PUBLICATION OF THE NETHERLANDS GEODETIC COMMISSION
(UITGEGEVEN DOOR DE RIJKSCOMMISSIE VOOR GRAADMETING EN WATERPASSING)

GRAVITY EXPEDITIONS AT SEA

1923—1930.

VOL. I.

THE EXPEDITIONS, THE COMPUTATIONS AND THE RESULTS.

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DELFT — N.V. Technische Boekhandel en Drukkerij J. Waltman Jr. — 1932.

PREFACE.

A few personal words may precede this report. I wish to express my feelings of deep gratitude towards the two institutions which have given me these great opportunities for important research work, to the Netherlands Geodetic Commission, whose president, Prof. Muller, has continually been willing to promote the plans, and to the Netherlands Navy, whose authorities have always consented to make these expeditions possible by allotting submarines for this work. This cooperation of the Navy with scientific enterprise on this scale is probably without precedent in Naval History.

I wish to acknowledge thankfully the unfailing support and friendship of Prof. Muller during all these years. I feel that his help has played a decisive part in bringing about this work. The last token of his kindness regards this report; he assisted me by reading the proofs.

I wish to acknowledge with the same strong feelings of indebtedness the support and cooperation of the captains of the submarines, Lieuts. Doorman, Beckman, Van der Kun and Mante, without whose untiring assistance the results would not have been as valuable and as complete as they are. Likewise I wish to mention the helpful cooperation of the officers and the crews of the ships. The good friends I made during these long voyages are a personal asset which I value highly.

This is, concentrated in a few lines, what I wish to express when sending out this report into publicity.

F. A. VENING MEINESZ.

NOTICE.

This volume contains the report of the maritime gravity expeditions of the Netherlands Geodetic Commission during the years 1923—1930. The results are reduced to sea-level without further reduction; they are put together in the list on pages 101 et seq.

A second volume will contain the isostatic reductions of the results and the discussion of their interpretation.

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CHAPTER I.

Historical.

During the Gravity Survey of Holland in the years 1912-1921, the mobility of the soil in the Northern and Western part of the country caused difficulties, which have led ultimately to the development of a new method for determining gravity at sea. In the swampy parts of Holland, no fixed base could be found for the pendulum apparatus, and it was, therefore, necessary to take special measures for ensuring the accuracy of the observations notwithstanding these macro-seismic movements of the apparatus. This end was reached by a method of swinging two pendulums at the same time in the same swinging plane; in this way the principal effect of the mobility of the apparatus, the effect of the horizontal accelerations, could be eliminated. The observations were made with the ordinary Stückrath apparatus, in which four pendulums swing two by two in planes, perpendicular to each other. For further details we may refer to the publication of the Netherlands Geodetic Commission: „Observations de Pendule dans les Pays-Bas", Waltman, Delft.

The success of this method of eliminating the effects of disturbing movements of the apparatus led to a further investigation of its possibilities in order to see if it could also be applied on board of ships. After developing the method and adapting the equations to the greater movements, which could be expected, this proved to be possible, provided the ship's movements do not exceed a certain limit. This condition can be satisfied by making the observations on board of submarines during submergence; in this way the ship gets below the wave disturbance and the rolling and pitching is reduced to a small and very gradual movement. Even during rough weather it is easy to reach a depth, where the ship is sufficiently quiet; for an ordinary wave movement, a depth of 20 meters is usually enough, for long ocean waves it may be necessary to submerge to 30 meters or more. A further advantage of the submarine is the fact that during submergence it is moved by electromotors, which do not bring about vibrations. The idea of making the observations on board of submarines was first mentioned to the writer by Prof. Dr. Van Iterson, Director of the Dutch Government Mines.

Some preliminary experiments having been made during the summer of 1923 o/b a submarine of the Netherlands Navy in the neighbourhood of the Dutch Naval Base, Helder, and these experiments having proved satisfactory, it was resolved to put the method to a thorough test during a longer voyage. A good opportunity was offered in the autumn of 1923 by the voyage from Holland to Java of three Dutch submarines, Hr. Ms. K II, K VII and K VIII, accompanied by a mother ship, Hr. Ms. Pelikaan. The Netherlands Geodetic Commission, President Prof. Dr. J. J. A. Muller, Secretary Prof. Ir. Hk. J. Heuvelink, asked permission for the writer to embark with the necessary apparatuses o/b of one of these submarines and to make experiments during the voyage. The permission was granted by the Minister of the Navy, his Exc. Mr. E. P. Westerveld.

Before the beginning of this voyage the apparatus had to be adapted to the projected method. The principal alteration to the Stückrath apparatus was the making of a photographic recording device; the elimination method, applied during the observations in Holland, had been carried out with the old visual method, but this would be impossible for the newly developed method, which had to cope with the greater disturbances, caused by the ship's movements. Details about this method are to be found in the publication of the Netherlands Geodetic Commission: „Theory and Practice of Pendulum Observations at Sea" and details about the apparatuses used during this first voyage are given in the next chapter.

The observations have been carried out o/b Hr. Ms. K II, Lieut. L. A. C. M. Doorman commanding. Besides 26 gravity determinations at sea, observations have been made in the harbours, Gibraltar, Tunis, Alexandria, Suez, Colombo and Sabang.

During the first trip from Helder to Gibraltar rough weather made it impossible to work the apparatus, even at considerable depth below the surface, because the angular deviations of the ship exceeded the allowable limit of half a degree. The difficulty was remedied at Gibraltar, where, thanks to the cooperation of the Dock-yard of the British Navy, the apparatus could be mounted in a suspension device. This took away the greatest part of the ship's rolling and henceforward the apparatus functioned satisfactorily under all conditions.

The method proved to be a complete success. Certain secondary disturbing terms, which would be difficult, if not impossible to eliminate, appeared to be negligible. The consequence of this was, that the accuracy of the gravity determinations exceeded what was expected; the mean error proved to be only 4 or 5 milligals. Details about these and related points are given in the next chapter.

For the continuation of the investigations the first step had to be the improvement of the apparatus: it was desirable to build a new apparatus especially adapted to the method. This was done in 1920 at the workshop of the Royal Netherlands Meteorological Institute at De Bilt by the Chief Mechanic, L. M. van Rest, after the plans of the writer. Thanks are due to the Director of this Institute, Prof. Dr. E. van Everdingen for allowing its construction and to Dr. C. Schoute, Adj. Director for his valuable advice. A detailed description of the apparatus is given in the publication: „Theory and Practice of Pendulum Observations at Sea", with the exception of the suspension arrangement and the photographic recording apparatus, which in 1925 had not yet got the final shape mentioned in this publication. In 1925 the apparatus was suspended on one axis only, in the same way as during the first voyage, so that only the rolling of the ship was eliminated, and the recording apparatus was put at some distance from the pendulum apparatus. A description of these arrangements is found in Chapter III, which deals with the work done in 1925.

In order to put the new apparatus to the test, a voyage was made in the autumn of 1925 from Helder to Alexandria on board of a new submarine, Hr. Ms. K XI, which was leaving Holland for the Netherlands East Indies. Permission was again granted by the Minister of the Navy. A subsidiary object of the voyage was to get some more gravity data for this route than had been obtained during the first voyage. Observations were made at 9 sea-stations and at the harbours of Sevilla, Tunis and Alexandria. The results are given in Chapter III.

The apparatus proved to be satisfactory. The accuracy of the observations was slightly enhanced — the mean error of the gravity results may now be estimated at 3 to 4 milligals — but the chief advantage was the great simplification of the computations. While the computing of the observations of the first voyage had been difficult and had taken at least two days per station, they were now easy and could be managed in a few hours per station. There were only two things, for which an alteration appeared advisable.

The first thing was a detail concerning unexpected friction in the suspension of the two auxiliary damped pendulums. It could easily be remedied.

The second thing was more important. The apparatus being only suspended round an axis parallel to the ship, the rolling of the ship was eliminated but not the pitching. It was therefore necessary to keep the pitching between narrow limits; a tilt of the length-axis of the ship of more than half a degree could not be allowed. By submerging to a sufficient depth, this condition can be fulfilled, but it is a severe strain for the two men steering the vertical rudders and it can only be done by careful and capable steering. Moreover, it is impossible to maintain this steady position when men circulate through the ship. During all the observations of the voyages of 1923 and 1925, it had, therefore, been necessary to keep the whole crew at their places. This also was a strain, which it would be worth while to take away for future expeditions.

The only way to meet the difficulty, would be to suspend the apparatus also in the other direction, i.e. to put it in a complete gimbal-suspension. In that way greater ship's movements could be allowed, the crew could be permitted to move about and the watches could be changed without endangering the success of the observations. The construction of a gimbal-suspension meant, however, a serious change of the apparatus; the recording apparatus had to be put on top of the pendulum apparatus, the path of the light-rays from one to the other had to be folded up by reflexions in order to retain its length, without making the apparatus too bulky and a number of minor alterations had to be made. This was carried out in the spring of 1926. Some further details are given in Chapter IV, which contains the report of the next expedition in the years 1926—1927.

This expedition was already planned long beforehand. Its principal scientific object was to use the new method for getting data about the Figure of the Earth, more especially about its equatorial cross-section, which is an old and still unsettled problem of Geodesy. Measurements of arc and continental gravity determinations seem to point towards a slight ellipticity, which it is difficult to explain from a theoretical standpoint. With this end in view, a voyage was planned from Holland to Java by way of the Panama Canal; combined with the values found in 1923 along the route from Holland to Java by way of the Suez Canal, a complete and continuous ring of gravity values, encircling the Earth, would be obtained, which would obviously give valuable material for this problem. Moreover, the continuity around the whole Earth was not the only advantage of the material, that would thus be got; probably it would also be less locally disturbed than the continental gravity, because most of the sea-values would be determined over depths of more than 4000 meters and so irregularities of mass in the crust would be at a greater distance from the observer and would therefore give less attraction anomalies. A second reason for expecting less local gravity anomalies at sea is the absence of erosion, which on the continents strongly and locally modifies the topography and therefore the attraction

In connection with these plans, the Netherlands Geodetic Commission addressed a request to the Minister of the Navy, his Exc. Mr. E. P. Westerveld, that one of the new submarines, built for the Colonies, would take the route to Java via Panama in stead of via Suez, permitting gravity research along that route. This was a great request as the distance would be more than 20,000 miles, partly over long unbroken ocean stretches. With sincere appreciation mention may be made of the consent that was given and of the cooperation of all the authorities of the Navy, that were concerned.

The route was fixed in such a way, that the scientific results might be expected to be most valuable. Besides the principal object, it would be possible to get data about isostasy and about eventual deviations of isostasy for many interesting parts of the Earth's crust, i.e. the Atlantic and Pacific Oceans in general, the Mid-Atlantic Ridge, the Nares Deep North of Porto Rico, the continental shelf between Panama and San Francisco, the Hawaiian Ridge with the adjoining Renard Deep, the Nero Deep near Guam, the Yap Deep, the Philippine Deep and the Eastern part of the East Indian Archipelago. In connection with these problems, the route was chosen via the following harbours: Horta (Azores), Las Palmas (Canarian Isls), Curaçao (West Indies), Colon, Panama, Mazatlan (W. Coast of Mexico), San Francisco, Honolulu, Guam, Yap, Manilla, Amboina (Moluccas), Banda (id), Bima (Sumbawa) to Surabaya (Java). The voyage would be carried out by Hr. Ms. K XIII, Lieut. L. G. L. van der Kun commanding, and would last more than six months and a half.

The K XIII left Helder the 26th of May, 1926, and arrived in Surabaya the 13th of December. A hundred and fourteen days were spent at sea. Save the first trip from Helder to Horta, and a few days later on, the expedition was favoured by good weather. Together 128 gravity data were got, of which 15 in the above harbours.

After arriving in Java a request was made to the Commander of the Navy in the Netherlands East Indies, Vice-Adm. Goossens, for a subsidiary expedition to investigate the Java Deep to the South of Java in the Indian Ocean. This request was again granted. In Februari 1927 a two weeks trip was made with Hr. Ms. K XIII over this deep, during which 26 stations were observed at sea besides observations in the harbours of Surabaya and Batavia. For all details about the great expedition and about this last trip we must refer to Chapter IV.

Special mention may be made of the fact that the isostatic reductions of the gravity results of all the foregoing expeditions, covering together about 200 stations, have kindly been made by the Bureau of the U. S. Coast and Geodetic Survey in Washington, without any charge to the Dutch Commission. Sincere thanks are due for this important cooperation to the late Director of this Service, E. Lester Jones, and to the Chief of the Division of Geodesy, Dr. William Bowie, to whose interest and intercession this great contribution is due.

The results of the expedition of Hr. Ms. K XIII are communicated in Chapter IV. They will be discussed at full length in the second volume of this publication, which will appear later. We will here only mention the principal outcome. Using the formula for normal gravity, accepted by the Geodetic Section of the Geodetic and Geophysical Union at its conference at Stockholm in 1930, which corresponds to a rotational Figure of the Earth, there are deviations which can not be explained by an elliptic shape of the equator. Their distribution makes the impression of being irregular but there are indications, that they are related with the great configurations of the Earth's crust; in general the oceans have a tendency to show positive anomalies. Clearer still is a relation with the tectonic activity of the crust; all areas where tectonic activity may be assumed, show great gravity anomalies. In the writer's opinion there is every reason to suppose, that the fields of gravity anomalies and the deviations of the Figure of the Earth, which gave rise to the hypothesis of the flattening of the equator, are caused by the processes, that are going on in the Earth's crust.

New indications about the relations of gravity and tectonic activity have also been found by the maritime gravity expedition, organized by the U. S. Navy in cooperation with the Carnegie Institution of Washington in the West Indies during the fall of 1928; the results have been published in: "Publications of the U. S. Naval Observatory", second series, Vol. XIII, App. I. The Netherlands Geodetic Commission has cooperated to this expedition by lending the apparatus; the observations have been carried out by Dr. Fred. E. Wright, Mr. Elmer. B. Collins and the writer.

In the mean time a last alteration of the apparatus had been made; in the spring of 1928 the upper part, i. e. the photographic recording apparatus with accessories, had been reconstructed and at the same time a number of smaller improvements had been introduced. This had brought the apparatus to the shape, described in the publication: "Theory and Practice of Pendulum Observations at Sea". A first trial of the improved apparatus was made during a short trip near Helder in July 1928. A more decisive test followed during the American expedition, which has been mentioned above. The results being satisfactory, this shape was adopted as final.

The conviction, that the clearing up of the relation between gravity and tectonic activity would be of primary importance for both sides of gravity research: the geodetic problem of the Figure of the Earth and the geophysical problem of the investigation of the condition of the Earth's crust, gave rise to plan a further expedition, i. e. a complete gravimetric survey of the seas in the Netherlands East Indies and the adjoining parts of the Indian and Pacific Oceans. This part of the Earth's surface is especially appropriate for the elucidation of these problems, because it is tectonically very active, as is shown by the great number of earthquake-centres and volcanoes and by the geological data, and it has the advantage of being well investigated geologically, seismically and topographically. The submarine topography is likewise known in detail; prior to 1929 a great many soundings have already been made, but since then, the hydrographic expedition of Hr. Ms. Willebrord Snellius under leadership of Mr. Van Riel has added more than 30.000 echo-soundings over the whole Eastern part of the Archipelago, thereby giving us a detailed knowledge of the sea-floor.

In connection with the above plan the Netherlands Geodetic Commission addressed a request to the Commander of the Indian Naval Forces, Vice-Admiral Ten Broecke Hoekstra. Sincere thanks are due to him for his consent to this extensive plan: for more than eight months he allotted a submarine for this purpose.

Between June 12, 1929, and February 16, 1930, Hr. Ms. K XIII, Lieut. G. Mante commanding, has made three expeditions through the Archipelago, together covering nearly 16000 miles and providing gravity data for 233 stations. During the first expedition of two months in the Eastern part, continuous rough weather was met with, but the two other expeditions were more lucky in this regard. The short distance between the stations, usually 40—60 miles, brought about an excessive number of divings every day, viz. three or four times per 24 hours; this made the expeditions rather strenuous.

The 233 gravity stations in combination with those, which had already been observed in 1923, 1926 and 1927, form a network over the whole Achipelago and over the adjoining strips of the Indian and Pacific Oceans, giving, with the exception of the islands, which have not yet been investigated gravimetrically, a complete knowledge of gravity over this area. Details about the distribution of the stations, about the expeditions and about the results are given in Chapter V.

The principal outcome of the investigations can be given in a few words. Gravity shows strong deviations of isostasy, distributed in a remarkably simple way without direct relation to the complicated topography of the Archipelago. They show undoubtedly a narrow relation with the seismic data, with the tectonic activity and with the distribution of volcanoes. This points to the supposition that the principal tectonic phenomena take place in the deeper layers of the crust and that they have a more simple character than the surface deformations, which are responsible for the surface topography of the crust.

In volume II a more detailed hypothesis will be given about what is going on in the crust; according to this hypothesis the principal feature is a buckling of the crust towards the inside along a line running through the whole Archipelago. In the opinion of the writer no other hypothesis fits all the facts, given by geology, seismology and gravimetry, as well. The results found in the Indian Archipelago have also thrown new light on the results of the other expeditions.

CHAPTER II.

Voyage of Hr. Ms. K II from Holland via Suez to Java September 18 - December 24, 1923.

Preliminary.

Method and Apparatus. During the gravimetric survey of Holland, difficulties were experienced in the Western part of the country because the swampiness of the soil prevented finding a sufficiently stable foundation for the pendulum apparatus. This led to the elaboration of a method by means of which the effects of small movements of the apparatus may be eliminated. This method, described in detail in „Observations de pendule dans les Pays Bas", Waltman, Delft, consists in swinging at the same time two pendulums in the same plane on the same support. When the pendulums get the same amplitude in opposite phases the mean of the two periods is free from disturbance.

The observations in Holland have been made with the four pendulum Stückrath apparatus, of which a description is found in the same publication. This apparatus has two pairs of pendulums swinging in two perpendicular planes; for applying the method both pendulums of one pair are set swinging. The observations of the pendulums are made visually by means of a so-called coincidence apparatus.

The success of the method led to the question if the method could be altered in such a way, that the effects of bigger movements could also be eliminated, and if in this case it would be possible to apply it on board of ships.

As to the first point it could easily be shown that even for greater horizontal movements of the apparatus and independently of the initial amplitudes and phase difference, two isochronous pendulums, swinging in the same plane, swing in such a way that the difference of their angles of elongation is undisturbed. This differential angle may be considered as the angle of elongation of a fictitious pendulum with the same period as those of the original pendulums. As it is undisturbed, this fictitious pendulum can be used for the computation of gravity. For details about this method as e.g. the effect of vertical movements and rotations, the effect of slight deviations from isochronism of the original pendulums, and a great many other points, I may refer to the publication: „Theory and Practice of Pendulum Observations at Sea", Waltman, Delft.

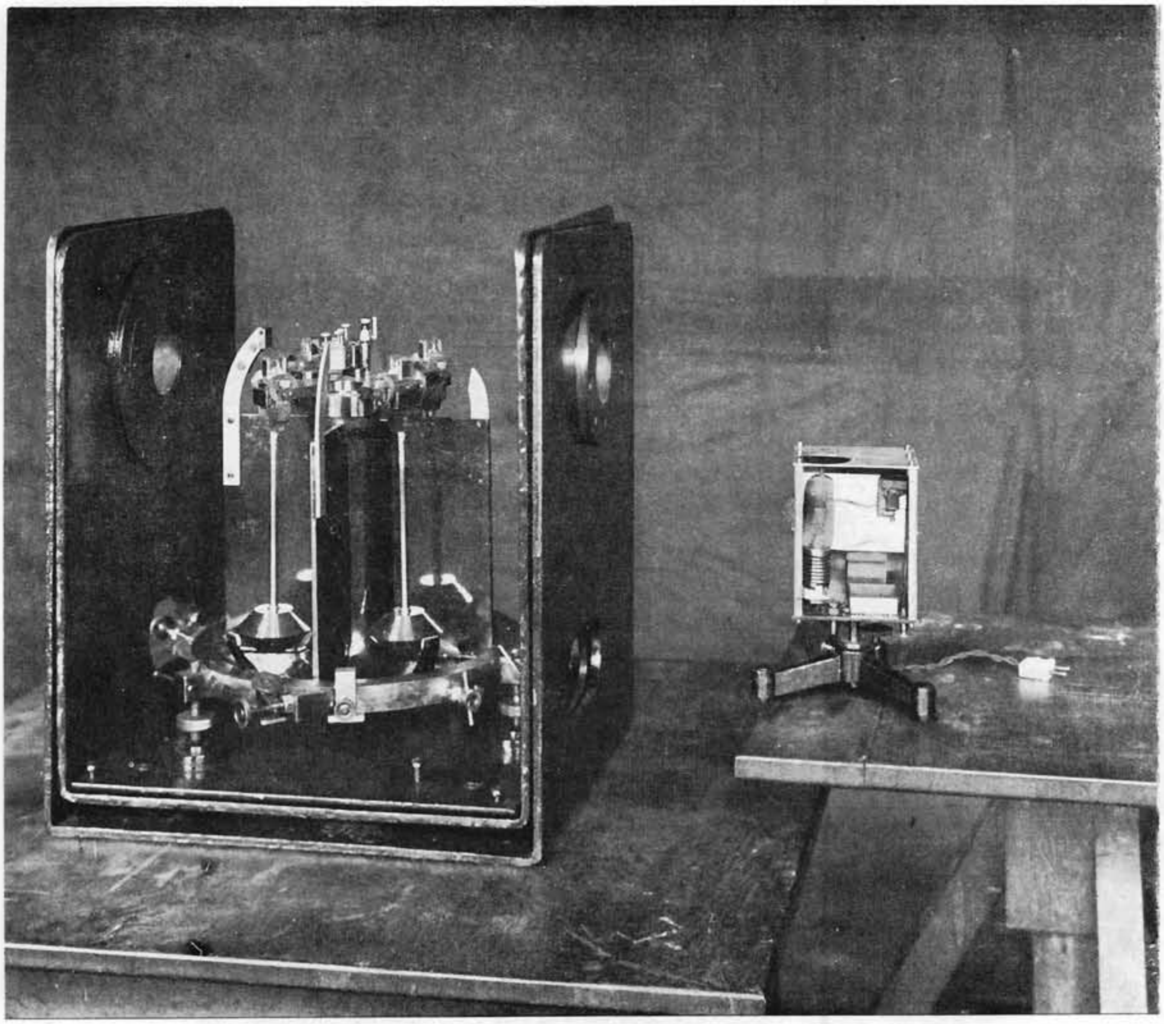
The first experiments with this method have been made in May 1922 on board of a small steamer of the "Koninklijke Paketvaart Maatschappij", by kind permission of the Directors, during a trip on the North Sea, between Ymuiden and Flushing. As the sea was rough, these experiments had no chance of success, but during the passage of the ship through the North Sea Canal between Amsterdam and Ymuiden, the impression about the possibilitie of the method were not unfavourable. One thing, however, was at once clear, i.e. that no success could be expected if the Stückrath apparatus, with which the experiments had been made, was not provided with a photographic recording apparatus. The changes of amplitude and phase of the pendulums are so sudden, even in case the ship's movements are small, that visual observation would not be able to follow them. Another point had also become clear, as well by these experiments as by theoretical research, i.e. that the ship's movements should have to be small for allowing the application of the method.

While engaged in gathering data abou the magnitude of ship's movements under different conditions, the writer got a valuable advice from Prof. Dr. Ir. Van Iterson, Director of the Dutch Government Mines, to try the experiments on board of a submerged submarine, because in these conditions the ship is below the wave movement and therefore steady. The first experiments made in the spring of 1923 on board a Dutch submarine in the roadstead of the Naval Base at Helder, completely confirmed these expectations; the ship's movements were imperceptible and the amplitudes of the pendulums fairly regular. This meant a good chance of success for the application of the method at sea.

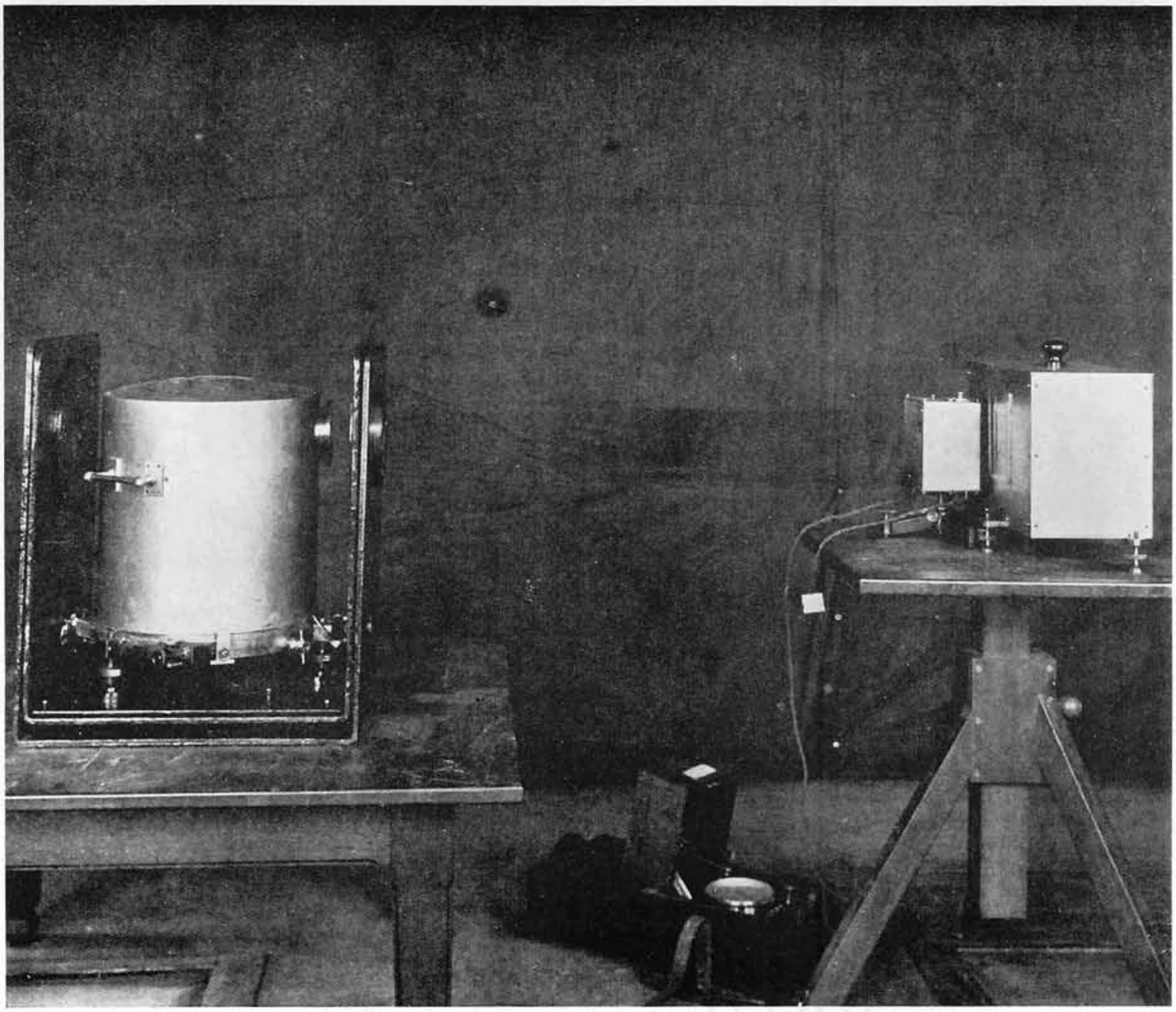
At once steps were taken for asking further cooperation of the Netherlands Navy. A good opportunity for making a large submarine trip was offered by the projected voyage of three submarines with a mother-ship from Helder to Batavia in the autumn of 1923. The Minister of the Navy kindly gave his consent for mounting the apparatus on board of one of these submarines, Hr. Ms. K II, and for allowing the writer to embark on this ship and to make experiments during the trip. The principal object of the trip would be to test the method, but at the same time it was hoped that already valuable gravity material could be obtained.

During the few months which were left before the day of departure, a photographic recording device had to be made for replacing the coincidence apparatus of the Stückrath apparatus. This has been done at the work-shop of the Meteorological Institute at De Bilt by the Chief Mechanic, Mr. van Rest, after the plans of the writer. The round window of the metal hood of the pendulum apparatus was provided with a lens with a focal distance of 1.10 meter. At a little less than this distance an electric arc lamp was mounted in a special apparatus behind a small circular hole of a diameter of 0,5 mm; this hole was the source of light for the recording. It could be shut by a small shutter, passing before it when activated by the current of an electrical circuit, which was closed and opened every half-second by a chronometer; in this way the light was interrupted every half-second for a short moment and these interruptions coincided with the chronometer-beats. Besides this shutter, the light-apparatus was provided with a second shutter, which could be moved by a clock-work in such a way that it passed twenty times per second before the light aperture. This last arrangement was made for providing the recorded curve with a great many time-marks during the interval of one pendulum-swing; as nothing was known about a number of secondary effects of the movement of the apparatus on the pendulum movement, it was thought desirable to be able to check the pendulum movement at all these intermediate moments. As, however, the results of the observations soon showed that these secondary effects were all negligible, the last time-marks were no longer necessary and the second shutter was not used. The curves show therefore only the interruptions corresponding with the beats of the chronometer.

The light emitted by the light-apparatus entered the Stückrath apparatus through the



Left: Stückrath Apparatus, opened, mounted in the cradle.
Right: Light Apparatus, opened.



Complete Apparatus, without black cloth cover.
Left: Stückrath Apparatus mounted in the cradle.
Right: Light Apparatus, Recording Apparatus, Chronometer.

lens and was separated inside by prisms and mirrors in four beams. Each beam struck the mirror of one of the pendulums and was returned nearly along the same line, through the lens, towards the slit of the recording apparatus, which was mounted just besides the light-apparatus at a distance of about 115 cm of the lens. The whole arrangement is represented on the photograph. During the observations it was covered by a black cloth to keep out stray light.

Because of the movement of the pendulums the returning lightbeams were moving up and down in the vertical slit of the recording apparatus. Behind this slit a strip of photographic paper was moved along horizontally by a clock-work.

In this way the four pendulums were recorded separately on the paper, as is shown on the reproduction of parts of a few records on pages 17 a. 18; these records also show the interruptions corresponding to the chronometer-beats, which are used for the time-measurements. For deducing the period of the fictitious pendulums, we have to combine the records, viz. for one fictitious pendulum we use the records of the two pendulums, swinging in one plane, and for the other those of the pendulums swinging in the other plane. For the way in which these computations are made, I may refer to "Theory and Practice of Pendulum Observations at Sea", page 89.

Besides the records of the pendulums, it was also necessary to get a record of the position of the swinging planes of the two pairs, because a correction must be applied for the tilting of these planes; the need for this correction is easily understood when we realize that in case the plane is not vertical, gravity itself is not determined but the component of gravity in this plane (see "Theory and Practice of Pendulum Observations at Sea", page 12).

For the determination of these angles of tilt, however, no separate records are needed, because the tilt of one of the planes may be deduced from the records of the pendulums swinging in the other plane. To recognize this, we may consider that in the above way we did not record the angle of elongation Θ, i.e. the angle between the axis of the pendulum and the vertical, but the angle between the axis of the pendulum and a certain fixed line in the apparatus. If we call the angle between the vertical and this fixed line α, we may notice that α represents likewise the angle of tilt of the second plane, i.e. the angle we wish to know. According to what has been said, we recorded the angle $\Theta + \alpha$ and as Θ is changing much quicker than α and varies during one pendulum-period between $+ a$ and $- a$, if a is the amplitude of the pendulum, we see that the recorded angle fluctuates between $\alpha + a$ and $\alpha - a$; α is therefore represented by the mean of those values or in other words by the curved axis of the pendulum record. In the same way the axis of the record of the second pair represents the tilt of the swinging-plane of the first pair.

The other reductions, as e.g. the reduction to infinitely small amplitude, can also be computed by means of the pendulum-records. About the way in which these computations are made, details may be found in "Theory and Practice of Pendulum Observations at Sea", page 89.

The Netherlands Geodetic Commission owned two sets of four pendulums, belonging to the Stückrath apparatus: an invar set and a brass set. Because of the magnetic properties of invar and the uncertainty about the magnetic field which perhaps might occur aboard submarines, the brass set was chosen, although of course the effect of uncertainties of the temperature would be greater for this set. It was however felt that this last uncertainty would be less serious than the first as it would be easier to estimate its effect and likewise easier to reduce it.

As the brass pendulums (Nrs. 88, 89, 90; and 91) were not sufficiently isochronous for the application of the method, this had to be remedied before making the base observations at De Bilt, which had to precede the voyage. It was done by drilling holes in the lower surface of the pendulum bulbs in such a way that the amount of mass which was taken away, altered the pendulum-periods in the way that was desired. This amount of mass was first computed approximately and drilled away and then the isochronizing was perfected experimentally. For the computation the following formula was deduced:

If T = period of the pendulum,
I = moment of inertia of the pendulum round the rotation axis,
M = moment of mass round the rotation axis,
l = I/M = mathematical length of the pendulum,
h = distance from the rotation axis to the centre of gravity,
s = distance from the rotation axis to the centre of the mass that is taken away,
m = mass of the pendulum,
dT = change of the period of the pendulum,
dm = mass which is taken away,

We have:

$$T^2 = \pi^2 \frac{I}{M\,g}$$

and differentiating, taking into account $dI = -\,s^2\,dm$ and $dM = -\,s\,dm$:

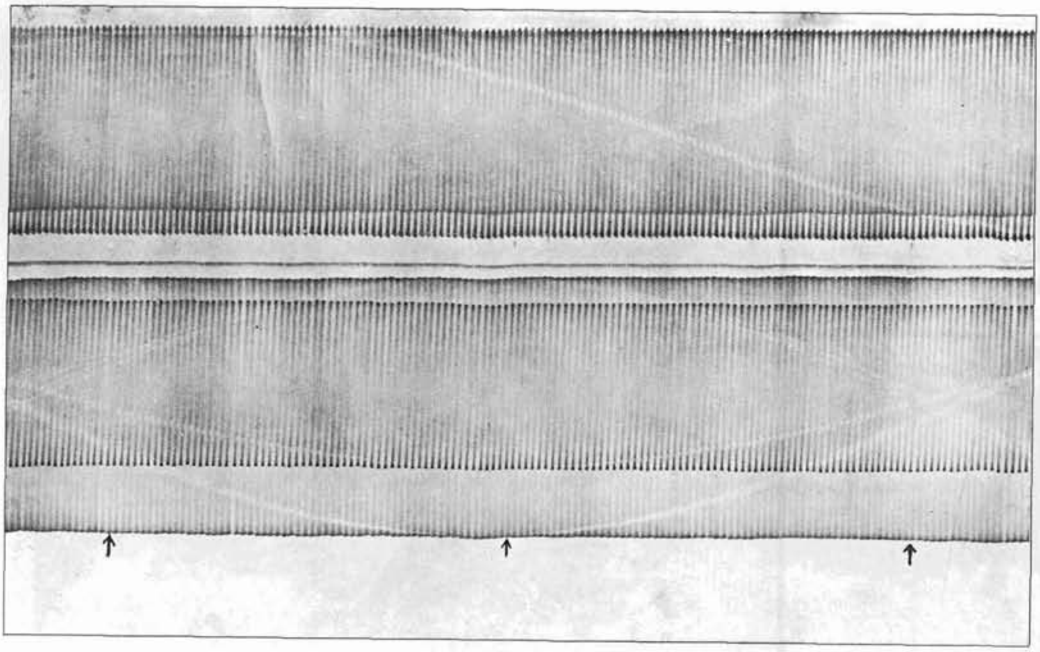
$$2\,T\,dT = \frac{\pi^2\,(M\,dI - I\,dM)}{g\,M^2} = -\,\frac{\pi^2\,s\,(s-l)}{g\,m\,h}\,dm$$

which gives:

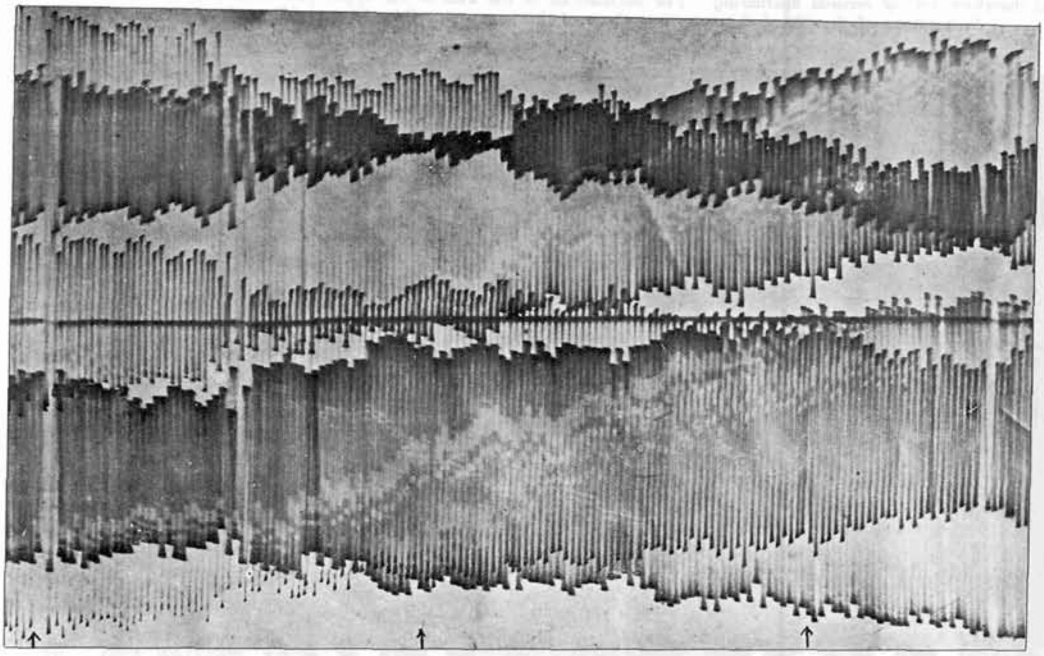
$$dm = -\,\frac{2\,m\,g\,h\,T\,dT}{\pi^2\,s\,(s-l)}$$

Base Observations. The base observations were made at the Dutch Gravity Base Station De Bilt on August 25, 1923. In the morning and the evening, the rythmic timesignals of Paris were taken, observing aurally the coincidences with the chronometer. The time-interval between these signals was filled up with pendulum observations made in the old way with the coincidence apparatus. First, one of the pendulum-pairs, Nrs. 88 and 90, was observed, swinging with equal amplitudes in opposite phase; then the second pair, Nrs 89 and 91, in the same way; then again the first pair and so on, alternatively, till at the end four observations of each pair had been made. The position of the pendulums in the apparatus was: Nr 88 left-back, Nr 89 left-front, Nr 90 right front and Nr 91 right back; the sides marked A were inside for all the pendulums.

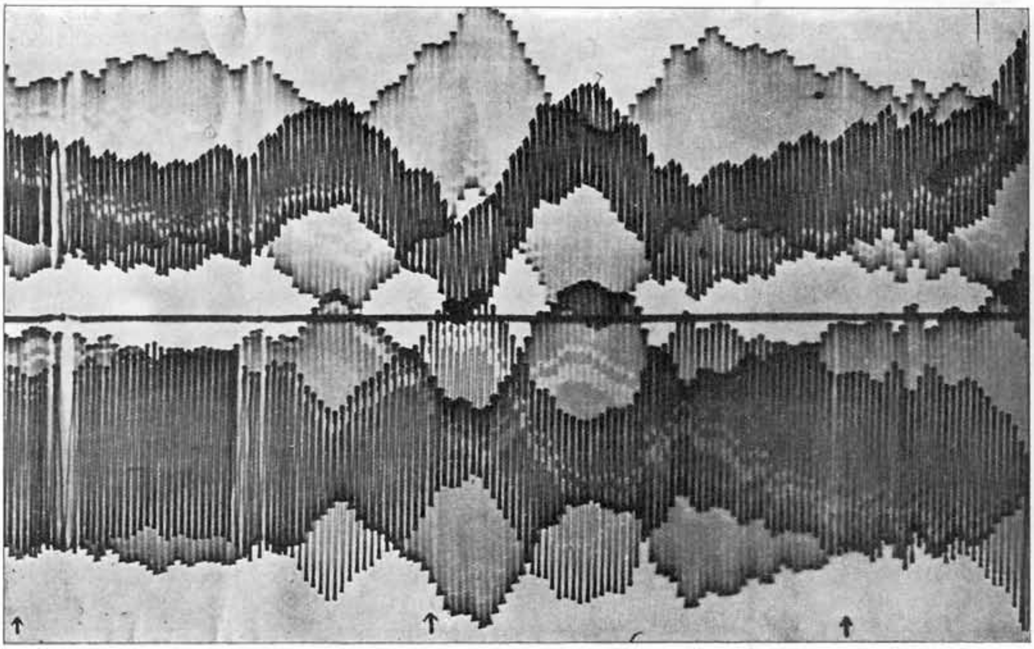
It was resolved to use the opportunity of this voyage to the Netherlands Indies for making a precise gravity comparizon between De Bilt and some station in the Indies, which afterwards, when a gravity survey of the Indies will be taken up, can be used as Base-station. As the possibility was realized that the brass pendulums would not stand the strain of the sea-observations without loosing their invariability, the invar pendulums were also carried along, reserving this set solely for this end. From 21 till 24 August base-observations were made with these pendulums in De Bilt. As this gravity comparizon will be treated of in another publication, no further details will be given about it.



