1868

Report of the Commissioner on the Variations of the Magnetic Needle

Maine Commissioner on Variations of the Magnetic Needle

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STATE OF MAINE.

EXECUTIVE DEPARTMENT,
Augusta, February 27, 1868.

To the Senate and House of Representatives:

I have the honor to transmit the Report of the Commissioner on the Variations of the Magnetic Needle, which is a work of great value, and in my opinion should be printed for public use.

J. L. CHAMBERLAIN.

STATE OF MAINE.

Resolve in relation to the variations of the magnetic needle.

Resolved, That the governor and council be and hereby are authorized to appoint a commissioner, if by them deemed expedient, who shall ascertain all available facts in relation to the variations of the magnetic needle throughout the State from its first settlement down to the present time, and deposit a record of the same with the clerk of the courts in each county of the State, where it shall be accessible to all persons wishing to refer thereto; said commissioner shall hold his office during the pleasure of the governor and council, not to exceed two years, and shall be paid for his services such compensation as by them may be deemed equitable and just.

Approved February 23, 1866.

To the Governor and Council of Maine:

Having been commissioned in conformity with the foregoing Resolve, it now becomes my duty to submit a report of my investigations, and the results which I have been able to obtain, under its requirements.

At the date of my commission—May 8, 1866—I was under previous engagements to make certain surveys in the vicinity of the State line between Maine and New Hampshire. And being employed for several months in that service, but little could be done under the commission, except to ascertain the *change of declination* on certain favorable portions of the State line since the year 1858, at which time the line was renewed by authority of the two States, and reported in the Land Agent's Report for 1859. Meanwhile, however, I employed Samuel Johnson, A. M., of Jackson, to assist in collecting, from various sources, such available facts as were to be had relative to the "variations of the magnetic needle," and by corresponding with the makers and venders of astronomical instruments, to ascertain the adaptability of the different kinds of instruments used for this purpose, and their relative expense. These instruments being quite expensive, and wishing to avoid any outlay which might be deemed of doubtful expediency, I learned, on inquiry, that a *loan* of an instrument might be obtained, in behalf of the State, from the Department of the U. S. Coast Survey, at Washington; and through the kindness of Prof. Peirce, Superintendent, and of the Hon. J. E. Hilgard, Assistant in charge of the office of the U. S. Coast Survey, I obtained, in June, 1867, the loan of a six-inch repeating Theodolite, made by Troughton and Simms of London, and for the safe-keeping and return of which the State is held responsible.

About the same time, I was kindly advised by Mr. Hilgard to call upon Prof. Peirce, then at Cambridge, and learn the destination of his surveying parties in Maine, and especially to witness the magnetic observations then being made (or about to be made) on Manomet hill, near Plymouth, by Capt. C. O. Boutelle, Assistant in the Coast Survey, and who had formerly made observations at several of the magnetic stations in Maine; from either of whom valuable information in furtherance of our object would be readily imparted. Accordingly, I called on the Professor, and obtained from him a letter of introduction to Capt. Boutelle, requesting him to render all possible aid towards the prosecution of our labors. But, on meeting with Capt. B., I soon found from his affable deportment, and his willingness to aid in the matter, that "introductory letters" were uncalled for. Still, as neither his party nor his instruments had as yet arrived, this call proved, in the main, premature, yet by no means useless, either to myself or the State. In connection with my researches in the Land Office at Boston, I again called, by invitation, in August, and remained a few days (and *nights* also), with Capt. Boutelle and his party at their encampment on Manomet hill, where I had an opportunity to witness the *modus operandi* of their astronomical and magnetic observations, for which the weather, just at that time, proved uncommonly favorable.

For the hospitality extended to me during my stay at Manomet, and for the information so kindly imparted by Capt. Boutelle and his assistants (Messrs. Agnew and Peirce), I would here, in behalf of the State, tender my grateful acknowledgments.

Before I left the station at Manomet, the party was visited by the Superintendent of the Coast Survey, with whom I had the pleasure of further extending my acquaintance. During this interview Prof. Peirce very kindly offered (as soon as the necessary arrangements could be made), to detail one of his Assistants on the Coast Survey to aid in making the proposed magnetic observations in Maine; it being the understanding that the Assistant's salary should continue under the department,—his board and travelling expenses to be paid by the State.

It being the design to extend the Coast Survey still further into the interior, this labor, if performed in connection with that survey, might be, in some degree, beneficial to the department, and at the same time vastly important to the State. Owing to the superior character of the instruments used on the Coast Survey, and the superior *skill* acquired by the constant *practice* of those employed in that service, it seems very desirable that such observations as are yet to be made in this State should be done in conformity with those which have already been made by the same parties nearer the coast.

And since the *changes* in the declination of the needle, at any particular place, are of more practical importance than its absolute *amount*, some legal provision should be made whereby the *direction* *of meridian lines* may be *perpetuated*, upon the face of the earth. This might be done at a trifling additional expense, at the same time that meridians are being determined for the purpose of ascertaining the declination of the needle, simply by erecting upon the meridian lines two or more permanent stone posts with pointed spikes of copper or brass, accurately inserted in their tops, and in the precise range of the meridian; so that, by taking their magnetic bearings from time to time, these periodical *changes* could be at once determined and set off upon the vernier of the compass. But, as the *declination* of the needle and its *annual change* are different in different places, these monuments should be established in various localities throughout the State.

To meet these requirements, the Resolve seems to have contained no specific provision; and not wishing to make an expenditure beyond the expressed or implied provisions of the resolve, I postponed, for the time being, the establishment of meridian lines thus perpetuated by monuments, believing that the very generous proposal made by the Superintendent of the Coast Survey will be gladly accepted, and such further legislation had on the subject as the exigencies of the case seem to demand. In the meantime, I have collected such facts in relation to *past observations* made on the variations of the needle in this State, as were considered either interesting or useful. To obtain these facts, I have sought information from every available source within my knowledge. Besides examining the various works on Land Surveying which have been published in this country, I have examined as extensively and thoroughly as time and opportunity rendered possible, such works on the subject as were to be found in our public and private libraries,—have consulted numerous official documents, and scientific journals; also the field-books and early records of surveys, as contained in the land offices of Maine and Massachusetts. But, prior to the commencement of the U. S. Coast Survey, I find, comparatively speaking, but few of the variations of the needle, as observed in this State, recorded; and owing to the doubtful character of some of the earliest of these observations, we are unable to place implicit reliance on them.

