Henry Briggs and the dip table

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Abstract

Henry Briggs is well known for his invention of the logarithms with base 10 - the *Briggsian* logarithms. However, he was quite an old man with respect to the usual standards of his times when he started work on logarithms. It is much less known that the young Briggs was in the centre of a group of men who were the leading sientists of the day and contributed to such diverse topics as navigation on sea and trigonometry. We give an overview of what is known of the pre-logarithmic Briggs and discuss his contribution to William Gilberts theory of magnetic dip in some detail.

1 Henry Briggs and his Gresham circle

We do not know much about the life of Henry Briggs and only the invention of the Briggsian logarithms - the logarithm with base 10 - has served to carry his name well into into our times. However, Briggs was in the center of a circle of copernicans in Greham College, London, long before his work on logarithms started.

The confusion starts already with the date of birth of Briggs. Many authors like Goldstine[1] give 1556 as the year of birth but the Halifax Parish Register has survived and gives February 1561 as the correct date. The reason for the confusion was discussed by Hallowes[2] who traced the wrong date back to Ward[3]:

> *Ward, not knowing Brigg's date of birth, tried to deduce it from statements of his age at his death. ... Later writers have blindly accepted Ward's date.*[4]

Hallowes goes on with

> *... in the Halifax Parish Register of Baptisms we read "Henricus filius Thome Bridge de Warley, Februarius xxiii, 1560"*

and remarks

[1] H.H. Goldstein — A History of Numerical Analysis: From the 16th through the 19th Century. *Springer Verlag, New York, Heidelberg, Berlin, 1977*

[2] D.M. Hallowes — Henry Briggs, Mathematician. *Transactions of the Halifax Antiquarian Society, 79-92, 1962*

[3] J. Ward — The lives of the professors of Gresham College. *London, pp. 120-129, 1740*

[4] after Hallowes

In those days, of course, the new year was reckoned as commencing on the 25th day of March, as is clear from the register itself. January and February 1560 comming after December 1560 and before March 25th 1561, so his date of baptism in modern reckoning was 23rd February 1561.

In the Biographical Archive of the St John College in Cambridge exists a copy of the entry in the Parish Register which reads as follows:

N.& Q (6) 7, 207: Halifax Parish Register:
2 July 1559. Thomas bridge and Issabell beste mat. contrxerunt.

23 February 1560. Henricus filius Thome bridge de Warley (baptised).

Hence, the name *Bridge* was in use as well. The place of birth was Warley Wood in Yorkshire and it is partly this Yorkshire background that will bring Briggs much later to Oxford.
At age 16 in the year 1577 Briggs was immatriculated in St John's College, Cambridge, where he graduated as Bachelor of Arts in 1581 (or 1582) and became Master in 1585. In 1588 - the year the Spanish Armada was defeated in the Channel - he was elected Fellow of St John's College. Much later Smith writes about this time[5]:

He was now his own master, and devoted that happy leisure with redoubled application to mathematical study, to which he seemed to be drawn by some natural bent. He did not content himself with the outer skin and superficialities of those sciences, but made his way into the very marrow and the inner secrets. This course of study made him a finished mathematician; and he achieved an ever higher reputation not only among his colleagues but also throughout the University.

In 1592 Briggs was elected Examiner and Lecturer in Mathematics which nowadays corresponds to a professorship. In the same year he was elected *Reader of the Physic Lecture founded by Dr Linacre* in London. One hundred years before the birth of Briggs, Thomas Linacre was horrified by the pseudomedical treatment of ill people by hair dressers and vicars who did not shrink back from chirurgical operations without a trace of medical instruction. He founded the *Royal College of Physicians of London* and Briggs was now asked to deliver lectures with medical contents. The Royal College of Physicians was the first important domain for Briggs to make contact with men outside the spheres of the two great universities and, indeed most important, he met William Gilbert who was working on the wonders of the magnetical forces and who revolutionized modern science only a few years later.
While England was on its way to become the worlds leading sea force the two old english universities Oxford and Cambridge were in an alarming state of sleepyness[6]. Instead of working and teaching on the forefront of modern research

[5] Th. Smith — A Memoir on the life and work of that most famous and most learned man Mr Henry Briggs. *Logarithmica Britannica I, Appendix(i), Cambridge, Ixvii-Ixxii, 1952. Written 1707, translated from Latin by J.T. Foxell, 1943*

[6] Ch. Hill — Intellectual Origins of the English Revolution. *Oxford University Press, 1965*

in important topics like navigation, geometry, astronomy, the curricula were directly rooted in the ancient greek tradition. Mathematics included reading of the first four or five books of Euclid, medicine was read after Galen and Ptolemaus ruled in astronomy. When the founder of the english stock exchange (Royal Exchange) in London, Thomas Gresham, died, he left in his last will money and buildings in order to found a new form of university, the Gresham College, which is still in function. He ordered the employment of seven lecturers to give public (!) lectures in theology, astronomy, geometry, music, law, medicine, and rhetorics mostly in english (!) language. The salary of the Gresham professors was determined to be £50 a year which was an enormous sum as compared to the salary of the Regius professors in Oxford and Cambridge[7]. The only conditions on the candidates for the Gresham professorships were brilliance in their field and an unmarried style of life.
Briggs must have been already well known as a mathematician of the first rank since he was chosen to be the first Gresham professor of Geometry in 1596. Modern mathematics was needed badly in the art of navigation and public lectures on mathematics were in fact already given in 1588 on behalf of the East India Company, the Muscovy Company, and the Virginia Company. Even before 1588 there were attempts by Richard Hakluyt to establish public lectures and none less than Francis Drake had promised £20[8] but it needed the national shock of the attack of the Armada in 1588 to make such lectures come true.
During his time in Gresham College Briggs became the center of what we can doubtlessly call the Briggsian circle. Hill writes[9]:

> *He* [i.e. BRIGGS] *was a man of the first importance in the intellectual history of his age, ... Under him Gresham at once became a centre of scientific studies. He introduced there the modern method of teaching long division, and popularized the use of decimals.*

The Briggsian circle consisted of true copernicans; men like William Gilbert who wrote *De Magnete*, the able applied mathematician Edward Wright who is famous for his book on the errors in navigation, William Barlow, a fine instrument maker and men of experiments, and the great popularizer of scientific knowledge, Thomas Blundeville. Gilbert and Blundeville were protégés of the Earl of Leicester and we know about connections with the circle of Ralegh in which the brilliant mathematician Thomas Harriot worked. Blundeville held contacts with John Dee who introduced modern continental mathematics and the Mercator maps in England[10]. Hence, we can think of a scientific sub-net in England in which important work could be done which was impossible to do in the great universities. It was this time in Gresham College in which Briggs was most productive in the calculation of tables of astronomical and navigational importance.

[7] HILL p. 34.
[8] Ibid.
[9] Ibid. p. 37.
[10] Ibid. p.42

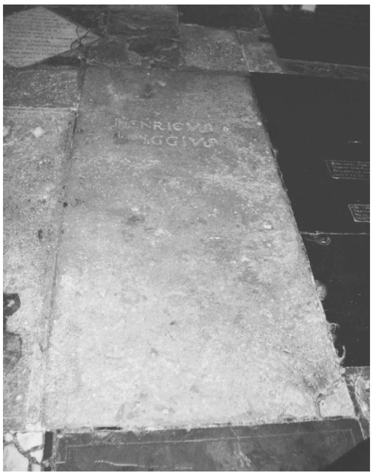


Figure 1: The grave of Henry Briggs

Meanwhile some open-minded people at the universities Oxford and Cambridge had felt the need for a reform in the curriculum. In Oxford, the most important names are Thomas Bodley, founder of the Bodleian Library, and Henry Savile. Savile was a wealthy copernican who lectured in Merton College on geometry and astronomy and he was a Yorkshire man. Within his lifetime he established two professorships - the Savilian chairs for geometry and for astronomy. In recruiting the first Savilian professor of geometry Savile chose Henry Briggs, not only because he was another Yorkshire man, but also because his fame as a first-rate mathematician had spread throughout the country. In 1620 Briggs moved from London to Oxford where he worked mainly on his logarithms until his death on the 26th of January, 1630 (Julian calendar). He was buried in the chaple of Merton College as a puritan, i.e. under a plain stone with the inscription *Henricus Briggius.*

2 William Gilberts dip theory

The role of William Gilbert (1544-1603) in shaping modern natural sciences can not be overestimated and a recent biography of Gilbert[11] emphasizes his importance in England and abroad. Gilbert, a physician and member of the Royal College of Physisicans in London, became interested in navigational matters and the properties of the magnetic needle in particular, by his contacts to seamen and famous navigators of his time alike. As a result of years of experiments, thought, and discussions with his Gresham friends, the book *De Magnete, magneticisque corporibus, et de magno magnete tellure; Physiologia nova, plurimis & argumentis, & experimentis demonstrata* was published in 1600[12]. It contained many magnetic experiments with what Gilbert called his *terrella* - the little earth - which was a magnetical sphere. In the spirit of the true copernican Gilbert deduced the rotation of the earth from the assumption

GVILIELMI GIL-
BERTI COLCESTREN-
SIS, MEDICI LONDI-
NENSIS,

DE MAGNETE, MAGNETI-
CISQVE CORPORIBVS, ET DE MAG-
no magnete tellure; Phyfiologia noua,
plurimis & argumentis, & expe-
rimentis demonftrata.