Harbour of Tunis.
Ship perfectly quiet, amplitude nearly constant, angular movements negligible and therefore axis of the four records steady.

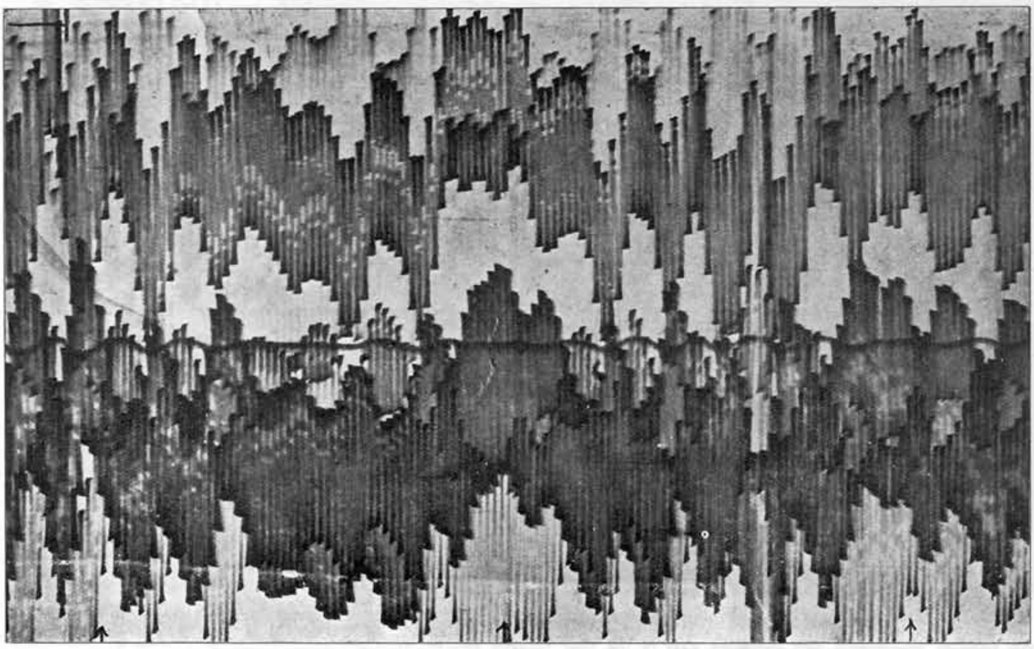


Harbour of Suez.
Small angular movements and therefore axis of the four records steady, amplitudes strongly variable because of the effect of the surface waves on the ship.



Record of Sea-station.

Amplitudes steady because of the horizontal accelarations of the ship being small, angular movements rather strong and therefore axis of records fluctuating. The fluctuations of the axis of the upper pair (Nrs 89 and 91) show the fluctuations of the tilt of the swinging plane of the lower pair (Nrs 88 and 90), and vice versa



Record of Sea-station.

Amplitudes fairly regular, axis of records strongly fluctuating because of irregular angular movements of the apparatus.

On September 17, 1923 the apparatus was transported to the Naval Base Helder, and was put aboard Hr. Ms. K II, the submarine which was appointed for the observations. It was mounted in the central control room between the two periscopes, where enough distance was available for putting both Stückrath apparatus and recording apparatus in the axis of the ship at the desired distance of 1.15 meter. The pendulums were put in the Stückrath apparatus and remained inside for the whole voyage. To prevent their bumping against the support during the movement at the surface of the sea, which would be detrimental for their invariability, the bulbs were fixed with small cushions, which had to be taken out before each observation. The knife-edges were of course protected by lifting the pendulums when not in use. The apparatus could be covered with a brass gauze cover in order to make experiments about eventual effects of electrical or magnetical fields.

On the evening of September 17 a time-signal was observed and afterwards a pendulum observation was made in the harbour of Helder. The result was in good agreement with the value of gravity which had been found at the land-station of Helder in 1920.

The voyage.

On September 18, the submarines, Hr. Ms. K II, K VII and K VIII, Lieutenants L. A. C. M. Doorman, C. H. Brouwer and C. Baron Van Asbeck commanding, left Helder, accompanied by a mothership, Hr. Ms. Pelikaan, of which the Captain, Commander E. M. Wissmann was in command of the squadron. As I mentioned already, I was on board of the K II, a submarine of 630 tons with a staff of 5 officers and a crew of 24 men. The staff consisted of

Lieutenant L. A. C. M. Doorman, Captain,
Lieutenant Jhr. E. J. van Holthe, executive officer,
Lieutenant C. J. W. van Waning,
Lieutenant L. C. Koolen, in command of the engine-room,
Lieutenant H. Riemers, second in command of the engine-room.

I wish to acknowledge with gratitude the kind assistance they all gave me in carrying out the scientific research and the good friendship I met with on board of the K II and of the other ships. In particular I wish to mention Captain Doorman, who gave his whole-hearted cooperation for furthering the success of the observations. Likewise I feel indebted to Captain Wissmann, the Commander of the squadron.

During our voyage of more than three months, we touched the following ports:

Helder	dep. 18 September,	
Gibraltar	arr. 27 September, dep. 3 October,	No gravity obs.,
Tunis	arr. 7 October, dep. 11 October,	Gravity Stat. Nr. 5,
Alexandria	arr. 18 October, dep. 25 October,	Gravity Stat, Nr. 9,
Port Said	arr. 26 October, dep. 26 October	No gravity obs.,

Ismailliya	arr. 26 October, dep. 28 October,	No gravity obs.,
Suez	arr. 28 October, dep. 31 October,	Gravity Stat. Nr. 11,
Aden	arr. 7 November, dep. 13 November,	Gravity Stat. Nr. 16,
Colombo	arr. 25 November, dep. 5 December,	Gravity Stat. Nr. 24,
Sabang (near N. point Sumatra)	arr. 11 December, dep. 17 December,	Gravity Stat. Nr. 29,
Tanjung Priok (harbour of Batavia)	arr. 24 December,	No gravity obs.

Our first trip from Helder to Gibraltar was not favoured by good weather. Leaving Helder, we found at once a rough sea and the storm continued five and a half days till we sighted Cape Villano on the N. W. coast of Spain on the evening of September 23. Only those who know submarine life, can imagine what life is like in these conditions. Even those who are sea-sick proof, suffer from the strong ship's movements, the stuffy air inside the ship, the wet clothes which refuse to dry in the humid atmosphere and numerous other small inconveniences. The worst, however, was that it proved impossible to make any observations. Even at a depth of thirty meters and more, the ship was rolling several degrees to each side and as the apparatus was fixed in the ship and theoretical considerations made clear that no observations could be made unless the tilt did not exceed half a degree, nothing could be done.

Considering this experience I resolved to make use of the opportunity of our next stay in port for trying to mount the apparatus in a cradle in such a way that at least the rolling of the ship would be eliminated; I was afraid that else observations would be only possible with an exceptionally quiet sea. The pitching of the ship having been much smaller, the need for a suspension in this direction was less urgent.

The last days of our first trip were more quiet. On the 26th of September the sea was even so smooth, that the chances of success for an observation seemed good. The K II submerged near the spanish coast and the ship's movements being less than the allowable limit, an observation could be made. In the afternoon the K II submerged a second time in deeper water in order to get gravity data about the coastal effect. This time two observations were made, the first going eastward and the second going westward, in order to check the accuracy of the observations: If the accuracy had been statisfactory, the two values of gravity ought to differ by an amount, corresponding with double the Eötvös effect. This effect is caused by the change in the centrifugal acceleration of the Earth's rotation, caused by the west-east component of the ship's speed; this effect being proportional to the first power of this component, the sign of the effect ought to be different for an eastward course and a westward course [1]).

[1]) See: "Theory and Practice of Pendulum Observations at Sea" page 90.

At Gibraltar the records were developed and provisionally computed. I was glad to see that my expectations of the method were completely confirmed: all three observations had been successful. The last ones showed the right difference corresponding to the Eötvös effect; after reducing for this effect, the results differed only by 2 milligal. No record showed any trace of disturbance terms, corresponding to secundary effects of the ship's movements and this was important as the elimination of these effects would have been difficult, if not impossible. This allowed to hope for a greater accuracy of the sea-observations than was thought possible beforehand. The further results confirmed these hopes; the mean error of the observations appeared to be only slightly greater than that for land observations, viz. 4 to 5 milligal.

By the kind permission of the Naval authorities, the Dock-yard of the Britisch Navy at Gibraltar made the cradle for suspending the pendulum apparatus. As our stay was short only a few days were available; sincere thanks are due to those who were in charge of it for the expeditious way in which it was done and to Lieutenant Koolen for his assistance in making the necessary arrangements.

The cradle is represented on the photograph of page 13. It is suspended by means of a ball-bearing, which Captain Doorman had put at my disposal. The apparatus was put inside the cradle in such a way that the hole of the ball-bearing coincided with the glass window of the apparatus. In this way the rays coming from the light-apparatus entered the cradle through this hole and after being reflected by the pendulum mirrors left it in the same way towards the slit of the recording apparatus. Two things were thus obtained: First the pendulum apparatus was suspended round an axis which practically coincided with the plane of the knife-edges and so the horizontal components of the pendulum reaction on the agate planes could have no effect on the position of the cradle and could not therefore bring about a systematic periodic movement of this cradle. Secondly the pendulum apparatus moving in the cradle with regard to the recording apparatus, rotated round an axis coinciding with the line connecting the centre of the lens of the pendulum apparatus with the centre of the vertical slit of the recording apparatus. Thus, this relative movement gave only horizontal movements to the images on the photographic paper and practically no vertical ones and as all the measurements on the records are made in a vertical sense, no errors in these measurements resulted.

The suspension proved to be a success and henceforth observations were always possible, independent of the state of the sea. Although we had again some rough weather during our passage through the Indian Ocean between Aden and Colombo, no trouble was experienced in making pendulum observations at a depth of thirty meters; the pendulum apparatus kept easily inside the allowable limits of tilt.

Our further voyage was not marked by special occurrences. Of course the temperature inside the ship got high during our passage of the Red Sea. In the central control room it went up to 37 degrees centigrade during submergence and this being accompanied with nearly hunderd percent humidity, it made the impression of being much more. During our twelve days passage through the Indian Ocean between Aden and Colombo, the sea was fairly calm with the exception of the last days. It was curious to see that on the first day of this stormy weather the water was still calm at twenty meters depth although the surface was already much disturbed. On the second day however, the situation was different: at twenty meters the wave-movement was clearly perceptible. Apparently longer waves had gradually formed, bringing about a deeper disturbance of the water.

Leaving Colombo we had quiet weather again and we kept it during the whole voyage to Batavia. The last days I was not aboard the K II; after having finished the last observation north of Strait Malacca, my presence aboard the submarine was no longer necessary and I changed over to the mother-ship, Hr. Ms. Pelikaan.

A few details may be given regarding the pendulum observations. After the ship had submerged and the trim had been established, the first thing to do was to open the apparatus, to take out the cushions fixing the pendulum-bulbs without touching the pendulums themselves, and to put back the cover of the apparatus. Then the other preparations were made: the light was switched on, the positions of the light-apparatus and the recording apparatus were adjusted and the electrical circuit connecting the break-circuit of the chronometer with the coils of the light-shutter, was established. Then the pendulums were lowered on their knife-edges and amplitudes were given; first the pendulums of one pair were set swinging with equal amplitudes in opposite phase and then those of the other pair. The photographic paper having been set going, the observation had begun. It was continued for fifteen to twenty minutes. The thermometer of the Stückrath apparatus was read at the beginning and at the end. Likewise the barometer and the hygrometer.

During the observation the whole crew had to keep still, as otherwise the helmsmen of the vertical rudders would have had too much difficulty in keeping the ship's axis sufficiently steady, i.e. inside half a degree deviation.

The above programme shows that only some five to ten minutes elapsed between the moment of opening the apparatus and the beginning of the observation and this is of course a risk as far as the steadiness of the temperature is concerned. Still I don't estimate the resulting uncertainty of the mean temperature during the observation at more than $0.^{\circ}1$ to $0.^{\circ}2$, which corresponds to an uncertainty in the value of gravity of 2 to 4 milligal.

The choice of the stations was more or less limited by the route of the ships, but thanks to the cooperation of Commander Wissman and Captain Doorman details could be changed and adapted to the scientific interests. Where it was possible, pairs of observations have been made over submarine slopes, one being made over the upper end and one over the lower end of the slope. Continuous rows of stations had been planned above the oceanic parts of the route, but the circumstances mentioned above prevented observations during the passage through the Atlantic. In the Indian Ocean the programme could be followed. South of Ceylon, over the steep continental slope, a pair of observations has been made, one at the top and one at the foot of the slope.

At four stations, Nrs. 2, 4, 7 and 10, two observations were made for checking the Eötvös effect, one of the observations being made with eastward course and the other with westward course. The results completely confirmed the existence of this effect; if necessary, the ship's speed could have been deduced from the difference of the two values for g with an accuracy of a fraction of a mile. After applying the Eötvös reduction according to the formula of page 91 of "Theory and Practice of Pend. Obs. at Sea", the following results for these four stations were found:

Nr. 2	26 September	979.911
		979.913
Nr. 4	6 October	979.997
		979.996
Nr. 7	17 October	979.545
		979.553
Nr. 10	25 October	979.442
		979.441

According to the formula, a difference of one milligal would correspond to an error of the speed in both directions of 0.07 mile if the observations had been made at the equator.

During the second half of the voyage, experiments have been made regarding eventual electrical effects. At four stations, Nrs. 13, 15, 19 and 31, two observations were made (at Nr. 19 three), one in normal conditions and one with the apparatus in a brass gauze cover. The following results show that no systematical difference has been found. Apparently disturbances by electrical fields need not be feared.

Nr. 13	3 November,	with cover	978.680
		without cover	978.690
Nr. 15	5 November,	without cover	978.377
		with cover	978.378
Nr. 19	19 November,	with cover	978.137
		with cover	978.137
		without cover	978.141
Nr. 31	18 December,	with cover	978.099
		without cover	978.106

At gravity station Nr. 18, on November 17, a curious experience occurred, which, since then, has never been observed again: one of the pendulums, viz. Nr. 89, gradually lost its amplitude. The observation was twice repeated and both times the same thing happened again. As the effect of the movements of the apparatus ought to have a completely fortuitous character, this systematic decrease of amplitude practically excluded this possibility. The apparatus was opened afterwards and nothing could be found save a small particle of dust on the agate plane. The records showed that the amplitude of the fictitious pendulum derived from the pendulums 89 and 91 was perfectly regular; the amplitude showed no other decrease than the normal effect of the surrounding air. The period of this fictitious pendulum was likewise regular and corresponded with the period of the second fictitious pendulum. In these circumstances no scruples were felt in using the record in the normal way for deriving gravity.

In some of the harbours, viz. Tunis, Alexandria, Suez, Aden, Colombo and Sabang, observations were made, partly because of the gravity value itself and partly for getting the possibility of future checks of the pendulums by means of subsequent observations; this might be valuable if something would occur with the pendulums during the further part of the voyage.

In Sabang an observation was made in the ship on December 12 and then the apparatus was mounted on land in a shed at a distance of less than hundred meters. Here a long series of observations between two time-signals were made with the invar pendulums on December 15. The results were in perfect agreement with those found on December 12:

Nr. 29	12 December, Sabang o/b. Hr. Ms. K II,	$g_0 = 978.182$
	15 December, Sabang, shed,	$g_0 = 978.184$

The geographical positions of the gravity stations were derived by the officers from the nautical data required for the navigation. The positions in the harbours could of course be given with greater accuracy than those at sea; these data define sufficiently the spot where the ship had been mooring during the observations. The accuracy of the positions of the sea-stations can generally be estimated at 1 to 2 miles; as the data of the other ships of the squadron had also been available, the error will only seldomly exceed this value. The data about the sea-currents, necessary for the computation of the Eötvös effect, are more vague (see also page 89 et seq.). I think that probably no errors greater than half a mile per hour have occurred and that they have generally been less than a quarter of a mile per hour.

Another possibility of errors in the results of the observations was brought about by the uncertainty of the rate of the chronometer during the observations, because the observations were made during twenty minutes while the rate was determined from times signals which were twenty-four hours apart. It is therefore important that the chronometer made by the firm of Ulysse Nardin (Le Locle, Switzerland), was a good one; the fluctuation of the daily rates on consecutive days only seldomly exceeded 0.1 seconds.

The rates were determined by a wireless time-signal received once a day. For the observations made in the base-station at De Bilt and for the first part of the voyage up to Alexandria, the rythmical time-signals of Paris were used (wave-length 2200 meter). Afterwards these signals could no longer be heard and the rythmical signals of Lyon were taken (wave-length 14000 meter). At Colombo these signals also disappeared and no other signal being available, I had to fall back on the ordinary signal of Calcutta. While the accuracy of the reception of the rythmical signals was at least a few hundredths of a second, the accuracy of the reception of this last signal was no more than two tenths of a second. In this way the mean error of the rates since Colombo will be about 0.3 sec., which corresponds with a mean error in the result for gravity of 6 milligal. The observations in Sabang are an exception, because there the receiving station of the "Pelikaan" could be used, and this allowed to receive the rythmical time-signals of Bordeaux (wave-length 23000 meter).

The rythmical time-signals were received by determining aurally the coincidences with the beats of the chronometer; they have not therefore the extreme accuracy of the time-signals during the subsequent voyages, when the method was used of putting the break-circuit of the chronometer in series with the telephone of the wireless. While this last method gives a mean error which is less than 0.01 sec., the mean error during the voyage of the K II may be estimated at 0.02 sec. This corresponds to a mean error in the result for gravity of less than half a milligal. The real mean error, however, is greater because of the unknown fluctuations of the rate between the time-signals.

Soundings have not been made during the voyage.

After arriving in Batavia, the apparatus was transported to the Meteorological Observatory, where two series of observations have been made, one with the brass pendulums and one with the invar pendulums. The values given by both sets are in good harmony:

Batavia, 29 December, brass pendulums, $g_0 = 978.156$.
Batavia, 1 January, invar pendulums, $g_0 = 978.160$.

For the determination of the rates during these observations, the rythmical time-signals of Bordeaux at $20^h.01$ Greenwich $= 3^h.21$ Java time have been used. Those of $8^h.01$ Greenwich could not be heard. The invar pendulums have been observed at low air-pressure during the whole duration of 24 hours between two signals. The brass pendulums were observed at atmospheric pressure in order to observe as much as possible in the same conditions as during the voyage; between 9 o'clock in the morning till mid-night six observations were made, three of one pendulum-pair and three of the other.

After arrival in Batavia, as well as before leaving Holland, the corrections were determined of the aneroid and the hair-hygrometer, that have been used during the voyage. For the thermometer of the Stückrath apparatus, the old corrections were used, determined in 1921 by the "Preussische Reichsanstalt". Because the observations are differential, a change of these corrections since 1921 would have no effect if they had only been constant during the voyage.

A month after arrival in Batavia I left the Indies on board of a liner of the Mij. "Nederland" and arrived in Amsterdam on the 5th of March. The apparatus was at once transported from Amsterdam to De Bilt. During the sea-voyage some experiments have been made with the pendulum apparatus in order to see if observations could also be carried out on board of surface-ships, provided the sea is calm. The results were not satisfactory for ships in motion: the vibration caused by the engines brought about a slipping of the knife-edges when the apparatus got out of its normal position; if the ship is so steady that the tilt of the apparatus keeps inside narrow limits, no sliding occurred and observations were possible, although even then the amplitudes of the pendulums were irregular and continuous care was necessary for stopping the observation if the amplitudes became too great.

Final Base Observations.

The apparatus was mounted in De Bilt and control observations were made on March 20 and April 3, 1924. The programme was the same as during the base-observations before the voyage: A Paris rythmical time-signal was taken in the morning and in the evening and in the interval between, eight pendulum observations were made, i.e. four of the pair Nrs. 88—90 and four of the pair Nrs. 89—91. The results were in good agreement with those found in August 1923 before the voyage. This confirmed the constancy of the pendulums, which had already been concluded from the nearly constant difference during the whole voyage of the mean pendulum periods of the two pairs. As the risk of alterations had been greater than during ordinary land-observations, this result was gratifying.

The base-observations at De Bilt, as well as the observations in Batavia, have been carried out with the old coincidence apparatus, i. e. by means of visual observation. The observations in the shed at Sabang were recorded photographically with the new recording apparatus.

New Determination of the Temperature Constants.

The temperature constants of the brass pendulums had formerly been determined by Prof. Haasemann in Potsdam and the following values had been found [1]:

$$C_{88} = 47.03$$
$$C_{90} = 46.94$$
$$C_{89} = 46.39$$
$$C_{91} = 46.98$$

In applying these values to the observations at De Bilt and at Batavia, a systematical difference was found between the results at both stations: the differences of the pendulum-periods were different. The most probable explanation was an error of the temperature constants. Because the temperatures of both sets of observations had been widely different, this would have a systematical effect. It was resolved, therefore, to repeat the determination of the constants.

This has been done in June 1924 at the Geodetical Institute of Potsdam, where the Director, Geh. Dr. E. Kohlschütter, kindly gave permission to make the observations and to use the apparatus, constructed formerly by Prof. Haasemann, for keeping the pendulum apparatus at constant, high or low, temperatures [2].

During nine days series of observations were made; during the first seven days six pro day, i. e. three times the pair 88—90 and three times the pair 89—91, each pair being observed in the usual way with equal amplitudes in opposite phase; during the last two days each pair was observed twice. The mean temperatures of the nine series were: 6°.78, 40°.04, 39°.25, 8°.15, 7°.66, 42°.01, 41°.98, 8°.98, and 8°.49. Between days of different temperatures two days elapsed without observations for giving the apparatus time to adopt the new temperature.

The results gave the following constants:

$$C_{88} = 45.88$$
$$C_{90} = 46.91$$
$$C_{89} = 47.07$$
$$C_{91} = 47.48$$

The mean value of these constants practically coincides with the mean value of the old constants. This was gratifying as it eliminated all doubt as to the reduction of the observations made formerly with these pendulums in Holland; the mean of the four pendulum periods, which was used for the computation of gravity, would not be affected by the change of the constants.

By computing the mean error of the mean of the pendulum-periods for high temperature by comparing the values for the different days, and by doing the same for the mean of the pendulum periods at low temperature, we may deduce the following mean error for the mean of the temperature-constants: 0.20.

The application of the new constants on the results of the observations in De Bilt and Batavia brought about a perfect agreement in the differences of the pendulum-periods.

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[1]) Verh. der Int. Erdmessung, Budapest 1908 II, p. 5 and 11.

[2]) See description in: Veröff. des Kön. Preuss. Geod. Instit. N. F. Nr. 71.

The Computations, the Results and the Mean Errors.

A. The computation of the Base Observations at De Bilt.

The Base-Observations at De Bilt were computed in the ordinary way, like, for instance, the land observations in Holland, which also were made with two pendulums swinging at the same time [1]). The pendulum-periods were reduced for amplitude, temperature, effect of the air, elastic sway of the apparatus and rate.

The mean of the four pendulum periods (Nrs. 88, 89, 90 and 91) after reduction was:

25 August,	1923	0.5012511 sec.
20 March,	1924	0.5012509 „
3 April,	1924	0.5012514 „

showing a good agreement of the values before and after the voyage. For the computation of the results of the voyage, the value 0.5012511 sec. was adopted.

For the differences of the pendulum-periods $T_{89} - T_{91}$, $T_{88} - T_{90}$ and $\frac{1}{2}(T_{88} + T_{90}) - \frac{1}{2}(T_{89} + T_{91}) = d$, the values found immediately after arriving in Batavia, have also been used. The following results, expressed in 10^{-7} sec., were available:

Station, Date	$T_{89} - T_{91}$	$T_{88} - T_{90}$	d
De Bilt, 25 August, 1923,	+ 11.5	+ 22.2	+ 28.2
Batavia, 29 December, 1923,	+ 15.1	+ 36.0	+ 29.8
De Bilt, 20 March, 1924,	+ 19.1	+ 33.5	+ 39.5
De Bilt, 3 April, 1924,	+ 12.6	+ 28.3	+ 33.4
Adopted value	+ 16	+ 28	+ 30

The first two differences were used for the computations of the corrections for deviation of isochronism during the voyage (Theory and Practice of Pend. Obs. at sea, page 8 or 20). The value of d was used for comparizon with the value found during the voyage for the difference of the periods of the fictitious pendulums.

B. The computation of the Observations at Sea.

The measuring of the photographic records and the computations have been made according to the formulas, that are mentioned in Appendix II to Chapter I and in § 6 of Chapter III of "Theory and Practice of Pend. Obs. at Sea". Details about these computations may be found in "Observations de Pendule sur la Mer", 1923, Waltman, Delft. As since this voyage a new apparatus has been built, especially adapted to the method, and as the observations with this apparatus and in particular the computations of the records are considerably easier, it does not seem probable that in the future any further observations at sea will be made with the Stückrath apparatus. In these circumstances it appears useless to go into detail considering the computations of this voyage or to reproduce a complete specimen of these computations in this publication. The only point I wish to mention, is, that the measurements

[1]) Observations de Pendule dans les Pays Bas, Waltman 1923.

for computing the position of the pendulum-vector of the fictitious pendulums at the beginning and at the end of the observation, have both been made for twenty different seconds. The means of these twenty positions were used for deducing the speed of rotation of this vector and the period of the corresponding fictitious pendulum, this period being the time in which the vector describes half a revolution. For getting an insight in the accuracy of this proceeding and in the efficiency of the method for eliminating the horizontal movements, the mean irregularities of the extremity of the vector were deduced for each observation from the twenty measurements and the following result was found for the mean value of these mean irregularities for all the observations of the voyage:

Mean irregularity in the sense of the vector: 0.25 mm.

Mean irregularity perpendicular to the vector: 0.45 mm.

The second irregularity is greater than the first because of the effect of the vertical accelerations of the ship being superimposed on the regular rotation of the fictitious pendulum-vector, leaving its length undisturbed but giving a fluctuation to the angular movement.

From the irregularities of the positions of the fictitious pendulum-vector in the beginning and at the end of each observation, the mean error of the period of the fictitious pendulum may be derived. These mean errors are mentioned in the list of results hereafter. The mean value of these mean errors is 6 10^{-7} sec. Here and there, greater values occur. They are partially brought about by the fluctuations caused by the vertical accelerations and partially by incomplete or obscure records, preventing the measurement of twenty good second-marks. For observations made with quiet sea, the mean error is usually not greater than 2 or 3 10^{-7} sec.; for rougher sea it may attain values of 15 10^{-7} sec.

After deriving the periods of the fictitious pendulums, these periods were reduced for the amplitudes of the original pendulums, for the temperature, for the effect of the surrounding air, for the rate, for the deviation of isochronism of the original pendulums and for the tilt of the swinging-plane. Then the difference d was taken of the reduced periods of the two fictitious pendulums for checking the constancy of the pendulums; and the mean of both periods for the computation of gravity. The values of d are mentioned in the table of the results.

The value of gravity, deduced from the mean of the periods, had to be corrected for the Eötvös effect and reduced to sea-level by a free-air reduction combined with a reduction for the attraction of the layer of water above the ship. The formulas for these reductions may be found in „Theory and Practice o. P. O. a. S.". page 90 et seq. The results are put together in the following table.

This table begins with the number and date of the observations. Then follows the depth at which the observation has been made, the mean errors m_T of the periods of the two fictitious pendulums and the value of the difference d, then the reduced value of gravity and lastly the mean error of this value.

The geographical positions and the sea-depths are not given in this table; the positions may be found under the same station-number in the synopsis of the gravity results on page 100 et seq. The sea-depths will be given in Vol. II of this publication; they are exclusively derived from the naval charts as no soundings were made during this voyage. The gravity results for each station and the mean error of these results are repeated on page 100 et seq.; in case more than one observation was made at the same station, only the resulting mean value with its mean error is given. For Tunis and Alexandria, the results are combined with those found during the next voyage in 1925.

C. Results of the Gravity Observations Voyage Hr. Ms. K II, 1923.

Nr.	Date	Depth m.	m_T (88-90) 10^{-7} sec	m_T (89-91) 10^{-7} sec	Diff. *d* 10^{-7} sec	g_0	Mean error of g_0 in milligal	Remarks
1	26 September	25	7.7	2 8	24	979 939	5	
2A	26 „	25	5.5	4.2	46	979.911	5	
2B	26 „	25	6.4	2.5	43	979.913	5	
3	4 October	20		1.8		979.879	6	
4A	6 „	25		15.0		979 997	8	
4B	6 „	25		14.7		979.996	8	
5	7 „	2	2.8	2.7	27	979.928	4	Tunis
6	15 „	9	3.7	4.5	28	979.742	5	
7A	17 „	15	4.5	3.8	51	979.545	5	
7B	17 „	15	3.6	2.0	36	979.553	5	
8	18 „	12	4.4	2.6	51	979.430	5	
9	18 „	2	6.0	3.3	35	979.428	5	Alexandria
10A	25 „	12	9.0	1.7	10	979.442	5	
10B	25 „	12	0.9	1.5	13	979.441	5	
11	30 „	2	5.3	3.4	42	979.334	4	Suez
12	1 November	15	5.4	5.0	22	979.074	5	
13A	3 „	15	1.6	1.2	41	978.680	5	
13B	3 „	15		2.9		978.690	5	
14	5 „	15	4.9	3.3	20	978.407	5	
15A	5 „	15	4.8	2.5	45	978.377	5	
15B	5 „	15	11.2	2.6	46	978.378	5	
16	7 „	2	16.6	5.3	12	978.323	5	Aden
17	16 „	15	6 7	16.7	37	978.287	6	
18	17 „	15	17.1	7.4	18	978.186	6	
19A	19 „	20	8.9	13.1	26	978.137	6	
19B	19 „	20	15.3	8.7	24	978.137	6	
19C	19 „	20	8.8	7.8	29	978.141	5	
20	20 „	20	13.1	11.1	37	978 113	6	
21	21 „	20		8.9		978.105	6	
22	22 „	20	4.2	4.2	24	978 117	5	
23	24 „	20	4.0	5.1	23	978.105	5	
24	28 „	2	8.6	4.2	45	978.146	7	Colombo
25	5 December	20		4.0		978.170	7	
26	5 „	20		8.5		978.019	8	
27	8 „	15	6.0	5.7	24	978.073	7	
28	10 „	20	7.2	8.3	16	978.029	7	
29	12 „	2	4.3	4.1	60	978.182	4	Sabang
30	18 „	20	4.6	4.1	34	978.101	7	
31A	18 „	20	4.6	3.2	29	978.103	7	
31B	18 „	20	6.0	6.0	32	978.109	7	
32	19 „	15		3.8		978.079	7	

The results are computed with a value for g in de Bilt of 981.268.

For those observations where the value m_T for the pair 88-90 is left out, the record of the corresponding pair was not clear enough to be measured; this was mostly caused by the record of Nr 90, which was always less clear than the other ones. The results have in this case been derived from the pair 89-91 only; the mean period of this pair was increased by $15\ 10^{-7}$ sec. i.e. half of the adopted value for d, in order to get the mean period of the whole set.

D. The Mean Error of the Results.

A great many causes combine to bring about a certain mean error of the result for the gravity reduced to sea-level. The principal causes are the uncertainties of the temperature, of the period of the fictitious pendulums, of the rate during the observation and of the east-west component of the sea-current, necessary for the computation of the Eötvös effect. Finally, the constancy of the pendulums may be doubtful, but as this was not the case during the voyage, this cause may here be left out. Other causes of error can usually be neglected.

A valuable date about the first two points is given by the deviations of the difference d of the reduced periods of the fictitious pendulums. These deviations are caused by the errors of the pendulum-periods, combined with those of the different reductions and at least part of the uncertainty of the temperature. The mean value of these deviations has been found to be $13\ 10^{-7}$ sec. The corresponding mean error of the mean of the two fictitious pendulum-periods which is used for the deduction of the gravity, is half of this amount, $6.5\ 10^{-7}$ sec., and the resulting mean error for the gravity $0.39 \times 6.5 = 2.5$ milligal. This value, however, is based on a mean value for the mean error of the fictitious pendulum period, i.e. for $m_T = 6\ 10^{-7}$ sec. For those observations where m_T has been greater (see the table), this has to be increased correspondingly [1]). Likewise it was increased for the observations of which the record of one pair could not be used, so that the results had to be deduced from one pair only.

The effect of the uncertainty of the rate cannot be deduced from the observations of this voyage, but data about this cause of error may be found in the results of subsequent expeditions, made with more than one chronometer. A critical discussion of the results of the expedition of 1926-27 page 63 shows that the mean value of this effect may be estimated at 3.9 milligal. Since Colombo, however, it was greater, as has been mentioned on page 24. With the exception of the observations made at Sabang, the uncertainty for these stations because of this effect has to be put at 6 milligal.

According to an estimate of the uncertainty of the sea-current, the mean error of the reduction for the Eötvös effect has been put at 2 milligal; in exceptional cases it may be more but often less. This value of the mean error has been deduced for the equator; for higher latitudes it must be multiplied by the cosine of the latitude.

The combined effect of these three parts of the error has been found by adding the squares and taking the root of the sum. These total mean errors are given in the last column of the above table and in the table at the end of this volume. They do not seem too low if we compare them with the differences of the values found for those stations, where more than one observation has been made. For the observations in harbours no correction for the Eötvös effect was needed and so this part of the error was zero.

[1]) This was done by adding to the square of the mean deviation of d the sum of the squares of the m_T for both fictitious pendulums, minus 2×6^2 and by taking the root of this sum instead of the mean deviation itself.

CHAPTER III.

Voyage o/b Hr. Ms. K XI from Holland to Alexandria.

October 15—November 12, 1925.

Preliminary.

The successful issue of the voyage of 1923 had shown that the pendulum method for determining gravity at sea gives a satisfactory accuracy. This result led to the continuation of the investigations. An expedition was projected from Holland via Panama to Java and in connection with these plans it was resolved to build a new apparatus for facilitating the observations and the computations. As a thorough trial of this apparatus before the beginning of the expedition would be necessary, the Netherlands Geodetic Commission addressed a request to the Minister of the Navy for permitting the writer to embark with the apparatus o/b Hr. Ms. K XI, which would leave Holland for the Indies in the autumn of 1925, and to make experiments on board this submarine between Holland and Alexandria.

The Apparatus.

The plans for the apparatus were made in the spring of 1925. Its fundamental principle was not to record photographically each pendulum separately, as had been done during the voyage of 1923, but to record at once the difference of the angles of elongation of a pair of pendulums swinging in the same plane. As has been explained in the previous chapter, this differential angle may be considered as the angle of elongation of a fictitious pendulum, that is undisturbed by the horizontal movements of the apparatus. In this way the record would be nearly regular, because the principal disturbance would be eliminated, and this would make the computations easier, quicker and more accurate.

The principle has been incorporated in an apparatus with three pendulums, swinging in the same plane and combined in two pairs, Nrs. 1—2 and Nrs. 2—3. The recording light-rays strike first the mirror of one pendulum of a pair and then the mirror of the other pendulum from the other side and thus a record is made of the corresponding fictitious pendulum. For the other pair the same is done. The old pendulums of the Stückrath apparatus have been used.

An auxiliary damped pendulum indicates the position of the swinging-plane and a second damped pendulum serves to get a record of the middle pendulum with regard to the vertical, necessary for the computation of the amplitude-reduction of the pendulums.

For further particulars of the apparatus, we may refer to "Theory and Practice of Pendulum Observation at Sea", where a detailed description is given. Some explanations, however, are necessary, because the apparatus did not at once get the final shape of that publication.

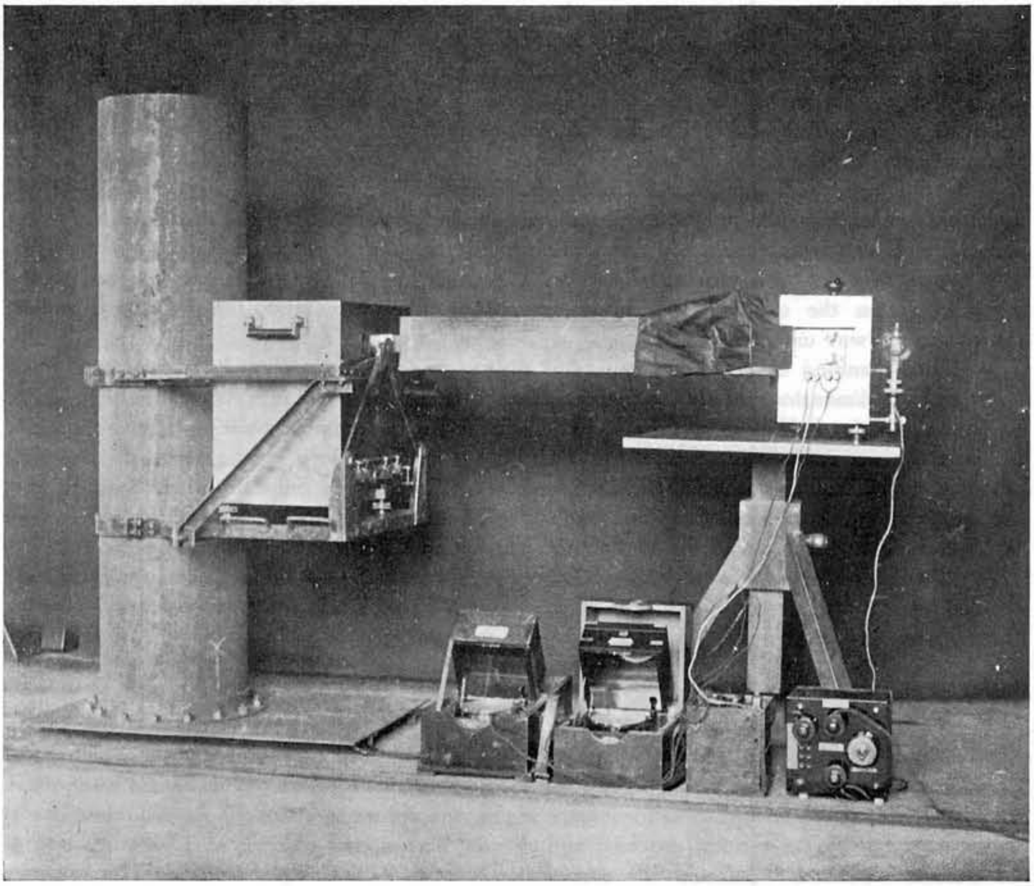
In 1925 only the pendulum apparatus itself was built and as this part has practically not been modified, no details about it will be given. The recording was done with the apparatus of the voyage of 1923, which was put at a distance of somewhat more than a meter from the pendulum apparatus in such a way, that the slit was in the axis of the right lens of this last apparatus; this lens was afterwards used as entry lens for the light-rays, but it was originally the outgoing lens of the pendulum apparatus.

The light, an electric arc lamp of the Edison Swan Cy, was put behind the recording apparatus and sent out its rays through a box in the left side of this apparatus and through a horizontal slit in the front partition of it. This slit of a width of 0.1 mm was the light-source for the recording. It was arranged in such a way that it was in the axis of the left lens, then entry lens, of the pendulum apparatus at a distance equalling the focal distance of this lens, and so the light-rays were made parallel inside the pendulum apparatus. After leaving this apparatus through the right lens, they were focussed by this lens towards the photographic paper at a distance of 1.13 meter. When entering the recording apparatus, they passed a cylinder-lens which concentrated the images of the horizontal light-slit in a point on the paper. The light-source being a slit instead of a circular hole, as during the first voyage, the luminosity of the images on the paper was considerably increased, although the slit had a width of half the diameter of the hole for making the images sharper.

In order to leave free passage to the in and outgoing light-rays, the brass cover of the pendulum apparatus was provided with two windows before the lenses. Between the right window and the slit of the recording apparatus a black tube prevented stray light from entering the slit.

Like the arrangement of the final apparatus, described in "Theory and Practice of Pend.Obs.a.Sea", the light-emission could be interrupted for a moment by the passage before the light-slit of two small shutters, operated each by a chronometer by means of an electrical current. In this way the records were provided with the time-indications of two chronometers instead of one. This reduces the error resulting from the uncertainty about the fluctuations of the rate during the interval between the time-signals; at the same time, the comparizon of the results, given by both chronometers, allows to estimate the magnitude of this error. The second chronometer was also a "Nardin" chronometer (Locle, Switzerland), which had been ordered for the purpose. The regularity of the rate has been as satisfactory as that of the old one.

The current used for the light-shutters was reduced to 40 milliamp, which was about ten times less than the current used during the first voyage; this was done to save the break-circuit of the chronometer and to enhance the regularity of the rate. The clock-work of the recording apparatus was provided with a second, slower, speed for use during the middle part of the observation in order to save photographic paper. One of the light-shutters got an arrangement by means of which the amplitude of its movement could be reduced in such a way that the light-emission was interrupted during the whole interval between the making and the breaking of the chronometer-contact. This was likewise intended for use during the middle part of the observation; it was meant for facilitating the reading of the phase of the pendulums, which else would be difficult incase the amplitude is small. As an accurate description of all these arrangements is found in the description of the final apparatus, that is mentioned above, no further details will be given.



New Pendulum Apparatus.
Left: New Pendulum Apparatus in its cradle.
Right: Recording and Light Apparatus.
Below: Chronometer and Resistance of Swan Electric Arc Lamp.