In reporting the variations of the needle as observed at different periods within the borders of our own State, it might seem, at first blush, extraneous to notice observations made upon it in other parts of the world. But it must be remembered that "the magnetic force of the earth is a planetary force, and is confined to no limited locality." Hence, the necessity of being able to compare observations which have been made from time to time, in places widely remote from each other, in order to arrive at any just conclusion as to the character and the amount of change to be allowed for at any particular place or locality. In the preparation of this report, I have aimed at *usefulness*, rather than *originality*, and would therefore acknowledge my indebtedness, for much that is valuable in these pages, to various writers on the subject, among whom are Professors Lovering, Loomis and Wells, from whose able discussions on magnetism, as well as from those of several French and English writers on the same subject, I have freely compiled and collected whatever was deemed pertinent to the subject under consideration. The main design of this commission was, as I apprehend, to collect certain facts which had already been discovered, and to embody them in a tangible form for future reference. In arranging these facts, I have, in most instances, chosen to restate them very nearly, if not quite, in the same language in which they were originally expressed. This I have done in preference to attempting a *disguised compilation*, which may be regarded as the pettiest form of plagiarism. It has also been my aim to embody in this report such general rules and directions as would enable the Land Surveyor to determine (approximately, at least), the declination of the needle for himself, and with the instruments used in ordinary surveys.

For this purpose, a table of Azimuths of the North Star becomes necessary; and by the able assistance rendered by M. C. Fernald, A. M., Principal of Foxcroft Academy, an original table of azimuths, extending forward to the close of the present century, and for every fifth minute of latitude within the limits of the State, also time-tables for the culminations and elongations of the star have been computed, and will, it is confidently believed, be found reliable. But, for those who may prefer to calculate the azimuths for themselves, I have inserted the *data* by which these tables may be either tested, computed or extended.

The tables of Declination for the State of Maine, so far as we have been able to extend them, are inserted at the end of the report, so that the results of observations made hereafter, may be added as an appendix.

Respectfully submitted,

By your obedient servant,

NOAH BARKER.

EXETER MILLS, February 22, 1868.

COMMISSIONER'S REPORT

ON THE

MAGNETIC NEEDLE.

I.

Historical Account of the Magnetic Compass, and its Variations.

The Magnetic Needle is the essential part of the instrument known as the Circumferentor, or Surveyor's Compass. It is simply a slender bar of hardened steel properly magnetized, having its extremities tapered to a thin edge or point, and nicely balanced upon a pivot in the centre of the compass-box in such a way that it can turn freely in a horizontal direction. Such a needle, when properly balanced and left to itself, will, after a series of vibrations growing shorter and shorter upon either side, come finally to a state of rest, and in such a direction that one of its extremities, or magnetic poles, will point toward the north, and the other toward the south. If the position of the needle be altered or reversed, it will always turn and vibrate again until its poles have attained the same or a *similar* direction as before.

It is this remarkable property of the magnetic needle, of always assuming a similar direction, that renders the compass so valuable to the mariner and the surveyor. These peculiar *directive properties*, called the *polarity of the needle*, are acquired by MAGNETISM.

But when or by whom magnetism was first discovered and brought into use is not certainly known. It is evident, however, that in the early part of the twelfth century, the attractive properties of the lodestone, or natural magnet, were known, and soon after applied in guiding the barks of navigators through trackless seas. But the instruments that were then used for this purpose were so rudely constructed that they hardly deserve the name of compasses, being merely fragments of the natural lodestone fixed to a painted cork which floated on the surface of the water, and thus indicated, as was supposed, the north and south points of the horizon. Simple as this contrivance may now seem, it was doubtless regarded by its discoverers with no less astonishment than if it had been a visible representative of the DEITY, or the spirit of God moving upon the face of the waters!

The magnetic compass is claimed to have been discovered by the Chinese, and as to the priority of its invention, there can be little hesitation in ascribing it to that nation, for it is noticed in their annals as early as A. D. 1117.

The *variation of the needle* from the true north appears to have been first observed by Peregrini, an Italian philosopher, in 1279.

The phenomenon, however, seems to have excited but little attention at the time, and was not generally known till more than two centuries afterwards, when Columbus, during his first trans-Atlantic voyage in 1492, made the startling discovery that the needle deviated in its direction from the North Pole of the heavens, and was not, therefore, that infallible guide at sea, which it had been previously regarded.

The Mariner's Compass was in use among the Arabs about the year 1242, and was doubtless communicated to them either directly or indirectly by the Chinese, and by this means became known in Europe during the Crusades; about which time it was used on the Mediterranean.

The invention of the Mariner's Compass, though the exact date of it is lost in obscurity, was applied to maritime purposes about the year 1403; and the enlargement of navigation, and the discovery of America in 1492, were the important consequences.

The Canaries, or Fortunate Islands, were the first land discovered by the Europeans after the introduction of the Mariner's Compass; and these became known to the Spaniards early in the fourteenth century.

It will be remembered that Columbus, in his first voyage of discovery, in 1492, steered first to these islands, and then directed his course west, by compass, into unknown seas. It was during this voyage, as before stated, that Columbus first observed and made known the *variation of the compass*, an appearance which has never yet been *fully* and *satisfactorily* explained by all the researches of science, and which made a most discouraging impression, at the time, on the crews of this bold and intrepid commander.

Thus we find it was many years after the discovery of the compass before it was even suspected that the magnetic needle did not range itself exactly with the true meridian—i. e. due north and south—and point *accurately* to the poles of the earth. But about the middle of the sixteenth century, observations were made in France and England, which fully proved that the needle pointed to the eastward of the true north; and after it had become more generally and extensively used, it was found to vary not only from the true meridian, but to vary differently in different places; and, finally, that the variation was not stationary in the *same* place, for any length of time. Still, as an "*ostrich-feather*" in the ancient Egyptian hieroglyphics was regarded as the "symbol of *truth*," so, in modern times the *magnetic needle* is often referred to as an emblem of truth and stability—it being considered rather complimentary than otherwise, to be regarded "*true as the needle to the pole*"—while in reality, nothing can be more fluctuating and uncertain in its tendencies.

To ascertain the *true cause* of the various changes and fluctuations to which the magnetic needle is subject, many experiments have been made, and volumes written in support of theories on which to base calculations both for the present and the future; yet time and observation have proved the fallacy of them all.

In 1530, the first *variation chart* was made by Alonzo de Santa Cruz, instructor to Charles V.

