readings. Instead of obtaining improved results, it was found that the latter became worse. It was concluded that unknown causes of error must be at work in the testing apparatus, and that the circle would have to be examined on the actual apparatus on which it was to be used. The examining process consisted in measuring a fixed angle, determined by a direct sight at a mark and a sight at an image of the mark reflected in a mirror rigidly attached to the telescope and covering half the object-glass. The mirror could be replaced by a constant-deviation prism. The mark, which consisted of a small orifice lighted by an electric lamp, was placed at a distance of 40 m. The position of the eye was determined by a peep-hole. A comparison of the errors thus determined with those obtained on the testing apparatus reveals considerable systematic differences. In discussing the methods of fixing the circle on the instrument and on the testing apparatus, the author has shown the action of the different constraints imposed on the circle in the two cases. They lead to different deformations of the circle, and consequently to different systematic errors in the graduation. The author concludes from this that the errors must be determined on the circle when actually in position on the instrument.

TWO FUNDAMENTAL GEOGRAPHICAL INVENTIONS.

(Extract from the *Geographical Review*, New York, July 1935, page 511)

The invention of a map projection universally used by geographers and sailors has made the name of Gerhard MERCATOR known to every educated person. To MERCATOR'S teacher, GEMMA FRISIUS (1508-1555), belongs the credit for two inventions of far more fundamental value - yet, by the irony of fate, few but specialists in the history of geography are familiar with GEMMA'S name.

When a young man of only twenty-one, GEMMA, who later became a professor of medicine at Louvain, published a book entitled *De principiis astronomiae* (1530). In a short chapter in this work the epoch-making suggestion is made that clocks or watches, when carried from one place to another and not allowed to run down, may be used for the determination of longitudes. "The invention of the fusée, about 1525, improved portable timepieces to such an extent that they became capable of a more or less uniform 'continuus motus' during 24 hours — even of a 'perpetuus motus', if wound up in time". GEMMA'S other great invention was that of the method of triangulation as a basis for topographical surveying. To a second edition of Peter APIAN'S *Cosmographicus liber* edited by GEMMA and published in 1533 he appended a *Libellus de locorum describendorum ratione*, in which this method is explained and exemplified. "The horizontal use of an astrolabe for the determination of azimuths of celestial bodies was centuries old; GEMMA was the first to realize that by determining the bearings of terrestrial landmarks, and by repeating the observations at several stations, a network could be drawn on paper which would give, by the intersections of corresponding pointings, a map of the country surveyed".

The geographical importance of GEMMA'S work was made clear in a brief article by Dr. E.G.R. TAYLOR in 1927 ("The Earliest Account of Triangulation", *Scottish Geogr. Mag.* Vol. 43, 1927, pp. 341-345). The quotations in the preceding paragraph are from a recent and more comprehensive study by Dr. A. POGO ("Gemma Frisius, His Method of Determining Differences of Longitude by Transporting Timepieces (1530), and His Treatise on Triangulation (1533)", *Isis*, Vol. 22, 1934-1935, pp. 469-506). Scholars are indebted to Dr. POGO for a discussion of biographical and bibliographical problems concerning GEMMA'S work, a detailed analysis of the *Libellus*, and a complete facsimile reproduction of the full text of the *Libellus* from a copy in the Library of Congress.

A MARINHARIA DOS DESCOBRIMENTOS

(THE ART OF NAVIGATION DURING THE AGE OF DISCOVERIES)

by

CAPTAIN A. FONTOURA DA COSTA, PROFESSOR AT THE NAVAL COLLEGE AT LISBON.

Captain FONTOURA DA COSTA has kindly presented a copy of this monumental work to the Library of the INTERNATIONAL HYDROGRAPHIC BUREAU.

This book was published in the *Anais do Club Militar Naval* in serial form, commencing in Volume LXIII, Nos. 3 & 4 (March-April, 1933) and ending in Volume LXIV, Nos. 7 & 8 (July-August, 1934), and mention of parts has been made at various times in the *International Hydrographic Bulletin*. These parts have now been collected in a handsome volume (edition limited to 250 copies) of some 500 pages.