The apparatus was suspended in a new suspension arrangement, which was adapted to the conditions on board of the ship. It was again mounted in the central control-room. where it was fixed against the metal tube in which the back periscope disappears. Two metal strips round this tube bore the suspension arrangement, as shown by the photograph on page 33, which represents the apparatus hanging against a copy of this tube.

Like the arrangement during the first voyage, the suspension was only movable round one axis. This axis was parallel to the axis of the lenses of the pendulum apparatus and struck this apparatus in the middle between those lenses and in the same horizontal plane with the agate knife-edges of the pendulums. I mentioned already in the previous chapter that this last point is necessary for eliminating any possible systematical effect of the horizontal component of the pendulum-reaction on the movement of the cradle. The second point avoided by the above arrangement was the interference of the relative movement of pendulum apparatus and recording apparatus with the pendulum records: a consideration of the path of the light-rays shows that this relative movement only brought about horizontal movements of the light-images on the cylinder lens of the recording apparatus and as this lens was vertical, the recording was undisturbed.

The planning of pendulum apparatus and suspension arrangement had been complicated by the small dimensions of the available space on board of the ship. As no other spot could be found o/b the K XI nor o/b the K XIII, allotted for the future expedition, it was necessary to construct the apparatus accordingly. The maximum dimensions in the sense of the ship's axis had to be less than 39 cm because the front periscope left only this room free. During the pendulum observations this periscope had to be raised for allowing the light-rays to reach the recording apparatus and for affixing the black tube between both apparatuses.

The pendulum apparatus with accessories were constructed at the Meteorological Institute at De Bilt by the Chief Mechanic Mr. L. M. van Rest. During the construction, the Adj. Director of this Institute, Dr. C. Schoute gave valuable advice.

Base Observations.

The apparatus was finished on October 5. The next day it was mounted at the Dutch gravity base-station in the cellar of the Meteorological Institute, and experiments were made. On October 7, the base-observations were made, a continuous series of six pendulum observations between the rythmical morning and evening time-signals of Paris at 10 o'clock and at 22 o'clock. The first, third and fifth observation were made with equal amplitudes in opposite phase for the two outer pendulums and no amplitude for the middle one save the small amplitude which it received by lowering on the knife-edge. The second, fourth and sixth observation were made with the middle pendulum getting a small amplitude: these observations were made for getting data about this pendulum. During the base-observations the apparatus was mounted on its footscrews on a stone foundation. The pendulums were put in the apparatus in the following order: from left to right Nrs. 88, 90 and 89, the two outer ones with the sides marked A to the right and the middle one with this side to the left,

On October 8 the apparatus was transported to Helder and mounted in Hr.Ms. K XI in the way, that has already been mentioned. On October 9 some experiments were made during a small trip near Helder. The results appeared satisfactory. The records were remarkably regular, the amplitudes of the fictitious pendulums for instance showed no fluctuations at all, which was in good agreement with the elimination principle of the apparatus. No land observations in Holland with an ordinary apparatus would have shown the same regularity, as the macro-seismic movements of the soil always bring about disturbances.

The Voyage.

On October 15, Hr. Ms. K XI left Helder for the voyage to the Indies. The ship measured 730 tons at the surface and 800 tons during submergence. The crew consisted of 30 men: the Captain, Lieut. G.E.V.L. Beckman, two officers, Lieuts. W. F. H. Backer, and H. van Schreven, two officers of the engine-room, Lieuts. J. Kooijman and A. Hoogkamer, and 25 petty officers and men. Sincere thanks are due to them for their spirit of cooperation and for the assistance I found on board with regard to the scientific experiments.

During the trip to Alexandria, the following ports have been touched:

Helder	dep. 15 October,	
Sevilla	arr. 21 October, dep. 27 October,	Gravity Stat. Nr. 3.
Tunis	arr. 1 November, dep. 7 November,	Gravity Stat. Nr. 8.
Alexandria	arr. 12 November,	Gravity Stat. Nr. 12.

Although the principal object was to give the new apparatus a trial, I tried to choose the stations, as far as the route of the ship allowed it, in such a way, that the results would give valuable data. Together twelve stations have been observed, three in harbours and nine at sea. North of the African coast a pair of observations were made in a profile perpendicular to the continental slope (stations Nrs. 6 and 7). The results, however, were not accurate enough to give a clear indication about the coastal effect on gravity.

The trip was favoured by good weather with the exception of only one day after leaving Tunis. We had a severe storm then, but only during a short time. With this exception the sea was always calm.

The pendulum apparatus proved to work satisfactorily, but two questions have given trouble. The first point concerned the cradle. It was originally suspended by metal spindles but during the first part of the voyage it appeared already that these spindles had too much friction. The cradle could not always follow instantaneously the movements of the ship and then sudden movements occurred when at last the friction was overcome. This point was set right at the first port, Sevilla. Under the able direction of the officer in command of the engine-room, Mr. Kooijman, the spindles were replaced by steel knives, supported by grooves. The alteration proved to be efficient: the friction-effects had disappeared. The interchange was made on board of the K XI by the personnel of the ship.

The second point had regard to the damped pendulums for the recording of the swinging-plane and of the middle pendulum. They were suspended by steel knives, oscillating on steel grooves, and apparently this arrangement brought about some friction, which caused the pendulums to deviate slightly from the vertical position. Thus their indications of the vertical were not sure. As this point could not be remedied during the trip, all the observations are subject to the resulting uncertainties. This did not matter for the recording of the middle pendulum as the only effect was to make the record fluctuate up and down without affecting the amplitudes and phases which had to be read.

For the computation of the reduction for the tilt of the swinging-plane, the matter was different; the shifting of the record of the tilt gave an erroneous value for this reduction. If the tilt had been small, this would not have affected the accuracy of the observations, because the reduction for the tilt is proportional to the square of the tilting-angle and so errors of the zero-line of this record have less effect if the deviations are small.

This however, had not been the case. The swinging-plane having been perpendicular to the length-axis of the ship and the apparatus not having been suspended round an axis for eliminating the movements of this length-axis, these movements ware fully imparted to the swinging-plane. As no difficulties had been suspected, no trouble was taken to keep the ship as steady as possible and so fluctuations of the swinging-plane of more than one degree often occurred. The result was a loss of accuracy, which was considerable for those observations during which the tilt had fluctuated much. The result of the gravity, mentioned in this chapter, are provided with indications of the probable mean error, taking this point into account.

All the pendulum observations have been made during submergence. After the ship had submerged and the trim had been established, the observation could at once begin, because in the new apparatus the pendulums could be released without opening the apparatus and so the temperature inside was not disturbed. After the electric arc lamp had been switched on and the chronometer circuits had been established, the cradle was put in action, the pendulums lowered on their knife-edges and the recording apparatus adjusted in such a way that the light-images struck the slit. Then the clock-work for the movement of the photographic paper was put in motion and the pendulums were set swinging. The outer pendulums got as well as possible equal amplitudes in opposite phases and the middle one was released without amplitude.

After five minutes of great paper-speed followed twenty-five minutes of small speed and then again five minutes of great speed to finish the observation. For further details about this programme, we may refer to "Theory and Practice of Pendulum Observations at Sea", p. 22 and 63.

At most of the stations, two observations were made: one with the cradle in action and one with the cradle fixed. This was done for investigating whether the cradle had no systematic effect on the results. Because of the above errors, these checks lost the necessary accuracy for most of the stations, but for the harbour-stations, where no tilt occurred, they have been valid. The results show no trace of a systematical difference:

Nr. 3, Sevilla,	cradle in action,	$g_0 = 979.966$
	cradle fixed,	$g_0 = 979.968$
Nr. 8, Tunis	cradle fixed,	$g_0 = 979.925$
	cradle in action,	$g_0 = 979.925$
Nr. 12, Alexandria,	cradle in action,	$g_0 = 979.437$
	cradle fixed,	$g_0 = 979.435$

The geographical positions of the stations and the data about the sea-currents were provided by the officers. As the sky was usually clear, the mean error of the positions of most of the sea-stations may be estimated at less than 2' ; the positions in the harbours are more accurate. Regarding the East-West components of the sea-currents, necessary for the computation of the Eötvös effect, the same may be said as in the previous chapter, page 24.

In De Bilt and during the first part of the voyage, the rythmical time-signals of Paris were used. After leaving Tunis, these signals became fainter and I changed over to the rythmical Bordeaux signals. The signals were received by putting the break-circuit of the new Nardin chronometer (mean time) in series with the telephone of the wireless receiving set and by observing the appearing and the disappearing of the signals in the telephone (see next chapter, page 49). Before and after the reception, the second Nardin chronometer beating sidereal time was compared aurally with the first one by means of the method of coincidences.

At all the sea-stations, echo-soundings were made with the ordinary sonic signalling machine of the Fessenden type which was aboard. The time-interval was measured with an ordinary stop-watch and so the accuracy of these intervals did not exceed 0,1—0.2 sec. corresponding to a depth-difference of 75 to 150 meters. More than once a double echo was heard, i.e. a second echo appeared at the same interval after the first one, as the first one had been after the signal. Once even three echo's were heard. All the echo's could clearly be taken.

After having left Alexandria, the ship continued towards Port Said, but during this passage no observations have been made. In Port Said, on the 22nd of November, the apparatus was transported to the liner bound for Holland, with which I returned home. During this trip to Holland some experiments were made, giving the same impression as to the possibility of using the apparatus on surface ships, as had been obtained when returning in 1924 from the Indies: The vibration caused by the ship's engines is detrimental to the observations, especially if tilting of the apparatus favors the slipping of the knife-edges of the pendulums.

After arrival in Amsterdam on December 6, the apparatus was transported on the same day to the gravity base station, De Bilt.

Final Base Observations.

The final base observations have been made on four days: 10 December and 12 December 1925, 14 January and 15 January 1926. On each day five pendulum observations were made in continuous sequence between the morning and evening rythmical time-signals of Paris. Most of these observations were made in the normal way, giving equal amplitude in opposite phase to the outer pendulums and releasing the middle one without giving amplitude; one or two observations of each day were made for checking the period of the middle pendulum with this pendulum having also amplitude. The apparatus was mounted with its foot-screws on a stone foundation.

The results of these base-observations were in sufficient agreement with the results before the departure.

Before and after the voyage, the corrections were determined of the aneroid, that had been used o/b the K XI, and of the hair-hygrometer, with which the new apparatus had been provided. For the thermometer inside the apparatus, the old corrections were used, determined in the "Preussische Reichsanstalt" in 1921.

The Computations, the Results and the Mean Errors.

A. The computation of the Base-Observations at De Bilt.

The base-observations at De Bilt were computed according to the formulas of "Theory and Practice o. P. O. a. S.", §§ 1—5 of Chapter III. The computation of the reduction to infinitely small amplitude and of the correction for deviation of isochronism was, however, made slightly otherwise, because, the apparatus being mounted on a stone foundation, the sway was not great enough to apply the formula of § 4. To compute them in this case, it was necessary to get further data about the amplitude and the phase of the middle pendulum in the interval of about two hours between the records at the beginning and at the end of the observations and therefore two intermediate records of a few minutes were made.

The means of the reduced periods of the two fictitious pendulums formed by the combination of the pendulums Nrs. 89 with 90 and 88 with 90 were:

7 October 1925,	0.5012520 sec.
10 December 1925,	0.5012504 „
12 December 1925,	0.5012515 „
14 January 1926,	0.5012508 „
15 January 1926,	0.5012510 „
Adopted value	0.5012514 „

The results are not as well in harmony with each other as for the base-observations of the first voyage, but the agreement was sufficient.

For the differences of the pendulum-periods $T_{90} - T_{89} = U_{90,89}$, $T_{90} - T_{88} = U_{90,88}$ and $T_{88} - T_{89} =$ the difference d of the fictitious pendulum-periods, the following values were found

Date	$U_{90,89}$	$U_{90,88}$	d
7 October 1925,	+ 19	— 13	+ 32
10 December 1925,	+ 5	— 18	+ 23
12 December 1925,	+ 30	— 2	+ 28
14 January 1926,	+ 25	— 5	+ 30
15 January 1926,	+ 26	— 4	+ 30
Adopted value	+ 21	— 9	+ 30

The differences $U_{90,89}$ and $U_{90,88}$ were used for the computation of the corrections for deviation of isochronism; the difference d of the fictitious pendulum-periods for the checking of the constancy of the pendulums during the voyage.

B. The computation of the Observations at Sea.

The measuring of the photographic records and the computation of the results have been made according to the methods given in §§ 1—5 of Chapter III of "Theory and Practice of P. O. a. S.".

The results are put together in the following table, giving consecutively the Nr. of the station, the date, the depth below sea-level at which the observation was made, the value of the difference *d* of the fictitious pendulum-periods, the value of gravity reduced to sea-level and the mean error of this last value.

The geographical positions are given in the synopsis of the gravity results at the end of this volume, where the station-numbers of the voyage are mentioned besides the numbers of the list. The gravity results for each station where more than one observation was made, have been combined in one resulting value with its mean error in the corresponding column; in the same way the results for Tunis and for Alexandria have been combined with those found during the previous voyage. The depths, determined by echo-soundings, will be given in Vol. II of this publication.

The results have been computed with a value for *g* at De Bilt of 981.268.

C. Results of the Gravity Observations.

Voyage Hr. Ms. K XI, 1925.

Nr.	Date	Depth m.	Diff. *d* 10^{-7} sec.	g_0	Mean error of g_0 in milligal	Remarks
1 A	17 October	13	47	981.007	10	
1 B	17 ,,	13	70	981.023	10	
2	18 ,,	25	56	980.616	6	
3 A	26 ,,	2	30	979.966	5	Harbour of
3 B	26 ,,	2	37	979.968	5	Sevilla
4 A	28 ,,	13	25	979.822	13	
4 B	28 ,,	25	40	979.857	6	
5	29 ,,	13	33	979.916	6	
6 A	30 ,,	13	44	979.888	11	
6 B	30 ,,	13	34	979.901	16	
7	30 ,,	13	35	979.905	13	
8 A	2 November	2	30	979.925	4	Harbour of
8 B	2 ,,	2	28	979.925	4	Tunis
9 A	8 ,,	13	32	979.881	15	
9 B	8 ,,	13	42	979.888	16	
10	9 ,,	25	26	979.748	15	
11 A	10 ,,	25	24	979.597	10	
11 B	10 ,,	25	29	979.618	7	
12 A	12 ,,	2	29	979.437	3	Harbour of
12 B	12 ,,	2	29	979.435	3	Alexandria

D. The Mean Error of the Results.

In three ways the new apparatus reduced the mean errors of the observations. First, by bringing back the error of the determination of the fictitious pendulum-periods to a so much smaller amount, that we can neglect it with regard to the other errors. Secondly by the fact, that the apparatus needs no longer to be opened before the beginning of the observations; this makes the temperature more stable and diminishes the uncertainty of the corresponding correction. Thirdly by the use of two chronometers, which reduces the error of the correction for the rate.

A detailed examination of the mean errors of the results obtained with the new apparatus is made in the next chapter, page 61 et seq. The value that is deduced there cannot, however, be applied without correction to the results of the voyage of the K XI, because the defective functioning of the damped pendulums gave rise to serious uncertainties regarding the correction for the tilt of the swinging-plane. These errors were occasioned by the shifting of the position of zero tilt on the recording-strip by small but unknown amounts and so the readings of the tilt were erroneous by this same amount. As the correction for the tilt is proportional to the square of the tilting-angle, the resulting errors of this correction were proportional to the first power of the tilt.

Taking this proportionality into account, we made an estimate of the mean error of each value for gravity brought about by this cause and increased the normal mean error for gravity reduced to sea-level, deduced in the next chapter, by a corresponding amount by adding the squares and taking the root of the sum. The values for the mean error found in this way, are given in the above table. They seem to be in good agreement with the differences of the observations, made at the same station.

The results of the observations made at Tunis and at Alexandria agreed fairly well with those found during the first voyage:

Tunis	7 October, 1923,	979.928
	2 November, 1925,	979.925
Alexandria	18 October, 1923,	979.428
	12 November, 1925,	979.436

CHAPTER IV.

Voyage of Hr. Ms. K XIII from Holland via Panama to Java May 27—December 13, 1926 with investigation of the Java Deep in February 1927.

Preliminary.

Apparatus. The voyage to Alexandria had shown, that the new pendulum apparatus was satisfactory. One point, however, had to be improved: there appeared to be too much friction between the steel knife-edges of the damped pendulums and the steel grooves which support them, and so the pendulums did not indicate accurately enough the position of the vertical. The remedy was easy. On both sides of the pendulums the knives were replaced by steel points and the steel grooves were replaced by agate ones: on one side a groove and on the other a circular cup. This arrangement took away all perceptible friction so that angular movements of the apparatus gave no longer any change in the equilibrium position of the pendulums.

Another improvement gave more trouble. It was resolved to change the suspension of the apparatus, which up to the present moment had been suspended round one axis, in a complete gimbal suspension. In this way not only the rolling of the ship would be eliminated but also the changes of position of the length-axis of the ship. It would no longer be necessary to keep the whole crew at their places during the observations in order to enable the helmsmen at the vertical rudders to keep the ship's axis sufficiently quiet, i. e. inside half a degree deviation. This would mean a considerable practical advantage. Moreover, for future use of the apparatus in other conditions, it would likewise be valuable.

Suspending the apparatus in gimbals involved the necessity of combining the recording apparatus with the pendulum apparatus in one whole. Keeping it at the distance of more than one meter would mean a voluminous gimbal arrangement, which could never be put in a submarine. The recording apparatus was therefore mounted on top of the pendulum apparatus in the way the photograph on page 44 shows and the light-rays between both parts were folded up by reflections on prisms in such a way that the light-distance between pendulum apparatus and photographic paper remained the same; in this way the recordings were kept on the same scale.

The gimbal arrangement also involved the introduction of flexible cords for applying to the apparatus all necessary manipulations without disturbing its steady position. These manipulations are needed for the change of the speed of the photographic paper, the change of the system of light-interruption by the chronometer, the marking of the paper with pin-pricks for identification, the opening of the control-window and the projection of the light-rays on the scale for checking the relative positions of the images.

The arrangement having been superseded afterwards by a new one, which is described in detail in "Theory and Practice of Pendulum Observations at Sea", we refrain from a detailed description.

Soundings. It would be desirable to combine soundings with the gravity observations, first because the topographic reduction cannot be made without a sufficient knowledge of the topography of the sea-bottom, and secondly because this knowledge is necessary for the interpretation of the results. The Netherlands Navy consented to acquire a new sounding machine: the Hughes Sonic Depth-finder, and to mount it on board of the submarine. The firm of Hughes and Sons (London), however, had trouble in finishing the manufacturing of this apparatus in time, because it was the first of its kind and the stage of experimenting with it had not yet been quite left behind. Partly because of this circumstance and partly because of the necessity of adapting the apparatus to the Fessenden Sonic System, which was already aboard, the depth-finder has not come up to the expectations. It did not yield satisfactory results and the soundings had to be made with the ordinary Fessenden apparatus in combination with accurate stop-watches for measuring the echo-interval.

Time Signals. Through the kind intercession of Dr. William Bowie the U. S. Coast and Geodetic Survey has been willing to lend to the expedition a wireless recording apparatus, constructed by Mr. Brown of this Service. It gave good results when tried before the expedition left Holland but during the voyage difficulties were met, caused by the effect of the vibrations of the engines on the relay; the recording of the wireless time-signals had therefore to be given up. The reception of these signals has now been done in the same way as during previous voyages by putting the telephone of the wireless in series with the break-circuit of one of the chronometers.

For the first part of the cruise rythmic time-signals from Europe and America would certainly be available, but it appeared doubtful if this would also be true for the Pacific. It seemed possible that I would be unable to hear any signal of high precision during that part of the voyage and the experience during the trip has confirmed these doubts.

To meet this difficulty the Commission asked the assistance of the Topographic Service of the Netherlands East Indies. Through the active intercession of Prof. Ir. J. H. G. Schepers, Chief of the Triangulation Brigade of that Service, a time-service was organized in the few months that were still available. Once a day a rythmic signal of the same type as that which is given by Bordeaux, has been sent out by the great wireless station of Malabar (near Bandung on Java) on a 19 Kilometer-wave. It was received and checked daily by means of astronomic observations by the Engineers of the Top. Serv. Irs. Poldervaart, Scharpf and Breyer at the "Bosscha" Astronomical Observatory at Lembang near Bandung. The signals were continued during the interval between July 10 till the arrival in Java and were afterwards taken up again twice daily for the trip in the Indian Ocean in February 1927.

Sincere thanks are due for this timely assistance to the Chief of the Netherlands Indian Radio Service, the late Ir. de Groot, and to other authorities of this Service, to the late Mr. Bosscha who kindly gave the necessary funds for the apparatuses, to the Head of the Topographic Service and to Prof. Ir. Schepers.

The signals could already be heard in Curaçao and could easily be taken regularly since our passage through the Panama Canal.

Base Observations. The Base observations were made at the Dutch Gravity Base-station De Bilt on May 9 and May 10, 1926, following the normal programme*): on each day five pendulum observations of somewhat more than two hours each, filling up the space between two time-signals at twelve hours interval. In this case the rythmic signals of Bordeaux at $8^h.01$ and $20^h.01$ Greenwich Time were taken. Four of the pendulum observations were begun with the two outer pendulums of the row of three having equal amplitude (about $35' = 2$ cm. amplitude on the photographic record) in opposite phase and the middle one hanging free with as little amplitude as is practically obtainable by lowering the pendulums as carefully as possible; the fifth observation was begun with the pendulum at the left having about 35′ amplitude, the middle one half as much in the same phase and the right one one and a half times as much in opposite phase.

The pendulums have been mounted in the apparatus in the normal way: from left to right Nrs. 88, 90, and 89, the two outer ones with the side marked A to the right and the middle one with this side to the left.

After transporting the apparatus on May 16 to Helder, the Naval Base where the submarine was stationed, it was mounted aboard in the central control-room against the tube which shelters the back periscope. This was done by means of two metal strips encircling this tube, to which were fastened by screws the two vertical triangles, supporting the knives of the gimbal-ring.

On May 18 a series of control observations were made near Helder, which gave satisfactory results, showing that the differences of the pendulum-periods had not changed during the transport and giving a value for g which was in good agreement with the value found at the land-station at Helder in 1920.

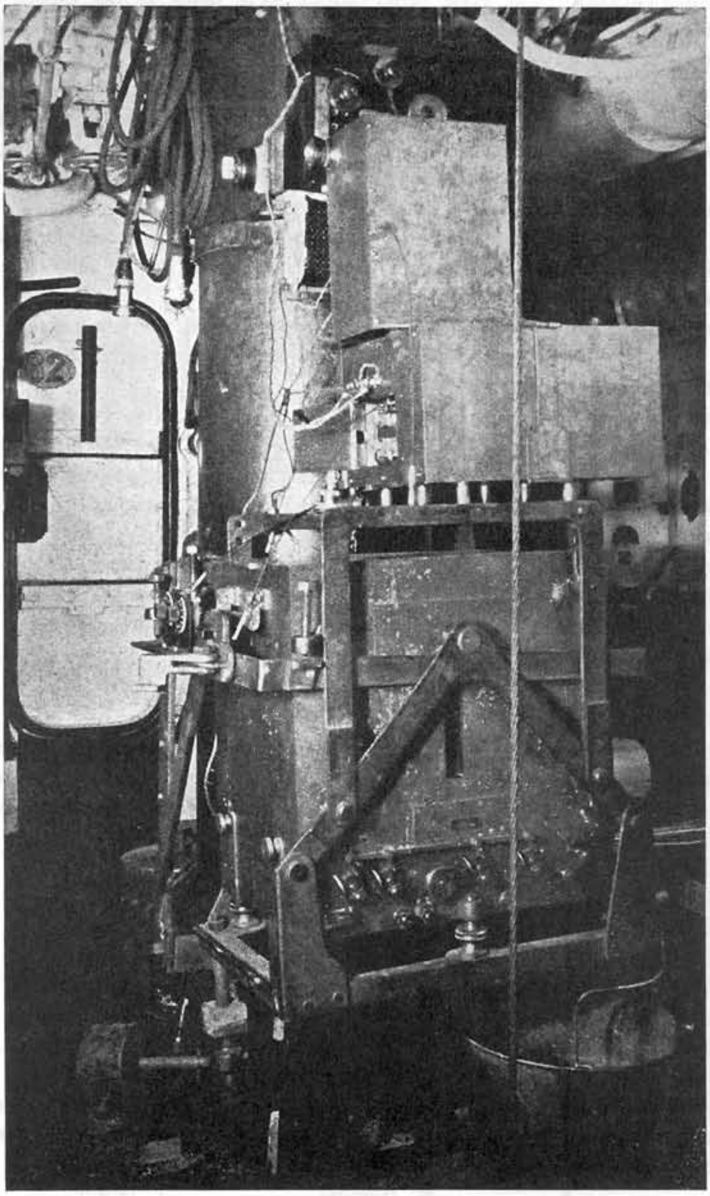
The Voyage.

On May 27 Hr. Ms. Submarine K XIII, built by "Fyenoord" at Rotterdam for the Netherlands Indian Fleet, left the port of Helder for its great cruise. The ship measured 730 tons at the surface and 800 tons during submergence. Its crew consisted of the Captain, 4 Officers, and 26 Petty Officers and Men:

Lieut. L. G. L. van der Kun, Captain.
Lieut. J. J. L. Willinge, Executive Officer.
Lieut. M. S. Wytema.
Lieut. J. C. van der Linden, in command of the engine-room.
Lieut. J. van Sandwijk, second in command of the engine-room.

W. C. Thysse, Chief of the boat.
J. C. A. Scheuerman.
F. J. de la Fonteyne.
F. E. L. de Rechteren van Hemert.
W. Wydoogen.
W. G. J. Dries.
J. Boonstra.
E. J. Freriks.
J. W. Scheer.
P. van den Heuvel.
G. H. J. Bussing.
D. Janse.
O. W. Hen.
H. J. Vlaming.
W. F. J. Besançon.
F. Blondel.
F. B. Reinders.
G. P. Monshouwer.
P. J. Signorgo.
H. J. Franzani.
J. Goetheer.
H. E. Cornelissen.
A. R. van der Reyden.
F. B. Sloof.
J. Jaggie.
D. van de Waal.

*) See for this programme: Theory and Practice of Pend.Obs.at Sea, p. 25 et sq.



Pendulum Apparatus mounted in the Central Control Room of Hr. Ms. K XIII.

They all contributed by their helpful assistance and continuous good-comradeship to the good spirit during the whole of the nearly seven month duration of the voyage and to the success of the scientific work. More especially I wish to mention Captain Van der Kun, who by numerous submergences, often in difficult circumstances, made it possible to come back with the complete and valuable material which is given in this report and the Officers who all gave their whole-hearted cooperation to the scientific object of the cruise. I take this opportunity for expressing my sincere thanks as well for the assistance in my work as for the friendship and good companionship, which I met with o/b the K XIII during our long peregrination.

In connection with the scientific objects: the Mid-Atlantic Ridge, the Porto Rico Deep, the continental coast between Panama and San Francisco, the Renard Deep near the Sandwich Islands, the Nero Deep near Guam, the Yap Deep, the Philippine Deep and the Eastern part of the Indian Archipelago, the route was chosen as indicated on the accompanying map and the following ports were touched:

Helder	dep. 27 May	
Horta (Azores)	arr. 6 June dep. 9 June	Gravity Obs. Nr. 5
Las Palmas (La Luz Harbour)	arr. 14 June dep. 21 June	Gravity Obs. Nr. 11
Curaçao	arr. 8 July dep. 20 July	Gravity Obs. Nr. 29
Cocosolo (near Colon)	arr. 24 July dep. 28 July	Gravity Obs. Nr. 34
Balboa (near Panama)	arr. 28 July dep. 30 July	Gravity Obs. Nr. 35
Mazatlan (Sinaloa)	arr. 10 August dep. 16 August	Gravity Obs. Nr. 48
San Francisco	arr. 24 August dep. 8 September	Gravity Obs. Nr. 57
Honolulu	arr. 20 September dep. 2 October	Gravity Obs. Nr. 73
Guam	arr. 21 October dep. 28 October	Gravity Obs. Nr. 94
Yap	arr. 31 October dep. 2 November	Gravity Obs. Nr. 99
Manila	arr. 9 November dep. 18 November	Gravity Obs. Nr. 108
Amboina	arr. 25 November dep. 30 November	Gravity Obs. Nr. 115

Banda	arr. 1 December dep. 2 December	Gravity Obs. Nr. 117
Bima (Isl. of Sumbawa)	arr. 7 December dep. 10 December	Gravity Obs. Nr. 126
Surabaya	arr. 13 December	Gravity Obs. Nr. 128

In total 128 gravity-stations have been observed, i.e. 113 at sea and 15 in the harbours.

The position of the ship in the different harbours can be inferred from the geographical positions given in the synopsis at the end of this publication.

The first trip from Helder to Horta was a difficult one for everybody. After a fairly smooth beginning in the North Sea and in the Channel, we met rougher weather during the passage of the Atlantic, which caused a great deal of rolling and pitching. Besides, much had to be done on board of the ship, which being a new one, was not yet adjusted in all its details. On June 2nd the first gravity observation was made and since then, observations have been made regularly once every day and often more than once, when the topography made it desirable to get more data. Over the profiles e.g. perpendicularly to the coast of Central and North America, and over the ocean deeps, three or four submergencies were made per day.

In the beginning the records have been developed on board with a special developing arrangement but shortly after Las Palmas the water got too warm to go on with it. Since then the records were developed in the next port.

With the exception of the first trip, of a few days on the West coast of Mexico and near Guam no rough seas have been met. Between Guam and Manilla the cruise brought us in a region where often taifuns occur, but we were lucky in this regard: a few days before our passage a taifun was blowing, leaving us a disturbed sea, but the taifun moved westward quick enough for keeping behind it. Although with these few exceptions we did not have rough passages, the sea was generally not quiet enough for living on the lower deck of the submarine or for opening the hatches in this deck. This makes it impossible to take exercise and the air inside the ship gets stuffy and hot. Thus the longer crossings were a heavy strain, especially those between Las Palmas and Curaçao of 17 days and between Honolulu and Guam of 19 days. As we did not generally follow shipping routes, we seldom saw other ships: between Honolulu and Guam, for instance, no ship was met; the ocean appeared completely deserted and our small submarine world was isolated amidst blue skies and blue seas.

The day of October 9 was a short one for us: At 9 o'clock in the morning we passed the 180th meridian and we jumped on October 10. Another memorable day was the 24th of November; we passed then between Manilla and Amboina for the first time the equator and although the ship did not give much room for celebrating this event, we made the most of it thanks to the sea leaving the lower deck accessible. One of the officers and five of the men who had never been across it before, underwent the usual ceremonies.

The most memorable day of all, however, was the 13th of December, the long looked-out for day, on which we arrived at last at our port of destination: Surabaya. I do not think any of us will easily forget the last hours we spent on board, when entering the Western entrance channel of the port of Surabaya amidst the submarines and other ships, which gave us a welcome home.

I cannot go here into further details about our long voyage nor about the many days we spent in port and the kind reception and great hospitality we met everywhere. For those who feel interested I may refer to the book, published by my friends, the officers Van der Linden and Wytema; „Met Hr. Ms. K XIII naar Nederlandsch Indië", Scheltema & Giltay, Amsterdam.

During the whole voyage the pendulum observations have been made according to the programme given in „Theory and Practice of Pendulum Observations at Sea" on page 24. As well as is practically possible on board a moving ship, the two outer pendulums got the same amplitudes in opposite phase. For obtaining this, the amplitude-handles must be turned away at the moment that the apparatus is level. We can try to realize this by doing it at the moment that the bubble of the small outside level passes through the level position or at the moment that the light-images, which for this end are projected on the scale below the recording apparatus, pass through the positions corresponding to a level position of the apparatus, but both methods are difficult to put into practice. A ten or twenty percent difference between both amplitudes will therefore often occur. As suitable amplitude was chosen 35′ corresponding to 2 cm on the photographic record. The middle pendulum was released without giving amplitude.

The observation began with five minutes at great paper-speed and greatest amplitude of motion of the left shutter, then followed twenty minutes at small paper-speed and reduced amplitude of motion of this shutter and finally five minutes in the same way as the first five minutes.

Nearly all the observations have been made during submergence at depths, varying from periscope depth at thirteen meters till thirty meters and once at forty meters, dependent on the state of the sea. For long ocean waves a greater depth is necessary than for waves in inland seas; on the oceans we submerged mostly at a depth of thirty meters. As a general rule the movements of the apparatus must not be so big that the apparatus risks hurting the iron structure that supports it; in case of doubt it is well to check this during a few minutes before lowering the pendulums on their knife-edges. Secondly the movements must not bring about too great movements of the middle pendulum; 6 or 7 cm. double amplitude on the record must be considered as an upper limit. This can be checked by turning from time to time the light-rays on the scale, but this cannot be done for more than a moment as it interrupts the recording. It can likewise be done by looking at the pendulum itself through the window, through which the temperature is read. In case the movements threaten to get too big, a greater depth of submergence is desirable.

More or less as experiments a few observations have been made at the surface of the sea, i.e. Nrs. 15, 107, 114, 124 and 127. This appeared to be a risky undertaking under nearly all circumstances as the amplitude of the middle pendulum was usually so irregular that continuous care was necessary to prevent too great amplitudes. The cause of these irregular movements, even when the sea is quiet, is probably the effect of small surface waves on the ship; submergence at small depth takes them immediately away. It is of course necessary to stop the Diesel engines during these surface observations to prevent the vibrations imparted to the ship.

The observations in the harbours have likewise been made at the sea-surface; even in these cases some irregularity of amplitude occurred, but mostly not enough to give reason for close watchfulness. In the harbour of Honolulu, where the ship lay bumping against the quay, it was twice necessary to make a new beginning before an acceptable observation was obtained.

In most of the harbours two observations were made, one with the gimbal suspension in action and one with this suspension fixed, in order to see if this suspension does not give systematical disturbances of the pendulum periods. As the results of these observations show nothing has been found:

Nr. 5	Horta	suspension in action	980.160
		suspension fixed	980.163
Nr. 11	Las Palmas	suspension fixed	979.390
		suspension in action	979.390
Nr. 29	Curaçao	suspension in action	978.437
		suspension fixed	978.435
Nr. 48	Mazatlan	suspension fixed	978.869
		suspension in action	978.866
Nr. 57	S. Francisco	suspension fixed	980.000
		suspension in action	979.996
Nr. 94	Guam	suspension fixed	978.542
		suspension in action	978.536
Nr. 99	Yap	suspension fixed	978.479
		suspension in action	978.477
Nr. 108	Manilla	suspension fixed	978.362
		suspension in action	978.362
Nr. 115	Amboina	suspension fixed	978.183
		suspension in action	978.180
Nr. 117	Banda	suspension in action	978.275
		suspension fixed	978.272

A few times, i. e. for the stations Nrs. 69, 87 and 104, two observations have been made at the same spot, one with eastward speed and one with westward speed. This was done for checking the speed of the ship at a given number of rotations of the screw by means of the Eötvös effect; as this speed may change gradually because of the hull of the ship getting foul during a long voyage in tropical waters, this check was welcome.

Twice another check has been made. During submergence a refrigerating machine was usually working for cooling the ventilation air for the batteries and this machine gave a slight vibration to the ship. At stations Nrs. 31 and 68 two observations have been made one after the other with this machine in action and off, to see if the vibration had any effect on the pendulum periods. The result was in the negative.

Nr. 31	refrigerating in action	978.237
	refrigerating off	978.242
Nr. 68	refrigerating in action	978.933
	refrigerating off	978.935

At the end of the voyage I had some trouble because of the prisms and lenses getting slightly blurred by a microscopic fungus-effect on the glass which is well know in the tropics.

This caused the records to get fainter, but as they still could be read, no measures were taken for cleaning, because this would have brought about a risk of disturbing the adjustment of the light-rays. After arrival in Java I cleaned the apparatus and during the next expedition, south of Java, the images were normal again.

Arriving in Surabaya, two observations have been made in the submarine-harbour, on the 15th and the 16th of December. Besides giving the value of gravity for this harbour, these observations have been meant as a provisional check of the pendulums at the end of the long trip, because if anything would happen with the pendulums afterwards during the transportation to Holland, other gravity observations would be possible in Surabaya for making this check valid.

The pendulum apparatus had given complete satisfaction in its new shape. The gimbal suspension had proved a marked success in lessening the strain during submergence. Of the 128 observations during the voyage, only two had gone wrong, Nrs. 36 and 37, because the photographic paper got stuck and was torn through without my noticing it. In the new recording apparatus which was constructed afterwards, this point has been provided for, first by lessening the friction of the paper and secondly by introducing an indicator which shows the movement of the paper.

The aneroid used for obtaining the pressure of the air during the observations, was compared in most harbours, i.e. in Helder, Horta, Las Palmas, Curaçao, Balboa, Mazatlan, San Francisco, Honolulu, Guam and Surabaya, with a mercury barometer which was aboard. The hair-hygrometer of the pendulum-apparatus was likewise checked in these harbours, except in Balboa and San Francisco: this was done by means of a psychrometer taken along for this purpose. Foı the thermometer of the pendulum-apparatus, the old corrections were used, determined in the "Preussische Reichsanstalt" in 1921.

The reception of the time-signals had been continually satisfactory. It was done by putting the break-circuit of one of the chronometers, shutting and opening the current for half a second, in series with the telephone of the wireless receiving set and noting the appearing and disappearing of the rythmic time-signals in the telephone. A rough estimate of the time of the dashes given at intervals of sixty signal-points, identifies the number of the signal-points

The disappearing of the signals was also noted, although it cannot be so clearly observed as the moment of appearing. This was done in order to be more independent of the intensity of the signals, which may vary much during a voyage like this; a faint signal, appears later and disappears earlier than a strong signal and so the mean of both times remains about the same.

The second chronometer was aurally compared before and after the reception of the time-signal with the first one by means of coincidences.

Up to the 7th of July the signals of Bordeaux have been taken twice a day, i.e. at 8^h01 Greenwich and at 20^h01 Greenwich. As they became faint in the neighbourhood of the Antilles, I changed over to the rythmic Annapolis time-signals. They, however, give the complication that their rythm is the same as that of the mean time chronometer. They were, therefore, received with an auxiliary chronometer, whose rate was altered by one seventieth in order to make it different enough from the time-signal rythm to get several coincidences during the five available minutes. The auxiliary chronometer was aurally compared before and afterwards with the other chronometers by observing coincidences.

During the stay at Curaçao, it was tried for the first time, and with success, to receive the Malabar signals from Java. After having passed the Panama Canal, they could regularly be taken, and when a few days after leaving San Francisco the Annapolis signals became faint, they were exclusively used for the determination of the rates.

The list on page 66 shows the time-signals and the rates of the chronometers during the first part of the voyage. This may give an idea about the fluctuations of the rates, that occurred during this trip.

The geographical positions of the gravity stations were determined by the officers. Besides those observations as were necessary to ensure the navigation, as many astronomical determinations were made as the state of the sky allowed, in order to reach the greatest possible accuracy of those positions. A study of the data that have been used, led to an estimation of the accuracy of each latitude and longitude, and these figures have been inserted in the list of stations at the end of this publication.

The officers also furnished the data concerning the sea-currents which were used for computing the reduction for the Eötvös effect. The accuracy of these data is difficult to estimate. Besides the uncertainties brought about by the errors of position of the ship, we get the question if the current during the pendulum observation was the same as the mean current during the interval between the astronomical determinations, which is the only thing that can be deduced. Two uncertainties are combined as far as this question is concerned: First the uncertainty whether fluctuations of the current have occurred; this is always possible, but it is less probable in the open ocean than near coasts or in straits. Secondly if the current during the pendulum observation at a depth of twenty or thirty meters has the same direction and speed as at the surface of the sea; if there would be a difference, the mean value deduced from the ship's positions would be about the same as the mean surface value, because the submergences are always short with regard to the time-interval between the astronomical determinations, and it would differ from the value needed for the computation of the Eötvös effect, i.e. the depth-value. As a personal estimate, I think that errors in the east-west component of the current will only exceptionally attain values of half a mile per hour and generally less than a quarter of a mile per hour.

The echo-sounding method proved to be successful during submergence. At the surface the echo could usually not be taken: first because of the dispersion of the echo-sound by the waves and secondly because of the disturbing noises in the telephone by the same cause. During submergence the echo was usually clear, although often more or less blurred. Even in these cases, however, it could be observed with an accuracy, which was generally not below a twentieth of a second, corresponding to an uncertainty of the depth of about 40 meters. In exceptional cases no clear echo could be heard as e.g. during the observation at station Nr. 14. Over part of the Philippine Deep no echo at all could be discerned and also over the other deeps, moments occurred when the echo disappeared.

The time between the signal and the echo was taken by means of accurate stop-watches— of which the needle makes one revolution in three minutes, and which allow an accuracy of reading of a hundredth of a second. The button of the watch was pressed at the same time as the signalling handle of the Fessenden Sonic apparatus and by the same man with his other hand. In this way both actions were synchronous up to a few hundredths of a second. At the time the echo gets back, the position of the needle was read on the dial without stopping the needle. In this way it was thought that the greatest accuracy would be obtained, because pressing the button at the moment of hearing the echo would be sure to give a slight retardation, expecially in those cases that the echo was faint. Every sounding was repeated a number of times, mostly ten times, and the mean was taken.