In 1600, Dr. Gilbert, a cotemporary of Francis Bacon, published his work ("De Magnete"), and from his observations and experiments on Magnetism and Electricity, this may claim to be regarded as the first step towards a scientific knowledge of these powers. After Gilbert, were Dr. Hooke and Dr. Halley, who published their theories on this subject in the seventeenth century. The latter, after publishing his Theory of Magnetism in 1683, and procuring the result of observations made in different parts of the world, formed a *Variation Chart*, which was published in 1700, and intended as a guide to mariners. On this chart, the lines of the variation of the compass were drawn; and by them he proposed to find, not only the variation of the needle, but the *longitude of places;* but the difficulty of determining the variation, combined with other causes, prevented this method from being sufficiently accurate to be generally useful; hence Halley's Chart has long since gone out of use.

The other variation charts which followed Halley's sea chart, are the predicted chart of Montaine and Dodson for 1745-6,—on which they laid down the results of fifty thousand observations collected from the records of the English admiralty and the papers of naval officers;—that in the Magnetic Atlas of Hansteen of Norway, for 1787; and that of Professor Barlow in 1833. In 1840, Professor Loomis published a variation chart of the United States. Another similar chart was prepared by Professor A. D. Bache, late Superintendent of the U. S. Coast Survey, and published in his official report for 1856.

Variation charts contain lines, on each of which the variation is everywhere the same, and which are called *isogonic lines.* The principal among these lines is that of *no variation.* But, as the line of "no variation" is continually changing its position on the face of the earth, these charts soon become, like calendars, out of date, and are useful then only as references to the past.

The latest magnetic chart which has been published in this country, is that prepared in the U. S. Coast Survey office, 1866, showing the "Isogonic Lines for the year 1870." By permission of Professor Peirce, the present superintendent of that survey, this chart has been copied and appended to this report. On this chart will be seen the position of the line of *no variation* in the United States for the years 1801, 1850 and 1870 At the former date, it crossed the eastern part of Lake Erie, and has gradually receded so far to the west that, in 1870, it crosses the western part of the same lake, passing near Cleveland, Ohio

The direction assumed by a horizontal needle in any given place upon the earth's surface, is called the *magnetic meridian.* The *magnetic equator* is a line of double curvature, cutting the geographical equator at more than two points; and on this line the intensity of the magnetic force is the weakest, and increases as we approach the magnetic poles.

The *true meridian* of any given place or point on the earth's surface is a line running due north or south from that point; and this line, if continued in the same direction, must pass through both poles of the earth, cut the terrestrial equator at right angles, and return to the place of beginning, and thus form a great circle.

The direction of a needle which would point due north and south at any place will, therefore, be the true or terrestrial meridian of that place. The deviation of the needle from due north and south, or the angle formed by the magnetic meridian and the terrestrial meridian, is called the variation, or more properly the *declination of the needle.* There are two lines, at least, upon the earth's surface along which the needle does not vary, but points to the true north and south. These are called the eastern and western lines of no variation, and are exceedingly irregular and changeable. The line of *no variation* is not a meridian, or any simple line round the earth, but an irregular curve, having in one place different branches. The *magnetic parallels for dip* are not the same as those for intensity; and neither system has a symmetry coëxtensive with the whole earth. These lines in the northern hemisphere are not an exact counterpart of similar ones in the southern hemisphere. Compass-needles all over the earth do not point to the same spot, and therefore *magnetic* meridians have but a remote resemblance to *geographical* meridians. The *position* of the *lines of no variation* was described by Professor Wells, in 1857, as follows:

"The western line of no variation begins in latitude 60°, to the west of Hudson's Bay, passes in a south direction through the American lakes, to the West Indies and the extreme eastern point of South America. The eastern line of no variation begins on the north in the White Sea, makes a great semi-circular sweep easterly, until it reaches the latitude of 71°; it then passes along the Sea of Japan, and goes westward across China and Hindoostan to Bombay; it then bends east, touches Australia, and goes south.

In proceeding in either direction, east or west from the lines of no variation, the declination of the needle gradually increases, and becomes a maximum at a certain intermediate point between them. On the west of the eastern line, the declination is west; on the east, it is east.

At Boston, in the United States, the declination is about 9½° west; in England it is about 24° west; in Greenland, 50° west; at St. Petersburg, 6° west."

The western line of no variation *now* passes through Cleveland, Ohio; and thence running southeasterly (or about S. 24½° E.), passes near Raleigh, in North Carolina, and is still receding slowly to the west. At all places lying to the east of this line—including the New England States, New York, New Jersey, Delaware, Maryland, nearly all of Pennsylvania, and the eastern half of Virginia and North Carolina—the variation is westerly, i. e. the north end of the needle points to the west of due north. At all places lying to the west of this line—including the Western and Southern States—the variation is easterly, i. e. the north end of the needle points to the east of due north. This variation increases in proportion to the distance of the place on either side of the line of no variation, reaching more than 21° of easterly variation in Oregon, and about 20° of westerly variation in the northeasterly part of Maine.

In 1861, the King of Bavaria was having executed, at his own expense, a magnetic chart of Europe, to which several years had already been devoted. M. Lamont, the director of the work, communicated to the Academy of Sciences of Paris, many interesting facts in regard to the inclinations and declinations of the needle in the principal ports of France, Spain and Portugal. According to his table, the declination was, in 1861, at Toulon, 16° 45′ west ; at Marseilles, 17° 7′ ; at Oporto, 22° 10′ ; at Brest, 22° 33′ ; at Cherbourg, 21° 38′ ; and at Dunkerque, 20° 10′. This declination has, within a century, been diminishing at an average rate of 7′ per year.

If the variation of the needle were constant, it would be of no practical importance to the surveyor. A line run by the compass at one time could be retraced on the same bearing at any other. The variation is, however, subject to continual changes—some of them having a period of many years, perhaps several centuries, others being *annual* or *diurnal*, and some accidental, or temporary.

II.

Secular Change.

When we compare the direction of the magnetic needle now with what it was one, two, or three hundred years ago, the change which it has undergone during such long period is called the *secular change*, to distinguish it from others which are call *periodical*. Not because it is imagined that the first are not also periodical; but because their periods are of such mighty lengths, that a single heaving of the great heart of nature in these directions endures longer than generations of men, or even perhaps the human race.

