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THE C. I. W. DEFLECTOR IN USE ON THE *CARNEGIE* FOR DETERMINING THE MAGNETIC HORIZONTAL INTENSITY AND THE MAGNETIC DECLI- NATION AT SEA.

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Early in 1905, in order to supplement the Lloyd-Creak dip circle for obtaining magnetic intensities at sea, especially in low magnetic latitudes, the first of us devised a deflecting apparatus which could be readily attached to an ordinary liquid compass used in navigation, thus permitting the determination of the magnetic horizontal intensity direct, as well as of the magnetic declination.¹ This "deflector" has been used throughout the ocean work accomplished on board the *Galilee*, 1905-'08, and on the *Carnegie*, 1909-'13, by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The purpose of the present paper is to describe briefly the development of this instrument; it may be recalled that when it was first devised, Bidlingmaier's "double compass" had not yet been perfected and, even if it had been, it would not have answered our special requirements, chief among which was that of simplicity, both from the standpoint of instrumental detail and that of computation and availability of the instrument for both declination and horizontal intensity work.

Briefly described, the apparatus is an application of the sine deflection method. The deflecting magnet, instead of being mounted, however, in the same horizontal plane with the deflected magnet and off to one side, for example, to the east or to the west, as in most forms of field magnetometers and in Neumayer's "deviations-magnetometer" (used on the *Gauss*), is mounted vertically above, or below, the center of the deflected magnet system or

¹ *Ter. Mag.*, v. 11, 1906, pp. 78-83; v. 14, 1909, pp. 167-168.

[PLATE II.]

compass card. The mechanical details are such that, when the sighting device is set upon the north or south point of the compass card in equilibrium, the deflecting magnet is at right angles to the north and south diameter of the compass (assumed to define the magnetic axis of the card) and hence the principle of the simple sine deflection method is secured. The method and order of observation is such that double deflection angles are observed. If we designate the single deflection angle by u , the value of the horizontal intensity, H , is obtained by means of the formula:

$$H = \frac{mC}{\sin u}$$

where m is the magnetic moment of the deflecting magnet at the time of the observation, and C , a quantity involving the deflecting distance and its changes with temperature, induction and distribution effects. In practice the value of mC is determined at every port visited, simultaneous observations being made ashore with the deflector and the standard field magnetometer belonging to the ocean outfit. Two deflecting distances are used, as also two different magnets, so as to eliminate, as far as possible, uncertainties in the values of mC . The shore observations also supply the data necessary for the determination of the temperature coefficient. From a series of such port observations, the results being reduced to some standard temperature, as for example, 20° centigrade, the change in the value of mC with time and magnetic field may be quickly determined by graphical methods with sufficient accuracy for sea work, if the magnets are well-seasoned ones and have received the proper care in transit from port to port.

The deflectors as used have been intended primarily for the determination of the horizontal intensity, but to provide checks against the standard declination instrument, they have been equipped with azimuth devices so as to permit securing declination observations also. In the original instruments, the Ritchie or the Negus standard azimuth attachments were used for this purpose, but in the later types, manufactured by the Department, simpler and more readily controllable azimuth devices are introduced.

The liquid type of compass has been used for all the deflectors, the liquid acting as a damping device and thus making it possible to secure settings with much greater rapidity than would be possible, for example, with a Kelvin compass. The type of deflecting magnet now used, and selected after numerous experiments with various shapes and styles, is of cylindrical form similar to those used by the Department in some of its magnetometers.

The instruments so far constructed may be designated under two classes, viz.: *A*, the type in which the deflecting magnet supports are carried on a framework rotating on the compass bowl, and the deflection angles are read directly on the card graduation; *B*, the type in which the deflecting magnet-supports form a

permanent attachment to the bowl, the bowl itself being rotated when settings are made and the angles being read by vernier on a graduation made on the edge of the bowl. So far 4 of these instruments have been constructed, designated, respectively, Nos. 1, 2, 3, and 4.

Deflectors Nos. 1 and 2. These were of the type *A* and, in general, both were along the same lines of construction. For descriptions and illustrations, see references given in footnote (1). This type, used in the *Galilee* work, has been superseded by the type *B*.

*Deflector No. 3.*² This instrument was used on the *Carnegie* during the whole of her first cruise (1909-'10) and on her second cruise (1910-'11) as far as Cape Town, South Africa. It is of the type *B*, and was designed and constructed in the shop of the Department, utilizing the experience obtained with deflectors Nos. 1 and 2 on the *Galilee's* cruises in the Pacific Ocean. The latter work had shown some inherent defects in the instrument, due chiefly to the fact that navigation compasses already on hand had to be used for deflectors Nos. 1 and 2. Thus in a heavy sea there would at times occur a lifting of the framework carrying the deflecting magnet, and hence a momentary alteration of the deflection distance would result, and consequently a change in the constant *mC*. Various improvements were accordingly introduced in No. 3; however, as these were embodied in No. 4, now in use, they need not be enumerated here.

