An Absolute Standard Barometer

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Abstract

An absolute standard barometer recently installed at the Japan Meteorological Agency, Tokyo, is described. It is essentially a syphon barometer made of glass tube 30 mm in internal diameter. The two mercury menisci can be equally formed by operating the mercury reservoir hydrostatically connected with the mercury column. The vacuum in the space above the mercury is measured by a Geisler tube. The barometric height is read measuring the position difference of two menisci by means of a standard scale and a cathetometer. The average temperature of the mercury column is determined from the readings of two thermometers hung on the mercury column. It was intended that the accuracy of a single reading of the barometer should be in the order of 0.01 mmHg, while in practice, it is found that the standard deviation of errors included in the observed values is 0.03 mmHg. The result of its comparison with the present JMA's standard barometer gives that the mean correction of the JMA's standard in relation to the new absolute standard barometer is -0.20 mmHg.

1. Introduction

The calibration of barometers in Japan has been carried out by the Central Meteorological Observatory, the name of which was changed to the Japan Meteorological Agency after 1957. The first standard barometer for the calibration, which was imported about forty years ago, was a movable scale mercury barometer with an internal diameter of about 25 mm, manufactured by Cassela, London. It was damaged by the Great Kanto Earthquake in 1923. The second standard barometer was selected out of several Fortin barometers, which had been calibrated and given their instrumental corrections before the Earthquake by means of the first standard barometer, being affirmed to be in the best order by their mutual comparison. The second was also ruined by the fire of the Observatory caused by lightning stroke in 1940. The third standard barometer was, in the same manner as the second one, selected out of several Fortin barometers which had been calibrated by the second. The third is now used as the JMA's standard barometer, and has been compared with the standard barometers in Calcutta, Hong Kong, and Peking (1) (2).

Although the corrections of the second and the third standard barometers were carefully examined, there might be some uncertainty

in them. The necessity of establishing an absolute standard barometer was acutely felt, and the work was set to by Yoshitake, one of the present authors, but was forced to be interrupted by the second World War. Several years after, the work was taken over and continued by Takeuchi, one of the present authors, and the late Mr. H. Endo, and a preliminary model of an absolute standard barometer with an internal diameter of about 15 mm was completed. It was found that the readings of the JMA's standard barometer were somewhat higher than those of the model absolute at their comparison. A few years ago, the Central Inspection Institute of Weights and Measures of Japan produced an absolute standard barometer of the same type for the determination of the boiling point of water (3).

The present absolute standard barometer described hereafter was designed and constructed after these barometers, being intended to have an accuracy of the order of 0.01 mmHg.

2. Description of Absolute Standard Barometer

A photograph of the complete set of the present Absolute Standard Barometer is shown in Fig. 1.

It is essentially a siphon barometer, with a tube made of hard glass, as shown diagrammatically in Fig. 2. The internal diameters of the parts A and B of the glass tube are both 30 mm. The parts A and B are set coaxially in a vertical line and 760 mm apart one above the other. The connecting part C of the tube between A and B has an internal diameter of about 10 mm, and most of the part is covered by glass jackets, which consist of three parts, each of them contains circulating water for keeping the mercury column at a constant temperature.

The upper end of A is connected through a glass tube D and rubber tubes to a rotary oil pump so that the space above the mercury can be evacuated. As a pressure of less than .01 mmHg is easily obtained by a single rotary oil pump, an oil diffusion pump included in the design was not equipped. The part D is connected with a Geisler tube G, by which the vacuum above the mercury is satisfactorily measured. The end of D can be vacuum-tightly closed by cocks i and j. The end of B is open to the pressure of the air, and also can be closed by a cock k.

At the bottom of C branches a limb of a glass tube E, which is extended into a reservoir R. The mercury in the barometer

tube is hydrostatically connected with the mercury in the reservoir. By raising or lowering the reservoir mounted on a vertical screw, the mercury levels in A and B can be changed as required. The opening F of the reservoir can be, at the uppermost position of the reservoir, sealed on vacuum-tightly to the widened part of E. The reservoir has a side opening O for pouring mercury in. A drainage cock l is attached to the bottom of the tube E.