LONDINI
EXCVDEBAT PETRVS SHORT ANNO
MDC.

Figure 2: De Magnete

[11]S. Pumfrey — Latitude & the Magnetic Earth. *Icon Books, Ltd., 2002*

[12]I refer to the english translation W. Gilbert — De Magnete. *Dover Publications, 1958* by P. Fleury Mottelay which is a reprint of the original of 1893. There is a better translation by Sylvanus P. Thompson from 1900 but while the latter is rare the former is still in print.

of it being a magnetic sphere.
Concerning Briggs the most interesting chapter in *De Magnete* is Book V: *On the dip of the magnetic needle*. Already in 1581 the instrument maker Robert Norman had discovered the magnetic dip in his attempts to straighten magnetic needles in a fitting on a table. He had observed that an unmagnetized needle could be fitted in a parallel position with regard to the surface of a table but when the same needle was magnetized and fitted again it made an angle with the table. Norman published his results already in 1581[13] but he was not read.

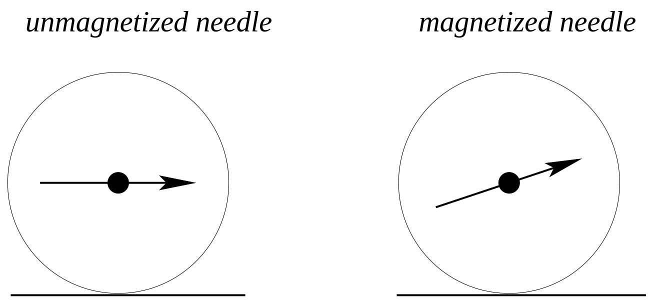
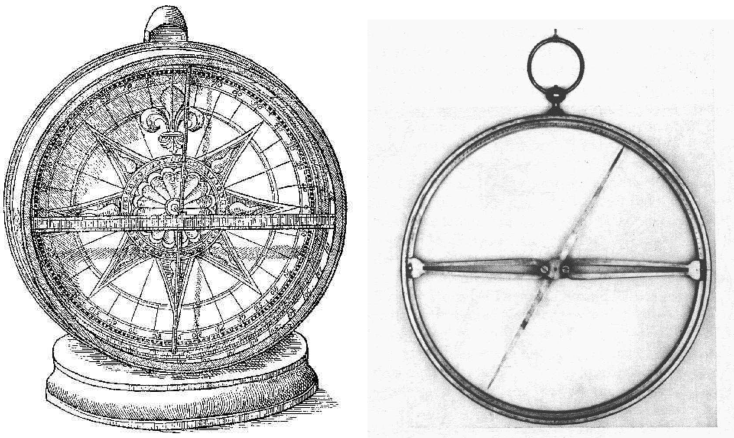


Figure 3: Norman's discovery of the magnetic dip



(a) The dip ring after Gilbert in *De Magnete*

(b) A dip ring used in the 17th century

Figure 4: Dip rings

[13] R. Norman — The New Attractive *London, 1581.* Even before Norman the dip was reported by the german astronomer and instrument maker Georg Hartmann from Nuremberg in a letter to the Duke Albrecht of Prussia from 4th of March, 1544, see H. Balmer — Beiträge zur Geschichte der Erkenntnis des Erdmagnetismus, *Verlag H.R. Sauerländer & Co., Aarau, 1965*, p.290-292.

In modern notion the phenomenon of the dip is called *inclination* in contrast to the *declination* or *variation* of the needle[14]. Anyway, Norman was the first to build a *dip ring* in order to measure the inclination. This ring is nothing else but a vertical compass. Already Norman discovered that the dip varied with time!

However, Gilbert believed that he had found the secrets of magnetic navigation. He explained the variation of the needle by land masses acting on the compass which fitted nicely with the measurements of seamen but is wrong, as we now know.

Concerning the dip let me give a summary of Gilbert's work in modern terms. Gilbert must have measured the dip on his terrella many, many times before he was led to his

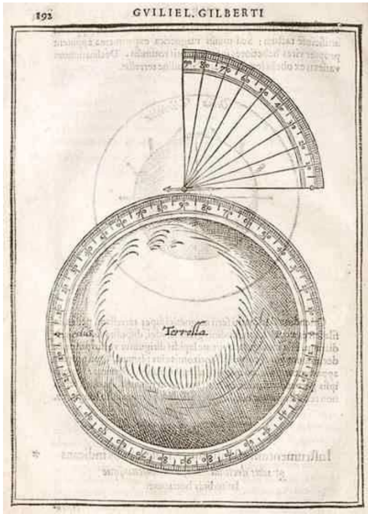


Figure 5: Measuring the dip on the terrella in *De Magnete*

First hypothesis: *There is an invertible mapping between the lines of latitude and the lines of constant dip.*

Hence, Gilbert believed to have found a possibility of determining the latitude on earth from the degree of the dip. Let β be the latitude and α the dip. He then formulated his

Second Hypothesis: *At the equator the needle is parallel to the horizon, i.e.* $\alpha = 0°$. *At the north pole the needle is perpendicular to the surface of the earth, i.e.* $\alpha = 90°$.

He then draws a conlcusion but in our modern eyes this is nothing but another

Third hypothesis: *If* $\beta = 45°$ *then the needle points exactly to the second equatorial point.*

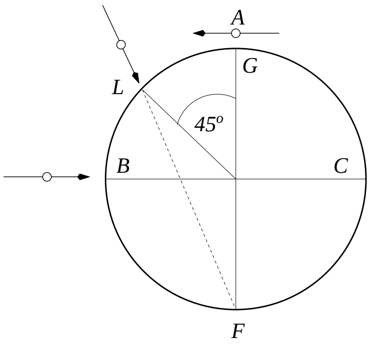


Figure 6: Third hypothesis

What he meant by this is best described in figure 6. Gilbert himself writes

> *... points to the equator F as the mean of the two poles.*[15]

Note that in figure 6 the equator is given by the line $A - F$ and the poles are B (north) and C so that our implicit (modern) assumption that the north pole is always shown on top of a figure will not be satisfied.

From his three hypothesises Gilbert concludes correctly:

First Conclusion: *The* rotation *of the needle has to be faster on its way from A to L than from L to B.* Or, in Gilbert's words[16]:

[14] A word of warning is appropriate here: in Gilbert's time many authors used the word *declination* for the *inclicnation.*

[15] Gilbert p. 293

[16] Ibid. p.293

... the movement of this rotation is quick in the first degrees from the equator, from A to L, but slower in the subsequent degrees, from L to B, that is, with reference to the equatorial point F, toward C.

And on the same page we read:

... it dips; yet, not in ratio to the number of degrees or the arc of the latitude does the magnetic needle dip so many degrees or over a like arc; but over a very different one, for this movement is in truth not a dipping movement, but really a revolution movement, and it describes an arc of revolution proportioned to the arc of latitude.

This is simply the lengthy description of the following
Second Conclusion: *The mapping between latitude and dip can not be linear.*
Now that Gilbert had made up his mind concerning the behaviour of the mapping at $\beta = 0°, 45°, 90°$ a construction of the general mapping was sought. It is exactly here where *De Magnete* shows strange weaknesses, in fact, we witness a qualitative jump from a geometric construction to a *dip instrument.*
Gilbert's geometrical description can be seen in figure 7. I do not intend to

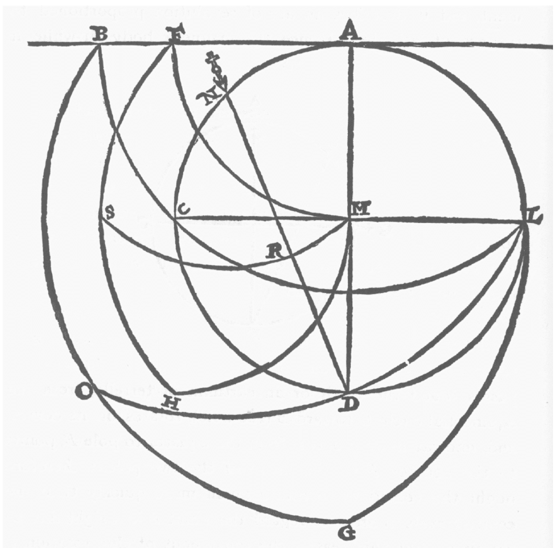


Figure 7: Gilbert's geometrical construction of the mapping in *De Magnete*

comment on this construction because this was done in detail elsewhere[17], but it is *not* possible to understand the construction from Gilbert's writings in *De Magnete*. Even more surprising, while all figures in *De Magnete* are raw wood cuts in the quality shown before, suddenly there is a fine technical drawing of the resulting construction as shown in figure 8. The difference between this drawing and all other figures in *De Magnete* and the weakness in the description of the construction of the mapping between latitudes and dip angles suggest that at least this part was not written by Gilbert alone but by some of his friends in the Gresham circle. Pumfrey speaks of *the dark secret of De Magnete*[18] and

[17] Th. Sonar — Der fromme Tafelmacher. *Logos Verlag, Berlin, 2001*
[18] Pumfrey p.173ff.