For reducing the echo-intervals to depths the tables of the British Hydrographic Office have been used. The mean error of the depths given in the list of the stations in the second volume is estimated to be 50 meters at the highest and usually less.

Gravimetric Survey of the Java Deep.

After arriving in Java, a request was adressed to the Commander of the Netherlands Indian Naval Forces, Admiral Gooszen, in behalf of a further investigation, viz. a gravimetric survey of the Java Deep, South of the island of Java. Several reasons coincided for making such a survey particularly interesting. Besides the interest attached to every ocean deep, it was known that nearly all the earthquakes in that part of the Indies have their centres over or near this deep and so, as tectonic activity means tectonic forces working in the crust, great deviations of isostatic equilibrium might be expected. It would be important to detect the way in which these deviations are distributed.

Lastly this deep had been recently covered with a network of echo-soundings, made by the submarine squadron in 1925, and so the submarine topography was known in detail. A gravimetric survey would therefore find all the necessary conditions for success.

Admiral Gooszen gave a favorable decision and the survey took place in the first half of February 1927. The K XIII left Surabaya in the afternoon of February 5 and arrived at Tanjung Priok, the harbour of Batavia, in the morning of February 15 after 24 submergencies. With two surface observations, Nrs 130 and 155, this makes a total of 26 gravity observations which have been numbered in continuation of those of the previous voyage; besides, observations have been made before leaving, in the submarine-harbour of Surabaya, for checking the pendulums with the values found in Surabaya after our arrival in December, and in Tanjung Priok after our arrival there.

As the sea was exceptionally quiet for the time of the year, our trip would have been agreeable if the great number of submergencies, several of them during the night, had not meant a heavy strain. Once a critical moment arrived. During the submergence of station Nr. 138 the ship fell to a depth of 80 meters, i.e. considerably more than its depth-limit. Luckily everybody kept cool and it was possible to bring the ship back to its normal level, after which the observation could be made.

Soon after our arrival in Batavia, I left the Indies and returned to Holland with the apparatus.

Final Base Observations.

The apparatus was mounted again in the base-station De Bilt and control observations were made on four days: May 21, May 24, June 15, June 18, 1927, according to the normal base-station programme. The results were in good agreement with those made in May 1926 before the voyage.

The Computations, the Results and the Mean Errors.

A. The computation of the Base-Observations at De Bilt.

The base-observations at De Bilt were computed according to the formulas of "Theory and Practice o.P.O.a.S.", §§ 1—5 of Chapter III. The mean of the reduced periods of the two fictitious pendulums, formed by the pendulum-pairs 89—90 and 88—90, was consecutively:

9 May 1926,	0.5012503
10 May 1926,	0.5012505
21 May 1927,	0.5012508
24 May 1927,	0.5012504
15 June 1927,	0.5012510
18 June 1927,	0.5012510
Adopted Value	0.5012506

For the differences of the pendulum-periods $T_{90} - T_{89} = U_{90,89}$, $T_{90} - T_{88} = U_{90,88}$ and $T_{88} - T_{89} =$ the difference of the fictitious pendulum-periods d, the following values have been found, expressed in 10^{-7} sec.

Date	$U_{90,88}$	$U_{90,88}$	d
9 May 1926,	+ 34	+ 6	+ 28
10 May 1926,	+ 23	— 5	+ 28
21 May 1927,	+ 33	— 7	+ 40
24 May 1927,	+ 31	— 9	+ 40
15 June 1927,			+ 44
18 June 1927,			+ 47
Adopted Values	+ 31	— 4	+ 35

The adopted value of d has been used for checking the differences d of the two fictitious pendulums. The differences $U_{90,89}$ and $U_{90,88}$ were used for the computation of the corrections for deviation from isochronism, but although the values before and after the voyage agree fairly well with each other, the differences d of the fictitious pendulums that have been found in this way, prove beyond doubt that during the voyage the middle pendulum, Nr. 90, has not been as stable as the other ones. For part of the trip the deviations of d show a correlation with the factors with which $U_{90,89}$ and $U_{90,88}$ are multiplied for computing the correction for deviation of isochronism and this correlation disappears when the values of $U_{90,89}$ and $U_{90,88}$ are increased. This obviously means that T_{90} has changed by this amount.

To find the amount of the change that best adapts itself to the results of the observations, I made the computations with the above mean values of $U_{90,89}$ and $U_{90,88}$ increased with an unknown term x, and computed x by means of the method of least squares from the series of equations, obtained by equalling each value of d found in this way as a linear function of x, to its normal value 35 10^{-7} sec. I did this for five groups of stations: Nrs. 1—32, 33—67, 68—97, 98—128 and the stations of the trip South of Java 129—156, and found consecutively in unities of 10^{-7} sec: $x = 16, 13, 19, 22$ and 8. Adopting 16 for the stations 1—97, 22 for the stations 97—128 and zero for the trip South of Java, and taking into account the pendulum constants for the corrections for temperature and air-density:

	Temperature Constants	Air-Density Constants
Nr. 88	45.88 per centigrade	665.9
Nr. 89	47.07 „ „	673.2
Nr. 90	46.91 „ „	668.4

the following formulas were obtained for computing the differences $U_{90,89}$ and $U_{90\,88}$ at the temperatures t° and air-densities D of the observations

For Stations Nrs. 1—97,

$$U_{90,89} = 47 - 4.8\ D - 0.16\ t^{\circ} = 42 - 0.16\ t^{\circ}\ 10^{-7}\ \text{sec.}$$
$$U_{90,88} = 12 + 2{,}5\ D + 1.03\ t^{\circ} = 14 + 1.03\ t^{\circ}\ 10^{-7}\ \text{sec.}$$

For Stations Nrs. 97—128,

$$U_{90,89} = 53 - 4.8\ D - 0.16\ t^{\circ} = 48 - 0.16\ t^{\circ}\ 10^{-7}\ \text{sec.}$$
$$U_{90,88} = 18 + 2.5\ D + 1.03\ t^{\circ} = 20 + 1.03\ t^{\circ}\ 10^{-7}\ \text{sec.}$$

For Stations Nrs. 129—156,

$$U_{90,89} = 31 - 4.8\ D - 0.16\ t^{\circ} = 26 - 0.16\ t^{\circ}\ 10^{-7}\ \text{sec.}$$
$$U_{90,88} = -4 + 2.5\ D + 1.03\ t^{\circ} = -2 + 1.03\ t^{\circ}\ 10^{-7}\ \text{sec.}$$

As variations of the middle pendulum practically only affect the differences of the fictitious pendulum-periods and not the mean of these periods, the accuracy of the gravity results of the voyage is not affected by this cause.

B. The computation of the Observations at Sea.

The measuring of the photographic records and the computations of the results were made according to the methods given in §§ 1—5 of Chapter III of "Theory and Practice of P. O. a. S.".

For deriving the periods of the fictitious pendulums, the usual method was applied of determining the coincidences, i. e. the passages of the chronometer-marks through the axis of the pendulum-records. This was done by measuring the positions of twenty chronometer-marks at regular distances of two seconds after each other, chosen in such a way that the passage coincided approximately with the tenth or eleventh second-mark; the exact time of the passage can then be computed according to formula 70 of "Theory and Practice of P.O.a.S.". A specimen of a computation is given on page 78 of that publication. For harbour stations and for all the other stations where the curve of the chronometermarks showed no fluctuations because no vertical accelerations made themselves felt, only ten marks were measured.

This method for determining the passage-times takes longer than the graphical method described on pages 78 and 79 of the above publication, but the writer thought it desirable to apply it for obtaining data about the relative accuracy of both methods; as the graphical method had already been applied for the provisional computations of most of the observations during the voyage, a comparizon could be made. The list of the results on pages 56 et sq. contains the mean errors m_T and m_T' of the pendulum-periods for both methods, determined with the same chronometer, Nardin Nr. 212, sidereal time. For each pendulum record two passages were measured at the beginning and two at the end of the observation.

In the following way m_T and m'_T were determined. For the computational method the mean error of each passage was derived from the ten or twenty measurements of chronometer-marks in the way described in "Theory and Practice of P. O. a. S." p. 78, i. e. by comparing the values for the passage given by the mean of the first and the last chronometer-mark, of the second and the one before the last, of the third and the second one before the last, and so on. The value of m_T was deduced from the mean error of the passage.

For the graphical method, the times of the passage were compared with the times found by means of the computational method and for each observation the mean value of these differences was deduced; for a normal observation eight differences were available; two at the beginning and two at the end of each of the two fictitious pendulum records. Accepting the passage-times according to the computational method as true values, these mean values were used for determining the mean error of the pendulum periods. In reality we find in this way $\sqrt{m^2_T + m'^2_T}$ and so finally this value was corrected by taking the root of its square diminished by m^2_T.

The comparizon of the two methods by means of this list of m_T and m'_T is not quite fair to the graphical method because this method was applied for provisional computation during the voyage, i. e. in unfavorable circumstances for accurate work and without aiming at great accuracy. Still the list makes it clear that, although the mean errors are bigger for this method, they are so small with regard to the other mean errors of the gravity determination, that it can safely be applied without risking a perceptible increase of the resulting mean error for gravity. (As gravity is deduced from the mean of two fictitious pendulum-periods determined with two chronometers, the mean error of gravity is only $0.20 \times m_T$ milligal).

The mean of all the m'_T for the graphical method is 4.2 10^{-7} sec and of the m_T for the computational method 1.8 10^{-7} sec. For getting further insight, I also determined the mean for the harbour-stations and for a group of ocean-stations, viz. between Las Palmas and Curaçao and between San Francisco and Guam, Honolulu excepted. For the harbour-stations the curve of the chronometer-marks shows certainly no fluctuations corresponding to vertical accelerations while for the ocean-stations this fluctuation is maximum because of the great vertical accelerations caused by the ocean-swell. The results were

	Harbour-stations	Ocean-stations
m'_T, graphical method	3.8 10^{-7} sec	4.2 10^{-7} sec
m_T, computational method	1.1 10^{-7} sec	2.0 10^{-7} sec.

We see that the advantage of the computational method is not greater for the ocean-stations, although here the graphical method incurs the error inherent to the drawing of a straight line through the fluctuating curve of the marks. Apparently this error can be neglected and so for ocean-stations, the above conclusion remains likewise true; we can safely adop the graphical method.

For the final computations, the curves of the marks made by the second chronometer, Nardin Nr. 2081, mean time, were also measured, in order to obtain likewise the value of the reduced pendulum-periods, based on this chronometer, but as the periods of the pendulums are not much different from the period of mean time, these curves have a low inclination and a long coincidence-interval and so only one passage through the axis could be determined at the beginning and one at the end of the observation. In some cases even no passage was available and I had to measure an arbitrary series of marks and use the method of computation treated on page 79 of "Theory and Practice o.P.O.a.S." under B. This same method had to be used in exceptional instances for the other chronometer-curve also. The mean error of the pendulum periods determined by this method may be estimated to be the same as for the computational method, if at least the marks that have been measured are not too near the border of the record.

At most of the stations where the observations were made at the sea-surface, the observation could not be continued during the normal time-interval because of the pendulum-amplitudes becoming too big. The consequence is a somewhat greater mean error of the periods. For station Nr. 15, this is further increased by the irregularity of the record.

The application to the pendulum-periods of the corrections for temperature, for air-density, for reduction to infinitely small amplitude, for deviation of isochronism, for tilt of the swinging-plane and for rate did not present any special feature, that has not yet been treated of in "Theory and Practice of P. O. a. S.". Neither is it necessary to enlarge on the reduction of the results for gravity to sea-level or on the corrections for the Eötvös effect, which have been made according to the formulas of pages 90—92 of this publication.

The data of the observations and results of the computations are put together in the following table, giving consecutively the Nr. of the station, the date, the depth below sea-level at which the observation was made, the double amplitudes of the two fictitious pendulums in mm on the records, the duration of the observation, the increase of the temperature during the observation given by the thermometer of the apparatus and by the temperature recording mechanism of the apparatus, both in centigrades, the factors of $U_{90,89}$ and $U_{90,88}$ in the formula for the correction for deviation of isochronism, the mean of the m_T and of the m'_T of both fictitious pendulums, m_T and m'_T being the mean errors of the unreduced periods according to chronometer Nardin Nr. 212, computed with the computational method and with the graphical method, the value of the difference d of the reduced periods of the fictitious pendulums, the differences v between the means of the fictitious pendulum-periods given by chronometer Nardin 212 and those given by chronometer Nardin 2081, the value of gravity reduced to sea-level and the mean error of this last value.

The geographical positions of the stations with the mean errors of these positions are given in the synopsis at the end of this volume. In this list the station-numbers of the voyage are mentioned besides the numbers of the list. The gravity results for those stations where two observations have been made, are combined in one resulting value and its mean error is given in the corresponding column. The sea-depths, most of them determined by echo-soundings, will be given in Vol. II of this publication.

The gravity results are computed with a value of g at De Bilt of 981.268.

Results of the Gravity Observations made o/b Hr. Ms. K XIII, 1926—1927.

Nr.	Date, 1926 / Harbours	Depth Observ.	$2a_{90.89}$	$2a_{90.88}$	Duration Observ.	Change Temp. Therm.	Change Temp. Record	Factor $U_{90.89}$	Factor $U_{90.88}$	m_T	m'_T	d	v	g_0	m_g
		m.	mm	mm	min	°	°			10^{-7} sec.					m.gal
1	2 June	28	37	52	26	+0.30	+0.57	−0.097	+0.073	2	5	45		980.549	4
2	3 „	28	45	45	29	+0.22	+0.54	−0.064	+0.080	1	7	28	− 2	980.515	4
3	4 „	28	51	38	23	+0.14	+0.40	+0.182	−0.245	4	6	38		980.348	4
4	5 „	28	49	43	25	+0.20	+0.43	+0.025	−0.028	3	6	42		980.213	4
	Horta														
5A	6 June	2	46	45	24	+0.10	+0.13	+0.002	−0.002	1	3	41	−24	980.160	3
5B	6 „	2	46	48	27	+0.13	+0.44	+0.109	−0.104	1	3	44		980.163	3
6	10 „	18	43	35	26	+0.21	+0.44	+0.151	−0.180	2	5	33	−20	979.894	4
7	11 „	18	35	36	25	−0.09	−0.16	−0.123	+0.116	2	4	24	+ 2	979.639	4
8	12 „	18	39	33	24	−0,17	−0.07	−0.154	+0.182	2	4	15	− 4	979.403	4
9	13 „	18	32	40	26	−0.11	−0.10	−0.266	+0.212	2	4	29	− 6	979.272	4
10	14 „	18	29	33	28	−0.06	−0.03	−0.069	+0.061	3	3	40	− 9	979.207	4
	Las Palmas														
11A	14 June	2	33	34	26	+0.08	+0.53	−0.145	+0.141	1	8	29	+13	979.390	3
11B	14 „	2	32	38	26	+0.13	+0.23	+0.109	−0.029	1	3	42	+ 7	979.390	3
12	22 „	18	37	34	26	+0.02	+0.10	+0.022	−0.024	3	4	22	+ 8	979.146	4
13	23 „	18	37	31	27	−0.03	−0.60	−0.030	+0.035	2	4	31	+ 2	979.090	4
14	24 „	19	34	35	27	−0.10	−0.12	−0.056	+0,056	1	5	28	+ 3	979.032	4
15	25 „	2	48	36	12	−0.06	+0.13	−0.61	+0.55	9		47	+ 9	979.014	5
16	26 „	36	30	39	25	+0,09	+0.17	+0.120	−0.092	2	4	29	+38	978.968	4
17	27 „	29	34	34	27	+0,02	+0.40	−0.068	+0.068	4	4	45	−20	978.935	4
18	28 „	28	28	40	31	+0.18	+0.43	+0.096	−0.068	2	5	25	+ 6	978.901	4
19	29 „	18	34	34	26	+0.01	+0.10	+0.200	−0.285	2	3	38	−20	978,911	4
20	30 „	18	32	37	27	+0.09	+0.23	−0.238	+0.205	2	5	37	− 2	978.884	4
21	1 July	18	40	32	30	−0.02	+0.09	−0.015	+0.019	2	5	37	− 7	978.854	4
22	2 „	19	34	30	26	−0.10	−0 03	−0.059	+0 067	2	3	34	+ 3	978.801	4
23	3 „	18	31	37	26	+0.13	+0.24	−0.226	+0.189	2	4	39	−11	978.763	4
24	4 „	28	31	37	28	+0,16	+0.20	+0.026	−0.022	1	3	37	−18	978.744	4
25	5 „	28	28	39	32	+0.14	+0.26	−0.171	+0.120	1	5	39	+21	978.706	4
26	5 „	28	34	32	33	−0.09	+0.06	−0.039	+0.041	1	5	44	+ 1	978.287	4
27	6 „	18	38	29	27	−0.09	−0.03	+0.118	−0.155	1	3	32	− 7	978.547	4
28	6 „	18	37	27	25	+0 00	+0.04	+0.189	−0.269	1	3	33	−12	978.458	4
	Curaçao														
29A	8 July	2	32	31	27	+0.26	+0.34	−0.066	+0.066	1	3	36	+ 2	978 437	3
29B	8 „	2	32	37	27	+0.20	+0.23	−0.210	+0.171	1	3	36	+ 1	978.435	3
30	20 „	18	38	32	26	+0.00	+0.07	−0.045	+0.044	1	5	35	+14	978.260	4

Nr.	Date, 1926 / Harbours	Depth Observ.	$2a_{90.89}$	$2a_{90.88}$	Duration Observ.	Change Temp. Therm.	Change Temp. Record	Factor $U_{90.89}$	Factor $U_{90.88}$	m_T	m'_T	d	v	g_0	m_g
		m.	mm	mm	min	°	°			10^{-7} sec.					m.gal
31A	21 July	18	33	36	24	+0.09	+0.17	+0.003	−0.003	1	4	48	− 5	978.237	4
31B	21 „	18	39	34	23	+0.16	+0.03	+0.108	−0.124	1	5	34	− 4	978.242	4
32	23 „	18	36	37	26	+0.02	+0.30	+0.161	−0 157	1	4	49	+ 9	978.177	4
33	23 „	18	40	36	30	+0.07	+0.07	−0.045	+0.051	2		26	+27	978.178	4
	Colon														
34	25 July	2	40	33	30	+0.13	+0.27	+0.168	−0.182	1	2	32	+18	978.253	3
	Panama														
35	30 July	2	35	38	24	+0.20	+0.40	+0.012	+0.026	1	2	34	− 2	978.247	3
38	1 August	18	35	33	26	+0.06	+0.13	+0.047	−0.050	2	4	39	+10	978.173	4
39	3 „	18	40	32	26	+0.08	+0.20	+0.151	−0.094	3	3	38	+16	978.252	4
40	5 „	28	40	30	27	−0.02	+0.03	+0.012	+0.010	4	3	41	+19	978.366	4
41	6 „	18	36	33	27	0.00	+0.17	+0.019	−0.021	3	3	31	+ 9	978.421	4
42	6 „	18	40	28	15	+0.03	+0.13	−0.175	+0.250	5	4	49	− 4	978.408	4
43	6 „	18	39	30	21	−0.03	−0.13	−0.003	+0.010	2	4	32	−18	978.329	4
44	7 „	18	37	35	19	−0.02	−0.13	−0.092	+0.092	1	4	35	−21	978.457	4
45	8 „	18	36	32	27	0.00	−0.03	−0.064	+0,072	2	3	39	+ 4	978.423	4
46	8 „	18	35	34	31	+0.10	+0 26	−0.074	+0.076	2	2	44	− 4	978.454	4
47	8 „	11	35	30	29	0.00	−0.03	+0.187	−0.160	4	3	41	+15	978.575	4
	Mazatlan														
48A	10 August	2	31	20	24	+0.09	+0.10	+0.658	−0.845	2	4	36	+14	978.868	3
48B	10 „	2	43	24	18	+0.07	+0.14	+0.220	−0.412	2	5	29	+11	978.865	3
49	18 „	18	38	32	25	+0.07	+0.07	−0.053	+0.012	4	3	36	−11	978.928	4
50	19 „	18	41	33	25	+0.10	+0.46	+0.060	−0.075	3	4	26	−12	979.089	4
51	19 „	28	40	34	27	+0.02	+0.47	−0.005	−0.071	2	3	35	+ 4	979.079	4
52	20 „	18	37	37	27	−0 03	−0.07	−0.125	+0.128	3	5	42	−27	979.059	4
53	20 „	18	41	33	26	+0.21	+0.57	+0.095	−0.018	2	3	35	+ 7	979.233	4
54	21 „	18	33	40	29	+0.01	−0.06	+0.030	−0.026	3	7	36	−35	979.404	4
55	22 „	18	33	42	25	+0.20	+0.30	−0.212	+0.219	2	4	37	+ 1	979.588	4
56	23 „	28	30	38	26	+0.15	+0.37	−0.160	+0.084	2	4	38	−19	979 807	4
	S. Francisco														
57A	24 August	2	45	34	24	+0.20	+0.37	+0.066	−0.009	1	4	24	−29	980.000	3
57B	25 „	2	44	32	22	+0.15	+0.10	−0.037	−0.003	1	2	37	−20	979.996	3
58	9 September	28	35	39	29	−0.01	+0.27	−0.051	+0.046	3	7	34	+ 5	979.942	4
59	9 „	28	41	36	26	+0.03	+0,23	+0.045	−0.051	3	5	30	+ 1	979.898	4
60	10 „	18	37	40	26	−0.18	−0.04	−0.127	+0.155	3	4	45	−25	979.840	4
61	11 „	29	32	42	25	+0.04	+0.30	−0.152	+0.112	2	4	52	−17	979.716	4

Nr.	Date, 1925 / Harbours	Depth Observ.	$2a_{90.89}$	$2a_{90.88}$	Duration Observ.	Change Temp. Therm.	Change Temp. Record	Factor $U_{90.89}$	Factor $U_{90.88}$	m_T	m'_T	d	v	g_0	m_g
		m.	mm	mm	min	°	°			10^{-7} sec.					m.gal
62	12 September	18	37	36	27	+0.18	+0.50	−0.130	+0.027	2	5	35	−39	979.592	4
63	12 „	28	34	38	25	+0.22	+0.47	+0.168	−0.154	2	3	31	+ 4	979.510	4
64	14 „	28	41	32	26	−0.10	−0.06	−0.076	+0.085	1	3	35	−37	979.352	4
65	14 „	18	35	32	26	+0.02	+0.17	−0.114	+0.134	2	4	26	+15	979.269	4
66	15 „	23	36	36	27	+0.19	+0.27	+0.272	−0.247	2	6	40	−22	979.169	4
67	17 „	18	35	35	25	−0.08	+0.03	−0.049	+0.049	3	3	28	+11	979.039	4
68A	18 „	18	37	36	25	0.00	+0.04	−0.076	+0.080	2		34	−18	978.933	4
68B	18 „	18	34	28	27	0.00	+0.06	+0.085	−0.104	2		26	0	978.935	4
69A	19 „	18	32	34	24	−0.02	0.00	+0.031	+0.032	2	5	34	+22	978.882	4
69B	19 „	18	34	35	26	+0.01	+0.10	+0.142	−0.138	2	4	36	+17	978.880	4
70	19 „	30	32	41	26	+0.04	+0.23	−0.022	+0.017	1	2	37	−35	978.793	4
71	20 „	28	37	33	26	+0.15	+0.43	+0.038	−0.042	1	2	33	−14	978.660	4
72	20 „	18	35	37	24	+0.07	+0.13	+0.069	−0.032	2	5	31	−17	978.889	4
	Honolulu														
73	21 September	2	40	40	18	+0.06	+0.20	+0.030	+0.088	1	3	18	+ 1	978.943	3
74	3 October	28	38	34	26	−0.02	+0.23	+0.076	−0.088	2	3	36	− 4	978.685	4
75	3 „	28	43	34	26	+0.12	+0.17	+0.051	−0.065	2	3	34	−11	978.697	4
76	5 „	28	39	36	26	−0.07	+0.03	+0.138	−0.150	2	3	27	− 9	978.663	4
77	6 „	28	35	41	28	0.00	+0.13	−0.200	+0.171	2	5	27	+13	978.669	4
78	7 „	28	35	30	26	−0.06	−0.27	+0.031	−0.037	2	3	31	− 5	978.669	4
79	8 „	28	40	33	28	−0.23	−0.17	+0.095	−0.118	2	3	31	+ 9	978.662	4
80	9 „	36	40	35	27	−0.02	+0.07	−0.232	+0,266	2	3	26	−15	978.551	4
81	9 „	28	37	38	27	+0.07	+0.13	+0.116	−0.108	2	5	36	+ 2	978.523	4
82	10 „	28	41	39	25	+0.07	+0.27	+0.080	−0.085	3	3	21	− 1	978.544	4
83	12 „	28	28	33	25	+0.06	+0.10	+0.100	−0.085	2	5	35	−18	978.442	4
84	13 „	28	35	40	27	+0.05	+0.13	−0.014	+0.012	2	4	36	+11	978.416	4
85	14 „	18	41	35	27	−0.17	−0.07	−0.224	+0,263	2	4	27	− 3	978.412	4
86	15 „	28	27	35	27	0.00	+0.17	−0.007	+0.006	2	4	36	0	978.362	4
87A	16 „	28	41	30	25	−0.01	0.00	−0.006	+0.009	2	5	50	− 2	978.336	4
87B	16 „	28	40	34	28	+0.18	+0.30	+0.028	−0.032	2	4	36	− 9	978.332	4
88	16 „	28	33	32	27	+0.20	+0.43	−0.085	+0.147	2	5	30	+ 4	978.310	4
89	18 „	28	33	33	26	−0.01	+0.03	+0.124	−0.131	2	6	38	+ 5	978.309	4
90	19 „	28	29	33	26	+0.04	+0.13	−0.085	+0.076	2	8	35	−30	978.280	4
91	19 „	28	40	36	26	+0.05	+0.20	+0.050	−0.056	2	4	40	−10	978.198	4
92	20 „	28	36	36	27	+0.11	+0.10	−0.203	+0.224	1	5	37	− 9	978.055	4
93	20 „	28	33	40	25	+0.06	+0.10	−0.303	+0.250	2	6	27	− 1	978.399	4
	Guam														
94A	28 October	2	40	39	25	+0.11	+0.10	−0.128	+0.131	1		23	+10	978.542	3
94B	28 „	2	33	32	25	+0.08	+0.10	−0.397	+0.366	1	4	48	−11	978.536	3

Nr.	Date, 1926 / Harbours	Depth Observ.	$2a_{90.89}$	$2a_{90.88}$	Duration Observ.	Change Temp. Therm.	Change Temp. Record	Factor $U_{90.89}$	Factor $U_{90.88}$	m_T	m'_T	d	v	g_0	m_g
		m.	mm	mm	min	°	°			10^{-7} sec.					
95	28 October	28	35	33	27	+0.10	+0.30	+0.068	−0.041	2	4	34	− 4	978.389	4
96	29 "	28	39	34	25	+0.15	+0.33	+0.074	−0.141	1	5	41	−26	978 300	4
97	30 "	28	34	40	28	−0.02	+0.07	−0.162	+0.138	2	3	27	− 4	978.284	4
98	30 "	28	38	36	22	+0.16	+0.30	−0.005	−0 019	2	5	29	− 5	978.038	4
	Yap														
99A	31 "	2	41	38	25	+0.18	+0.30	+0.390	−0.432	1		62	+ 2	978.479	3
99B	31 "	2	35	31	25	+0,17	+0.17	−0.197	+0.181	1	5	34	+24	978.477	3
100	2 November	28	34	30	26	0.00	+0 03	−0.015	+0.016	3	2	31	− 9	978.190	4
101	3 "	28	34	39	26	+0.14	+0.20	−0.118	+0 100	3	6	33	− 2	978.204	4
102	4 "	28	38	38	26	+0.09	+0.03	−0.113	+0 113	2	5	40	− 2	978.217	4
103	5 "	28	32	39	30	+0.05	+0 20	−0.206	+0.169	2	4	32	− 2	978.256	4
104A	5 "	28	38	34	36	+0.06	0.00	+0.008	−0.009	1	6	34	−12	978.258	4
104B	5 "	28	38	34	22	+0.19	+0.43	+0 013	−0.015	2	6	44	− 3	978 265	4
105	6 "	28	34	35	26	+0.07	+0.33	+0.162	−0.157	1	4	31	+ 2	978.015	4
106	6 "	18	38	33	27	+0.02	0.00	+0.242	−0.279	1	7	11	− 8	978.483	4
107A	8 "	2	44	30	13	+0.03	+0.10	+0.761	−1.081	2		34	−14	978.341	4
107B	8 "	2	35	41	11	+0.17	+0.07	+0.834	−0.712	3		10	+23	978.343	4
	Manila														
108A	9 November	2	34	42	27	+0.13	+0.13	−0 191	+0.155	1	1	22	+10	978.362	3
108B	9 "	2	34	39	28	+0.16	+0.17	+0.303	−0.174	1	2	49	+ 2	978.362	3
109	20 "	18	38	36	26	+0.07	+0.20	+0.011	+0.011	2	2	36	+17	978.141	4
110	22 "	11	34	33	26	+0.12	+0.17	−0.144	+0.148	1	4	52	+ 2	978.162	4
111	23 "	18	34	38	23	+0.03	+0.07	−0.065	+0.087	2	4	24	+ 7	977.833	4
112	24 "	11	36	38	28	+0.08	+0.13	+0.081	−0.074	1	2	35	−16	978.058	4
113	24 "	24	36	38	27	−0.02	0.00	−0.006	+0 006	2	3	38	−22	978.052	4
114	24 "	2	28	40	27	−0.03	+0.03	−0.057	+0.040	1	5	38	−32	978.001	4
	Amboina														
115A	25 November	2	37	43	32	+0.10	+0.13	0.000	0 000	1	3	37	−21	978.183	3
115B	25 "	2	40	33	28	+0.05	+0.10	−0.015	+0.016	1		31	−27	978.180	3
116	30 "	18	35	35	27	+0.10	+0,10	−0.126	+0 114	2	7	46	− 8	978 052	4
	Banda														
117A	1 December	2	37	40	28	−0.03	−0.03	−0 019	+0 018	1	5	26	− 2	978.275	3
117B	1 "	2	43	33	26	−0.01	−0.07	+0.037	−0.047	1		24	+23	978.272	3
118	2 "	18	38	31	26	−0.01	+0.10	+0.068	−0.084	1	4	35	+ 5	978 125	4
119	2 "	10	37	39	28	−0-02	+0.03	−0.175	+0.227	1	7	39	+ 3	978.143	4
120	3 "	11	35	37	27	+0.11	+0.27	+0.097	−0.060	1	7	39	−10	978 039	4
121	3 "	10	35	30	27	+0.10	+0.13	+0.123	−0.143	1	6	42	+ 4	978.112	4
122	3 "	18	31	32	25	−0.03	−0 07	−0.062	+0.050	1	5	40	+ 2	978.019	4
123	3 "	11	36	32	28	−0.05	0.00	−0.064	+0.071	1	7	21	+ 3	978.233	4
124	5 "	2	31	41	19	+0.02	0.00	+0.148	−0.175	2		38	−20	978.155	4

Nr.	Date, 1926 / Harbours	Depth Observ.	$2a_{90.89}$	$2a_{90.88}$	Duration Observ.	Change Temp. Therm.	Change Temp. Record	Factor $U_{90.89}$	Factor $U_{90.88}$	m_T	m'_T	d	v	g_0	m_g
		m.	mm	mm	min	°	°			10^{-7} sec.					
125	6 December	28	33	37	27	−0.07	−0.10	−0.152	+0.188	1	7	33	+16	978.032	4
	Bima														
126	7 December	2	40	33	24	+0.02	+0.03	−0.275	+0.344	2		25	+ 2	978.279	3
127A	11 „	2	38	36	11	+0.05	+0.07	+0,503	−0.458	2		46	−17	978.167	4
127B	11 „	2	43	31	15	+0.06	+0.07	−0.072	+0.100	2		28	−10	978.180	4
	Surabaya														
128A	15 December	2	37	35	30	0.00	+0.06	−0.003	+0.003			29	− 5	978.138	3
128B	16 „	2	38	33	26	+0.01	−0.05	−0.085	+0.098	1		32	− 4	978.135	3
129	3 February	2	40	30	29	+0.07	−0.17	+0.05	−0.07	0	6	38	+13	978.137	3
130	4 „	2	46	35	20	+0.15	+0.17	−0.59	+0.78	0		65	− 3	978.158	4
131	4 „	18	33	38	26	+0.02	+0.13	+0.087	−0.076	4		39	−13	978.312	4
132	4 „	28	38	38	26	+0.01	+0.10	+0.090	−0.090	3		42	− 9	978.115	4
133	5 „	18	40	35	26	+0.12	+0.23	−0.079	+0.091	3		42	− 5	978.172	4
134	5 „	18	33	39	27	+0.18	+0.17	+0.15	−0.13	3		51	+ 4	978.088	4
135	5 „	18	38	30	26	+0.04	+0.07	−0.023	+0.029	3		48	−19	978.297	4
136	5 „	18	38	31	28	−0.09	−0.10	−0.103	+0.128	3		58	− 4	978.323	4
137	6 „	18	41	31	28	−0.07	−0.20	−0.148	+0.195	3		44	+13	978.321	4
138	7 „	18	36	37	26	+0.29	+0.30	−0.017	+0.016	2		61	− 7	978.272	4
139	7 „	18	39	34	27	0.00	0.00	+0.128	−0.143	2		46	0	978.051	4
140	7 „	18	35	37	24	−0.01	+0.03	+0.128	−0.123	1		43	− 5	978.174	4
141	8 „	18	36	37	26	+0.06	+0.07	+0.090	−0.089	2		48	+ 4	978.158	4
142	8 „	18	36	35	30	+0.04	+0.13	−0.029	+0.030	1		52	− 4	978.268	4
143	8 „	29	37	30	28	+0.09	+0.20	+0.007	−0.009	1		49	0	978.296	4
144	9 „	19	40	31	27	−0.11	−0.13	+0.14	−0.18	2		52	+ 6	978.085	4
145	10 „	18	34	37	30	+0.04	+0,07	−0.14	+0.12	1		40	− 9	978.118	4
146	10 „	28	36	37	26	+0.10	+0.23	−0.23	+0.22	1		35	− 5	978.292	4
147	10 „	18	36	34	26	+0.06	+0.10	−0.21	+0.23	2		23	+ 3	978.290	4
148	11 „	28	39	31	34	+0.03	+0.10	−0.08	+0.10	2		40	+19	978.251	4
149	12 „	18	35	36	28	+0.12	+0.27	+0.11	−0.10	2		54	+20	978.219	4
150	12 „	28	36	29	22	+0.04	+0,13	−0.03	+0.04	1		46	+ 5	978.094	4
151	13 „	29	35	39	27	+0.12	+0.23	+0.17	−0.15	1		68	+ 2	978.108	4
152	13 „	28	32	31	26	+0.04	+0.10	−0.09	+0.09	0		46	+20	978.096	4
153	13 „	28	37	36	27	−0.04	0.00	+0.05	−0.05	1		49	− 5	978.076	4
154	14 „	28	35	37	22	+0.07	+0.17	−0.03	+0.03	0		36	− 5	978.246	4
155	14 „	2	27	47	15	+0.08	+0.13	−0.72	+0.63	0		20	+19	978.149	4
	Tanj. Priok														
156A	15 February	2	38	33	26	+0.05	+0.05	−0.12	+0.14	0		33	−16	978.170	3
156B	15 „	2	32	28	22	+0.01	+0.05	−0.12	+0,14	0		32	− 4	978.171	3

D. The Mean Error of the Results.

The new pendulum apparatus, besides bringing back the computations to a few hours per station, also considerably reduces the mean error of the observations. This is done in three ways; by reducing the error of the determination of the pendulum-periods, by lessening the uncertainty of the temperature and by using two chronometers, which reduces the error caused by the uncertainty of the rate. We will successively examine these points.

I. The Error of the Determination of the Pendulum-Periods.

This error has already been discussed in the previous paragraph. A comparizon of the list of m_T for the first voyage on page 29 and of m_T for this voyage in the above list, shows that the error is reduced by the use of the new apparatus. The mean value of all the m_T for the first voyage was 6 10^{-7} sec and for this voyage, using the computational method 1,8 10^{-7} sec and using the graphical method 4.2 10^{-7} sec.

Besides the computation of the mean errors of the determinations of the pendulum-periods according to the two methods, another point has been investigated for this voyage. Several times it has been mentioned in "Theory and Practice of P.O.a.S." that the effects on the periods of the fictitious pendulums of a number of smaller disturbance terms may be neglected if the amplitudes do not show fluctuations. An inspection of the photographic records shows at once that no short-periodical fluctuations are perceptible; the borders of the pendulum-records are absolutely regular; only when the ship's movements had been considerable, i.e. for some of the observations made at the sea-surface, a slight fluctuation of less than a tenth of a millimeter may occasionally be detected. We may therefore consider this point as settled. In connection with it, it may be pointed out, that this result allows to attribute the mean error of 0.25 mm (see page 28) found during the first voyage for the extremity of the pendulum-vector of the fictitious pendulum in the sense of this vector, i.e. for the amplitude of this pendulum, to the errors, inherent to the method of determining this vector. There seems no reason to accept real fluctuations of the amplitude during this voyage, as the great number of observations during the last voyage did not show any trace of them.

Still, another point seemed worth while investigating: Are there no gradual changes of the amplitudes of the fictitious pendulums? I have, therefore, examined the first twenty-five records of this voyage and measured the amplitude of the fictitious pendulums as well as the data necessary for the computation of the disturbances of these amplitudes, brought about by the deviation of isochronism and by the fact that the pendulum amplitudes are not infinitely small. The formulas for these disturbances can be found on page 21 of "Theory and Practice o.P.O.a.S". The quantity $a_2 \; sin \; (\varphi_2 - \varphi)$ of these formulas may be measured immediately in the records, in an analogous way as the quantity $b = a_2 \; cos \; (\varphi_2 - \varphi)$ is measured (page 81 of this publ.); it is the amplitude on the grey part of the lower record (see phot. page 84 of that publ.) measured below the tops of the black triangles of the two upper records, i.e. halfway between the arrows in this picture.

The results of the investigation, after applying these corrections, were satisfactory. The mean error of the damping coefficients of the fictitious pendulums, deduced from the amplitudes at the beginning and at the end of the observations, was 3.5 10^{-6}. This corresponds to a mean change of the amplitude during the observation of less than 0.1 mm. This mean error can easily be explained by an error in the computations of the above corrections Even if it would be a real effect of secondary disturbances caused by the vertical accelerations or other causes mentioned in "Theory and Practice o.P.O.a.S." p. 10 et seq. the disturbance of the pendulum period, that might be expected according to formula 10 of that publication, would only be 2.8 10^{-7} sec.

We may conclude that during the whole voyage the amplitudes of the fictitious pendulums have shown no trace of short-periodical or gradual variations indicating secondary effects of the vertical accelerations or of other causes. As the number of observations is considerable, I think that this result settles this point satisfactorily for future observations made in analogous circumstances.

II. The error of the Temperature Correction.

As the constants of the pendulums are well-known, this error is practically caused by the uncertainty of the temperatures of the pendulums. This uncertainty is less for observations made with the new apparatus than for those made during the first voyage, because it is not necessary to open the apparatus to release the pendulums before the beginning of the observations and this favors the stability of the temperature. A second advantage with regard to this point is the possibility of heating up the apparatus a few degrees some hours before the beginning of the observations; as the temperature inside the ship often rises quickly after submergence, this contrivance allows to obtain that during the observation the temperature inside the apparatus is about the same as outside. Lastly, in order to get a check of the regularity of the temperature, the apparatus, besides the ordinary thermometer of the Stückrath type, readable in fifths of degrees, has been provided with a recording device that makes a photographic record of the temperature of the air inside the apparatus. The temperature-corrections of the pendulum-periods have been computed with the temperatures given by the ordinary thermometer and the other data were exclusively used for checking.

The list of the results of pages 56—60 contains the changes of the temperatures during the observations as they were given by the ordinary thermometer and by the recording device. These data allow an estimate of the magnitude of the error in the temperatures used for the computations of the corrections. I computed two mean values for the whole series of observations: First, the mean value of the change of temperature during the observation given by the ordinary thermometer; this gave $0^{\circ}.147$ corresponding to 6.9 10^{-7} sec. in the temperature correction of the pendulum-periods. Secondly, the mean value of the difference of the two data for the change of the temperature; this gave $0^{\circ}.108$, corresponding to 5.1 10^{-7} sec. in the temperature correction of the pendulum-periods. Considering these two figures, I think that an estimate for the mean error of the temperature-correction of the pendulum-periods of 5 10^{-7} sec., which corresponds to a mean error of 2 milligal in the gravity result, is likely to be near the truth.

III. The Mean Error of the Rate-correction.

This error is reduced by using two chronometers. Each chronometer gives an independent result for the mean of the periods of the two fictitious pendulums; if their irregularity of rate is about the same, as in our case, they can be combined by taking the mean value of these results. The mean error is in this way reduced by the factor $\frac{1}{2}\sqrt{2}$.

The use of two chronometers has the additional advantage that the difference v of the two results gives a valuable date for estimating the error brought about by this cause. The values of v for this voyage are mentioned in the list on pages 56—60. The mean value, i.e. the root of the sum of the squares being 14.0 10^{-7} sec, the corresponding mean error cf the mean of the two fictitious pendulum-periods is half of this value, i.e. 7.0 10^{-7} sec, giving a mean error of the result for gravity of 2.8 milligal.

