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# DEVIATIONS OF THE COMPASS : A GRAPHIC METHOD.

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THE linear equations of Poisson express the force on the compass-needle of an iron ship, in terms of the local magnetic force of the earth, in a form which is purely analytical. If, however, the geometrical point of view be taken, the two forces appear as vectors, connected by the special kind of relation known as projective. Some of the simple and well-known methods of projective geometry thus

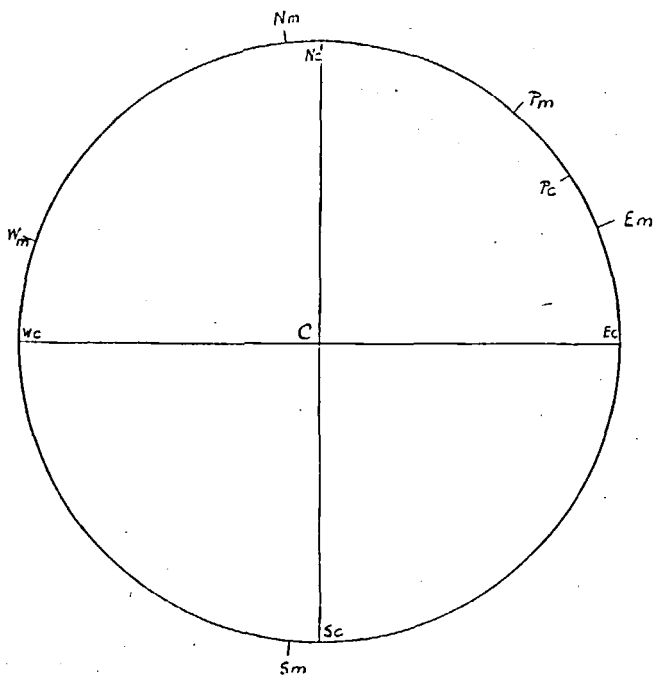


FIG. 1.

associate themselves very readily with the treatment of compass-deviation; and the intention of the following paper is to state and explain briefly, without mathematical demonstration of their truth, some of the geometrical theorems which are thus available, and which seem likely to be of practical use.

## §§ 1. DESCRIPTION OF FIGURE AND NOTATION.

The figure consists fundamentally of a circle, centre  $C$ , representing an ordinary compass diagram. The circumference should, for convenience, be graduated in compass points and degrees; but these are omitted in the accompanying figures. Any course, whether true magnetic or by disturbed compass, is to be represented by a point marked on the circumference of the circle at the proper angular distance from the top or north point of the diagram. For magnetic and compass courses which *correspond* to each other, the same letter will be used to name the two points which represent them, a subscript  $m$  or  $c$  being attached to the letter according as it marks a magnetic course or a compass course. Thus (Fig. 1) the points  $P_m$   $P_c$  represent a magnetic course N.  $40^\circ$  E. and the compass course N.  $56^\circ$  E. corresponding to it; so that  $P_c$   $P_m$ , the deviation, reckoned positive when with the sun, is here equal to  $-16^\circ$ . The north point of the diagram, if representing a compass course due north, will be called  $N_c$ , and the corresponding magnetic course will be represented by a point  $N_m$ ; and similarly for other points of the compass. As an additional distinction, in the diagram, between magnetic and compass courses the letters representing magnetic courses are placed outside the circle, and the letters representing compass courses are placed inside the circle.

