Terrestrial Magnetism

and

Atmospheric Electricity

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THE MAGNETIC SURVEY OF THE NORTH PACIFIC OCEAN: INSTRUMENTS, METHODS, AND PRELIMINARY RESULTS.[1]

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NEED OF OCEANIC SURVEYS.

As is well known, the Carnegie Institution of Washington authorized its Department of Terrestrial Magnetism to undertake a magnetic survey of the North Pacific Ocean, and made a provisional allotment of $20,000 to cover the initial costs of its inauguration and progress during the year 1905, in accordance with a plan submitted by Messrs. L. A. Bauer and G. W. Littlehales.[2] [The allotment for 1906 has been sufficiently enlarged to permit the continuous and uninterrupted prosecution of the work, and ample assurance has been received of similar allotments, so that the systematic magnetic survey of the oceanic areas, not alone of the North Pacific Ocean, is now an assured fact.]

A single quotation will suffice to show that there were good grounds for the undertaking of an oceanic magnetic survey, and for beginning first of all with the Ocean, so rapidly developing in commercial importance—the North Pacific Ocean.

Professor Arthur Schuster states as his opinion: "I believe that no material progress of terrestrial magnetism is possible until the magnetic constants of the great ocean basins, especially the Pacific, have been determined more accurately than they are at

[1] Summary of two addresses before the Philosophical Society of Washington, (October, 1905, and April, 1906), and before the American Physical Society (in October, 1905), with additions to date.

[2] See *Terr. Mag.*, Vol. IX, p. 163.

present. There is reason to believe that these constants may be affected by considerable systematic errors. It is possible that these errors have crept in by paying too much attention to measurements made on islands and along the sea coast. What is wanted are more numerous and more accurate observations on the sea itself."

When it is recalled that the oceanic areas embrace nearly three-fourths of the entire surface of the Earth, it is easily understood how preponderating the effect of lack of accurate data over this portion of the globe may be upon the settlement of the greater problems pertaining to the Earth's magnetism.

To illustrate: it may be recalled that I made a carefully guarded announcement about three years ago that the Earth was seemingly losing its magnetic energy.[3] This conclusion resulted from careful calculations based upon the best magnetic maps available to date. It may further be recalled that later I repeated my computations of the Earth's magnetic moment or intensity of magnetization, this time dependent upon actually observed quantities on islands and continents, distributed as uniformly over the globe as the distribution of land would permit, and I found that from 1890 to 1900 there apparently had occurred a shrinkage of the Earth's magnetic moment at about the same rate per year, as had been deduced from the magnetic charts between 1840 and 1885, viz., about $\frac{1}{2400}$ part annually. This rate of shrinkage is so large that were it to continue in the same proportion year after year, the Earth would lose half of its present amount of magnetism in 1660 years.[5]

As stated, this result has been arrived at in two totally different ways, and based each time upon entirely dependent data, and, as far as I know, the methods employed have not been questioned. Yet, the deduction is such a startling one, and, if it be true, will have such an important bearing on problems of terrestrial physics, that it behooves us to be cautious until we can once more verify the matter with the aid of fresh data over the seas as well as on land.

Another interesting outcome of my analysis of the Earth's

[3] *Terr. Mag.*, Vol. VIII, 1903, pp. 97–108.

[4] *Terr. Mag.*, Vol. IX, 1904, pp. 182–186.

[5] This, of course, does not imply that in another 1660 years the Earth will have lost all of its magnetism, but merely that in 3,300 years the amount of magnetism would be one-fourth that at the present time, etc.

permanent magnetic field—one that was certainly not looked for—was that our knowledge of the distribution of the Earth's magnetism was as well known for the epoch 1840–45 as for the later epoch 1885, perhaps even better known, in spite of the fact that magnetic surveys had multiplied, and had been zealously prosecuted by various countries since the earlier epoch.[6] However, these additional surveys applied chiefly to land areas, and not until the recent Antarctic expeditions were observations forthcoming from Southern Oceans. It was necessary, therefore, in the construction of the magnetic charts for 1885 to use a great deal of the same material as was used by Sabine in his charts for 1840–45, and to refer it to 1885, with the aid of more or less conjectural rates of secular change.

This conclusion emphasized forcibly the uselessness of attempting a re-determination of the magnetic constants of the Earth with the aid of the data at present available, and I have been informed that an attempt in that direction which had been begun by an eminent foreign magnetician has been abandoned since the announcement of this conclusion.

Again, an exhaustive examination of all magnetic data possessed up to date, seemed to point to the existence of a system of vertical Earth-air electric currents passing from the air into the Earth and vice versa, these currents being associated apparently with the general circulation of the air, so that over the region of the Earth where we have in general upward air currents, as in the equatorial regions, we have an upward flow of positive electricity, and where the air currents proceed in general downward, we have a downward stream of positive electricity.[7]

This is the deduction from the magnetic data. Students of atmospheric electricity, however, have difficulty in harmonizing the strength of the current deduced with the known electric facts of the atmosphere; though I have been informed by certain investigators that the phenomena of radioactivity and other recently observed phenomena may possibly help in supplying the connecting link. Be that as it may, the settlement of this question was considered important enough to form the subject of a special resolution at the meeting of the International Association of Academies held in London, May, 1904.

The proposition submitted to the Association by the Berlin

[6] *Terr. Mag.*, Vol. VIII, p. 127.
[7] See *Terr. Mag.*, Vol. IX, p. 127.

Academy, as the result of a paper by the eminent investigators von Bezold and Schmidt, called for a magnetic survey along a line, or rather a small strip around the entire globe, near the parallel 50° North. If the line integral of the magnetic force taken along this closed circuit be found equal to zero, the proof of the non-existence of the electric currents above referred to will be proven, at least for that part of the Earth. If, on the other hand, the line integral be found to have had an appreciable value, then conclusions will result regarding the existence and direction of the currents.

Since such a line integral must, to a great extent, traverse oceanic areas, it was decided by the Association to appoint a Committee which should first consider the question as to the reliability of the determination of the magnetic elements at sea. Though I am a member of this Committee, I am not aware that anything has as yet been done by it. This paper, however, may be regarded as a first contribution to the settlement of the question as to the accuracy of magnetic data acquired at sea.

These prefatory remarks will serve to present briefly the present status of some of the greater problems of the Earth's magnetism. Their final solution will not be had until the completion of an accurate magnetic survey of the oceans as well as of the land. However great this task of the General Magnetic Survey of the Earth may appear, I have now had sufficient experience to know that with good system and management, and ample funds, the work can be completed in a period of about fifteen years—the time being primarily dependent upon the resources at disposal. [During the present year, the writer will resign his official duties in connection with the Magnetic Survey of the United States, now over two-thirds completed, in order to devote his entire energies to the directing of this greater task.]

We owe it to the enlightened interest of the administrators of the Carnegie funds that already sufficient encouragement has been given to warrant its becoming generally known that the magnetic survey of the oceanic areas has at last been seriously undertaken by an organization in which confidence can be placed.

It is also gratifying that in addition to the co-operation of the Carnegie Institution in this great enterprise, assurance has been received of the co-operation and good will of the existing foreign organizations engaged in magnetic work. A resolution to this effect was likewise passed at the meeting held last September at Innsbruck, Austria, of the International Committee on Terrestrial Magnetism and Atmospheric Electricity, composed chiefly of directors of meteorological and magnetic institutions.