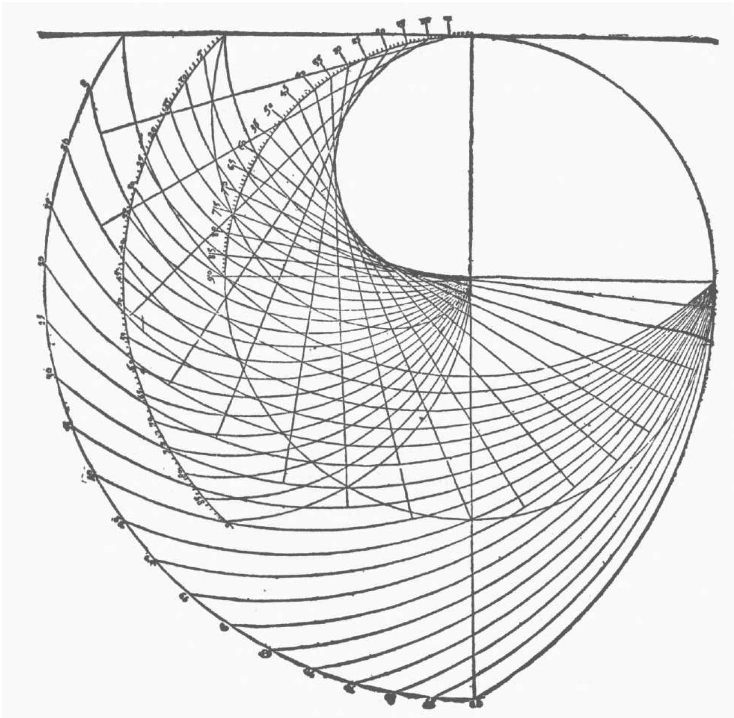


Figure 8: The fine drawing in *De Magnete*

gives evidence that Edward Wright, whose *On Certain Errors in Navigation* had appeared a year before *De Magnete*, had his hands in some parts of Gilberts book[19]. There is no written evidence that Briggs was involved too but it seems very unlikely that the chief mathematician of the Gresham circle should not have been in charge in so important a development as the dip theory. We shall see later on that the involvement of Briggs is highly likely when we study his contributions to dip theory in books of other authors.

3 The Briggsian tables

If we trust Ward[20] the first published table of Henry Briggs is the table which represents Gilbert's mapping between latitude and dip angles in Thomas Blundevilles book

[19]In E.J.S. Parsons, W.F. Morris — Edward Wright and his Work. *Imago Mundi III, 1939, pp.61-71* we find the following remarks: *Wright, and his circle of friends, which included Dr. W. Gilbert, Thomas Blundeville, William Barlow, Henry Briggs, as well as Hakluyt and Davis, formed the centre of scientific thought at the turn of the century. Between these men there existed an excellent spirit of co-operation, each sharing his own discoveries with the others. In 1600 Wright assisted Gilbert in the compilation of De Magnete. He wrote a long preface to the work, in which he proclaimed his belief in the rotation of the earth, a theory which Gilbert was explaining, and also contributed chapter 12 of Book IV, which dealt with the method of finding the amount of the variation of the compass. Gilbert devoted his final chapters to practical problems of navigation, in which he knew many of his friends were interested.*

[20]Ward loc.cit.

The Theoriques of the seuen Planets, shewing all their diuerse motions, and all other Accidents, called Passions, thereunto belonging.

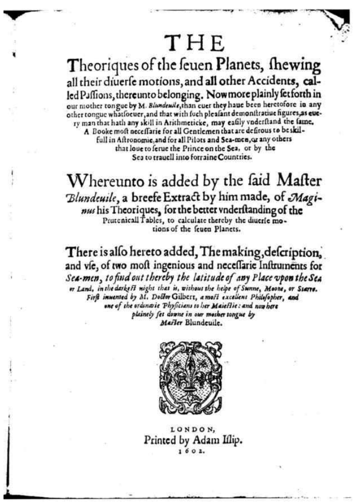
Whereunto is added by the said Master Blundeuile, a breefe Extract by him made, of Magnus his Theoriques, for the better vnderstanding of the Prutenicall Tables, to calculate thereby the diuerse motions of the seuen Planets.

There is also hereto added, The making, description, and vse, of the two most ingenious and necessarie Instruments for Sea-men, to find out therebye the latitude of any place vpon the Sea or Land, in the darkest night that is, without the helpe of Sunne, Moone, or Starre. First inuented by M. Doctor Gilbert, a most excellent Philosopher, and one of the ordinarie Physicians to her Maiestie: and now here plainely set down in our mother tongue by Master Blundeuile.

London

Printed by Adam Islip.

1602.



THE
Theoriques of the ſeuen Planets, ſhewing all their diuerſe motions, and all other Accidents, called Paſſions, thereunto belonging. Now more plainly ſet forth in our mother tongue by M. *Blundeuile*, than euer they haue been heretofore in any other tongue whatſoeuer, and that with ſuch pleaſant demonſtratiue figures, as euery man that hath any skill in Arithmeticke, may eaſily vnderſtand the ſame.
A Booke moſt neceſſarie for all Gentlemen that are deſirous to be skilfull in Aſtronomie, and for all Pilots and Sea-men, or any others that loue to ſerue the Prince on the Sea, or by the Sea to trauell into forraine Countries.

Whereunto is added by the ſaid Maſter *Blundeuile*, a breefe Extract by him made, of *Maginus* his Theoriques, for the better vnderſtanding of the Prutenicall Tables, to calculate thereby the diuerſe motions of the ſeuen Planets.

There is alſo hereto added, The making, deſcription, and vſe, of two moſt ingenious and neceſſarie Inſtruments for *Sea-men, to find out thereby the latitude of any Place vpon the Sea or Land, in the darkeſt night that is, without the helpe of Sunne, Moone, or Starre. Firſt inuented by M. Doctor* Gilbert, *a moſt excellent Philoſopher, and one of the ordinarie Phyſicians to her Maieſtie: and now here plainely ſet downe in our mother tongue by Maſter* Blundeuile.

LONDON,
Printed by Adam Iſlip.
1602.

Figure 9: Title page

Blundeville is an important figure in his own right[21,22]. He was one of the first and most influencial *popularizers* of scientific knowledge. He did not write for the expert, but for the layman. i.e. the *young gentlemen* interested in so diverse questions of science, writing of history, map making, logic, seamenship, or horse riding. We do not know much about his life[23] but his role in the Gresham circle is apparent through his writings. In *The Theoriques* Gilbert's dip theory is explained in detail and a step-by-step description of the construction of the dip instrument is given. I have followed Blundeville's instructions and constructed the dip instrument again elsewhere[24]. The final result is shown in Blundeville's book as in figure 10. In order to understand the geometrical details it is necessary to give a condensed description of the actual construction in figure 7 which is very detailed given in *The Theoriques*. We start with a circle $ACDL$ representing planet earth as in figure 11. Note that A is an equatorial point

[21] D.W. Waters — The Art of Navigation. *Yale University Press, 1958*, pp. 212-214

[22] E.G.R. Taylor — The Mathematical Practioners of Tudor & Stuart England. *Cambridge University Press, 1954*, p.173

[23] A. Campling — Thomas Blundeville, of Newton Flotman, co. Norfolk (1522-1606). *Norfolk Archaeology 21, 336-360, 1921-23*

[24] Th. Sonar — William Gilberts Neigungsinstrument, I: Geschichte und Theorie der magnetischen Neigung. *Mitt. der Math. Gesellschaft in Hamburg, Band XXI/2, 45-68, 2002.* See also Sonar — Der fromme Tafelmacher, loc.cit.