The barometer tube and a pure nickel

Fig. 1. The Complete set of the absolute standard barometer.

standard scale S of 1 meter in length and with H cross section, manufactured by SIP, Geneva, are mounted side by side on a rigid frame work with three leveling screws, as shown in Fig. 1.

The procedure of pouring mercury into the barometer tube is as follows. The mercury for use in the barometer tube is chemically cleaned and distilled six times in vacuum, and the glass tube and the reservoir are also carefully cleaned before setting up. First of all, the

reservoir is raised up to its uppermost position for sealing its opening F, and the cocks k and l are closed. Then the mercury is carefully poured into the reservoir through the opening O, which is thereafter connected to the rotary oil pump by means of rubber tubes. By operating the pump, the inside of the barometer tube and the upper space in the reservoir is evacuated and kept in vacuum with the cocks i and j closed. The vacuum is affirmed by the Geisler tube. Then the pressure over the reservoir mercury is gradually increased so as to force the mercury over the top of the tube E into the barometer tube. Thus the mercury is filled in the barometer tube in vacuum and free from grease. The reservoir is lowered, the opening being parted from the widened part of the tube E. During its rest, the reservoir is lowered until the mercury levels in A and B come down under their working ranges in order to keep the tubes from the contamination by mercury.

Fig. 2. The Schematic view of the absolute standard barometer

The barometric height is read measuring the position difference of two meniscuses in A and B, by means of the standard scale and a cathetometer, which is equipped with two telescopes each having an eye-piece micrometer and a level. The reservoir is raised until the mercury levels go up to the middle of A and B, and then the micrometer cross wires are set on the respective meniscuses. The two meniscuses are almost equally formed, since the difference in the capillary depression of the mercury surface for 30 mm in diameter is negligibly small according to Gould (4). Turning the cathetometer on to the standard scale, the positions of the micrometer cross wires are read on the scale. The systematic errors, which may be included in the determined positions of two meniscuses, are to be in the same sign, so the error of the barometric height is to be reduced by subtraction.

The temperature of the mercury column is determined by the mean of the readings of two thermometers T_1 and T_2 , engraved to 0.1°C , which are hung in two of the jackets as shown in Fig. 2. Water was not filled in these jackets in the present practical measurement, because the diurnal variation of the barometer room temperature has not exceeded 1°C , and two electric fans were operated for circulating the room air before measurement. Temperature differences between T_1 and T_2 were less than 0.08°C in practice.

3. Comparisons with Other Barometers

The absolute standard barometer A installed in the ASB room was compared with the JMA's standard barometer B_3 installed in the calibration room by means of two traveling barometers P_1 and P_2 . A Fuess normal barometer N also installed in the ASB room was directly compared with the absolute standard barometer. Characteristics of these barometers are as follows:

1) Absolute Standard Barometer (A)

Type	Syphon
Manufacturer	Shibata, Tokyo
Date of construction	1958
Bore of tube	30 mm
Scale	Pure nickel, H cross section
Scale manufacturer	SIP, Geneva

Scale units	Millimeters
Temperature for which true readings are given	0°C
Linear coefficient of expansion of scale	0.0000126/°C
2) JMA's Standard Barometer (B ₃)	
Type	Fortin
Manufacturer	K. Suzuki, Tokyo
Serial number of instrument	No. 1319
Date of construction	1923
Bore of tube	15 mm
Linear coefficient of expansion of scale	0.0000184/°C
Scale units	Millimeters
Temperature for which true readings are given	0°C
Least count of vernier	0.1 mm
Present accepted correction	-0.02 mmHg
3) Fuess Normal Barometer (N)	
Type	Syphon
Manufacturer	R. Fuess, Berlin
Serial number of instrument	No. A 4578
Bore of tube	15 mm
Linear coefficient of expansion of scale	0.0000148/°C
Scale units	Millimeters
Temperature for which true readings are given	0°C
Least count of vernier	0.02 mm
Present accepted correction	0.00 mmHg, given by P.T.R. in 1953
4) Traveling Barometer No. 1 (P ₁)	
Type	Fortin
Manufacturer	K. Suzuki, Tokyo
Serial number of instrument	No. K 7427
Bore of tube	10 mm
Scale units	Millimeters
Temperature for which true readings are given	0°C
Least count of vernier	0.1 mm
5) Traveling Barometer No. 2 (P ₂)	
Type	Fortin
Manufacturer	K. Suzuki, Tokyo
Serial number of in-	

strument	No. K7189
Bore of tube	10 mm
Scale units	Millimeters
Temperature for which true readings are given	0°C
Least count of vernier	0.1 mmHg.

