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A DETERMINATION OF THE RELATIVE VALUES OF GRAVITY AT POTSDAM AND WASHINGTON

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A DETERMINATION OF THE RELATIVE VALUES OF GRAVITY AT POTSDAM AND WASHINGTON[1]

ABSTRACT

The first gravity connection between Washington and the international base station at Potsdam, Germany, was made in 1900 by G. R. Putnam, then a member of the Coast and Geodetic Survey. The value determined by Putnam was used as a basis for all precise gravity measurements in the United States up until the adoption of the new value resulting from the 1933 connection with Potsdam which is described in the following pages.

Since 1929 the position of the Washington gravity base station has through necessity been transferred to three different locations because of building operations and for other reasons. This made desirable a new connection with Potsdam because of the resulting slight uncertainty in the value of gravity for the last location of the base in the new Department of Commerce Building. A more important reason for the desirability of a new connection, however, was the fact that a direct connection with Potsdam made by A. H. Miller, of Canada, in 1929 and an indirect one made by F. A. Vening Meinesz in 1928, gave values for Washington several milligals higher than the standard value. Another important justification for the work was that the National Bureau of Standards had requested a connection between that Bureau and Potsdam in order that the recent absolute measurement of gravity made by Paul R. Heyl could be accurately compared with the absolute measurements at Potsdam which have been used as a basis for most of the relative measurements of gravity in all countries of the world during the past 30 or more years. Legislative authority was obtained for the new connection and the observations were started in the fall of 1932 and were completed in March 1933. The values obtained for the two Washington stations are as follows: Department of Commerce, Coast and Geodetic Survey base (adopted value), 980.118 gals (this is 5 milligals higher than the value previously in use); National Bureau of Standards (adopted value), 980.100 gals.

HISTORICAL INTRODUCTION

Relative comparisons of the value of gravity between base stations which have been in existence over a long period of time are principally of interest when considered in the light of the past history of the stations. It is especially interesting to note the changes in the values of gravity which have been determined at different times for the same station. The Washington base station serves as a good example for such a study, as it has been in existence throughout the era of precise gravity observations.

Observations for determining differences of gravity were begun in the United States by C. S. Peirce of the Coast Survey, in 1873. Peirce used invariable and reversible meter pendulums, swung in open air, and with only an approximate correction for the flexure of the support.

[1] The author of this publication lost his life in an accident on June 17, 1935, when he had the preparation of this manuscript nearly completed. Upon examining the manuscript it was found desirable to add a paragraph here and there and to include a few references to publications, but otherwise the text of this publication remains as Lieutenant Brown had written it, with only slight editorial changes.

At the time of his death Lieutenant Brown was working on another publication which was to give a detailed description of the gravity apparatus that was designed and perfected by him in 1931 and 1932 and had been named the Brown gravity apparatus in recognition of his services. Unfortunately only a small part of the manuscript had been written, and it is impracticable to complete that publication at the present time.

In 1875–76 Peirce was sent to Europe to make observations at several gravity base stations which had been used in the great European surveys. Peirce used a Bessel reversible pendulum and observed at Paris, France; Geneva, Switzerland; Berlin, Germany; Kew, England; and Hoboken, New York.[2] This was the first gravity connection between the United States and Europe made by an American observer.

By the end of the nineteenth century there had been a number of connections, some of them rather indirect and made mostly by observers from other countries, between Washington and European base stations. A list of these connections is given by G. R. Putnam in United States Coast and Geodetic Survey Report for 1894, page 48. Omitting one outstanding value made by Kater in 1817, a simple mean of the remaining 29 values in the list as reduced to the Coast and Geodetic Survey base station at 205 New Jersey Avenue SE., Washington, D. C., gives 980.107 gals. The provisional value for this base station which had been adopted several years earlier was 980.098 gals.

The latter remained the adopted value for Washington until 1900, when Putnam made a connection with several of the European stations, the most important of which was Potsdam, later to be designated the international gravity base station. Putnam obtained a value for Washington of 980.111 gals based on Potsdam.[3] This value was changed to 980.112 following the publication of Borrass's world adjustment in 1911.[4]

This value of 980.112 gals remained unquestioned until 1928 when F. A. Vening Meinesz of the Netherlands obtained a value at Washington (New Jersey Avenue base station) of 980.120 with his apparatus.[5] The determination made by Vening Meinesz was not a direct connection with Potsdam, but the rather large difference between the accepted value and the value obtained by him caused some concern.

In 1928 A. H. Miller of the Dominion Observatory, Ottawa, Canada, connected the Canadian base station at Ottawa with Greenwich and Potsdam, and followed this work by a series of observations at Washington (New Jersey Avenue base station) in 1929.[6] Miller obtained a value for Washington of 980.118 gals. This was in fairly close accord with the result obtained by Vening Meinesz and further indicated the probability that the value in use for Washington was too small.

The first gravity base station established in Washington was located in the northeast corner of the basement of the Administration Building of the Smithsonian Institution. In January 1893 the Washington base at the Smithsonian Institution was connected with the base at the Coast and Geodetic Survey office at 205 New Jersey Avenue, SE., where a pendulum room had been established in the southwest corner of the basement. In 1929 the latter base station

[2] See U. S. Coast and Geodetic Survey Report for 1876, pp. 203 and 204.

[3] See U. S. Coast and Geodetic Survey Report for 1901, p. 355.

[4] See Bericht über die relativen Messungen der Schwerkraft mit Pendelapparaten in der Zeit von 1808 bis 1909 und über ihre Darstellungen im Potsdamer Schweresystem by E. Borrass, Comptes Rendus des Séances de la seizième Conférence générale l'Association géodésique internationale, vol. III, 1911, p. 5.

[5] This apparatus was designed especially for gravity work at sea. Dr. Vening Meinesz brought it to this country in 1928 at the invitation of the U. S. Navy and the Carnegie Institution of Washington for work in West Indian waters. See Publications of the United States Naval Observatory, Second Series, Vol. XIII, App. 1, Washington, 1930.

[6] A determination of the relative values of gravity at Potsdam, Greenwich, Ottawa, and Washington, by A. H. Miller, Publications of the Dominion Observatory, Ottawa, Vol. XI, No. 2, 1931.

was destroyed by building operations, and for the next 3 years the original base station at the Smithsonian Institution was used as a reference point. During this period a pendulum room was under construction in the new Department of Commerce Building on Constitution Avenue, NW., and in April and May 1932 a connection was made between it and the Smithsonian Institution. The several changes in the position of the base station since Putnam's connection with Potsdam in 1900, and the uncertainty as to the correctness of the gravity value being used, as shown by the observations of Miller and Vening Meinesz, made it desirable to obtain a new direct connection with the Potsdam base.

It was accordingly decided that at the first opportunity a new direct connection should be made between Washington and Potsdam. The need for such a connection was made more imperative because of the important absolute determination of gravity then being made at the National Bureau of Standards by Paul R. Heyl of that bureau. In order to realize the full international significance from Dr. Heyl's work it was essential that his base of operations be connected to the Potsdam international base with the greatest practicable precision. A request for this connection was made in a letter from the Director of the Bureau of Standards dated August 20, 1930.