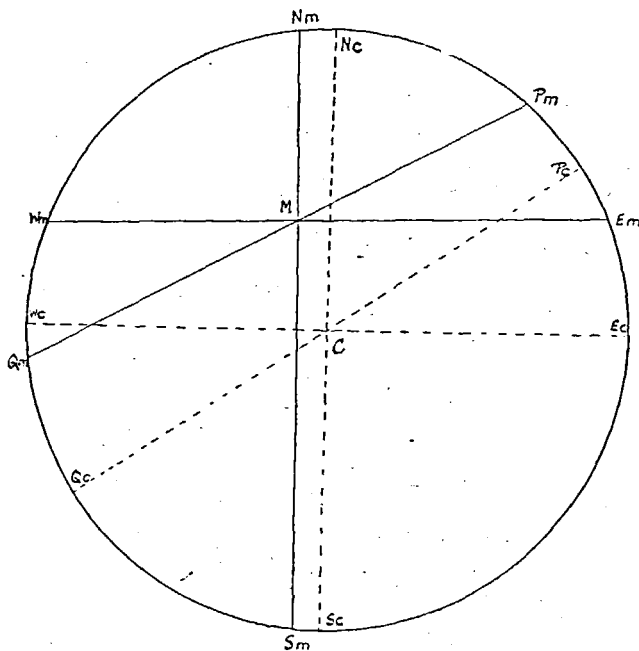


FIG. 2.

## §§ 2. MAGNETIC CHORDS AND THEIR CONCURRENCY.

If points representing exactly opposite compass courses are taken, as  $N_c$  and  $S_c$ , or  $E_c$  and  $W_c$ , or  $P_c$  and  $Q_c$  (Fig. 2), these pairs of points are situated at the ends of diameters  $N_c$   $S_c$ ,  $E_c$   $W_c$ ,  $P_c$   $Q_c$ , all passing through the centre  $C$ ; but the lines  $N_m$   $S_m$ ,  $E_m$   $W_m$ ,  $P_m$   $Q_m$ , joining the points

which give the corresponding magnetic courses, will usually be chords and not diameters of the circle. They will be called for brevity *magnetic chords*. It can be shown that all magnetic chords meet in a point, which will be called *M*. In Fig. 3 are shown the 8 magnetic chords corresponding to 8 pairs of opposite compass courses for the case of H.M.S. "Trident," taken from the Admiralty Manual (1901), p. 57. The deviations are as follows:—

Ship's Head by Compass.	Deviation of Compass.	Ship's Head by Compass.	Deviation of Compass.
N	- 3° 10'	S	+ 3° 10'
NNE	+ 8° 10'	SSW	- 3° 0'
NE	+ 16° 50'	SW	- 9° 40'
ENE	+ 20° 30'	WSW	- 16° 10'
E	+ 20° 20'	W	- 21° 10'
ESE	+ 18° 5'	WNW	- 24° 0'
SE	+ 14° 40'	NW	- 22° 0'
SSE	+ 9° 40'	NNW	- 14° 50'

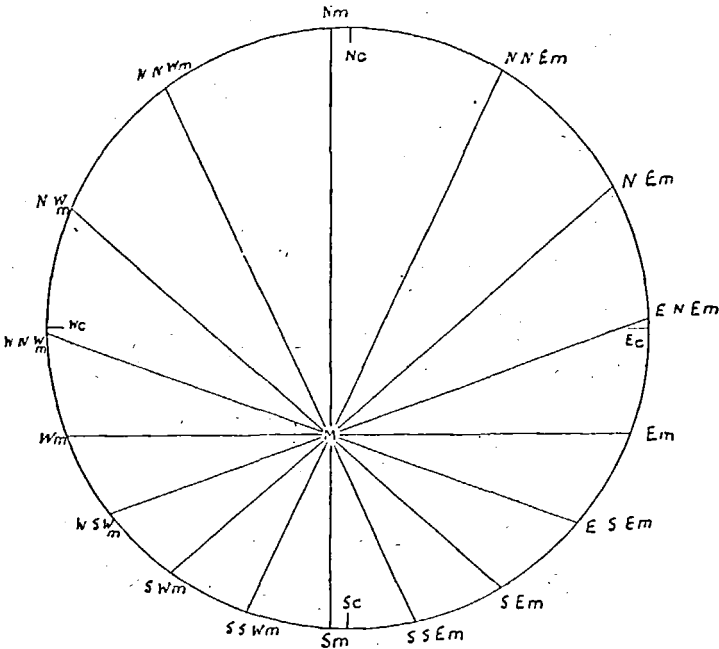


FIG. 3.

§§ 3. DIAGONALS AND THEIR CONCURRENCY.

