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Gravity

By

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GRAVITY

GRAVITY OBSERVATIONS IN 1921

The gravity work for the season of 1921 consisted of a relative determination of the force of gravity at Ottawa, the Canadian base station, by comparison with Washington, D.C., (which has been in turn connected with stations in Europe by the observations of G. R. Putnam. See page 387 of this report), and the establishment of five new gravity stations in Northwestern Canada.

The comparison between Ottawa and Washington was made during the months of March and April. Following this, the five field stations occupied during the summer were Peace River in Alberta, and Resolution, Providence, Simpson, and Norman in the Northwest Territories. The positions of these settlements are shown on the map accompanying this report.

With the exception of two stations on Baffin island, established by G. R. Putnam of the U. S. Coast and Geodetic Survey in 1896*, these stations are very much farther north than any that have been previously established in Canada. Norman, in latitude 64° 54′, approximately, is about 7 minutes north of the most northerly of the gravity stations established in Alaska by the United States Coast and Geodetic Survey, and is only about one hundred miles south of the Arctic circle.

The results of the observations of this season are shown in the tables in this report. The determinations were made with the same half-seconds pendulum apparatus used in all previous work in this country. The only important changes that have been introduced in taking the observations this year have been the substitution of 12-hour for 8-hour swings, and at field stations, the use of wireless telegraphy to obtain the chronometer errors.

The apparatus, its use, the method of reducing the observations and the purpose of these observations are fully described in previous publications of this Observatory as well as in several publications of the U. S. Coast and Geodetic Survey†, where the first apparatus of the Mendenhall type was designed and constructed. The Canadian reports that contain this information as well as the account of all previous work in this country are the following:

Appendix 2. Report of the Chief Astronomer, 1905. Report of Otto Klotz, LL.D., on Field Astronomical Observations and Description of Half-seconds Pendulum Apparatus.

Appendix 2. Report of the Chief Astronomer, 1907. Gravity, Seismology and Magnetic Work by Otto Klotz, LL.D.

Publications of the Dominion Observatory, Ottawa. Vol. II, No. 10, and Vol. III, No. 9. Gravity, by F. A. McDiarmid, B.A.

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*Appendix No. 6, Report of the U. S. Coast and Geodetic Survey, 1897.

†In a publication (1921) of the U.S.C. & G. survey entitled "Modern Methods for measuring the intensity of Gravity" by Clarence H. Swick, Geodetic computer, a very complete and interesting description of the apparatus is given. In addition to an historic outline in which earlier forms of apparatus are described the publication contains full directions for the use of the modern gravity apparatus and several tables which are very useful in the reductions.

DETERMINATION OF THE FORCE OF GRAVITY AT THE CANADIAN BASE STATION, OTTAWA

In order to make the comparison with Washington, the periods of the three pendulums constituting the complete set were first determined in Ottawa. The apparatus was set up on the gravity pier in the basement of the Observatory and observations extending over an interval of three days, from March 14 to 17, were made. Two swings of approximately 12 hours each were made with each pendulum. For the purpose of determining their rates the two chronometers that were used to obtain the coincidences were compared with the standard Riefler clock of the Observatory before and after each 12-hour swing. After correcting for the daily rate of the clock (which seldom exceeds 0·1 second per day) it was therefore possible in the three days' time to make two independent determinations of the period of each pendulum.

When these determinations were completed the whole apparatus was then taken to Washington and set up on the gravity pier in the basement of the U.S. Coast and Geodetic Survey. The observations were begun on April 2, and continued until April 8, when two independent determinations of the period of each pendulum had again been made. Each value obtained was the result of two 12-hour swings. The rates of the chronometers were obtained by comparison with the noon signals from the Naval Observatory. These were received in the pendulum room, each day, during the observations, over the wire of the Western Union Telegraph Co. and recorded on a chronograph.

After completing the observations at Washington, the apparatus was brought back to Ottawa and the periods of the pendulums were again determined with the apparatus set up on the gravity pier in the Observatory. These observations were made between April 20 and 23, and exactly the same procedure was followed as in the first standardization in March.

The results of the observations are shown in detail in Table V and, in a more condensed form, in Table III; for convenience, the periods of the pendulums, as well as the deduced values of g, resulting from the March and April observations are collected in the following Table:

TABLE I

March 14 to 17

	Pendulum No. 1	Pendulum No. 2	Pendulum No. 3	Mean
	^{s}·5013477	^{s}·5014659	^{s}·5014395	^{s}·5014177
	·5013475	·5014658	·5014397	·5014177
Mean	^{s}·5013476	^{s}·5014658	^{s}·5014396	^{s}·5014177
Deduced g (in dynes)	980·6178	980·6171	980·6164	980·6171

TABLE I—*concluded*

April 20 to 23

	Pendulum No. 1	Pendulum No. 2	Pendulum No. 3	Mean
	^{s}·5013474	^{s}·5014642	^{s}·5014386	^{s}·5014167
	·5013468	·5014650	·5014384	·5014167
Mean	^{s}·5013471	^{s}·5014646	^{s}·5014385	^{s}·5014167
Deduced g (in dynes)	980·6198	980·6220	980·6207	980·6208
Change in Period April-March	−5	−12	−11	−10
Mean value of g from March and April observations	980·6188	980·6195	980·6185	980·6190 ∓·0015

The final result of the determination which gives for Ottawa 980·619 dynes is based on the value 980·112 dynes* for gravity at the Coast and Geodetic Survey Office. This value depends upon the absolute determination of the value of gravity at Potsdam, Germany, and upon the adjustment of the net of base stations throughout the world. The observations used in the adjustment to connect Washington with stations in Europe were made by G. R. Putnam, who made determinations with the half-seconds pendulum apparatus at Washington, Kew, Greenwich, London, Potsdam and Paris, in 1900.

Two relative determinations of the force of gravity at Ottawa have been made before, one in 1902† and another in 1914‡. The determination of 1902 was made for a station in Ottawa, about two miles distant from the Observatory and it is not possible, therefore, to compare the present results with it. The 1914 and 1921 results are, however, for exactly the same pier in Ottawa. The value adopted from the results of 1914 observations was 980·615 dynes. This was based on the results of two pendulums, the exact mean deduced from the results being about half-way between 980·616 and 980·615 dynes. The difference between the two determinations is therefore a little over ·003 dyne. If the results of the two standardizations in Washington and the first standardization of pendulum No. 2 in Ottawa had been used in the computations the weighted mean of the results from all three pendulums would have given 980·617 dynes as the 1914 result, which, considering the fourth place of decimals, differs by less than ·002 dyne from the present result. As the 1914 determination and the present one appear on the whole to be of about equal weight, it is proposed to adopt for g at Ottawa the mean of the last-mentioned value and the 1921 result. The adopted value for Ottawa is then 980·618 dynes, the mean of all available observations. In forming this mean it makes a difference of less than ·001 dyne, whether the results of pendulum No. 2 are included in the 1914 observations or not.

*Special publication No. 40, U.S.C. & G. Survey, p. 49.
†Appendix 2, Report of the Chief Astronomer, 1905.
‡Publications of the Dominion Observatory, Ottawa, Vol. II, No. 10, Gravity.

FIELD WORK.

The field work was carried out in connection with the latitude and longitude work of the Observatory for the season. A party consisting of three members of the staff was sent out, one to take the star observations, another in charge of the wireless apparatus for receiving the time signals, and the third to make the gravity measurements. The wireless had to be made use of in the longitude work owing to the fact that the four stations in the Mackenzie river district are from 500 to 1,200 miles distant from the nearest telegraph station.

All the five field stations are within the great basin of the Mackenzie river. The town of Peace River, in northern Alberta, is situated at the confluence of Peace and Smoky rivers, Resolution on the south shore of Great Slave lake, about 10 miles west of the mouth of the Slave river, and Providence, Simpson and Norman, on the Mackenzie itself, within the area at present under investigation for its oil possibilities.

WIRELESS TEST AT PEACE RIVER

Peace River, which at the time was the terminus of the Central Canada railway, and also the end of the telegraph line, was the first station on the summer program and was occupied during the latter part of May. In addition to establishing both an astronomical and a gravity station at this point, setting up at this place served the further purpose of testing the apparatus under conditions which were likely to prevail at the more distant stations in the Mackenzie district. For the gravity work an important test was a comparison of the results obtained by the use of the clock over the wire from the Observatory and those obtained by the wireless in determining the chronometer errors. After making the required number of swings with the Observatory clock to complete the determination at Peace River, one of the pendulums whose period was already known was redetermined independently, using the wireless signals for that purpose. The result of the comparison will be seen in Table V, under Peace River. Swings Nos. 1 to 8 were made with the Observatory clock and swing No. 9 was made using the wireless signals from Annapolis, at noon and 10 p.m., on May 30. Pendulum No. 1 was the pendulum chosen for the comparison. It will be seen that the wireless result for its period is very close to the second clock value and differs by only 5 units, approximately, from the mean of the two clock values,—a very satisfactory result, especially when it is considered that the wireless result is based on an interval of only 10 hours, while the results obtained with the clock are in each case derived from two swings that together lasted 24 hours.

