



## A NEW TYPE OF POLAR CHART

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METHOD OF NAVIGATING IN THE POLAR REGIONS WITH THE MAGNETIC COMPASS

by

CAPTAIN L. TONTA, *Director.*

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1. Let the position of the *North Magnetic Pole* on the Earth's surface, assumed to be *spherical*, be taken as the fundamental pole of a system of orthogonal spherical co-ordinates. By analogy with the geographical co-ordinates, that is to say, with the co-ordinates for which the fundamental pole is the *geographical pole*, the co-ordinates will be called *paramagnetic latitude* and *paramagnetic longitude*.

The lines of co-ordinates of the new system will be paramagnetic parallels (small circles with planes perpendicular to the polar axis of the system) and paramagnetic meridians (great circles passing through the polar axis) (\*).

The following notations will be adopted to designate the geographical co-ordinates.

$\varphi$  = Geographical Latitude  
 $L$  = Geographical Longitude

and

$\mu$  = Paramagnetic Latitude  
 $M$  = Paramagnetic Longitude

the paramagnetic co-ordinates.

2. The geographical position of the North Magnetic Pole and the configuration of the Arctic basin are such that the whole Arctic region can be represented on a conformal cylindrical projection (Mercator) by taking, as the axis of the cylinder, the diameter of the sphere passing through the North Magnetic pole, that is to say, the polar diameter of the new system of paramagnetic co-ordinates. Thus, the paramagnetic meridians will be represented by parallel straight lines the separating distance of which will be proportional to their respective difference of paramagnetic longitude, and the paramagnetic

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(\*) The term "paramagnetic" has not been adopted with the idea of creating a new word, but only to prevent confusion with names to which a definite meaning has been given by habitual practice. For example, the term "magnetic meridian" has a precise meaning in navigation and in mathematical geography in general, which is different from that attributed to the paramagnetic meridian.

parallels will be represented by straight lines perpendicular to the above, separated by distances corresponding to the well-known law of meridional parts.

In the new system, the whole Arctic basin, with the adjacent coasts, is represented in a quadrilateral, bounded by paramagnetic meridians,  $135^{\circ}$  of paramagnetic longitude apart, and by the paramagnetic latitudes of  $45^{\circ}$  and  $83^{\circ}$  (\*).

3. It is considered that this new type of chart will facilitate navigation in the Arctic regions *by means of the magnetic compass*. In fact, the proposed chart possesses the properties of the ordinary nautical chart, the same methods can be used and, in addition, all the disadvantages of the polar charts in present use are avoided.

However, with the new chart, it is obviously necessary to adopt a new convention for the method of measuring courses (and in general azimuths). Thus the courses should no longer be referred to the geographical meridians, as is usually done in navigation, but to the paramagnetic meridians; *i.e.*, they will be reckoned from the North line of the paramagnetic meridian. These courses, reckoned in this manner (courses which answer the same purpose and which have a signification analogous to the true courses in ordinary navigation) will be called paramagnetic courses.

The straight line joining two points on the chart will represent a loxodromic line of the *new system*, *i.e.* the arc of the spherical spiral passed over going from one of the points to the other on a constant paramagnetic course. This course can be measured directly on the chart by the angle which it makes with the line of the paramagnetic meridians.

The expression "loxodromic line of the new system" indicates that it relates to a spherical spiral the pole of which coincides with the magnetic pole which has been taken as the fundamental pole of the system of paramagnetic co-ordinates.

4. This particular method of measuring courses, necessitated by the new type of chart, is in itself a great advantage. A clearer, simpler and more logical representation of the lines of equal variation is in fact obtained. Naturally a signification differing from the ordinary meaning is given to the term "variation"; in the new method it is defined as the angle which the line of the horizontal component of the earth's magnetic field (direction of a magnetic unaffected by the iron of a ship) makes with the paramagnetic meridian. The variation, reckoned as above, (*i.e.* from North of the paramagnetic meridian) will be called *paramagnetic variation*, in order to distinguish it from the magnetic variation which, according to usual practice, is reckoned from North of the geographical meridian. The clear and simple distribution of the lines of equal variation makes it easier and more convenient to convert the courses, *i.e.* the conversion of the paramagnetic course (taken directly off the chart) to the magnetic course, *i.e.* to the course reckoned (as usual) from North of the undisturbed needle. This conversion, when the value of

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(\*) It should be noted that British Admiralty Chart No 2282 (Mercators projection) "Arctic Ocean and Greenland Sea", which is commonly used for navigating off the shores of Spitsbergen and Franz Joseph Land, reaches the geographical parallel of  $82^{\circ}$  N.

the paramagnetic variation is known, is made by the usual method employed in ordinary navigation for converting the true course to the magnetic course.