If points  $P_c$ ,  $Q_c$  are taken (Fig. 4) representing any two compass courses, and if  $P_m$ ,  $Q_m$  represent the corresponding magnetic courses, then if  $MP_m$  meets  $CQ_c$  (produced if necessary) in  $G$ , and if  $MQ_m$  meets  $CP_c$  (produced if necessary) in  $L$ ,  $GL$  may be called (in contradistinction to the fixed diagonal  $CM$ ) the *working diagonal* of the quadrilateral figure

formed by the four lines. It can be shown that all such working diagonals pass through one and the same point, which will be called  $D$ .

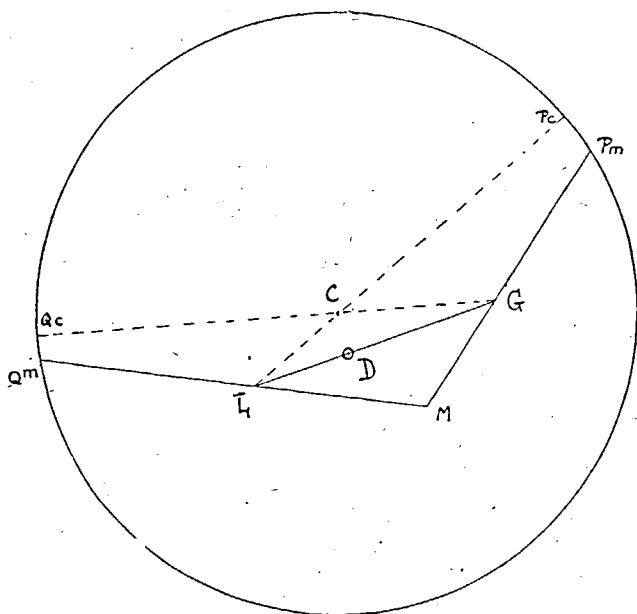


FIG. 4.

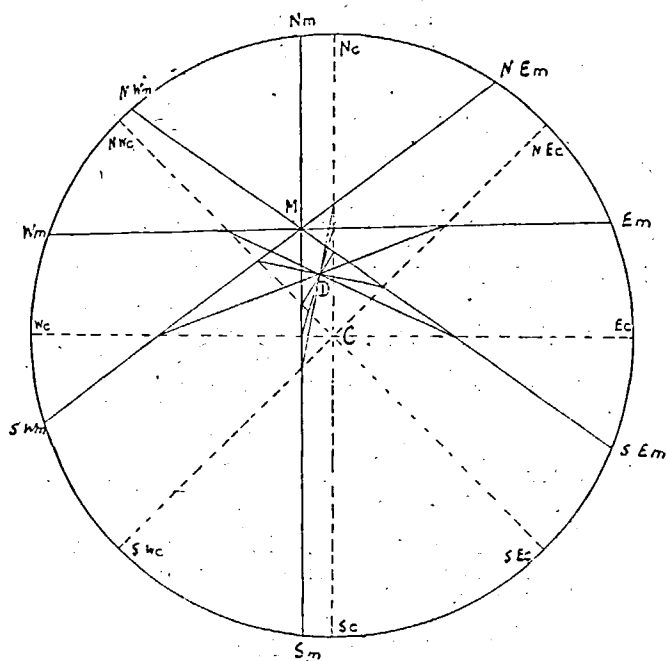


FIG. 5.

In Fig. 5 are shown all the concurrent working diagonals, six in number, which are obtainable by taking compass courses on the cardinal and inter-cardinal points with the magnetic courses corresponding to them. The deviations in the figure are taken from the case of H.M.S. "Warrior," Admiralty Manual, p. 163.