PROGRAM OF OBSERVATIONS

Legislative authorization for a Washington-Potsdam gravity connection was obtained for the fiscal year of 1933, and the observations necessary to the execution of the project were carried out by the writer under the Director's Orders and Instructions dated December 22, 1932. A copy of the instructions under which the work was done is given below:

DECEMBER 22, 1932.

To: Lieut. EDWIN J. BROWN,
U. S. Coast and Geodetic Survey,
Washington, D. C.

From: The DIRECTOR,
United States Coast and Geodetic Survey.

Subject: INSTRUCTIONS.

You will please make a determination of the difference in the intensity of gravity between Washington, D. C., and the world gravity base station at Potsdam, Germany. The primary purpose of this work is to obtain a very accurate gravity connection between a station at the Bureau of Standards at which absolute gravity determinations are being made and the Potsdam station. You should also obtain a connection between the new gravity base station at the Commerce Building and Potsdam.

In making the observations you should use the method outlined in the general instructions on pages 32 to 34 of Special Publication No. 69 except that you should strive to obtain greater accuracy than that at an ordinary field station. It is recommended that you use nine pendulums (six of bronze and three of invar) and two knife edges and that you carry out the following program as nearly as feasible: (1) Obtain 12 independent determinations at the Department of Commerce station by swinging each of six pendulums (three bronze and three invar) on each of the two knife edges, each determination to begin and end with an accurate comparison of your chronometers with the clock at the Naval Observatory either by means of radio time signals or a direct wire connection. (2) Obtain 18 independent determinations at the Bureau of Standards by swinging each of the nine pendulums on each of the two knife edges. The Shortt clock used by Dr. Heyl for his absolute-gravity determinations will give you excellent time control for this part of the work if it is available. (3) Obtain 18 independent determinations at the Potsdam station by again swinging each of the nine pendulums on each of the two knife edges. The time control for this part of the work can probably be obtained from the Potsdam Observatory but in any case you should make sure that the accuracy of the time control is unquestionably sufficient for the purpose. (4) Obtain 18 independent determinations at the Bureau of Standards by swinging each of the nine pendulums on each of the two knife edges. (5) Obtain 12 independent determinations at the Department of Commerce station by swinging each of six pendulums (three bronze and three invar) on each of the two knife edges.

Preliminary arrangements for the work at Potsdam have been made with Dr. E. Kohlschütter, director of the Geodetic Institute at Potsdam. Upon your arrival at Potsdam you should get in touch with Dr. Kohlschütter in order to complete the arrangements.

APPARATUS AND OBSERVING METHODS

The Mendenhall quarter-meter pendulum apparatus developed by the Coast and Geodetic Survey was used for the observations. This apparatus is described in Special Publication No. 69 of this Bureau. One important change was made, however, in the coincidence apparatus which is used in comparing the pendulums with the timepiece. The mechanical device for opening the shutter of the flash box was replaced by a neon tube which was made to flash at each second of the timepiece by means of a thermionic coupling. This made it possible to obtain greater accuracy in the comparisons.

The individual swings of the pendulums were of 12 hours' duration. Two knife edges were used, and each pendulum was swung twice on each of the knife edges. In all other respects the observations were carried out in the usual manner described in Special Publication No. 69.

Flexure corrections were determined by means of a Peters' type of interferometer, a measurement being made at the beginning and end of the swings on each knife edge. This normally required four measurements at each station occupied, the knife edges being changed but once at each station.

Conditions for flexure measurement were excellent at both the Commerce Building and the Bureau of Standards. At Potsdam conditions were less satisfactory, but fairly accurate observations could be made during the early morning hours, and the required precision was obtained by increasing the number of observations.

The invar pendulums were tested for magnetism, by means of a sensitive compass needle, before and after each swing. The invar dummy pendulum which serves as a holder for the thermometer inside the receiver was also tested at the beginning and end of each series of observations. It has been found by experiment that to cause an appreciable effect on the period, an invar pendulum of the type used must be magnetized sufficiently to produce a deflection of the compass needle exceeding 3 degrees of arc, with the compass pivot placed 13 centimeters from the pendulum head. For the work described, the needle was made much more sensitive to deflection by reducing the pivot distance to 9 centimeters. On one swing the observed deflection reached 3 degrees. For all other swings the deflection in no case exceeded 2 degrees, and averaged about 40 minutes. The practice followed was to demagnetize the pendulum by use of a solenoid whenever the deflection of the compass needle exceeded 40 minutes.

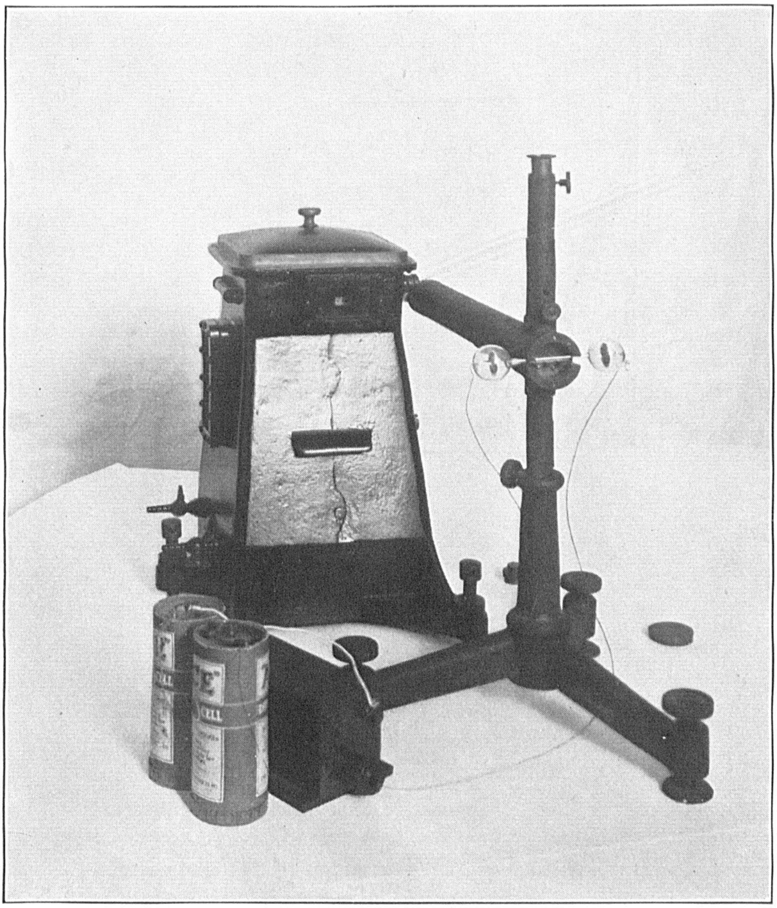

FIGURE 1.—GRAVITY RECEIVER AND INTERFEROMETER.