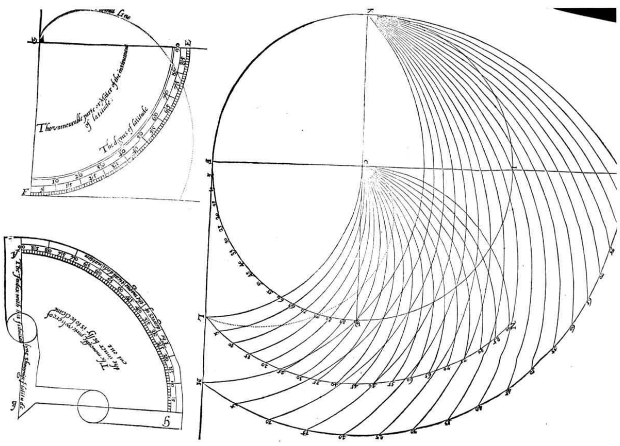


Figure 10: The dip instrument in *The Theoriques*

while C is a pole. The navigator (and hence the dip instrument) is assumed to be in point N which corresponds to the latitude $\beta = 45°$. In the first step of the construction a horizon line is sought, i.e. the line from the navigator in N to the horizon. Now a circle is drawn around A with radius AM (the earth's radius). This marks the point F on a line through A parallel to CL. A circle around M through F now gives the arc $\overset{\frown}{FH}$. The point H is constructed by drawing a circle around C with radius AM. The point of intersection of this circle with the outer circle through F is H. *If the dip instrument is at* A*, the navigator's horizon point is* F*. If it is in* C*, the navigator's horizon will be in* H*.* Correspondingly, drawing a circle through N with radius AM gives the point S, hence, S *is the point at the horizon seen from* N. Hence to every position

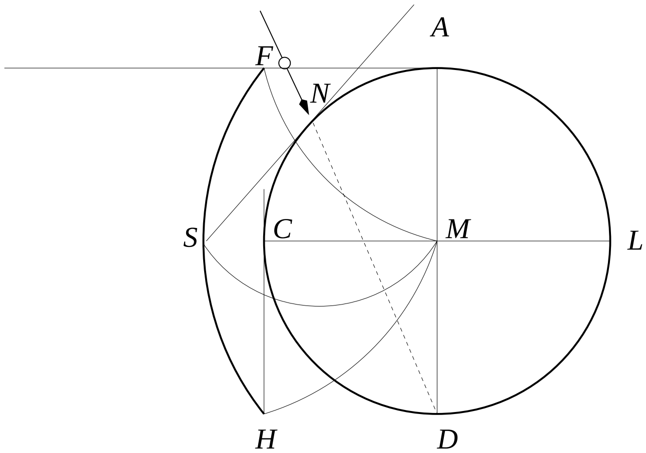


Figure 11: The *Quadrant of dip*

N of the needle there is a *quadrant of dip* which is the arc from M to a corresponding point on the outer crircle through F. If N is at $\beta = 45°$ latitude as in our example we know from Gilbert's third hypotheses that the needle points to D. The angle between S and the intersection point of the quadrant of dip with the direction of the needle is the dip angle. The remaining information

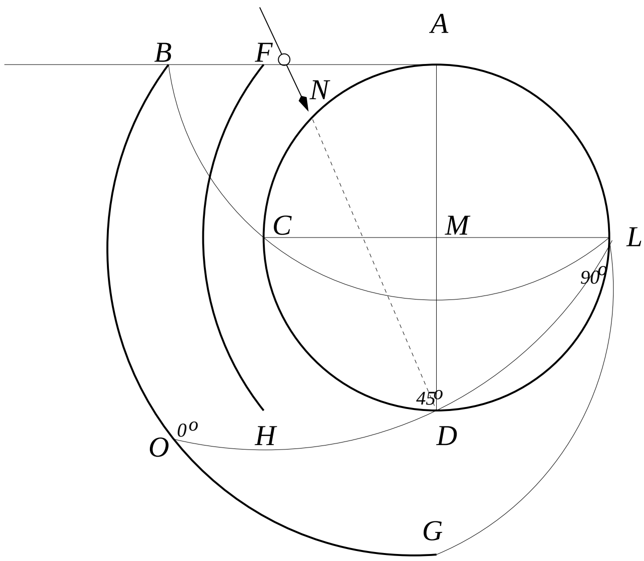


Figure 12: The *Quadrant of rotation*

missing is the point to which the needle points for a general latitude β. This is accomplised by *Quadrants of rotation* which implement Gilbert's idea of the needle *rotating* on its way from A to C. The construction of these quadrants is shown in figure 12. We need a second outer circle which is constructed by drawing a circle around A through L. The intersection point of this circle with the line AF is B and the second outer circle is then the circle through B around M. Drawing a circle around C through L defines the point G on the second outer circle. These arcs, $\overset{\frown}{GL}$ and $\overset{\frown}{BL}$, are the *quadrants of rotation* corrsponding to the positions C and A, respectively, of the needle. Assuming again the dip instrument in N at $\beta = 45°$. Then the corresponding quadrant of rotation is constructed by a circle around N through L and is the arc $\overset{\frown}{OL}$. This arc is now divided in 90 parts, starting from the second outer circle (0°) and ending at L (90°). Obviously, in our example, according to Gilbert, the 45° mark is exactly at D.
Now we are ready for the final step. Putting together all our quadrants and lines, we arrive at figure 13. The needle at N points to the mark 45° on the arc of rotation $\overset{\frown}{OL}$ and hence intersects the quadrant of dip (arc $\overset{\frown}{SM}$) in the point S. *The angle of the arc* $\overset{\frown}{SR}$ *is the dip angle* δ.
We can now proceed in this manner for all latitudes from $\beta = 0°$ to $\beta = 90°$ in steps of 5°. Each latitude gives a new quadrant of dip, a new quadrant of rotation, and a new intersection point R. The final construction is shown in figure 14. However, in figure 14 the construction is shown in the lower right quadrant instead of in the upper left and uses already the notation of Blundeville instead of those of William Gilbert.

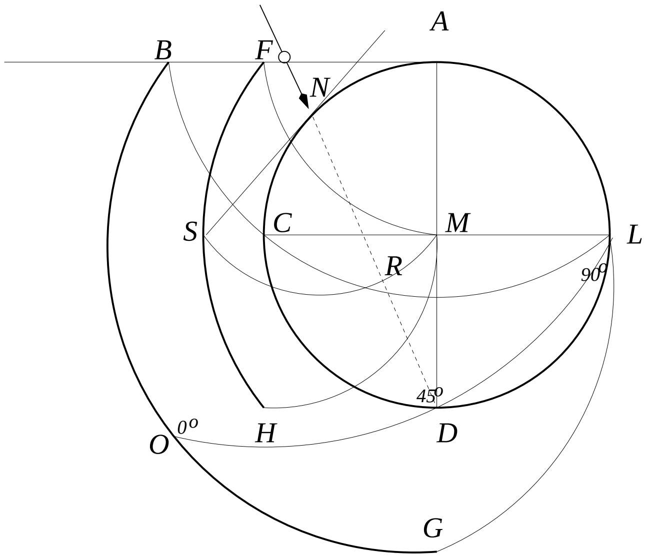


Figure 13: The final steps

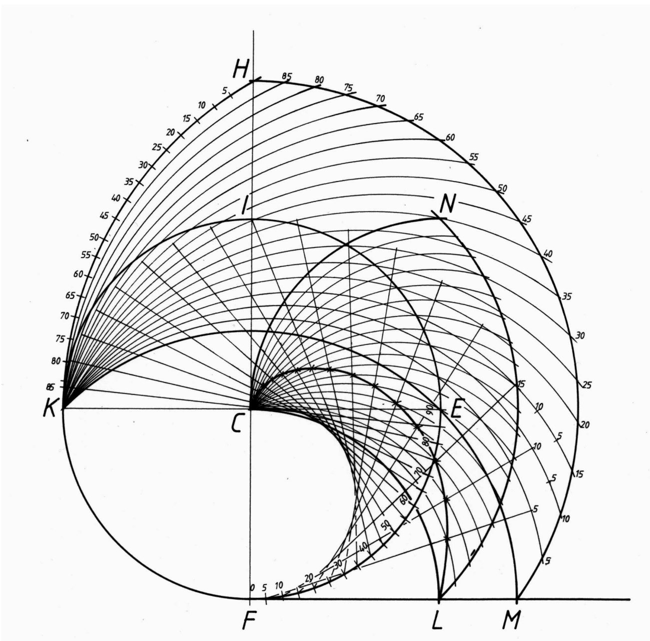


Figure 14: The construction of Gilbert's mapping

The main goal of the construction, however, is a spiral line which appears, after the removal of all the construction lines, as in figure 15 and can already be seen in the upper left picture in Blundeville's drawing in figure 10. The spiral line consists of all intersection points R.