#### §§ 4. NUMBER OF OBSERVED DEVIATIONS NECESSARY TO DETERMINE $M$ AND $D$ .

To find the point  $M$  it suffices to observe deviations on any two pairs of opposite compass courses  $X_c$  and  $Y_c$ ,  $U_c$  and  $V$  (Fig. 6); for the

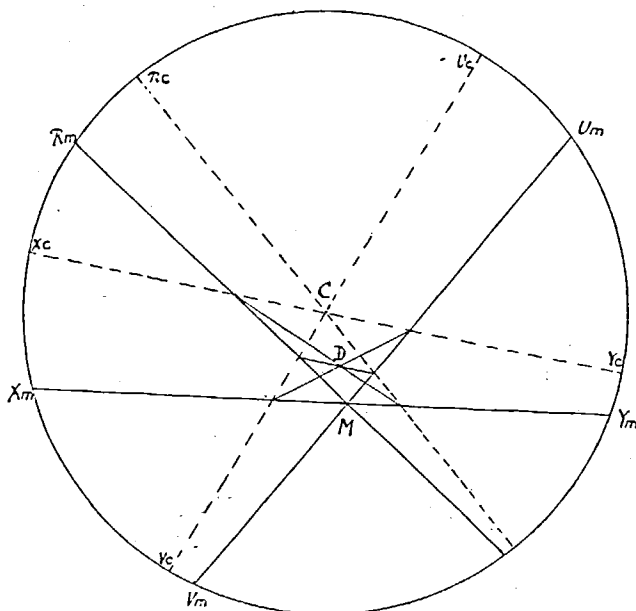


FIG. 6.

magnetic chords  $X_m$ ,  $Y_m$ ,  $U_m$ ,  $V_m$  thus found give the point  $M$  as their intersection. To find  $D$  the deviation must be known on any one other compass course  $R_c$ ; for then the magnetic chord  $MR_m$  corresponds to  $CR_c$  as does  $MX_m$  to  $CX_c$  and  $MU_m$  to  $CU_c$ , and hence (§§ 3)  $D$  is determined as the point of intersection of any two of the three working diagonals that can be drawn.

#### §§ 5. GRAPHIC CONSTRUCTION FOR DEVIATION ON ANY COURSE, MAGNETIC OR BY COMPASS.

The foregoing geometrical results lead to the following graphic method of finding the deviation on any course:—

With the observed deviations on five compass courses as data (two pairs out of the five being on opposite compass points) let  $M$  and  $D$  be found as in §§ 4; and let  $P_c$ ,  $P_m$  be any one of the five pairs of points used in the construction.

Then—

- i. To find the compass course  $Q_c$  corresponding to any given magnetic course  $Q_m$ .—Let  $MQ_m$  meet  $CP_c$  (produced if necessary) in  $L$ , and let  $LD$  meet  $MP_m$  in  $G$ : then  $CG$  meets the circle in the required point  $Q_c$  (Fig. 4).
- ii. To find the magnetic course  $Q_m$  corresponding to any given compass course  $Q_c$ .—Let  $CQ_c$  (produced if necessary) meet  $MP_m$  in  $G$ , and let  $GD$  meet  $CP_c$  (produced if necessary) in  $L$ ; then  $ML$  meets the circle in the required point  $Q_m$ .

It will be clear that in making repeated use of the above constructions the particular pair of points  $P_m, P_c$  first used may, if convenient, be

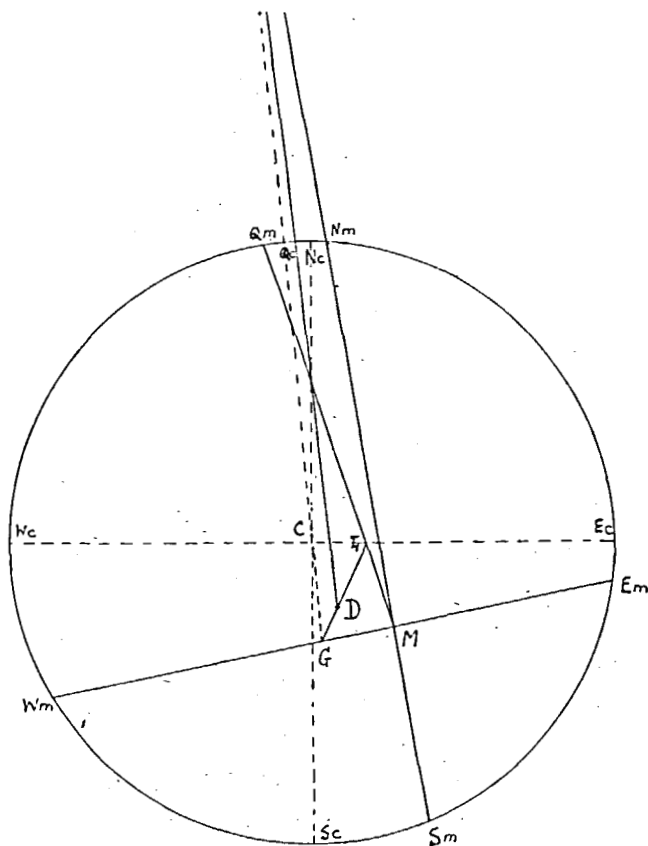


FIG. 7.