The Author has made deep research and the book is a veritable mine of information for those who wish to study the early history (mainly Portuguese) of the art of navigation and the instruments, charts and tables used by the navigators of the heroic period of overseas discovery.

Some extracts from a summary of the work published (in French) by the Author, in the January-February 1935 number of the *Anais*, are inserted.

As is but natural, the Introduction opens with references to Prince HENRY THE NAVIGATOR "of brilliant Lusitanian intelligence allied to the more energetic and cold persistence of the British" (his mother was Philippa, daughter of JOHN OF GAUNT) and to King JOHN II "the great continuer of his marvellous plan", and gives a short account of their activities.

Chapter 1 deals with Navigational Instruments and it is interesting to learn that, as early as in the middle of the 15th century, quadrants (not reflecting, however) were in use for observing the altitudes of heavenly bodies. In addition to these "Nautical Quadrants", Astrolabes, Kamals and Cross Staves are described as also are the Astronomical Observations taken during the 15th century.

> Portuguese seamen of the 15th to 17th centuries used two kinds of instruments: those which gave directly the angular altitude of the observed body (astrolabe, quadrant, etc.) and those which gave it by means of two linear elements (the cross-staff and "kamals" or Indian tables similar to the more modern gunner's coign).
>
> *The Nautical Astrolabe and Quadrant*
>
> *The Astrolabe.* — This instrument was used from the earliest times. Originally an armillary sphere, which was not conveniently portable, it was converted into a plane or a planisphere on the polar stereographic projection. This latter form was known to the Egyptians in the 3rd or 2nd century B.C. and was inherited from them by the Greeks. From these it passed to Spain through the Moors whose occupation of the south of the Peninsula marked the culmination of Arab scientific culture.
>
> For use at sea, seamen required a simpler instrument than this plane astronomical astrolabe which merely gave them the altitudes of the bodies observed. Gradually the Lusitanian constructors simplified it until it was reduced to the outer graduated circle, becoming a ring — the *rodela* — with a suspension, but retaining the alidade — the *mediclina* — provided with its two little brackets with their respective sights. But first its dimensions had to be greatly increased thus allowing closer division of the limb, hence greater accuracy, even to half a degree.
>
> The oldest engraving of the nautical astrolabe, that at the end of the 1528 edition of the *Repertorio dos Tempos* by Valentim FERNANDES, has been lost. The chart of Diogo RIBEIRO (1529) however contains at the lower end of its eastern extremity a drawing of a maritime astrolabe the disc of which is not entirely cut away.
>
> The only nautical astrolabe still in existence in Portugal is that at the Observatory of the University of Coimbra. It is but recently that a nautical astrolabe was recovered from the bottom of the sea which belonged to the *nau Madre de Deus*, of the fleet of the Indies, which was lost off Nagasaki in 1610.
>
> The graduation of the nautical astrolabe was on the two upper quarters of the circle only, beginning at 0 at the ends of the horizontal diameter, and ending at 90° at the ends of the vertical diameter, immediately under the suspending ring. Soon, however, (at the end of the 15th or the beginning of the 16th century) the graduation was inverted, the 0 being placed at the upper end of the vertical diameter and the 90° at the ends of the horizontal diameter: this modification gave the zenith distance directly.

The quadrant. — The celebrated "Libros del Saber", by ALFONSO X, mention two sorts of Arab astronomical quadrants which were identified later: the *novus*, for solving astronomical problems and the *vetus*, which was used only for time and geometrical solutions.

From the former, by simplification and lightening, came the nautical quadrant beginning with the time of the Infante. However it was not until the 16th century that it was reduced to a frame in the form of a segment with its graduated arc, its sights and its plumb-line.

Our cosmographers invented other similar instruments, among them the graduated ring of Pedro NUNEZ, to whom we owe the basic idea, ingenious in theory, of an instrument for the evaluation of the smallest divisions of a circle, from which CLAVIUS, HEDRACUS and VERNIER developed the *nonius* of our day, which is called *vernier* by many nations.