I have said nothing regarding the *practical* and *economical* importance of the magnetic survey of the North Pacific Ocean, e. g., as applying to the needs of the mariner. Suffice it to say that no one until now has been able to tell precisely how closely the prevailing magnetic charts could be relied upon.

Thus, Captain Creak, for many years Superintendent of the Compass Department of the British Admiralty, now retired, said some years ago: "The North Pacific Ocean is, with the exception to the voyage of the *Challenger*, nearly a blank as regards magnetic observations."

My address will, in some measure, answer this question, and it will be seen that the outcome of this survey has likewise a real economic value.

Previous Oceanic Magnetic Surveys.

Before passing to the present ocean magnetic survey let us briefly refer to previous work.

The first attempt at an oceanic magnetic survey was made by the noted astronomer, Edmund Halley, between 1697 and 1701. He was put in command of a sailing vessel, the *Paramour Pink*, on which he made several voyages in the North and South Atlantic Ocean, penetrating to the 52° of south latitude. Only the magnetic declination was determined, since at that time instruments for measuring dip and intensity at sea had not been invented. He embodied the results of these observations on a chart of the "Lines of Equal Magnetic Variation," which method of portraying the distribution of the magnetic elements he first successfully introduced.

Passing over various succeeding expeditions, we come to the most serious and first really important undertakings for magnetic science in general, viz., those of the *Erebus*, the *Terror* and the *Pagoda* of 1840-45, chiefly in the Southern Oceans. Here we have the first elaborate attempt at the determination of the three magnetic elements at sea, the Fox dip circle for measuring dip and intensity at sea having just been invented. This work was under the direction of Sabine, who has done so much for the advancement of magnetic science, and was most carefully executed. Not only was it ably directed, but the commanding officers of the vessels, one of whom, for example, was Captain Ross, the discoverer of the North Magnetic Pole, were most zealous and painstaking. The attempt was made to secure full series of observations daily, and these were secured at times under great physical difficulties, as, for instance, in the Antarctic regions. The ships were repeatedly "swung," and every attempt was made to determine accurately the deviation constants.

It will be of interest to point out in this connection that it was not alone the invention of an instrument for measuring the dip and intensity at sea that made this memorable and remarkable work possible, but also the elaboration of the mathematical theory of the deviations arising from the unavoidable iron on board a vessel, published by Poisson a year before the inception of the survey in 1839. Working with Poisson's formulæ, Archibald Smith, at Sabine's request, put the determination of the various necessary corrections in a practical form, so that they could be successfully applied.

We can only mention the expedition of the Austrian frigate *Novara*, which secured a valuable series of declination data while circumnavigating the globe in 1857–1860.

Next were the two notable expeditions of the *Challenger*, 1872–76, and the *Gazelle*, a German vessel, 1874–76. Both of these measured the three magnetic elements over various regions of the globe.

Mention must also be made of important work done by the French Navy, e. g., that of the *Dubourdieu*, in 1896, and of other vessels and the work of the recent Antarctic expeditions.

The work of the Coast and Geodetic Survey vessels also deserves brief notice, for it was the successful inauguration of the magnetic work on these vessels, in 1903, which gave me the experience required for the undertaking of the Carnegie Institusion oceanic work. Since 1903, the said vessels have utilized every opportunity in passing from port to port, while engaged on their regular surveying duties, to determine the three magnetic elements. Thus valuable series of observations have been obtained along the Atlantic and Pacific Coasts and in the Gulf of Mexico.

Present Ocean Magnetic Survey.

The Vessel Galilee.

After considerable advertising on the part of the Consulting Hydrographer of the Department, Mr. G. W. Littlehales, during

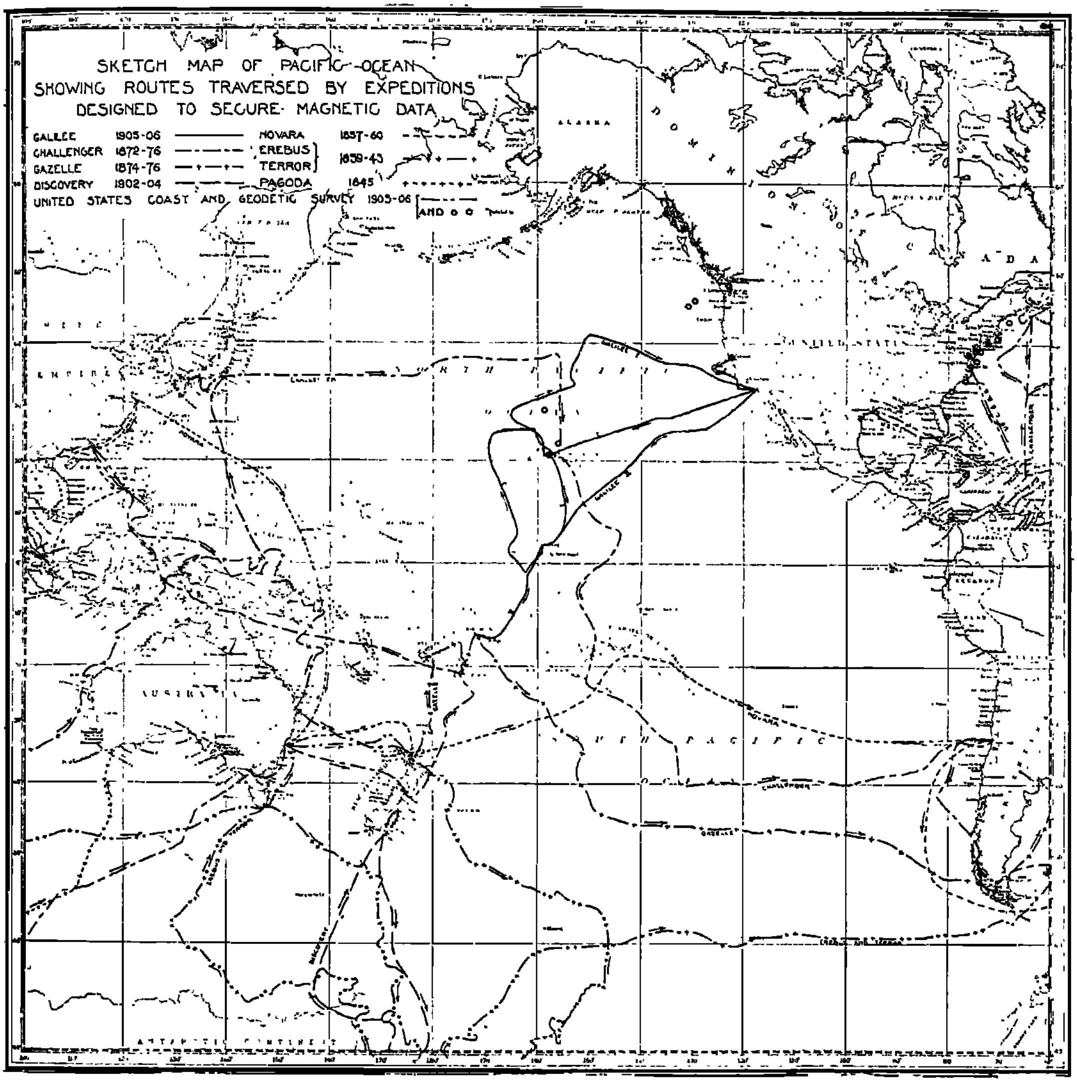


FIG. 1. Showing the routes traversed by various vessels which have secured magnetic data The cruises of the *Galilee* up to May, 1906, are shown by full lines.