This conclusion is only right as long as no disturbances occur during the observations, that affect the chronometer-rates systematically in the same way. As the temperature inside the ship is generally higher during submergence than at the surface of the sea, this case could arise if both chronometers had a temperature effect in the same sense. In our case the temperature-constants of both chronometers were negligible.

For checking this point, I computed the arithmetical mean of the values of v for five different parts of the voyage. I found

Nrs. 1—32	$v =$	— 1	10^{-7} sec.
Nrs. 33—67	$v =$	— 4	,,
Nrs. 68—97	$v =$	— 5	,,
Nrs. 98—128	$v =$	— 2	,,
Nrs. 129—156	$v =$	— 1	,,

and for the whole voyage $v = -$ 2.7 10^{-7} sec., i.e. a negligible quantity. There seems to be no cause for suspecting a systematical effect of any importance.

IV. The Computation of the Total Mean Error of the Gravity Result.

The total mean error of the gravity result was computed by combining the data for the mean deviation of the difference d of the two fictitious pendulum-periods with the mean value of the difference v of the two means of the fictitious pendulum-periods given by the two chronometers. This was founded on the following considerations.

The deviations of d are brought about by a number of causes. First by the error of the derivation of the fictitious pendulum-periods from the records, which has been examined above. The corresponding part of the mean error of the mean of these periods is half of the corresponding part of the mean deviation of their difference d.

Secondly it arises from the uncertainty of the temperature. This is only affecting d as far as differences of temperature of the pendulums occur. It appears, however, logical to suppose these differences of the pendulum temperatures to be of the same order of magnitude as the differences between the pendulum temperatures and the temperature of the pendulum body in which the thermometer of the apparatus is encased. Accepting this supposition, we have the same result as above: the corresponding part of the mean error of the mean of the fictitious pendulum-periods is half of the corresponding part of the mean deviation of d.

d is further subject to the effect of the errors of the computations of the reductions to infinitely small amplitude and of the corrections for deviation of isochronism. As has been pointed out in "Theory and Practice o.P.O.a.S.", p. 25, these errors are about the same with opposite sign for the two fictitious pendulums, provided the normal conditions for these pendulums have been realized during the observation viz. equal amplitudes in opposite phases. The consequence is that the errors affect principally the difference d of the fictitious pendulum-periods and only slightly the mean of these periods. If we put again the corresponding part of the mean error of this mean of the periods at half of the corresponding part of the mean deviation of d, we certainly over-estimate this part of the error.

Lastly d is subject to the effect of the instability of the pendulums. If we accept the changes of the periods to have a fortuitous character, we may again put the corresponding part of the mean error of the mean fictitious pendulums-periods at half of the corresponding part of the mean deviation of d. For changes of the middle pendulum, this is even too much; here again the mean of the periods is not affected if the normal swinging conditions of the pendulums have been realized.

Resuming, we see that all the causes of error that have been mentioned, are satisfactorily taken into account if we put the mean error of the mean of the two fictitious pendulum-periods at half of the mean deviation of d. As this mean deviation has been determined at $8\ 10^{-7}$ sec. the mean error is thus found to be $4\ 10^{-7}$ sec.

There are however a few errors that affect the mean period without affecting the difference d. These are the correction for the air-density, that for the tilt of the swinging-plane and that for the rate of the chronometer. The first two errors may be neglected if the barometer is sufficiently checked, the air-density constant determined satisfactorily and if the damped pendulum of the pendulum apparatus that indicates the tilt, has functioned well. These conditions have been fulfilled during the past voyage.

So the only error that has still to be taken into account, is that of the correction for the rate. This may be done by combining the above value of the mean error with half of the mean value of v. This over-estimates the corresponding mean error, because v is not only affected by the rate-irregularities but also by the errors of the derivation of the pendulum-periods from the records, which have already been taken into account above. The errors of the corrections don't affect v.

Secondly, incase v is great, we can often tell which chronometer is responsible for this disagreement of the results by looking at the daily rates of the chronometers. In that case we may give less weight to the value given by the chronometer of which the rate varies most and this diminishes the mean error of the result.

Resuming, we find that the value, found by taking the root of the sum of the squares of half of the mean deviation of d and of half of the mean value of v, is a good and not too favorable estimate of the mean error of the mean pendulum-period, that is used for the deduction of gravity. We thus find for this mean error

$$\sqrt{4^2 + 7^2} = 8.06$$

and for the gravity result

$$m_g = 0.39 \times 8.06 = 3.1 \text{ milligal}$$

V. The Mean Error of the Gravity Result reduced to Sea-Level.

The errors of the reduction of the gravity-result to sea-level can be neglected, as the depth below sea-level and the density of the sea-water are always known accurately.

The correction for the Eötvös effect is, however, liable to errors, dependent on the uncertainty of the data for the East-West component of the sea-current. As an estimate, founded partly on the experience gathered during the cruise in the Indian Archipelago in 1929—1930, I should think that in normal conditions the uncertainty is less than a quarter of a mile per hour, corresponding at the equator to an uncertainty of 1.8 milligal for the gravity-correction. At other latitudes this is more favorable as it is multiplied with the cosine of the latitude. With regard to these figures, it seems not too optimistic to introduce a mean error of 2 milligal for this correction. In exceptional circumstances this had to be increased.

For harbour-stations this error is of course zero.

Resuming, we find for normal stations:

Mean Error for Sea-stations:	3.7 milligal.
Mean Error for Harbour-stations:	3.1 milligal.

These mean errors, as well as all those mentioned in the lists of results of this publication refer to the difference of gravity from the value at the Base-Station De Bilt. The absolute mean error has to be increased by combining these values with the mean error of the gravity at De Bilt, which is 3.1 milligal.

For station Nr. 15 of this voyage the above value of the mean error had to be increased, because the mean error of the determination of the pendulum-periods had been considerably greater.

List of Daily Rates of the chronometers Nardin 2081 and Nardin 212.

Time-signal		Daily Rates	
Date 1926	Greenw. Time	2081	212
28 May	8.04	−2.36	−1.86
29 „	8 04	−2 94	−2.00
30 „	8.04	−2.63	−1.69
31 „	8.04	−2 54	−1.81
1 June	8.04	−2.78	−1.77
2 „	8.04	−2.59	−1.77
2 „	20.04	−2.78	−1.79
3 „	8 04	−2.72	−1.81
3 „	20.04	−2 78	−1.79
4 „	8.04	−2 58	−1.88
4 „	20.04	−2.77	−1.86
5 „	8 04	−2.79	−1:98
5 „	20.04	−2.80	−1.82
6 „	8.04	−2.76	−1.79
6 „	20.04	−2.66	−1 78
Horta			
9 June	20.04	−2.33	−1.84
10 „	20.04	−2.05	−1.83
11 „	8.04	−2.54	−1 86
11 „	20.04	−2.49	−1.77
12 „	8.04	−2.47	−1.81
12 „	20.04	−2.40	−1.64
13 „	8.04	−2.37	−1.60
13 „	20.04	−2.42	−1.41
14 „	8.04	−2.32	−1.48
14 „	20.04	−1.93	−1.50

Time-signal		Daily Rates	
Date 1926	Greenw. Time	2081	212
Las Palmas			
21 June	20.04	−1 82	−1.57
22 „	8.04	−1.82	−1.51
22 „	20 04	−2.09	−1 53
23 „	8.04	−2 14	−1.60
23 „	20.04	−2.04	−1.55
24 „	8.04	−2.12	−1.64
24 „	20.04	−2.11	−1.55
25 „	8.04	−2.17	−1.68
25 „	20 04	−2.12	−1.55
26 „	8.04	−1.94	−1 66
26 „	20.04	−1.93	−1.65
27 „	8.04	−2 13	−1.70
27 „	20.04	−2.06	−1.68
28 „	8.04	−1.96	−1.72
28 „	20.04	−2.11	−1.86
29 „	8.04	−2.07	−1.50
29 „	20.04	−2.18	−1.52
30 „	8.04	−2.11	−1.66
30 „	20.04	−2.04	−1.56
1 July	8 04	−2.20	−1.69
1 „	20.04	−2.08	−1.62
2 „	8.04	−1.96	−1.49
2 „	20.04	−2.12	−1.65
3 „	8.04	−1.99	−1 62
3 „	20.04	−2.22	−1.68
4 „	8.04	−2 01	−1.57
5 „	8.04	−2.03	−1 33
6 „	8.04	−2.09	−1.47
7 „	8.04		

CHAPTER V.

Expeditions of Hr. Ms. K XIII through the Netherlands East Indies.

Nr. 1. June 12 - August 12, 1929.
Nr. 2. October 8 - November 14, 1929.
Nr. 3. January 2 - February 15, 1930.

Preparations and Preliminary Observations.

Apparatus. In the spring of 1928, the upper part of the new pendulum apparatus had been renewed. This reconstruction, made again in the work-shop of the Meteorological Institute at de Bilt by the chief mechanic, Mr. L. M. van Rest, replaced the old recording apparatus, which in 1926 had been combined with the pendulum apparatus. The object of the reconstruction was twofold: to bring the shape of this part into better harmony with the other parts of the apparatus and to introduce a few improvements. The most important were:

The number of guiding rolls for the strip of photographic paper was reduced and accordingly the friction of the movements of the paper was diminished. The light images now strike the paper on a part which is in contact with one of the guiding rolls and in this way a slight tension is already sufficient to keep the paper in place. This reduction of the paper tension favored an improvement of the mechanism for the changing of the speed of the paper movement.

An indicator was introduced for showing the movement of one of the guiding rolls. In this way it would no longer be possible that, because of the paper tearing through or some similar accident, the paper movement would stop without the observer noticing it, as had been the case for two stations during the previous voyage which in this way had been lost.

In order to make it easier to take out the part of the paper that has been recorded, a black cloth arrangement and a paper cutter were introduced. An indicator was fixed up for showing the amount of paper that is still unused.

By reconstructing the little levers that are operated by the chronometers for interrupting the light-rays on every second, the necessary current was brought back to about 40 milliamperes in stead of nearly ten times as much in the old apparatus. This makes it possible to work them without relay, without undue risk for the break-circuits of the chronometers.

The new apparatus was tried in July 1928. On July 12 a series of observations was made in Hr. Ms. Submarine O IX in the roads of the Naval Base Helder, east of the island of Texel. The test was successful, the recording apparatus worked satisfactorily. The mean result for gravity was 981.347. This value is in fair agreement with the value of 981.340, found in 1920 in the neighbouring land-station of Helder at a distance of about 8 Km; a difference of 3 milligal is explained by the difference of latitude and the remaining difference is within the limits of possible gravity differences at this distance and also within the limits of the mean errors of the observations.

In the fall of the same year the writer made an expedition in the West Indies on board of a submarine of the U.S. Navy, the U.S.S. S-21. This expedition was organized by the Navy in cooperation with the Carnegie Institution of Washington. Together 49 stations were occupied in the Gulf of Mexico, the Caribbean, over the Bartlett Deep, the Nares Deep and over adjoining waters. The results were published by the Naval Observatory in Vol. XIII, App. I of its Publications. The Netherlands Geodetic Commission, besides allowing the writer to accept this invitation, consented to lend the apparatus. The writer in making the observations was assisted by Dr. Fred. E. Wright of the Geophysical Laboratory of the Carnegie Institution and by Mr. Elmer B. Collins of the Hydrographic Office. The apparatus gave entire satisfaction and so its actual shape was accepted as final.

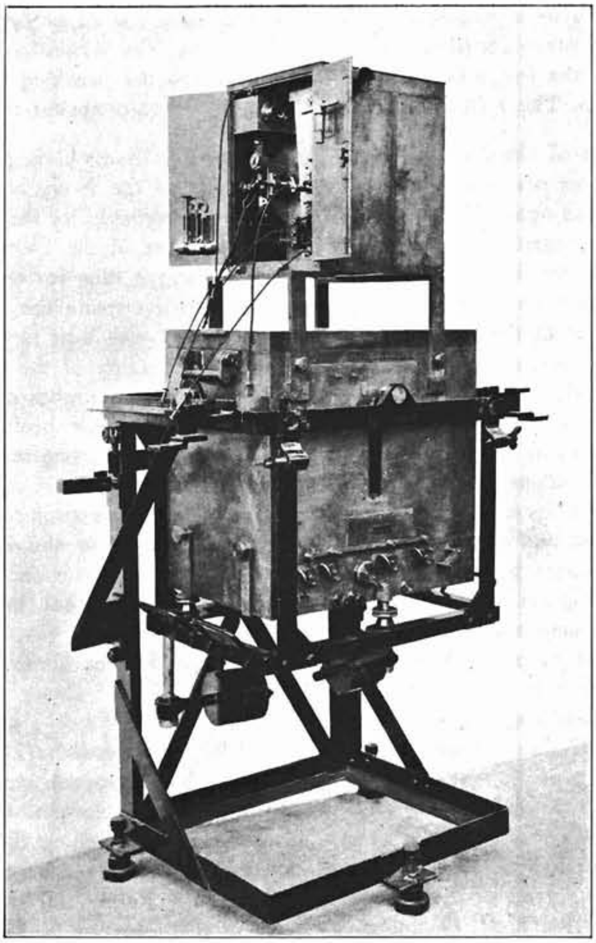
Coming home towards the end of December, the writer took up the preparations for the projected gravity survey of the seas of the Netherlands East Indies, for which the consent given by the Commander of the East Indian Fleet, Vice Admiral Ten Broecke Hoekstra, had opened the possibility.

Base Observations. The base-observations were made at the base-station at De Bilt on March 28 and April 3, 1929. The normal programme was followed, for details of which we may refer to Theory and Practice of P.O.a.S., p. 25 et seq. Five observations of somewhat more than two hours each, were made in a continuous sequence between the rythmic time-signals of Bordeaux at $8.^h01$ and $20.^h01$ Greenwich time. Four of the observations were made with the two outer pendulums having equal amplitudes of about 2 cm on the record and opposite phase and the middle one having no amplitude. The fifth observation, made for getting data about the middle pendulum, was started with the left pendulum having twice as much amplitude as the middle one in the same phase and the right pendulum three times as much in opposite phase. The pendulums were mounted in the normal way: from left to right Nrs. 88, 90, and 89; the two outer ones with the side marked A to the right and the middle one with this side to the left. The apparatus was hanging in the gimbals.

Transportation to the East Indies. On April 8 the apparatus was transported to Amsterdam and shipped aboard the S.S. "Johan de Witt" of the Cy. "Nederland" which left the next day for the Indies. A new gimbal suspension stand was taken along, made by the "Nederlandsche Seintoestellenfabriek" at Hilversum for replacing the old one, which had suffered from use and transportation.

During the voyage to the Indies, observations have been made in the Atlantic and in the Indian Ocean on those days that the sea was sufficiently quiet. Thanks are due to Captain Van Meeuwen and to his Officers for their cooperation. As far as the vibration caused by the ship's engines was concerned, a fairly favourable spot was found in a small room adjoining the executive officer's cabin, but the apparatus was still subject to slight vibrations and their effect was clearly visible in the record of the middle pendulum. Although the records of the fictitious pendulums were undisturbed, some doubt is felt about the reliability of the results and a further investigation will be necessary before a publication of the results is admissible. An exception is made for the observations in the harbours Colombo, Sabang, Belawan and Singapore, of which the results are inserted at the end of the list of stations of this chapter under the numbers 234—237.

With calm sea the observations were usually possible. Still, even in this case the amplitudes of the pendulums were rather irregular and continuous attention was necessary in



Apparatus after reconstruction, hanging in the new gimbal-suspension. The uppert part is the new recording apparatus; the light-box is opened, showing the flexible cords for manipulating the apparatus during the observations.

order to stop the observation when the amplitudes threatened to become too great. It was not easy to predict whether an observation could be made, because unexplained effects came in, giving from time to time greater amplitudes than could be expected considering the state of the sea, and on other occasions the reverse occurred. The writer got the impression that the main cause of the irregularity of the amplitudes was the breaking of the waves against the hull of the ship. The rolling and the pitching of the ship appear to have less effect.

Preparation of the Expeditions. After arrival in Batavia, the program of the coming submarine expeditions was discussed at the Department of the Navy and shortly afterwards finally settled. It was again Hr. Ms. K XIII that was appointed for the work. Sincere thanks are due to the authorities, especially to the Commander of the Fleet, Vice Admiral Ten Broecke Hoekstra, for allotting a submarine for so long a time for this scientific research.

The main problem of the investigations being to determine the relation of gravity to the tectonic activity of the Earth's crust, this view-point was kept in the foreground when the routes and the stations were planned. Where the direction of the tectonic action could be conjectured, profiles were arranged in the direction of the supposed forces, viz. perpendicular to the axes of folding or to the rows of islands. In these profiles the stations were projected at the critical points where the topography showed some marked change, and in general at distances not surpassing 50 or 60 miles. Where the direction of the tectonic activity was doubtful, as for instance east of Celebes, the stations were projected as far as possible over the whole area and at distances not much greater than the above value. Besides the seas of the archipelago, broad adjoining strips of the Indian Ocean and of the Pacific were included in the program. The distribution of the 233 stations that have been occupied is represented on the map accompanying this publication.

The problem to obtain the necessary time signals for the expeditions was solved by the cooperation of the Radio Service of the Netherlands East Indies, the Bosscha Observatory at Lembang (Java) and the Topographic Service. Twice a day, i. e. at $7^h.47$ and at $19^h.47$ Java Time ($= 0^h.27$ and $12^h.27$ Greenwich Time) a rythmic time signal of the same type as that of Bordeaux and of other European stations was emitted on long wave of $\pm$ 8000 m. It was sent out by a pendulum clock at the observatory and a special time service was instituted at this observatory for checking the rates of this clock, of which Ir. Poldervaart, of the Topographic Service, was in charge. Thanks are due to Ir. Van Weelderen, Head of the Radio Service, Colonel Kuiper, Head of the Topographical Service and Prof. Ir. J. H. G. Schepers, Head of the Geodetic Section of this Service as well as to the Director of the observatory, Dr. Voûte, for their cooperation in organizing this time-service, without which the expeditions would have been impossible. The signals could regularly be received and so the rates of the two chronometers, Nardin 212 and Nardin 2081, could be determined with satisfactory accuracy.

Base Observations on Java. For two reasons it was advisable to make secondary base observations on Java. First because of the prospect that in the future gravity observations will be made on the islands, which will supplement the sea observations, and which will be connected with the Indian base-station of Bandung on Java, mentioned in Chapter II. It was therefore desirable to provide a direct connection of the sea observations with this same base-station.

Secondly the gravimetric survey at sea would be made during three separate expeditions, covering together nearly a year, and it appeared risky to trust the constancy of the pendulums without intermediate check over this long time-interval.

A complete series of base-observations have, therefore, been made at the base-station at Bandung in room Nr. 19 of the Technical High-school, i.e. in the same room where the base-observations had been made in 1924. A cable connection with the Bosscha Observatory at Lembang being available, one of the shutters of the recording apparatus could be operated directly by one of the pendulum clocks of this observatory. The other shutter was operated by the chronometer Nardin Nr. 212.

Because of this arrangement, it was not necessary to observe time signals and to make continuous observations in the interval: the rate of the pendulum clock was regular enough for being sure of the rate at all moments of the day. In total, 14 observations of about two hours each have been made, 4 on May 22, 2 on May 23, 3 on May 24 and 5 on May 25. Save for two observations on May 25, made for checking the middle pendulum, for which the amplitudes had the special values mentioned above for De Bilt, all the observations were made in the normal way with the outer pendulums swinging with equal amplitudes and in opposite phase and the middle pendulum without amplitude. The apparatus was hanging in its gimbal suspension. The air pressure was read on a mercury barometer. A check was made on the position of the line of zero tilt on the record and this check agreed well with the position found in De Bilt before departure. The differences of the pendulum periods were likewise in good agreement with the values at de Bilt.

After finishing the observations in Bandung, the apparatus was transported to Surabaya, where the submarine expedition would start. It was put aboard of the K XIII in the beginning of June in the same position as during the expedition of 1926—1927, i. e. in the central control room, hanging against the encasing cylinder of the back periscope.

The First Voyage.

At 8 o'clock of June 12, Hr. Ms. K XIII left Surabaya for the first of the three expeditions, which together would cover 156C0 miles. This first voyage towards the Eastern part of the Archipelago was the longest, nearly 7000 miles, and contained the greatest number of gravity stations, viz. one hundred and five. The staff of the ship was formed by

Lieutenant G. Mante, Captain,
Lieutenant K. van Dongen, Executive Officer,
Lieutenant S. den Boeft, Navigator,
Lieutenant C. van der Linden, in command of the engine-room,
Lieutenant S. P. Visser, second in command of the engine-room.

while the crew consisted of 18 Dutch petty officers and men and 10 native men.

I wish to acknowledge with gratitude the helpful assistance which all the officers of the ship gave me in carrying out the research and I wish to mention with special thanks the kind cooperation of Captain Mante who took great pains in behalf of the investigations. His task was a strenuous one as the number of stations was great and the distance small, so that we had to dive many times and usually three or four times in 24 hours. Moreover the navigation was often troublesome, because our route took us away from the normal shipping routes and brought us several times near coral reefs, while the irregular current conditions in the Archipelago increased the difficulties.

During this first trip we touched the following ports or roadsteads:

Surabaya	dep. 12 June	
Tjempi Bay, Isl. of Sumbawa	arr. 14 June dep. 14 June	Gravity Obs. Nr. 3
Endeh, Isl. of Flores	arr. 19 June dep. 19 June	Gravity Obs. Nr. 14
Kupang, Isl. of Timor	arr. 20 June dep. 21 June	Gravity Obs. Nr. 16
Saumlaki, Isl. of Jamdena (Tenimber Isls)	arr. 25 June dep. 27 June	Gravity Obs. Nr. 26
Tual, Isl. of Nuhu Roa (Key Isls)	arr. 29 June dep. 30 June	Gravity Obs. Nr. 34
Dobo, Aru Isls	arr. 1 July dep. 1 July	Gravity Obs. Nr. 36
Arguni Bay, New Guinea	arr. 2 July dep. 3 July	Gravity Obs. Nr. 39, 40
Banda Neira, Banda Isls	arr. 5 July dep. 8 July	Gravity Obs. Nr. 47
Amboina	arr. 10 July dep. 18 July	Gravity Obs. Nr. 55
Sorrong, W. of New Guinea	arr. 19 July dep. 19 July	Gravity Obs. Nr. 61
Tobelo, Isl. of Halmaheira	arr. 22 July dep. 22 July	Gravity Obs. Nr. 69
Siao, Sangir Isls	arr. 26 July dep. 26 July	Gravity Obs. Nr. 78
Ternate, W. of Halmaheira	arr. 27 July dep. 1 Aug.	Gravity Obs. Nr. 82
Labuha, Isl. of Batjan	arr. 1 Aug. dep. 3 Aug.	Gravity Obs. Nr. 83
Surabaya	arr. 12 Aug.	

In all these ports or roadsteads, observations were made at the surface of the water with the exception of Endeh, Kupang and of the Bay of Siao, where the sea was too rough. The observations at the Islands of Banda Neira and Amboina were made at practically the same spot where observations had been made in 1926 during the expedition of the previous chapter. The exact position of the gravity stations in the harbours is sufficiently indicated by the latitude and longitude data in the list of stations at the end of this publication.

The whole trip was characterized by continuous rough seas and this made it still more strenuous than it would already have been because of the excessive number of divings at all times of day and night. Save on one day in the Misool Archipelago and two days in returning to Surabaya, the hatches in the deck had always to be closed and this increased the stuffiness of the atmosphere inside. No exercise on deck was possible. The trip has been a difficult one for the whole crew and I wish to mention with appreciation the good spirit which continued to reign. A good thing was the diversion created by the numerous islands and shores on our route. Few parts of the world will provide a more beautiful impression than this tropical archipelago, favoured by nature with a luxurious vegetation and in most parts with impressive mountain formations.

Near the island of Serua, an accident happened, which might easily have taken the life of one of the crew. One of the radio-men, Corporal Postema, was swept away by an unexpected wave and thrown overboard. The sea was too rough to allow the lowering of the little shore-boat but by a good chance the life-buoy which was thrown out, came down near him and he could swim towards it. The Captain succeeded in time in bringing the ship near to him and he could be hoisted aboard before the sharks had got hold of him.

For further details about our trip and the harbours that have been touched as well as about the other two expeditions I may refer to a paper in the Geographical Journal of April 1931, which gives an account of our peregrinations.

During the whole expedition and also during the two following ones, sonic soundings have been made by means of the Fessenden apparatus for sonic communication, with which the submarine was provided. During this first trip, however, it was not possible to get echos at the surface of the sea and so soundings were only carried out during submergence. After arrival in Surabaya new microphones were fixed up in the bottom of the ship and since then, soundings were also possible at the surface when the sea was not exceptionally rough.

For the measuring of the echo-time no apparatus was available and so this had to be done with stop-watches. By using special watches, however, indicating 50th of seconds, a satisfactory accuracy could be obtained. For avoiding errors caused by lags in stopping, the sounding was made in the following way. When the sending key of the sonic apparatus was pressed down with one hand, the stop-watch was set going by the other hand. This arrangement ensured the isochronism of both operations up to a few hundredths of a second. When the echo came back, the watch was not stopped, but the dial was read. In this way the observation was practically made in the same way as is done when the fathometer is used. The system worked satisfactorily. Where comparizon with older soundings was possible, the results were in good agreement; no systematic error could be discovered. The soundings have been made by the radio-men.

During a few observations to the south west of the island of Sumba, no soundings could be obtained as no audible echo came back, probably because of a wrong adjustment of the receiving set. This would have meant a serious draw-back for the topographic reduction of these stations, if no help had come from another side. At the same time with the gravity expeditions, the oceanographic expedition of the "Willebrord Snellius" under leadership of

Mr. Van Riel of the Meteorological Institute of De Bilt, was operating in the archipelago and Mr. Van Riel consented kindly to make a special trip for supplying the missing data. In general the great number of soundings, more than 30.000, made by this expedition in the whole eastern half of the Archipelago, have been of great help for the reduction of the gravity observations and for the interpretation of the results.

The positions of the stations and the data for the currents, necessary for the computation of the Eötvös effect, were provided by the officers. Great pains were taken for obtaining as great an accuracy as possible. The assumed uncertainty of all these data was noted down and is given in the list at the end of this chapter and in the final list of positions at the end of this publication.

The time-signals have been observed in the same way as during the previous expedition. The break-circuit of one of the chronometers, Nardin Nr. 2081, was put in series with the telephone of the radio and the appearing and disappearing of the signal was determined. The second chronometer, Nardin Nr. 212, was compared aurally with the first one by means of the method of coincidences. The rates of the chronometers during the first part of this trip have been put together in a table at the end of this chapter; they may give an idea about the rate-fluctuations, which occurred during these expeditions.

The pendulum observations have been made in the normal way. The outer pendulums were started with equal amplitudes in opposite phase and no amplitude was given to the middle one. The observations were continued for half an hour, 5 minutes great paper-speed at the beginning and at the end and 20 minutes slow speed in the middle. The atmospheric pressure was read on the aneroid of the ship in the central control room. This aneroid was checked with a mercury barometer in Amboina, where a correction of — 6.5 mm. was found and in Surabaya after coming back, where a correction of — 5 mm. was obtained. The hair hygrometer, used for determining the humidity in the apparatus was compared from time to time with a psychrometer; its correction varied only with a few percent.

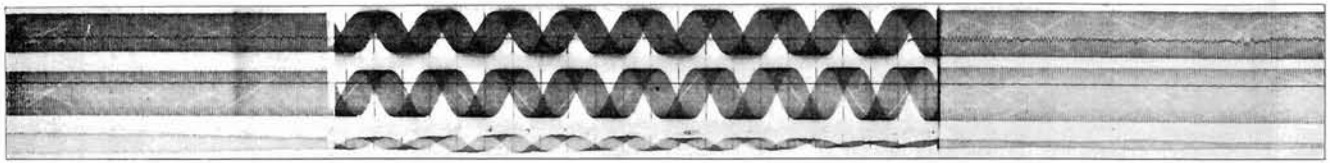
Throughout the whole duration of the research the temperature in the ship has been more stable than during previous expeditions. It has, therefore, never been necessary to heat the apparatus before the observation as had been done during the expedition of 1926 for the reason described on page 62.

At station Nr. 8 and at station Nr. 96, two observations have been made, one in eastward course and one in westward course, for checking the ship's speed for the normal number of revolutions of the screw, 135 per minute, which had been adopted for all the submergencies. The difference of the two observed values for gravity at the same station is due to double the Eötvös effect, corresponding to this speed. It is therefore clear that the speed can be derived from this difference. The result was:

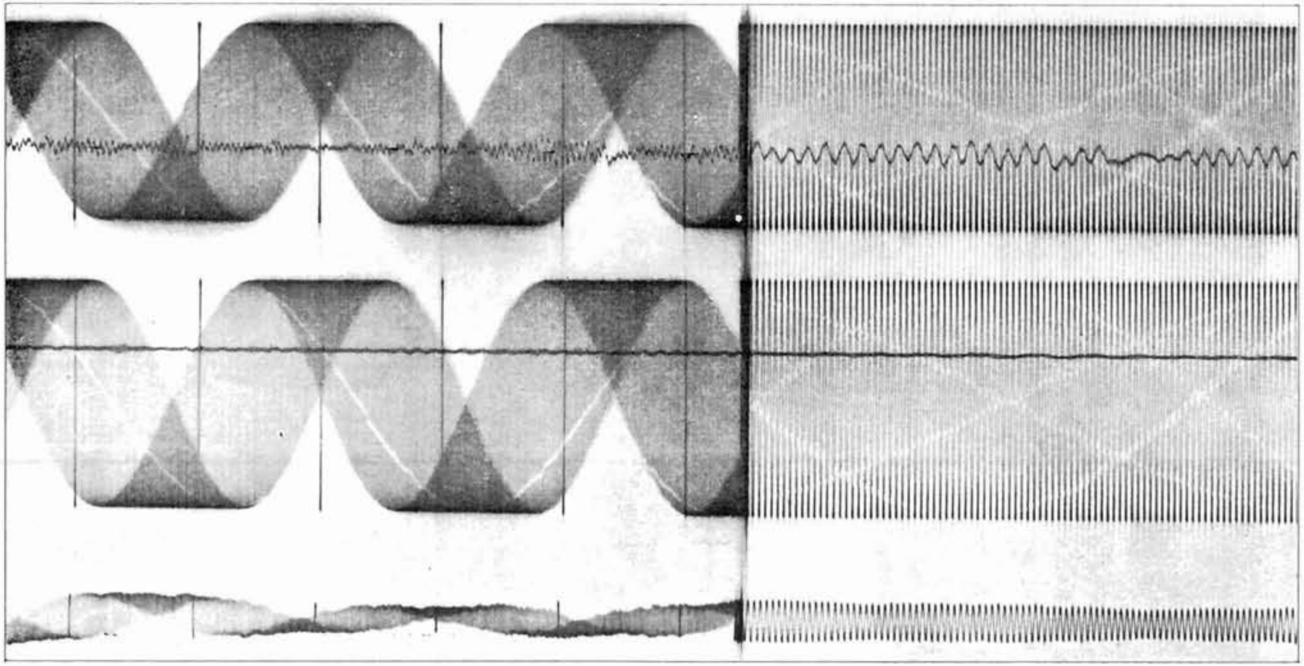
for station Nr. 8: 3.6 knots,
for station Nr. 96: 3.2 knots.

As the ship's bottom was foul in the second case, these values were in good agreement. In connection with later determinations during the next trips, values of 3.8 and 3.3 knots have been accepted for these stations. For the other stations corresponding values were adopted, made up in consideration of the state of the ship's hull during the trip.

At station Nr, 38, two observations were made for checking the effect of the slight



A complete sea-station record of the apparatus in its final shape.



Part ot this record on true scale.

vibrations caused by the refrigerating machine. The second observation was made after stopping this machine. The results were:

refrigerating on:	978.137,
refrigerating off:	978.130.

Taken together with the values found during the next expeditions, we may conclude that no effect can be traced.

At stations Nrs. 25, 53, 83, 95 and 98, two observations were made, one after the other. The spots of these observations were therefore only a few miles apart — incase of Nr. 83, in the harbour of Labuha, at the same spot —, and as the topography of the sea-bottom was regular in all these cases, we may assume that the difference of gravity for each pair of stations is insignificant. The results may, therefore, be used as check on the accuracy of the determinations. The following values of gravity have been found:

Station	Nr. 25	978.136,
		978.142,
Station	Nr. 53	978.055,
		978,056,
Station	Nr. 83	978.175,
		978.169,
Station	Nr. 95	978.145,
		978,150,
Station	Nr. 98	978,179,
		978.182.

Likewise at stations Nrs. 19, 28, 41, 93 and 100 a second observation was made a few miles further than the first one, but in these cases it was done because the topography of the bottom was irregular in order to lessen the uncertainty resulting from the topographic reductions. The values are therefore not immediately comparable.

The observations at the stations of Banda Neira and Amboina give a check on the values found in 1926 which are mentioned in the previous chapter.

Banda Neira	1926	978.274
	1929	978.273
Amboina	1926	978.182
	1929	978.187

The agreement is satisfactory.

At station Nr. 97 a serious accident happened to the pendulums. After finishing the observation, I probably omitted to lift the pendulums from their knife-edges or they got lowered in some other way and so they have been subjected during several hours to the vibrations and the motion of the ship at the surface of the sea. I proceeded at once to a microscopical examination of the knife-edges and no severe damage was found, but still the ultimate computation of the observations showed that two of the pendulums had undergone a change of period. Luckily there is a great probability that the third one has remained constant. The consequences of this accident for the mean errors of the results will be discussed in detail in the next paragraph. Here we will only mention that from this time onward the checks on the periods of the pendulums have been multiplied as far as possible.

The first opportunity occurred in Surabaya where the gravity had already been determined in 1926. Four observations were, therefore, made in this harbour, regularly distributed over a period of twenty-four hours between two time-signals. The time-signal in the middle of this period has also been taken for better check on the four observations.

I further resolved to take the apparatus and the pendulums to Bandung in the interval before the next expedition for checking the pendulum periods also at this base-station. The results of these checks are discussed in the next paragraph; they were fairly satisfactory as far as they showed that the pendulums had regained some constancy of period again, but evidently they had not become quite as stable as they had been before the accident happened.

On Sept. 11, 13, 14 and 15, observations were made, in total 13, in the same room of the Technical High-school where the base-observations of 1924 and of May 1929 had been made. The apparatus was mounted on the foot-screws and all the observations were made with only two pendulums swinging at the same time and with the third pendulum fixed with the amplitude-handle. This arrangement was chosen for obtaining a clearer check on the differences of the periods of the pendulums.

As the middle pendulum had changed so much that the deviation of isochronism had become greater than was desirable, its period was corrected on Sept 18 by screwing a little silver screw in the lower surface of the pendulum-bob. The apparatus was then mounted again in its gimbals and a new set of observations following the normal program for base-observations was started on Sept 19 and continued on Sept 20, 21 and 29. Together 13 observations were made, of which the results are communicated in the next paragraph.

The time-service arrangements for these observations were identical with those of May 1929. On October 1, the apparatus was transported back to Surabaya for the second expedition round the island of Celebes.

The Second Voyage.

On October 2 the apparatus was mounted again on board of Hr. Ms. K XIII in the same way as for the previous voyage. In the evening of Oct. 4, a series of observations was started for further check on the pendulums, but this series had to be given up as the spring of the clock-work for the paper movement in the recording apparatus broke. After putting in a new spring on Oct. 5, the observations were started again. Four observations were made, regularly distributed between the two morning time-signals of 7 and 8 October. The evening time-signal of October 7 was also taken for further check. The observations were made according to the normal program for sea-observations.

An aneroid barometer, borrowed from the Technical High-school in Bandung, was compared with a mercury barometer at the Naval Yard of Surabaya. During the trip, the air-pressure was also read on this barometer as a check on the readings of the aneroid in the central control room. Both aneroids were also compared after the trip.

At 9 o'clock of October 8, the K XIII left Surabaya for the second expedition, covering a route of more than 4000 miles round the island of Celebes, during which gravity was observed at 65 stations. Only slight changes had occurred in the staff and in the crew of the ship: Lt. Van der Linden had left for Holland and the engine-room was now in command of Lieut. S. P. Visser, while Lieut. H. Deutekom took his place as second in command.

During this trip we touched at the following ports or road-steads:

Surabaya	dep. 8 Oct.	
Kolaka (S. E. part of Celebes)	arr. 12 Oct. dep. 13 Oct.	Gravity Obs. Nr. 116
Buton (S. E. of Celebes)	arr. 14 Oct. dep. 15 Oct.	Gravity Obs. Nr. 119
Gorontalo (N. part. of Celebes)	arr. 22 Oct. dep. 24 Oct.	Gravity Obs. Nr. 138
Menado (N. part of Celebes)	arr. 26 Oct. dep. 28 Oct.	Gravity Obs. Nr. 144
Donggala (W. coast of Celebes)	arr. 31 Oct. dep. 1 Nov.	Gravity Obs. Nr. 154
Balikpapan (E. coast of Borneo)	arr. 2 Nov. dep. 4 Nov.	Gravity Obs. Nr. 157
Pare-Pare (W. coast of Celebes)	arr. 6 Nov. dep. 6 Nov.	Gravity Obs. Nr. 163
Makassar (W. coast of Celebes)	arr. 7 Nov. dep. 11 Nov.	Gravity Obs. Nr. 164
Surabaya	arr. 14 Nov.	

The observations in all these ports or roadsteads could be made at the surface of the water. With the exception of Gorontalo two observations were made in each place.

The expedition was favoured by calm seas and so it was usually possible to open the hatches in the lower deck. This means better ventilation in the ship. Besides we could often be on this deck and take some exercise and thus the trip was more agreeable than the first one.

Concerning the observations, we may refer to what has been said for the first expedition. The hair hygrometer of the apparatus was checked several times during the trip with a psychrometer.

Three times, two observations were made at the same spot for checking the speed of the ship during submergence, one observation being made by eastward speed and one by westward speed. The difference of the observed gravity values gives twice the Eötvös effect corresponding to that speed and in this way the speed may be derived. The results were:

Obs. Nr. 110: speed 3.9 knots,
Obs. Nr. 167: speed 3.5 knots.
Obs. Nr. 170: speed 3.7 knots.

The number of revolutions of the screw was always the same during submergence. The value of 3.9 knots was accepted for the speed at the beginning of the expedition when the ship was clean, and the mean of the last two values, i.e. 3.6 knots, was taken for the speed at the end with foul bottom.

Twice a check was made about the effect on the observations of the slight vibrations given by the refrigerating machine. After the normal observation, a second one was made with this machine stopped. The results gave:

Obs. Nr. 137	977.969	refrig. on.
	977.973	refrig. off.
Obs. Nr. 168	978.133	refrig. on,
	978.137	refrig. off.

We may conclude that, within the limits of accuracy, no effect was found.

The results of the double observations in the harbours and roadsteads give a check on the accuracy of the observations. The following values were found:

Station Nr. 116, Kolaka,	978.084
	978.080
Station Nr. 119, Buton,	978.161
	978.167
Station Nr. 144, Menado,	978.208
	978.205
	978.214
Station Nr. 154, Donggala,	978.124
	978.125
Station Nr. 157, Balikpapan,	978.072
	978.070
Station Nr. 163, Pare-Pare,	978.111
	978.120
	978.112
Station Nr. 164, Makassar,	978.140
	978.136

After return in Surabaya, observations were again made for checking the periods of the pendulums. Six observations were regularly distributed over 36 hours between the morning time-signal of 15 November and the evening time-signal of 16 November. The signals of 15 November, evening, and 16 November, morning, were also taken for further check. The last signal was originally meant to close the series, but as the reception was slightly unsatisfactory, the observations were continued till the next signal.

The Third Voyage.

On December 19 the apparatus was brought to the instrument workshop of the Naval Yard in Surabaya for checking the position of the line of zero tilt. After mounting it on the foot-screws, and levelling it, a record was made. On the next days a few observations were made in the same place for checking the difference of the pendulum-periods.

On December 28, the apparatus was mounted again in the K XIII and the usual four checking observations were made in the interval between the morning time-signals of 30 and 31 December. The evening time-signal of 30 December was also taken for improving the accuracy of the check.

At 7 o'clock of the morning of January 2, 1930, the K XIII left Surabaya again for our third expedition round the island of Sumatra, which would finish the program of the research. With the exception of a few changes, of which we wish to mention the replacing of Lieut. H. Deutekom by Lieut. A. Pluim, the staff and the crew of the ship had remained the same since the previous trip. The route covered about 5000 miles and included 62 new stations. We touched at the following harbours or roadsteads:

Surabaya	dep. 2 Jan.	
Tanjung Priok, harb. of Batavia	arr. 4 Jan. dep. 8 Jan.	Gravity Obs. Nr. 176
Benkulen, W. coast of Sumatra	arr. 10 Jan. dep. 10 Jan.	Gravity Obs. Nr. 179
Kantorei Bay, Isl. of Siberut	arr. 14 Jan. dep. 14 Jan.	Gravity Obs. Nr. 190
Padang, W. coast of Sumatra	arr. 14 Jan. dep. 17 Jan.	Gravity Obs. Nr. 192
Sibolga, W. coast of Sumatra	arr. 18 Jan. dep. 18 Jan.	Gravity Obs. Nr. 193
Gunung Sitoli, Isl. of Nias	arr. 19 Jan. dep. 20 Jan.	Gravity Obs. Nr. 195
Sabang, Isl. of Pulu Wai	arr. 24 Jan. dep. 27 Jan.	Gravity Obs. Nr. 207
Belawan, harbour of Medan	arr. 29 Jan. arr. 3 Feb.	Gravity Obs. Nr. 211
Pulu Sambu, near Singapore	arr. 5 Feb. dep. 5 Feb.	Gravity Obs. Nr. 215
Palembang, on Musi River	arr. 8 Feb. dep. 10 Feb.	Gravity Obs. Nr. 223
Tanjung Pandan, Isl. of Billiton	arr. 11 Feb. dep. 12 Feb.	Gravity Obs. Nr. 226
Surabaya	arr. 15 Feb.	