The Cross-staff and similar instruments

The Cross-staff (arbalest, bâton de JACOB, etc.). — This instrument which was first described by L. BEN GERSON, was unknown to the Portuguese seamen of the 15th century who must have received it from European foreigners in about the first fifteen years of the 16th century; anyway, it was then that they began to use it and it remained in use until fairly late in the 18th century.

The Kamal or Indian tables. — The episode of the Arab pilot (known as CANA or CANAQUA by Portuguese writers) received by VASCO DA GAMA at Melinde is well known. G. FERRAND identified this pilot as the great master IBN MAJID, who is the author of several important nautical works. The Arab instrument with three tablets which CANAQUA showed to DA GAMA was a kamal which, with a single tablet provided with a cord, was used for a time by our seamen under the names of "tavoleta" (tablet), used by João DE LISBOA, and "Indian tables", for those brought home by the celebrated Mestre João after CABRAL's voyage.

The cord was marked off by knots which gave the altitudes in "isbas" of 3.2° each, which our seamen promptly altered to read in degrees. The principle of this instrument is absolutely the same as that of the cross-staff.

Astronomical Observations in the 15th century

The first direct mention of the nautical use of the quadrant is by Diogo GOMES in his account of the discovery of Guinea. Therein is the following celebrated passage: "And I possessed a quadrant when I went to that country and I wrote on the small tablet of the quadrant the altitude of the arctic pole". This refers to a voyage undertaken in 1460.

The navigator Diogo D'AZAMBUJA used an astrolabe in 1481 and, according to the well known marginal notes of COLUMBUS:

(1) Portuguese seamen, and probably he also, when on board Lusitanian vessels, observed the altitude of the sun, before 1484, with quadrants and other instruments (these latter can only have been astrolabes);

(2) Mestre José VISINHO and others, from 1485 onwards, determined the latitudes in Guinea by means of altitudes of the sun.

(3) Bartolomeu DIAS used the astrolabe during his voyage to the Cape of Good Hope (1487-1488).

Vasco DA GAMA used the astrolabe in 1497-1498 and, during CABRAL's voyage in 1500, solar and stellar observations were taken.

Chapters 2 to 4 describe the rules for obtaining Latitudes by means of the Pole Star, the Sun, the Southern Cross and other stars, which were employed by the navigators of the 14th, 15th and 16th centuries and contain descriptions and some examples of the Astronomical Tables then in use.

Chapter 5 discusses the methods of determining Longitude, which methods, before and even for more than a century after the discovery of the *Lunar-distance* method by WERNER in 1514, were, at their very best, unreliable and some were even misleading. For some time after the lunar-distance method had been propounded, its use was precluded at sea for want of instruments of sufficient accuracy in measuring angles; other methods could not be employed as there was no accurate means for determining the time. It was not until about two and a half centuries later that these requirements were fulfilled by the invention of the sextant and the construction of a reliable marine chronometer.

The "Altura de Leste-oeste" (East-West Altitude)

The problem of obtaining position at sea, i. e. the simultaneous determination of both latitude and longitude, is solved quickly in our days by the seamen of the world. But, until late in the 18th century, only one of these co-ordinates was available, viz. latitude, particularly at noon; as for longitude, called by the Portuguese "East-West Altitude", this could not be calculated when at a distance from the coasts of Africa although the necessity for so doing was fully realized. Duarte PACHECO, like COLUMBUS, implicitly recognises this defect but does not discuss it for want of a definite origin.

The "East-West Altitude" by the Variation of the Compass (the "Magnetic Mecometry"). — Leaving aside the pseudo-determinations of longitude by COLUMBUS and VESPUCCI, which have been admirably criticized by WAGNER and Luciano PEREIRA DA SILVA, we will pass on to the interesting solution by the *variation of the magnetic needle.*

It was assumed that the variation of the compass — its *nordestear* and *noroestear* — increased towards the East and towards the West in proportion to the difference of longitude, beginning at a *true meridian* passing between the islands of San Miguel and Santa Maria (Azores), on which the needle was true, as far as meridians at 90° from this true meridian where the variation reached its maximum of 4 points. On this assumption it was easy to determine longitude.