replaced by any new pair of points to which the constructions lead. The use of the points  $A_m, A_c$  ( $S_m, S_c$  being the same thing) or  $E_m, E_c$  ( $W_m, W_c$  being the same thing) suggests itself for the sake of symmetry; and the *alternative* use of both these ways recommends itself, as a matter of practical expediency, by giving an obvious means of keeping the points  $G$  and  $L$  within the limits of the figure. Fig. 7 shows the convenience of this choice.



### §§ 6. CHANGES PRODUCED IN THE DIAGRAM BY CHANGE OF MAGNETIC LATITUDE, ETC.

If the magnetic chords corresponding to any given set of compass courses be once drawn, alterations of time and place will need only a new diagram in which the new chords are drawn through a new position of  $M$  in directions parallel to their original directions. The new position of  $M$  can be found from new observations of deviation on any *two* compass courses. For if (Fig. 8) the magnetic course corresponding to compass course  $P_c$  changes from  $P_m$  to  $P'_m$ , and the magnetic course corresponding to compass course  $Q_c$  changes from  $Q_m$  to  $Q'_m$ , then lines drawn through  $P'_m$   $Q'_m$  parallel to  $P_m M$ ,  $Q_m M$  intersect in  $M'$  the new position of  $M$ . The new position of  $D$ , if wanted, is easily found by §§ 3.

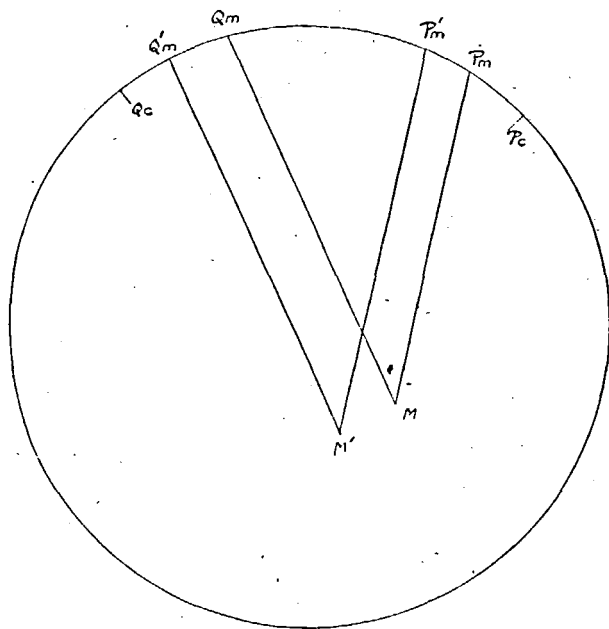


FIG. 8.

### §§ 7. COMPARISON WITH NAPIER'S DIAGRAM.

The Graphic Method here described has certain points of resemblance to Napier's Deviation Diagram. The circumference of a circle replaces the axis of the Napier Diagram as a line on which points are taken to represent both compass courses and magnetic courses: the magnetic chords and the radii of the circle play the part of the plain and dotted lines, and the point  $D$ , serving as the means of connection, takes somewhat the part of the hand-drawn curve of the Napier Diagram. Beyond this however the Napier Diagram method offers no analogy with the present one; for the circle method needs only ruler and compasses in the working, is exact instead of approximate in its results, needs as data the deviations on only

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large; and that when the semicircular deviation is small the points  $M$  and  $D$  may approach so close to the point  $C$  that the part of the construction depending on the use of the working diagonal  $GDL$  becomes cramped and uncertain. A simple expedient whereby to evade this difficulty without increasing the size of the figure is to take a *false position* for  $M$ : to draw chords, that is, through some arbitrary point  $M'$  at any convenient distance from  $C$ , parallel to the actual magnetic chords through  $M$ : then the rest of the work may be quite conveniently done as if for the point  $M'$ , and any chords obtained from  $M'$  may be finally transferred back, by parallels, to  $M$ . [It is in any case recommended that the figures drawn in practice should have at least double the size of those which accompany the text as illustrations.]