The comparison among the absolute standard barometer, two traveling barometers and Fuess normal barometer was carried out by Shimizu on Jan. 13th through Feb. 20th, in 1959. The traveling barometers were side by side hung on a column in the ASB room, on the opposite side of which the Fuess barometer was installed. The fiducial points of these three barometers were set on the same level as the middle point of the tube B of the absolute standard barometer.

Fans are started about an hour before each observation is made, and stopped just before the observation. The reservoir is raised and the readings of the attached thermometers on A, P₁, P₂, and N are taken one by one. Then the two horizontal cross wires of the cathetometer are set on the respective menisci and the settings of the barometers P₁, P₂ and N are made. The time required for the settings is about 1 minutes. Thereafter, all the readings are taken.

The results obtained are shown on Table 1. Instrumental corrections are applied to the thermometers only. Capillary depression corrections are included in the uncorrected readings of the Fuess barometer in accordance with Gould (4). Corrections of the barometers P₁, P₂ and N in relation to the absolute standard barometer A obtained from Table 1 are shown on Table 2.

It is found that the mean correction of the Fuess normal barometer in relation to the present absolute is equal to that given by P. T. R..

The traveling barometers, P₁ and P₂, were then removed to the barometer calibration room and hung side by side with the JMA's standard barometer B₃. The comparison among them was carried out on Feb. 24th through 26th. The results are shown on Table 3. As the constructions and thermal conditions of these three barometers are same, their uncorrected readings can be directly compared. Corrections of P₁ and P₂

Table 1. Simultaneous readings of the absolute standard barometer A, two traveling barometers P_1 and P_2 , and Fuess normal barometer N.

Date of reading	Absolute standard barometer (A)			Traveling barometer (P_1)			Traveling barometer (P_2)			Fuess normal barometer (N)		
	Uncorrected reading	Temperature	Reduction to 0°C	Uncorrected reading	Temperature	Reduction to 0°C	Uncorrected reading	Temperature	Reduction to 0°C	Uncorrected reading	Temperature	Reduction to 0°C
1959	mmHg	°C	mmHg	mmHg	°C	mmHg	mmHg	°C	mmHg	mmHg	°C	mmHg
Jan. 13	759.05	3.78	758.56	759.27	3.9	758.78	759.29	3.9	758.80	759.08	4.1	758.57
14	761.51	3.78	761.02	761.60	3.9	761.11	761.62	3.9	761.13	761.46	3.9	760.97
16	755.71	3.75	755.23	755.80	3.8	755.33	755.80	3.8	755.33	755.61	3.9	755.12
19	762.66	2.81	762.30	762.87	3.0	762.50	762.86	3.0	762.49	762.66	3.0	762.29
20	769.13	2.69	768.78	769.30	2.8	768.95	769.28	2.8	768.93	769.10	2.8	768.75
20	766.71	2.68	766.36	766.88	2.8	766.53	766.90	2.8	766.55	766.74	2.9	765.37
21	763.37	2.98	762.98	763.52	3.2	763.13	763.55	3.2	763.16	763.35	3.1	762.97
22	763.56	3.36	763.12	763.74	3.5	763.31	763.77	3.5	763.34	763.54	3.4	763.12
24	770.14	4.42	769.57	770.28	4.5	769.72	770.28	4.5	769.72	770.12	4.5	769.56
Feb. 2	765.33	5.76	764.58	765.52	5.8	764.79	765.52	5.8	764.79	765.27	6.0	764.52
3	760.53	5.88	759.77	760.69	6.0	759.95	760.68	6.0	759.94	760.47	6.0	759.73
14	763.21	7.55	762.23	763.33	7.6	762.39	763.39	7.6	762.45	763.13	7.6	762.19
14	763.48	7.57	762.50	763.63	7.6	762.69	763.67	7.6	762.73	763.38	7.7	762.43
16	765.41	7.81	764.40	765.54	7.9	764.55	765.60	7.9	764.61	765.37	8.0	764.37
16	765.63	7.95	764.60	765.80	8.0	764.80	765.84	8.0	764.84	765.65	8.1	764.64
17	756.36	8.52	755.28	756.55	8.5	755.50	756.53	8.5	755.48	756.41	8.6	755.35
17	756.02	8.70	754.91	756.20	8.7	755.13	756.17	8.7	755.10	756.07	8.8	754.98
18	765.00	9.27	763.80	765.08	9.2	763.94	765.09	9.2	763.95	764.92	9.3	763.76
18	765.78	9.43	764.57	765.93	9.4	764.76	765.95	9.4	764.78	765.80	9.5	764.62
20	755.96	9.11	754.80	755.14	9.2	754.01	755.11	9.2	753.98	754.94	9.2	753.81