The cosmographer Alonso DE SANTA CRUZ, a great plagiarist of Pedro NUNEZ, attributes this method to the Spanish apothecary Felipe GUILLEN. In 1519 this man came and offered his services to Dom MANOEL at Lisbon where he was bitterly scoffed at by satire and in verse by our great comic writer Gil VICENTE.

Other authors maintain that the inventor was Antonio PIGAFETA, of MAGELLAN's fleet, who left a written report of the memorable voyage together with *Regole sull' Arte del Navigare* (Rules for the Art of Navigation). As this famous Tuscan has not sufficient nautical knowledge to describe the methods of navigation and still less to invent new ones, these rules must have been drawn up by Ruy FALEIRO who went to Spain with Ferdinand MAGELLAN in 1517. This makes it likely that the method was invented by this Ruy while he was still in Portugal and João DE LISBOA was writing his *Livro de Marinharia* (Book of Navigation).

This strange method, which was condemned by the great navigator Dom João DE CASTRO, who ascertained its entire falsity by practical application, was still advocated by SANTA CRUZ. Upheld by various foreign authors, among them the ingenious MERCATOR (1546), SANUTO (1558) and William BOURNE (1577), it came back to Portugal in the 17th century supported by Cristovão BRUNO, Mariz CARNEIRO and others; it was then that it was definitely disposed of.

Other methods for determining longitude. — Conjunctions, lunar distances and eclipses were well known about the middle of the 16th century but were of no practical value particularly for want of instruments and tables. It should be noted however that the famous first suggestion for the determination of longitude by means of a timepiece came from Hernando COLUMBUS (son of Christopher) who put it before the famous "Junta de Badajoz" on 13th April 1524.

Chapter 6 contains descriptions of the compasses employed. Many of these appear to have been very similar to those used well into the latter part of the 19th century though, for want of good steel, the "Pilotos" (Navigators), always carried with them loadstones so that the needles could be remagnetised when they began to lose their directive force. The cards in use towards the end of the 16th century (and possibly earlier) carried two needles but, about 1614, a "Piloto" (whose name is unknown) pointed out the errors which the incorrect situation of the two needles might introduce. He counselled the use of a single needle the points of which were placed accurately under the N. and S. points of the card and this soon became the general practice. Though it was not until 1560 that CARDAN described the system of suspension of the compass bowl which, in several countries, bears his name, in 1551 CORTÈS, in describing the mariner's compass, mentions that the compass-box is supported by "circles annexed one to the other so that the compass swings not when the vessel sways".

This chapter deals also with the recognition and determination of the variation of the compass and of its deviation. As early as in 1525 compasses for taking bearings and ascertaining the variation were already in use. (Examples of early Tables of Solar Amplitudes are given).

The "Agulha de Marear" or Compass

The first compass for bearings, still very crude, described by João DE LISBOA (1514) in that confused and sometimes enigmatic language which he uses in his *Livro de Marinharia,* must have been known to the seamen of Dom João II. The celebrated suspension attributed to CARDAN (1560) had been in use in Portugal since Pedro NUNEZ (1537) who used these trunnioned rings, with articulations like the beams of steelyards. Hence the name *balança* as they were called by us later.

The Variation of the Compass. — It is to the Portuguese seamen of the 15th century that the invention of the terms *nordestear* and *noroestear* must be attributed. These are applied exclusively to the variation of the compass to eastward and to westward.

The words "declination" (magnetic variation), "deviation" (due to the vessel) and "error" (sum of the declination and deviation) were not used with the limited meanings which they now have until the 18th century. At the time of which we speak the *variação* signified an increase or a decrease in the *nordestear* or *noroestear* of the compass.

By whom, where and when was the variation of the compass discovered ? This is a somewhat complex problem to which no discovery of concrete facts has brought a solution.

The Chinese were aware of this variation as early as the 8th century. Foreign compass-makers and the seamen of the Mediterranean must have known of it from the 14th century.