my absence in Europe early in 1905, the brig *Galilee* was selected as the best vessel on the Pacific Coast available for the proposed work. The subsequent experience has shown that the choice was a good one. The *Galilee* is a wooden sailing vessel, built in 1891, at Benicia, California, by Mathew Turner, an experienced ship builder, from whom the vessel is chartered, with sailing master and crew of ten men. Her length is 132.4 feet; breadth, 33.4 feet; depth, 12.6 feet, and she has a displacement of about 600 tons. She is one of the fastest sailing vessels of her size in the Pacific Ocean, her greatest record being 308 knots in twenty-four hours, with full cargo. The principal changes required were the substitution of the steel rigging by hemp rigging; the removal, as far as practicable, of the iron parts in the vicinity of place of observation; the construction of an entirely non-magnetic flying or observing bridge, running fore and aft between the two masts and elevated above the deck so that the instruments would be at a height of fifteen feet above the deck and twenty-five feet or more from the principal bolts in the sides of the vessel, and the building of the living quarters for the scientific personnel. While, then, this vessel was not entirely non-magnetic, not having been especially built for the purpose, the effect of the remaining iron, as will be seen later, was so slight as to produce, at the places of observations, the smallest deviation co-efficients of any vessel thus far engaged in magnetic work, including the two recent Antarctic ships, the *Gauss* and the *Discovery*, both partly designed especially for magnetic work. After a first trial cruise, a few modifications were made, and at the end of the first cruise, last December, some additional changes were undertaken which have resulted in further improvement.

On page 144, Vol. X, of this Journal, is given a cut showing the condition of the vessel on her first cruise. See also Plate I, March issue of current volume. The illustration (Fig. 2) opposite represents the condition of the vessel on the present or second cruise, the principal alterations over last year consisting in the extension of the observing bridge and the removal of the galley to forward of the foremast.

Cruises and Personnel.

The first cruise consisted of an experimental trip from San Francisco to San Diego, Cal., during which various instruments and methods were subjected to trial under my direction, I having accompanied the expedition as far as San Diego. Magnetic observations were made at various places on the shores around San Francisco Bay, and the most suitable place for swinging ship by their means was determined. The ship was swung with the aid of a tug on August 2d, 3d, and 4th, in San Francisco Bay, between Goat Island and Berkeley, California, and the various deviation coefficients were determined. On August 5th the *Galilee* sailed from San Francisco, secured magnetic observations daily to a greater or less extent, according to conditions of the weather and sea, swung twice under sail, and arrived at San Diego August 12th. After some further alterations had been made here, the magnetic elements observed at four

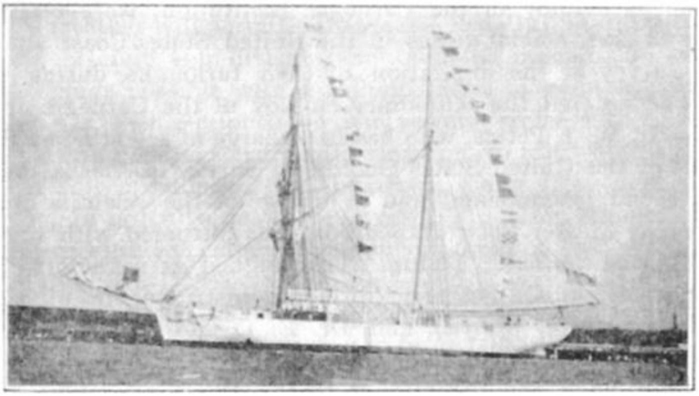


FIG. 2. The *Galilee* at San Diego, California, on February 22, 1906, dressed in honor of Washington's birthday.

shore stations, and the ship deviations again determined from two days' swings, the vessel set sail on September 1st for a cruise which embraced the Hawaiian Islands, Fanning Island, Magnetic Equator, back again in a circuit to the west, between the Hawaiian Islands and Midway Island, returning to Honolulu, and starting once more from there, proceeding somewhat to the northward of latitude 40° N., and returning to San Diego, December 9th. During this period of three and one-third months, two complete circuits, each of considerable area, were made, the combined length of the two being somewhat over 10,000 nautical miles. The expedition was in the command of Mr. J. F. Pratt, an experienced officer of the Coast and Geodetic Survey, who also supervised the alterations of the vessel, as stated above. He was assisted by Dr. J. H.

Egbert, surgeon and magnetic observer, Mr. J. P. Ault, magnetic observer, and Mr. P. C. Whitney, watch officer and magnetic observer. The entire work of 1905 is referred to as "*First Cruise.*" (See Fig. 1.)

Upon the return of the vessel the necessary harbor swings and control shore observations were carried out December 11th to 18th, before any of the subsequent alterations were made on the ship and on the instruments. During this period I was obliged to make another trip to the Pacific Coast, in order to settle the various matters relating to the continuation of the work and the proposed alterations. The scientific personnel had to be reorganized, as the former members, with the exception of Mr. Ault, who was in the permanent employ of the Carnegie Institution, were obliged to return to their official duties in the United States Coast and Geodetic Survey at the expiration of their furloughs, during which they had entered the temporary employ of the Carnegie Institution. Mr. W. J. Peters, who has had charge of scientific exploring parties of the United States Geological Survey in Alaska, and had been second in command and in charge of the scientific work of the recent Ziegler Polar Expedition, was intrusted with the command of the *Galilee.* To him were assigned as assistants Mr. J. P. Ault, Mr. J. C. Pearson (formerly instructor in physics at Bowdoin College, Maine), and Dr. E. C. Martyn, surgeon and recorder. Mr. Peters took command of the party in January, 1906, and upon the completion of the ship's alterations, shore magnetic observations, and various ship swings, set sail from San Diego on March 2d last for Fanning Island, where he arrived March 31st. Leaving there he proceeded to Apia, Samoan Islands, arriving on May 2d. Upon the completion of the comparisons of the instruments at the Samoan Magnetic Observatory, and various ship swings, he next set his course for the Fiji Islands, reaching there on May 17th, and is now on his way to Yokohama via Marshall Islands and Guam. From Yokohama he will proceed to Kiska, Aleutian Islands, then possibly to Sitka, if the season for good work be not too far advanced, and then return to San Diego, Cal. San Diego, on account of its equable climate the entire year, was chosen in preference to San Francisco, as a convenient base station or home port for the various cruises. The entire cruise of 1906, which will be known as the "*second cruise,*" will embrace about 20,000 nautical miles; the vessel is expected back at San Diego towards end of year. (See Fig. 2.)

The general principle followed is to secure complete control of each instrumental constant in every available manner, and to obtain independent checks upon the observed values of the magnetic elements by securing simultaneously two independent determinations of each element, as far as possible, under different conditions; i. e., different observers, different instruments, and at different stations on the observing bridge, so that the ship correction will be either of varying amount or even of different sign. Besides the special harbor swings, with both helms made on different days, when a tug is available for swinging ship, swings at sea, under sail, are prescribed at as frequent intervals as conditions of sea and weather will permit. Under sail, usually one and sometimes two out of eight equi-distant points will be missed. In order to make swings possible with a sailing vessel in calm weather, the *Galilee* has been equipped on her second cruise with a naphtha launch swung at the stern davits when not in use. With the aid of this the ship is pulled around or drawn along, if need be, in calm weather, in order to make progress. This has been tried with some success in the calm weather encountered on part of the recent cruise from San Diego to Fanning Island.