Table 2. Corrections of barometers P_1 , P_2 , and N in relation to the absolute standard barometer A, obtained from Table 1.

Date of reading	Correction in relation to the absolute standard barometer		
	Traveling barometer ($A-P_1$)	Traveling barometer ($A-P_2$)	Fuess normal barometer ($A-N$)
1959	mmHg	mmHg	mmHg
Jan. 13	-0.22	-0.24	-0.01
14	-0.09	-0.11	0.05
16	-0.10	-0.10	0.11
19	-0.20	-0.19	0.01
20	-0.17	-0.15	0.03
20	-0.17	-0.19	-0.01
21	-0.15	-0.18	0.01
22	-0.19	-0.22	0.00
24	-0.15	-0.15	0.01
Feb. 2	-0.21	-0.21	0.06
3	-0.18	-0.17	0.04
14	-0.16	-0.22	0.04
14	-0.19	-0.23	0.07
16	-0.15	-0.21	0.03
16	-0.20	-0.24	-0.04
17	-0.22	-0.20	-0.07
17	-0.22	-0.19	-0.07
18	-0.14	-0.15	0.04
18	-0.19	-0.21	-0.05
20	-0.21	-0.18	-0.01
Mean correction	-0.18	-0.19	0.01

Table 3. Simultaneous readings of the JMA's standard barometer (the third standard barometer) B_3 , two traveling barometers P_1 , and P_2 .

Date and time of reading	Temperature	Uncorrected reading of JMA's standard barometer (B_3)	Uncorrected reading of traveling barometer (P_1)	Uncorrected reading of traveling barometer (P_2)
		mmHg	mmHg	mmHg
1959	°C	mmHg	mmHg	mmHg
Feb. 24 1030	8.2	768.82	768.77	768.78
1100	8.2	768.41	768.40	768.38
1130	8.2	768.26	768.26	768.28
1200	8.2	767.90	767.89	767.91
25 1000	5.6	770.82	770.78	770.83
1030	5.6	770.92	770.90	770.88
1100	5.7	770.83	770.78	770.81
1130	5.8	770.60	770.57	770.61
1200	5.9	770.48	770.46	770.49
1230	6.0	770.14	770.13	770.11
1300	6.1	769.88	769.89	769.88
1330	6.1	769.92	769.90	769.92
26 1230	5.5	770.61	770.57	770.59
1300	5.5	770.42	770.41	770.41
1330	5.5	770.05	770.07	770.03
1400	5.5	770.18	770.17	770.14
1430	5.4	770.05	770.05	770.02
1500	5.4	770.01	770.01	770.00
1530	5.4	770.00	770.00	770.01
1600	5.4	770.01	770.00	770.00

Table 4. Corrections of traveling barometers P_1 and P_2 in relation to the JMA's standard barometer (the third standard barometer) B_3 , obtained from Table 3.