Portuguese seamen will have had some idea of it from the middle of the 15th century for they applied the names of *nordestear* and *noroestear* to it, as said earlier. The first known mention of the word is by COLUMBUS (13th September 1492) who notes it as something expected, the Portuguese seamen whom he met having certainly informed him of it.

Magnetic variation being known, it is but natural that the methods of measuring it should be gradually improved first by the Polar Star, later by the sun and then by the Southern Cross. Hence improvements in compasses also, in which Pedro NUNEZ had a hand in that he invented his "shadow instrument" though with another object in view.

Little by little the methods were perfected and LAVANHA, in 1600, published the first *Tabua das Amplitudes do Sol* (Table of Solar Amplitudes) based, of course, on the knowledge at that time of its position or longitude (*). The honour of having drawn the table up in its present form (in 1608) is due to Manoel DE FIGUEIREDO.

The Portuguese authors of Sailing Directions, particularly since the great Dom João DE CASTRO (1538), mentioned the variations observed in the seas on which they sailed. It is to them that we owe a great part of our knowledge of this phenomenon during this brilliant age.

Some foreign authors attribute the first isogonic chart to Alonzo DE SANTA CRUZ (abt. 1545), but this was really a sort of track-chart, with meridians at every 15°, intended to demonstrate that the longitude varied with the *nordestear* and *noroestear* of the compass, in other words a chart showing the "East-West Altitude" according to the variation.

It is to Cristovão BRUNO (BORRO, BORRI or BURRO) that we owe the first draft of an isogonic chart (first quarter of the 17th century).

(*) *The Portuguese word* lugar *which is translated here as "longitude", really means the angle less than* 90° *measured to the right or left from the first point of Aries or the first point of Libra.*

Deviation of the compass. — That extraordinary man, Dom João DE CASTRO, who joined to a vast erudition the observing sense of the seaman, noted the deviation of the compass 128 years before Guillaume DENYS (1666) and recorded it at Mozambiqué on 5th August 1538 in the following precise terms:

> " ...o ferro do qual berço chamava a si as agulhas e as fazia desviar desta maneira... "
>
> (...the iron of which (gun) cradles drew to itself the needles and caused them to deviate thus...)

Local attraction. — It was again Dom João DE CASTRO who was the first to recognise local attraction. He records it at the Pagoda River of Baçaim on 13th December 1538.

In the next chapter (Nº 7) the Author discusses the navigational charts and globes in use in the 14th and 15th centuries and their gradual development and adaptation to the purposes of the longer voyages undertaken.

Globes on which a number of great circles were drawn were much in use by navigators in the 16th century, for those of them who made long voyages in the open ocean were well aware of the defects in the projections on which their charts were constructed. According to the Author it was Pedro NUNEZ (NONIUS) who first proposed the construction of charts "with a constant scale for the meridians and with that for the parallels proportional to the secant of the middle latitude". Thus we come to MERCATOR's Chart, the first of which, drawn by his own hand, was completed in 1569. This is the chart of which the INTERNATIONAL HYDROGRAPHIC BUREAU has published a full size reproduction. (*).

This chapter is illustrated with reproductions in colour of some of the beautiful compass roses which were illuminated on the charts of this period.

Nautical Charts

It is probable that the earliest charts were rectangular and drawn up on the projection of MARINUS of Tyre, but referred to the parallel of Lisbon (39° in round figures) and with a ratio of 9 to 7 between the degrees of latitude and longitude.

Naturally the explorations carried out beyond the equator led to the prolongation of charts into the southern hemisphere, thus the parallel of Lisbon was abandoned and the equatorial circle was taken as the line of reference. Hence square plane charts.

The oldest of such charts now known with a graduated meridian is that of Pedro REINEL (? 1505) but the graduation must have been known in the 15th century seeing that CANTINO's Chart (1502) shows the equator and the tropics, which implies a knowledge and the use of a graduated meridian.

In Portugal, in the first half of the 16th century, the meridian which passes through Cape St. Vincent, the "meridiano des operaçoes" of Dom João DE CASTRO, was used *graduated* as the meridian of reference or prime meridian.

As for a *graduated equator* we find it for the first time on the celebrated chart by an anonymous Portuguese (about 1520) known as KUNSTMANN IV.