TEMPERATURE CONDITIONS

At Peace River the experiment was also tried of taking the observations in a tent. A good solid pier was erected in the open and the apparatus set up on it, but owing to the great changes of temperature that were experienced in the tent the results of the observations were unsatisfactory. These changes were due to the normal changes that take place between night and day in this part of the country at this time of the year. Quite often the temperature during the day rose to 80° or 85° F., while at night it dropped nearly to freezing point. As might be expected, the variations of temperature that occurred in the tent were particularly rapid and troublesome in the mornings and evenings.

The observations that were used at Peace River in making the determination were those taken in the cellar of the Government Telegraph building where the temperature conditions were entirely satisfactory. Fortunately at all of the later stations it was not necessary to have recourse to the tent for taking the observations. Through the kindness of the officials of the Hudson's Bay Co., as well as of the Roman Catholic mission at Resolution, good log buildings were placed at the disposal of the observer at the various posts. With the exception of Peace River there are no cellars suitable for pendulum rooms at any of the places. However, the log buildings made quite satisfactory temperature rooms and in most cases required little trouble to convert them into suitable places for taking the observations. The largest range of temperature as recorded on the dummy pendulum thermometer at any of the stations was about 2° C. Usually this change was of the order of about 1° C, but it was quite often less than that.

USE OF WIRELESS TO DETERMINE THE CHRONOMETER RATES

At the four stations in the Mackenzie district either the wireless or the astronomical observations were available for obtaining the rates of the chronometers. The wireless signals were used, however, almost entirely for the purpose at all these stations. The result of the test at Peace River had already proven satisfactory and moreover, it was most convenient in taking the observations to have the regular chronometer comparisons that were made possible by the wireless signals, at certain definite times each day. It was also possible in this way to complete the work in much less time and far more satisfactorily than would have been possible with star observations owing to the fact that the weather was very poor for observing on most nights during the summer in this part of the country.

While other wireless signals were received only the time signals from Annapolis were used for the gravity determinations, and of these the signals sent out at noon were the ones usually selected. The periods of the pendulums were therefore, as a rule, determined from the combined results of two swings of about 12 hours each, the mean rate of the chronometers for the 24 hours obtained from the signals being applied to each swing. In some cases the same pendulum had to be kept swinging longer than 24 hours in order to make the determination of its period. This occurred when it was impossible to make the necessary time comparison at the end of the 24 hours and the pendulum had then to be kept swinging till the time comparison was obtained. This happened for example at Peace River (See Table V, Peace River, Swings 5-8). It was impossible to get through on the wire to Ottawa on the night of May 25. The pendulum was therefore kept swinging till the night of the 26th when a time comparison was obtained and the determination completed. A similar circumstance occurred with the wireless signals at Simpson (Table V, Simpson, Swings 1-6). The regular noon signals were not sent out from Annapolis on July 24, and there was some doubt about the rates as determined by the comparison on July 23, so that the pendulum was kept swinging from July 22 to July 25. In other cases 10-hour swings were made, an independent determination being completed in that time by making use of the noon and 10 p.m. signals on the same day. Swings 8 - 12 at Providence are examples of this. It was found at Providence that the 10-hour swings suited the temperature conditions of the pendulum room somewhat better. At other stations the 10-hour swings were made more for a check on previous determinations of the period of any given pendulum, an extra value of its period being thereby obtained without much time being required for it.

At Norman, regarded as the most important station of the season, a check on the work was also secured by making use of the star observations in the ordinary way to obtain the period of one of the pendulums. The value of the period obtained in this way for pendulum No. 1 (Table V, Norman, Swings 4B, 5B and 6A) is $^{s}\cdot5009392$, which is very close to $^{s}\cdot5009388$, the mean of the three values from swings 1-6 obtained from the wireless comparisons. Apart from the errors of observation that might account for the small discrepancy the difference between the two values might also be partially explained by the different arcs* of vibration in the two cases. Swing No. 6A was a swing of only about one hour, consequently the final amplitude of the swing was much larger than usual as the pendulum was started with the usual displacement.

If the results of the observations for any of the stations are compared it will be seen that with few exceptions the agreement obtained by the use of the wireless is as good as could be expected from any other method of time comparison, and in this connection it should also be remembered that all the field stations are at great distances from the sending station. It would therefore appear that even for stations located on a telegraph line the question of which method to adopt to determine the chronometer errors is largely a matter of the relative cost. For stations away from the wire there can be no doubt about the choice.

All the wireless signals used in the gravity work were not only recorded at each of the stations but also at Ottawa, where their correction was determined from the standard Observatory clock.

ACCURACY OF THE OBSERVATIONS

Owing to the fact that at most of the stations there was plenty of time for making the gravity observations, advantage was taken of the opportunity to make repeated determinations of the period of at least one pendulum for each station. This operation affords an obvious test of the accuracy of the observations and also adds to the accuracy and strength of the final result for the station. If the values obtained for the pendulum chosen at any one station are compared it will be found that they agree to within a few units of the seventh place of decimals. Of the several repetitions that were made there are only two cases in which the differences are of any importance. At Simpson, the two values determined for the period of pendulum No. 1 differ by 27 units of the seventh decimal place. However, the mean of the two determinations gives for the force of gravity at Simpson nearly the same result as that obtained from the 8 swings of pendulum No. 3, so it is apparent that the two values obtained for pendulum No. 1 lie on opposite sides of the true value, which is probably not very different from the mean of the two determinations of its period. Also at Norman, swing No. 7 (a 10-hour swing) gives a

*See App. No. 1 Report of U.S.C. & G. Survey, 1894, p. 41.

result for the period of pendulum No. 1, which differs by about 20 units from the three previous results. There appears to be no doubt that the last observation is in error, but owing to the number of observations it does not affect the final result to any appreciable extent.

The values of g deduced from each pendulum are given for each station in Table III. The agreement between the results is an indication that no large relative changes in the pendulums took place during the season. In deducing the value of g for the various field stations the value of the period that has been assumed for the period of each pendulum at Ottawa was the arithmetical mean of the results obtained at Ottawa at the beginning and end of the season in April and October.

The probable errors of the observations alone do not in any case exceed ·001 dyne, and for most of the stations are only about one-half of this, but in order to estimate the uncertainty in the final result for each station there must be added to the error of observation the several errors that are constant throughout a set of observations at the station. Briefly, these are errors arising out of (1) uncertainties in the instrumental correction constants; (2) errors in the flexure observations; and (3) changes in the periods of the pendulums. The errors due to (1) and (2) are estimated at less than ·001 dyne. The error due to (3) may be anything from zero up to ·0036 dyne. Taking into consideration, then, all possible sources of error, the final values of g adopted for the field stations may be in error anywhere from about ·001 to about ·005 dyne with respect to Ottawa.

CHANGES IN THE PENDULUMS

The results of the standardizations made before the commencement of the field work and after its completion are shown in the following Table:

TABLE II

Date	Pendulum No. 1	Pendulum No. 2	Pendulum No. 3	Mean
April 20-23	s·5013471	s·5014646	s·5014385	s·5014167
Oct. 27-Nov. 4	·5013455	·5014628	·5014365	·5014149
Change in Period April-Nov.	−16	−18	−20	−18

As stated already the mean of the two standardizations was used for the Ottawa periods of the pendulums. The error in the mean period of the three pendulums assumed for Ottawa cannot then be in error for any of the field stations by more than 9×10^{-7} seconds. This corresponds to an error of about ·0036 dyne or ·004 dyne approximately. This statement is of course based upon the reasonable assumption that no changes took place in the pendulums during the season greater than those observed between the beginning and end of the season at Ottawa. If the changes were gradual throughout the season, the error due to the changes in the pendulums would at most of the stations be less than ·004 dyne, while at the mid-season station it would be zero. On the other hand if the changes occurred suddenly just before the first or just after the last field station the results would all be in error by the same amount, ·004 dyne.

GRAVITY ANOMALIES FOR STATIONS OF 1921

The differences between the observed and computed values for the gravity stations are shown in the last column of Table IV. In arriving at the computed value the formula $\gamma = 978{\cdot}039\ (1 + \cdot 005294 \sin^2 \phi - \cdot 000007 \sin^2 2\phi)$* has been used to obtain the value of the force of gravity at sea-level, and in reducing to the elevation of the station only the so-called free-air method has been used. It is proposed later to make the isostatic reductions for the stations when better maps of the country are available. It is expected this will be some time during the course of this year. Another reason for postponing these reductions is the uncertainty in the present assumed elevations of the stations from Resolution north. It is possible that the elevation now adopted for any of these stations may be from 40 to 50 feet in error. However, when the Sixth meridian (118° Longitude W.) has been produced to meet the traverse on the Mackenzie river, as proposed for the coming season by the Topographical Surveys Branch, then the elevation of the river at that point and possibly of Great Slave lake as well will be definitely known. This point will be somewhere near Providence and from the elevation of it alone it will be possible to estimate very closely the elevations of both Providence and Resolution. As the fall in the Mackenzie river is, on the whole, very uniform it will be possible also to estimate the elevations of the stations farther down the river much more accurately than at present.