To give an idea of the extent of this *secular change*, the following table of observations made at Paris, London, and other places, is presented. The progressive change in the position of the magnetic needle at the same place was discovered by Gunter, in 1622, in comparing the results of observations at London :

Declination of the Needle at Paris between the years 1541 and 1854.

Years.	Variation	Years.	Variation
1541,	7° 00′ East.	1805,	22° 5′ West.
1550,	8 00 "	1814,	22 34 " Max.
1580,	11 30 "	1816,	22 25 "
1618,	8 00 "	1823,	22 23 "
1640,	3 00 "	1827,	22 20 "
1666,	0 00 Min.	1828,	22 5 "
1681,	2 30 West.	1829,	22 12½ "
1700,	8 10 "	1835,	22 3 "
1759,	18 10 "	1851,	20 25 "
1760,	18 20 "	1853,	20 17 "
1780,	19 55 "	1854,	20 10 "

By the above table it appears that from the first observation, in 1541, to 1580, the change in the declination at Paris was 4° 30′ in 39 years, being at a mean annual rate of 6′.92. From 1580 to 1666 the change was 11° 30′ in 86 years, being at the rate of 8′.02 annually. From 1666 to 1814 the change was 22° 34′ in 148 years, being a mean annual change of 9′.14. And from 1814 to 1854 the declination at Paris slackened 2° 24′ in 40 years, which, at a mean rate, is 3′.6 a year.

Declination of the Needle at London between the years 1576 and 1843.

Years.	Variation.	Years.	Variation.
1576,	11° 15′ East.	1747,	17° 40′ West.
1580,	11 17 " Max	1774,	21 16 "
1622,	5 56 "	1775,	21 43 "
1634,	4 3 "	1776,	21 47 "
1640,	3 7 "	1777,	22 12 "
1657,	0 0 Min.	1778,	22 20 "
1665,	1 23 West.	1779,	22 28 "
1666,	1 36 "	1780,	22 41 "
1672,	2 30 "	1815,	24 27.3 " Max.
1683,	4 30 "	1831,	24 00 "
1692,	6 0 "	1843,	23 8 "
1723,	14 17 "		

By this table it appears that from the first observation, in 1576, to 1657, the change in the declination at London was 11° 15′ in 81 years, which, at a mean rate, is 8′.33 a year. From 1657 to 1815 it changed 24° 27′ in 158 years, which is at the rate of 9′.22 a year. And between 1815 and 1843 the declination slackened at a mean rate of 2′.82 a year.

Declination of the Needle at the Cape of Good Hope between the years 1605 and 1839.

Years.	Variation.	Years.	Variation.
1605,	0° 30′ East	1791,	25° 40′ West.
1609,	0 12 West.	1839,	29 9 "

For a period of about 234 years the declination at the Cape had been on the increase at the average rate of 7′.56 a year. A comparison of the observations made between 1841 and 1850 shows that the westerly motion has materially slackened, if it has not entirely stopped, it being only 0′.49 annually from 1841 to 1846, and 2′.16 from 1846 to 1850; whereas for the last two centuries it had averaged seven or eight minutes a year.

The declination at Cambridge, U. S., in 1708, was 9° west. In 1788 it was 6° 38′. In 1810 it was 7° 30′. In 1840 it was 9° 18′. In 1855 it was 10° 54′. From 1708 to 1793 it diminished at the rate of 1′.8 annually. From 1810 to 1840 it increased at the rate of 3′.6 annually. The change from an easterly to a westerly motion probably occurred about 1807.

In Providence, R. I., the declination in 1717 was 9° 36′. It had diminished to 6° 10′.8 in 1790; and increased again to 9° 15′ in 1845.

The declination at Great Slave Lake increased 3° between 1825 and 1857.

Mr. C. A. Schott has discussed the observations made in the United States, and obtained the result that the maximum declination in the Northern States was about 1679; that the minimum occurred about 1804; and that the period of half an oscillation is not far from 125 years. It also appears that, while the date of the minimum declination at Boston is 1778, the same did not occur at Havana until 1810; the general value for the whole Atlantic coast being 1797. Attention is also called to the fact that the maximum of westerly declination in the United States was nearly synchronous with the minimum in Europe. But the amplitude of the secular change is five times greater in Northern Europe than here.

The observations made at Toronto, Canada West, in 1841 and 1842, give an increase of *westerly* declination amounting to 4′.77 a year. From 1843 to 1848 the *east* declination at the English station at Hobarton, in Australia, increased 1′.46 annually.

But no *annual* rate can be fixed on as a certain rule for the declination of the needle, as its motion is much more rapid in some years than in others. It will be seen by the "table of declinations at London," that, from 1774 to 1780, the annual *inequality* of the declination was exceedingly great.

In June, 1805, the late Surveyor General of Connecticut, George Gillet, Esq., commenced observing the declination of the needle at Hebron, in that State, and continued his observations to June, 1835. The same compass, with the same needle, was set at the same place, and to the same object. During that period, the north end of the needle declined to the west 1° 20′. At the former date, the declination was 4° 50′ west. It was also found there, that the annual motion was not uniformly steady. In some years it was more rapid than in others, and, in one or two instances, for a period of three or four years, *none*, except the diurnal motion, could be discovered.

III.

Diurnal Change.

Besides the variation from the true north and south, the magnetic needle is subject to a diurnal variation. The diurnal fluctuation in the position of the needle was first observed by Graham, at London, in 1722. In studying its laws, he made one thousand observations in that year. The greatest difference of position amounted to 55′, and the average daily change was 35′. The character of the diurnal change may be inferred from the following magnetic history of a day at Cambridge. A long series of observations on the daily change was made at Cambridge, U. S., by Professor Stephen Sewall in 1786, 1787 and 1788.

Another series of observations with the magnetometers of Gauss and Lloyd were made in 1840 and 1841, by Mr. W. C. Bond and Professor Joseph Lovering. From all which it appears that at about eight o'clock in the morning the needle is in its most easterly position; from that time until about two o'clock it moves to the west; from that time until evening it moves to the east; and from eight or nine o'clock in the evening until three in the morning it moves west again; after which it returns to the place with which we started, so as to be ready the next day at eight o'clock in the morning to enter again upon a similar set of oscillations. This is the general description of the daily change. The diurnal magnetic phenomenon, however, exhibits varieties at different places, and even at the same place. The times at which the most easterly and westerly positions are reached are not precisely fixed, but have a range of one or two hours.

In the U S. Coast Survey Report for 1839, Plate No. 37, the means of the times of the greatest eastern and western diurnal movement of the needle were given as 10 o'clock A. M. and 5 o'clock P. M.