## APPENDIX.

### §§ 10. THE *Exact Coefficients* OF THE DEVIATION FORMULA.

The geometrical method here described takes no account explicitly of the *exact coefficients*,  $\mathfrak{A}$ ,  $\mathfrak{B}$ ,  $\mathfrak{C}$ ,  $\mathfrak{D}$ ,  $\mathfrak{E}$  which appear in the trigonometric formula (Admiralty Manual, p. 101, formula 11) expressing the deviation in terms of the angle of the magnetic course; for the construction derives the deviations on all courses directly from the observed deviations on five. But it is natural that the values of the coefficients should be intimately associated with the figure, and they may easily be obtained from it.

Taking the radius of the circle as unity, the distances of the point  $D$  from lines  $E_c W_c$  and  $N_c S_c$  are respectively equal to  $\mathfrak{B}/2$  and  $\mathfrak{C}/2$ ; the values being taken positive when  $D$  is situated in the south-east quadrant, with suitable reversals of sign in the other three quadrants.

The values of  $\mathfrak{A}$ ,  $\mathfrak{D}$ , and  $\mathfrak{E}$  seem to be given most simply by the ratio  $GD/DL$  (Fig. 4) for special positions of the diagonal  $GDL$ . Putting  $GD/DL = (1-n)/(1+n)$ , and taking  $P_c Q_c$  in all possible ways at cardinal and inter-cardinal points, values of  $n$  are obtained as shown in the following table:—

$P_c$	$Q_c$	$n$
$E_c$	$N_c$	$\mathfrak{D}$
$NE_c$	$NW_c$	$\mathfrak{E}$
$NE_c$	$N_c$	$\mathfrak{A} + \mathfrak{D} + \mathfrak{E}$
$E_c$	$NW_c$	$-\mathfrak{A} + \mathfrak{D} + \mathfrak{E}$
$N_c$	$NW_c$	$\mathfrak{A} - \mathfrak{D} + \mathfrak{E}$
$E_c$	$NE_c$	$\mathfrak{A} + \mathfrak{D} - \mathfrak{E}$

The substitution of the opposite compass point for any one here given as  $S_c$  for  $N_c$ , etc., gives only the same working diagonal and so the same value of  $n$  over again.

Any three of the six cases (all shown in Fig. 5) usually suffice to give the values of  $\mathfrak{A}$ ,  $\mathfrak{D}$ , and  $\mathfrak{E}$ .

[Among the 20 possible sets of three there occur four sets which, exceptionally, determine only  $\mathfrak{D}$  or  $\mathfrak{E}$  and the sum or difference of the other two coefficients.]

For purposes of accurate measurement it is convenient to select those cases which give the longest diagonals.

# §§ 11. CHANGES PRODUCED IN THE DIAGRAM BY CHANGE OF MAGNETIC LATITUDE, ETC.

The coefficients  $\mathfrak{B}$ ,  $\mathfrak{C}$  have values, at any time and place, depending partly on the local intensity and dip of the earth's magnetic force, and partly also on the ship's permanent and retained magnetism. Alterations in these elements caused by lapse of time or change of position or both will thus alter the values of  $\mathfrak{B}$  and  $\mathfrak{C}$  and will consequently cause displacement of the point  $D$  (and also of the point  $M$ ) to a new position in the diagram.

The coefficients  $\mathfrak{A}$ ,  $\mathfrak{D}$ ,  $\mathfrak{E}$ , on the other hand, have values depending only on the coefficients of magnetic induction of the soft iron of the ship. Their constancy involves (as may be shown) constancy of direction of all magnetic chords. It is this fact that is made use of in the construction of §§ 6.