5. If the distribution of the magnetic forces at the surface of the Earth corresponded with the simplifying hypothesis of a magnet situated at the centre of the globe and lying in the polar diameter of the paramagnetic system, the paramagnetic meridians would coincide with the projection on the surface of the earth of the lines of magnetic force and the paramagnetic variation would be nil. The actual distribution differs appreciably from the above regular hypothetical distribution but, nevertheless, an examination of the magnetic chart reproduced as Fig. 1 (in which the dotted lines represent the lines of force) (\*) shows that in the Arctic regions, the appearance of the lines of force, although differing from those of the paramagnetic meridians, is fairly regular and that there is an obvious similarity between the two systems of lines.

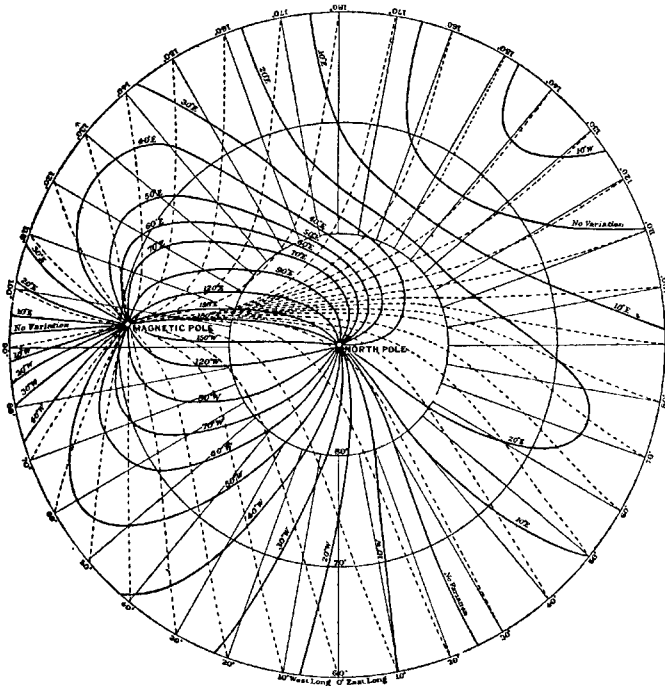


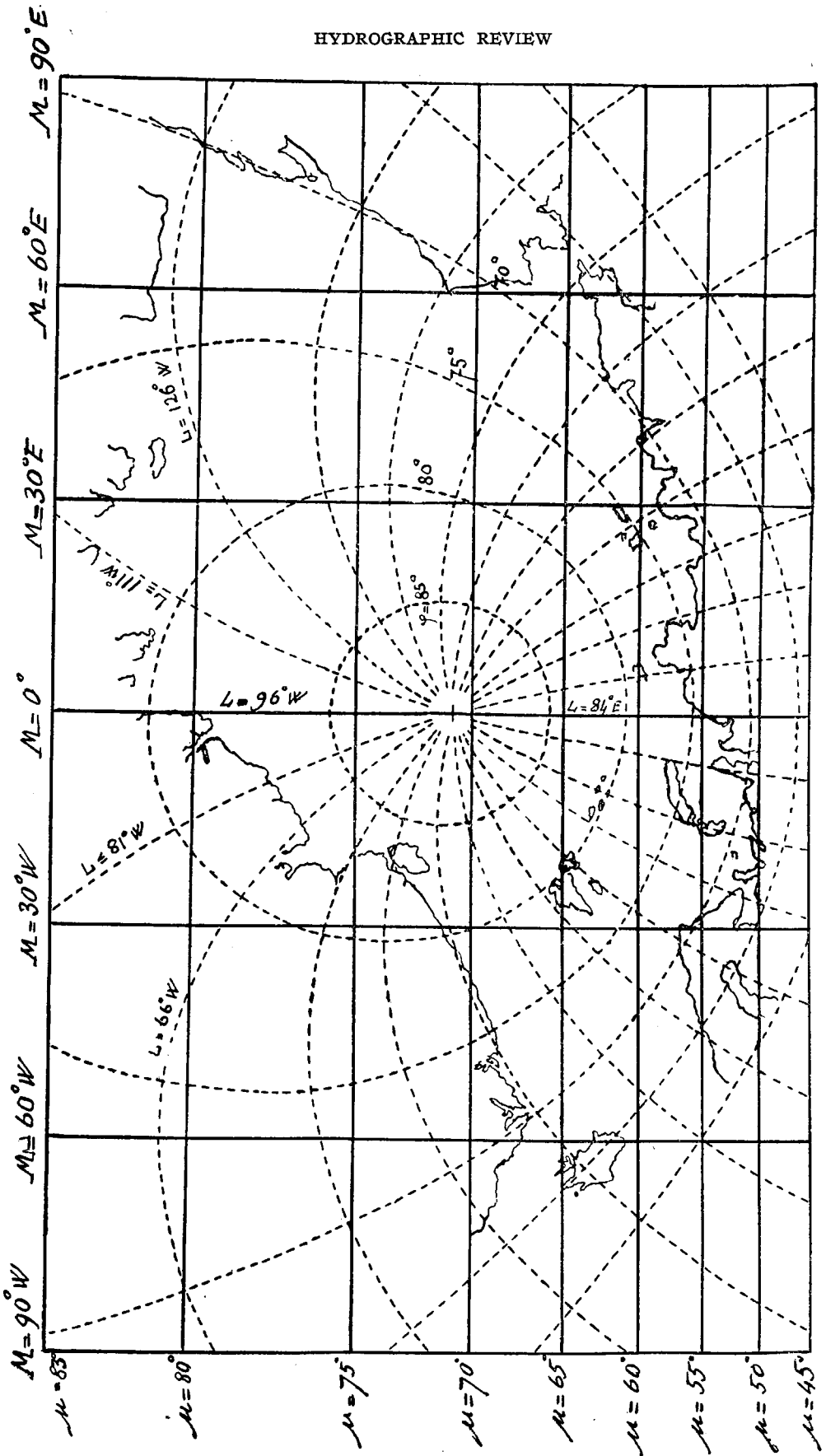
Fig. 1.

Lines of force and curves of equal magnetic variation in the neighbourhood of the North Pole.  
(Reproduced from *The Geographical Journal*, Dec. 1923).

Consequently, the lines of equal paramagnetic variation will appear, both severally and collectively, but little different from those of the paramagnetic meridians. They differ, however, from the lines of equal magnetic variation which converge on two points (the geographical and magnetic poles) as they

(\*) This figure is reproduced from the interesting article by Spencer JONES, entitled *The Magnetic Variation in the Neighbourhood of the North Pole*, published in *Geographical Journal*, Vol. XII, No 6, December 1923.

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(Fig. 2)

converge on one point only, the North magnetic pole, which lies outside the region represented.

With the new system of representation and with the method explained above for determining and converting courses, all those difficulties which are deplored by mariners who have used ordinary polar charts and methods for navigation with the magnetic compass, are avoided. Those charts and methods, which involve taking into consideration converging meridians and an inextricable network of lines of equal magnetic variation (see Fig. 1) make the solution of course problems very difficult and uncertain.

6. On the new chart, the construction of the lines of equal paramagnetic variation is certainly a delicate and laborious operation, and it is made even less easy by the scarcity of existent data but, nevertheless, the difficulty will certainly not be greater than that which is met with in drawing the curves of equal magnetic variation: on the contrary, seeing that the form of these curves is more regular, it will make their construction easier. (\*)

7. The proposed new type of chart of the Arctic regions is shown in Fig. 2. The thick lines represent the net of paramagnetic meridians and parallels, and the dotted curves represent the geographical meridians and parallels. The properties of these curves are well known (\*\*) and their construction presents no difficulty.