At all these stations the observations could be made at the surface of the water. Save in the Kantorei-Bay and at Pulu Sambu, two observations have been made at each station, while four were made at Tanjung Priok. These last observations were made according to the same schedule as the base observations at Surabaya.

With only a few exceptions, the expedition was favoured by fairly calm weather, but during part of the route through the Indian Ocean, the sea was too rough to open the hatches. For details about this trip we may again refer to the paper in the Geographical Journal of April 1931, which was mentioned in the account of the first trip.

The program of the observations and all other details relative to the pendulum observations, the time-signals or the soundings, were similar to those of former expeditons. The aneroid in the central control room has again been checked before and after the voyage with the mercury barometer of the Naval Yard in Surabaya; in both cases a correction of —6.1 mm was found. The hair hygrometer of the pendulum apparatus was compared three times with a psychrometer, giving a correction of — 2 percent.

Twice a double observation was made for checking the underwater speed of the ship by means of the Eötvös effect. One observation being made with eastward speed and one with westward speed, the difference of the observed values of gravity gives twice the Eötvös effect, from which the speed can be derived. The results were:

Obs. Nr. 185 : speed 3.7 knots,
Obs. Nr. 222 : speed 3.8 knots.

The results for the harbours and stations where more than one observation have been made, are

Station Nr. 176, Tanjung Priok,	978.167
	978.164
	978.163
	978.159
Station Nr. 192, Padang,	978.055
	978.059
Station Nr. 193, Sibolga,	978.047
	978.049
Station Nr. 195, Gunung Sitoli,	978.063
	978.062
Station Nr. 207, Sabang,	978.188
	978.188
Station Nr. 211, Belawan,	978.069
	978.071
	978.074
	978.074
Station Nr. 223, Palembang,	978.119
	978.114
Station Nr. 224,	978.116
	978.112
Station Nr. 226, Tanjung Pandan,	978.086
	978.091

The comparizon of these values gives a check on previous estimates of the accuracy of the observations. The results of the double observation at Benkulen are not mentioned because they cannot be used for this purpose without further investigation; the first observation was made in the harbour, while the second one was made during a submergence after leaving Benkulen at a distance of three miles from the first observation and rapid changes of gravity may be expected in that direction. The same is true for station Nr. 189.

Another check is given by the values found on board of the liner "Johan de Witt" during the trip from Holland to the Indies in the harbours of Sabang and Belawan and by the value for Sabang found in 1923 and the value for Tanjung Priok found in 1927.

Sabang, Station	Nr. 207,	(K XIII)	978.188
	„	(K XIII)	978.188
	Nr. 235,	(J.d.W.)	978.186
	Nr. 29,	(1923)	978.182
Belawan, Station	Nr. 211,	(K XIII)	978.069
	„	(K XIII)	978.071
	„	(K XIII)	978.074
	„	(K XIII)	978.074
	Nr. 236,	(J.d.W.)	978.069
Tanjung Priok, Station	Nr. 176,	(K XIII)	978.167
	„	(K XIII)	978.164
	„	(K XIII)	978.163
	„	(K XIII)	978.159
	Nr. 156,	(1927)	978.170

The slight difference for Tanjung Priok between the value found in 1927 and the mean of the values of this expedition, 978.163, is probably caused by the lack of stability of the pendulums which has been mentioned.

After returning in Surabaya, the usual base-observations have been made according to the normal schedule. The time-signals of 17 February, morning and evening, and of 18 February, morning and evening, were taken and six pendulum observations were distributed regularly over the total time, i.e. two in each interval between two time-signals.

In March the apparatus was transported to Bandung, where it was mounted again in the gravity base-station in room Nr. 19 of the Physical Laboratory of the Technical High-school On 20—23 March twelve observations have been made, i.e. ten according to the normal schedule with the outer pendulums in opposite phase with equal amplitudes and two according to the special schedule for getting data about the middle pendulum. Time was provided again by the Bosscha Observatory at Lembang in the same way as during previous base-observations: one of the pendulum clocks, by means of a special wire, operated one of the shutters of the recording apparatus and so its ticks were directly recorded in the pendulum records.

These observations practically close the gravity research in the Netherlands East Indies. Afterwards the apparatus was used for experiments, which implied a risk of change for the pendulum periods, particularly after the accident that had occurred during the first expedition rendering them more sensitive for damaging effects. This risk has proved to have been real, because the periods, found at De Bilt after returning to Holland, do not agree well with the periods determined at Bandung during the above observations. We will therefore base our computations of the Netherlands-Indian stations, as far as the closing base-station is concerned, on these Bandung base observations and not on the subsequent observations at De Bilt.

We can be short in communicating the events, following on these Bandung observations, because they have no longer any direct bearing on our subject. After finishing the work at Bandung, the apparatus was mounted in an automobile in orde to investigate the feasibility of a method for a quick gravity survey on land. The car was provided with a radio receiving set amplifying the time-signals so much, that they could operate one of the shutters of the recording apparatus. The time-signals were sent out by another pendulum apparatus at the base-station of Bandung by means of a light-ray reflecting on one of the pendulum-mirrors and, in coming back passing over a photo-electric cell, which was coupled with a radio sending apparatus. In this way the swinging of the pendulum at the base-station was recorded directly on the record of the pendulum apparatus in the field and thus the comparizon of both apparatuses was obtained directly without need of a time-service.

Arrangements were made that these pendulum time-signals were sent out twice daily for one hour. When the time for these signals approached, the automobile, containing the pendulum apparatus, stopped, the apparatus was set working without taking it out of the car and the signals were recorded in the record. After finishing, the car drove on to the next station. where the program was repeated when the time for the next set of signals arrived. In this way two stations could be observed daily. The accuracy of these one hour observations proved equal to normal land observations extended over long time intervals. An accuracy of one milligal seemed easily attainable.

Between the observations, the pendulums were left in the apparatus in order not to disturb the temperature conditions. Probably however, the springs in which the pendulums are fixed after lifting them from their knife-edges, were not quite adequate with regard to the heavy movements occurring during the running of the car. The pendulums, at least. showed slight changes of period after coming back to Bandung. It seems easy to take away this difficulty in the future, either by reconstructing the springs, which hold the pendulums in the apparatus, or by making a more adequate support of the apparatus during the transportation so that the severest shocks are taken away.

In the beginning of May the apparatus was brought to Batavia, where it was shipped on board the S.S. "Indrapura" of the "Rotterdamsche Lloyd", with which the writer returned to Holland. During the trip, the apparatus was mounted in the baggage room of this liner and experiments were made. This time the apparatus has been put with the swinging planes of the pendulums parallel to the length-axis of the ship and this arrangement appeared a decided improvement on the position parallel to the beam, which had been adopted for previous observations on board of surface-ships. The amplitudes of the pendulums were, for instance, less irregular than during the experiments made on the liner "Johan de Witt" in 1929. This experience could be explained by the supposition mentioned before, that the main disturbance of the pendulums is caused by the breaking of the waves against the hull, as this effect will evidently be much less in the direction of the length-axis of the ship than in the direction of the beam. Notwithstanding this favourable circumstance, doubt is felt about the reliability of the results, because the ship was even more liable to vibrations than the

„Johan de Witt". Further investigation will be necessary before a conclusion can be drawn. The observations have been made in the Indian Ocean and in the Mediterranean. Thanks are due to Captain Ruhaak and his officers for the facilities accorded in connection with these investigations.

After arriving in Holland the apparatus was brought back to the base-station of De Bilt, where base observations according to the normal schedule for base-stations have been made on July 1 and July 3.

The Computations, the Results and the Mean Errors.

A. The Computations.

The observations have been computed and reduced according to the methods of §§ 1—5 of Chapter III of Theory and Practice of Pendulum Observations at Sea. The periods of the fictitious pendulums were derived with the graphical method of page 78 of this publication, because the computations of the results of the previous voyage had shown that the slight increase of accuracy obtained by the computational method of pages 75 et seq. was not worth while to justify the considerable increase of work brought about by this method. As the computations don't show any special features, I shall refrain from mentioning the details, which can be found in the above publication.

When combining the two means of the reduced fictitious pendulum periods given by the two chronometers, Nardin 212 and Nardin 2081, the arithmetical mean was adopted incase the difference v of these two means was not more than 20 10^{-7} sec. When the difference v was greater, the means were combined with different weights, inversely proportional to the fluctuations of the rates of the chronometers during the three consecutive time-signal intervals preceding, during and following the observation.

When the observation was near a time-signal, the correction for the rate was not made according to the rate during the time-signal interval during which the observation took place but according to an interpolation between this rate and the rate during the adjacent time-signal interval.

The normal system of comparing the reduced pendulum periods at the stations of the voyage with those found at the base-station of De Bilt, had to be modified considerably because of the accident which happened to the pendulums during the first expedition, between station Nr. 97 and station Nr. 98. Up to station Nr. 97, the normal way was followed of comparing the mean of the periods of the fictitious pendulums with the mean of these periods at De Bilt, but this value at De Bilt had to be derived exclusively from the results of the base-observations before the expedition. The following data for the mean of the fictitious pendulum periods: $^1/_2\ (T_{89} + T_{88})$ and for their difference $T_{88} - T_{89} = d$ were available

	$^1/_2\ (T_{89} + T_{88})$	d
28 March 1929	0.5012505 sec.	45 10^{-7} sec.
3 April 1929	0.5012512 „	45 „ „
Adopted value	0.5012509 „	45 „ „

These values were in good agreement with the values found in De Bilt in the beginning of 1929 after returning from the expedition with the U.S. Submarine S—21:

7 January 1929	0.5012511 sec.	42 10^{-7} sec.
8 January 1929	0.5012509 „	43 „ „

As the adopted values of $^1/_2$ $(T_{89} + T_{88})$ and d could not be checked by observations after coming back to Holland, there is a slight risk of a change of the pendulums during the first part of the expedition up to station Nr. 97, but this risk is negligible, first because the values of the difference d found during this part, are in good agreement with the above value and secondly because pendulum Nr 89 did not show any change when coming back to Surabaya after the first expedition, so that we may not only conclude that it was not affected by the accident, but also that it had undergone no change during the preceding part of the trip.

For the stations of the first expedition, following the accident, i. e. the stations Nrs. 96—105, the fact of pendulum Nr. 89 not having been affected was made use of. Pendulums Nrs. 88 and 90 not only showed a change of period after the accident, but evidently their periods were not even constant during the first days afterwards. In these circumstances the values of these periods were not used at all and the result for the gravity at these stations was exclusively derived from pendulum Nr. 89. This was done by computing the value for the mean period $^1/_2$ $(T_{89} + T_{88})$ by adding half of the normal value of $T_{88}—T_{89}$, i. e. 22.5 10^{-7} sec, to the period T_{89} of the first fictitious pendulum.

For applying the corrections for deviation of isochronism, we have to know the differences of the period of the middle pendulum, Nr. 90 with those of the others. For the stations up to Nr. 97 I could use the values found in De Bilt on March 28 and April 3 by means of the special observations made for checking this pendulum. They gave

$$T_{90} - T_{89} = + 34 \quad 10^{-7} \text{ sec.}$$
$$T_{90} - T_{88} = - 11 \quad 10^{-7} \text{ sec.}$$

which corresponds to the following formula for the differences of the periods at atmospheric pre sure and at a temperature t°

$$U_{90-89} = + 30 - 0.16\ t^\circ\ 10^{-7} \text{ sec.}$$
$$U_{90-88} = - 8 + 1.03\ t^\circ\ 10^{-7} \text{ sec.}$$

The data obtained for these differences during the observations at Bandung in May 1929 agreed with these values up to a few unities of the 7th decimale place *), and so these values were adopted.

For the stations Nrs. 96—105 following on the accident the only available figures for U_{90-89} were those determined after arrival in Surabya. This brings about some uncertainty as it is questionable whether pendulum Nr. 90 was at once stable after undergoing the change; for pendulum Nr. 88 this was certainly not the case and Nr. 90 had changed its period considerably more than Nr. 88. This uncertainty cannot be taken away and so the gravity results for these stations must be considered to be less accurate than the others. This point has been taken into account for deducing the mean errors mentioned in the list at the end of this volume.

*) In Bandung was found $T_{90} - T_{89} = + 38\ 10{-}^7$ sec.
$T_{90} - T_{88} = - 14\ 10{-}^7$ sec.

The values for the differences of the pendulum periods were found in Surabaya to be

$$T_{88} - T_{89} = + \ 18 \quad 10^{-7} \text{ sec.}$$
$$T_{90} - T_{89} = - \ 179 \quad 10^{-7} \text{ sec.}$$
$$T_{90} - T_{88} = - \ 197 \quad 10^{-7} \text{ sec.}$$

which gives for the differences at atmospheric pressure and temperature t°:

$$U_{90-89} = - \ 183 - 0.16 \ t^{\circ}$$
$$U_{90-88} = - \ 194 + 1.03 \ t^{\circ}$$

After the accident I resolved to adopt a new base-station for the next two expeditions. For this new base-station I took Surabaya checked by observations at Bandung. At Surabaya three observations had been made in 1926 and 1927, communicated in the preceding chapter. which were in good harmony. At Bandung the results of two long series of observations were available, one made in 1924 with a set of invar pendulums and one made in May 1929, anterior to the first expedition, with the same pendulums as had been used for the expedition. The results of the two sets don't agree as perfectly as might be expected when looking at the series themselves. The figures for Surabaya and for Bandung were

	Surabaya		Bandung
15 December, 1926	978.138	January, 1924 (invar)	977.981
16 December, 1926	978 135	May, 1929 (brass)	977.988
3 February, 1927	978.137	Adopted value	977.988
Adopted value	978.137		

According to the discussions of the mean errors in the preceding chapter, the mean error of each value in Surabaya is 3.1 milligal and so the adopted value has a mean error of 1.8 milligal, which seems acceptable when looking at the mutual agreement.

For Bandung the mean error of each value ought to be less than one milligal but the two results show a much greater difference. Probably we have to look for the cause of this lack of agreement in some irregularity of the invar pendulums, which may have been brought about by molecular changes or by magnetic influences. As the brass pendulums are immune for both effects, the result given by these pendulums has heen adopted and the other value has been neglected. The comparizons between Surabaya and Bandung in 1929 and 1930 have confirmed this view.

In order to make the computations more uniform and to get a better insight in the pendulums, the base-observations of the pendulums at Surabaya and at Bandung have all been brought back to the original base-station of De Bilt, that is to say that the adopted gravity difference with De Bilt was used for computing the periods of the pendulums which would have been found at De Bilt if the base-observations had been made there. These adopted gravity differences were, according to the above values for Surabaya and for Bandung:

De Bilt — Surabaya: 3131 milligal
De Bilt — Bandung: 3280 milligal

In this way the following set of values have been found for the periods at De Bilt of the pendulums Nrs. 89 and 88 and for their mean value and their difference d

Observation Station	Date	T_{89}	T_{88}	$\frac{1}{2}(T_{89}+T_{88})$	d	Number of Obs
De Bilt	28 March/13 April 1929	0.5012487	0.5012532	0.5012509	45 10^{-7} sec.	10
Surabaya	12/13 Aug. 1929	0.5012488	0.5012506	0.5012497	18 „ „	4
Bandung	Sept. 1929	0.5012484	0.5012492	0.5012488	8 „ „	13
Surabaya	7/8 Oct. 1929	0.5012474	0.5012504	0.5012489	30 „ „	4
Surabaya	15/16 Nov. 1929	0.5012470	0.5012500	0.5012485	30 „ „	6
Surabaya	30/31 Dec. 1929	0.5012457	0.5012496	0.5012476	39 „ „	4
Surabaya	17/18 Febr. 1930	0.5012448	0.5012481	0.5012464	33 „ „	6
Bandung	20—23 March 1930	0.5012461	0.5012473	0.5012467	12 „ „	8

The last column gives the number of pendulum observations from which these values have been deduced.

Evidently the pendulums had not quite recovered their original stability but the variability was small and so the resulting uncertainty for the observations of the second and third expeditions is not great. For the second expedition from October 8 till November 14, 1929, a mean value for the fictitious pendulums at De Bilt was adopted of 0.5012487 and for the third expedition from January 2 till February 15, 1930, a value of 0.5012470. The values for the differences d of the two fictitious pendulums found during the expeditions at the different stations were in fair agreement with the above values for d and so we may feel practically sure that no serious fluctuations of the pendulum periods did occur.

The comparizon of the figures of the first two lines shows that pendulum Nr. 89 has not undergone a change of period during the first expedition. As has already been mentioned, this fortunate fact furnished the possibility to save the last stations of this trip subsequent to the accident which befell the pendulums.

The comparizon of the values found in Surabaya and in Bandung shows the truth of the statement that the adopted values of the gravity for those two stations are in good agreement, which would not have been the case if the value for Bandung given by the invar pendulums had been used.

The period of the third pendulum, Nr. 90 had been so much disturbed by the accident, that I resolved to isochronize it again with the other pendulums before starting for the next expedition. This was done in Bandung, in September 1929, by screwing a small silver screw in the bottom of the pendulum-bulb. It continued to show greater fluctuations than the other pendulums, but as this pendulum has no perceptible effect on the result for gravity because its effect on the period of one fictitious pendulum approximately balances its effect on the other, this is not serious (see pag. 24 of Theory and Practice of Pend. Obs. a. S.). For the second expedition the following formulas for the differences of the periods were used for the correction for deviation of isochronism

$$U_{90-89} = -64 - 0.16\,t^{\circ}$$
$$U_{90-88} = -84 + 1.03\,t^{\circ}$$

These values were derived from the differences d of the two fictitious pendulum periods by the method mentioned in the preceding chapter on page 52. This method deduces the values for U, which make the deviation of d from its normal value as small as possible. The difference of the two values of U must, of course, remain compatible with the difference of the periods of Nr 89 and Nr 88.

For the third expedition, new formulas had to be used because pendulum Nr. 90 had changed again in the interval. During this last trip, however, this pendulum remained constant. When reducing the values of its period found in Surabaya before and after this expedition to De Bilt in the same way as we did already for the other pendulums, the following values are found:

Before the expedition: 0.5012431
After the expedition: 0.5012429

From these values the following formulas for the differences from the other pendulum periods at atmospheric pressure and temperature t° are derived

$$U_{90-89} = -30 - 0.16\, t^{\circ}\ 10^{-7} \text{ sec.}$$
$$U_{90-88} = -63 + 1.03\, t^{\circ} \quad ,, \quad ,,$$

These formulas were used for the correction for deviation of isochronism of the observations of the third expedition.

The results of all the expeditions have been put together in the following table, giving consecutively the Nr. of the station, the date, the depth below sea-level at which the observation was made, the change of the temperature during the observation in centigrades as given by the thermometer of the apparatus, the factors of U_{90-89} and of U_{90-88} in the formula for the correction for deviation of isochronism, the differences d of the reduced periods of the fictitious pendulums, the differences v between the means of the fictitious pendulum periods given by chronometer Nardin 212 and those given by chronometer Nardin 2081, the W—E component of the current, used for the computation of the Eötvös effect and the mean error of this component, and lastly the value of gravity reduced to sea-level and the mean error of this value.

The temperatures of the central control room and of the apparatus have been more stable during these expeditions than during previous ones, and so I can refrain from giving further indications about them.

The geographical positions of the stations with the mean errors of these positions are given in the synopsis at the end of this volume. In this list the station-numbers of the voyage are mentioned behind the numbers of the list. For those stations where more than one observation has been made, the results have been combined in one value and the list of mean errors gives the error of this combined value. The results found at Banda, Amboina, Tanjung Priok and Sabang have been combined with those of previous expeditions. The sea-depths, determined during the voyage by echo-soundings, will be given in Vol. II of this publication.

The gravity results have been computed with a value of g for De Bilt of 981.268.

Results of the Gravity Observations in the Netherlands East Indies.

Nr.	Date, 1929 / Harbours	Depth Observ.	Change Temp.	Factor $U_{90\ 89}$	Factor $U_{90.88}$	d	v	Current W-E comp.	Current mean error	g_0	m_g
		m	°			10^{-7} sec.		naut. miles			m.gal
1	13 June	18	+0.16	−0.147	+0.144	41	− 2	0.0	0.3	978.147	4
2	14 „	18	+0.05	−0.156	+0.141	38	3	+1.1	0.1	978.244	3
	Tjempi Bay										
3	14 June	2	−0.02	+0.299	−0.390	65	− 4	0.0	0.0	978.256	3
4	15 „	18	+0.00	−0.110	+0.126	60	− 3	0.0	0.3	978.194	4
5	15 „	28	+0.00	+0.159	−0.164	55	−36	0.0	0.4	978 076	4
6	16 „	18	+0.01	0.085	+0.097	55	−18	0.0	0.4	978.211	4
7	16 „	18	+0.08	+0.147	−0.146	36	+19	0.0	0.5	978.303	5
8A	16 „	18	+0.00	+0.047	+0.061	46	−18	0.0	0.4	978.327	4
8B	16 „	18	+0.11	0.245	+0.209	48	−18	0.0	0.4	978.323	4
9	17 „	18	+0.07	+0.010	−0.010	42	+26	−1.3	0.5	978.291	5
10	17 „	18	−0.05	−0.073	+0.091	38	+26	−1.3	0.5	978.133	5
11	18 „	18	+0.05	+0.065	−0.077	59	−20	−0.5	0 3	978.325	4
12	18 „	18	+0.00	+0.180	0.201	48	+ 7	−0.5	0.2	978.182	3
13	19 „	18	−0.07	−0.059	+0.058	51	+ 2	−0.5	0.2	978.148	3
	Endeh										
14	19 June	18	+0.09	+0.022	0.025	45	− 1	0.0	0.3	978.231	4
15	20 „	18	−0.05	−0.130	+0.095	40	− 2	−0.5	0.3	978.065	4
	Kupang										
16	20 June	10	+0.05	+0.299	−0.252	70	− 3	−0.6	0.2	978.179	3
17	21 „	18	+0.01	0 128	+0.100	52	+ 3	0.0	0.4	978.160	4
18	21 „	18	−0.05	−0.045	+0.049	52	+ 4	−0.8	0.4	978.104	4
19A	21 „	18	+0.05	+0.006	+0.015	48	− 9	−1.0	0.4	978.238	4
19B	21 „	18	+0.05	−0.140	+0.125	40	+20	−1.0	0.4	978.250	4
20	22 „	18	+0.01	−0.025	+0.021	56	− 1	−0.4	0.2	978.247	3
21	23 „	18	+0.04	0.349	+0.268	44	−13	−0.7	0.2	978.081	3
22	23 „	18	+0.05	+0.025	−0.063	52	+ 7	−1.3	0.3	978.106	4
23	23 „	18	+0.09	+0.072	−0.045	60	20	0.0	0.5	978.092	5
24	25 „	19	+0.02	−0.006	+0.043	48	−17	0 0	0.5	978.239	5
25A	25 „	19	+0.11	+0.185	−0.281	57	+ 8	1.6	0.5	978.136	5
25B	25 „	18	+0.04	−0.101	−0.036	55	− 8	−0.9	0.5	978.142	5
	Saumlaki										
26	25 June	2	+0.00	−0.078	+0.076	48	−10	0.0	0.0	978.133	3
27	27 „	18	+0.13	+0.057	0.060	52	−23	−0.1	0.2	978 097	3
28A	28 „	18	−0 04	+0.028	−0.006	52	− 11	−0.2	0.2	978.070	3
28B	28 „	18	−0.02	+0.134	−0.177	62	− 5	−0.2	0.2	978 052	3
29	28 „	18	+0.02	−0.130	+0.105	42	+16	0.0	0.2	978.233	3

Nr.	Date, 1929 / Harbours	Depth Observ.	Change Temp.	Factor $U_{90\,89}$	Factor $U_{90\,98}$	d	v	Current W-E comp.	Current mean error	g_0	m_g
		m	°			10^{-7} sec.		naut. miles			m.gal
30	28 June	18	+0.02	+0.011	−0.014	52	+ 2	−0.2	0.2	978.170	3
31	28 „	18	+0.00	+0.029	+0.005	50	−16	−0.2	0.2	978.157	3
32	29 „	18	+0.00	+0.190	−0.230	60	− 2	0.0	0.3	977.853	4
33	29 „	18	+0.04	+0.039	−0.050	60	+14	0.0	0.2	978.066	3
	Tual										
34	29 June	2	+0.18	+0.165	−0.204	64	+ 1	0.0	0.0	978.157	3
35	1 July	18	+0.01	−0.005	+0.006	42	−38	−0.3	0.2	977.946	3
	Dobo										
36	1 July	2	+0.10	+0.027	−0.024	66	+18	0.0	0.0	978.159	3
37	1 „	18	−0.03	+0.073	−0.064	42	+11	0.0	0.2	978.044	3
38A	2 „	9	+0.02	+0.145	−0.118	72	+ 5	0.0	0.0	978.137	3
38B		9	+0.06	+0.061	−0.094	58	−14	0.0	0.0	978.130	3
39	2 „	2	+0.13	−0.265	+0.353	43	+ 3	0.0	0.0	978.109	3
40	2 „	2	+0.01	+0.071	−0.085	50	− 6	0.0	0.0	978.105	3
41A	3 ,	11	−0.02	−0.269	+0.291	38	+ 5	−0.3	0.2	978.189	3
41B	3 „	18	+0.01	−0.077	+0.077	40	− 4	−0.4	0.2	978.169	3
42	4 „	18	+0.03	−0.034	+0.037	42	−18	0.0	0.2	978.051	3
43	4 „	11	+0.03	+0.022	−0.041	46	+ 2	−0.5	0.2	978.112	3
44	4 „	18	+0.09	+0 007	−0.014	52	−15	0.0	0.2	978.006	3
45	4 „	18	+0.00	−0.019	+0.022	42	+ 3	0.0	0.2	978.120	3
46	5 „	18	+0.15	−0.045	+0.074	38	−36	−0.2	0.2	978.154	3
	Banda Neira										
47	5 July	2	+0.17	−0.034	+0.041	42	− 5	0.0	0.0	978 273	3
48	8 „	23	+0.13	−0.016	−0.037	54	−18	0.0	0.3	978.056	4
49	8 „	23	−0.01	−0.062	+0.063	42	−15	0.0	0.2	978.053	3
50	9 „	18	+0.21	−0.058	+0.059	40	−12	−0.3	0.4	978.002	4
51	9 „	18	+0.12	−0.031	+0.024	40	−10	−0.3	0.3	978.121	4
52	9 „	11	+0.13	+0.179	−0.200	41	+ 2	0.0	0.2	978.137	3
53A	9 „	11	−0.02	−0.053	+0.054	41	+ 4	0 0	0.2	978.055	3
53B	9 „	18	−0.04	+0.073	−0.044	52	− 8	0.0	0.2	978.056	3
54	10 „	18	−0.01	+0 043	−0 061	48	+ 2	0.0	0.3	977.896	4
	Amboina										
55	10 July	2	+0.06	−0.311	+0.263	52	− 2	0.0	0.0	978.187	3
56	18 „	11	+0.09	+0.104	−0.108	57	+ 8	−0.3	0.3	978.100	4
57	18 „	18	+0.02	−0.034	+0.027	45	−18	−0.5	0.3	978.121	4
58	18 „	18	+0.00	−0.023	+0.019	47	− 4	−1.0	0.3	978.057	4
59	19 „	11	+0.00	−0.263	+0.264	52	−26	−1.2	0.3	978.062	4
60	19 „	11	+0.00	−0.006	+0.011	44	+ 2	−1.7	0.4	978.117	4

Nr.	Date, 1929 / Harbours	Depth Observ.	Change Temp.	Factor $U_{90.89}$	Factor $U_{90.88}$	d	v	Current W-E comp.	Current mean error	g_0	m_g
		m	°			10^{-7} sec.		naut. miles			m.gal
	Sorrong										
61	19 July	2	+0.06	−0.124	+0.140	50	+15	0.0	0.0	978.143	3
62	20 „	1	+0.10	+0.053	−0.052	44	+18	0.0	0.4	978.013	4
63	20 „	18	+0 04	−0.003	+0.045	52	+13	0 0	0.1	978 168	3
64	21 „	19	−0.07	−0.016	+0.039	49	−10	0 0	0.1	978.101	3
65	21 „	18	+0.00	−0.048	+0.053	40	−15	0.0	0.1	978.166	3
66	21 „	18	+0.00	−0.089	+0.110	37	− 5	0.0	0.3	978.511	4
67	22 „	18	+0 00	+0.126	−0 117	49	− 2	−0.3	0.3	978.112	4
68	22 „	11	+0 15	+0.036	−0.047	57	+ 1	0.0	0.3	978 079	4
	Tobelo										
69	22 July	2	+0.04	−0 116	+0.123	36	+ 7	0.0	0.0	978.144	3
70	23 „	11	+0.01	+0.151	−0.122	52	− 5	−1.9	0.7	978.170	6
71	23 „	18	+0.04	+0.117	−0 134	47	− 2	0.0	0.4	978.081	4
72	24 „	18	−0.01	+0.120	−0.072	48	−31	−1.5	0.6	978.113	5
73	24 „	18	−0.01	+0.194	−0.244	68	− 6	+2.0	0,6	978.108	5
74	24 „	18	0.00	−0.278	+0.203	42	− 2	+1 6	0.6	978.015	5
75	25 „	18	+0.04	−0 071	+0.066	51	+14	−0.1	0.3	978.046	4
76	25 „	18	+0 01	−0.006	+0.006	48	−11	+0.9	0.4	978.097	4
77	26 „	18	+0.00	−0.119	+0.130	38	−27	+0.9	0.4	978.276	4
	Siao										
78	26 July	11	+0.14	−0.248	+0.248	41	−13	0.0	0.1	978.258	3
79	27 „	18	−0.04	+0.040	−0.046	58	+ 8	0.0	0.2	977.975	3
80	27 „	18	−0.01	−0.030	−0.006	60	− 5	+2.3	0.7	977.877	6
81	27 „	18	+0.01	+0.007	−0.043	51	+12	0.0	0.3	978.094	4
	Ternate										
82	27 July	2	+0.06	+0.136	−0.160	45	−38	0.0	0.0	978.187	3
	Labuha										
83A	1 Aug	2	+0 02	−0 039	−0.123	40	+45	0.0	0.0	978.175	3
83B	1 „	2	+0.04	−0.120	+0.117	48	+10	0.0	0.0	978.169	3
84	3 „	18	+0 00	−0.111	+0.101	36	+ 2	0.0	0.2	977.835	3
85	4 „	18	−0 01	−0.242	+0.213	36	−18	0.0	0.2	977.961	3
86	4 „	11	+0.06	+0.159	−0.155	46	− 6	0.0	0,2	978.290	3
87	4 „	18	+0.00	−0.009	+0.009	46	−17	0.0	0.2	978.127	3
88	5 „	18	−0.01	0.072	+0,071	48	− 8	−1.2	0.5	978.103	5
89	5 „	18	+0 05	−0 069	+0.065	22	− 4	−0.8	0.3	978.072	4
90	5 „	11	+0.12	+0.197	−0.225	55	− 8	0.0	0.2	978.120	3
91	6 „	18	+0.01	+0.005	+0.015	36	−14	0.0	0 3	978.096	4

Nr.	Date, 1929 / Harbours	Depth Observ.	Change Temp.	Factor $U_{90.89}$	Factor $U_{90.88}$	d	v	Current W-E comp.	Current mean error	g_0	m_g
		m	°			10^{-7} sec.		naut. miles			m.gal
92	6 Aug.	18	+0.09	+0.094	−0.110	46	+15	−0.4	0.3	978.122	4
93A	6 „	18	−0.01	+0 411	−0.420	64	− 7	0.0	0.3	978.120	4
93B	6 „	18	+0,05	+0.180	−0.201	40	−12	0.0	0.3	978.147	4
94	7 „	18	+0.00	−0.127	+0.176	44	−18	−0.3	0.3	978.133	4
95A	7 „	18	+0.01	+0.123	−0.129	54	+ 7	0.0	0.2	978.145	3
95B	7 „	18	+0.08	+0.167	−0.195	54	− 4	0.0	0.2	978.150	3
96A	7 „	18	+0.01	+0.015	+0.021	42	−15	+0.2	0.3	978.155	4
96B	7 „	18	+0.06	+0.186	−0.157	47	−14	+0.2	0.3	978.157	4
97	8 „	11	+0.09	−0.059	+0.059	60	+13	+0.5	0.3	978.151	4
98A	8 „	18	+0.00	+0.089	−0.094	−67	−15	0.0	0.2	978.179	5
98B	8 „	18	+0.00	+0.032	−0.032	−71	−15	0.0	0.2	978.182	5
99	9 „	18	−0.07	+0.243	−0.173	− 5	+11	0,0	0.2	978.154	5
100A	9 „	11	+0.09	+0 014	−0.013	3	+24	+0.6	0.2	978.199	5
100B	9 „	11	+0.07	−0.080	+0.077	15	+18	+0.6	0.2	978.221	5
101	9 „	11	−0.03	+0.385	−0.393	3	+24	+0.6	0.2	978.166	5
102	10 „	18	0.00	−0.010	+0.010	0	+ 0	+0.3	0.2	978.024	5
103	10 „	11	+0.06	−0.060	+0.013	− 1	−14	−0 7	0.3	978.267	6
104	10 „	18	+0.02	−0.120	+0.120	4	−20	−1.0	0.5	978.045	6
105	10 „	18	−0.08	+0 066	−0.062	5	+10	−1.0	0.4	978.105	6
106	8 Oct.	18	+0.04	+0.095	−0.079	38	−13	−0.9	0.2	978.141	4
107	9 „	9	+0.12	−0.060	+0.067	21	−19	−0.4	0.2	978.178	4
108	9 „	18	−0.02	+0.036	−0.046	34	−18	−0.4	0.2	978.154	4
109	10 „	18	−0.01	+0.189	−0.188	19	+ 2	−0.4	0.2	978.156	4
110A	10 „	10	+0.02	−0,044	+0.055	36	−23	−0.6	0.1	978.162	3
110B	10 „	18	+0.03	−0.047	+0.057	32	− 9	−0.6	0.1	978.162	3
111	11 „	18	−0.04	+0.073	−0.069	27	−61	+0.0	0.2	978.108	6
112	11 „	9	+0.01	−0.290	+0.266	38	− 7	+0.0	0.2	978.171	4
113	11 „	9	+0.16	−0.040	+0.040	20	−12	+0.1	0.2	978.179	4
114	11 „	18	−0.10	+0.008	−0.009	22	+ 9	−0.4	0.4	978.029	5
115	12 „	18	−0.03	−0,010	−0.010	24	−15	−0.4	0.4	978.017	5
	Kolaka										
116A	12 Oct.	2	+0.04	−0.260	+0.290	39	+30	0.0	0.0	978.084	3
116B	12 „	2	+0.04	−0.011	+0.013	24	− 8	0.0	0.0	978.080	3
117	13 „	18	+0.00	−0.040	+0.034	24	+31	0 0	0.2	978.116	4
118	14 „	18	−0.05	+0.062	−0.068	19	−12	−0.4	0.3	978.139	4
	Buton										
119A	14 Oct.	2	+0.09	−0.048	+0.010	32	− 9	0.0	0.0	978.161	3
119B	14 „	2	−0.01	−0.015	+0.013	28	+16	0.0	0.0	978.167	3
120	15 „	18	+0.08	−0.040	+0.039	36	+30	0.0	0.2	978.134	4
121	16 „	18	−0.14	+0.110	−0.109	30	+28	−0.3	0.2	978.186	4

Nr.	Date, 1929 / Harbours	Depth Observ.	Change Temp.	Factor $U_{90\,89}$	Factor $U_{90\,98}$	d	v	Current W-E comp.	Current mean error	g_0	m_g
		m	°			10^{-7} sec.		naut. miles			m gal
122	16 Oct.	18	−0.01	−0.169	+0.162	16	− 2	−0.8	0.4	978.094	5
123	16 „	18	−0.11	−0.054	+0.050	20	− 5	0.0	0.2	978.115	4
124	17 „	20	−0.01	+0.100	−0.088	14	−10	−0.6	0.3	978.143	4
125	17 „	18	+0.08	+0.055	−0.046	22	+36	−0.9	0.3	978.100	4
126	18 „	18	+0.06	−0.075	+0.089	28	+ 7	0.0	0.2	978.167	4
127	18 „	18	−0.02	−0.035	+0.036	30	+23	−0.4	0.3	978.051	4
128	18 „	18	−0.04	+0.170	−0.202	11	− 8	−0.3	0.3	978.014	4
129	19 „	18	+0.00	−0.005	+0.005	22	+27	+0.4	0.2	978.033	4
130	19 „	18	−0.06	−0.027	+0.028	34	−14	0.0	0.2	978.125	4
131	20 „	18	+0.05	+0.119	−0.117	22	+34	+0.3	0.2	977.867	4
132	20 „	9	+0.13	+0.003	−0.003	18	+ 3	0.0	0.2	978.003	4
133	20 „	18	+0.07	−0.171	+0.187	29	−15	0.0	0.2	978.051	4
134	21 „	18	−0.03	+0.049	−0.045	18	+12	0.0	0.1	978.020	3
135	21 „	18	+0.01	+0.006	−0.006	31	+26	0.0	0.2	978.008	4
136	21 „	18	+0.06	−0.049	+0.055	24	+ 6	+1.0	0.3	978.066	4
137A	22 „	18	−0.10	−0.044	+0.045	24	+12	+0.4	0.2	977.969	4
137B	22 „	18	−0.09	+0.025	−0.025	24	+ 4	+0.4	0.2	977.973	4
	Gorontalo										
138	22 Oct.	2	+0.00	+0.125	−0.053	40	− 1	0.0	0.0	978.140	3
139	24 „	18	+0.03	+0.160	−0.153	20	−13	+0.5	0.3	977.942	4
140	25 „	18	−0.09	−0.037	+0.036	23	− 4	+0.4	0.3	978.166	4
141	25 „	18	+0.09	+0.203	−0.227	17	+ 8	+0.2	0.2	977.967	4
142	25 „	18	+0.10	+0.070	−0.059	33	+40	−0.3	0.3	978.077	4
143	26 „	18	−0.08	−0.025	+0.027	18	+ 2	+1.4	0.3	978.191	4
	Menado										
144A	26 Oct.	2	+0.11	+0.011	−0.011	27	−19	0.0	0.0	978.208	3
144B	26 „	2	+0.08	+0.036	−0.022	40	−28	0.0	0.0	978.205	3
144C	26 „	2	−0.05	+0.012	−0.012	24	−16	0.0	0.0	978.214	3
145	28 „	18	+0.16	−0.033	+0.036	32	+46	−0.2	0.2	978.127	5
146	28 „	18	+0.03	−0.230	+0.223	28	− 7	−0.1	0.3	978.034	4
147	29 „	18	−0.01	−0.057	+0.057	32	−36	0.0	0.2	978.092	4
148	29 „	18	−0.02	+0.148	−0.146	34	− 2	0.0	0.2	978.058	4
149	30 „	10	+0.00	−0.090	+0.086	30	−26	+1.2	0.3	978.193	4
150	30 „	18	+0.00	+0.024	−0.018	34	+14	−0.6	0.2	978.007	4
151	31 „	18	−0.11	−0.005	+0.005	30	− 5	+2.2	0.5	978.122	5
152	31 „	18	+0.03	−0.014	+0.013	24	+40	+1.3	0.4	978.156	5
153	31 „	18	+0.10	+0.030	−0.045	28	+28	−1.3	0.7	978.025	6