At other times the magnetic observations are made on the ship's course, the endeavor being to distribute the observations over varying courses as far as possible. In other words, the attempt is to vary the magnitude and sign of the deviation corrections between successive swings as much as possible for the conditions encountered.

Upon arrival at a port, besides harbor swings, shore observations are made, both with the set of absolute land magnetic instruments (Cooke magnetometer and Dover dip circle—an earth inductor ordered was not available for this cruise) and with the ship magnetic instruments, consisting of an L. C. dip circle, Standard Ritchie liquid compass, and L. B. deflector, described below. And wherever there is a magnetic observatory, e. g., at Honolulu, Samoa, Tokio, and Sitka, all instruments are compared with the observatory standards. Thus sufficient opportunities are afforded for the required control of the instrumental constants.

The magnetic declination on board ship is determined chiefly with a Standard 8-inch Ritchie United States Navy liquid compass and azimuth circle of latest pattern, and some secondary results are likewise secured with a second Ritchie liquid compass, provided with a Negus azimuth circle, and also with a Kelvin dry compass and azimuth attachment. Practically every modern azimuth device has been given a trial, and none has been found equal to the essentials of all the varied conditions encountered. In general, the simplest devices are found to be the best. With a bright sun and in fairly calm weather, good results can be obtained by a careful observer with either of the best azimuth circles at present in use. The observers on the *Galilee* were found, in general, for the varied conditions encountered, to give preference to the Ritchie azimuth circle noted above, this having both a prism reflection device for fairly bright sun, as also a direct vision method. There is apparently considerable room here for improvement, for it frequently happens that under conditions which would still permit securing good azimuth observations on land, none can be made at sea, because of the Sun being either too high or too faint to admit of obtaining good results with the available azimuth devices. It is hoped to construct an instrument for use in the next cruise which will overcome this difficulty.

The difficulties of always securing azimuth observations at sea is further increased by the meteorological conditions frequently encountered on the Pacific, viz., clouds and fog. For example, on the cruise from San Francisco to San Diego last summer, we went out to sea 150 miles to get beyond the fog prevailing on the Coast at that time of the year, and not until the fourth day out did we secure azimuth observations, and, hence, declination results. *In fact, the problem of securing the magnetic bearings of celestial objects, and hence results for magnetic declination, is the most serious one encountered in the steady progress of the magnetic survey of the North Pacific Ocean.* In time of cloud or fog, results for magnetic dip and intensity can be obtained, but none for magnetic declination. If, for example, the *Galilee* does not leave Yokohama in time to complete the northern part of her present circuit during July, August, and September, she may have but very few opportunities to secure declinations on the return portion of her cruise. She may encounter on this entire portion weather that would ordinarily be characterized as fine navigation weather, admitting the securing of sufficient sextant observations for the navigating of the vessel, but she may yet fail to obtain satisfactory magnetic declination results and in sufficient number chiefly on account of the instrumental difficulties above mentioned.

Practically every difficulty for securing magnetic results at sea, with the desired degree of accuracy, has been surmounted, as will be seen from the specimen results shown later, with the exception of this particular one—how to secure magnetic declinations when no celestial object is visible with the aid of which a true azimuth can be determined. On land, the magnetic meridian can be referred to some fixed object, the azimuth of which may be determined at leisure and when the skies permit. At sea, in cloudy weather, no such fixed object is to be had. Tests are to be made as to how far a device similar to the Anschütz gyroscope will solve this problem.

The dip or inclination and total intensity are determined with the well known Lloyd-Creak dip circle. During the present cruise the original instrument has been improved so as to admit of not only securing deflection observations over the entire Pacific Ocean, but likewise at two distances. For the deflection distance provided in the original instrument, deflections failed on the first cruise before reaching Honolulu; i. e., when a dip of about 40° was reached. (See Figure 1.) Each of the two operations for total intensity (deflections and loaded dip observations) are treated separately in the reductions and the constants independently determined. Each deflection observation, long distance and short distance, gives, moreover, a dip determination, and in addition regular dip observations are made with the two needles provided for this purpose. In 1905 the agreement between the dip obtained from the said deflection observations and as derived with the regular dip needles, was not always satisfactory. Upon investigation it was found that this was entirely due to the lateral play of the suspended intensity needle, No. 3, in the jewels: namely, in these L. C. dip circles, the maker does not always get the pivots of the various needles provided of precisely the same length, hence, in order not to have the jewels so close as to bind on the pivots of any one needle, they are put far enough apart to prevent this. It thus happens that for the needle with the shortest pivots, which, in the present case, happened to be intensity needle No. 3, some lateral play resulted. When rubbing the brass point with the ivory scraper, or owing to the motion of the ship the suspended needle may move closer or farther away from the fixed deflecting needle (No. 4), by a fraction of a millimeter—sufficient to produce an appreciable error in the observations. It only required a change in the deflecting distance from 7.3 cms. to 7.9 cms., to make the instrument and method available over the entire Pacific Ocean instead of for the limited area noted above. The jewels are adjusted so as to fit needle No. 3 and other needles substituted for those that were found to bind for this position of the jewels. This instrument has proven in our hands, as well as on the Coast and Geodetic Survey vessels, a satisfactory instrument, contrary to the experience of the observer of the German Antarctic Expedition. With the further improvements as noted above, it appears to be well adapted for its purpose. Especial

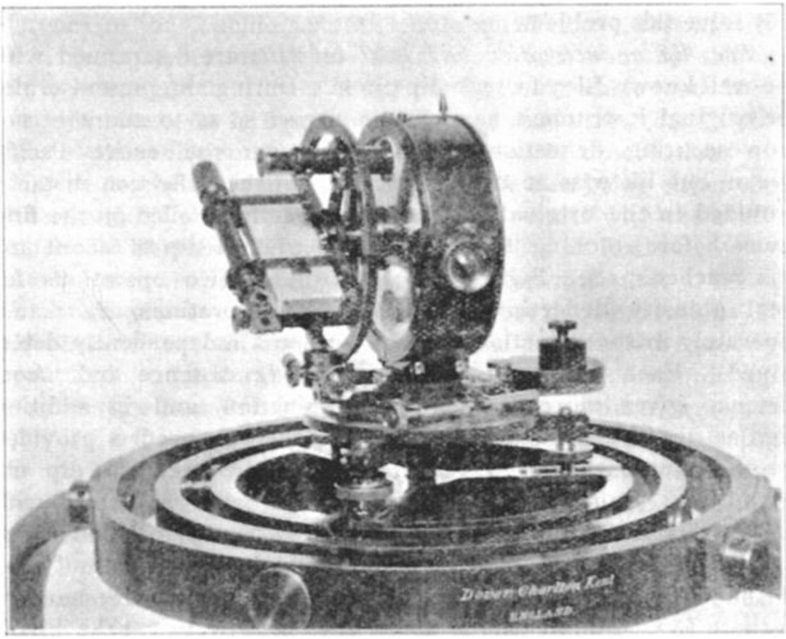


FIG. 3. The L. C. dip circle, mounted on gimbal stand, as used on board the *Galilee*, showing the modifications mentioned above.

attention has also been paid to the accurate balancing and leveling of the instrument, with the aid of an adjustable counterpoise, when mounted on board ship on the gimbal stand. [For certain shore work, I have also had added a compass attachment and an astronomical telescope so as to make it a universal instrument— a theodolite, dip circle and magnetometer combined. See Fig. 3.]