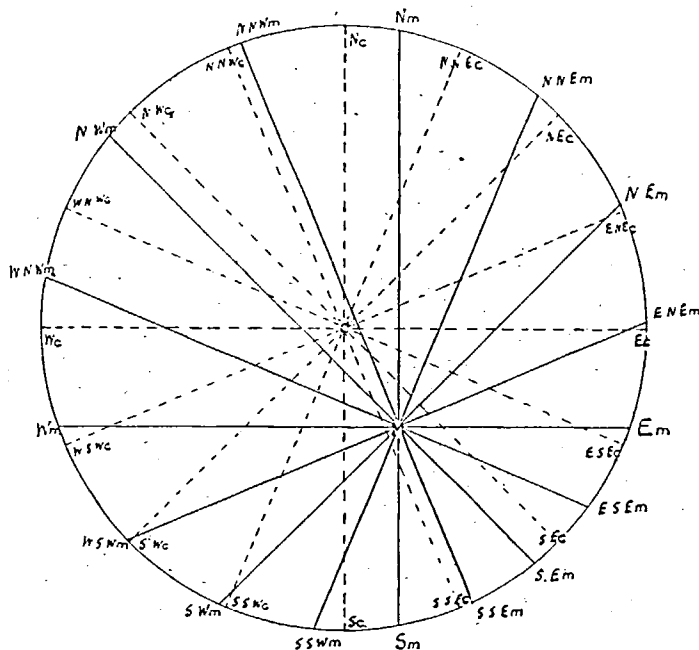


FIG. 10.

# §§ 12. CASE WHEN THE DEVIATION IS ENTIRELY SEMICIRCULAR.

If mechanical correction has given zero values to  $\mathfrak{A}$ ,  $\mathfrak{D}$ ,  $\mathfrak{E}$ , the magnetic chords through  $M$  will be found to lie parallel to the corresponding diameters through  $C$ . The point  $D$  then falls midway between  $C$  and  $M$ , and its use both in the construction and in giving the values of  $\mathfrak{B}$  and  $\mathfrak{C}$  may be dispensed with; for the rule of parallelism serves for the construction, and the distances of  $M$  from  $E_c$ ,  $W_c$  and  $N_c$ ,  $S_c$  give (in this special case)  $\mathfrak{B}$  and  $\mathfrak{C}$ . Observed deviations on any two courses serve, as in §§ 6, to determine  $M$  and thus to find the deviation on any other course. Fig. 10 illustrates this special case.

## §§ 13. CASE OF ANY FIVE KNOWN DEVIATIONS.

It may be worth mentioning that if the deviations are observed on five compass courses taken at random, so that no two of the five are opposite, then the determination of  $M$  may still be made geometrically, with the use of the ruler only, though not so immediately as in §§ 2. [The problem is that of finding a point of projection such that five given points projected from it shall give a pencil projective with a given pencil.] The point  $D$  can then be immediately found (§§ 3), and the rest is as before.

## §§ 14. THE CASE OF A SMALL SEMICIRCULAR DEVIATION.

Remarks similar to those of §§ 9 apply to the method (§§ 10) of deriving the values of  $\mathfrak{A}$ ,  $\mathfrak{D}$ , and  $\mathfrak{G}$  from the ratio  $GD/DL$ . If the semicircular deviation should be altogether absent, this variation of the method becomes not merely convenient but necessary. It may be regarded as a hypothetical change of magnetic latitude, justified in its use by §§ 11.

## §§ 15. REMARK ON THE NOTATION.

In the foregoing paragraphs there has been no occasion to speak of true magnetic courses coinciding exactly with the cardinal points; and therefore no notation has been suggested for them. The north point of the diagram has been marked  $N_c$  as representing a compass course due north; and  $N_m$  (not the north point) has represented the corresponding magnetic course; and similarly for other points of the compass. It goes without saying, however, that the north point may be used as marking a *magnetic course* due north; in which case the corresponding *compass course* will be marked at some point not the north point of the diagram. The introduction of a distinct notation for these points is superfluous for the present paper; but an explicit recognition of their existence may guard against a possible confusion.