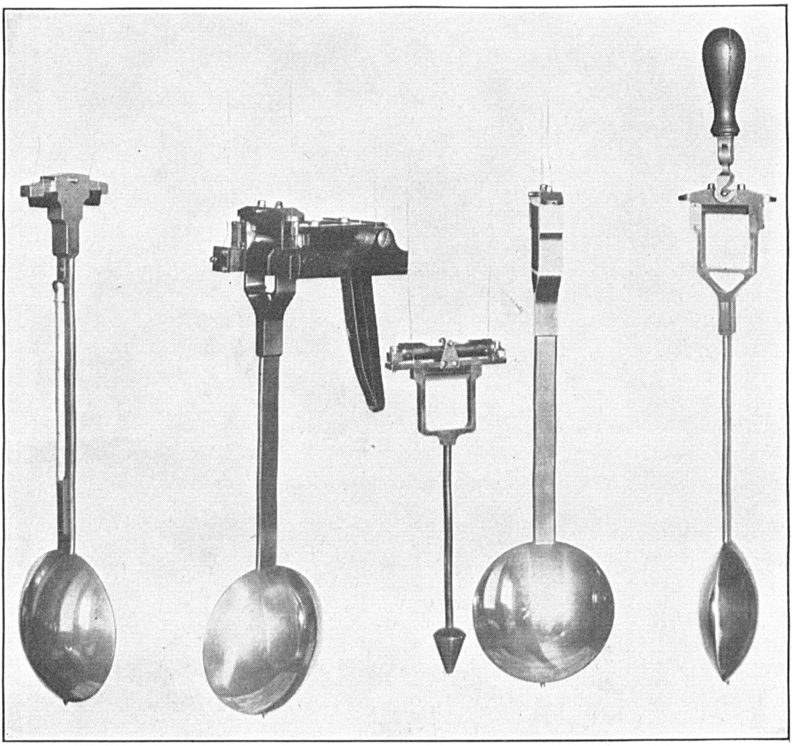

FIGURE 2.—GRAVITY PENDULUMS AND KNIFE EDGE.

At left is shown the dummy pendulum which holds the thermometer. It is not allowed to swing. The small pendulum at the center carries a level vial and is used to level the knife edge. The other three views are of the gravity pendulum. The manner of supporting it on the knife edge is shown to the left of the center.

For the observations at the Commerce Building base, time was furnished by a direct wire connection to one of the transmitting clocks at the United States Naval Observatory. This clock was compared with the standard clocks of the Observatory at each observing period. Clock corrections and rates were furnished by the Observatory time service.

At the Bureau of Standards a connection was made to the Shortt clock which is used as a timepiece for the absolute-gravity determinations. The time was taken "photo-electrically" from the master pendulum of the Shortt clock. Dr. Heyl's staff furnished the clock corrections and rates, which were determined by means of daily comparisons with the United States Naval Observatory radio time signals.

At Potsdam connection was made to the standard Riefler Clock No. 186 of the Geodetic Institute, one of three similar standard clocks. The clock corrections were obtained by star observations made by the Geodetic Institute, and the rates used were based on intercomparison of all three clocks. The accuracy of the clock corrections was increased by daily comparisons, at 1 p. m., with the crystal clocks of the Physikalisch-Technische Reichsanstalt. The comparisons made with the crystal clocks proved particularly valuable throughout the period of the gravity observations as but few clear nights were available for star observations.

LOCATIONS AND ELEVATIONS OF STATIONS

The Commerce Building base is in the specially constructed gravity room no. B 817 in the basement of the Department of Commerce Building, about 200 feet from the southwest corner of the building. It is now used by the Coast and Geodetic Survey as a base for all field gravity observations. The observations were made on the west pier. The top of this pier is 0.7 foot above mean sea level, and about 5 feet below the ground level.

The observations at the Bureau of Standards were made in a subbasement of the East Building, in the small room adjoining that used by Dr. Heyl in making the absolute measurements. The gravity receiver was placed on the concrete floor of the basement. This floor is 297.9 feet above mean sea level and about 31 feet below ground level.

The observations at Potsdam were made on the pier in the Ostkeller of the Geodetic Institute. The Ostkeller is one floor below the room in which the Potsdam absolute measurements were made. It is the same room used by Putnam in 1900, and adjoins the room in which Miller observed in 1928. The knife edge of the Coast and Geodetic Survey apparatus was found to be 4.48 meters below the knife edge of the absolute apparatus. The value of gravity deduced for the Ostkeller pier is 981.2750 gals, this being the value that Miller used for essentially the same location. The following translation of a letter received from Dr. Kohlschütter explains the relationship of the various gravity determinations made at the Geodetic Institute at Potsdam.

POTSDAM, GERMANY,
April 9, 1935.

The DIRECTOR,
United States Coast and Geodetic Survey,
Washington, D. C.

DEAR DIRECTOR: Dr. Putnam, as well as Lieutenant Brown, made their observations in the pendulum cellar, which is designated as northeast cellar in the Veröffentlichungen des Geodätischen Instituts; in verbal conversation it is usually called "east cellar" since there is no other observing cellar on the east side of the building. Undoubtedly both men observed in the same room. The elevation of the present pendulum pier which Lieutenant Brown used is 82.64 meters above sea level. The elevation of the pier used by Dr. Putnam may have been several centimeters different—not more than 10 centimeters. That pier probably stood at the same place as the one used by Lieutenant Brown, since as early as 1897 I made my standardizations for the gravity measurement in German East Africa at the same place, and since then have made all gravity connections to this place. This place is 21 meters N. 65° E. from the pier used by Kühnen and Furtwängler for the absolute gravity determination.

The absolute gravity value for Potsdam Geodätischen Instituts Pendelsaal is 981.274 gals and is referred to the elevation 87.00 meters above sea level.

(Signed) KOHLSCHÜTTER.

CHRONOLOGY

The first series of observations made at the Commerce Building base were begun on November 26, 1932, and were completed on December 14. The apparatus was then moved to the Bureau of Standards where observations were started on December 19, 1932, and were completed January 8, 1933.

Before the instruments were shipped to Germany, authority was obtained, through the German Ambassador in Washington, for free entry of the equipment into Germany. A detailed declaration was also made for the use of the United States Customs on reentry of the equipment into the United States. The instruments were packed at the Coast and Geodetic Survey Office in the presence of a United States customs inspector in order that they might be placed aboard ship at Baltimore without the necessity of customs inspection at that place.

The writer sailed from Baltimore on the S. S. *City of Baltimore* on January 18, 1933, arriving in Hamburg on January 31. The instruments were shipped by express from Hamburg to the Geodetic Institute at Potsdam, where they arrived on February 2. Observations were begun at Potsdam on February 4 and completed February 25.

Embarkation was made at Bremen on the S. S. *City of Newport News*, on March 3, 1933, for the return voyage. At 11:40 a. m. on the following day, while steaming through fog off Borkum Riff, the *Newport News* was in collision with the S. S. *Arucas*, and was heavily damaged. The hold in which the gravity instruments were stowed was cut open and flooded, but as the instruments were above the water line on the opposite side of the hold from the point of collision, they suffered no damage, either from water or shock.