Date and time of reading	Correction in relation to the JMA's standard barometer	
	Traveling barometer ($B_3 - P_1$)	Traveling barometer ($B_3 - P_2$)
1959	mmHg	mmHg
Feb. 24 1030	0.05	0.04
1100	0.01	0.03
1130	0.00	-0.02
1200	0.01	-0.01
25 1000	0.04	-0.01
1030	0.02	0.04
1100	0.05	0.02
1130	0.03	-0.01
1200	0.02	-0.01
1230	0.01	0.03
1300	-0.01	0.00
1330	0.02	0.00
26 1230	0.04	0.02
1300	0.01	0.01
1330	-0.02	0.02
1400	0.01	0.04
1430	0.00	0.03
1500	0.00	0.01
1530	0.00	-0.01
1600	0.01	0.01
Mean correction	0.02	0.01

in relation to the JMA's standard barometer B_3 obtained from Table 3 are shown on Table 4.

The results of the comparison between the present absolute and the JMA's standard barometer by means of the two traveling barometers are shown on Table 5, obtained from Tables 2 and 4. The mean correction of the JMA's standard in relation to the absolute standard barometer is found to be -0.20 mmHg.

4. Estimated Accuracy of a Single Reading of the Absolute Standard Barometer

The standard deviations of the corrections, $(A - P_1)$, $(A - N)$, and $(N - P_1)$, are obtained from Table 2 as follows:

Correction	Standard deviation
$A - P_1$	0.03_7
$A - N$	0.04_5
$N - P_1$	0.03_6

If the standard deviation of single observa-

Table 5. Final results of the comparison between the absolute standard barometer A and JMA's standard barometer (the third standard barometer) B_3 , obtained from Tables 2 and 4.

		Absolute standard barometer (A)	JMA's standard barometer (B_3)
Number of observations made,	(a) with P_1 (b) with P_2	20 20	20 20
Mean correction, in mmHg,	(a) with P_1 (b) with P_2	-0.18 -0.19	0.02 0.01
Standard deviation of corrections, in mmHg,	(a) with P_1 (b) with P_2	0.04 0.04	0.02 0.02
Maximum deviation in corrections, in mmHg,	(a) with P_1 (b) with P_2	0.09 0.09	0.04 0.03
Minimum deviation in corrections, in mmHg,	(a) with P_1 (b) with P_2	0.00 0.00	0.00 0.00

Final Results of the Comparison

Mean correction of JMA's standard barometer B_3 in relation to the absolute standard barometer A

$$(A - B_3)_1 = (A - P_1) - (B_3 - P_1) \\ = -0.18 - 0.02 = -0.20 \text{ mmHg,}$$

$$(A - B_3)_2 = (A - P_2) - (B_3 - P_2) \\ = -0.19 - 0.01 = -0.20 \text{ mmHg}$$

tions of the individual barometers; A, P_1 , and N, are denoted respectively by a , p , and n , the following equations can be written by the definition of the standard deviation.

$$a^2 + p^2 = 0.037^2$$

$$a^2 + n^2 = 0.045^2$$

$$n^2 + p^2 = 0.036^2$$

Now a is obtained to be 0.03 mmHg.

The value of 0.03 mmHg is reasonable for the accuracy of a single observation with the absolute standard barometer.

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絶 対 標 準 気 圧 計

吉 武 素 二・清 水 逸 郎・竹 内 清 秀
(気 象 庁)

気象庁に最近設置された絶対標準気圧計についてのべる。その構造は、内径 30 mm の硬質ガラスを使用したサイフォン型水銀気圧計に属する。2 つの水銀のメニスカスは水銀だめを動かすことにより形を整えることができる。上のメニスカスの上部は真空にしてあり、ガイスラー管によりその真空度が測定される。下のメニスカスは大気に通じており、2 つのメニスカスの高さの差はカセットメータにより側に並べて吊してある標準尺と比較測定される。水銀柱の温度は、一定の温度に保つようにしてあるウオータージャケットに入れた温度計で測定される。この気圧計の読みの精度は 0.01 mmHg を目指したが、実際測定を行つてみると読みの標準偏差は 0.03 mmHg であつた。気象庁の現在ある標準気圧計の平均補正值は -0.20 mmHg であることがわかつた。