The diurnal range of the declination at Eastport, Me., as observed successively by Messrs. G B. Vose, S. Walker, E. Goodfellow, A. T. Mosman and H. W. Richardson, all attached to the Coast Survey, is given in the following table. The difference between the maximum and minimum value of the declination set down in the table for each month, is the mean of four days of observations:

Month.	1860.	1861.	1862.	1863.	1864.	Means of 5 years.	Observed annual inequality	Corrected for 11 years inequality.	Corrected annual inequality.
January	15′ 2	8′.6	12′.1	10′.6	11′.4	11′.6	−2.1	−0′.4	−2′.5
February	12.6	11.7	11.0	8.0	9.0	10.5	−3.2	−0.3	−3.5
March	16.4	18.1	13.1	11.8	13.0	14.5	+0.8	−0.2	+0.6
April	16.0	13.6	18.4	16.6	11.6	15.2	+1 5	−0.1	+1.4
May	18.7	8.8	14.2	15.6	15.9	14.6	+0.9	0.0	+0.9
June	18.1	12.3	17.7	15.5	13.2	15.4	+1.7	0.0	+1.7
July	13.0	16.3	17.8	14.6	13.6	15.1	+1.4	0.0	+1.4
August	21.5	18.7	19.8	14.5	-	18.3	+4.6	0.0	+4.6
September	19.5	18.8	17.4	15.5	-	17.5	+3.8	+0.1	+3.9
October	18.7	10.4	14.1	14.2	-	14.0	+0.3	+0.2	+0.5
November	13.7	9.2	8.9	8.9	-	9.9	−3.8	+0.3	−3.5
December	7.8	9.0	8.0	6.4	-	7.5	−6.2	+0.4	−5.8
Annual Means	15.9	13.0	14.4	12.7	-	13.7			

The average difference between the seven values of 1864 and the mean of the four years preceding is —1′.6. Applying this to the four years means for the remaining five months, the interpolated means for 1864 become, for August, 17′.0; for September, 16′.2; for October, 12′.8; for November, 8′.6; and for December, 6′.2. The column headed "means of five years" is completed with the aid of these values. The interpolated mean for 1864 is 12′.4. The average annual change is —0′.9.

The *eleven year* inequality in the range of the diurnal movement appears quite plainly in the annual means. The year 1860 was one of maximum and 1866 of minimum, according to the observations of the solar spots; in 1865 the average range will therefore be a little above 12′, and in 1866 a little below this value, giving a range of variability due to the eleven years inequality of nearly 4′. The corresponding quantity at Philadelphia is nearly 2′ from observations between 1840 and 1845.

Our series of observations extends over less than one-half of the eleven year period, a correction has therefore been applied to obtain the annual inequality in the diurnal range free from the eleven year period, as shown in last column of above table.

The diurnal range reaches a maximum in August and a minimum in December.

Epochs of greatest diurnal deflection. The average epochs of the morning east elongation and the afternoon west elongation are given in the following table:

	East Elongation.		West Elongation.			East Elongation.		West Elongation.	
	H.	M.	H.	M.		H.	M.	H.	M.
January,	8	30	1	20	July,	7	20	1	00
February,	8	40	1	50	August,	7	10	0	20
March,	8	20	1	10	September,	7	30	0	50
April,	7	50	1	10	October,	7	50	1	10
May,	7	10	0	20	November,	8	00	1	00
June,	6	50	0	40	December,	9	00	1	00

For the summer half year from April to September included, the morning east elongation occurs at 7h. 20m., and for the winter half year from October to March included, the east elongation occurs at 8h. 20m.; at Philadelphia these epochs were 7h. 33m. and 8h. 24m. respectively. For the summer half year the afternoon west elongation occurs at 0h. 40m., and for the winter half year at 1h. 20m. At Philadelphia these epochs were 1h. 8m. and 1h. 25m. respectively. On the average for the year, the turning epochs are 7h. 50m. A. M. and 1h. 0m. P. M.

The amplitude of the oscillation is greater in summer than in winter, and is greater in high magnetic latitudes than it is near the magnetic equator. Thus at Cambridge in June and July it is fifteen minutes of arc, and in December and January it is ten.

Prior to 1837, observations were wanting to show whether or not the daily variations have the same direction in places where the declination is westerly and in those where it is easterly. But this deficiency has been supplied by some of the Russian observations, and by the English station at Hobarton, in Australia. It is now known that from about eight o'clock until about two P. M., the needle in the northern hemisphere moves westerly; so that if the variation is west, it is greatest at two o'clock, and if east, it is least at two o'clock. South of the magnetic equator everything is reversed; that is, the south end of the needle moves there as the north end moves in the northern hemisphere, and consequently in the two hemispheres the *same* end of the needle moves in opposite ways. In some places, as at Paris, the needle has a single instead of a double daily oscillation. After reaching its western limit at two o'clock, it moves east until about ten in the evening, and then remains stationary until next morning.

In consequence of the diurnal change, it is evident that a line run in the morning cannot be retraced with the same bearings at noon. We should therefore record not merely the date at which a survey is made, but also the time of day at which any important line was run, and also the state of the weather, whether clear or otherwise, as the state of the atmosphere has much to do with the diurnal change. This change is greater in a clear day than when the sky is overcast, and not perceptible if the day is entirely cloudy, and is greater in summer than in winter.

IV.

Annual Change.

As the magnetic elements of the earth fluctuate during the hours of the day, so they also have an annual period of change, by which they are made greater at one season of the year than at another. The annual change in the position of the magnetic needle was first pointed out by Cassini, who made observations at Paris from 1780 to 1790. As the daily change is accurately ascertained only by observing carefully for many days, so the annual change cannot be detected except by years of observations at various seasons. Hence it is not surprising that the character and the amount of the annual change are even now much more imperfectly understood than those of the daily changes.

Since the time of Cassini's observations at Paris, in 1780, the amount of this change has been very different some years from what it was in others, and has varied from one minute to nine minutes. So far as the character of the change may be inferred from a few years of observation at the Cape of Good Hope and at Hobarton, the declination is greatest in the summer months of the station, although in one case the declination is westerly, and in the other easterly. The amount of the change is only one, two or three minutes.