In addition to obtaining the *horizontal intensity* by means of dip and total intensity measurements with the L. C. dip circle, a simple deflection apparatus has been devised for observing the horizontal intensity direct which has been in successful use since the beginning of the work. For one reason or another, previous appliances for measuring the horizontal intensity at sea had not proven entirely satisfactory. Briefly described, the present device consists of a sine deflection method, the deflecting magnet, instead of being mounted in the same horizontal plane with the deflected magnet, and off to one side, e. g., to the east or to the west, as in most forms of field magnetometers, is mounted *vertically* above the center of the deflected magnet system, which, in the present instance, consists of an ordinary 8-inch Ritchie-Negus liquid compass. A bridge, with a disk on top for carrying the deflecting magnet, was attached at right angles to the sight line or sight bows of the latest form of Negus azimuth circle, provided with the said liquid compass. These sight bows, consisting of two stout parallel brass wires bent into bows, as shown in Fig. 4, and somewhat over a millimeter apart, define the sight plane passing between them and a brass pointer, with the aid of which the compass is read, or any point thereof set upon; they take the place of the telescope in the field magnetometer. To make a setting with the deflecting magnet mounted on the disk, turn the azimuth circle, carrying the deflector and sight bows, until the brass pointer is over the south end of the compass card, then, since the magnet, by construction, is mounted at right angles to the sight line or bows, and as the latter were set directly over or parallel to the north and south diameter of the compass (assumed for the present to define the magnetic axis of the compass card), it follows that in the position of equilibrium between magnet and card, the magnetic axes of the two are at right angles to each other, and hence the condition of the simple sine deflection method secured. Both lubber lines, marked on the inside of the compass bowl, are then directly read on the compass card to the nearest tenth of a degree, holding the eye so as to avoid parallax. Thus one of four operations required to complete a set is made. Let us say, in operation *a*, the north end of magnet was towards the east, and the setting of the brass pointer, with the aid of the bows, was made on the south point of the compass card; then, in *b*, the azimuth circle would be turned so as to make a setting on the north point of the compass card, the north end of the magnet now being to the west; next, *c*, turn magnet around on its support, so that north end will be east, setting, however, again on north point of compass, and finally *d*, turn azimuth circle, set pointer on south point of compass, north end of magnet being now west. In brief, practically the same four deflection positions usual in land magnetometers are carried out with this apparatus at sea. Thus the difference in the lubber line readings for operations *a* and *b*, or *c* and *d*, or *b* and *c*, or *a* and *d*, gives twice the angle by which the compass card is deflected from the magnetic meridian due to the presence of the deflecting magnet overhead, and the mean of any two of readings mentioned gives the magnetic meridian, barring errors of eccentricity of mounting and of magnetic axes. The mean deflection angle, or the mean magnetic meridian reading, will be free of errors, due to the latter causes. As a matter of fact, the magnetic meridian reading of the card is also read before the deflecing magnet is mounted, and again after removal. For each of the operations noted above, the temperature of the magnet is read, as well as the time noted for each reading.

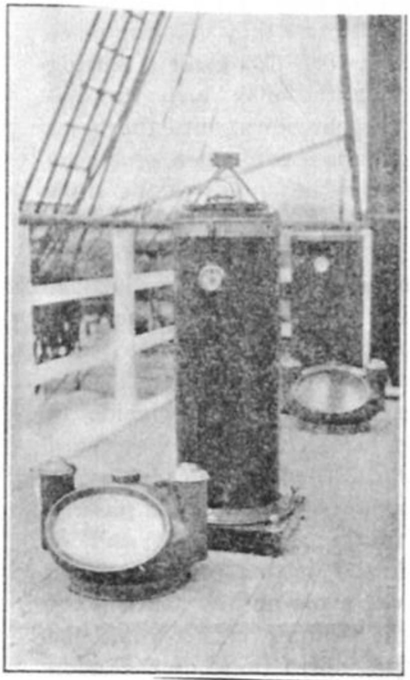


FIG. 4*a*. L. B. deflector mounted on Ritchie-Negus liquid compass.

FIG. 4*b*. Showing how observations for horizontal intensity are made with the L. B. deflector.

This is, in principle, the device. Crude as it may appear to the experienced magnetician accustomed to refined land methods, it is capable of yielding a most satisfactory degree of accuracy even for shore work. The liquid of the compass acts as a beautiful damping device, enabling settings to be made with great rapidity and ease, five to ten minutes sufficing to give a fair value of *H*. The form of mounting adopted not only preserves a sufficient constancy in the distance between the centers of the card and magnet, but also avoids the troublesome rocking of the deflected magnet during the ship' motions, as occurs in that style of ship magnetometer where th . deflecting magnet is mounted off to one side.

The deflecting magnet is mounted for the present in a paraffined wooden block, to the bottom of which is a disk, with lugs which fit in holes in the disk on top of the bridge or supports, so as to admit of putting block with magnet in an invariable position, direct or reversed. A thermometer is inserted in a hole in this block (see Fig. 4). It will be observed that the magnet, when placed inside the block, need thereafter not be touched during a complete set, the entire block, with magnet inside, being reversed.

The method here employed not being an absolute one, since it is dependent upon a knowledge of the magnetic moment of the deflecting magnet and its variation with time, various styles of magnets have been employed, as well as two deflecting distances have been provided, a separate block for each magnet having been constructed. At first, four magnets were used: a hollow, cylindrical magnet, made by Tesdorpf as an auxiliary magnet for one of his field magnetometers, this magnet being designated No. 45; next, a long tube as well as a short tube magnet, each consisting of a bundle of magnetized wires, such as are used in liquid compasses; and, finally, intensity needle No. 4, used with the L. C. dip circle.

My purpose in utilizing the latter needle was because its magnetic moment can be completely controlled by the loaded dips and deflection observations with the L. C. dip circle, so that combination observations of dip circle and deflector would practically amount to an absolute method. Extensive experiments were made with these four magnets at Washington and at the Cheltenham Magnetic Observatory in the Spring of 1905, and repeated on Goat Island, San Francisco, in July, 1905, after the instrument had been transported across the continent.

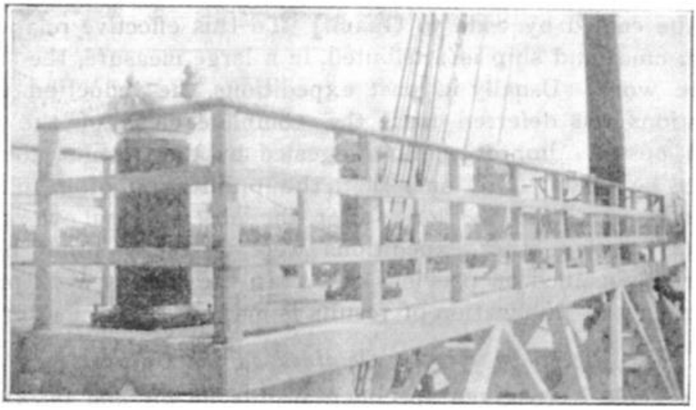
The results were so satisfactory that the ship observations could be restricted to magnet 45 and the long tube magnet (NL).

It was deemed best not to use intensity needle 4, in spite of the obvious advantage noted, because the dip circle needles should not be handled any more frequently than necessary, to guard against injury to the exceedingly delicate pivots and against the danger of vitiating a whole series of observations.

At every port corresponding observations are made, ashore, with this deflector and the standard field magnetometer, and thus a combined intensity constant determined at various temperatures, this constant being a function of the magnetic moment of the magnet, deflecting distance, etc. The experience thus far, especially with magnet 45, has been very satisfactory. The complete set of observations also calls for rotation of magnet within its block through 180°—in other words, every means is taken to eliminate possible changes.