The present estimate of the elevations was made as follows:

The elevation (about 691 feet) of Slave river, where the 30th base line of the Dominion Lands Survey system crosses it, is known from the levels run in connection with the survey of this base line. The intersection of the base line and the river is in latitude about 59° 08′, and about 65 miles above Fitzgerald. Excluding Smith rapids the average fall in the river from the base line to the lake has been taken as 6 inches to the mile. This is the average fall in Peace river, from Vermilion chutes (about 50 miles below Ft. Vermilion) to the confluence of Slave and Peace rivers, and is also the estimated average fall in Slave river below Smith rapids, according to the Geological Survey. After allowing for the 109 feet drop in Smith rapids, the total fall in the river from the base line to the lake is thus estimated at 231 feet, which gives for the elevation of Great Slave lake 460 feet. This also gives for the average fall of the Mackenzie 5·3 inches per mile, which has been used in conjunction with the surveyed distances of the various stations from the lake to obtain the elevation of the river at the various points.

A notable thing about the anomalies is the fact that they are all negative. With the exception of Peace River only a small part of the anomaly in each case can be accounted for by the local topography. At Peace River, which is situated in the deep valley of the river, about one-half of the anomaly at that place could be accounted for by the river valley which is about 800 feet deep and over a mile wide. On either side of the valley

*Investigations of Gravity and Isostasy by Wm. Bowie, special publication No. 40, U.S.C. & G. Survey, p. 134.

back from the river the country is, for the most part, fairly level. At the other stations only about ·002 to ·003 dyne, at the most, could be attributed to the local topography in each case. With the exception of Norman, the stations are located in level country extending for considerable distances. In so far, then, as topography and compensation may be effective in producing the anomalies, we are concerned at these stations only with distant topography and compensation. It is quite possible that for these places the distant topography and compensation that are effective in producing a considerable part of the negative anomalies is the topography, and more especially the compensation of the range of mountains which lie over to the west of the line joining the stations.

The stations Resolution, Providence and Simpson are all located (as is also Ottawa) on fairly extensive Paleozoic formations. Although it can not be said that there is any relation between the anomalies and the geological formations for the 42 stations in Canada that have so far been reduced by the Hayford method, it is interesting to note that the results of gravity investigations in the United States* have shown that the anomalies by both the free-air and isostatic methods of reduction tend to be negative for stations situated on Paleozoic formations in that country. If the average width of the formation at the stations in the Mackenzie district is taken to be about 200 miles a depth of 15,000 feet of material of this formation or of matter of equivalent density would hardly account for ·010 dyne of the anomaly at each station.

A comparison of the free-air anomalies for the four northern stations is of considerable interest. In this connection it is to be remembered that whatever error there may be in the actual elevations, there can hardly be much error in the elevations of the stations relatively to one another. Resolution, Providence and Simpson, about 160 miles apart and all on a Paleozoic formation, have about the same negative anomaly, but Norman has a negative anomaly about twice the magnitude of any of the former three stations. Norman is situated in a low mountainous country and being located on the river is generally below the level of the surrounding country. Part of the Norman anomaly is undoubtedly due to this fact. It may also be pointed out that Norman is situated on a bed of Tertiary formation† extending for about 30 or 40 miles each way in a horizontal direction. Owing to the lighter material usually present in this formation and to the limited horizontal extent of it at Norman, we have a state of affairs that might be expected to produce a large negative anomaly provided there is some depth to the formation or to material of less than normal density. However, it is not advisable to attempt to draw any very definite conclusions from the anomalies until the isostatic reductions have been made and until there is a greater certainty about the elevations. Moreover, it would seem likely that, when the corrections for topography and compensation are made, these anomalies will be small.

DESCRIPTIONS OF STATIONS

Descriptions of the gravity stations, occupied in the field during the season of 1921, are given below. The astronomical stations to which they are referred were established at the same time as the gravity stations. A cement pier for the reception of the pendulum case was erected at each station.

*Special Publication No. 40, U.S.C. & G. Survey.
†The Mackenzie River Basin, by Chas. Camsell and Wyatt Malcolm, Geological Survey of Canada, p. 76.

Peace River, Alberta.—A pier, the top of which was about 2 feet above the floor level, was erected in the southwest corner of the cellar of the Government Telegraph office. It is 1063 feet above mean sea-level, and is 150 feet south and 57 feet west of the astronomical station. The elevation of the pier was determined from the Topographical Surveys bench-mark on the east boundary of the property of Revillon Frères.

Resolution, N.W.T.—At this place the top of the pier was about 2 feet above the floor level and was erected in the west side of a log building 18 feet by 20 feet with a lean-to, belonging to the Roman Catholic mission. The building was formerly set apart by the mission for the use of Indians who were at the post in the winter and were in need of shelter. It is about 100 feet west of the church and 50 feet from the shore of Great Slave lake. The gravity pier is 12 feet south and 24 feet west of the astronomical station and is 10 feet above the level of the lake.

Providence, N.W.T.—A pier, the top of which was about 2 inches below the floor level, was erected in the center of a log building 18 feet by 20 feet, owned by the Hudson's Bay Co., and kept for the accommodation of Indians coming to the post during the winter. The pier is 32 feet north and 24 feet west of the astronomical station and was 35 feet above the water level of the Mackenzie river in front of the Hudson's Bay Co.'s landing on July 15.

Simpson, N.W.T.—The pier was placed in the northeast corner of the old warehouse of the Hudson's Bay Co., the top of the pier being one foot above the floor level. It is 80 feet south and 15 feet west of the astronomical station and was 39 feet above the water level of the Mackenzie river in front of the Company's landing on July 30.

Norman, N.W.T.—A pier, the top of which was about 2½ feet above the floor level, was erected in the north side of the Hudson's Bay Co.'s old powder magazine. It is 92 feet south and 95 feet west of the astronomical station and was 50 feet above the water level of the Mackenzie river in front of the Hudson's Bay Co.'s landing on August 19.

SUMMARY OF RESULTS (TABLES)

In the following Tables are given the periods of the pendulums at all the stations occupied during 1921, and the resulting values of the force of gravity in dynes.

TABLE III

Station	Periods of Pendulums in Seconds			Value of g in Dynes			
	1	2	3	1	2	3	Weighted Mean
Ottawa (March 14-17).........	s ·5013476	s ·5014658	s ·5014396	980·618	980·617	980·616	....
Washington, D.C., U.S.A.......	·5014769	·5015950	·5015686	....	....	....	980·112
Ottawa (April 20-23)..........	·5013471	·5014646	·5014385	980·620	980·622	980·622	980·619
Peace River..................	·5011254	·5012430	....	981·482	981·482	....	981·482
Resolution...................	·5010084	·5011252	·5010985	981·941	981·943	981·945	981·942
Providence...................	·5010040	·5011225	·5010966	981·958	981·954	981·953	981·955
Simpson......................	·5009925	....	·5010833	982·003	....	982·005	982·004
Norman.......................	·5009385	·5010563	·5010295	982·215	982·213	982·215	982·214
Ottawa (Oct. 27-Nov. 4).......	·5013455	·5014628	·5014365	....	....	....	980·618

TABLE IV

PRINCIPAL FACTS FOR GRAVITY STATIONS OCCUPIED DURING THE SEASON OF 1921

Station	Latitude			Longitude			Elevation	Computed g at Sea-level	Correction for Elevation	Computed Gravity at Station	Observed Gravity at Station	Anomaly Observed-Computed
	°	′	″	h	m	s	Metres	Dynes	Dynes	Dynes	Dynes	Dynes
Ottawa............	45	23	38	5	02	52	83	980·656	−·026	980·630	980·618	−·012
Peace River........	56	14	05	7	49	09	324	981·611	−·100	981·511	981·482	−·029
Resolution.........	61	10	06	7	34	42	143	982·008	−·044	981·964	981·942	−·022
Providence.........	61	21	14	7	50	37	145	982·022	−·045	981·977	981·955	−·022
Simpson...........	61	51	39	8	05	23	126	982·060	−·039	982·021	982·004	−·017
Norman...........	64	54	01	8	22	17	89	982·281	−·027	982·254	982·214	−·040