The daily, monthly and yearly variations of the needle are supposed to be occasioned by variations in the temperature of the earth's surface, depending upon the changes in the position and action of the sun. Observations on the temperature of the earth have afforded some reason for believing that the points upon the earth's surface where the greatest degree of cold is experienced, or where the yearly mean of the thermometer is lowest, coincide with the location of the magnetic poles, and that the *Isothermal lines* may also correspond with the *lines of equal variation.*

Observations made for a great number of years have also seemed to show that the entire magnetic condition of the earth is subject to a periodical change, but neither the cause nor the laws of this change are as yet fully understood.

Professor Owen, in his address before the British Association, in 1858, says: "It has been determined that there are periodical changes in the magnetic elements depending on the hour of the day, the season of the year, and on what seemed strange, intervals of *eleven years.* Also, that besides these regular changes, there were others of a more abrupt and seemingly irregular character—Humboldt's 'magnetic storms'—which occur simultaneously at distant points of the earth's surface. Major General Sabine, than whom no individual has done more in this field of research since Halley first attempted 'to explain the change in the variation of the magnetic needle,' has proved that the magnetic storms observed diurnal, annual and *undecennial periods.* But with what phase or phenomenon of earthly or heavenly bodies, it may be asked, has the magnetic period of *eleven years* to do? The coincidence which points to, if it does not give, the answer, is one of the most remarkable, unexpected and encouraging to patient observers.

"For thirty years a German astronomer, Schwabe, had set himself the task of daily observing and recording the appearance of the sun's disc, in which time he found the spots passed through periodic phases of increase and decrease, the length of the period being about eleven years. A comparison of the independent evidence of the astronomer and magnetic observer has shown that the undecennial magnetic period coincides, both in its duration and in its epochs of maximum and minimum, with the same period observed in the solar spots."

The following observations on this subject are taken from Professor Bache's communication published in the American Journal of Science for September, 1867.

"*Mean monthly values of the declination*, observed at Eastport between August, 1860, and July, 1864.

The minutes given in the table are to be added to 17°.

Month.	1860, 1861.	1861, 1862.	1862, 1863.	1863, 1864.	Means.
August	58′.1	59′.5	60′.1	64′.2	60′.5
September	56.9	61.1	61.1	63.6	60.7
October	57.2	60.1	60.8	63.7	60.5
November	59.8	61.7	63.5	64.3	62.3
December	58.5	59.2	62.3	62.7	60.6
January	56.5	61.0	62.1	62.8	60.6
February	58.1	60.6	60.5	62.5	60 4
March	58.1	58.4	61.7	63.4	60.4
April	58.7	61.2	62.0	63.0	61.2
May	58.0	60.1	61.1	61.6	60.2
June	61.0	59 3	60.7	61.2	60.5
July	58.1	59.2	60.7	62.0	60.0
	58.2	60.1	61.4	62.9	60.65

The average value for the period is 18° 00′.65.

Annual effect of the secular change.—We deduce the annual effect of the secular change directly from the preceding table.

Annual increase of declination between	1861	and	1862,	1′.9
" " "	1862	"	1863,	1 .3
" " "	1863	"	1864,	1 .5
Average annual increase of west declination,				1 .6

Which, considering the locality, appears a remarkably small value. According to our previous information we might have expected an annual increase of about 4′. Either the above small result indicates a local deviation from the general law, or else at this most *easterly* station we are approaching the period of stationary condition which, from previous researches, may be expected to take place before the close of the present century.

In July, 1865, the declination was again observed in order to obtain a confirmation of its small annual increase; from four days of observation 18° 04′.7 was found, and since the annual mean is found by adding 1′.4 (vide previous years) the declination for 1865 becomes 18° 06′.1, and the annual increase apparently equals 2′.4.

The annual mean declination corrected for imperfect number of observations in 1860 and 1864, is as follows:

In 1860,	17° 57′.1 W.	In 1863,	18° 02′.3 W.
In 1861,	17 59 .2 "	In 1864,	18 03 .7 "
In 1862,	18 00 .6 "	In 1865,	18 06 .1 "

Annual inequality of the declination.—The difficulty of establishing this inequality experimentally is well known, and long continued and frequent observations have failed to furnish a satisfactory general elucidation of this subject, in reference to which the Coast Survey Report for 1860, pp. 311–12, may be consulted.

The values for Eastport have been derived as follows:

Month.	17°+	Corrections for secular change.	Corrected declination.	Annual inequality.
August	60′.5	+0.7	61.2	+0.55
September	60.7	+0.6	61.3	+0.65
October	60.5	+0.5	61.0	+0.35
November	62.3	+0.3	62.6	+1.95
December	60.6	+0.2	60.8	+0.15
January	60.6	+0.1	60.7	+0.05
February	60.4	—0.1	60.3	—0.35
March	60.4	—0.2	60.2	—0.45
April	61.2	—0.3	60.9	+0.25
May	60.2	—0.5	59.7	—0.95
June	60.5	—0.6	59.9	—0.75
July	60.0	—0.7	59.3	—1.35

The annual range keeps probably within 2′, and it is not clear whether the annual inequality is subject to a variation of a comparatively short period, a question which remains to be cleared up by future observations. The effect of the annual inequality (at Eastport) is to diminish the west declination in July and to increase it in November, these being the months when it reaches its greatest amount."

V.

Magnetic Storms.

"Besides the daily, annual and secular disturbances in the earth's magnetism, there are others which seem irregular, and which, in our ignorance, we call abrupt and capricious. On these occasions the needle does not tremble as it points, but shivers.

The records of unusual magnetic disturbances already published by the British Government in a separate volume, furnish the means of confirming some things which were known before, and of adding to the accuracy and extent of our knowledge upon the subject. These magnetic *storms* or *hurricanes*, as Humboldt calls them, whirl the needle about as the wind shakes a dry leaf, arresting it in the midst of its daily and annual vibrations, and driving it sometimes in the opposite direction. Even these motions of the needle would be considered gentle if compared with such as we usually call violent. But if we contrast them with the ordinary motions of the needle, they are as extraordinary and as tempestuous as the creaking and bending and twisting of the great branches of a tree in the fury of a storm when compared with the usual inaudible flutter of the delicate foliage.

The motion of the needle, when under the influence of a magnetic storm, differs not only in extent but in character from its usual steady and circumscribed oscillation. At Fort Reliance, in the latitude of about 63° north, a disturbance of 8° has been observed by an Arctic navigator, Captain Back, in his voyage of 1833–5.