The central meridian of the chart is the meridian common to the two systems of co-ordinates (paramagnetic and geographical), *i.e.* the great circle of the Earth which passes through the geographical and magnetic North poles.

It appears necessary to insert the network of lines of *geographical* co-ordinates on the chart because the problems of navigation by dead reckoning (for the solution of which the new type of chart is specially constructed) are connected with those of astronomical navigation, and for the latter, the geographical co-ordinates are necessary (\*\*).

It must be remembered that the adoption of the new type of chart does not dispense with the ordinary type used in Arctic navigation (stereographic projection on the geographical pole) for the solution of problems of astronomical navigation. In fact the stereographic projection is more suitable than any other for rapid and easy determination of astronomical position lines. It would not be possible to solve the same problems by means of the new type of chart, as it would introduce complications which it is necessary to avoid.

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(\*) For methods of constructing the lines of equal magnetic variation, see article by Spencer JONES, mentioned above, paragraphs 5 and 6, pages 421 and 422.

(\*\*) These curves are identical with the altitude curves used in the well-known problem of astronomical navigation. See the important treatise on this subject by Commander GUYOU in the French *Annales Hydrographiques*, 1901, pages 60 and following.

(\*\*\*) This diagram of geographical co-ordinates should be drawn in thin lines so as to avoid confusion with the other lines of the plan.

8. The point, the co-ordinates of which are

$$\begin{aligned}\varphi &= 71^{\circ}00' \text{ North} \\ L &= 96^{\circ}00' \text{ West (*)}\end{aligned}$$

has been taken as the geographical position of the North magnetic pole. Obviously this is only an approximate position. The fact that it does not perfectly coincide with the true position is of no importance in the present case. On the other hand, it is known that the position of the magnetic pole is subject to slow changes of position and, consequently, to considerable uncertainty. The paramagnetic meridian which passes through the geographical pole and which, therefore, coincides with the geographical meridian of  $84^{\circ}$  East has been chosen as the origin of the paramagnetic longitudes. ( $M = \text{zero}$ ).

The Mercator's projection represented on fig. 2 results, in part, from the development of the cylinder circumscribed about the sphere the tangent of which is the great circle which cuts the geographical Equator at  $L = 6^{\circ}$  W. and  $L = 174^{\circ}$  E., and which has its respective vertices at the points :

$$\varphi = 19^{\circ} \text{ N.}, \quad L = 84^{\circ} \text{ E.}, \quad \varphi = 19^{\circ} \text{ S.}, \quad L = 96^{\circ} \text{ W.}$$

The chart, fig. 2, is bounded by the meridians  $M = 90^{\circ}$  E., and  $M = 90^{\circ}$  W., hence it extends over  $180^{\circ}$  of paramagnetic longitude. However, it may be seen (as already stated in paragraph 2) that the whole of the Arctic basin may be represented by limiting the extent to  $135^{\circ}$  so that if the paramagnetic meridians  $M = 90^{\circ}$  E. and  $M = 45^{\circ}$  W., are taken as boundaries, the chart will be limited as follows :

$$\begin{aligned}\text{between } M &= 90^{\circ} \text{ E. and } M = 45^{\circ} \text{ W.} \\ \text{and } \mu &= 45^{\circ} \text{ N. and } \mu = 83^{\circ} \text{ N.}\end{aligned}$$

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(\*) The "Map Information Office of Survey and Maps" gives the position for 1922 as  $\varphi = 70^{\circ}51' \text{ N.}$ ,  $L = 96^{\circ}00' \text{ W.}$  (See *Hydrographic Bulletin*, April 1928, page 105). The following is an extract from the above-mentioned article by Spencer JONES.

"No determination of the position of the north magnetic pole seems to have been made since that by Ross in 1830 until Amundsen's *Gjoa* Expedition, 1903-5.