Following the collision, the *Newport News* proceeded to Hamburg under her own power, arriving there March 5. On the arrival of the S. S. *City of Baltimore* in Hamburg, transfer was made to that ship, which sailed from Hamburg on March 10 and arrived in Baltimore on March 23.

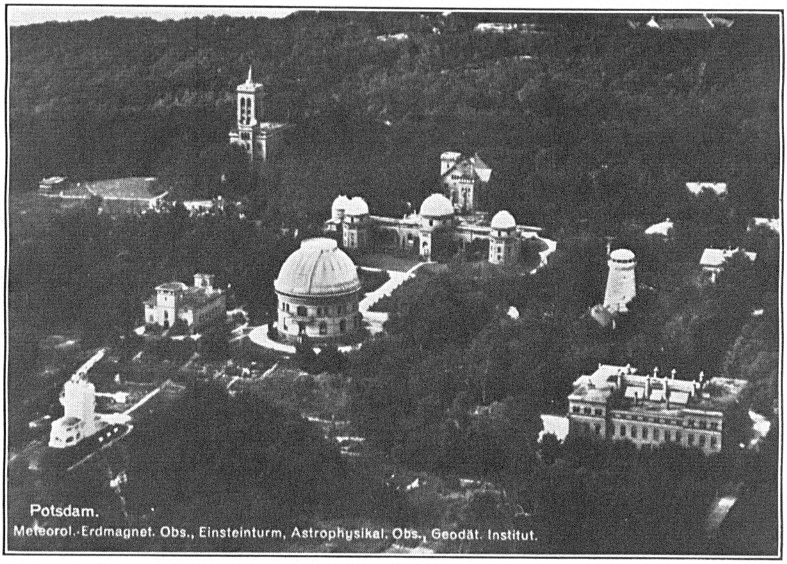

FIGURE 3.—GEODETIC INSTITUTE AT POTSDAM.

The Geodetic Institute is the rectangular-shaped building in the right foreground. The gravity observations were made in the basement in the far right-hand corner of the building.

The second series of observations at the Bureau of Standards were begun on April 1, 1933, and completed April 20. The instruments were then taken to the Commerce Building base for the final observations at that point, which were begun April 23 and completed May 6.

The work incidental to the observations at the Washington stations was made much easier by the kindness of Capt. J. F. Hellweg, superintendent of the Naval Observatory, officials of the Observatory Time Service, and by the cooperation of Dr. Heyl's staff at the Bureau of Standards, in permitting connections to be made directly to their accurate clocks, and in furnishing the clock corrections and rates for the periods of observation. A great deal of assistance was also received at the Geodetic Institute at Potsdam, where Dr. Kohlschütter and his staff, by their kindly services, made the performance of the work a very pleasant task.

All ocean travel was made on ships of the Baltimore Mail Line, and appreciation is expressed for the many courtesies extended by Captain Cross of the *City of Baltimore* and Captain Wright of the *City of Newport News*. The care exercised by them in the handling and stowage of the gravity instruments had an important bearing on the successful completion of the gravity observations. In particular was this true at the time of the accident to the *Newport News*, where careful stowage alone saved the instruments from great damage.

RESULTS OF THE OBSERVATIONS

The pendulum observations and reductions are given in table I. An abstract of the values of the periods and the period differences between the stations is given in table II. The chief purpose of presenting this table is to show the comparative results obtained at the first and second occupation of the Washington stations. In table III are shown the final gravity results for each pendulum on each of the two knife edges.

49079°—36——2

TABLE I.—*Pendulum observations and reductions*

COMMERCE BUILDING BASE

Swing no.	Pendulum[1]	Knife edge	Date	Total arc		Temperature	Pressure	Period uncorrected	Corrections (seventh decimal place)					Period corrected
				Initial	Final				Arc	Temperature	Pressure	Rate	Flexure	
			1932	*mm*	*mm*	° *C.*	*mm*	*s.*						*s.*
7	A-4	A-II	Dec. 1	7.9	1.7	21.79	61.85	0.5008718	−17	−280	+3	−2	−12	0.5008410
8	A-4	A-II	Dec. 2	8.1	1.5	21.56	68.05	.5008717	−17	−271	−3	+1	−12	.5008415
9	A-5	A-II	do	8.2	1.8	21.85	56.55	.5007005	−19	−286	+8	−2	−12	.5006694
10	A-5	A-II	Dec. 3	8.2	1.6	22.05	56.75	.5007004	−18	−295	+8	+1	−12	.5006688
11	A-6	A-II	do	7.8	1.6	22.20	56.75	.5006677	−17	−301	+8	0	−12	.5006355
12	A-6	A-II	Dec. 4	8.2	1.6	22.35	57.9	.5006683	−18	−307	+7	−1	−12	.5006352
3	B-7	A-II	Nov. 29	7.9	1.8	20.16	57.85	.5008880	−18	−14	+6	−3	−12	.5008839
4	B-7	A-II	Nov. 30	7.8	1.8	20.31	60.15	.5008879	−18	−15	+4	+1	−12	.5008839
5	B-8	A-II	do	8.2	2.0	20.56	57.85	.5008198	−20	−16	+6	−1	−12	.5008155
6	B-8	A-II	Dec. 1	8.2	1.8	20.91	61.25	.5008201	−19	−17	+3	−2	−12	.5008154
1	B-9	A-II	Nov. 26	7.9	1.9	21.36	56.25	.5007922	−18	−18	+7	+2	−12	.5007883
2	B-9	A-II	Nov. 28	7.7	1.7	19.81	63.5	.5007919	−16	−13	+1	−1	−12	.5007878
17	A-4	A-I	Dec. 7	8.1	1.8	22.77	57.45	.5008756	−19	−321	+7	−1	−11	.5008411
18	A-4	A-I	Dec. 8	8.1	1.6	22.85	58.2	.5008759	−18	−324	+6	+1	−11	.5008413
21	A-5	A-I	Dec. 9	8.1	1.7	23.50	58.5	.5007076	−18	−355	+6	−3	−11	.5006695
22	A-5	A-I	Dec. 10	8.0	1.6	23.80	60.05	.5007086	−17	−368	+5	+3	−11	.5006698
19	A-6	A-I	Dec. 8	8.2	1.7	22.90	61.6	.5006715	−18	−330	+3	0	−11	.5006359
20	A-6	A-I	Dec. 9	8.3	1.5	22.90	65.1	.5006720	−17	−330	0	−4	−11	.5006358
13	B-7	A-I	Dec. 5	7.8	1.8	22.31	56.35	.5008902	−18	−20	+7	+1	−11	.5008861
14	B-7	A-I	Dec. 6	7.9	1.9	22.31	56.55	.5008906	−18	−20	+7	0	−11	.5008864
25	B-7	A-I	Dec. 14	8.2	2.0	21.81	58.8	.5008909	−20	−19	+5	0	−12	.5008863
15	B-8	A-I	Dec. 6	8.2	2.1	22.31	57.1	.5008213	−21	−20	+6	−1	−11	.5008166
16	B-8	A-I	Dec. 7	8.1	1.8	22.51	57.8	.5008211	−19	−21	+6	−1	−11	.5008165
23	B-9	A-I	Dec. 13	8.1	1.9	21.81	60.1	.5007943	−19	−19	+4	0	−12	.5007897
24	B-9	A-I	do	8.0	1.8	21.81	60.9	.5007942	−18	−19	+3	0	−12	.5007896