TABLE V

PENDULUM OBSERVATIONS AND REDUCTIONS

STATION: OTTAWA. OBSERVER: A. H. MILLER

Date	Swing Number	Pendulum	Position	Knife-edge	Coincidence Interval: Chronometer No. Dent 52866	Coincidence Interval: Chronometer No. Dent 48419	Arc: Initial	Arc: Final	Temperature	Pressure	Period Uncorrected: Chronometer No. Dent 52866	Period Uncorrected: Chronometer No. Dent 48419	Corrections (7th Decimal Place): Arc	Corrections: Temp.	Corrections: Pressure	Corrections: Rate D 52866	Corrections: Rate D 48419	Corrections: Flexure	Period Corrected: Chronometer No. Dent 52866	Period Corrected: Chronometer No. Dent 48419	Period Corrected: Mean
1921																					
March 14-15........	1	1	D	1	188·14	185·04	8·0	1·9	12·80	55·9	·5013323	·5013547	−18	+ 92	+ 7	+ 83	− 143	− 9	·5013478	·5013476	
" 15..........	2	1	D	1	188·32	184·93	8·0	1·9	12·57	55·9	·5013311	·5013555	−18	+ 102	+ 7	+ 83	− 163	− 9	·5013476	·5013474	
																Mean.	....	....	·5013477	·5013475	·5013476
March 16..........	3	2	D	1	172·87	168·70	7·9	2·1	12·76	54·0	·5014504	·5014863	−20	+ 94	+ 9	+ 83	− 281	− 9	·5014661	·5014656	
" 16..........	4	2	D	1	172·94	168·97	7·5	2·0	12·61	54·0	·5014498	·5014839	−18	+ 100	+ 9	+ 77	− 261	− 9	·5014657	·5014660	
																Mean.	....	....	·5014659	·5014658	·5014658
March 17..........	5	3	D	1	176·36	171·11	7·5	2·0	12·68	54·0	·5014216	·5014653	−18	+ 97	+ 9	+ 99	− 335	− 9	·5014394	·5014397	
" 17..........	6	3	D	1	176·45	171·62	7·3	2·0	12·44	54·0	·5014209	·5014610	−17	+ 107	+ 8	+ 99	− 302	− 9	·5014397	·5014397	
																Mean.	....	....	·5014395	·5014397	·5014396
April 20-21........	1	1	D	1	186·36	182·77	7·8	1·7	15·57	61·0	·5013451	·5013716	−17	− 24	+ 2	+ 74	− 195	−10	·5013476	·5013472	
" 21..........	2	1	D	1	186·48	183·10	7·7	1·7	15·40	65·0	·5013442	·5013691	−17	− 17	− 2	+ 74	− 178	−10	·5013470	·5013467	
																Mean.	....	....	·5013473	·5013469	·5013471
April 21-22........	3	2	D	1	171·56	167·96	7·9	1·7	15·58	60·6	·5014615	·5014929	−17	− 24	+ 2	+ 74	− 237	−10	·5014640	·5014643	
" 22..........	4	2	D	1	171·58	167·96	7·8	2·0	15·50	62·8	·5014613	·5014929	−18	− 21	0	+ 85	− 229	−10	·5014649	·5014651	
																Mean.	....	....	·5014645	·5014647	·5014646
April 22-23........	5	3	D	1	174·46	170·74	7·7	1·3	15·76	72·1	·5014371	·5014685	−14	− 32	− 8	+ 76	− 232	−10	·5014383	·5014389	
" 23..........	6	3	D	1	175·04	170·51	8·2	1·8	15·79	71·2	·5014323	·5014705	−19	− 33	− 7	+ 130	− 252	−10	·5014384	·5014384	
																Mean.	....	....	·5014384	·5014386	·5014385

TABLE V—*Continued*

PENDULUM OBSERVATIONS AND REDUCTIONS—*Continued*

STATION: WASHINGTON, D.C. OBSERVER: A. H. MILLER

Date	Swing number	Pendulum	Position	Knife-edge	Coincidence Interval		Arc		Temperature	Pressure	Period Uncorrected		Corrections (7th Decimal Place)						Period Corrected		
					Chronometer						Chronometer					Rate			Chronometer		Mean
					No. Negus 2490	No. Negus 1836	Initial	Fianl			No. Negus 2490	No. Negus 1836	Arc	Temp.	Pressure	N 2490	N 1836	Flexure	No. Negus 2490	No. Negus 1836	
April 2	1	1	D	1	165·43	169·31	7·9	1·8	16·69	62·6	·5015158	·5014810	−18	− 71	+ 1	− 309	+ 49	−10	·5014751	·5014761	
" 2-3	2	1	D	1	165·17	169·31	7·7	1·8	16·44	63·4	·5015182	·5014810	−17	− 60	0	− 309	+ 49	−10	·5014786	·5014772	
																Mean			·5014768	·5014767	·5014767
April 3	3	1	D	1	165·66	169·48	7·9	1·9	16·42	59·3	·5015137	·5014795	−18	− 60	+ 4	− 311	+ 55	−10	·5014742	·5014766	
" 3-4	4	1	D	1	164·93	169·28	8·0	1·7	16·47	65·8	·5015204	·5014812	−17	− 62	− 2	− 311	+ 55	−10	·5014802	·5014776	
																Mean			·5014772	·5014771	·5014771
April 4	5	2	D	1	153·36	156·47	9·1	2·0	17·19	64·2	·5016355	·5016029	−23	− 92	0	− 298	+ 45	−10	·5015932	·5015949	
" 4-5	6	2	D	1	152·96	156·44	7·8	1·8	17·30	66·6	·5016398	·5016032	−17	− 96	− 3	− 298	+ 45	−10	·5015974	·5015951	
																Mean			·5015953	·5015950	·5015951
April 5	7	2	D	1	153·18	156·30	8·2	1·9	17·55	68·4	·5016374	·5016046	−19	− 107	− 4	− 295	+ 41	−10	·5015939	·5015947	
" 5-6	8	2	D	1	152·89	156·23	7·8	1·8	17·84	64·1	·5016405	·5016053	−17	− 119	0	− 295	+ 41	−10	·5015964	·5015948	
																Mean			·5015951	·5015948	·5015949
April 6	9	3	D	1	155·96	158·71	7·5	1·5	18·03	67·9	·5016081	·5015802	−15	− 127	− 4	− 262	+ 38	−10	·5015663	·5015684	
" 6-7	10	3	D	1	155·49	158·65	7·4	1·6	18·19	64·3	·5016130	·5015808	−15	− 134	0	− 262	+ 38	−10	·5015709	·5015687	
																Mean			·5015686	·5015685	·5015686
April 7	11	3	D	1	155·97	158·56	8·1	1·4	18·37	74·1	·5016081	·5015817	−16	− 141	− 9	− 249	+ 40	−10	·5015656	·5015682	
" 7-8	12	3	D	1	155·55	158·62	7·6	1·4	18·24	64·3	·5016124	·5015811	−14	− 136	0	− 249	+ 40	−10	·5015715	·5015691	
																Mean			·5015686	·5015686	·5015686

TABLE V—*Continued*

PENDULUM OBSERVATIONS AND REDUCTIONS—*Continued*

STATION: PEACE RIVER, ALBERTA. OBSERVER: A. H. MILLER

Date	Swing number	Pendulum	Position	Knife-edge	Coincidence Interval: Chronometer No. Dent 52866	Coincidence Interval: Chronometer No. Dent 48419	Arc: Initial	Arc: Final	Temperature	Pressure	Period Uncorrected: Chronometer No. Dent 52866	Period Uncorrected: Chronometer No. Dent 48419	Corrections (7th Decimal Place): Arc	Temp.	Pressure	Rate D 52866	Rate D 48419	Flexure	Period Corrected: Chronometer No. Dent 52866	Period Corrected: Chronometer No. Dent 48419	Mean
May21-22..........	1	1	D	1	226·31	218·98	7·8	1·7	10·61	61·0	·5011071	·5011443	−17	+ 184	+ 1	+ 42	− 356	−16	·5011265	·5011239	
" 22...........	2	1	D	1	228·14	219·54	7·9	1·7	9·25	62·6	·5010982	·5011414	−17	+ 241	− 1	+ 42	− 356	−16	·5011231	·5011265	
																Mean.........			·5011248	·5011252	·5011250
May 22-23.........	3	1	D	1	228·54	219·11	7·9	1·7	8·59	65·8	·5010963	·5011436	−17	+ 269	− 4	+ 74	− 427	−16	·5011269	·5011241	
" 23............	4	1	D	1	228·51	218·16	7·8	1·6	9·02	70·0	·5010965	·5011486	−16	+ 251	− 8	+ 74	− 427	−16	·5011250	·5011270	
																Mean..............			·5011259	·5011255	·5011257
May 24-25.........	5	2	D	1	207·06	199·14	7·5	1·5	8·58	64·9	·5012103	·5012586	−15	+ 269	− 3	+ 89	− 376	−16	·5012427	·5012445	
" 25............	6	2	D	1	207·13	199·73	8·1	1·2	8·36	66·6	·5012099	·5012548	−15	+ 278	− 5	+ 89	− 376	−16	·5012430	·5012414	
" 25-26.........	7	2	D	1	206·88	199·08	8·0	1·5	8·59	69·4	·5012114	·5012589	−16	+ 269	− 7	+ 89	− 376	−16	·5012433	·5012443	
" 26............	8	2	D	1	207·36	199·80	7·7	2·0	8·16	63·0	·5012085	·5012544	−18	+ 287	− 1	+ 89	− 376	−16	·5012426	·5012420	
																Mean..............			·5012429	·5012430	·5012430
May 30............	9	1	D	1	230·02	220·78	7·2	1·9	8·70	66·0	·5010892	·5011349	−16	+ 264	− 4	+ 138	− 317	−16	·5011258	·5011260	·5011259