"The position assigned by Ross was  $70^{\circ}5' \text{ N. lat.}$ ,  $96^{\circ}46' \text{ W. long.}$

"The magnetic observations made on the occasion of Amundsen's expedition are being reduced and discussed at the Meteorological Institute, Christiania. Approximate values of the position of the magnetic pole were kindly communicated by the Director, as follows :

From declination observations.....	Lat. $70^{\circ}35' \text{ N.}$	Long. $96^{\circ}10' \text{ W.}$
» horizontal intensity observations ....	» $70^{\circ}40'$	» $96^{\circ} 5'$
» dip observations .....	» $70^{\circ}40'$	» $95^{\circ}55'$

"These values may be subject to some revision, but as the position of the pole may vary by as much as two or three degrees of latitude during magnetic disturbances, the observations are sufficiently well represented by assuming the position  $70^{\circ}40' \text{ N. lat.}$ ,  $96^{\circ}5' \text{ W. long.}$  If the difference between this determination and that of Ross is due to a true secular variation in the position of the pole, modern observations should be better represented by assuming  $70^{\circ}50' \text{ N. lat.}$ ,  $96^{\circ}0' \text{ W. long.}$  This position has been constructed for the position of the charts." (page 421).

"The magnetic pole is, however, not a fixed point, and, as far as I am aware, no information is available as to the nature of its movements: it is conceivably possible that it may deviate from its mean position by a degree or two in latitude for considerable periods, and if this were so, the residual discordances could be accounted for." (page 423).

and if  $1 \frac{m}{m}$  is taken as the length of  $10'$  of parallel ( $1^\circ = 6 \frac{m}{m}$ ), the dimensions of the chart of the Arctic polar basin will be :

$$\begin{aligned} \text{Length} &: 810 \frac{m}{m}. \\ \text{Breadth} &: 657.6 \frac{m}{m} \end{aligned}$$

The scale for the paramagnetic parallel of  $71^\circ$ , on which the geographical pole is situated, is approximately :

$$\frac{1}{6,000,000}$$

9. Transformation of the co-ordinates.

The conversion of the values of the geographical co-ordinates  $\varphi$  and  $L$  of a given point  $A$  to the corresponding values  $\mu$  and  $M$  of the paramagnetic co-ordinates, in any single spherical figure comprised between two arcs of great circles, is very simple and depends on the solution of the spherical triangle  $PPmA$  ( $P$  = North geographical pole;  $Pm$  = North paramagnetic pole) in which the side  $PPm = 19^\circ$ , the side  $PA$  and the angle included between  $PmPA$  are known.

10. In short, the method of navigating by means of the magnetic compass is based on the following fundamental principle: For polar navigation the same advantages are obtained as in navigating in ordinary latitudes with a Mercator's chart, but the line of origin from which the courses are determined must be changed. *These courses should no longer be referred to the system of geographical meridians but to a system of imaginary meridians passing through an imaginary conventional pole, distinct from the geographical pole and situated outside the polar region.* It is this simple artifice which constitutes the originality of the method.

It would seem, at first, natural to choose the North magnetic pole as the imaginary pole. The reason for this choice and the resulting adoption of the system of magnetic co-ordinates, are set forth above in paragraphs 4 and 5.

In other words, a solution, in which the system of orientation would be in agreement with the real natural phenomenon of orientation, appeared worthy of attention and not without a certain attractiveness. The magnetic pole is, in fact, the pole of orientation on which navigation with the magnetic compass is based.

11. Nevertheless, it must be recognised that this choice entails certain disadvantages. The magnetic pole, although outside the Arctic basin, is very close to it and, therefore, the imaginary paramagnetic parallel which limits the new type of Mercator's chart to the Northward, is very high ( $\mu = 83^\circ$ ) and, consequently, the higher regions of the chart suffer from excessive expansion. This disadvantage may be overcome by placing the imaginary North pole at a point further from the polar basin.

For example, let the point be in :

$$\begin{aligned} \varphi &= 60^\circ \text{ N.} \\ L &= 96^\circ \text{ W.} \end{aligned}$$

This point is situated on the same geographical meridian as the magnetic pole, and is distant about  $11^\circ$  from it, on the opposite side to the Arctic basin.