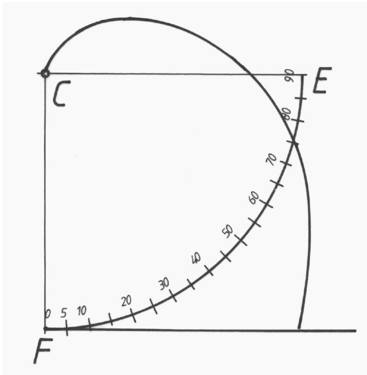


Figure 15: The *mater* of the dip instrument in *The Theoriques*

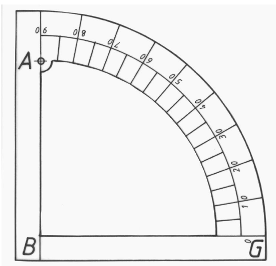


Figure 16: The quadrant

Together with a quadrant which can rotate around the point C of the *mater* the instrument is ready to use. In order to illustrate its use we give an example. Consider a seamen has used a dip ring and measured a dip angle of 60°. Then he would rotate the quadrant until the spiral line intersects the quadrant at the point 60° on the inner side of the quadrant. Then the line $A-B$ on the quadrant intersects the scale on the mater at the degree of latitude; in our case 36°, see figure 17. However, accurate reading of the scales becomes nearly impossible for angles

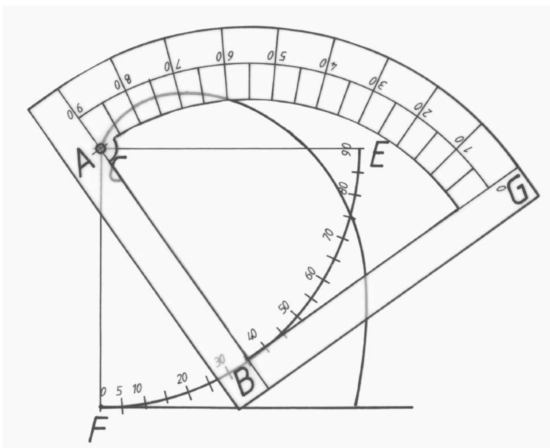


Figure 17: Determining the latitude for 60° dip

of dip larger than 60° and the reading depends heavily on the accuracy of the construction of the spiral line. Therefore, Henry Briggs was asked to compute a table in order to replace the dip instrument by a simple table look-up. At the very end of Blundeville's *The Theoriques* we find the following appendix[25]:

> *A short Appendix annexed to the former Treatise by Edward Wright, at the motion of the right Worshipfull M. Doctor Gilbert*
>
> *Because of the making and using of the foresaid Instrument, for finding the latitude by the declination of the Magneticall Needle, will bee too troublesome for the most part of Sea-men, being notwithstanding a thing most worthie to be put in daily practise, especially by such as undertake long voyages: it was thought meet by my worshipfull friend M. Doctor Gilbert, that (according to M. Blundeuiles earnest request) this Table following should be hereunto adioned; which M. Henry Briggs (professor of Geometrie in Gresham Colledge at London) calculated and made out of the doctrine and tables of Triangles, according to the Geometricall grounds and reason of this Instrument, appearing in the 7 and 8 Chapter of M. Doctor Gilberts fift[h] booke of the Loadstone. By helpe of which Table, the Magneticall declination being giuen, the height of the Pole may most easily be found, after this manner.*
> *With the Instrument of Declination before described, find out what the Magneticall declination is at the place where you are: Then look that Magneticall declination in the second Collum[n]e of this Table, and in the same line immediatly towards the left hand, you shall find the height of the Pole at the same place, unleße there be some variation of the declination, which must be found out by particular obseruation in euery place.*
>
> *The Table followes on the next Page.*

The next page (which is the final page of the book) indeed shows the table. Figure 18 shows the Appendix. In order to make the numbers in the table more visible I have retyped the table.

First Column.	*Second Column.*		*First Column.*	*Second Column.*		*First Column.*	*Second Column.*	
Heighs of the Pole.	*Magnetical declination.*		*Heighs of the Pole.*	*Magnetical declination.*		*Heighs of the Pole.*	*Magnetical declination.*	
Degrees.	*Deg.*	*Min.*	*Degrees.*	*Deg.*	*Min.*	*Degrees.*	*Deg.*	*Min.*
1	2	11	31	52	27	61	79	29
2	4	20	32	53	41	62	80	4
3	6	27	33	54	53	63	80	38
4	8	31	34	56	4	64	81	11
5	10	34	35	57	13	65	81	43
6	12	34	36	58	21	66	82	13
7	14	32	37	59	28	67	82	43
8	16	28	38	60	33	68	83	12
9	18	22	39	61	37	69	83	40
10	20	14	40	62	39	70	84	7
11	22	4	41	63	40	71	84	32
12	23	52	42	64	39	72	84	57
13	25	38	43	65	38	73	85	21
14	27	22	44	66	35	74	85	44
15	29	4	45	67	30	75	86	7
16	30	45	46	68	24	76	86	28
17	32	24	47	69	17	77	86	48
18	34	0	48	70	9	78	87	8
19	35	36	49	70	59	79	87	26
20	37	9	50	71	48	80	87	44

[25] see figure 18

21	*38*	*41*	*51*	*72*	*36*	*81*	*88*	*1*
22	*40*	*11*	*52*	*73*	*23*	*82*	*88*	*17*
23	*41*	*39*	*53*	*74*	*8*	*83*	*88*	*33*
24	*43*	*6*	*54*	*74*	*52*	*84*	*88*	*47*
25	*44*	*30*	*55*	*75*	*35*	*85*	*89*	*1*
26	*45*	*54*	*56*	*76*	*17*	*86*	*89*	*14*
27	*47*	*15*	*57*	*76*	*57*	*87*	*89*	*27*
28	*48*	*36*	*58*	*77*	*37*	*88*	*89*	*39*
29	*49*	*54*	*59*	*78*	*15*	*89*	*89*	*50*
30	*51*	*11*	*60*	*78*	*53*	*90*	*90*	*0*

Before we discuss this table in detail it is again worthwhile to review the relations between Gilbert, Briggs, Blundeville and Wright[26]:

> *Briggs was at the center of Gilbert's group. At Gilbert's request he calculated a table of magnetic dip and variation. Their mutual friend Edward Wright recorded and tabulated much of the information which Gilbert used, and helped in the production of* De Magnete. *Thomas Blundeville, another member of Brigg's group, and - like Gilbert - a former protégé of the Earl of Leicester, popularized Gilbert's discoveries in* The Theoriques of the Seven Planets *(1602), a book in which Briggs and Wright again collaborated.*

It took Blundeville's *The Theoriques* to describe the construction of the dip instrument accurately which nebulously appeared in Gilbert's *De Magnete*. However, even Blundeville does not say a word concerning the computation of the table. Another friend in the Gresham circle, famous Edward Wright, included all of the necessary details in the second edition of his *On Errors in Navigation*[27] the first edition of which appeared 1599. Much has been said about the importance of Edward Wright[28] and he was certainly one of the first - if not the first - who was fully aware of the mathematical background of Mercator's mapping[29].
It is in Chapter 14 where Wright and Briggs explain the details of the computation of the dip table. We read:

[26] Hill, loc.cit. p.36
[27] E. Wright — Certaine Errors in Navigation Detected and Corrected with Many additions that were not in the former edition as appeareth in the next pages. *London, 1610*
[28] Parsons, Morris loc.cit.
[29] Sonar — Der fromme Tafelmacher. loc.cit., p. 131 ff.

A short Appendix annexed to the former Treatise by *Edward Wright*, at the motion of the right Worshipfull M. Doctor *Gilbert*.

Because the making and vsing of the foresaid Instrument, for finding the latitude by the declination of the Magneticall Needle, will bee too troublesome for the most part of Sea-men, being notwithstanding a thing most worthie to be put in daily practise, especially by such as vndertake long voyages: it was thought meet by my worshipfull friend M. Doctor Gilbert, *that (according to M.* Blundeuiles *earnest request) this Table following should be hereunto adioined; which M.* Henry Brigs *(professor of Geometrie in* Gresham *Colledge at London) calculated and made out of the doctrine and tables of Triangles, according to the Geometricall grounds and reason of this Instrument, appearing in the 7 and 8 Chapter of M. Doctor* Gilberts *fift booke of the Loadstone. By helpe of which Table, the Magneticall declination being giuen, the height of the Pole may most easily be found, after this manner.*

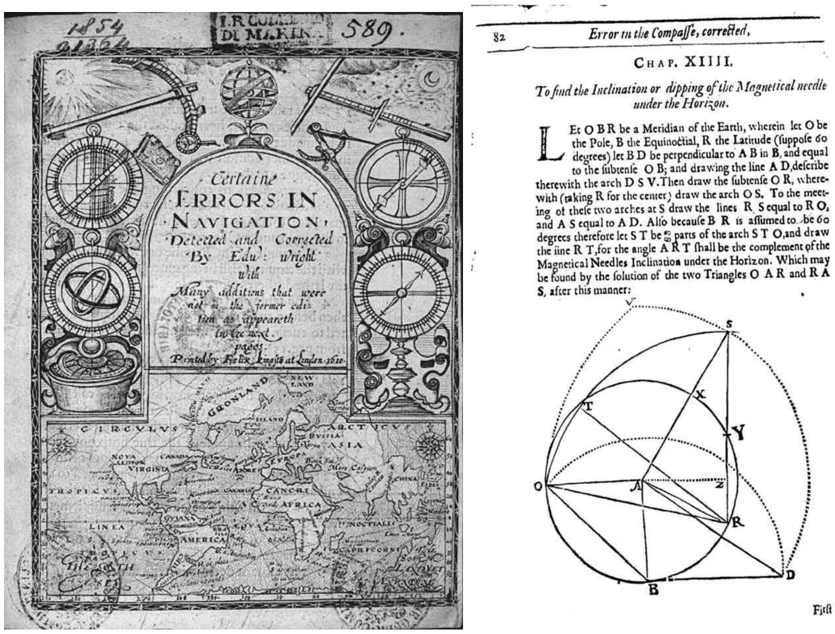
With the Instrument of Declination before described, find out what the Magneticall declination is at the place where you are: Then looke that Magneticall declination in the second Collumne of this Table, and in the same line immediatly towards the left hand, you shall find the height of the Pole at the same place, vnlesse there be some variation of the declination, which must be found out by particular obseruation in euery place.