One point more requires attention. On board ship, the line of reference — the lubber line is turning with the ship so that the deflection angle deduced from two consecutive settings, e. g., *a* and *b*, would require a correction equal to the difference in the ship's headings between the two settings. These possible errors are eliminated as follows: If but one observer is available, who must likewise record for himself, then directions are given to the helmsman to hold a certain course as nearly as possible for an hour to an hour and a half, and to "sing" out when he is on the course. During this period about eight complete sets can be made by a skillful observer, using two magnets, covering all positions, and embracing thirty-two independent settings. This interval of time is sufficient to cause the errors due to shiftings of course, and hence of lubber line, during settings, to be in the nature of accidental errors, so that the mean of all readings will yield a satisfactory result. Or still better, if a second person is available, who can also record for the observer, he will place himself at the Standard Compass and call out when ship is on the course, whereupon the observer quickly makes his setting, having previously made an approximate setting. Owing to the damping effect of the liquid in the compass, as noted above, a set of four readings, from which a value of H is derived, can be made even on board ship under trying conditions of sea, within five to fifteen minutes. I have tried both methods here described, and have found these preferable to actually taking course readings of standard compass, with the aid of which corrections to the observed deflection angles are applied.

In order to have a convenient and uniform method of designating the ship instruments, it has been decided to call the above deflector the L. B. deflector, the first initial L standing for Lamont, who was the first to introduce the sine deflection method, and B standing for the name of the inventor of the instrument. We thus have on board the L. C. dip circle[1] for measuring the total intensity and dip, and the L. B. deflector for measuring the horizontal intensity. Further details regarding this instrument will be deferred until it has been put in its final form; certain experiments are to be made with regard to the best magnets to be employed and as to the relative dimensions and form of magnet and of compass card.



Kelvin Compass — L. B. Deflector — Ritchie Standard Compass — L. C. Dip Circle

FIG. 5. View of observing bridge, looking aft, showing positions of instruments for experimental cruise, San Francisco to San Diego, in 1905.

It would seem as though this convenient deflector may likewise have an economical value in the practical application of the theory of ship deviations to the adjustment of compasses, as it admits of a ready and simple determination of the ratio by which the ship's iron affects the value of the horizontal intensity at the standard compass.

Reduction and Control of Results.

Observations on board ship are not allowed to accumulate, but are reduced promptly, and are forwarded from the first mailing port to the office at Washington, where they are immediately

[1] In this case, the *L* stands for Lloyd, who introduced the principle of measuring total intensity with the dip circle; and *C* for Creak, who successfully converted the Fox ship dip circle into a convenient absolute instrument.

subjected to a careful examination, and the final reduction is made as far as may be possible. At each cable port, the commander of the vessel reports his arrival and experience, and holds the departure of the vessel subject to advice from the office. Thus the office and the ship are, throughout, in close touch with each other, and possible improvements can readily be communicated. [For example, while this article is being put in shape for the printer, May 28th, the observations on the present cruise, made during April, are in the office at Washington, and will, in a few days—before the vessel is heard from at Guam—be completely revised and examined, so that, if necessary, any additional direction may be cabled by code to Guam.] To this effective relation between office and ship is attributed, in a large measure, the success of the work. Usually in past expeditions, the reduction of observations was deferred until the complete close of the work, when possible improvement, suggested by the results, could no longer be made. Not only that, the publication of results has generally occurred so long after the observational work was completed, that other expeditions were unable to profit by the experience gained on previous ones. In the present work prompt reduction and publication of results is made a special matter.

Specimen Results Obtained on the Galilee.

In Table I are given specimen results for *dip and intensity* as obtained on the *course* during the first cruise of the *Galilee* (1905), as the result of observations extending over three-quarters to one hour. As the ship's deviation corrections, as well as all other necesssary corrections, have been applied to the results, and, as stated, these are different for the various instruments, we have afforded by the table some means of judging of the *absolute*, not merely relative, accuracy obtained.

Glancing over the *dip results* first, it will be noted that they range from 60° in the northern magnetic hemisphere to 1½° in the southern, thus affording a good means of judging as to the success encountered with the L. C. dip circle by the methods used on the *Galilee*. The two observers were alternated, he who made the dip and intensity observations with the L. C. dip circle one day, while the other observer was simualtaneously making *H* observations with the L. B. deflector at the next opportunity took his turn with the latter instrument, and *vice versa*. The observations with the two dip needles were made so that mean time (or mean position

TABLE I.

Specimen Results of Dip and Intensity Observations made on Course by the Galilee. First Cruise, 1905.

[All corrections have been applied.]

Date. 1905.	Latitude.	Longitude West of Greenwich.	Ship's Course.	Dip. Needle. 1	Dip. Needle. 2	Dip. Diff. 1–2	Horizontal Intensity. (C. G. S. U.) L. C. Dip Circle. Deflections. Direct.	Deflections. Reversed	Loaded Dip. Set 1	Loaded Dip. Set 2	L. B. Deflector. 45 U	45 D	NL U	NL D	Condition of Sea.
	° ′	° ′		° ′	′	′									
Sep. 7	27 39 N	134 31	W SW	50 36	34	+ 2	.298	.298	.294	.295	.287	.288	.288	.289	moderate
Sep. 9	26 54 N	139 12	W SW	50 14	16	— 2	.290	.291	.287	.288	.287	.287	.290	.289	moderate
Sep. 15	21 57 N	156 05	W SW	41 20	20	0	. . .	. . .	.292	.294	.291	.289	.292	.291	moderate
Oct. 4	10 33 N	155 06	S	23 08	18	—10	. . .	. . .	.316	. . .	.325	.323	.324	.322	moderate
Oct. 8	4 15 N	158 38	SW	12 07	04	+ 3	. . .	. . .	.341	. . .	.340	.339	.339	.337	smooth
Oct. 16	0 09 S	161 44	SW	1 27	17	+10	. . .	. . .	.348	. . .	.347	.346	.347	.347	rough
Oct. 17	1 17 S	162 57	SE	—1 29	30	+ 1	. . .	. . .	.355	. . .	.348	.349	.352	.351	moderate
Oct. 31	24 09 N	168 42	N	41 13	17	— 4	. . .	. . .	.289	. . .	.285	.285	.287	.286	smooth
Nov. 18	29 17 N	163 28	N	48 08	07	+ 1	.272	.273	.272	.273	.270	.272	.272	.272	choppy
Dec. 2	36 35 N	129 32	E	59 50	50	0	.260	.260	.262	.263	.260	.258	.260	.261	smooth

of ship) for needle 1 would correspond to that of needle 2. It will be noted that the difference between the two needles rarely goes above five minutes, and is generally less. In order to show that the above table gives a fair representation of the remarkable accuracy reached, it may be stated that out of thirty-eight dip observations obtained on *course* during first cruise, there were twenty-three in which the difference between the needles 1 and 2 was from 0′ to 4′; 9, from 4′ to 8′; 4, from 8′ to 12′, and only two in which the difference was from 12′ to 20′. When more elaborate observations are possible, e. g. during complete swings, an accuracy is reached that approaches that on land with the same instrument. Thus, out of eleven shore observations at different places with the same instrument, there were three in which the two needles differed from each other by less than 2′, and eight in which the difference was between 2′ and 4′.