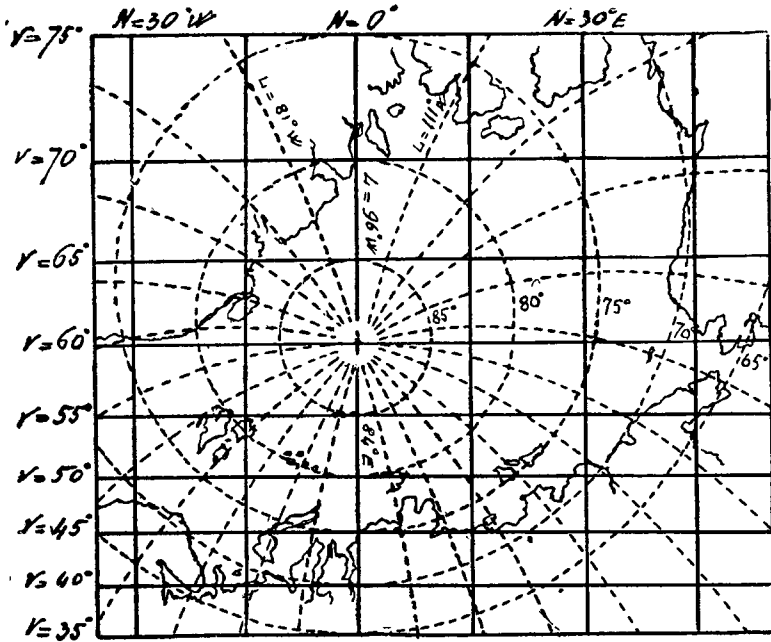


Fig. 3

Hence, by choosing this *imaginary* pole as fundamental pole of the system of imaginary co-ordinates :

$v$  = imaginary latitude

$N$  = imaginary longitude

and by taking the diameter of the sphere which passes through the imaginary pole as the axis of the cylinder, the whole Arctic region is represented on conformal cylindrical projection (Mercator). The net of imaginary meridians and parallels will answer the same purpose as the paramagnetic network described above.

Moreover, instead of the magnetic course, it would be necessary to consider the *imaginary* course *i.e.* measured from the imaginary meridians; *lines of equal imaginary variation* would be drawn on the chart, the *imaginary variation* being the angle between the direction of the horizontal component of the Earth's magnetic field (the direction taken up by an undisturbed magnetic needle) and the imaginary meridian.

This type of chart is represented in Fig. 3. The whole Arctic basin with its adjacent coasts, can be included in the quadrilateral bounded by the imaginary parallels  $72^\circ$  and  $35^\circ$  and two imaginary meridians,  $90^\circ$  of (imaginary) longitude apart.

12. Now, as the natural result of this reasoning, an original solution presents itself, which is considered to be worthy of special attention.

Nothing prevents the imaginary North pole (\*) from being placed on the geographical Equator :

$\varphi = 0^\circ$ ,  $L = 96^\circ$  W. (meridian of the North magnetic pole).

(\*) The name North attributed to this pole has obviously a quite conventional signification, and serves to define the direction of the imaginary meridian to which the imaginary variation will be referred.



Thus, the imaginary equator coincides with a geographical meridian and, therefore, the Arctic regions appear on the equatorial zone of the new system of imaginary co-ordinates. If, therefore, the Arctic basin be represented on the conformal cylindrical projection (Mercator), and if the diameter of the earth which passes through the imaginary pole be taken as the axis of the cylinder, a chart will be obtained, the distortions of which are very small. The group of parallel straight lines representing imaginary meridians will serve, as in the preceding cases, to give the directions of the imaginary courses. To convert an imaginary course to a magnetic course proper it will be necessary to know the imaginary variation (viz., the variation measured from the imaginary meridian) and, consequently, lines of equal imaginary variation, etc. must be drawn on the chart.

This method of representing the Arctic region presents notable advantages, not only because the distortions are very small (and in consequence the scale varies little throughout the chart) (\*) but also because the loxodromic lines of the new system (represented on the chart by straight lines) may be considered within the limits of the regions represented, as having approximately the same length as arcs of great circles having the same extremities.

In reality, this third type of chart is a representation of the Arctic regions on what is known as *Mercator's inverse projection*, with the addition of the rectilinear and orthogonal network of imaginary co-ordinates.