The Table followes on the next Page.

First Collumn.	Second Collumn.		First Collumn.	Second Collumn.		First Collumn.	Second Collumn.	
Height of the Pole.	Magneticall declination.		Height of the Pole.	Magneticall declination.		Height of the Pole.	Magneticall declination.	
Degrees.	Deg.	Min.	Degrees.	Deg	Min	Degrees.	Degr.	Min.
1	2	11	31	52	27	61	79	29
2	4	20	32	53	41	62	10	4
3	6	27	33	54	53	63	80	38
4	8	31	34	56	4	64	81	31
5	10	34	35	57	13	65	81	43
6	12	34	36	58	11	66	82	13
7	14	32	37	59	28	67	82	43
8	16	28	38	60	33	68	83	12
9	18	22	39	61	37	69	83	40
10	20	14	40	62	39	70	84	7
11	22	4	41	63	40	71	84	32
12	23	52	42	64	39	72	84	57
13	25	38	43	65	38	73	85	21
14	27	22	44	66	35	74	85	41
15	29	4	45	67	30	75	86	7
16	30	45	46	68	24	76	86	28
17	32	24	47	69	17	77	86	48
18	34	0	48	70	9	78	87	8
19	35	36	49	70	59	79	87	26
20	37	9	50	71	48	80	87	44
21	38	41	51	72	36	81	88	1
22	40	11	52	73	23	82	88	17
23	41	39	53	74	8	83	88	33
24	43	6	54	74	52	84	88	47
25	44	30	55	75	35	85	89	1
26	45	54	56	76	17	86	89	14
27	47	15	57	76	57	87	89	27
28	48	36	58	77	37	88	89	39
29	49	54	59	78	15	89	89	50
30	51	11	60	78	13	90	90	0

A.318.

Figure 18: The Appendix



82 Error in the Compasse, corrected.

CHAP. XIIII.

To find the Inclination or dipping of the Magneticall needle under the Horizon.

LEt O B R be a Meridian of the Earth, wherein let O be the Pole, B the Equinoctial, R the Latitude (suppose 60 degrees) let B D be perpendicular to A B in B, and equal to the subtense O B; and drawing the line A D, describe therewith the arch D S V. Then draw the subtense O R, wherewith (taking R for the center) draw the arch O S. To the meeting of these two arches at S draw the lines R S equal to R O, and A S equal to A D. Also because B R is assumed to be 60 degrees therefore let S T be $\frac{60}{90}$ parts of the arch S T O, and draw the line R T, for the angle A R T shall be the complement of the Magnetical Needles Inclination under the Horizon. Which may be found by the solution of the two Triangles O A R and R A S, after this manner:

First

(a) The title page of the second edition

(b) First page of the 14th Chapter

Figure 19: On Certain Errors in Navigation

CHAP. XIIII

To finde the inclination or dipping of the magneticall needle under the Horizon

> *Let OBR be a meridian of the earth, wherein let O be the pole, B the æquinoctal, R the latitude (suppose* 60 *degrees) let BD be perpendicular to AB in B, and equall to the subtense OB; and drawing the line AD, describe therwith the arch DSV. Then draw the subtense OR, wherewith (taking R for the center) draw the lines RS equall to RO, and AS equall to AD. Also because BR is assumed to be* 60 *deg. therefore let ST be $\frac{60}{90}$ parts of the arch STO, and draw the line RT, for the angle ART shall be the cõplement of the magnetical needles inclinatiõ vnder the Horizon. Which may be found by the solution of the two triangles OAR and RAS, after this manner:*

Again using notation different from *De Magnete* and *The Theoriques* we can identify Gilbert's construction with ease (now, however, in the lower right quadrant). The computation follows:

> *First the triangle OAR is giuen because of the arch OBR, measuring the same* 150 *degr. and consequently the angle at R* 15 *degr. being equall to the equall legged angle at O; both which together are* 30 *degr. because they are the complement of the angle OAR (150 degr.) to a semicircle of* 180 *degr.*

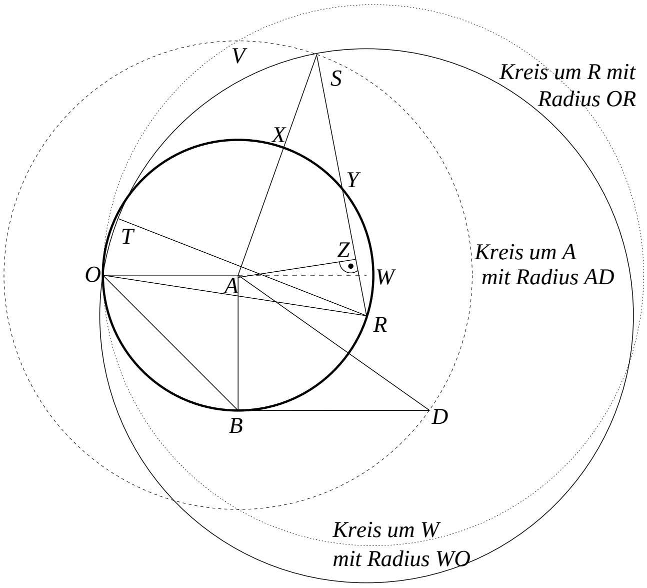


Figure 20: Concerning the computation of latitude from the angle of dip (The german notation "Kreis um A mit Radius AD" simply reads "Circle around A with radius AD")

Hence, the computation starts with the triangle OAR drawn in bold in figure 21. Since Wright/Briggs has given the point R at an angle of 60° as measured from B, the arc OBR corresponds to an angle of $90° + 60° (= 180° - 30°) = 150°$. Hence, in the triangle OAR the angle at A is just $90° + (90° - 30°) = 150°$. The triangle OAR is isosceles and therefore the angles at O and R are the same. Since the sum of the angles is 180° this leaves only 15° each for these angles.

> *Secondly, in the triangle ARS all the sides are giuen AR the Radius or semidiameter* 10,000,000*: RS equal to RO the subtense of* 150 *deg.* 19,318,516*: and AS equall to AD triple in power to AB, because it is equal in power to AB and BD, that is BO, which is double in power to AB.*

Triangle ARS is now exploited in detail, see figure 22, where S lies on the circle around A with radius AD *and* on the circle around R with radius OR. The line AR is the radius of our 'earth'; it is here assumed that the value is 10000000[30]. Now what is the meaning of the *subtense* and where does the number 19318516 come from? It holds in every triangle that the quotient of two sites relates like the sine of the opposing angles. In triangle OAR it therefore holds

$$\frac{OR}{AR} = \frac{\sin 150°}{\sin 15°},$$

and hence $OR(\equiv RO) = AR\frac{\sin 150°}{\sin 15°} = 19318516(.5257...)$. Since O and S are

[30]This number ist the *Whole sine*, i.e. a hypothetical hypothenuse to which all trigonometric functions are related. If the *Whole sine* was taken too small the results were not expressible in terms of integer numbers (the notation of decimal numbers was clear to Briggs but not to most of his contemporaries), if it was chosen too large it resulted in too many digits.