Passing next to the *horizontal intensity results*, it will be seen that for September 7th there are eight separate results given, each of which was derived from observations over a time interval of five to ten minutes. The mean time and position of ship for the first four results as obtained with the L. C. dip circle (observing total intensity and dips) corresponds to the mean time of last four results derived independently with the L. B. deflector. With the explanations of the methods already given, the particular operation from which a tabulated result has been derived will be clear from the headings of the respective columns. Thus:

L. C. dip circle, deflections direct (.298); deflections suspended needle reversed, i. e., face of needle turned around (.298); next, loaded dip observations, set 1 (.294), made before deflections; and next, set 2 (.295), made after deflections. *L. B. deflector*, observations with magnet 45, letters up (.287); next, same magnet, letters down, i. e., magnet rotated through 180° inside block (.288); next, tube magnet *NL*, letters up (.288); and, finally, same magnet *NL*, letters down (.289).

The result adopted for any one instrument would be the mean of the four results pertaining to it. September 7th was the first real experience of the two observers with the methods prescribed for the simultaneous observations; though the agreement must be considered fair for ship work, better results were subsequently obtained. See e. g., September 9th, November 18th, and December 2d. On the other days it will be seen that blanks occurred in the case of L. C. dip circle, this being due to the fact already mentioned, that in the original condition of the instrument, deflections became impossible for the region in which the dip was less than about 40°. The observers continued, however, the loaded dip observations, but not as extensively as was desirable, they having gotten the impression from the observations in the low magnetic latitudes that the results would be valueless. When reduced, however, they agreed, as will be seen, very satisfactorily with the results from the L. B. deflector, used without difficulty with entire success throughout the whole region traversed—as will be seen by inspection of the results. Captain Creak says: "In equatorial regions good values of the horizontal force, taken on board ship, would be a boon." There can, apparently, be no question but what, in the deflector used on the *Galilee*, we have the means of getting this magnetic element with the desired accuracy, and that, furthermore, good results can be, and in fact are, being obtained with the L. C. dip circle, whether from deflections or loaded dip on the present cruise of the *Galilee*, now that the former defects of the instrument have been rectified as above described.

The time is too brief to set forth in equal detail the results for declination obtained. But one illustration as to the possible accuracy which can be obtained with a good liquid compass must suffice. I shall give the results observed in a choppy sea while swinging near Goat Island, San Francisco, last August on sixteen points, with both helms:

Date. 1905.	Observed Magnetic Declination Corrected for Diurnal Variation.	Remarks.
August 2, . . .	17° 42.′3 E.	Even keel.
" 3, . . .	45. 0	List 4° to 5° to port.
" 4, . . .	39. 6	List 4 to 5 to starboard.
	Mean, 17° 42.′3	

From corresponding observations on shore at three stations (the ship having been swung at about the middle point of the three), the declination obtained with the standard magnetometer was 17° 39.′2, hence the value of A in the deviation formula would be found equal to + 3.′1.

Table II will give an idea of the size of the harmonic deviation co-officients for the various elements, as applying to the *Galilee* on her *second* cruise. Since independent determinations were made on several days, using various methods, this table again affords the means of judging as the accuracy of the magnetic observations made on board ship. While these results were obtained in a harbor, the conditions, on account of inclement weather and high tides, were, by no means, specially favorable, as would be the case, for example, on a *smooth* sea. While it will take an expert to fully appreciate the wonderful agreement shown in this table, certainly even the magnetician, whose experience has been solely confined to land measurements, can not fail to be impressed with the accuracy reached in ship determinations.

TABLE II.

Harmonic Deviation Coefficients of the Galilee in 1906, at San Diego, California.

Date.	Declination.				Inclination.				Horizontal Intensity. Units of 4th Dec. C.G.S.)			
1906.	*B*	*C*	*D*	*E*	*B*	*C*	*D*	*E*	*B*	*C*	*D*	*E*
	′	′	′	′								
Feb. 26	−8	−2	+8	−5	Ritchie Stand. liq. comp. (Sun observed.)				By Prism.			
Feb. 26	−6	−3	+8	−2					" Alidade.			
Mar. 1	−8	−3	+10	−5					" Prism.			
Mar. 1	−11	−4	+10	−6					" Alidade.			
Feb. 16	+24	−2	−10	+4	Ritchie-Negus liq. comp. and L. B. deflector.				Compared with Standard			
Feb. 26	+20	−5	−7	+10					" " "			
Mar. 1	+28	−2	−4	+5					" " "			
Feb. 16-Mar. 1	[+32]	[−5]	[−15]	[+2]					From *H* Coefficients.			
					′	′	′	′				
Feb. 16	L. C. dip circle.				+14	+5	+1	−5	Regular dip.			
Feb. 26					+15	+2	−3	−3	Deflections, short distance			
Mar. 1					+14	+8	−2	−4	" long "			
									′	′	′	′
Feb. 26	L. C. dip circle, dip and total intensity.								−15	−8	−3	−1
Mar. 1									−23	−8	+6	+3
Feb. 16	L. B. deflector on Ritchie-Negus liq. comp.								0	+31	−6	−14
Feb. 26									+4	+24	−4	−10
Mar. 1									+8	+24	+3	−11

[In the above table, in each case *B* is the coefficient of sin ς, *C* of cos ς, *D* of sin 2 ς, and *E* of cos 2 ς in the usual deviation formulæ.]

Table III gives a tabulation of the twelve constants which represent the induced and permanent magnetic forces of the chief vessels which have thus far determined the three magnetic elements at sea. The data for the first four vessels have been taken from Bidlingmaier's article, page 486, of the recent edition of Neumayer's "Anleitungen." *Sm.* in the table means a small value. It will be noticed that for the *Galilee* (1905), in each position of instrument the constants are, in general, smaller than those in previous vessels, and that, furthermore, as already pointed out, the deviation corrections for two different instruments and methods, e. g., in getting *H*, are of varying amount and even of different sign, so that the resultant effect, as shown in the last column, is very small. Owing to the further changes made in the *Galilee* upon her return from the first cruise, and, judging from the results at hand, it is evident that the *Galilee* magnetic constants for 1906 have been reduced still further.

TABLE III.

Tabulation of Constants for chief Vessels engaged in Oceanic Magnetic Work.

[All expressed in units of 3d decimal, C. G. S., except λ.]

CONSTANT.	Erebus. 1839 to 1842.	Challenger 1873 to 1876.	Gazelle. 1874 to 1876.	Gauss. 1901 to 1903.	Galilee 1905.			
					Stand. Comp.	L. B. deflector.	L. C. dip circle.	Mean.
$\lambda = 1 + \left(\frac{a+e}{2}\right)$	0.991	0.999	0.984	1.003	. . .	1.003	1.001	1.002
$\frac{A'}{d} = \frac{1}{\lambda}\left(\frac{d-b}{2}\right)$	0	+ 2	+ 6	+ 5	0	. . . .	. . .	0
$\frac{D'}{d} = \frac{1}{\lambda}\left(\frac{a-e}{2}\right)$	+ 7	+ 6	+ 11	+ 21	+ 4	− 2	− 1	+ 1
$\frac{E'}{d} = \frac{1}{\lambda}\left(\frac{d+b}{2}\right)$	sm.	0	− 2	0	− 4	+ 1	− 4	− 2
g	+ 27	0	+ 13	− 5	.	. . . .	+ 1	+ 1
h	sm.	0	+ 9	0	. . .	. . . .	− 1	− 1
c	+ 26	+ 8	+ 21	− 12	− 1	+ 6	− 5	0
f	sm.	0	− 7	+ 1	+ 2	− 1	+ 4	+ 2
k	+ 3	− 33	− 21	− 13	. . .	. . . .	+ 10[1]	+ 10[1]
P	sm.	+ 13	+ 8	+ 2	+ 1	+ 2	+ 3	+ 2
Q	sm.	0	− 3	0	− 1	0	− 10	− 4
R	sm.	− 40	− 2	− 2	. . .	. . . .	0[1]	0[1]

[1] Approximate values.