TABLE V—*Continued*

PENDULUM OBSERVATIONS AND REDUCTIONS—*Continued*

STATION: RESOLUTON, N.W.T. OBSERVER: A. H. MILLER

Date	Swing number	Pendulum	Position	Knife-edge	Coincidence Interval		Arc		Temperature	Pressure	Period Uncorrected		Corrections (7th Decimal Place)						Period Corrected		
					Chronometer						Chronometer					Rate			Chronometer		
					No. Bond 627	No. Dent 48419	Initial	Final			No. Bond 627	No. Dent 48419	Arc	Temp.	Pressure	B 627	D 48419	Flexure	No. Bond 627	No. Dent 48419	Mean
Sept. 8............	1	1	D	1	269·31	245·26	7·7	1·3	5·43	66·0	·5009301	·5010214	−14	+ 401	− 5	+ 423	− 469	− 9	·5010097	·5010118	
" 8-9............	2	1	D	1	270·19	247·11	8·0	1·4	5·29	62·0	·5009270	·5010137	−15	+ 407	− 1	+ 423	− 469	− 9	·5010075	·5010050	
																Mean...........			·5010086	·5010084	·5010085
Sept. 9............	3	1	D	1	268·97	245·98	8·0	1·4	5·72	66·0	·5009312	·5010184	−15	+ 389	− 5	+ 404	− 448	− 9	·5010076	·5010096	
" 9-10..........	4	1	D	1	266·89	245·30	8·1	1·6	7·12	60·0	·5009385	·5010212	−18	+ 330	+ 2	+ 404	− 448	− 9	·5010094	·5010069	
																Mean...........			·5010085	·5010083	·5010084
Sept. 10............	5	1	D	1	266·32	244·38	8·0	2·0	7·30	63·2	·5009405	·5010251	−19	+ 323	− 1	+ 384	− 463	− 9	·5010083	·5010082	·5010082
" 11............	6	2	D	1	236·35	220·11	7·8	1·7	7·91	61·0	·5010600	·5011384	−17	+ 297	+ 1	+ 372	− 400	− 9	·5011244	·5011256	
" 11-12.........	7	2	D	1	235·55	219·89	8·0	1·7	8·27	64·5	·5010636	·5011396	−17	+ 282	− 3	+ 372	− 400	− 9	·5011261	·5011249	
																Mean...........			·5011252	·5011252	·5011252
Sept. 13............	8	3	D	1	240·70	223·86	7·8	2·0	9·52	61·7	·5010408	·5011193	−18	+ 230	0	+ 373	− 409	− 9	·5010984	·5010987	·5010985

TABLE V—*Continued*

PENDULUM OBSERVATIONS AND REDUCTIONS—*Continued*

STATION: PROVIDENCE, N.W.T. OBSERVER: A. H. MILLER

Date	Swing number	Pendulum	Position	Knife-edge	Coincidence Interval		Arc		Temperature	Pressure	Period Uncorrected		Corrections (7th Decimal Place)						Period Corrected		
					Chronometer						Chronometer					Rate			Chronometer		Mean
					No. Dent 52866	No. Dent 48419	Initial	Final			No. Dent 52866	No. Dent 48419	Arc	Temp.	Pressure	D 52866	D 48419	Flexure	No. Dent 52866	No. Dent 48419	
June 26...........	1	2	D	1	217·68	213·69	8·1	2·1	18·70	67·6	·5011511	·5011727	−20	− 155	− 4	− 98	− 299	−10	·5011224	·5011239	
" 26-27..........	2	2	D	1	218·13	214·69	7·7	1·4	18·47	65·0	·5011487	·5011672	−15	− 145	− 1	− 98	− 299	−10	·5011218	·5011202	
" 27............	3	2	D	1	218·41	214·60	7·8	1·6	17·70	67·0	·5011473	·5011677	−16	− 113	− 3	− 98	− 299	−10	·5011233	·5011236	
																Mean...........			·5011225	·5011226	·5011225
June 27-28.........	4	2	D	1	218·23	215·32	7·5	1·3	17·94	67·0	·5011482	·5011638	−14	− 123	− 3	− 109	− 278	−10	·5011223	·5011210	
" 28............	5	2	D	1	218·81	215·35	8·0	1·9	17·07	64·7	·5011452	·5011636	−18	− 87	− 1	− 109	− 278	−10	·5011227	·5011242	
																Mean...........			·5011225	·5011226	·5011225
July 6............	6	2	D	1	221·10	217·03	7·8	1·7	15·41	63·1	·5011333	·5011546	−17	−17	0	− 84	− 264	−10	·5011205	·5011238	
" 6-7...........	7	2	D	1	219·47	216·74	8·1	1·8	16·33	64·6	·5011417	·5011561	−19	−56	− 1	− 84	− 264	−10	·5011247	·5011211	
																Mean...........			·5011226	·5011225	·5011225
July 7............	8	2	D	1	220·17	215·72	7·4	1·9	16·29	69·3	·5011381	·5011616	−17	− 54	− 5	− 67	− 300	−10	·5011228	·5011230	·5011229
" 9............	9	3	D	1	226·63	220·72	8·5	2·3	14·18	61·5	·5011055	·5011352	−23	+ 34	+ 1	− 90	− 386	−10	·5010967	·5010968	·5010967
" 10............	10	3	D	1	228·88	222·68	7·3	2·0	12·68	62·0	·5010947	·5011252	−17	+ 97	+ 1	− 53	− 359	−10	·5010965	·5010964	·5010965
" 11............	11	1	D	1	247·44	240·93	7·3	2·0	14·41	61·8	·5010124	·5010398	−17	+ 25	+ 1	− 82	− 354	−10	·5010041	·5010043	·5010042
" 12............	12	1	D	1	246·30	239·99	7·1	1·9	15·34	68·7	·5010171	·5010439	−16	− 14	− 5	− 88	− 356	−10	·5010038	·5010038	·5010038

TABLE V—*Continued*

PENDULUM OBSERVATIONS AND REDUCTIONS—*Continued*

STATION: SIMPSON, N.W.T. OBSERVER: A. H. MILLER

Date	Swing number	Pendulum	Position	Knife-edge	Coincidence Interval		Arc		Temperature	Pressure	Period Uncorrected		Corrections (7th Decimal Place)						Period Corrected		
					Chronometer						Chronometer					Rate			Chronometer		
					No. Dent 52866	No. Dent 48419	Initial	Final			No. Dent 52866	No. Dent 48419	Arc	Temp.	Pressure	D 52866	D 48419	Flexure	No. Dent 52866	No. Dent 48419	Mean
July 22............	1	3	D	1	230·55	224·46	7·8	1·5	13·83	59·8	·5010867	·5011163	−16	+ 49	+ 3	− 62	− 327	−13	·5010828	·5010859	
" 22-23..........	2	3	D	1	229·11	224·83	7·9	1·6	13·91	64·0	·5010936	·5011144	−17	+ 46	− 1	− 62	− 327	−13	·5010889	·5010832	
" 23............	3	3	D	1	229·60	224·32	7·8	1·5	14·06	68·0	·5010912	·5011170	−16	+ 39	− 5	− 62	− 327	−13	·5010855	·5010848	
" 23-24..........	4	3	D	1	230·28	224·54	7·5	1·5	14·61	71·8	·5010880	·5011159	−15	+ 16	− 8	− 62	− 327	−13	·5010798	·5010812	
" 24............	5	3	D	1	229·53	223·73	8·0	1·8	14·87	61·0	·5010916	·5011199	−18	+ 5	+ 2	− 62	− 327	−13	·5010830	·5010848	
" 24-25..........	6	3	D	1	230·17	224·66	7·8	1·5	14·89	64·5	·5010885	·5011153	−16	+ 5	− 2	− 62	− 327	−13	·5010797	·5010800	
																Mean.	......	....	·5010833	·5010833	·5010833
July 25............	7	3	D	1	228·84	223·66	8·0	1·6	15·56	68·0	·5010949	·5011203	−17	− 23	− 4	− 47	− 296	−13	·5010845	·5010850	
" 25-26..........	8	3	D	1	229·00	223·95	7·8	1·3	15·94	71·0	·5010941	·5011188	−15	− 39	− 7	− 47	− 296	−13	·5010820	·5010818	
																Mean.	......	....	·5010833	·5010834	·5010833
July 27............	9	1	D	1	250·02	243·32	8·1	1·6	15·87	64·5	·5010019	·5010296	−18	− 36	− 1	− 13	− 280	−13	·5009938	·5009948	
" 27-28..........	10	1	D	1	250·04	243·71	8·2	1·3	15·83	68·1	·5010018	·5010279	−16	− 35	− 4	− 13	− 280	−13	·5009937	·5009931	
																Mean.	......	....	·5009938	·5009939	·5009938
July 28............	11	1	D	1	250·67	243·68	8·0	1·2	15·42	63·5	·5009993	·5010281	−14	− 18	0	− 35	− 312	−13	·5009913	·5009924	
" 28-29..........	12	1	D	1	250·78	244·44	7·9	1·4	15·18	67·6	·5009989	·5010248	−15	− 8	− 4	− 35	− 312	−13	·5009914	·5009896	
																Mean.	......	....	·5009913	·5009910	·5009912