The *square charts* are always "rumadas" (ruled in rhumbs), the various lines bearing beautiful illuminated compass roses, generally dispersed artistically all over the chart.

In addition to these charts, globes, vividly coloured, were used and these also were sometimes provided with a net of rhumbs.

The Marine League

In the Peninsula the ALBATEGNI degree was employed.

This was of 56 2/3 miles (the so-called Italian mile of 1480 metres: 1618 yards) or 14 1/6 leagues of 4 miles, as witnesses COLUMBUS.

But this degree was shortly replaced by that of Abdul HASSAN of 66 2/3 miles or 16 2/3 leagues. This is that which is cited in the documents of the beginning of the 16th century though it originated in the previous century.

(*) I. H. B. Special Publication C. 2. *Reproduction of Mercator's Chart* 1569, *in* 18 *sheets' with Text and Translation of the Legends thereon* (price 250 French francs).

During their frequent voyages along the African coast the Portuguese must have recognised the shortness of the 16 2/3 league degree and therefore adopted that of 17 ½ leagues which was used until the end of the 18th century.

Duarte PACHECO, who was as learned as he was brave, proposed in 1505, in his *Esmeraldo*, a degree of 18 leagues which is nearer than is 17 ½ leagues to that now accepted of 111 kilometres, but this did not come into use until 1712 through Manuel PIMENTEL.

The Rhumb-Line of Pedro Nunez

The great mathematician Pedro NUNEZ not only recognised and demonstrated the principal defects of square charts (1534-1537) but he conceived and studied the rhumb-line, now also called the loxodrome, drawn on globes. There is reason to believe that he caused rhumb-lines to be drawn on spheres constructed by Portuguese experts, though no document of the period is available to prove it. He even invented a flexible spherical quadrant to facilitate drawing them.

Gerard KREMER of Rupelmonde, better known by his Latin name MERCATOR, able cosmographer, cartographer, draughtsman, engraver and constructor of instruments, drew up, in 1541, his famous *Loxodromic Globe* which was certainly based on the work of our Pedro NUNEZ.

Chapter 8 deals with the knowledge of the Tides at this time. It is certainly surprising to read that the Phoenicians were acquainted with the "Establishment of the Port" at Cadiz, and that the famous *Carta Catalan* (1375-77) included a diagram showing the "Establishment" for 14 ports on the coasts of France, Brittany, Normandy, and on the south coast of England. From the determination of the times of tides the Author passes to the Calendar and the various methods employed to memorize the elements to obtain the lunations.

Chapter 9 contains a description of the Portuguese *Roteiros* (Sailing Directions) of this period and of their contents.

In the next chapter (10) the Author describes the gradual development of the Traverse Table in the 15th, 16th and early 17th centuries, and compares the figures given by them with the correct values. The origin of the table (called *Toleta de Marteloio*) is unknown but, in the inventory, dated 1390, of the belongings of a Genoese called Uberto FOGLIETA there is an entry :

unum martelogium... item carta una pro navigando.

and thus it is evident that such tables were already in use at the end of the 14th century.

Chapter 11, which is entitled "Pilotage", begins with a quotation from a publication, dated 1929, of the Naval College at Lisbon entitled "Instructions as to the duties of him who is charged with the navigation of the ship".

"The conduct of the navigation of the ship retains, in Portugal,
the traditional name of Pilotage".

Thus this chapter deals with the practice of navigation at the period of discovery both by Dead Reckoning and by Astronomical Observations. In view of the lack of determinations of longitude it is extraordinary that the "pilotos" made so many successful voyages. To these brave Portuguese navigators the world owes a great deal of its knowledge of the seas on which we now sail in safety aided by instruments and methods undreamt of by them, but to the development of which they contributed a share.

The book closes with a summary of its conclusions and a bibliography of Portuguese nautical works, both printed and manuscript, previous to the year 1700. The bibliography contains many reproductions of title pages. This summary is as follows :

Conclusions

We have set out, in this work, how the Portuguese seamen theoretically and practically created the art of navigating, by gradually making of it a new science which, but much later, was developed abroad where it progressed until it reached its present perfection.