It may be moticed also that the *Galilee* corrections arise chiefly from the induced magnetization, and that the normal value of *H* is increased by the ship by about $\frac{1}{500}$ part.

The *general conclusions* resulting from the work of 1905, regarding the *attainable accuracy* in the values of the magnetic elements at sea, are:

1. On a vessel like the *Galilee*, with the small deviation coefficients encountered at the positions of the various instruments,

whenever she can be *swung* completely to the port and to the starboard, whether on sixteen or eight equi-distant headings, even in a moderate or a choppy sea, employing the methods introduced and having skilled observers, the average results obtained from the complete swings need not be much inferior in accuracy to the values obtained on shore with the best field instruments handled by experienced observers. The degree of accuracy appears to depend chiefly upon the amount of time or the number of days that can be spent on the work at any one place. Under ordinary conditions and in the absence of magnetic storms, if about the same time be spent on the complete observations at sea as would be devoted to similar observations on land on one day, it would appear that the magnetic declination, as well as the magnetic inclination or dip of the needle, can be determined within five minutes of the absolute value and the horizontal component of the Earth's magnetic force, within about $\frac{1}{500}$ part of its absolute value. If two or three days be devoted to the observations at one place, it is possible, as already stated, to reach results still more accurate; however, it will suffice for all purposes, regarded even from a purely scientific standpoint, to secure the accuracy in the determination of the magnetic elements at sea derived from a complete swing forward and back.

2. In a moderately rough sea, which still permits making observations, the average results derived from a complete swing forward and back, on about six to eight points, may be absolutely correct within five to ten minutes as far as the magnetic declination and dip are concerned, and the value of the horizontal intensity be absolutely correct within about $\frac{1}{200}$ to $\frac{1}{300}$ part.

3. Under favorable conditions of sea and weather, observations made on the *course* of the vessel, i. e., simply on one heading, if they be extended over about an hour, will yield average results that will be relatively correct within five to ten minutes in magnetic declination and dip and horizontal intensity to within $\frac{1}{200}$ to $\frac{1}{300}$ part. The absolute accuracy depends upon how correctly the deviation corrections, to be applied to the observations due to magnetism of the ship for the direction in which she is headed, can be determined from "swings" made several days before and after the observations.

Some difficulty was encountered on the first cruise respecting the effective control of the deviation corrections for the separate instruments, partly due to swings not being sufficiently frequent, partly to instrumental defects, as already pointed out, and partly to the ship itself. Nevertheless, when the results were completely reduced, and comparisons made such as, for example, given in Table II, they turned out to be better than was anticipated. In the present cruise, these difficulties have been very largely overcome, so that if the course observations cover a long enough interval, the absolute accuracy will not be much inferior to that for "swing observations." It should also be remembered that owing to the varying conditions under which the work is being done, outstanding deviation errors partake of accidental errors, which tend to annul each other in the construction of the isomagnetic lines from observations over a certain area.

In brief, it would appear that while an entirely non-magnetic vessel is a great desideratum—chiefly to avoid the necessity of devoting unnecessary time, labor, and money in the elimination or determination of errors due to disturbing causes which should not exist—results are being gotten now on the vessel Galilee, with the methods and instruments employed, that will satisfy the demands of the art of navigation as well as of magnetic science. The ideal vessel would be a non-magnetic sailing vessel, equipped with a certain amount of auxiliary power, for use in emergencies in making ports and in close shore work. Plans for such a vessel are under way, and it is hoped that the necessary funds will likewise soon be forthcoming.

Correctness of Present Magnetic Charts of North Pacific Ocean.

The following summary exhibits the differences between the values of the magnetic elements determined by the *Galilee* in 1905 and those scaled from the latest magnetic charts (declination, inclination, and horizontal intensity) of the German Admiralty for 1905, designated in the table *G. A*, as also from the latest isogonic chart of the British Admiralty for 1907, designated *B. A.* The table gives the combination of results within a certain area, the observed value always having been subtracted from the chart value; the horizontal intensity differences are given in units of third decimal *C. G. S.*

From this table the following facts appear for the region embraced:

1. The British Admiralty isogonic chart is, on the average, more correct than the German one; however, both charts show systematically too small values of easterly declination between San Fancisco and Honolulu by about 1° to 2°.

2. The latest isoclinic chart gives dips systematically too low by about 1° on the average.

3. The latest chart of lines of equal horizontal intensity gives uniformly too high values on the average by about $\frac{1}{25}$th part.

TABLE IV.

Differences in the Magnetic Elements Observed by the Galilee in 1905, and as scaled from present Charts.

Latitude. N.	Longitude W. of Gr.	Declination. B. A.	Declination. G. A.	Latitude. N.	Longitude. W. of Gr.	Incli'n. G. A.	Latitude. N.	Longitude. W. of Gr.	Horizontal Intensity. G. A.
°	°	°	°	°	°	°	°	°	
0.4	163.4	+ 0.5	+ 0.6	— 0.2	163.4	— 1.1	0.6	162.9	+ 3
3.4	159.0	+ 0.2	+ 0.3	1.2	160.7	— 1.1	1.2	161.0	+ 4
5.6	164.0	+ 0.4	+ 0.2	3.1	165.2	— 2.0	5.0	161.3	+ 9
6.4	155.8	+ 0.3	+ 0.2	6.9	156.4	— 1.7	13.4	162.9	+ 18
11.2	165.5	— 0.2	— 0.7	11.0	165.5	— 2.5	22.8	161.4	+ 23
19.5	155.7	— 0.1	— 0.8	18.6	155.9	— 0.8	23.5	150.4	+ 21
22.2	163.9	+ 0.1	— 0.8	22.8	161.4	— 1.0	24.9	164.9	+ 21
24.4	164.3	+ 0.2	— 0.8	22.9	158.4	— 0.4	34.8	124.1	+ 12
25.6	165.7	— 0.2	— 1.2	23.5	150.4	— 0.2	34.9	126.7	+ 7
26.8	138.5	— 1.0	— 1.6	25.1	166.2	— 1.4			
29.6	161.3	— 0.3	— 1.0	27.0	138.1	— 2.1			
34.8	124.1	— 1.1	— 0.9	29.3	163.5	— 2.4			
				34.9	126.7	— 0.5			
				35.4	129.3	— 0.3			

These conclusions are likewise borne out by the few observations obtained by the Coast and Geodetic Survey vessel *Patterson* on her cruise from Seattle to Honolulu in 1904. Furthermore, the last conclusion, No. 3, is likewise true for the Western Atlantic, as shown by all the observations of the Coast and Geodetic Survey vessels since 1903. So large an error in the intensity charts over the oceanic areas must have quite an effect on the determination of the Earth's magnetic constants. The errors in the charts are not at all surprising, when it is recalled how scanty the available data have been. Consult again Fig. 1.

At the end of the present cruise of the *Galilee*, it is proposed to publish in detail the entire work and results. It may then be worth while to make corrections to the present charts, and also to make tests of the potential hypothesis, i. e., of the existence of vertical electric currents for the various circuits.