TABLE V—*Continued*

PENDULUM OBSERVATIONS AND REDUCTIONS—*Continued*

STATION: NORMAN, N.W.T. OBSERVER: A. H. MILLER

Date	Swing number	Pendulum	Position	Knife-edge	Coincidence Interval		Arc		Temperature	Pressure	Period Uncorrected		Corrections (7th Decimal Place)						Period Corrected		
					Chronometer						Chronometer					Rate			Chronometer		Mean
					No. Dent 52866	No. Dent 48419	Initial	Final			No. Dent 52866	No. Dent 48419	Arc	Temp.	Pressure	D 52866	D 48419	Flexure	No. Dent 52866	No. Dent 48419	
Aug. 11............	1	1	D	1	270·86	261·56	8·7	1·3	11·44	62·5	·5009247	·5009576	−17	+ 149	0	+ 20	− 305	−10	·5009389	·5009393	
" 11-12.........	2	1	D	1	271·50	262·54	7·8	1·3	10·86	64·5	·5009225	·5009540	−15	+ 173	− 3	+ 20	− 305	−10	·5009390	·5009380	
																Mean.	....	....	·5009389	·5009387	·5009388
Aug. 12............	3	1	D	1	272·18	262·81	8·2	1·3	10·29	66·1	·5009202	·5009530	−16	+ 197	− 4	+ 22	− 308	−10	·5009391	·5009389	
" 12-13.........	4	1	D	1	272·68	263·28	7·7	1·2	10·04	67·9	·5009185	·5009514	−14	+ 208	− 6	+ 22	− 308	−10	·5009385	·5009384	
																Mean.	....	....	·5009388	·5009387	·5009387
Aug. 13............	5	1	D	1	272·59	263·25	7·9	1·2	9·53	69·5	·5009188	·5009515	−14	+ 229	− 7	+ 20	− 309	−10	·5009406	·5009404	
" 13-14.........	6	1	D	1	273·69	264·18	7·8	1·2	9·69	61·2	·5009151	·5009482	−14	+ 222	+ 1	+ 20	− 309	−10	·5009370	·5009372	
																Mean.	....	....	·5009388	·5009388	·5009388
Aug. 14............	7	1	D	1	271·75	263·61	8·2	2·3	9·49	61·8	·5009217	·5009501	−22	+ 231	0	− 52	− 328	−10	·5009364	·5009372	·5009368
" 15............	8	2	D	1	241·73	234·17	8·1	1·4	10·36	61·0	·5010364	·5010699	−16	+ 194	+ 1	+ 42	− 298	−10	·5010575	·5010570	
" 15-16.........	9	2	D	1	242·09	234·30	8·1	1·8	10·32	63·4	·5010348	·5010693	−19	+ 196	− 1	+ 42	− 298	−10	·5010556	·5010561	
																Mean.	....	....	·5010565	·5010565	·5010565
Aug. 16............	10	2	D	1	242·33	233·88	8·0	1·3	10·12	66·2	·5010338	·5010712	−15	+ 204	− 4	+ 46	− 304	−10	·5010559	·5010583	
" 16-17.........	11	2·	D	1	242·48	235·14	8·0	1·6	9·69	68·5	·5010332	·5010655	−17	+ 222	− 7	+ 46	− 304	−10	·5010566	·5010539	
																Mean.	....	....	·5010563	·5010561	·5010562
Aug. 17............	12	3	D	1	248·78	241·17	7·9	1·7	9·64	60·2	·5010069	·5010388	−17	+ 224	+ 2	+ 38	− 296	−10	·5010306	·5010291	
" 17-18.........	13	3	D	1	249·77	241·41	7·9	1·8	9·19	61·2	·5010029	·5010378	−18	+ 243	+ 1	+ 38	− 296	−10	·5010283	·5010298	
																Mean.	....	....	·5010295	·5010295	·5010295
Aug. 12-13.........	4B	1	D	1	272·86	263·49	6·6	1·2	9·97	68·2	·5009179	·5009506	−11	+ 211	− 6	+ 26	− 302	−10	·5009389	·5009388	
" 13............	5B	1	D	1	272·59	263·25	7·9	1·2	9·53	69·5	·5009188	·5009515	−14	+ 229	− 7	+ 26	− 302	−10	·5009412	·5009411	
" 13............	6A	1	D	1	272·49	262·52	7·8	6·9	10·10	61·0	·5009191	·5009541	−48	+ 205	+ 1	+ 26	− 302	−10	·5009365	·5009387	
																Mean.	....	....	·5009389	·5009395	·5009392

TABLE V—*Concluded*

PENDULUM OBSERVATIONS AND REDUCTIONS—*Concluded*

STATION: OTTAWA. OBSERVER: A. H. MILLER

Date	Swing number	Pendulum	Position	Knife-edge	Coincidence Interval: Chronometer No. Bond 627	Coincidence Interval: Chronometer No. Dent 48419	Arc: Initial	Arc: Final	Temperature	Pressure	Period Uncorrected: Chronometer No. Bond 627	Period Uncorrected: Chronometer No. Dent 48419	Corrections (7th Decimal Place): Arc	Temp.	Pressure	Rate: B 627	Rate: D 48419	Flexure	Period Corrected: Chronometer No. Bond 627	Period Corrected: Chronometer No. Dent 48419	Mean
Oct. 27	1	1	D	1	189·38	181·21	7·9	1·3	16·39	61·1	·5013236	·5013834	−15	− 58	+ 2	+ 302	− 300	− 8	·5013459	·5013455	
" 27-28	2	1	D	1	189·09	182·02	7·4	1·2	16·35	59·9	·5013256	·5013773	−13	− 57	+ 3	+ 278	− 235	− 8	·5013459	·5013463	
" 28	3	1	D	1	189·91	182·90	7·9	1·3	16·38	58·0	·5013200	·5013706	−15	− 58	+ 5	+ 333	− 176	− 8	·5013457	·5013454	
" 28-29	4	1	D	1	189·56	183·34	8·1	1·2	16·45	66·5	·5013223	·5013673	−15	− 61	− 2	+ 314	− 134	− 8	·5013451	·5013453	
Nov. 5-6	9	1	D	1	189·80	181·37	7·5	1·3	15·94	61·1	·5013207	·5013822	−14	− 39	+ 2	+ 299	− 311	− 8	·5013447	·5013452	
" 6	10	1	D	1	189·91	181·94	8·3	2·3	15·37	60·3	·5013200	·5013779	−22	− 16	+ 3	+ 305	− 283	− 8	·5013462	·5013453	
																Mean.	....	....	·5013456	·5013455	·5013455
Oct. 31	5	2	D	1	173·86	167·81	8·1	1·6	16·39	61·0	·5014421	·5014942	−18	− 58	+ 2	+ 288	− 230	− 8	·5014627	·5014630	
" 31-Nov. 1	6	2	D	1	173·81	168·39	8·3	1·5	16·41	60·8	·5014425	·5014891	−17	− 59	+ 3	+ 285	− 185	− 8	·5014629	·5014625	
																Mean.	....	....	·5014629	·5014628	·5014628
Nov. 3	7	3	D	1	177·53	170·30	7·9	1·6	16·13	62·6	·5014122	·5014723	−17	− 47	+ 0	+ 313	− 289	− 8	·5014363	·5014362	
" 3-4	8	3	D	1	177·68	170·86	8·0	1·6	16·00	58·5	·5014110	·5014675	−17	− 42	+ 5	+ 322	− 249	− 8	·5014370	·5014364	
																Mean.	....	....	·5014366	·5014363	·5014365