Nr.	Date, 1929 / Harbours	Depth Observ.	Change Temp.	Factor $U_{90.89}$	Factor $U_{90.88}$	d	v	Current W-E comp.	Current mean error	g_0	m_g
		m	°			10^{-7} sec.		naut. miles	naut. miles		m.gal
	Donggala										
154A	31 Oct.	2	+0.04	+0.050	−0.055	26	− 2	0.0	0.0	978.124	3
154B	31 ,,	2	+0.02	+0.024	−0.028	28	− 4	0.0	0.0	978.125	3
155	2 Nov.	18	+0.08	+0.090	−0.096	16	−16	−2.7	0.3	978.032	4
156	2 ,,	10	+0.15	−0.062	+0.059	29	+ 3	0.0	0.3	978.146	4
	Balikpapan										
157A	2 Nov.	2	+0.01	+0.026	−0.025	30	+49	0.0	0.0	978.072	3
157B	3 ,,	2	−0.07	−0.011	+0.011	25	−47	0.0	0.0	978.070	3
158	5 ,,	18	−0.02	−0.111	+0.097	20	+10	+0.4	0.3	978.053	4
159	5 ,,	18	−0.06	+0.029	−0.030	26	+34	+0.1	0.3	978.026	4
160	5 ,,	10	0.00	−0.022	+0.022	28	+ 6	0.0	0.2	978.047	4
161	5 ,,	18	−0.04	+0.092	−0.084	21	+18	+0.3	0.3	978.150	4
162	6 ,,	18	+0.01	−0.120	+0.120	32	+ 7	+0.1	0.3	978.027	4
	Pare Pare										
163A	6 Nov.	2	+0.13	−0.224	+0.182	57	+ 0	0.0	0.0	978.111	3
163B	6 ,,	2	+0.00	+0.037	−0.051	28	+34	0.0	0.0	978.120	3
163C	6 ,,	2	+0.04	−0.115	+0.147	30	−28	0.0	0.0	978.112	3
	Makassar										
164A	7 Nov.	2	+0.08	+0.251	+0.197	36	− 1	0.0	0.0	978.140	3
164B	8 ,,	2	−0.06	−0.085	−0.094	20	−18	0.0	0.0	978.136	3
165	11 ,,	18	−0.11	−0.006	+0.006	34	− 2	−0.6	0.3	978.090	4
166	12 ,,	18	+0.01	−0.062	+0.084	28	+ 6	−0.8	0.3	978.143	4
167A	12 ,,	18	+0.09	+0.148	−0.122	26	+ 4	+0.3	0.3	978.117	4
167B	12 ,,	18	+0.14	−0.018	+0.018	18	− 9	+0.3	0.3	978.120	4
168A	13 ,,	18	+0.00	+0.023	−0.022	26	−12	+0.2	0.2	978.133	4
168B	13 ,,	18	+0.03	−0.300	+0.292	30	− 9	+0.2	0.2	978.137	4
169	13 ,,	18	+0.11	+0.025	−0.024	29	+ 8	0.0	0.2	978.126	4
170A	13 ,,	18	+0.10	+0.149	−0.152	22	−14	+0.5	0.4	978.141	5
170B	13 ,,	18	+0.09	+0.029	−0.031	23	−15	+0.6	0.4	978.139	5
170C	13 ,,	18	+0.08	+0.117	−0.092	28	− 3	+0.6	0.4	978.142	5
	1930										
171	2 Jan.	10	+0.02	−0.067	+0.074	35	−34	+0.0	0.3	978.157	4
172	3 ,,	18	−0.04	+0.153	−0.171	32	−21	+0.0	0.2	978.158	4
173	3 ,,	11	−0.01	+0.028	−0.047	43	+ 0	+0.3	0.4	978.118	5
174	3 ,,	18	0.00	−0.142	+0.161	34	− 8	+0.5	0.3	978.123	4
175	4 ,,	11	+0.01	−0.027	+0.026	23	−12	+0.0	0.3	978.131	4
	Tanj. Priok										
176A	4 Jan.	2	+0.23	−0.097	+0.098	26	+18	0.0	0.0	978.167	3
176B	4 ,,	2	+0.15	−0.033	+0.033	38	+ 0	0.0	0.0	978.164	3
176C	4 ,,	2	−0.01	+0.142	0.149	41	− 6	0.0	0.0	978.163	3
176D	5 ,,	2	−0.07	+0.093	−0.093	34	− 6	0.0	0.0	978.159	3
177	9 ,,	28	−0.03	+0.134	−0.162	25	+ 8	+0.1	0.1	978.095	4
178	9 ,,	18	+0.15	+0.079	−0.087	23	+14	−0.1	0.2	978.112	4

Nr.	Date, 1930 / Harbours	Depth Observ.	Change Temp.	Factor $U_{90\,89}$	Factor $U_{90\,88}$	d	v	Current W-E comp.	Current mean error	g_0	m_g
		m				10^{-7} sec		naut. miles			m.gal
	Benkulen										
179A	10 Jan.	2	+0.01	−0.242	+0.214	8	− 1	0.0	0.0	978.132	3
179B	10 „	11	+0.13	+0.075	−0.038	36	− 7	+0.5	0.1	978.148	4
180	10 „	28	+0.03	+0.071	−0.069	38	− 1	0.0	0.2	978.032	4
181	11 „	28	+0.01	+0.113	−0.106	27	−11	0.0	0.2	978.152	4
182	11 „	28	+0.02	−0.117	+0.137	37	− 5	0.0	0.2	978.007	4
183	11 „	28	−0.03	−0.205	+0.213	44	+ 9	+0.3	0.3	978.151	4
184	12 „	28	−0.06	+0.011	+0.008	36	−37	+0.6	0.2	978.132	4
185A	12 „	28	+0.06	+0.124	−0.138	38	− 4	+0.5	0.2	978.102	4
185B	12 „	28	+0.01	+0.086	−0.090	36	− 2	+0.5	0.2	978.103	4
186	13 „	18	−0.06	+0.086	−0.095	36		+0.1	0.1	978.115	4
187	13 „	28	+0.09	+0.157	−0.163	38	+ 3	+0.2	0.1	978.092	4
188	13 „	28	+0.11	−0.074	+0.072	29	−14	+0.2	0.1	978.150	4
189A	14 „	28	−0.01	+0.006	−0.006	51	− 2	+0.2	0.1	978.020	4
189B	14 „	28	+0.03	+0.029	−0.030	39	+ 2	+0.2	0.1	978.000	4
	Kantorei Bay										
190	14 Jan.	2	+0.08	−0.080	+0.088	40	+ 3	0.0	0.0	978.117	3
191	15 „	18	+0.05	−0.008	+0.009	32	+ 2	−0.5	0.2	977.995	4
	Padang										
192A	15 Jan.	2	+0.00	−0.046	+0.051	32	−15	0.0	0.0	978.055	3
192B	15 „	2	+0.06	+0.022	−0.024	37	−16	0.0	0.0	978.059	3
	Sibolga										
193A	18 Jan.	2	+0.39	−0.127	+0.129	21	− 4	0.0	0.0	978.047	3
193B	18 „	2	+0.01	−0.008	+0.011	46	0	0.0	0.0	978.049	3
194	19 „	18	−0.04	−0.029	+0.029	34	+ 8	0.0	0.1	978.039	4
	G. Sitoli										
195A	19 Jan.	2	+0.04	+0.057	−0.124	30	+ 1	0.0	0.0	978.063	3
195B	19 „	2	−0.05	+0.043	−0.058	43	− 4	0.0	0.0	978.062	3
196	20 „	18	+0.02	+0.054	−0.063	33	+16	−0.1	0.2	978.107	4
197	20 „	28	+0.03	+0.023	−0.019	38	+16	0.0	0.2	977.975	4
198	21 „	28	+0.05	+0.008	−0.008	39	−19	0.0	0.2	978.132	4
199	21 „	28	+0.03	−0.003	+0.003	24	+19	+0.2	0.2	978.074	4
200	22 „	18	+0.02	+0.000	−0.010	21	+12	0.0	0.2	978.038	4
201	22 „	18	+0.10	−0.039	+0.039	38	+15	−0.5	0.3	978.046	4
202	23 „	28	−0.04	+0.022	−0.023	26	+ 4	−0.6	0.1	978.073	4
203	23 „	28	+0.15	+0.052	−0.048	36	−30	−0.6	0.1	978.055	4
204	23 „	28	+0.12	−0.011	+0.011	38	+13	−0.6	0.1	978.019	4
205	24 „	28	+0.00	−0.011	+0.011	30	+12	−0.7	0.1	978.135	4
206	24 „	28	−0.10	−0.008	+0.034	25	−12	−0.3	0.3	977.968	4

Nr.	Date, 1930 / Harbours	Depth Observ.	Change Temp.	Factor $U_{90.89}$	Factor $U_{90.88}$	d	v	Current W-E comp.	Current mean error	g_0	m_g
		m	°			10^{-7} sec.		naut. miles			m.gal
	Sabang										
207A	24 Jan.	2	+0.04	−0.076	+0.086	38	+ 7	0.0	0.0	978.188	3
207B	25 "	2	+0.00	+0.087	−0.116	34	− 8	0.0	0.0	978.188	3
208	28 "	18	+0.12	+0.020	−0.022	27	+ 2	−0.4	0.2	978.140	4
209	28 "	18	+0.20	+0.012	−0.013	28	+ 6	−0.6	0.2	978.104	4
210	28 "	18	+0.10	+0.014	+0.009	46	− 4	−0.7	0.2	978.094	4
	Belawan										
211A	29 Jan.	2	+0.16	+0.043	−0.042	28	− 4	0.0	0.0	978.069	3
211B	29 "	2	+0.14	−0.092	+0.090	29	+ 8	0.0	0.0	978.071	3
211C	29 "	2	−0.03	−0.011	+0.014	26	0	0.0	0.0	978.074	3
211D	30 "	2	−0.09	−0.023	+0.023	35	−17	0.0	0.0	978.074	3
212	3 Feb.	18	+0.01	+0.003	−0.003	32	0	−0.7	0.3	978.086	4
213	4 "	11	+0.14	−0.035	+0.037	34	+ 3	+0.3	0.1	978.086	4
214	4 "	11	+0.16	+0.143	−0.151	22	+ 1	−0.3	0.4	978.075	5
	P. Sambu										
215	5 Feb.	2	+0.14	−0.086	+0.114	22	+ 0	0.0	0.0	978.077	3
216	5 "	18	−0.07	+0.011	−0.022	22	− 2	0.0	0.2	978.073	4
217	6 "	18	+0.01	+0.030	−0.031	28	+13	0.0	0.4	978.084	5
218	6 "	11	+0.09	−0.111	+0.111	28	+17	0.0	0.2	978.080	4
219	7 "	18	−0.07	+0.033	−0.034	30	+11	0.0	0.2	978.090	4
220	7 "	18	+0.06	+0.035	−0.034	36	+21	0.0	0.2	978.083	4
221	7 "	18	+0.06	+0.030	−0.030	18	+ 1	0.0	0.1	978.081	4
222A	7 "	18	+0.09	−0.011	+0.011	28	+ 0	+0.1	0.2	978.096	4
222B	8 "	18	+0.07	−0.009	+0.009	34	−23	+0.1	0.2	978.099	4
222C	8 "	18	+0.14	−0.069	+0.068	28	−16	+0.1	0.2	978.103	4
	Palembang										
223A	8 Feb.	2	+0.04	−0.126	+0.117	36	+26	0.0	0.0	978.119	3
223B	8 "	2	−0.09	+0.043	−0.044	30	−14	0.0	0.0	978.114	3
224A	11 "	17	+0.03	−0.003	+0.003	24	− 6	+0.2	0.2	978.116	4
224B	11 "	17	+0.11	+0.033	−0.034	24	+13	0.0	0.1	978.112	4
225	11 "	11	+0.09	−0.139	+0.141	24	− 8	+0.9	0.3	978.100	4
	T. Pandan										
226A	11 Feb.	2	+0.11	+0.217	−0.250	24	+ 2	0.0	0.0	978.086	3
226B	11 "	2	+0.15	+0.005	+0.014	24	+11	0.0	0.0	978.091	3
227	13 "	18	+0.12	+0.159	−0.158	14	− 5	+0.3	0.3	978.098	4
228	13 "	11	−0.01	−0.188	+0.188	35	− 8	+0.3	0.3	978.082	4
229	13 "	18	+0.03	+0.015	−0.017	24	+ 9	+0.9	0.3	978.102	4
230	13 "	18	+0.00	+0.001	−0.001	38	+10	+0.2	0.3	978.109	4
231	14 "	18	+0.02	−0.043	+0.044	31	− 8	+0.2	0.3	978.110	4
232	14 "	18	+0.03	−0.045	+0.049	32	−10	+0.8	0.3	978.125	4
233	14 "	18	+0.00	+0.000	+0.000	32	− 5	+0.2	0.2	978.120	4

Results of the Gravity Observations o/b the S.S. Johan de Witt.

Nr.	Date, 1929 / Harbours	Elev. Observ.	Change Temp.	Factor $U_{90.89}$	Factor $U_{90.88}$	d	v	Current W-E comp.	Current mean error	g_0	m_g
		m	°			10^{-7} sec.		naut. miles			m.gal
	Colombo										
234	5 May '29	8	+0.01	−0.015	+0.017	68	−14	0.0	0.0	978.147	3
	Sabang										
235	8 May '29	8	+0.00	+0.070	−0.090	51	+21	0.0	0.0	978.186	3
	Belawan										
236	9 May '29	8	+0.00	+0.030	−0.034	56	- 31	0.0	0.0	978.069	3
	Singapore										
237	10 May '29	8	+0.01	−0.021	+0.022	66	8	0.0	0.0	978.087	3

1 Nautical Mile = 1853 Meters.

C. The Mean Error of the Results.

For a general discussion of the mean errors of gravity observations at sea I may refer to pages 61 et seq. of the previous chapter. The mean error of the value of the gravity in the ship has been found there to be 3.1 milligal and we will retain this value for all the observations up to the accident between station Nr. 97 and station Nr. 98. For the stations of the second and third expeditions, i. e. stations Nrs. 106 till 233 this mean error has to be combined with the mean error of 1.8 milligal of the gravity at the new base-station at Surabaya. This gives

$$m_g = \sqrt{3.1^2 + 1.8^2} = 3.6 \text{ milligal.}$$

The variability of the pendulums during these expeditions has been small enough for having no perceptible effect on the mean error of the results.

For the stations 98 till 105, the results have been derived from pendulum Nr. 89 only, because this pendulum had shown no change of period when coming back to Surabaya. We can take this into account in the deduction of the mean error according to the discussion on page 63 et seq. by substituting half of the square of the mean deviation of d instead of the square of half of this mean deviation.

It is difficult to take into account the uncertainty caused by the variability of the middle pendulum in the corrections for deviation of isochronism, but by increasing the square of the mean error of the reduced pendulum period by $100\ 10^{-14}\ \text{sec}^2$, this point seems liberally taken care of.

The combination of these effects gives a mean error of gravity of

$$m_g = 0.39 \times \sqrt{2 \times 4^2 + 7^2 + 100} = 5.2 \text{ milligal.}$$

D. The Mean Error of the Gravity Results reduced to Sea Level.

As has already been mentioned in the previous chapter, the error of the reduction of the gravity result to sea level can be neglected. For the error of the correction for the Eötvös effect we can now make a more accurate estimate than for the former expeditions, because during this voyage the uncertainty of the data for the current have as well as possible been determined. The uncertainties of the E—W component of the current, expressed in miles are mentioned in the above list. The mean error of the Eötvös effect expressed in milligal may be put at 7.5 times as much, because at these low latitudes, the cosine of the latitude, with which the effect is multiplied, may be neglected in the multiplication.

Combining the mean errors of the Eötvös effect with the m_g, by taking the root of the sum of the squares, we find the mean errors of the results reduced to sea-level, which are mentioned in the list at the end of this volume.

List of Daily Rates of the chronometers Nardin 2081 and Nardin 212.

Time-signal		Daily Rates	
Date 1929	Java Time	2081	212
	h m		
12 June	7 46		
		+3.10	-1 22
12 „	19 46		
		+2 88	-0.92
13 „	7 46		
		+2.82	0.99
13 „	19 46		
		+2.84	-0,59
14 „	7 46		
		+2.60	-1.08
14 „	19 46		
		+2.54	-0.35
15 „	7 46		
		+2.60	-0.90
15 „	19 46		
		+2.70	-0.61
16 „	7 46		
		+2.69	0.92
17 „	7 46		
		+2.66	1.04
17 „	19 46		
		+2.54	-0.94
18 „	7 46		
		+2.74	-1.13
18 „	19 46		
		+2.54	-1 25
19 „	7 46		
		+2.68	-0 88
19 „	19 46		
		+2.54	-0.78
20 „	7 46		
		+2.62	1 45
20 „	19 46		
		+2.68	-1.05
21 „	7 46		
		+2.74	-1.16
21 „	19 46		
		+2.74	-0.88
22 „	7 46		
		+2.74	0.98
22 „	19 46		
		+2.70	0 87
23 „	7 46		
		+2 70	1.13
24 „	7 46		
		+2.72	-1 14
24 „	19 46		
		+2.74	-1 02
25 „	7 46		
		+2 84	1.15
25 „	19 46		
		+2.66	-1.17
26 „	7 46		
		+2.86	-1.02
26 „	19 46		
		+2.82	-0.96
27 „	7 46		

Time-signal		Daily Rates	
Date 1929	Java Time	2181	2'2
	h m		
27 June	7 46		
		+2.94	-1.23
27 „	19 46		
		+2.94	-1.04
28 „	7 46		
		+2.94	-1.22
28 „	19 46		
		+2.90	-1.08
29 „	7 46		
		+2.82	-1.11
29 „	19 46		
		+2.62	-0.94
30 „	7 46		
		+2 70	-1.22
1 July	7 46		
		+2.82	-1.31
1 „	19 46		
		+2.74	-1.07
2 „	7 46		
		+2.54	-1.14
2 „	19 46		
		+2.76	-1.02
3 „	7 46		
		+2.82	-1.19
3 „	19 46		
		+2.66	-1.06
4 „	7 46		
		+2 52	-1 08
4 „	19 46		
		+2.36	-0.93
5 „	7 46		
		+2.22	-1.09
5 „	19 46		
		+2.06	-1.04
Banda Neira			
8 July	7 46		
		+2 34	-1.22
8 „	19 46		
		+2.24	-0.99
9 „	7 46		
		+2.20	-1.14
9 „	19 46		
		+2.16	-0.97
10 „	19 46		
		+2 88	-1.28
Amboina			
17 July	19 46		
		+2.91	-1.02
18 „	7 46		
		+2.45	-1.19
18 „	19 46		
		+2.96	-0.89
19 „	7 46		

Combined Table of the Positions and the Gravity Results reduced to sea-level of all the Expeditions.

This table contains the following columns. The first gives the number of the stations according to this table; the second the number of the stations as they were given during the expeditions and as they are mentioned on the maps and in the corresponding chapter; this chapter is indicated by its roman number in the same column. If this column contains more than one number, the station was occupied during more than one expedition. The third and fourth columns give the latitude φ with its mean error in nautical miles, the next two columns give the same indications for the longitude λ. Then follow two columns with the observed gravity result reduced to sea-level and its mean error; both these figures may be found in the tables of the chapters treating of the expeditions. The next column gives the value for normal gravity according to the formula of Cassinis, which was accepted as standard formula in 1930 by the meeting at Stockholm of the International Union for Geodesy and Geophysics. This formula is

$$\gamma_0 = 978.049\ (1 + 0.0052884\ \sin^2 \varphi - 0.0000059\ \sin^2 2\varphi).$$

The last column contains the gravity anomaly, i.e. the value of the observed gravity reduced to sea-level minus the value for normal gravity γ_0. In analogy to the normal use for stations on land, we may call this anomaly the free-air anomaly.

The isostatic reductions and other further reductions of the results will be given in the second volume of this publication. This will also contain a discussion of the results and their interpretation.

Stations that are only a few miles apart have been combined in one station by taking the mean of the two positions and the mean of the two results; mentioning them separately would have no real value. For the harbour of Benkulen, where an observation was made in the harbour and a second one a few miles outside, the position of the harbour station was given in stead of the mean position.

The mean errors of the positions of the sea-stations ought not be considered as based on exact mathematical foundation; it is not more than an estimate founded on the consideration of the different data used for their computation. For the first fourty-two stations it is only a rough estimate based on a general consideration of the circumstances; for the next hundred-fifty-three stations the estimate was made afterwards as well as this could be done; for the last two-hundred-thirty stations the estimate was made more carefully during the expeditions.

The mean error of the stations in the harbours has been computed with regard to the map that was used; in a good many cases it was less than 0.05 nautical miles and it was therefore put at 0.0 in the table.

It was not considered to be of any use to give the position of the harbour stations more accurately than in tenths of nautical miles; this allows already an identification within a hundred meters. The names of the harbours may be found in the lists on pages 29, 39, 56—60 and 89—97.

The stations of the Chapters II, III and IV are indicated on the first map, those of Chapter V on the second map, which also contains those stations of Chapters II and IV, that are located in the East Indies.

Table of the Gravity Results of all the Expeditions.

Nr. Stat.	Nr. Voyage	φ	m_φ miles	λ	m_λ miles	g_0	m_g	γ_0	A
		° ′		° ′					
1	1 II	36 55 N	2	7 20 W	2	979.939	5	979.910	+ 29
2	2 II	36 52 „	2	7 42 „	2	979.912	4	979.906	+ 6
3	3 II	36 17 „	2	1 05 „	2	979.879	6	979.855	+ 24
4	4 II	37 01 „	2	7 55 E	2	979.997	5	979.919	+ 78
5	5 II, 8 III	36 47.6 „	0.0	10 11.4 „	0.0	979.926	2	979.898	+ 28
6	6 II	34 58 „	2	16 47 „	2	979.742	5	979.743	− 1
7	7 II	32 06 „	2	24 32 „	2	979.549	4	979.505	+ 44
8	8 II	31 58 „	2	28 52 „	2	979.430	5	979.494	− 64
9	9 II, 12 III	31 09 „	0.2	29 52.4 „	0.2	979.434	2	979.428	+ 6
10	10 II	31 32 „	2	29 44 „	2	979.441	4	979.459	− 18
11	11 II	29 56.0 „	0.2	32 33.3 „	0.2	979.334	4	979.335	− 1
12	12 II	26 12 „	2	35 02 „	2	979.074	5	979.054	+ 20
13	13 II	20 42 „	2	38 28 „	2	978.685	4	978.693	− 8
14	14 II	15 11 „	2	41 58 „	2	978.407	5	978.402	+ 5
15	15 II	14 24 „	2	42 30 „	2	978.377	4	978.368	+ 9
16	16 II	12 47.6 „	0.0	44 58.8 „	0.0	978.323	5	978.302	+ 21
17	17 II	11 54 „	2	53 04 „	2	978.287	6	978.268	+ 19
18	18 II	10 02 „	2	55 25 „	2	978.186	6	978.205	− 19
19	19 II	7 57 „	2	61 54 „	2	978.139	4	978.148	− 9
20	20 II	7 53 „	2	65 58 „	2	978.113	6	978.146	− 33
21	21 II	7 56 „	2	68 46 „	2	978.105	6	978.147	− 42
22	22 II	8 06 „	2	72 48 „	2	978.117	5	978.151	− 34
23	23 II	7 20 „	2	77 28 „	2	978.105	5	978.133	− 28
24	24 II, 234 V	6 56.9 „	0.0	79 51.0 „	0.0	978.147	3	978.124	+ 23
25	25 II	5 50 „	2	80 12 „	2	978.170	7	978.102	+ 68
26	26 II	5 32 „	2	80 12 „	2	978.019	8	978.097	− 78
27	27 II	5 44 „	2	87 07 „	2	978.073	7	978.100	− 27
28	28 II	6 02 „	2	92 50 „	2	978.029	7	978.106	− 77
29	29 II, 207, 235 V	5 53.2 „	0.0	95 18.7 „	0.0	978.186	2	978.103	+ 83
30	30 II	6 01 „	2	96 55 „	2	978.101	7	978.106	− 5
31	31 II	6 01 „	2	96 59 „	2	978.106	6	978.106	0
32	32 II	4 26 „	2	98 53 „	2	978.079	7	978.080	− 1
33	1 III	49 04 „	2	05 55 W	2	981.015	7	980.996	+ 19
34	2 III	44 59 „	2	08 39 „	2	980.616	6	980.628	− 12
35	3 III	37 22.8 „	0.0	06 00 „	0.0	979.967	4	979.953	+ 14
36	4 III	36 10 „	2	3 25 „	2	979.851	5	979.845	+ 6
37	5 III	36 52 „	2	0 01 E	2	979.916	6	979.906	+ 10
38	6 III	37 08 „	2	4 17 „	2	979.894	10	979.928	− 34
39	7 III	37 05 „	2	4 28 „	2	979.905	13	979.924	− 19
40	9 III	36 20 „	2	15 31 „	2	979.884	11	979.859	+ 25
41	10 III	35 13 „	2	18 31 „	2	979.748	15	979.764	− 16
42	11 III	33 56 „	2	22 12 „	2	979.611	6	979.656	− 45
43	1 IV	44 18 „	6	15 27 W	6	980.549	4	980.566	− 17
44	2 IV	43 11 „	2	18 44 „	2	980.515	4	980.465	+ 50
45	3 IV	41 22 „	8	21 39 „	2	980.348	4	980.303	+ 45

Nr. Stat.	Nr. Voyage	φ		m_φ miles	λ		m_λ miles	g_0	m_g	γ_0	A
		°	′		°	′					
46	4 IV	39	48 N	3	24	57 W	3	980.213	4	980.163	+ 50
47	5 IV	38	31.8 ,,	0.0	28	37.4 ,,	0.0	980.162	3	980.051	+111
48	6 IV	36	23 ,,	2	26	43 ,,	3	979.894	4	979.864	+ 30
49	7 IV	33	42 ,,	2	24	19 ,,	5	979 639	4	979.636	+ 3
50	8 IV	30	48 ,,	2	22	30 ,,	2	979.403	4	979.401	+ 2
51	9 IV	29	20 ,,	6	19	15 ,,	2	979.272	4	979.286	− 14
52	10 IV	28	40 ,,	2	15	53 ,,	2	979.207	4	979.235	− 28
53	11 IV	28	09.3 ,,	0.0	15	25.2 ,,	0.0	979.390	2	979.196	+194
54	12 IV	27	13 ,,	2	17	48 ,,	3	979.146	4	979.127	+ 19
55	13 IV	26	33 ,,	2	21	37 ,,	2	979.090	4	979.079	+ 11
56	14 IV	25	44 ,,	4	25	19 ,,	5	979 032	4	979.020	+ 12
57	15 IV	25	07 ,,	4	28	50 ,,	2	979.014	5	978.978	+ 36
58	16 IV	25	00 ,,	3	32	30 ,,	4	978.968	4	978.969	− 1
59	17 IV	24	34 ,,	2	35	57 ,,	5	978.935	4	978.940	− 5
60	18 IV	24	03 ,,	2	39	34 ,,	4	978.901	4	978.905	− 4
61	19 IV	23	44 ,,	2	43	00 ,,	3	978.911	4	978.884	+ 27
62	20 IV	23	21 ,,	2	47	05 ,,	3	978.884	4	978.858	+ 26
63	21 IV	23	03 ,,	2	50	45 ,,	3	978 854	4	978.839	+ 15
64	22 IV	22	45 ,,	2	54	34 ,,	2	978.801	4	978.820	− 19
65	23 IV	22	17 ,,	2	58	24 ,,	3	978.763	4	978.790	− 27
66	24 IV	21	35 ,,	2	63	22 ,,	2	978 744	4	978.746	− 2
67	25 IV	20	44 ,,	4	65	37 ,,	7	978.706	4	978.694	+ 12
68	26 IV	19	32 ,,	3	66	46 ,,	5	978.287	4	978.625	−338
69	27 IV	18	24 ,,	1	67	42 ,,	1	978.547	4	978.562	− 15
70	28 IV	16	55 ,,	2	67	42 ,,	2	978.458	4	978.485	− 27
71	29 IV	12	06.4 ,,	0.0	68	56.1 ,,	0.0	978.436	3	978.276	+160
72	30 IV	12	00 ,,	2	69	12 ,,	2	978.260	4	978,272	− 12
73	31 IV	12	55 ,,	2	71	54 ,,	4	978.240	4	978.306	− 66
74	32 IV	10	22 ,,	3	77	13 ,,	2	978.177	4	978.216	− 39
75	33 IV	9	51 ,,	5	78	01 ,,	3	978.178	4	978.200	− 22
76	34 IV	9	22.4 ,,	0.0	79	53 3 ,,	0.0	978.253	3	978,186	+ 67
77	35 IV	8	57.5 ,,	0.0	79	33.9 ,,	0.0	978.247	3	978.174	+ 73
78	38 IV	7	01 ,,	2	82	37 ,,	2	978.173	4	978.126	+ 47
79	39 IV	10	21 ,,	2	88	30 ,,	5	978 252	4	978.215	+ 37
80	40 IV	13	35 ,,	2	95	27 ,,	2	978.366	4	978.333	+ 33
81	41 IV	15	03 ,,	5	98	20 ,,	5	978.421	4	978 396	+ 25
82	42 IV	15	17 ,,	2	98	23 ,,	2	978.408	4	978.407	+ 1
83	43 IV	15	35 ,,	2	98	20 ,,	2	978.329	4	978.421	− 92
84	44 IV	15	55 ,,	5	98	16 ,,	3	978.457	4	978.437	+ 20
85	45 IV	17	35 ,,	7	103	26 ,,	2	978.423	4	978.519	− 96
86	46 IV	18	01 ,,	7	103	25 ,,	2	978.454	4	978,542	− 88
87	47 IV	18	15 ,,	7	103	26 ,,	2	978.575	4	978.554	+ 21
88	48 IV	23	06.0 ,,	0.0	106	24.8 ,,	0.0	978.867	3	978.842	+ 25
89	49 IV	24	24 ,,	2	113	23 ,,	7	978.928	4	978.928	0
90	50 IV	26	32 ,,	2	115	40 ,,	2	979.089	4	979 077	+ 12
91	51 IV	27	02 ,,	2	115	21 ,,	2	979.079	4	979.114	− 35
92	52 IV	27	20 ,,	2	115	10 ,,	2	979.059	4	979.135	− 76
93	53 IV	29	13 ,,	6	117	06 ,,	2	979.233	4	979.277	− 44
94	54 IV	31	01 ,,	2	119	19 ,,	2	979.404	4	979 418	− 14
95	55 IV	33	12 ,,	3	121	30 ,,	2	979.588	4	979.595	− 7

Nr. Stat.	Nr. Voyage	φ	m_φ miles	λ	m_λ miles	g_0	m_g	γ_0	A
		° ′		° ′					
96	56 IV	35 50 N	2	122 43 W	2	979.807	4	979.816	− 9
97	57 IV	37 48.5 „	0.0	122 25.9 „	0.0	979.998	3	979.987	+ 11
98	58 IV	37 29 „	5	123 09 „	6	979.942	4	979.959	− 17
99	59 IV	37 06 „	3	123 54 „	2	979.898	4	979.926	− 28
100	60 IV	36 22 „	2	125 22 „	4	979.840	4	979.863	− 23
101	61 IV	34 46 „	2	128 34 „	7	979.716	4	979.726	− 10
102	62 IV	33 15 „	2	131 52 „	2	979.592	4	979.599	− 7
103	63 IV	32 12 „	2	134 01 „	2	979.510	4	979.513	− 3
104	64 IV	30 15 „	2	138 25 „	5	979.352	4	979.357	− 5
105	65 IV	28 57 „	2	141 14 „	2	979.269	4	979.257	+ 12
106	66 IV	27 27 „	2	144 21 „	2	979.169	4	979.144	+ 25
107	67 IV	25 45 „	2	147 43 „	2	979.039	4	979.022	+ 17
108	68 IV	24 19 „	2	150 48 „	3	978.934	4	978.923	+ 11
109	69 IV	22 57 „	2	153 40 „	2	978.881	4	978.832	+ 49
110	70 IV	22 13 „	2	155 24 „	2	978.793	4	978.786	+ 7
111	71 IV	21 45 „	2	156 13 „	2	978.660	4	978.756	− 96
112	72 IV	21 09.0 „	1	157 28.0 „	1	978.889	4	978.720	+169
113	73 IV	21 18.4 „	0.0	157 52.0 „	0.0	978.943	3	978.730	+213
114	74 IV	20 48 „	2	158 36 „	2	978.685	4	978.699	− 14
115	75 IV	20 29 „	2	160 30 „	4	978.697	4	978.680	+ 17
116	76 IV	19 58 „	2	164 56 „	6	978.663	4	978.650	+ 13
117	77 IV	19 31 „	2	168 27 „	2	978.669	4	978.624	+ 45
118	78 IV	19 07 „	2	171 35 „	3	978.669	4	978.602	+ 67
119	79 IV	18 37 „	3	175 00 „	4	978.662	4	978.574	+ 88
120	80 IV	18 06 „	2	178 14 „	2	978.551	4	978.546	+ 5
121	81 IV	17 47 „	3	179 33 E	3	978.523	4	978.529	− 6
122	82 IV	17 02 „	2	176 24 E	2	978.544	4	978.491	+ 53
123	83 IV	16 12 „	2	171 53 „	3	978.442	4	978.450	− 8
124	84 IV	15 32 „	2	168 27 „	2	978.416	4	978.418	− 2
125	85 IV	15 07 „	2	164 56 „	2	978.412	4	978.399	+ 13
126	86 IV	14 43 „	2	161 30 „	4	978.362	4	978.382	− 20
127	87 IV	14 05 „	2	158 08 „	2	978.334	4	978.354	− 20
128	88 IV	13 38 „	2	155 56 „	2	978.310	4	978.335	− 25
129	89 IV	12 42 „	2	150 58 „	3	978.309	4	978.298	+ 11
130	90 IV	12 02 „	2	147 38 „	2	978.280	4	978.273	+ 7
131	91 IV	12 20 „	5	146 00 „	2	978.198	4	978.284	− 86
132	92 IV	12 48 „	4	145 35 „	4	978.055	4	978.302	−247
133	93 IV	13 08 „	4	145 16 „	2	978.399	4	978.315	+ 84
134	94 IV	13 26.8 „	0.0	144 39.8 „	0.0	978.539	3	978.328	+211
135	95 IV	13 42 „	2	142 53 „	2	978.389	4	978.338	+ 51
136	96 IV	10 35 „	2	140 23 „	2	978.300	4	978.223	+ 77
137	97 IV	9 57 „	2	140 05 „	2	978.284	4	978.203	+ 81
138	98 IV	9 25 „	2	138 34 „	3	978.038	4	978.187	−149
139	99 IV	9 30.7 „	0.0	138 10.4 „	0.0	978.478	3	978.190	+288
140	100 IV	9 21 „	2	138 47 „	2	978.190	4	978.185	+ 5
141	101 IV	9 30 „	6	136 36 „	6	978.204	4	978.189	+ 15
142	102 IV	9 52 „	2	132 46 „	2	978.217	4	978.200	+ 17
143	103 IV	10 12 „	2	129 22 „	2	978.256	4	978.210	+ 46
144	104 IV	10 19 „	2	127 39 „	2	978.262	4	978.214	+ 48
145	105 IV	10 17 „	2	126 41 „	3	978.015	4	978.213	−198

Nr. Stat.	Nr. Voyage	φ	m_φ miles	λ	m_λ miles	g_0	m_g	γ_0	A
		° ′		° ′					
146	106 IV	10 16 N	2	125 59 E	2	978.483	4	978.213	+270
147	107 IV	13 19 ,,	2	121 38 ,,	2	978.342	4	978.322	+ 20
148	108 IV	14 35 2 ,,	0.0	120 57.9 ,,	0 0	978 362	3	978.376	− 14
149	109 IV	8 50 ,,	2	121 52 ,,	2	978.141	4	978.170	− 29
150	110 IV	4 35 ,,	2	123 44 ,,	2	978 162	4	978.082	+ 80
151	111 IV	0 29 S	2	125 59 ,,	2	977.833	4	978.049	−216
152	112 IV	1 45 ,,	2	126 57 ,,	2	978 058	4	978.054	+ 4
153	113 IV	2 35 ,,	2	127 12 ,,	2	978.052	4	978.059	− 7
154	114 IV	3 23 ,,	2	127 27 ,,	2	978.001	4	978.067	− 66
155	115 IV, 55 V	3 41.3 ,,	0.0	128 10.4 ,,	0.0	978.184	2	978.070	+114
156	116 IV	3 59 ,,	2	129 23 ,,	2	978.052	4	978.074	− 22
157	117 IV, 47 V	4 32.0 ,,	0 0	129 53.7 ,,	0.0	978.274	2	978.081	+193
158	118 IV	5 36 ,,	2	129 28 ,,	2	978.125	4	978 098	+ 27
159	119 IV	7 10 ,,	1	128 54 ,,	1	978.143	4	978.129	+ 14
160	120 IV	7 40 ,,	1	128 47 ,,	1	978.039	4	978.141	−102
161	121 IV	8 13 ,,	1	128 33 ,,	1	978.112	4	978.154	− 42
162	122 IV	8 48 ,,	1	128 26 ,,	1	978.019	4	978.170	−151
163	123 IV	9 36 ,,	1	128 07 ,,	1	978.233	4	978.192	+ 41
164	124 IV	7 52 ,,	1	121 57 ,,	1	978.155	4	978.146	+ 9
165	125 IV	7 45 .	1	119 58 ,,	1	978.032	4	978 143	−111
166	126 IV	8 27.1 ,,	0.1	118 42.7 ,,	0.1	978.279	4	978.160	+119
167	127 IV	7 53 ,,	1	114 54 ,,	1	978.174	4	978.146	+ 28
168	128IV,129IV	7 12.1 ,,	0.0	112 44.6 ,,	0.0	978.137	2	978 130	+ 7
169	130 IV	8 05.5 ,,	0 2	114 25.5 ,,	0,2	978 158	4	978.151	+ 7
170	131 IV	8 51 ,,	1	114 38 ,,	4	978.312	4	978.171	+141
171	132 IV	9 41 ,,	3	114 15 ,,	2	978 115	4	978.195	− 80
172	133 IV	10 23 ,,	3	113 55 ,,	2	978.172	4	978.216	− 44
173	134 IV	10 59 ,,	2	113 40 ,,	2	978.088	4	978.236	−148
174	135 IV	11 40 ,,	2	113 15 ,,	2	978,297	4	978.260	+ 37
175	136 IV	12 47 ,,	3	112 46 ,,	3	978.323	4	978.301	+ 22
176	137 IV	12 24 ,,	3	110 00 ,,	3	978 321	4	978 286	+ 35
177	138 IV	11 05 ,,	3	110 04 ,,	2	978.272	4	978.239	+ 33
178	139 IV	10 18 ,,	2	110 03 ,,	2	978.051	4	978.214	−163
179	140 IV	9 31 ,,	3	110 18 ,,	2	978.174	4	978.190	− 16
180	141 IV	9 00 ,,	2	110 33 ,,	2	978.158	4	978.175	− 17
181	142 IV	8 14 ,,	2	110 32 ,,	2	978.268	4	978.155	+113
182	143 IV	7 35 ,,	2	106 55 ,,	2	978.296	4	978.139	+157
183	144 IV	8 26 ,,	2	106 36 ,,	2	978 085	4	978 160	− 75
184	145 IV	9 21 ,,	2	106 21 ,,	2	978,118	4	978.185	− 67
185	146 IV	10 13 ,,	3	105 55 ,,	2	978.292	4	978.211	+ 81
186	147 IV	11 42 ,,	2	105 24 ,,	2	978.290	4	978.261	+ 29
187	148 IV	10 38 ,,	3	102 29 ,,	3	978 251	4	978.224	+ 27
188	149 IV	9 00 ,,	3	102 47 ,,	3	978.219	4	978 175	+ 44
189	150 IV	7 46 ,,	4	103 09 ,,	4	978.094	4	978.143	− 49
190	151 IV	7 04 ,,	2	102 29 ,,	2	978.108	4	978 127	− 19
191	152 IV	6 42 ,,	3	102 55 ,,	2	978.096	4	978.119	− 23
192	153 IV	6 58 ,,	2	104 07 ,,	2	978.076	4	978.125	− 49
193	154 IV	6 17 ,,	2	104 41 ,,	2	978.246	4	978.111	+135
194	155 IV	6 05.3 ,,	0 2	105 37.0 ,,	0.2	978.149	4	978 107	+ 42
195	156IV, 176V	6 05.6 ,,	0.0	106 53.0 ,	0.0	978.167	2	978.107	+ 60