BUREAU OF STANDARDS

Swing no.	Pendulum[1]	Knife edge	Date	Total arc Initial	Total arc Final	Temperature	Pressure	Period uncorrected	Arc	Temperature	Pressure	Rate	Flexure	Period corrected
1	A-4	A-I	Dec. 19	8.5	2.0	21.15	49.15	0.5008734	−21	−254	+15	−2	−10	0.5008462
2	A-4	A-I	Dec. 19-20	8.6	1.8	21.15	49.95	.5008734	−20	−254	+14	−2	−10	.5008462
3	A-5	A-I	Dec. 20	8.4	1.3	21.15	51.8	.5007024	−16	−257	+12	−2	−10	.5006751
4	A-5	A-I	Dec. 21	8.5	2.0	21.15	52.65	.5007029	−21	−257	+11	−2	−10	.5006750
5	A-6	A-I	do	8.2	1.8	21.13	49.8	.5006687	−19	−256	+14	−2	−10	.5006414
6	A-6	A-I	Dec. 21-22	8.4	2.0	21.15	50.65	.5006689	−21	−257	+13	−1	−10	.5006413
13	B-4	A-I	Dec. 25-26	8.2	2.35	21.23	12.0	.5008565	−22	−261	+49	−1	−10	.5008320
14	B-4	A-I	Dec. 26	7.85	1.7	21.33	59.45	.5008612	−17	−265	+5	−1	−10	.5008324
15	B-5	A-I	Dec. 26-27	8.3	1.6	21.35	61.0	.5007545	−18	−265	+3	−1	−10	.5007254
16	B-5	A-I	Dec. 27	8.55	1.9	21.35	61.2	.5007556	−20	−265	+3	−1	−10	.5007263
17	B-6	A-I	Dec. 27-28	8.1	1.5	21.30	62.85	.5007400	−17	−261	+2	−2	−10	.5007112
18	B-6	A-I	Dec. 28	8.1	1.5	21.27	63.65	.5007399	−17	−260	+1	−2	−10	.5007111
7	B-7	A-I	Dec. 22	8.5	2.0	21.06	53.9	.5008945	−21	−17	+9	−1	−10	.5008905
8	B-7	A-I	Dec. 22-23	8.1	2.7	21.21	54.9	.5008952	−23	−17	+8	−2	−10	.5008908
9	B-8	A-I	Dec. 23	8.3	2.6	21.56	57.3	.5008256	−24	−18	+6	−2	−10	.5008208
10	B-8	A-I	Dec. 23-24	8.0	2.1	21.31	61.75	.5008254	−20	−18	+3	−1	−10	.5008208
11	B-9	A-I	Dec. 24	7.8	2.3	21.26	60.0	.5007979	−20	−18	+4	−1	−10	.5007934
12	B-9	A-I	Dec. 24-25	8.8	1.8	21.31	11.85	.5007943	−21	−18	+44	−1	−10	.5007937
19	A-4	A-II	Dec. 28-29	8.1	1.65	21.35	62.05	.5008753	−18	−262	+2	−2	−9	.5008464
20	A-4	A-II	Dec. 29	8.1	1.65	21.35	62.85	.5008751	−18	−262	+2	−2	−9	.5008462
21	A-5	A-II	Dec. 29-30	8.3	1.4	21.35	61.0	.5007021	−16	−265	+3	−2	−9	.5006732
22	A-5	A-II	Dec. 30	8.5	1.45	21.35	61.25	.5007027	−18	−265	+3	−2	−9	.5006736
23	A-6	A-II	Dec. 30-31	8.5	1.6	21.35	31.1	.5006649	−19	−265	+31	−2	−9	.5006385
			1933											
30	A-6	A-II	Jan. 4-5	8.5	1.55	21.10	40.1	.5006655	−18	−255	+23	−1	−9	.5006395
31	B-4	A-II	Jan. 5	8.0	2.2	21.25	62.4	.5008584	−20	−262	+2	0	−9	.5008295
32	B-4	A-II	Jan. 5-6	8.0	1.6	21.25	63.0	.5008587	−17	−262	+2	−1	−9	.5008300
33	B-5	A-II	Jan. 6	8.15	1.6	21.13	61.5	.5007528	−18	−256	+3	−2	−9	.5007246
34	B-5	A-II	Jan. 6-7	8.2	1.8	21.13	62.75	.5007532	−19	−256	+2	−4	−9	.5007246
35	B-6	A-II	Jan. 7	8.2	1.6	21.10	60.9	.5007410	−18	−253	+3	−5	−9	.5007128
36	B-6	A-II	Jan. 7-8	8.1	1.45	21.10	61.2	.5007409	−17	−253	+3	−5	−9	.5007128
24	B-7	A-II	Dec. 31-Jan. 1	8.7	1.55	21.31	10.5	.5008884	−19	−18	+45	−2	−9	.5008881
25	B-7	A-II	Jan. 1-2	8.8	1.55	21.23	10.8	.5008888	−19	−17	+44	−2	−9	.5008885
26	B-8	A-II	Jan. 2-3	8.7	1.8	21.03	11.35	.5008205	−21	−17	+44	−2	−9	.5008200
27	B-8	A-II	Jan. 3	8.2	1.9	21.09	57.45	.5008246	−19	−17	+6	−2	−9	.5008205
28	B-9	A-II	Jan. 3-4	8.05	1.8	21.06	61.05	.5007976	−18	−17	+3	−3	−9	.5007932
29	B-9	A-II	Jan. 4	7.9	2.0	21.21	61.35	.5007979	−19	−17	+3	−4	−9	.5007933

[1] Pendulums B-7, B-8, and B-9 are of invar. The others are of bronze.