TABLE VI

PRINCIPAL FACTS FOR ALL GRAVITY STATIONS ESTABLISHED SINCE 1914

Station	Longitude	Latitude	Altitude	Computed *g* at sea-level	Corrections		Computed Gravity	Observed Gravity	Hayford Anomaly O—C	Bouguer Anomaly O—C	Free-Air Anomaly O—C
					Altitude	Topography and Isostatic Compensation					
	h. m. s.	° ′ ″	metres	dynes	dynes	dynes	dynes	dynes	dynes	dynes	dynes
1. Ottawa........	5 02 52	45 23 38	83	980·656	—·026	·000	980·630	980·618	—·012	—·021	—·012
2. Maniwaki......	5 03 55	46 22 28	169	980·745	—·052	—·001	980·692	980·688	—·004	—·024	—·005
3. Kingston......	5 05 55	44 13 37	79	980·553	—·024	·008	980·537	980·530	—·007	—·008	·001
4. Roberval.......	4 48 54	48 30 54	107	980·938	—·033	—·015	980·890	980·868	—·022	—·049	—·037
5. Tadoussac......	4 38 52	48 08 25	12	980·905	—·004	—·004	980·897	980·904	·007	·002	·003
6. Portneuf........	4 47 35	46 42 32	59	980·776	—·018	·005	980·763	980·763	·000	—·002	·005
7. St. Jérôme......	4 56 00	45 46 34	107	980·691	—·033	·006	980·664	980·681	·017	·011	·023
8. Ste. Anne-de-Bellevue.......	4 55 46	45 24 29	34	980·658	—·010	·003	980·651	980·663	·012	·011	·015
9. Mattawa.......	5 14 49	46 18 43	170	980·739	—·052	—·013	980·674	980·650	—·024	—·056	—·037
10. New Liskeard..	5 18 41	47 30 34	194	980·848	—·060	—·004	980·784	980·788	·004	—·022	·000
11. Cochrane.......	5 24 05	49 03 42	277	980·987	—·085	—·004	980·898	980·883	—·015	—·051	—·019
12. Sault Ste. Marie	5 37 18	46 30 26	186	980·757	—·057	—·005	980·695	980·680	—·015	—·041	—·020
13. Chapleau.......	5 33 37	47 50 26	430	980·878	—·133	·012	980·757	980·766	·009	—·027	·021
14. Port Arthur....	5 56 53	48 26 07	189	980·931	—·058	—·014	980·859	980·820	—·039	—·074	—·053
15. Rose Point.....	5 20 10	45 19 02	183	980·650	—·056	·001	980·595	980·606	·011	—·009	·012
16. Whitby........	5 15 46	43 52 43	84	980·520	—·026	—·004	980·490	980·461	—·029	—·042	—·033
17. Woodstock (Ont.).........	5 23 08	43 08 33	299	980·453	—·093	—·002	980·358	980·352	—·006	—·042	—·008
18. Windsor........	5 32 10	42 19 06	178	980·379	—·055	·000	980·324	980·341	·017	—·003	·017
19. St. John........	4 24 20	45 16 03	33	980·645	—·010	·016	980·651	980·663	·012	·024	·028
20. Moncton........	4 19 09	46 05 04	14	980·719	—·004	·014	980·729	980·728	—·001	·012	·013
21. Charlottetown..	4 12 30	46 13 55	8	980·732	—·002	·013	980·743	980·733	—·010	·002	·003
22. **Sydney.......	4 00 47	46 08 21	12	980·724	—·004	·014	980·734	980·731	—·003	·010	·011
23. Truro..........	4 13 06	45 21 40	18	980·654	—·006	·014	980·662	980·662	·000	·012	·014
24. Halifax.........	4 14 15	44 40 47	9	980·592	—·003	·008	980·597	980·574	—·023	—·016	—·015
25. Yarmouth.......	4 24 29	43 50 07	9	980·516	—·003	·014	980·527	980·543	·016	·029	·030
26. Woodstock (N.B.)........	4 30 18	46 09 02	56	980·725	—·017	·008	980·716	980·699	—·017	—·015	—·009
27. Edmundston...	4 33 18	47 22 11	148	980·835	—·046	—·010	980·779	980·774	—·005	—·032	—·015
28. Bathurst.......	4 22 36	47 37 10	5	980·858	—·002	·000	980·856	980·836	—·020	—·021	—·020
29. Percé..........	4 16 51	48 31 33	6	980·939	—·002	—·002	980·935	980·950	·015	·012	·013
30. Kenora.........	6 18 00	49 46 00	330	981·050	—·102	·018	980·966	980·974	·008	—·011	·026
31. Winnipeg.......	6 28 39	49 54 23	231	981·062	—·071	·002	980·993	980·930	—·003	—·027	—·001
32. Brandon........	6 39 47	49 50 54	366	981·057	—·113	—·002	980·942	980·956	·014	—·029	·012
33. Moose Jaw.....	7 02 07	50 23 26	541	981·105	—·167	·003	980·941	980·943	·002	—·056	·005

TABLE VI—*Concluded*

PRINCIPAL FACTS FOR ALL GRAVITY STATIONS ESTABLISHED SINCE 1914—*Concluded*

Station	Longitude	Latitude	Altitude	Computed g at sea-level	Corrections: Altitude	Corrections: Topography and Isostatic Compensation	Computed Gravity	Observed Gravity	Hayford Anomaly O—C	Bouguer Anomaly O—C	Free-Air Anomaly O—C
	h. m. s.	° ′ ″	metres	dynes	dynes	dynes	dynes	dynes	dynes	dynes	dynes
34. Medicine Hat...	7 22 40	50 02 25	664	981·075	—·205	—·002	980·868	980·868	·000	—·076	—·002
35. Calgary........	7 36 15	51 02 43	1044	981·164	—·322	—·022	980·820	980·823	·003	—·136	—·013
36. Banff...........	7 42 18	51 10 53	1376	981·176	—·425	—·012	980·739	980·753	·014	—·152	·002
37. Field...........	7 45 59	51 23 42	1239	981·194	—·382	—·060	980·752	980·748	—·004	—·202	—·064
38. Glacier........	7 49 58	51 15 44	1248	981·183	—·385	—·066	980·732	980·741	·009	—·198	—·057
39. Revelstoke.....	7 52 47	50 59 48	453	981·160	—·140	—·080	980·940	980·903	—·037	—·158	—·117
40. Kamloops......	8 01 19	50 40 42	352	981·131	—·109	—·073	980·949	980·947	—·002	—·115	—·075
41. North Bend....	8 05 51	49 52 17	152	981·059	—·047	—·122	980·890	980·889	—·001	—·140	—·123
42. Vancouver......	8 12 27	49 16 49	6	981·006	—·002	—·046	980·958	980·949	—·009	—·056	—·055
43. Peace River....	7 49 09	56 14 04	324	981·611	—·100	....	....	981·482	....	—·065	—·029
44. Resolution......	7 34 42	61 10 05	143	982·008	—·044	....	....	981·942	....	—·038	—·022
45. Providence.....	7 50 37	61 21 14	145	982·022	—·045	....	....	981·955	....	—·038	—·022
46. Simpson........	8 05 23	61 51 39	126	982·060	—·039	....	....	982·004	....	—·031	—·017
47. Norman........	8 22 17	64 53 59	89	982·281	—·027	....	....	982,214	....	—·050	—·040
Mean anomaly with regard to sign									—·003	—·043	—·014
Mean anomaly without regard to sign									·011	·048	·025

*The observations and the reductions for topography and compensation for stations 1 to 42 were made by F. A. McDiarmid. In making the computations the gravity reduction tables given on pages 30 to 47 of Special Publication No. 10 of the U.S. Coast and Geodetic Survey, were used. The corrections are therefore for an assumed depth of compensation of 113·7 kilometers.

The values of g at sea-level, in this table, have been computed from the formula $\gamma_o = 978{\cdot}039\,(1 + {\cdot}005294 \sin^2 \phi - {\cdot}000007 \sin^2 2\phi)$.

**Sydney was also determined by G. R. Putnam of the U. S. Coast and Geodetic Survey, in 1896, at a point in the town about 340 meters north of Mr. McDiarmid's station shown in the table. Making corrections for the differences in latitude and elevation between the two stations and for the change in the value adopted for g at Washington, Mr. Putnam's value for Sydney is 980·733 dynes. The difference between the two determinations is then only ·002 dyne — a good illustration of the accuracy of pendulum observations.