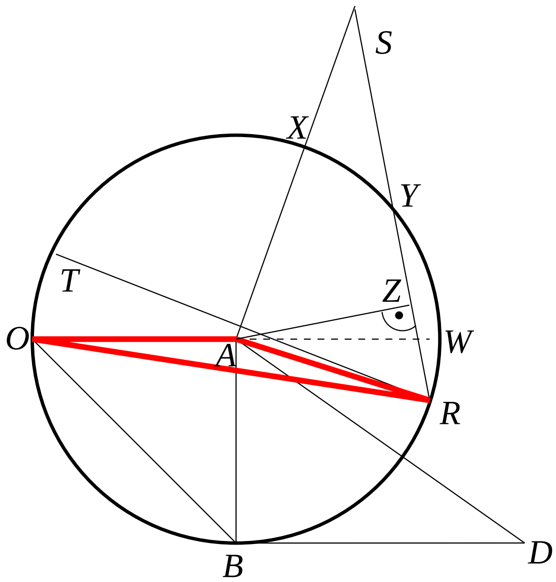


Figure 21: First step in the computation

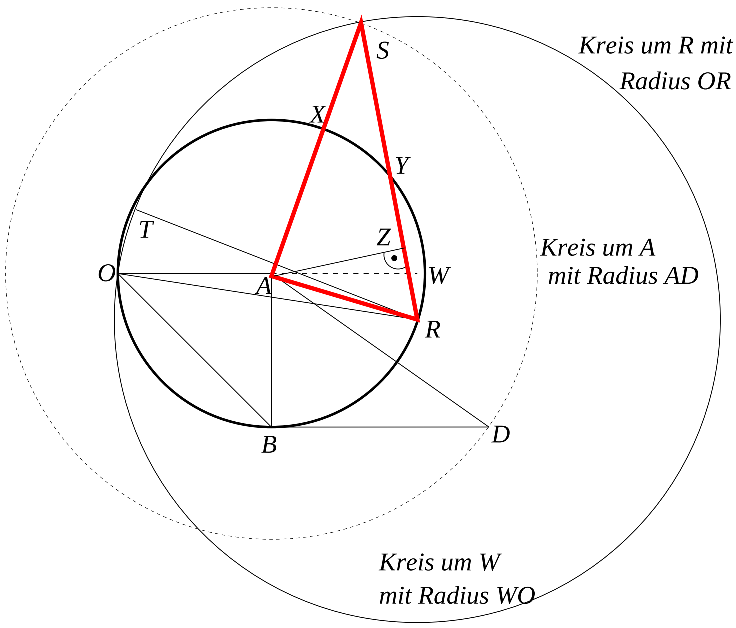


Figure 22: Second step in the computation

both located on the circle around R with radius OR it holds $RO = RS$. Furthermore certainly $AS = AD$, since D and S both lie on the circle around A with radius AD. Since $BD = OB$ (per constructionem) it follows $OB^2 = BD^2 = 2AB^2$ (Pythagoras) and therefore (Pythagoras again) $AD^2 = AB^2 + BD^2 = AB^2 + 2AB^2 = 3AB^2$. This is the meaning behind the notion of *triple in power to AB* ('squared three times as large as AB'). Hence, for AS it follows:

$$AS = AD = \sqrt{3} \cdot AB = 17320508(.0757...).$$

Wright/Briggs however does not compute this root but gives an alternative for its computation.

> *Or else thus: The arch OB being 90 degrees, the subtense therof OB, that is, the tangent BD is 14,142,136, which sought in the table of Tangents, shall giue you the angle BAD 54 degr. 44 min. 8 sec. the secant whereof is the line AD that is AS 17,320,508.*

In the triangle ABD we are given the lines AB und $BD = OB = \sqrt{2}AB = 14142135(.6237...)$. Therefore we have for the angle at A

$$\tan \angle A = \frac{BD}{AB} = \frac{\sqrt{2}AB}{AB} = \sqrt{2}$$

which, with the help of a pocket calculator, has the value

$$\angle A = 54.7356...^\circ = 54^\circ 44' 8''$$

which had to be read from a table by Wright/Briggs. Hence it follows

$$\sin \angle A = \frac{BD}{AD} = \frac{OB}{AD}$$

and therefore

$$AD = AS = \frac{OB}{\sin \angle A} = \sqrt{2} \cdot \frac{AB}{\sin 54.7356...^\circ} = 17320508(.0757...).$$

> *Now then by 4 Axiom of the 2 booke of Pitisc.*[31] *as the base or greatest side SR 19,318,516 is to yͤ summe of the two other sides*

[31] The German (Silesian) Bartholomäus Pitiscus (1561-1613) wrote the first useful textbook on trigonometry *Trigonometriae sive dimensione triangulorum libre quinque*, Frankfurt 1595, printed as an appendix to the *Astronomie* of Abraham Scultetus (Schultz) (D.E. Smith — History of Mathematics, Vol. I. *Dover Publications, 1958. Reprint of the first edition 1923*:). Independent editions were printed in Frankfurt 1599, 1608, 1612 and in Augsburg 1600. The first english translation was published in 1630 (D.E. Smith loc.cit. p. 331). Following F. Cajori — A History of Mathematical Notations. *Dover Publications, 1993. Reprint of the first edition printed in two volumes in 1928 and 1929* Pitiscus very likely coined the word *Trigonometry.* In K. Reich — Lehrbücher. In: Maß, Zahl und Gewicht: Mathematik als Schlüssel zu Weltverständnis und Weltbeherrschung. *Ausstellungskatalog Nr.60 of the Herzog August Library Wolfenbüttel, Harrassowitz Verlag, Wiesbaden, 2nd edt., 2001* the title of the book for 1595 is given as *Trigonometria sive de solutione triangulorum tractatus brevis et perspicuus* and 1614 appears as the date of the first english translation. The book mentioned by D.E. Smith above turns out to be only a revised version of the book mentioned by Reich and which actually carries the title *Trigonometriae Siue. De dimensione Triangulorum libre quinque.* The copy of the revised edition discussed by Reich as a piece of an exhibition (photography of the title page on p. 232) carries the year 1600.

SA and AR 27, 320, 508*; so is the difference of them SX* 7, 320, 508 *to the segment of the greatest side SY* 10, 352, 762*; which being taken out of SR* 19, 318, 516*, there remaineth YR* 8, 965, 754*, the halfe whereof RZ* 4, 482, 877*, is the Sine of the angle RAZ* 26 *degr.* 38 *min.* 2 *sec. the complement whereof* 63 *degr.* 21 *min.* 58 *sec. is the angle ARZ, which added to the angle ARO* 15 *degr. maketh the whole angle ORS,* 78 *degr.* 21 *min.* 58 *sec. wherof* $\frac{60}{90}$ *make* 52 *degr.* 14 *min.* 38 *sec. which taken out of ARZ* 63 *degr.* 21 *min.* 58 *sec. there remaineth the angle TRA* 11 *deg.* 7 *min.* 20 *sec. the cõplement whereof is the inclination sought for* 78 *degrees,* 52 *minutes,* 40 *seconds.*

The 'axiom' cited *4 Axiom* of the second book in the work of Pitiscus is the well known
Proposition of chords: *If two chords of a circle intersect then the product of the lengths of the two resulting segments of one chord equals the product of the lengths of the two segments of the other chord.*
In figure 23 the Proposition of chords yields

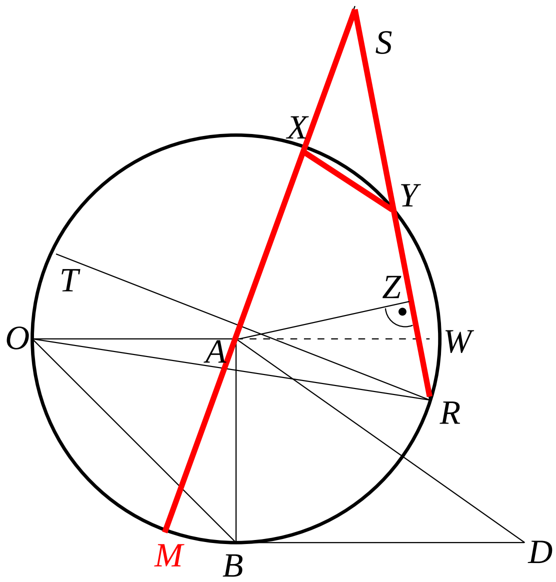


Figure 23: Proposition of chords

$$MS \cdot SX = SR \cdot SY,$$

and since $MS = AS + AB$ it follows

$$(AS + AB) \cdot SX = SR \cdot SY$$

and hence

$$\frac{SR}{AS + AB} = \frac{SX}{SY}.$$

At this point the calculations are fully understandable. Given are $AS = 17320508$, $AB = 10000000$, $SR = OR = 19318516$ and $SX = AS - AX =$

7320508; this yields

$$SY = \frac{SX(AS + AB)}{SR} = 10352762.$$

For the line YR it then follows $YR = SR - SY = 8965754$. *Per constructionem* (see figure 24) the point Z lies in the middle of the line YR. The half of

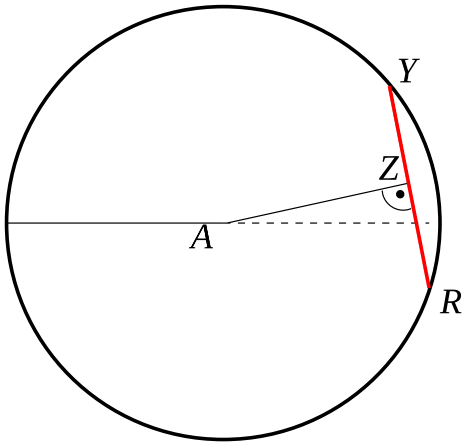


Figure 24: Z divides YR in the middle

YR is $RZ = 4482877$. Now $\sin\angle RAZ = \frac{RZ}{AR} = \frac{4482877}{10000000} = 0.4482877$, hence $\angle RAZ = 26.6339° = 26°38'2''$. In the right-angled triangle ARZ it follows for the angle $ARZ = 90° - 26°38'2'' = 63°21'58''$, see figure 25. The angle ARO

