1 and the height h_2 at a Site 2 are known then the atmospheric pressure P_2 at Site 2 can be calculated from the following equation:

$$P_2 = P_1 \exp \frac{0.068332(h1 - h2)}{(T_1 + T_2)} \tag{5}$$

where:
P_1 = pressure at Site 1, Pa,
P_2 = pressure at Site 2, Pa,
h_1 = height above mean sea level of Site 1, m,
h_2 = height above mean sea level of Site 2, m,
T_1 = atmospheric temperature at site 1, K, and

T_2 = atmospheric temperature at Site 2, K.

10.3 Table 1 provides a solution for selected values of $\frac{T_1 + T_2}{2}$ and P_1. For lateral distances less than 200 m and vertical distances less than 500 m, P_2 may be obtained from P_1 by adding the correction shown in Table 1 for each 1 m of height difference between h_1 and h_2.

11. Precision and Bias

11.1 The agreement between a single corrected reading using the Fortin-type mercurial barometer and reference measurements using primary and secondary standards has been found to be within 20 Pa **(4)**. The precision of repeated measurements made with a single instrument is ± 10 Pa **(4)**.

11.2 The agreement between single readings of aneroid barometers and reference measurements using primary and secondary standards has been found to be within ± 50 Pa **(4)**. The precision of repeated measurements made with a single instrument is ± 50 Pa **(4)**.

12. Keywords

12.1 aneroid barometer; atmospheric pressure; barometer; barometry; Fortin-type mercurial barometer; mercurial barometer; pressure

REFERENCES

(**1**) *Manual of Barometry*, Vol 1, First Edition 1963, U.S. Department of Commerce, Weather Bureau, U.S. Department of Air Force, Air Weather Service, U.S. Department of Navy, Naval Weather Service, Washington, DC.

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(**3**) Occupational Safety and Health Standards Subpact Z—Toxic and Hazardous Substances, Section 1910.1000 Air Contaminants, Table Z-2. 29 Code of Federal Regulations.

(**4**) "Guide to Meteorological Instruments and Observing Practices," *World Meteorological Organization*, WMOBA, No. 8, TP3, Fourth Edition 1971, Secretariat of WMO, Geneva, Switzerland.

(**5**) *Federal Meteorological Handbook No. 1, Surface Observations*, U.S. Department of Commerce, U.S. Department of Defense, U.S. Department of Transportation, effective July 1, 1975, available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

(**6**) List, R. J. (compiler), *Smithsonian Meteorological Tables*, Sixth Revised Edition, 1949, Fourth Reprint issued 1968, Smithsonian Institution Publications, SIPMA, Washington, DC.