Deflector No. 4. In practice it was found that the observations had better be made with the deflecting magnet both above and below the card, and that the graduation, ordinarily found on even the best of compass cards, was not sufficiently good, and also that a continuous graduation from 0° to 360° would prove advantageous. Furthermore, the varying conditions of temperature encountered in ocean work and the accompanying unequal expansion of the various instrumental parts, would at times cause a sticking or binding of the bearing surfaces, thus making it hard to secure accurate settings. To overcome these difficulties deflector No. 4 was designed and constructed by the Department; this instrument is shown in Figs. 1, 2, 3, 4, and 5 of Plate II. In order to secure good photographs of Figs. 3 and 4 it was necessary to remove the lower deflection arm. Fig. 5 shows the instrument complete; it will be described in detail, as it is the type used on board the *Carnegie* since 1911.

It differs from deflector No. 3 chiefly in that there are now two standards or deflection arms, so that the magnet may be mounted either above or below the compass card. Each standard has provision for four corresponding deflection distances. These deflection distances are approximately the same as those in deflector No. 3, viz., 172, 182, 192, and 201 mm. The upper standard, with the exception of the clamping device for holding the deflecting magnet in position, is made in one piece and so designed that it

²See Fig. 1, Pl. X, *Terr. Mag.* v. 14, 1909.

also serves in a general way to protect the sight vanes used in connection with the declination work. For avoiding parallax, two pieces are attached to the upper deflection standard, having "V" cuts placed centrally with the line of sight of the vanes; however this detail will be replaced subsequently by sights of the usual pattern with a hole and slit, the observers preferring this style.

The card graduation for this instrument (Fig. 1) is made on German silver, and is continuous from zero at the north magnetic point in a clockwise direction, as seen from above, through 360 degrees, the least count being one degree. Every ten-degree graduation is numbered, thus 1, 2, 3, 4, etc., to 35. The five-degree graduations are distinguished by somewhat greater length than single degree graduations. The diameter of the graduation of the card is 178 mm. The surface of the compass magnets and of the brass flange carrying the graduated circle, as well as the graduated surface have all been silver plated and made black, so that the graduations stand out as white lines against a black background. The bottom of the inside of the bowl has also been blackened, but the sides have been left with the bright silvered surface to provide, by reflection, suitable illumination for the graduation. The north point of the card has been marked by an arrow on the brass surface of the supporting flange and the other cardinal points were marked by means of straight lines. As in the case of deflector No. 3, the rim of the bowl is graduated into one-degree intervals, every ten-degree graduation being numbered, and is provided with two verniers which permit reading to one-tenth degree and estimation to five-hundredths degree. The diameter of this graduation is 248 mm.

The bowl, as for No. 3, has a cone bearing in its inner gimbal ring. In order, however, to effect greater ease of motion and, secondly, accuracy of setting, a ball bearing is provided, the adjustment of which is such that the cone surfaces are used for centering purposes, while the balls carry the weight of the instrument. The detail of this bearing is clearly shown in figure 2. Directly over the knife edge supports of the bearing ring are two pinions with milled heads, which may be used in finer setting of the bowl, the rack for this motion being fastened to the under side of the graduated rim. A single clamp is provided for clamping the bowl in its bearing; this clamp, however, is not for use in the sense of a slow motion in connection with the rack, but is simply intended to hold the bowl in position when necessary, and for use with the device for measuring angles between prominent objects when entering or leaving a harbor.

The arrangements for declination work with this instrument are in general similar to those of deflector No. 3. There is a long slit provided for bright line work, this mounting being set at an angle of about 55° , and a sighting wire for use in mark readings and for declination work by the shadow method. There is a universal level which is mounted at the center of the glass surface of the bowl and supported by means of arms attached at the side.

In case the level is broken, the arrangements are such it may be quickly removed and another put in its place. When the Sun is sighted upon for determining the magnetic declination, a sharp, bright line is thrown through the slit of the inclined vane upon the surface of the glass and a setting is made by shifting the bowl so that this bright line coincides with a central line etched on the glass, the card reading being made simultaneously. When the Sun is too low for the bright line method, direct observations on the Sun may be made by sighting through the inclined vane sight, using shade glasses as necessary. The shadow of the wire of the second vane is also sometimes used. In order to facilitate using either the bright-line method or the shadow method at lower altitudes than was possible with No. 3, two ground glasses have been mounted in the frame carrying the level on which lines are etched and suitably adjusted so that, when the instrument is level, they are in the vertical plane through the sights and the etched line on the surface of the glass.