TABLE I.—*Pendulum observations and reductions*—Continued

POTSDAM BASE

Swing no.	Pendulum [1]	Knife edge	Date	Total arc		Temperature	Pressure	Period uncorrected	Corrections (seventh decimal place)					Period corrected
				Initial	Final				Arc	Temperature	Pressure	Rate	Flexure	
			1933	*mm*	*mm*	° *C.*	*mm*	*s.*						*s.*
1	A-4	A-II	Feb. 4	8.3	2.1	3.20	42.41	0.5004979	−21	+487	+19	+18	−13	0.5005469
2	A-4	A-II	Feb. 4-5	8.4	1.6	3.30	45.05	.5004982	−19	+483	+16	+18	−13	.5005467
3	A-5	A-II	Feb. 5	8.2	1.9	3.55	46.3	.5003262	−19	+479	+15	+19	−13	.5003743
4	A-5	A-II	Feb. 5-6	8.1	1.75	3.74	49.2	.5003269	−18	+471	+12	+20	−13	.5003741
5	A-6	A-II	Feb. 6	8.2	2.1	3.89	42.68	.5002936	−21	+464	+18	+20	−13	.5003404
6	A-6	A-II	Feb. 6-7	8.2	1.95	3.96	49.11	.5002944	−20	+461	+12	+21	−13	.5003405
7	B-4	A-II	Feb. 7	8.05	2.2	4.05	44.0	.5004863	−20	+459	+17	+21	−13	.5005327
8	B-4	A-II	Feb. 7-8	8.45	1.7	4.08	53.0	.5004878	−19	+458	+8	+21	−13	.5005333
9	B-5	A-II	Feb. 8	8.05	2.15	4.19	40.75	.5003795	−20	+452	+20	+21	−13	.5004255
10	B-5	A-II	Feb. 8-9	8.0	1.9	4.32	43.56	.5003798	−18	+446	+17	+21	−13	.5004251
11	B-6	A-II	Feb. 9	8.3	2.0	4.39	47.6	.5003696	−20	+440	+13	+22	−13	.5004138
12	B-6	A-II	Feb. 9-10	8.0	1.65	4.50	53.0	.5003702	−17	+436	+8	+22	−13	.5004138
13	B-7	A-II	Feb. 10	7.95	2.4	4.65	43.0	.5005848	−21	+29	+16	+22	−13	.5005881
14	B-7	A-II	Feb. 10-11	8.5	2.6	4.60	43.5	.5005851	−25	+29	+15	+21	−13	.5005878
15	B-8	A-II	Feb. 11	7.95	2.4	4.50	48.1	.5005174	−21	+29	+12	+22	−13	.5005203
16	B-8	A-II	Feb. 11-12	8.1	1.95	4.40	48.9	.5005174	−20	+30	+11	+23	−13	.5005205
17	B-9	A-II	Feb. 12	8.2	2.25	4.40	53.0	.5004889	−22	+30	+7	+23	−13	.5004914
18	B-9	A-II	Feb. 12-13	8.2	2.1	4.55	53.7	.5004890	−21	+29	+6	+23	−13	.5004914
19	B-7	A-I	Feb. 13	8.2	2.3	4.83	50.19	.5005875	−22	+28	+10	+23	−12	.5005902
20	B-7	A-I	Feb. 13-14	8.15	2.0	4.80	48.0	.5005874	−20	+29	+12	+23	−12	.5005906
21	B-8	A-I	Feb. 14	8.2	2.1	4.83	54.0	.5005150	−21	+28	+6	+24	−12	.5005175
22	B-8	A-I	Feb. 14-15	8.4	2.1	4.66	45.5	.5005154	−22	+29	+14	+24	−12	.5005187
23	B-9	A-I	Feb. 15	8.2	2.5	4.74	51.5	.5004912	−23	+29	+8	+24	−12	.5004938
24	B-9	A-I	Feb. 15-16	8.0	1.9	4.60	53.9	.5004911	−18	+29	+6	+23	−12	.5004939
25	B-4	A-I	Feb. 16	8.0	2.75	4.48	48.5	.5004891	−24	+441	+12	+24	−12	.5005332
26	B-4	A-I	Feb. 16-17	7.95	2.0	4.32	52.2	.5004885	−19	+447	+9	+24	−12	.5005334
27	B-5	A-I	Feb. 17	8.0	2.3	4.30	51.5	.5003823	−21	+447	+9	+24	−12	.5004270
28	B-5	A-I	Feb. 17-18	8.2	1.9	4.37	54.7	.5003831	−19	+444	+6	+23	−12	.5004273
29	B-6	A-I	Feb. 18	8.4	2.0	4.45	47.0	.5003678	−21	+438	+14	+24	−12	.5004121
30	B-6	A-I	Feb. 18-19	8.15	1.85	4.38	51.8	.5003678	−19	+441	+9	+24	−12	.5004121
31	A-4	A-I	Feb. 19	8.1	1.9	4.38	50.49	.5005015	−19	+439	+11	+24	−12	.5005458
32	A-4	A-I	Feb. 19-20	8.25	1.8	4.38	54.7	.5005018	−19	+439	+6	+24	−12	.5005456
33	A-5	A-I	Feb. 20	8.2	1.8	4.30	45.9	.5003301	−19	+447	+15	+24	−12	.5003756
34	A-5	A-I	Feb. 20-21	8.2	1.85	4.13	52.95	.5003300	−19	+454	+8	+23	−12	.5003754
35	A-6	A-I	Feb. 21	8.4	2.1	4.12	45.4	.5002956	−22	+455	+16	+24	−12	.5003417
36	A-6	A-I	Feb. 21-22	8.2	1.9	3.98	50.75	.5002951	−19	+461	+10	+24	−12	.5003415
37	B-8	A-I	Feb. 22	8.1	2.6	3.83	45.3	.5005183	−23	+31	+14	+22	−12	.5005215
38	B-8	A-I	Feb. 22-23	8.5	2.4	3.83	50.85	.5005189	−23	+31	+9	+19	−12	.5005213
39	B-9	A-II	Feb. 23	8.25	1.7	3.75	49.8	.5004888	−18	+32	+10	+18	−12	.5004918
40	B-4	A-II	Feb. 23-24	7.95	2.45	3.72	50.61	.5004874	−22	+473	+10	+18	−12	.5005341
41	B-4	A-II	Feb. 24	7.95	2.4	3.64	53.94	.5004875	−21	+476	+7	+18	−12	.5005343
42	B-9	A-II	Feb. 24-25	7.9	2.8	3.63	48.95	.5004892	−23	+32	+10	+18	−12	.5004917
43	B-9	A-II	Feb. 25	7.5	4.0	3.73	52.2	.5004900	−28	+32	+8	+18	−12	.5004918
44	B-4	A-II	do	7.75	3.5	3.73	46.7	.5004875	−26	+472	+14	+18	−12	.5005341