At Toronto a sudden magnetic disturbance amounted to 1° 59′ in May, 1840. At the same time, the magnetometers at Cambridge were moved through 57′ in two hours. The effect at Philadelphia was a little less, viz., 55′.8. On other occasions the disturbance at Cambridge has exceeded one degree. The amplitude of this motion exceeds the whole diurnal range, and yet a large part of it is often described in a small fraction of a day. In May, 1840, forty-seven minutes of arc were traversed in eleven minutes of time. On the 18th of November, 1841, the magnetometer in the course of five hours swept backward and forward over an arc of 2° 50′, half a degree of which was described in five minutes. The peculiar character of the motion consists in sudden jerks or twitches breaking in upon the general vibration, and sometimes reversing its direction. These unusual disturbances acquire dignity and importance, and take the attitude of planetary rather than local phenomena, from the fact that they are felt almost simultaneously over whole hemispheres. The magnetic observatories organized in 1830 throughout the colossal empire of Russia by the government, reinforced in 1834 by twenty-three other observatories scattered over other parts of Europe, established by the private influence of an individual, took the charge of studying more closely the laws of the magnetic storms, until this enterprise was merged in the more general system which grew out of it in 1840.

The short intervals which Gauss introduced between successive observations enabled him to prove that the minute as well as the extraordinary changes at one place had an exact counterpart at all the other observatories. The materials on the same subject, collected upon this continent at Toronto, Philadelphia and Cambridge, in 1840 and 1841, manifested the same wonderful concert in the magnetic changes experienced at distant places as had already astonished the observers in Europe. On the 25th and 26th of September, 1841, the most remarkable magnetic hurricane occurred, leaving traces of itself in the registers, not only of Europe and America, but of St. Helena, India and Australia. The greatest disturbance which had occurred up to 1845 at Simla (E. I.) was on July 2d and 4th, 1842. It was also the greatest which had been observed at Dublin.

VI.

Auroral Disturbances.

The magnetic needle is subject also to disturbances from the passage of thunder storms, or from the occurrence of the aurora borealis. It is likewise sometimes violently agitated when no apparent cause exists. Such disturbances may result from the occurrence of a distant magnetic storm, which would otherwise be unperceived, or from the passage of electric currents through the atmosphere.

The phenomenon of the aurora borealis is supposed to be due to the passage of electric currents through the higher regions of the atmosphere—the different colors manifested being produced by the passage of the electricity through air of different densities.

In the northern hemisphere the aurora always appears in the north, but in the southern hemisphere it appears in the south; it seems to originate at or near the poles of the earth, and to extend upward, by a flickering motion, to the height of one or two hundred miles, and sometimes more. The aurora is not a local phenomenon, but is seen simultaneously at places widely remote from each other, as in Europe and America.

Auroras occur more frequently in the winter than in the summer, and are only seen at night. They affect not only the magnetic needle but also the electric telegraph, and as the disturbances occasioned in these instruments are noticed by day as well as by night, there can be no doubt of the occurrence of the aurora at all hours. The intense light of the sun, however, renders the auroral light invisible during the day.

The following account of an electrical disturbance of the telegraph was clipped from "*Portsmouth (N. H.) Journal*," under date of June 29th, 1867: "Nashville, Tenn., was visited, on the 17th, by an extraordinary electrical display. The telegraph operators very narrowly escaped, being compelled to cut the wires to save their instruments from destruction. As the operator on the Memphis line was transmitting a message he received a stunning shock; and from the brass points in the switch board lightning streamed six or eight feet into the room, and a ball of fire about a foot in diameter leaped from one of the wires to another, some feet distant."

The discovery that the magnetic needle was agitated during the presence of an aurora was first pointed out by Hiorter, in 1741, at Upsal, although it has usually been ascribed to Wargentin of Sweden. He states that on the 28th of February, 1750, the needle was disturbed by an aurora, so as to vibrate between 6° 50′ and 9° 1′ of west variation; and on April 2d it shifted from a like cause backward and forward between 4° 56′ and 9° 55′.

In 1834 and 1835, Prof. E. Loomis made a series of observations of the variations of the magnetic needle at Yale College. The instrument employed was a Variation Transit, by Dolland, belonging to the College. He states that he has repeatedly witnessed a similar effect on the needle, but has never seen the effect so great as here stated. He adds, that this disturbance of the needle by an aurora is not merely occasional, but almost invariable. During the continuance of his magnetic observations, he paid particular attention to the aurora, and in every instance when the aurora was considerable, there was a palpable agitation of the needle, and almost always a deflection to the amount of ten, twenty or thirty minutes, and in two instances of more than a degree. On the other hand, whenever the needle had experienced any unusual deflection, he had uniformly seen reason to ascribe it to an aurora.

The aurora, indeed, has not always been visible; and there are several reasons why it should not be. It might occur in the day time, when it would be wholly invisible, or during moonlight, or a cloudy night, when it would be nearly or wholly obscured. "But," continues the professor, "there has not occurred an instance during the period embraced in these observations, when the needle has suffered an unusual deflection, without an aurora being visible unless observations were frustrated by one of the causes above mentioned."

In describing the great auroras of August and September, 1859, in a paper read before the American Association for 1860, Prof. Loomis further says: "The disturbance of the magnetic instruments was well nigh unprecedented for violence, and it may be safely asserted that the phenomena extended over the entire circuit of the globe. The aurora of September 2d formed a belt of light encircling the northern hemisphere, extending southward in America to latitude 22½°, and reaching to an unknown distance on the north, until it pervaded an interval between the elevation of fifty and five hundred miles above the earth's surface."

VII.

Local Attraction.

The derangement of the magnetic needle caused by ferruginous substances in the ground is generally known under the name of *local attraction*. This is one of the most common sources of trouble and vexation in running lines with which the surveyor has to contend. As the sources of attraction are generally out of sight, the surveyor should be constantly on his guard, and in no instance should he leave a station without first taking a back sight, and seeing that his compass reverses truly, since even in those regions where but little such influence exists, it will sometimes be found at particular points. It sometimes likewise extends, without any change, over a considerable space, and thus may deflect the needle similarly at a number of stations.

Local attraction is found oftener in mountainous regions than in places where the land is level; still it occurs not unfrequently in bogs, and in the valleys of brooks flowing from highlands where mineral deposits are to be found. In the survey of *mineral lands* a local disturbance has been observed, causing a deflection of five, ten and sometimes more than twenty degrees in the distance of as many chains.