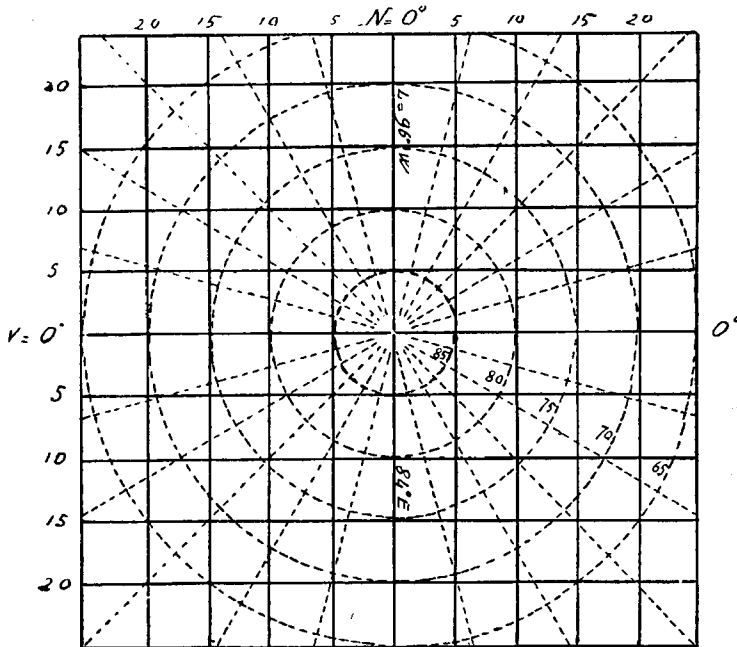


Fig. 4

(\*) The modulus, between the pole and the parallel 70°, varies from 1,000 to 1,064.

The construction of the net of lines of geographical co-ordinates is, in the present case, simpler than in the two preceding cases (\*).

Fig 4 represents this third type of chart. The polar basin is represented in a quadrilateral, bounded by two imaginary meridians,  $50^\circ$  of imaginary longitude apart and the imaginary parallels  $\nu = 23^\circ$  N., and  $\nu = 25^\circ$  S. (\*\*).

13. Two considerations have led to the study and the proposal of these new types of polar chart :

1) Experience, during the great polar flights carried out in the last few years, has shown that the magnetic compass acts very well in the whole region around the North geographical pole. That is why the magnetic compass on account of its simplicity and because it functions during fog, continues, and will continue, to be used as a means to determine the direction of flights. (\*\*\*)

The use of the solar compass is very (even too) limited. In the future the magnetic compass will be superseded by the *radio-compass* which will enable the course to be continuously checked with reference to a powerful radio-telegraphic pole suitably situated on one of the continents which surround the polar basin. For the present and for some time to come, we must remain in the practical domain of navigation by means of the magnetic compass. It should be observed, on the other hand, that assuming the creation of a powerful radio telegraphic pole and the resulting use of the radio-compass, it will be extremely advantageous (and perhaps necessary even) to use a chart of a type similar to that proposed. It will then be necessary to draw on the surface of the earth a system of lines of orthogonal spherical co-ordinates, the fundamental pole of which will coincide with the radio-pole, and to represent this network on Mercator's projection. Consequently, the principle which has been stated above remains valid also in connection with the hypothetical ideal radio-compass of the future.

2) Polar cartography, at the present time, makes the determination of courses very complicated and difficult. This is the unanimous opinion of all polar navigators.

In proposing this new type of chart for the polar regions, it is thought that a modest, but perhaps useful, contribution is made towards the solution of these problems.

It is hoped that this opinion will be shared by those who have the means to construct and try any of the proposed types of chart, that is to say, that some Hydrographic Office will be good enough to construct the chart, and that a polar navigator will kindly try it.

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(\*) Within the limits of the area depicted, the curves, representing the geographical parallels, may, in practice, be assumed to be ellipses of very slight eccentricity. (See note referred to, by GUYOU, *Annales Hydrographiques*, 1901, pages 89-90).

(\*\*) In this case also, the names South and North, attributed to the imaginary latitude have a conventional signification.

(\*\*\*) See "*Air Navigation Methods in the Polar Regions*" by O. M. MILLER, in the book *Problems of Polar Research*. American Geographical Society, Special Publication N° 7, 1928.