Nr. Stat.	Nr. Voyage	φ	m_φ miles	λ	m_λ miles	g_0	m_g	γ_0	A
		° ′		° ′					
196	1 V	7 47 S	2	116 16 E	2	978.147	4	978.143	+ 4
197	2 V	8 54 ,,	1	118 13 ,,	1	978.244	3	978.172	+ 72
198	3 V	8 45 ,,	1	118 25 ,,	1	978.256	3	978.168	+ 88
199	4 V	9 32 ,,	1	118 10 ,,	1	978.194	4	978.190	+ 4
200	5 V	10 23 ,,	5	117 56 ,,	5	978.076	4	978.216	−140
201	6 V	11 01 ,,	5	117 47 ,,	5	978.211	4	978.237	− 26
202	7 V	12 00 ,,	5	117 25 ,,	5	978.303	5	978.271	+ 32
203	8 V	12 45 ,,	3	117 12 ,,	3	978.325	4	978.300	+ 25
204	9 V	11 36.5 ,,	1	118 34.5 ,,	1	978.291	5	978.258	+ 33
205	10 V	11 13 ,,	3	119 20 ,,	3	978.133	5	978.244	−111
206	11 V	10 20.7 ,,	0.1	120 25.6 ,,	0.1	978.325	4	978.215	+110
207	12 V	10 22 ,,	2	121 05 ,,	2	978.182	3	978.216	− 34
208	13 V	9 29.5 ,,	0.5	121 21 ,,	0.5	978.148	3	978.189	− 41
209	14 V	8 54.5 ,,	0.5	121 36 ,,	0.5	978.231	4	978.173	+ 58
210	15 V	9 35 ,,	3	122 32 ,,	3	978.065	4	978.192	−127
211	16 V	10 07.8 ,,	0.2	123 32.0 ,,	0.2	978.179	3	978.208	− 29
212	17 V	10 27.2 ,,	1	123 48.2 ,,	1	978.160	4	978.218	− 58
213	18 V	10 48 ,,	3	124 10 ,,	3	978.104	4	978.230	−126
214	19 V	11 10 ,,	5	124 21 ,,	5	978.244	4	978.242	+ 2
215	20 V	10 15 ,,	3	126 43 ,,	3	978.247	3	978.212	+ 35
216	21 V	9 13 ,,	3	126 37 ,,	3	978.081	3	978.181	−100
217	22 V	8 54 ,,	2	126 40 ,,	2	978.106	4	978.172	− 66
218	23 V	9 19 ,,	2	127 09 ,,	2	978 092	5	978.184	− 92
219	24 V	9 35 ,,	2	131 04 ,,	2	978.239	5	978.192	+ 47
220	25 V	8 30 ,,	2	131 00 ,,	2	978.139	4	978.162	− 23
221	26 V	7 58.8 ,,	0.1	131 17.7 ,,	0.1	978 133	3	978.148	− 15
222	27 V	7 39.0 ,,	1	130 46.2 ,,	1	978.097	3	978.140	− 43
223	28 V	7 05 ,,	2	130 24 ,,	2	978.061	3	978.128	− 67
224	29 V	6 18.6 ,,	1	130 04.0 ,,	1	978.233	3	978.111	+122
225	30 V	5 40 ,,	2	130 12 ,,	2	978.170	3	978.099	+ 71
226	31 V	5 42 ,,	3	130 33 ,,	3	978.157	3	978.100	+ 57
227	32 V	5 36 ,,	3	131 08 ,,	3	977.853	4	978.098	−245
228	33 V	5 39 ,,	1	132 05 ,,	1	978.066	3	978 099	− 33
229	34 V	5 37.8 ,,	0.1	132 42.9 ,,	0.1	978.157	3	978.099	+ 58
230	35 V	5 35 ,,	3	133 40 ,,	3	977.946	3	978 098	−152
231	36 V	5 45.3 ,,	0.1	134 12.2 ,,	0.1	978.159	3	978.101	+ 58
232	37 V	4 42 ,,	2	133 38 ,,	2	978.044	3	978.083	− 39
233	38 V	3 45.0 ,,	0.1	133 39.5 ,,	0.1	978.134	3	978.071	+ 63
234	39 V	3 26.3 ,,	0.1	133 36.2 ,,	0.1	978.109	3	978.068	+ 41
235	40 V	3 13.8 ,,	0.1	133 38.5 ,,	0.1	978.105	3	978.065	+ 40
236	41 V	4 07.2 ,,	0.2	133 15.0 ,,	0.2	978.179	3	978.076	+103
237	42 V	4 31 ,,	2	132 24 ,,	2	978.051	3	978.081	− 30
238	43 V	4 45.1 ,,	0.2	131 41.7 ,,	0.2	978.112	3	978.084	+ 28
239	44 V	4 52 ,,	2	131 13 ,,	2	978.006	3	978.086	− 80
240	45 V	4 58 ,,	4	130 28 ,,	4	978.120	3	978.088	+ 32
241	46 V	4 20 ,,	3	128 29 ,,	3	978.154	3	978.078	+ 76
242	48 V	4 13 ,,	1	130 21.5 ,,	1	978.056	4	978.077	− 21
243	49 V	3 29.5 ,,	0.5	130 51.5 ,,	0.5	978.053	3	978.068	− 15
244	50 V	2 38 ,,	2	130 54 ,,	2	978.002	4	978.060	− 58
245	51 V	2 17 ,,	1	131 00 ,,	1	978.121	4	978.057	+ 64

Nr. Stat.	Nr. Voyage	φ	m_φ miles	λ	m_λ miles	g_0	m_g	γ_0	A
		° '		° '					
246	52 V	2 12.8 S	0.1	130 21.6 E	0.1	978.137	3	978 057	+ 80
247	53 V	2 20 ,,	1	129 28 ,,	1	978.056	3	978.058	− 2
248	54 V	2 26 ,,	2	128 09 ,,	2	977.896	4	978.058	−162
249	56 V	1 23 ,,	2	128 23 ,,	2	978.100	4	978.052	+ 48
250	57 V	0 40 ,,	2	128 43 ,,	2	978.121	4	978.050	+ 71
251	58 V	0 18 ,,	3	128 48 ,,	3	978.057	4	978.049	+ 8
252	59 V	0 38.5 ,,	1	129 34 ,,	1	978.062	4	978.050	+ 12
253	60 V	0 56.5 ,,	1	130 14.5 ,,	1	978.117	4	978.050	+ 67
254	61 V	0 53.5 ,,	0.0	131 14.2 ,,	0.0	978.143	3	978.050	+ 93
255	62 V	0 26 ,,	1.5	131 42 ,,	1.5	978.013	4	978.049	− 36
256	63 V	0 19.5 ,,	0.2	132 38.5 ,,	0.2	979.168	3	978.049	+119
257	64 V	0 20 N	1.5	132 39 ,,	1.5	978.101	3	978.049	+ 52
258	65 V	1 03.2 ,,	0.2	131 16.5 ,,	0.2	978.166	3	978.051	+115
259	66 V	1 27 ,,	1.5	130 46 ,,	1.5	978.111	4	978.052	+ 59
260	67 V	2 03 ,,	5	129 55 ,,	5	978.112	4	978.056	+ 56
261	68 V	1 52 ,,	2	128 48 ,,	2	978.079	4	978.054	+ 25
262	69 V	1 43.7 ,,	0.0	128 00.7 ,,	0.0	978.144	3	978.054	+ 90
263	70 V	2 49 ,,	2	128 34 ,,	2	978.170	6	978.061	+109
264	71 V	3 23 ,,	1	129 09 ,,	1	978.081	4	978 067	+ 14
265	72 V	4 42 ,,	1.5	129 23 ,,	6	978.113	5	978.084	+ 29
266	73 V	4 45 ,,	4	128 26 ,,	4	978.108	5	978.084	+ 24
267	74 V	4 54 ,,	4	128 13 ,,	4	978.015	5	978.087	− 72
268	75 V	4 33 ,,	2	127 03 ,,	2	978.046	4	978.081	− 35
269	76 V	4 23 ,,	1	126 25.5 ,,	1	978.097	4	978.079	+ 18
270	77 V	4 05 ,,	3	125 53 ,,	3	978.276	4	978.075	+201
271	78 V	2 44.6 ,,	0.2	125 27.5 ,,	0.2	978.258	3	978.061	+197
272	79 V	2 26 ,,	2	126 14 ,,	2	977.975	3	978.058	− 83
273	80 V	2 09 ,,	2	126 59 ,,	4	977 877	6	978.056	−179
274	81 V	1 12 ,,	1.5	127 00 ,,	1.5	978.094	4	978.051	+ 43
275	82 V	0 47.0 ,,	0.0	127 23.0 ,,	0.0	978.187	3	978.050	+137
276	83 V	0 38.5 S	0.1	127 27.2 ,,	0.1	978.172	3	978.050	+122
277	84 V	1 03 ,,	1	126 43 ,,	1	977.835	3	978.051	−216
278	85 V	1 20 ,,	1	126 03 ,,	1	977.961	3	978.052	− 91
279	86 V	1 56.6 ,,	0.2	125 19.0 ,,	0.2	978.290	3	978.055	+235
280	87 V	2 52 ,,	2	125 08 ,,	2	978.127	3	978.062	+ 65
281	88 V	3 32 ,,	2.5	124 58 ,,	2.5	978.103	5	978.068	+ 35
282	89 V	3 29 ,,	1.5	125 43 ,,	1.5	978.072	4	978.068	+ 4
283	90 V	3 49.5 ,,	0.1	126 30.0 ,,	0.1	978.120	3	978.072	+ 48
284	91 V	4 32 ,,	3	126 01 ,,	3	978.096	4	978 081	+ 15
285	92 V	5 06 ,,	2	127 00 ,,	2	978.122	4	978.090	+ 32
286	93 V	5 16 ,,	1	128 00 ,,	1	978.134	4	978.092	+ 42
287	94 V	6 19 ,,	3	128 21 ,,	3	978.133	4	978.111	+ 22
288	95 V	6 50 ,,	3	127 14 ,,	3	978.148	3	978.122	+ 26
289	96 V	6 59 ,,	2	126 04 ,,	2	978.156	4	978.125	+ 31
290	97 V	7 41.7 ,,	0.2	125 42.8 ,,	0.2	978.151	4	978.141	+ 10
291	98 V	7 20 ,,	3	124 41 ,,	1.5	978.180	5	978.133	+ 47
292	99 V	7 28 ,,	3	123 24 ,,	2 .	978.154	5	978.136	+ 18
293	100 V	8 08.2 ,,	0.1	122 43.5 ,,	0.1	978.210	5	978.152	+ 58
294	101 V	8 14.8 ,,	0.2	121 37.0 ,,	0.2	978.166	5	978.155	+ 11
295	102 V	7 50 ,,	2	120 48 ,,	2	978.024	5	978.145	−121

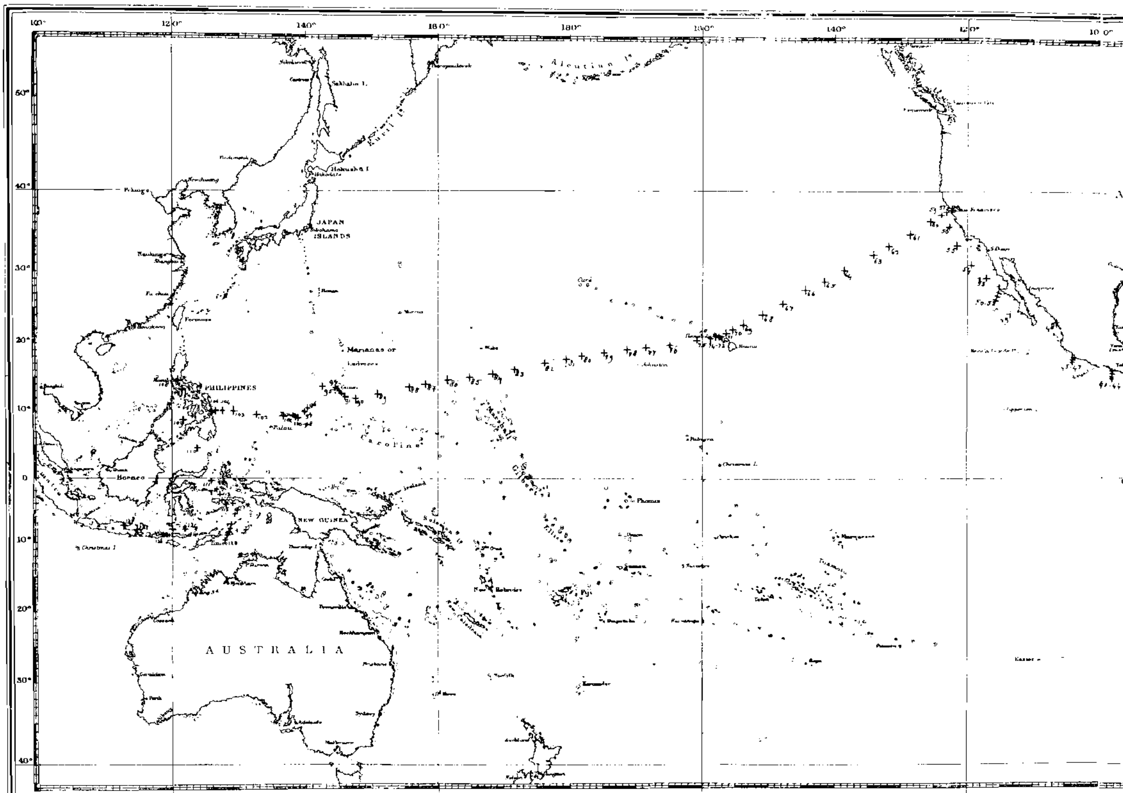
Nr. Stat.	Nr. Voyage	φ	m_φ miles	λ	m_λ miles	g_0	m_g	γ_0	A
		° ′		° ′					
296	103 V	8 20.0 S	0.2	119 49 0 E	0 2	978.267	6	978.157	+110
297	104 V	7 50 ,,	2	118 41 ,,	1	978.045	6	978.145	−100
298	105 V	8 02 ,,	2	117 17 ,,	2	978.105	6	978.149	− 44
299	106 V	7 19.9 ,,	0.3	113 51.6 ,,	0.2	978.141	4	978.133	+ 8
300	107 V	6 51.3 ,,	0.1	115 42.5 ,,	0.1	978.178	4	978.122	+ 56
301	108 V	6 25.5 ,,	1	116 51 ,,	1	978.154	4	978.113	+ 41
302	109 V	6 25.5 ,,	1	117 44 ,,	2	978.156	4	978.113	+ 43
303	110 V	6 29.2 ,,	0.2	118 51.2 ,,	0.2	978.162	3	978.115	+ 47
304	111 V	6 19 5 ,,	1	119 49 ,,	1	978.108	6	978.111	− 3
305	112 V	5 44.1 ,,	0.1	120 27.3 ,,	0.1	978.171	4	978.100	+ 71
306	113 V	4 45.8 ,,	0.1	120 28.6 ,,	0.1	978.179	4	978.084	+ 95
307	114 V	3 56 ,,	1.5	120 46 ,,	1.5	978.029	5	978.073	− 44
308	115 V	3 14 ,,	1.5	120 36 ,,	1.5	978.017	5	978.065	− 48
309	116 V	4 03.4 ,,	0.0	121 35.0 ,,	0.0	978 082	3	978.075	+ 7
310	117 V	5 03 ,,	1	121 22.5 ,,	1	978.116	4	978.089	+ 27
311	118 V	5 58 ,,	5	121 43 ,,	1.5	978.139	4	978.105	+ 34
312	119 V	5 27.3 ,,	0.0	122 37.0 ,,	0.0	978.164	3	978.095	+ 69
313	120 V	6 25 ,,	1	122 58 ,,	1	978.134	4	978.113	+ 21
314	121 V	5 58 ,,	0.2	124 12 ,,	0.2	978.186	4	978.105	+ 81
315	122 V	6 12 ,,	2.5	125 10 ,,	2.5	978.094	5	978.109	− 15
316	123 V	5 44 ,,	2	126 02 ,,	2	978.115	4	978.101	+ 14
317	124 V	5 07 ,,	2	125 06 ,,	2	978.143	4	978.090	+ 53
318	125 V	4 32 ,,	2	124 12 ,,	2	978 100	4	978.081	+ 19
319	126 V	3 51.5 ,,	1	123 15 ,,	1	978.167	4	978.072	+ 95
320	127 V	2 51 ,,	2.5	123 43 ,,	2.5	978.051	4	978.062	− 11
321	128 V	2 49 ,,	2	122 27 ,,	2	978.014	4	978.061	− 47
322	129 V	1 45 ,,	2	122 15 ,,	2	978.033	4	978.054	− 21
323	130 V	1 25.0 ,,	0.5	123 38.0 ,,	0.5	978.125	4	978.052	+ 73
324	131 V	0 40 ,,	1.5	124 36 ,,	1.5	977.867	4	978.050	−183
325	132 V	0 23.5 ,,	0.5	123 06.0 ,,	0.5	978.003	4	978.049	− 46
326	133 V	0 37.0 ,,	0.5	122 09.5 ,,	0.5	978.051	4	978.050	+ 1
327	134 V	0 45 ,,	1	121 18 ,,	1	978.020	3	978.050	− 30
328	135 V	0 35 ,,	1	120 29 ,,	1	978.008	4	978.050	− 42
329	136 V	0 01 ,,	1.5	121 15 ,,	1.5	978.066	4	978.049	+ 17
330	137 V	0 12 N	1.5	122 18 ,,	1.5	977.971	4	978.049	− 78
331	138 V	0 29.7 ,,	0.0	123 03.4 ,,	0.0	978.140	3	978.049	+ 91
332	139 V	0 07 S	1	124 00.5 ,,	1	977.942	4	978.049	−107
333	140 V	0 25 N	1	124 38 ,,	1	978.166	4	978.049	+117
334	141 V	0 42 ,,	3	125 43 ,,	3	977.967	4	978.050	− 83
335	142 V	1 33 ,,	1	125 46 ,,	3	978.077	4	978 053	+ 24
336	143 V	1 57.5 ,,	1	125 07 ,,	1	978.191	4	978.055	+136
337	144 V	1 29.8 ,,	0.0	124 50.1 ,,	0.0	978.209	2	978.052	+157
338	145 V	1 18.0 ,,	0.5	124 02.0 ,,	0.5	978.127	5	978.052	+ 75
339	146 V	1 58 ,,	2	123 15 ,,	2	978.034	4	978.055	− 21
340	147 V	2 49 ,,	1.5	122 48 ,,	1.5	978 092	4	978.061	+ 31
341	148 V	2 34 ,,	1.5	121 26 ,,	1.5	978.058	4	978.059	− 1
342	149 V	1 23.0 ,,	0.3	120 46.5 ,,	0.3	978.193	4	978.052	+141
343	150 V	2 06 ,,	2	119 46 ,,	2	978.007	4	978.056	− 49
344	151 V	1 36 ,,	2	119 03 ,,	1	978.122	5	978.053	+ 69
345	152 V	0 53.5 ,,	0.5	119 01.0 ,,	0.5	978.156	5	978.050	+106

Nr. Stat.	Nr. Voyage	φ	m_φ miles	λ	m_λ miles	g_0	m_g	γ_0	A
		° ′		° ′					
346	153 V	0 13 N	1	119 16.5 E	1	978.025	6	978.049	− 24
347	154 V	0 39.5 S	0.0	119 44 9 ,,	0.0	978.124	3	978.050	+ 74
348	155 V	0 42 ,,	1.5	118 26 ,,	1.5	978.032	4	978 050	− 18
349	156 V	0 51.5 ,,	0.5	117 43.0 ,,	0.5	978.146	4	978.050	+ 96
350	157 V	1 15.8 ,,	0.0	116 48.1 ,,	0 0	978.071	3	978.052	+ 19
351	158 V	1 48 ,,	2	117 44 ,,	2	978.053	4	978.054	− 1
352	159 V	2 10 ,,	2	118 23 ,,	2	978.026	4	978.056	− 30
353	160 V	2 34.5 ,,	0.2	118 46 5 ,,	0.2	978.047	4	978.059	− 12
354	161 V	3 11 ,,	2	118 04 ,,	2	978 150	4	978.065	+ 85
355	162 V	3 50 ,,	1.5	118 40 ,,	1.5	978.027	4	978.072	− 45
356	163 V	4 00.6 ,,	0.0	119 37.1 ,,	0.0	978.114	2	978.074	+ 40
357	164 V	5 07.7 ,,	0.0	119 24.4 ,,	0.0	978 138	3	978.090	+ 48
358	165 V	4 52 ,,	1	118 22 ,,	1	978.090	4	978.086	+ 4
359	166 V	4 50 ,,	2	117 18.5 ,,	1	978.143	4	978.086	+ 57
360	167 V	4 51.2 ,,	0.5	116 05.2 ,,	0.5	978.118	4	978 086	+ 32
361	168 V	5 10 ,,	1	114 53.5 ,,	1	978.135	4	978.091	+ 44
362	169 V	5 28 ,,	1	113 58.5 ,,	1	978.126	4	978.096	+ 30
363	170 V	6 07 ,,	2	113 28 ,,	2	978.141	4	978.108	+ 33
364	171 V	6 23 ,,	1	112 12 ,,	1	978.157	4	978.113	+ 44
365	172 V	5 43 ,,	1	111 00 ,,	1	978.158	4	978.100	+ 58
366	173 V	5 32 ,,	2	109 44 ,,	2	978.118	5	978.097	+ 21
367	174 V	5 18 ,,	2	108 30 ,,	2	978.123	4	978.093	+ 30
368	175 V	5 30 ,,	1.5	107 18 ,,	1.5	978.131	4	978.096	+ 35
369	177 V	5 35.5 ,,	0.3	103 58.0 ,,	0.3	978.095	4	978.098	− 3
370	178 V	4 51.1 ,,	0.1	103 22.0 ,,	0.1	978.112	4	978 086	+ 26
371	179 V	3 47 0 ,,	0 0	102 14.7 ,,	0.0	978.132	3	978.071	+ 61
372	180 V	4 09 ,,	1	101 45 ,,	1	978.032	4	978.076	− 44
373	181 V	4 29 ,,	1.5	101 17 ,,	1.5	978.152	4	978.080	+ 72
374	182 V	5 01 ,,	2 5	100 30 ,,	2.5	978.007	4	978.088	− 81
375	183 V	5 47 ,,	4	99 27 ,,	4	978 151	4	978.101	+ 50
376	184 V	6 24 ,	4	98 36 ,,	4	978.132	4	978.113	+ 19
377	185 V	5 34 ,,	3	98 02 ,,	3	978.102	4	978.098	+ 4
378	186 V	4 43 ,,	2	97 16 ,,	2	978.115	4	978 084	+ 31
379	187 V	3 54 ,,	2	96 36 ,,	2	978.092	4	978.073	+ 19
380	188 V	3 11 ,,	1.5	97 39 ,,	1.5	978.150	4	978.065	+ 85
381	189 V	2 34 ,	1,5	98 29 ,,	1.5	978.010	4	978.060	− 50
382	190 V	1 40.9 ,,	0.0	99 13.6 ,,	0.0	978.117	3	978.053	+ 64
383	191 V	1 20 ,,	1	99 48 ,,	1	977.995	4	978.052	− 57
384	192 V	1 00.1 ,,	0.0	100 22.1 ,,	0.0	978.057	3	978 051	+ 6
385	193 V	1 44.3 N	0.0	98 46.0 ,,	0.0	978.048	3	978.054	− 6
386	194 V	1 33 ,,	1	97 52.5 ,,	1	978.039	4	978.053	− 14
387	195 V	1 17.7 ,,	0.0	97 36.5 ,,	0.0	978 062	3	978.052	+ 10
388	196 V	1 21.5 ,,	0.5	97 03.0 ,,	0.5	978.107	4	978.052	+ 55
389	197 V	0 58.5 ,,	1	96 31 ,,	1	977.975	4	978.051	− 76
390	198 V	0 20 ,,	2	95 36 ,,	2	978.132	4	978.049	+ 83
391	199 V	0 26 S	3	94 30 ,,	3	978.074	4	978.049	+ 25
392	200 V	0 18 N	2	93 14 ,,	2	978.038	4	978.049	− 11
393	201 V	1 21 ,,	2	92 18 ,,	2	978.046	4	978.052	− 6
394	202 V	2 52 ,,	1	92 01 ,,	1	978.073	4	978.062	+ 11
395	203 V	3 39 ,,	1	92 43 ,,	1	978.055	4	978.070	− 15

Nr. Stat.	Nr. Voyage	φ	m_φ miles	λ	m_λ miles	g_0	m_g	γ_0	A
		° ′		° ′					
396	204 V	4 06 N	1	93 06 E	1	978.019	4	978.076	− 57
397	205 V	4 33 ,,	1	93 32 ,,	1	978.135	4	978.081	+ 54
398	206 V	5 12 ,,	2	94 12 ,,	2	977.968	4	978.091	−123
399	208 V	6 13 ,,	1.5	96 02 ,,	1.5	978.140	4	978.109	+ 31
400	209 V	6 26 ,,	2	96 38 ,,	2	978.104	4	978.113	− 9
401	210 V	5 35 ,,	2	97 20 ,,	2	978.094	4	978.098	− 4
402	211 V, 236 V	3 51.5 ,,	0.0	98 41.5 ,,	0.0	978.071	2	978.072	− 1
403	212 V	3 25.7 ,,	0.5	99 42.3 ,,	0.5	978.086	4	978.067	+ 19
404	213 V	2 45.8 ,,	0.5	101 09.4 ,,	0.5	978.086	4	978.061	+ 25
405	214 V	2 12.3 ,,	0.3	102 03.7 ,,	0.3	978.075	5	978.057	+ 18
406	215 V	1 09.3 ,,	0 0	103 54.0 ,,	0.0	978.077	3	978.051	+ 26
407	216 V	1 19 3 ,,	0.5	105 07.5 ,,	0.5	978.073	4	978.052	+ 21
408	217 V	0 45 ,,	1	106 21 ,,	1	978.084	5	978.050	+ 34
409	218 V	0 41.1 ,,	0.2	107 24.8 ,,	0 2	978.080	4	978.050	+ 30
410	219 V	0 25.5 S	1	107 33.5 ,,	1	978.090	4	978.049	+ 41
411	220 V	0 50 ,,	1	106 54.5 ,,	1	978.083	4	978.050	+ 33
412	221 V	1 14.0 ,,	0.5	106 00.0 ,,	0.5	978.081	4	978.051	+ 30
413	222 V	1 37.1 ,,	0.3	105 08.5 ,,	0.3	978.099	3	978.053	+ 46
414	223 V	2 59.4 ,,	0.1	104 46.2 ,,	0.1	978.116	3	978.063	+ 53
415	224 V	3 31 ,,	1	106 41.5 ,,	1	978.114	4	978.068	+ 46
416	225 V	3 09.7 ,,	0.5	107 23.9 ,,	0 5	978.100	4	978.065	+ 35
417	226 V	2 44.3 ,,	0 0	107 36.2 ,,	0.0	978.088	3	978.061	+ 27
418	227 V	2 19.1 ,,	0.7	108 39.3 ,,	0.7	978.098	4	978.057	+ 41
419	228 V	3 00 ,,	1.5	109 06 ,,	1.5	978.082	4	978.063	+ 19
420	229 V	3 43 ,,	1	109 20 ,,	1	978.102	4	978.071	+ 31
421	230 V	4 02 ,,	2	110 30 ,,	2	978.109	4	978.074	+ 35
422	231 V	4 22 ,,	2	111 22 ,,	2	978.110	4	978.079	+ 31
423	232 V	4 44 ,,	1 5	112 26 ,,	1.5	978.125	4	978.084	+ 41
424	233 V	5 37.9 ,,	0.5	112 33.7 ,,	0.5	978 120	4	978.099	+ 21
425	237 V	1 15.8 N	0.0	103 50.7 ,,	0.0	978.087	3	978.052	+ 35

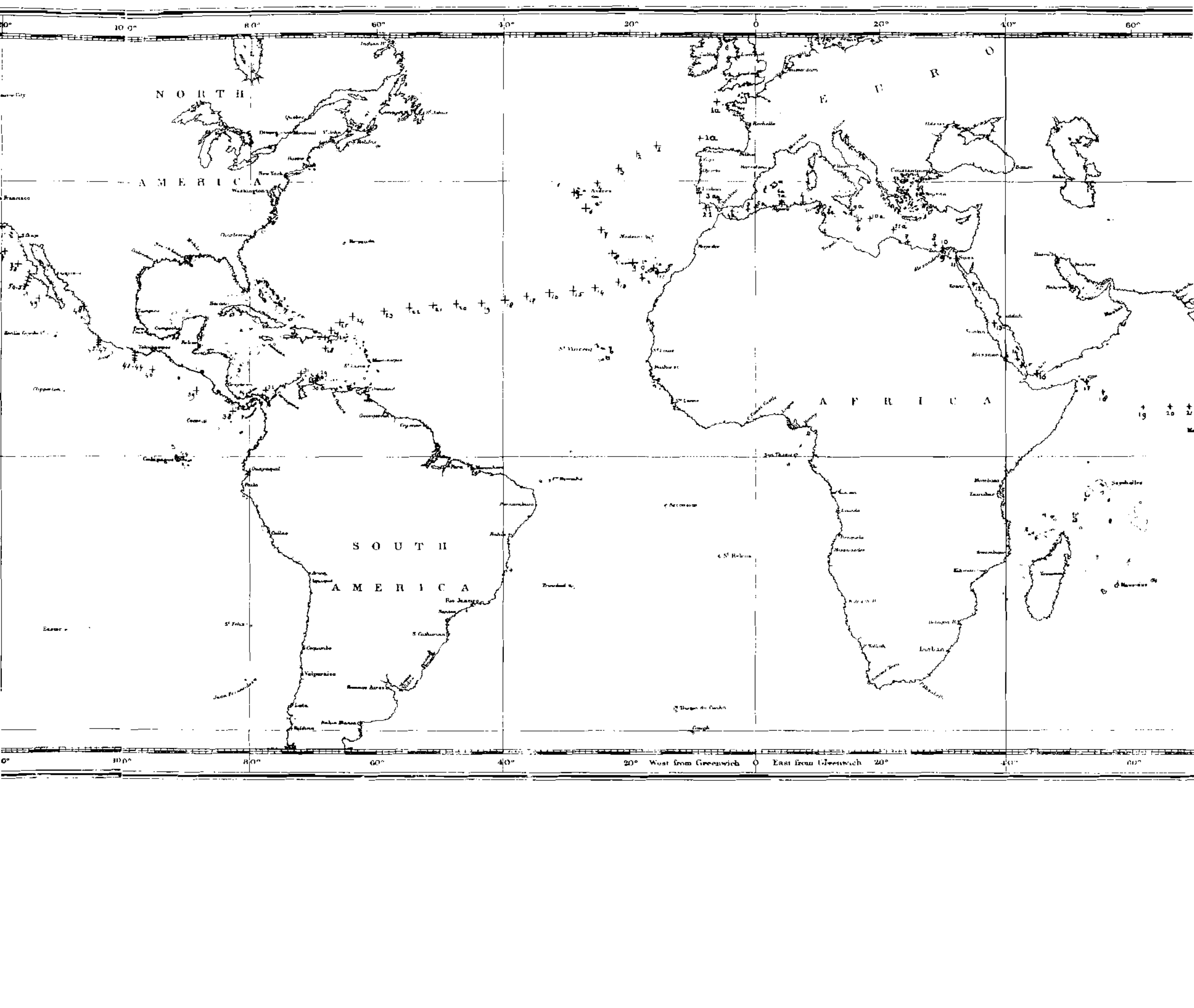
1 Nautical Mile = 1853 Meters.

I. Holland-Suez-Jav
II. Holland-Alexandr
III. Holland-Panama-

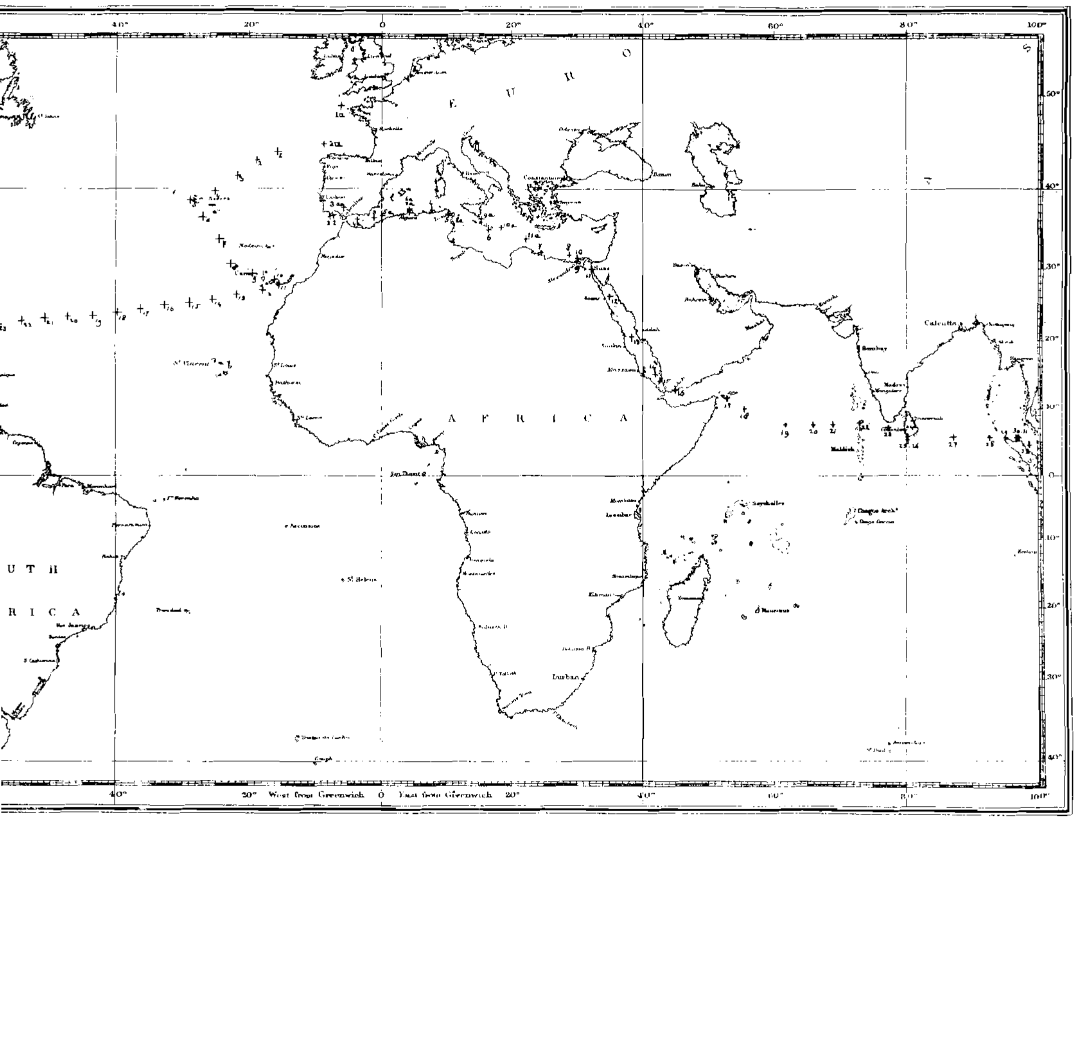


Maritime Gravity Stations.

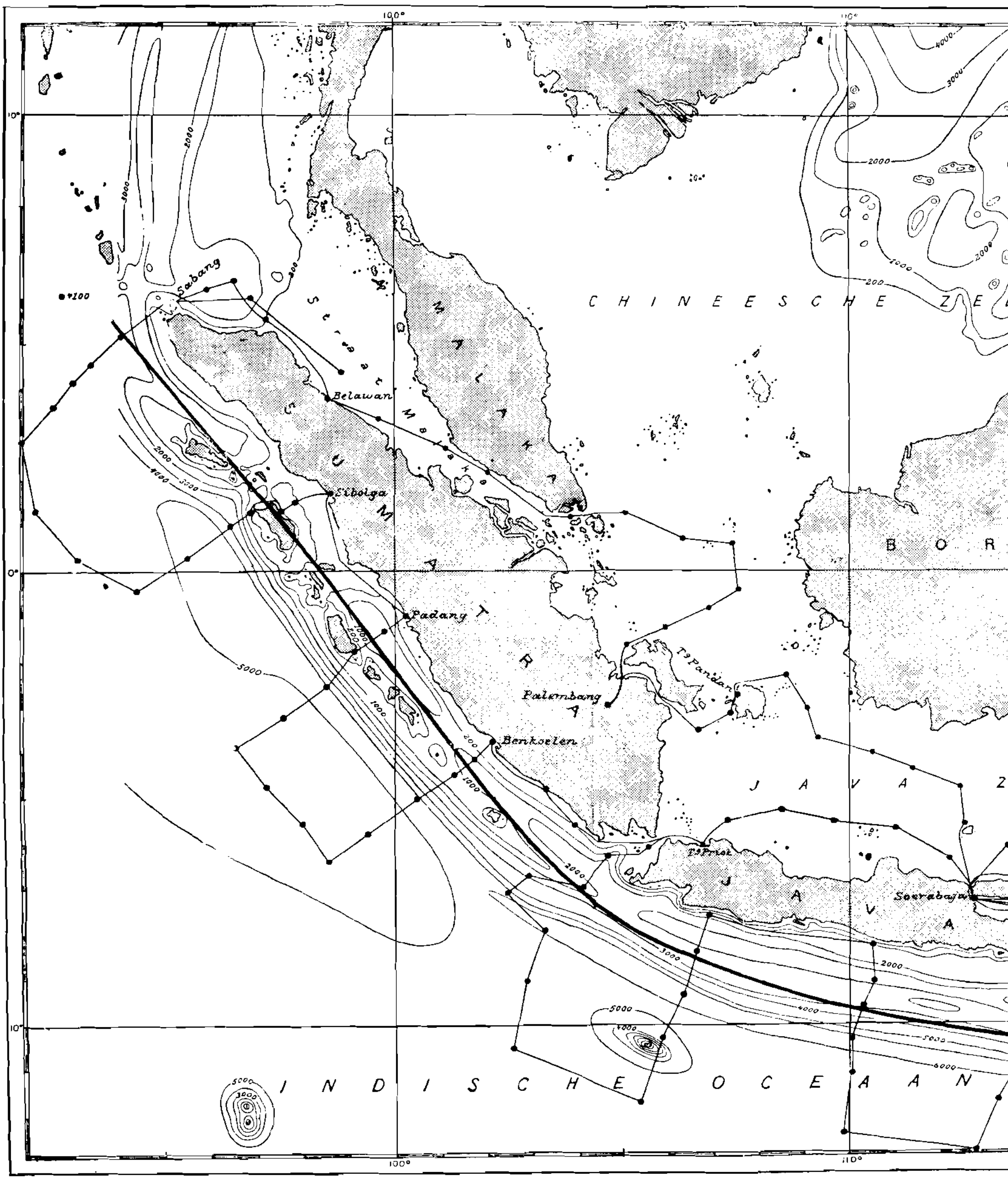
I. Holland-Suez-Java in 1923.
II. Holland-Alexandria in 1925, (stations indicated by *a* behind the number).
III. Holland-Panama-Java in 1926.



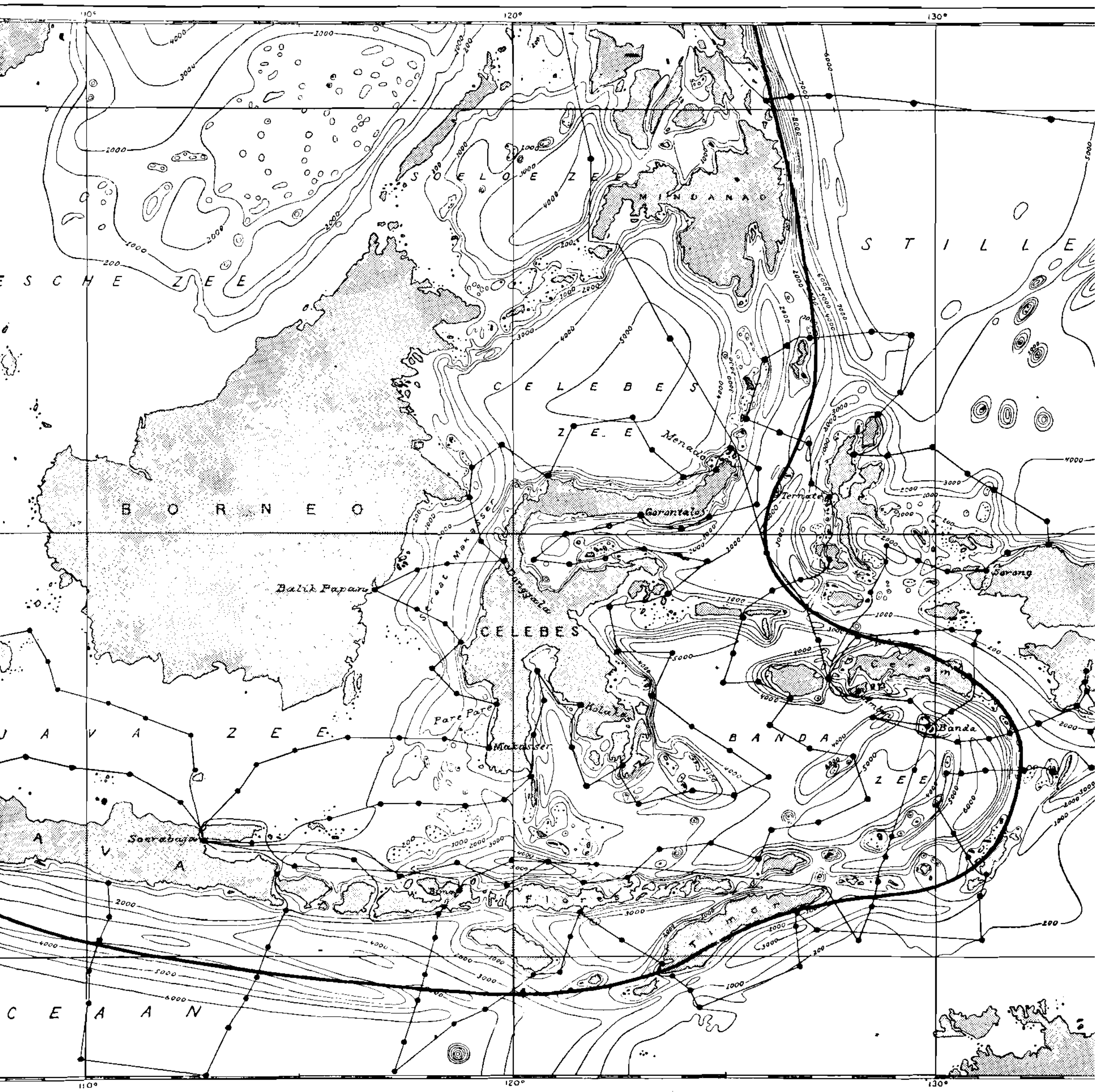
hind the number).



Maritime Gravity Stations in the I



ravity Stations in the Netherlands East Indies, 1923, 1926, 1927, 1929 and 1930.



ies, 1923, 1926, 1927, 1929 and 1930.