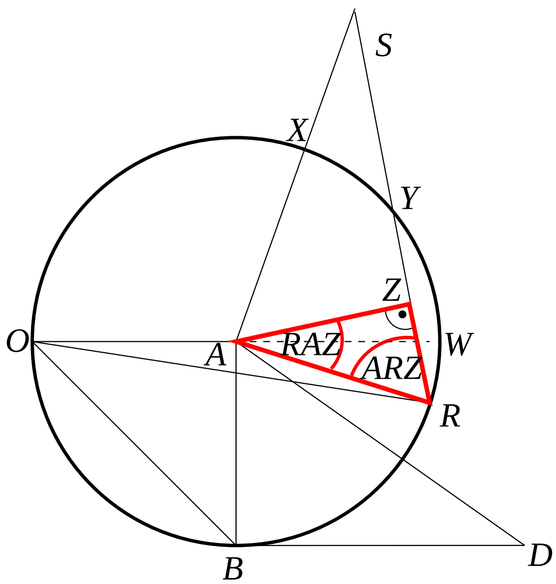


Figure 25: Computation of angles I

for a latitude of 60° for the point R is just 15°, because the obtuse angle in the

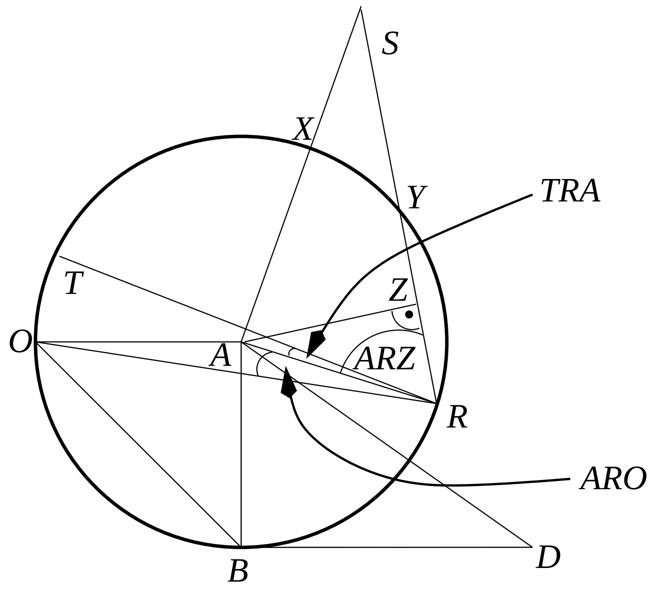


Figure 26: Computation of angles II

isosceles triangle ORA is $90° + 60° = 150°$. Thus, the result for the angle ORS is $ORS = ARO + ARZ = 78°21'58''$. Of this angle the part TRS is just the $\frac{60}{90}$th part, i.e. $TRS = 52°14'38''$. Hence,

$$\angle TRA = \angle ARZ - \angle TRA = 63°21'58'' - 52°14'38'' = 11°7'20''.$$

Therefore the angle of dip δ is the complementary angle of TRA:

$$\delta = 90° - \angle TRA = 78°52'40''.$$

But Briggs would not be the mathematician of first rank if he would not have immediately given a possibility to save computational work:

> *The Summe and difference of the sides SA and AR being alwaies the same, viz.* $27,320,508$ *and* $7,320,508$*, the product of them shall likewise be alwaies the same, viz.* $199,999,997,378,064$ *to be diuided by y^e side SR, that is RO the subtense of RBO. Therefore there may be some labour saued in making the table of magneticall inclination, if in stead of the said product you take continually but y^e halfe thereof, that is* $99,999,998,689,032$*, and so diuide it by halfe the subtense RO, that is, by the sine of halfe the arch OBR. Or rather thus: As halfe the base RS (that is, as the sine of halfe the arch OBR) is to halfe the summe of the other two sides SA & AR* $13,660,254$*, so is half the difference of theẽ* $3,660,254$ *to halfe of the segment SY, which taken out of half the base, there remaineth RZ y^e sine of RAZ, whose cõplement to a quadrãt is y^e angle sought for ARZ.*
>
> *According to this Diagramme and demonstration was calulated the table here following; the first columne whereof conteineth the height*

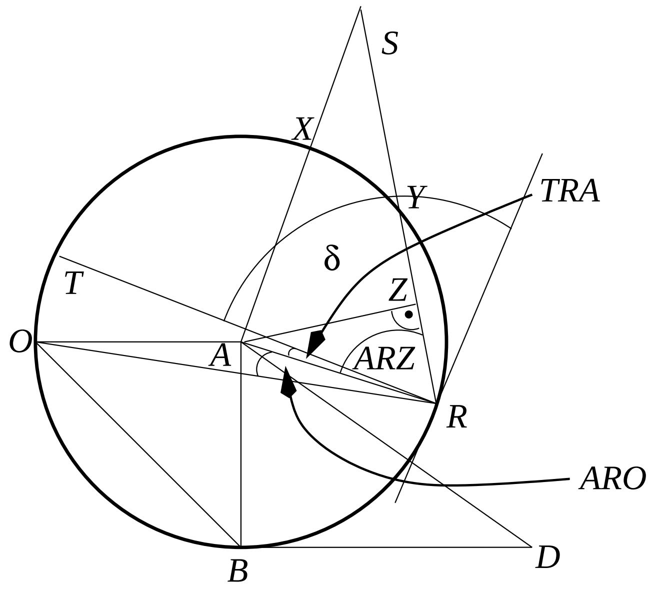


Figure 27: Computing of angles III

> *of the pole for euery whole degree; the second columne sheweth the inclination or dipping of the magnetical needle answerable thereto in degr. and minutes.*

At this point, as a final result, the Briggsian table is printed again.

4 Epilogue

Henry Briggs, who is known today only as the inventor of logarithms to base 10, should be remembered in the first place for his groundbreaking work in navigational tables. It is pityful that his role as a table maker is even neglected in modern publications[32] and that his admirers seem to be fixed at logarithms. In the work of the men of the Gresham circle on William Gilbert's dip instrument we are able to observe Briggs as a first-rate mathematician able to manipulate even complicated trigonometric identities. In fact, he contributed more tables[33] to Wright's *On Certain Errors* which were of astronomical nature, since he was also an able astronomer.
At the turn of the 16th to the 17th century England was blessed with several able applied mathematicians. One of them was the famous Thomas Harriot who, like Briggs, was involved in nautical matters. It would have been a delight if there would have been evidence that Briggs and Harriot actually met. This, however, can still not be proven today.

[32] M. Campbell-Kelly, M. Croarken, R. Flood, E. Robson — The History of Mathematical Tables: From Sumer to Spreadsheets. *Oxford Univ. Press 2003*
[33] Th. Sonar — Der fromme Tafelmacher, loc.cit.

84 *The Table of Magnetical Inclination.*

First col. Height of the Pole	Second col. Magnetical Inclination.		First col. Height of the Pole.	Second col. Magnetical Inclination.		First col. Height of the Pole.	Second col. Magnetical Inclination.	
Degrees	Degr.	Min.	Degrees	Degr.	Min.	Degrees	Degr.	Min.
1	2	11	31	52	27	61	79	29
2	4	20	32	53	41	62	80	4
3	6	27	33	54	53	63	80	38
4	8	31	34	56	4	64	81	11
5	10	34	35	57	13	65	81	43
6	12	34	36	58	21	66	82	13
7	14	32	37	59	28	67	82	43
8	16	28	38	60	33	68	83	12
9	18	22	39	61	37	69	83	40
10	20	14	40	62	39	70	84	7
11	22	4	41	63	40	71	84	32
12	24	52	42	64	39	72	84	57
13	25	38	43	65	38	73	85	21
14	27	22	44	66	35	74	85	44
15	29	4	45	67	30	75	86	7
16	30	45	46	68	24	76	86	28
17	32	24	47	69	17	77	86	48
18	34	0	48	70	9	78	87	8
19	35	36	49	70	59	79	87	26
20	37	9	50	71	48	80	87	44
21	38	41	51	72	36	81	88	1
22	40	11	52	73	23	82	88	17
23	41	39	53	74	8	83	88	33
24	43	6	54	74	52	84	88	47
25	44	30	55	75	35	85	89	1
26	45	54	56	76	17	86	89	14
27	47	15	57	76	57	87	89	27
28	48	36	58	77	37	88	89	39
29	49	54	59	78	15	89	89	50
30	51	11	60	78	53	90	90	0

whoſe

Figure 28: The Briggsian table in *On Certain Errors*

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