BUREAU OF STANDARDS

Swing no.	Pendulum [1]	Knife edge	Date	Initial arc	Final arc	Temperature	Pressure	Period uncorrected	Arc	Temperature	Pressure	Rate	Flexure	Period corrected
1	A-4	A-I	Apr. 1	7.85	1.8	21.25	54.1	0.5008742	−18	−258	+10	−2	−10	0.5008464
2	A-4	A-I	Apr. 1-2	8.3	1.7	21.30	56.6	.5008740	−18	−260	+7	−2	−10	.5008457
3	A-5	A-I	Apr. 2	8.3	2.25	21.23	56.35	.5007036	−22	−260	+8	−2	−10	.5006750
4	A-5	A-I	Apr. 2-3	8.15	1.7	21.15	48.3	.5007026	−18	−257	+15	−2	−10	.5006754
5	A-6	A-I	Apr. 3	8.2	1.7	21.25	57.85	.5006702	−18	−261	+6	−2	−10	.5006417
6	A-6	A-I	Apr. 3-4	8.4	1.85	21.23	59.35	.5006705	−20	−260	+5	−2	−10	.5006418
7	B-4	A-I	Apr. 4	8.2	1.9	21.15	50.95	.5008619	−19	−258	+13	−2	−10	.5008343
8	B-4	A-I	Apr. 4-5	8.1	1.9	21.13	53.2	.5008609	−19	−257	+11	−2	−10	.5008332
37	B-4	A-I	Apr. 19-20	8.2	2.1	21.55	50.85	.5008629	−21	−274	+13	−1	−11	.5008335
38	B-4	A-I	Apr. 20	7.95	1.85	21.47	53.95	.5008623	−18	−271	+10	−1	−11	.5008332
9	B-5	A-I	Apr. 5	7.95	1.7	21.13	54.85	.5007547	−17	−256	+9	−2	−10	.5007271
10	B-5	A-I	Apr. 5-6	8.3	2.05	21.15	56.5	.5007553	−20	−257	+8	−2	−10	.5007272
11	B-6	A-I	Apr. 6	8.15	1.90	21.13	53.8	.5007400	−19	−254	+10	−2	−10	.5007125
12	B-6	A-I	Apr. 6-7	8.2	1.95	21.17	55.35	.5007400	−20	−256	+9	−2	−10	.5007121

[1] Pendulums B-7, B-8, and B-9 are of invar. The others are of bronze.

TABLE I.—*Pendulum observations and reductions*—Continued

BUREAU OF STANDARDS—Continued

Swing no.	Pendulum [1]	Knife edge	Date	Total arc: Initial	Total arc: Final	Temperature	Pressure	Period uncorrected	Corrections (seventh decimal place): Arc	Temperature	Pressure	Rate	Flexure	Period corrected
			1933	*mm*	*mm*	° *C.*	*mm*	*s.*						*s.*
13	B-7	A-I	Apr. 7	7.95	2.1	21.08	51.95	.5008952	−20	−17	+10	−2	−10	.5008913
14	B-7	A-I	Apr. 7-8	8.0	2.15	21.26	52.85	.5008954	−20	−18	+10	−2	−10	.5008914
15	B-8	A-I	Apr. 8	8.2	2.4	21.31	60.8	.5008264	−22	−18	+3	−2	−10	.5008215
16	B-8	A-I	Apr. 8-9	8.3	1.8	21.41	51.0	.5008255	−19	−18	+11	−2	−10	.5008217
17	B-9	A-I	Apr. 9	8.1	2.3	21.29	54.05	.5007990	−21	−18	+9	−1	−10	.5007949
18	B-9	A-I	Apr. 9-10	8.3	2.2	21.31	55.9	.5007990	−21	−18	+7	−1	−10	.5007947
31	A-4	A-II	Apr. 16	7.95	2.6	21.45	54.55	.5008751	−23	−266	+9	−2	−11	.5008458
32	A-4	A-II	Apr. 16-17	8.25	1.75	21.43	55.65	.5008749	−18	−266	+8	−2	−11	.5008460
33	A-5	A-II	Apr. 17	8.3	1.7	21.53	56.1	.5007035	−18	−273	+8	−2	−11	.5006739
34	A-5	A-II	Apr. 17-18	8.4	1.8	21.57	57.55	.5007039	−20	−275	+7	−2	−11	.5006738
35	A-6	A-II	Apr. 18	8.35	2.25	21.55	72.8	.5006717	−22	−274	−8	−2	−11	.5006400
36	A-6	A-II	Apr. 19	8.5	2.0	21.55	47.45	.5006697	−21	−274	+17	−2	−11	.5006406
25	B-4	A-II	Apr. 13	8.0	1.8	21.40	57.15	.5008625	−18	−268	+7	−1	−11	.5008334
26	B-4	A-II	Apr. 13-14	8.2	1.8	21.43	58.65	.5008627	−19	−269	+6	−1	−11	.5008333
27	B-5	A-II	Apr. 14	8.15	1.8	21.38	55.9	.5007539	−19	−267	+8	−1	−11	.5007249
28	B-5	A-II	Apr. 14-15	8.45	1.85	21.43	57.6	.5007543	−20	−269	+7	−1	−11	.5007249
29	B-6	A-II	Apr. 15	8.2	2.0	21.55	53.7	.5007426	−20	−272	+10	0	−11	.5007133
30	B-6	A-II	Apr. 15-16	8.3	1.5	21.53	45.85	.5007412	−17	−271	+18	−1	−11	.5007130
19	B-7	A-II	Apr. 10	8.3	2.2	21.31	55.2	.5008936	−21	−18	+8	−1	−11	.5008893
20	B-7	A-II	Apr. 10-11	8.5	2.2	21.36	56.8	.5008937	−22	−18	+7	−1	−11	.5008892
21	B-8	A-II	Apr. 11	8.45	2.2	21.36	53.9	.5008246	−22	−18	+9	−1	−11	.5008203
22	B-8	A-II	Apr. 11-12	8.25	2.1	21.46	56.5	.5008247	−21	−18	+7	−2	−11	.5008202
23	B-9	A-II	Apr. 12	8.25	2.05	21.36	54.4	.5007971	−20	−18	+8	−2	−11	.5007928
24	B-9	A-II	Apr. 12-13	8.15	2.15	21.41	56.2	.5007973	−21	−18	+7	−1	−11	.5007929