RELATION BETWEEN GRAVITY ANOMALIES AND TOPOGRAPHY FOR THE FORTY-SEVEN STATIONS DETERMINED SINCE 1914

The results of the observations illustrate in a very striking manner the well-known relations between the Bouguer and free-air anomalies on the one hand and topography on the other, and emphasize the superiority of the isostatic method of reduction. The breaking down of the Bouguer rule—its tendency to give values of the force of gravity which for the continents and high ground are always greater than are observed and, for the sea coast, values which are too small—is very apparent from the following table in which the anomalies by the three methods of reduction are shown for topography of different characters.

TABLE VII

MEAN ANOMALIES

Group of Stations	Number of Stations	Average Elevation above Sea-Level	Mean Anomaly (with regard to sign) Observed—Computed			Mean Anomaly (without regard to sign) Observed—Computed		
			Hayford	Bouguer	Free Air	Hayford	Bouguer	Free Air
		Meters	Dynes	Dynes	Dynes	Dynes	Dynes	Dynes
1. Coast Stations................	7	12	−·002	+·006	+·007	·014	·016	·017
2. Stations on or within* 150 miles of the coast................	10	17	−·003	+·005	+·007	·012	·015	·016
3. Stations in the interior not in mountainous regions.........	29	238	−·003	−·034	−·007	·011	·036	·015
4. Stations in mountainous regions below the general level.......	7	701	−·004	−·149	−·069	·011	·149	·070

The table shows the Hayford anomalies to be practically independent of the nature of the topography. This is certainly most remarkable when one considers the vastly different kinds of topography that are represented by the four groups of stations. All the coast stations are on the Atlantic seaboard and six of the seven stations in Group 4 are in the most mountainous part of British Columbia. A greater contrast could hardly be imagined than that which exists between the topography of these two groups. The results for these stations, therefore, afford a very severe test of any method of reduction. The fact that the mean anomaly by the Hayford reduction is practically the same for all the groups is a point very much in its favor. As the reductions for these stations were made on an assumed depth of compensation of 113·7 kilometers it follows, on the assumptions of isostasy made, that the part of the country covered by the 42 Canadian stations is in isostatic equilibrium at a depth generally uniform throughout and which on the average cannot be far from 100 kilometers.

*Vancouver is not included in the table. Although this station is within 150 miles of the open coast, it would be more properly classed with the kind of topography represented by Class 4. A glance at the relief map of Canada will bear this out.

Quite different results are obtained by the Bouguer reduction. The mean anomaly with regard to sign varies from + ·006 dyne for coast stations to − ·034 dyne for stations in the interior and to −·149 dyne for stations in mountainous regions—results which illustrate in a most convincing manner the absolute failure of this method of reduction. In obtaining the theoretical Bouguer value of the force of gravity allowance is made for the height of the station above sea-level and account is also taken of the matter lying between the elevation of the station and sea-level, which as far as the computations are concerned is treated as so much excess attracting matter supported by an absolutely rigid crust of the earth.

In the free-air method, on the other hand, no account whatever is taken of the attraction of matter lying above sea-level which may be more briefly referred to as the topography. At first sight it might seem not a little surprising that results obtained by neglecting the attraction of this matter are nearer the truth than those obtained by taking it into account. However, from the point of view suggested by the theory of isostasy, this is readily understood. If the elevated portions of the country are fully compensated by material of density less than normal underneath we must expect the attraction of matter above sea-level to be largely balanced by the reduction in the normal attraction of the matter below. In fact, for stations located in extremely level country, the two effects theoretically balance one another almost completely. Neglecting the effect produced by distant topography and compensation the Free Air and Hayford methods, then, should give practically the same results for stations located on such topography. It will be seen that this is actually the case for the group of 29 stations in the interior, but not in mountainous regions. The mean anomalies for these stations differ by only ·004 dyne for the two methods of reduction and are in much closer agreement than for any of the other groups. For the coast stations the free-air method gives, on the average, values of the force of gravity that are too small, and for stations in mountainous regions below the general level values that are much too large.

The results obtained by the Bouguer method show very plainly that there must be some compensation for the material in the continent above sea-level, i.e., for the topography, while the results from the free-air method show that the topography cannot be neglected entirely. This naturally leads to the conclusion that any correct method of reduction must take account of both the topography and the compensation. This is exactly what is done in the Hayford or isostatic method of reduction. The topography and compensation of the entire surface of the earth are taken into consideration in the computations. For the 42 gravity stations that have so far been reduced by this method it gives results that are on the average very close to the observed values. By a change either in the depth of compensation or in the constants of the formula for γ_o the theoretical values on the average could be made to fit the average observed values exactly.

RELATION BETWEEN THE GRAVITY ANOMALIES AND THE GEOLOGICAL FORMATIONS

The 42 stations reduced by the Hayford method, arranged according to the geological formations, are shown with their respective anomalies, in the following Table:

TABLE VIII

Formation and Station Number	Anomaly in Dynes	Formation and Station Number	Anomaly in Dynes	Formation and Station Number	Anomaly in Dynes	Formation and Station Number	Anomaly in Dynes
Precambrian formations		Paleozoic formations		(Continued) Paleozoic formations		Tertiary formations	
2	−·004	1	−·012	27	−·005	35	+·003
4	−·022	3	−·007	28	−·020	42	−·009
5	+·007	6	·000	29	+·015	Unclassified.	
7	+·017	8	+·012	31	−·003	24	−·023
9	−·024	10	+·004	36	+·014	25	+·016
11	−·015	12	−·015	37	−·004		
13	+·009	16	−·029	40	−·002		
14	−·039	17	−·006	41	−·001		
15	+·011	18	+·017	Mesozoic formations			
19	+·012	20	−·001	23	·000		
30	+·008	21	−·010	32	+·014		
38	+·008	22	−·003	33	+·002		
39	−·037	26	−·017	34	·000		

SUMMARY

—	Number of Stations: Total Number	Number of Stations: With* Positive Anomalies	Number of Stations: With* Negative Anomalies	Mean Anomaly in Dynes: With Regard to Sign	Mean Anomaly in Dynes: Without Regard to Sign
Precambrian	13	7	6	−·005	·016
Paleozoic	21	9**	10**	−·003	·009
Mesozoic	4	2	2	+·004	·004
Tertiary	2	1	1	−·003	·006
Unclassified	2	1	1	−·003	·015
All Stations	42	20	20	−·003	·011

*For the purpose of this table an anomaly is considered positive when it is algebraically greater than −·003 dyne, the mean anomaly with regard to sign for all stations.

**Two of the stations on Paleozoic formations have anomalies of −·003 dyne.

The conclusion to be drawn from these tables is that, for most of the stations so far established in Canada, there is no definite relation between the geological formations and the gravity anomalies. If anything there is a slight tendency for stations on Precambrian formations to give values for the force of gravity which, on the average, are slightly less than normal. Of all stations the two having the largest negative anomalies are situated on this formation.

The four Mesozoic stations give a mean anomaly ·007 dyne greater than the normal mean. However, on account of the small number of stations on Mesozoic formations no great significance can be attached to this.

CONCLUSION

There is still a great deal of valuable information awaiting further investigation of the results of observations already taken. This will be undertaken as time permits and in conjunction with the investigation of the results of observations at stations it is proposed to establish in the future. With a greater number of properly selected stations on which to base conclusions the value of the results will be very much increased. Among the inquiries that it is proposed to make may be mentioned the investigation of a gravity formula that agrees best with observations taken in this country, of the value of the flattening of the earth toward the pole and of various results of interest in the study of isostasy.

In this connection it should be remarked that we have already a complete chain of stations from the Atlantic to the Pacific, and in Western Canada we shall soon have a fairly complete chain of stations from the south boundary of the country to a point well within the Arctic circle. These results should then be of the highest importance in investigating the variation of gravity with latitude, and considering the immense distances covered in both directions by the stations it should be possible, from the observations in this country, to obtain for the flattening or ellipticity of the earth a value that merits the greatest confidence.

It may be remarked that the results for our Canadian gravity stations have already been used in co-ordination with other similar results to obtain a formula representing best the theoretical value of gravity at any latitude and in any part of the world. This formula, which is the one used for γ_o in this publication, was derived by Dr. Wm. Bowie of the U. S. Coast and Geodetic Survey in 1917 from 216 stations in the United States, 42 in Canada, 73 in India, and 17 in Europe. There can be no doubt that this formula is a decided improvement on earlier ones. It may be mentioned that the results it gives for the force of gravity are published in the Smithsonian Meteorological Tables for every 20 minutes of latitude from the equator to the pole. A table for every degree of latitude is also published in the Smithsonian Physical Tables and in other scientific publications.

In conclusion, the writer would like to point out the need for good topographical maps. For the isostatic reductions these are essential, and it is also felt that their usefulness would not be confined to gravity work, but would serve many other useful purposes as well. The sectional maps now being published by the Topographical Surveys Branch will be very useful for stations in Western Canada, but in addition to maps of the country not covered by these, a contour or relief map of the whole country, compiled from the most recent information, would be very desirable.

Chief Geographer's Office