While the instrument is in use for declination and intensity work two cover plates, as shown in figure 3, have been provided, and are mounted on either side of the level support so as to cut out, when necessary, reflections from the glass surface which have been found troublesome. In order that the reflection of the opening of the wire sight may be cut off from the glass surface and not interfere with the direct reading of the card, a metal slide has been provided; there is also attached to the level supporting frame a shield in such a position that the image of the slit of the bright-line vane will not interfere with the reading of the card when using the bright-line method.

For use in measuring angles between prominent objects in entering a harbor, for example, there is a sighting ring for which a suitable bearing has been provided in the upper part of the bowl. Figure 4 shows this sighting device as mounted for use. Two opposite sides of this ring are partially cut off in order that it may be easily mounted or dismounted and a reading prism attached, by means of which the card may be read simultaneously with the sighting of the mark. The two vanes of this device are inclined in order that there may be no interference with other parts of the instrument.

The adopted scheme for the deflection observations is given below. The deflection distances, in the order of increasing magnitude, are designated for the upper standard, as U1, U2, U3, and U4, and for the lower, as L1, L2, L3, and L4. The double deflection distances are, respectively, 344, 364, 384, and 402 mm., the deflection-magnet bearings being such that the magnet-centers will be approximately equally spaced vertically on each side of the compass system. Owing, however, to the lack of symmetry of the compass magnets and the practical impossibility of aligning them absolutely under the condition of soldering necessary in construction, the eccentricity of the compass system appears to be about 3 millimeters. (In the next instrument the attempt will be made to

simplify the compass system.) For the distances 1 and 3, the sight line is L2 to 180° and L2 to zero, and for the distances 2 and 4, L2 to 270° and L2 to 90° . Observations for horizontal intensity are made in general by using two suitable deflection distances, that is, for example, U1 and L1 together with U3 and L3. The following is the *scheme of observation* using, for example, distances 1 and 3:

A.	Sight L2 to 180° ,	north end of deflecting magnet east,	distance U1	Reading
B.	" " " "	" " " "	east, " L1	same
C.	" " " 0° ,	" " " "	west, " L1	vernier
D.	" " " "	" " " "	west, " U1	for all.
E.	" " " "	" " " "	west, " U3	Reading
F.	" " " "	" " " "	west, " L3	same
G.	" " " 180° ,	" " " "	east, " L3	vernier
H.	" " " "	" " " "	east, " U3	for all.
I.	Sight L2 to 0° ,	north end of deflecting magnet east,	distance U3	Reading
J.	" " " "	" " " "	east, " L3	same
K.	" " " 180° ,	" " " "	west, " L3	vernier
L.	" " " "	" " " "	west, " U3	for all.
M.	" " " "	" " " "	west, " U1	Reading
N.	" " " "	" " " "	west, " L1	same
O.	" " " 0° ,	" " " "	east, " L1	vernier
P.	" " " "	" " " "	east, " U1	for all.

For distances 2 and 4 the scheme is similar, using, of course, the sights as stated above. The times of beginning and ending for each distance, as well as the temperatures, are recorded. The longer deflection distances are used for the higher magnetic latitudes.

In order to avoid any drag of the magnet card, two full minutes of time are allowed after the magnet is in position at the beginning of observation for each magnet (not distance), as also between each reversal of sights, that is to say, each reversal of the bowl; one full minute of time is allowed between all other positions.

The minimum time required for half set from the beginning of reading to end would be about 8 minutes, but in general, making allowance for interruption and repetition, a determination requires some 10 minutes of time. All possible precautions are taken against setting up motion of the liquid in the bowl by sudden reversals in sights, as well as to avoid lifting the card off the pivot by the action of the deflecting magnet during reversal of the bowl, the deflecting magnet being removed during such reversals and being held sufficiently far away to have no effect. The complete set, using two distances with repetitions of readings, as may be required by the conditions of sea, is made to extend over about an hour's time, during which simultaneous dip and intensity observations are made in the forward observing house with the L. C. dip circle as modified by the Department.

Fuller publication must be deferred for the volume of *Researches of the Department* to contain the results of all the observations obtained on board the *Carnegie* during her two cruises, 1909-1913.

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Fig. 1

Fig. 2

Fig. 5

Fig. 3

Fig. 4

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