COMMERCE BUILDING BASE

Swing no.	Pendulum [1]	Knife edge	Date	Total arc: Initial	Total arc: Final	Temperature	Pressure	Period uncorrected	Corrections (seventh decimal place): Arc	Temperature	Pressure	Rate	Flexure	Period corrected
19	A-4	A-II	May 3	8.1	1.8	23.98	49.9	0.5008804	−19	−371	+14	−1	−11	0.5008416
20	A-4	A-II	May 4	8.1	1.8	23.97	51.05	.5008797	−19	−370	+13	+2	−11	.5008412
21	A-5	A-II	do	8.2	1.6	23.74	61.5	.5007077	−18	−365	+4	+2	−11	.5006689
22	A-5	A-II	May 5	8.4	1.9	23.32	45.05	.5007055	−20	−348	+19	+1	−11	.5006696
23	A-6	A-II	do	8.5	1.95	23.14	46.05	.5006710	−21	−340	+18	0	−11	.5006356
24	A-6	A-II	May 6	8.15	1.75	23.09	49.25	.5006709	−18	−338	+15	+1	−11	.5006358
17	B-7	A-II	May 2	8.35	2.2	24.25	49.05	.5008892	−22	−26	+13	0	−11	.5008846
18	B-7	A-II	May 3	8.25	2.0	24.4	55.15	.5008895	−20	−26	+8	+1	−11	.5008847
15	B-8	A-II	May 1	8.5	2.2	23.82	48.0	.5008199	−22	−25	+14	+2	−11	.5008157
16	B-8	A-II	May 2	8.2	2.0	24.08	52.05	.5008203	−20	−25	+10	0	−11	.5008157
13	B-9	A-II	Apr. 30	8.35	2.2	23.45	48.05	.5007913	−22	−24	+14	−1	−11	.5007869
14	B-9	A-II	May 1	8.35	2.0	23.6	54.7	.5007928	−20	−24	+8	+1	−11	.5007882
1	A-4	A-I	Apr. 24	7.9	1.35	22.25	67.35	.5008746	−15	−299	−2	0	−11	.5008419
2	A-4	A-I	Apr. 25	8.3	1.9	22.57	47.75	.5008740	−19	−313	+16	+3	−11	.5008416
3	A-5	A-I	do	8.2	1.8	23.53	51.15	.5007084	−19	−357	+13	0	−11	.5006710
4	A-5	A-I	Apr. 26	8.3	1.7	23.74	55.5	.5007090	−18	−365	+9	+1	−11	.5006706
5	A-6	A-I	do	8.3	1.8	23.12	52.5	.5006727	−19	−339	+12	−1	−11	.5006369
6	A-6	A-I	Apr. 27	8.1	1.55	22.90	61.0	.5006727	−17	−330	+4	0	−11	.5006373
11	B-7	A-I	Apr. 29	8.2	2.2	23.35	49.0	.5008907	−21	−23	+13	+1	−11	.5008866
12	B-7	A-I	Apr. 30	8.1	1.95	23.5	56.05	.5008915	−20	−24	+7	0	−11	.5008867
9	B-8	A-I	Apr. 28	8.4	2.1	22.83	52.7	.5008211	−22	−22	+10	+1	−11	.5008167
10	B-8	A-I	Apr. 29	8.1	1.9	23.11	55.5	.5008215	−19	−23	+8	−1	−11	.5008169
7	B-9	A-I	Apr. 27	8.3	2.05	22.46	51.1	.5007945	−20	−21	+11	0	−11	.5007904
8	B-9	A-I	Apr. 28	8.05	1.85	22.61	59.15	.5007946	−19	−21	+5	+3	−11	.5007903

[1] Pendulums B-7, B-8, and B-9 are of invar. The others are of bronze.

TABLE II.—*Period differences between Washington stations and Potsdam*

Pendulum [1]	Knife-edge	Period Potsdam base	First Washington series				Second Washington series			
			Period Commerce base	Period Bureau of Standards	Difference Commerce-Potsdam	Difference Bureau of Standards-Potsdam	Period Commerce base	Period Bureau of Standards	Difference Commerce-Potsdam	Difference Bureau of Standards-Potsdam
		s.	*s.*	*s.*			*s.*	*s.*		
A-4	A-I	0.5005457	0.5008412	0.5008462	2955	3005	0.5008418	0.5008460	2961	3003
A-5	A-I	.5003755	.5006696	.5006750	2941	2995	.5006708	.5006752	2953	2997
A-6	A-I	.5003416	.5006358	.5006414	2942	2998	.5006371	.5006418	2955	3002
B-4	A-I	.5005333	----------	.5008322	-------	2989	----------	.5008336	-------	3003
B-5	A-I	.5004272	----------	.5007258	-------	2986	----------	.5007272	-------	3000
B-6	A-I	.5004121	----------	.5007112	-------	2991	----------	.5007123	-------	3002
B-7	A-I	.5005904	.5008863	.5008906	2959	3002	.5008866	.5008914	2962	3010
B-8	A-I	.5005198	.5008166	.5008208	2968	3010	.5008168	.5008216	2970	3018
B-9	A-I	.5004938	.5007896	.5007936	2958	2998	.5007904	.5007948	2966	3010
A-4	A-II	.5005468	.5008412	.5008463	2944	2995	.5008414	.5008459	2946	2991
A-5	A-II	.5003742	.5006691	.5006734	2949	2992	.5006692	.5006738	2950	2996
A-6	A-II	.5003404	.5006354	.5006390	2950	2986	.5006357	.5006403	2953	2999
B-4	A-II	.5005337	----------	.5008298	-------	2961	----------	.5008334	-------	2997
B-5	A-II	.5004253	----------	.5007246	-------	2993	----------	.5007249	-------	2996
B-6	A-II	.5004138	----------	.5007128	-------	2990	----------	.5007132	-------	2994
B-7	A-II	.5005880	.5008839	.5008883	2959	3003	.5008846	.5008892	2966	3012
B-8	A-II	.5005204	.5008154	.5008202	2950	2998	.5008157	.5008202	2953	2998
B-9	A-II	.5004916	.5007880	.5007932	2964	3016	.5007876	.5007928	2960	3012

TABLE III.—*Deduced values of g*

Pendulum [1]	Commerce Building base		Bureau of Standards base	
	Knife-edge A-I	Knife-edge A-II	Knife-edge A-I	Knife-edge A-II
A-4	980.1164	980.1213	980.0982	980.1026
A-5	980.1201	980.1191	980.1009	980.1017
A-6	980.1194	980.1186	980.0995	980.1024
B-4	----------	----------	980.1014	980.0984
B-5	----------	----------	980.1021	980.1017
B-6	----------	----------	980.1010	980.1027
B-7	980.1154	980.1143	980.0976	980.0967
B-8	980.1183	980.1187	980.1006	980.1004
B-9	980.1147	980.1147	980.0984	980.0941
Means	980.1176		980.1000	

[1] Pendulums B-7, B-8, and B-9 are of invar. The others are of bronze.

It is apparent from table II that a discrepancy exists between the values as determined by the bronze and by the invar pendulums. This difference amounts to about 3 milligals for both the Commerce Building and Bureau of Standards bases. The observing temperatures were about 20° C. lower at Potsdam than in Washington and the discrepancy may therefore be partially due to a slight error in the temperature coefficients of the pendulums. These coefficients were very carefully determined, however, and it is believed that they are of a high degree of accuracy.

The values of g obtained for the Commerce Building base, as well as those previously determined, are given below:

	Gals
Value from all pendulums (3 bronze, 3 invar)	980. 1176
Value from the 3 invar pendulums	980. 1160
Value from the 3 bronze pendulums	980. 1192
Miller's value (in 1929) reduced to Commerce base	980. 1191
Putnam's value (in 1900) reduced to Commerce base	980. 1127

Miller used three bronze pendulums on each of two knife-edges for his determination, which agrees almost exactly with the value for the bronze pendulums as shown above.

In deducing a final value for the Commerce base it was decided to consider the present determination as two separate measurements, one with the invar pendulums and one with the bronze, and to take a straight mean of these two values and of Miller's determination. This gives the following result:

	Gals
Miller	980. 1191
Brown (bronze)	980. 1192
Brown (invar)	980. 1160
Mean	980. 1181

ADOPTED VALUE FOR COMMERCE BASE=980.118 GALS.

In considering the observations at the Bureau of Standards, the first determination of period with pendulum B4 on knife-edge A II was found to stand out strongly from the mean, and rejection of this determination was considered well justified. A straight mean was taken of all other determinations, giving a value of 980.1000.

ADOPTED VALUE FOR BUREAU OF STANDARDS BASE=980.100 GALS.