The Lusitanian methods of navigation made possible the great discoveries with all their scientific, political and social consequences.

The following is a summary of the achievements of the Portuguese:

1.— *Observing instruments:*

(*a*) Adaptation of the astrolabe and the quadrant to navigation and their introduction to use at sea.
(*b*) The basic idea of the *vernier* (*nonius* of Pedro NUNEZ).

2.— *Heavenly bodies:*

(*a*) Adaptation for use at sea and drawing up of the *Rules for the nocturnal Hours* and for the *Altitude of the Pole by the North Star* (Polaris).
(*b*) Adaptation for use at sea and drawing up of the various *Rules for the Altitude of the Pole by the Sun* which were gradually perfected.
(*c*) Production of the *first complete Solar Tables*, from unknown previous tables, and of the *second such Tables* calculated by José VISINHO from the data in *Ha-jibbur Ha-gadol* of ZACUTO.
(*d*) Arrangement of the *first Quadrennial Solar Tables* for 1497-1500 (voyages of DA GAMA and CABRAL) also based on ZACUTO (*Almanach Perpetuum*).
(*e*) Production of the *second Quadrennial Solar Tables* for 1517-1520, by Gaspar NICOLAS from ZACUTO's work.
(*f*) *Discovery, delimination and naming* of the constellation *Southern Cross* and production of *Rules* therefor.
(*g*) Drawing up of *Rules for Polar altitude by Meridian altitude of diverse Stars* and identification of these stars.

3.— *The Compass:*

(*a*) Improvements in its fittings and adoption of *Gimbals* before CARDAN.
(*b*) Rudimentary construction of the *first instrument for taking bearings* (agulha de marcar).
(*c*) Adoption of the words *nordestear* and *noroestear* as definite names for the value and direction of that which later was to be called magnetic variation.
(*d*) Invention and use of practical methods of *calculating the nordestear* and *noroestear* of the compass by means of the Polar star, the Sun and the South point.
(*e*) Calculation of the first *Table of Solar Amplitudes* (by LAVANHA, 1600), its simplification, improvement and establishment in the form still in use (Manuel de FIGUEIREDO, 1608).
(*f*) Invention of the fantastic (though for long hotly disputed) method of "mecometry" which is the calculation of the *Altura de Leste-oeste* (Longitude) by the *variation of the compass.*
As a valuable result of this, the *first rough sketch of an isogonic chart* by Cristovão BRUNO.
(*g*) Earliest knowledge and noting of the *deviation of the compass* and *local attraction* (Dom João DE CASTRO, 1538).

4.— *Charts:*

(*a*) Transformation of *rectangular* into *square charts.*
(*b*) Adoption of the (equatorial) *degree* of 16 2/3 leagues and then of 17 ½ leagues when the former value had been found to be too small in practice.
(*c*) Adoption and use on square charts of one or more *graduated meridians* and of a *graduated equator.*
(*d*) Recognition and enumeration of the *defects in square charts* (Pedro NUNEZ, 1537).
(*e*) Conception and investigation of the *rhumb-line* (loxodrome) with its principal characteristics and its tracing on globes (Pedro NUNEZ).
(*f*) Suggestion by Pedro NUNEZ for the transformation of square charts into *reduced charts* in which the *scale is constant for meridians* and that *for the parallels is proportional to the cosine of the mid-latitude.*
(*g* Invention of *special parts of leagues* (LAVANHA, 1600) fo. use on square charts for the purpose of minimizing the defects of these charts.

5.— *Sailing Directions :*

(*a*) Gradual development of very detailed *Roteiros* (Sailing Directions) which have been well adapted (and a few reproduced textually) by all European navies.

(*b*) The Portuguese *writings on Roteiros* form a monument which no other nation possesses.

6.— *Pilotage :*

(*a*) Invention of various *methods of pilotage* which were used universally to nearly the end of the 16th century and some were carried on even during a great part of the next.

(*b*) Examination of the *coasts discovered or visited,* thus making possible the rapid development of their charting.

G. S. S.