But these strong attractions occasion less trouble to the surveyor than the more subtle ones where the needle is deflected only a few minutes of a degree, and therefore less easily detected.

The needle is also frequently deflected from its proper direction by reason of the electrical fluid collecting on the compass-glass. This will escape readily by washing the glass.

In running a line, when the surveyor finds the slightest indications of local attraction, he should go back to the initial station, and from it take the bearings of stakes set in different directions, both inside and outside of the tract to be surveyed, also their *reverse* bearings, and having in this way ascertained the proper allowance, if any, to be made for attraction, continue the line on the true course, by setting pickets or station-rods upon it, by the aid of the assistant.

VIII.

Magnetic Dip, or Inclination of the Needle.

A needle which, before it receives the magnetic power, rests on its centre parallel to the horizon, on becoming magnetical will incline toward the earth; this is called the inclination or dip of the needle.

This property of the magnetic needle was first discovered accidentally by Robert Norman, a compass maker at Radcliffe, about the year 1576. He relates that it being his custom to finish and hang up the needles of his compasses before he touched them, he found that immediately after the touch the north point of the needle would always dip or incline downward, pointing in a direction under the horizon, so that to balance the needle again, he was forced to put a piece of wax on the south end as a counterpoise. The constancy of the effect led him to measure the angle which the needle would make with the horizon, and he found it at London to be 71° 50′.

The present method of balancing the needle is to fit nicely a small coil of brass wire around the south end, so as to slide along the needle until the ends of it are perfectly horizontal.

For the ordinary purposes of land surveying the dip or *inclination* of the needle is seldom regarded, except to counterbalance its effect upon the needle by the method above described. But the magnetician regards with equal interest magnetic declination, dip and intensity.

Like the declination and dip, the intensity of the earth's magnetism varies very much in different parts of the earth; at the magnetic equator being the most feeble, and gradually increasing as we approach the poles. The intensity of terrestrial magnetism in different places may be measured by the number of vibrations made by a magnetic needle in a given time.

Tables showing the "dip" and "horizontal intensity" of the magnetic needle at several places in Maine, and for different years, may be found in the Coast Survey Report for 1856, page 215; and similar tables for Eastport, from 1860 to 1864 inclusive, are contained in the American Journal of Science and Arts, Vol. XLII, (second series), pages 147–9.

IX.

Magnetic Force.

The attractive power of magnets has received the name of *magnetic force*, being one of the seven great natural forces or agents in nature. This force, acting by repulsion as well as by attraction, becomes, in the case of terrestrial magnetism, where both poles of the needle are nearly equi-distant from the great centre of action, simply a directive power. Accordingly, it produces in the needle a motion of rotation, but gives to it no perceptible motion of translation. One end of the needle is made to point to the north, but the whole needle is not pushed to the north, or in any other direction; and the earth's magnetic action upon it does not modify in any sensible degree that weight which it derives from the earth's attraction of gravitation.

Magnetism developed through the agency of electrical or chemical action is termed electro-magnetism. But the distinction of magnets into common magnets and electro-magnets is an historical distinction, which holds good now in name more than in reality. It has been proved that the source of all magnetism is electricity, and that magnetism is one of the inseparable effects of current electricity. Among the earliest phenomena observed which indicated a connection between magnetism and electricity, it was noticed that ships' compasses have their directive power impaired by lightning, and that sewing-needles are rendered magnetic by electric discharges passed through them.

In 1820, a discovery was made by Professor Oersted of Denmark, which established beyond a doubt the connection of electricity and magnetism. He ascertained that a magnetic needle brought near to a wire, through which an electric current was circulating, was compelled to change its natural direction, and that the new direction it assumed was determined by its position in relation to the wire and to the direction of the current transmitted along the wire. Further experiments developed the following law: "Electric currents exert a magnetic influence at right angles with the direction of their flow, and when they act upon a magnetic needle they tend to cause the needle to assume a position at right angles to the direction of the current." By means of the galvanometer or electro-multiplier, the most feeble traces of electricity can be detected; and electric currents which would fail to influence the most sensitive gold leaf electrometer can be made to affect perceptibly the magnetic needle.

Electricity, unlike all other motive forces in nature, exerts its magnetic force laterally; all other forces exerted between two points act in the direction of a straight line connecting their points, but the electric current exerts its magnetic influence at right angles to the direction of its course.

When a magnetic pole is influenced by an electric current, it does not move either directly forward or directly from the conducting wire, but it tends to revolve about it. By the application of these facts, it has been discovered that rotary movements can be produced by magnets around conducting wires, and conversely, that conducting wires can be made to rotate around magnets.

Many things favor the belief that the earth is an electro-magnet, *par excellence*, such as would be made by winding a copper wire, in parallel strands, around an iron ball or shell, and then transmitting a voltaic current through it. This current of electricity would not only act directly upon the compass-needle, placing it at right angles to its own direction, as is seen in the case of common *galvanometers*, but it would render all the iron in the earth strongly magnetic for the time being; and the magnetism of this iron would conspire with the magnetic property of the current itself to direct the compass-needle. This, perhaps, gives the only reasonable explanation of the great strength of the earth's magnetism. A moment's examination will convince any one that currents of electricity, encircling the earth in a direction parallel to the magnetic equator, and running from the east to the west, can produce the same general phenomena as are actually witnessed.

In 1831, Barlow communicated to the Royal Society of London, a paper "On the Probable Electric Origin of all the Phenomena of Terrestrial Magnetism." He illustrated his views by the experiment, now so familiar, of winding a copper wire round an artificial globe, in the direction of its magnetic parallels, and while a voltaic current was traversing this wire, presenting a small compass-needle or a dipping needle to various parts of this miniature magnetic sphere. Again, says the Professor, "those who believe that the earth's magnetism is sustained entirely by the sun, and that the sun acts for this purpose in no mysterious way, but exclusively by heat, are far from arrogating to their theory such clearness of conception as to suppose that the process is a simple or a single one. And even those who look to some unknown and inexplicable power as the fountain-head of the earth's magnetism, do not hesitate to admit that the sun, in various ways, and by its heat also, produces the daily, annual, and perhaps other changes of Terrestrial Magnetism. For example, Canton, as early as 1756, without attempting to account for the great fund of magnetism in the earth, explained its diurnal variation by the help of the well-known fact that a magnet loses power when heated. Accordingly, that part of the earth on which the sun rises, being hotter in the forenoon than the region west of it, the needle moves towards the cool west. After the sun crosses the meridian, the western region is hotter than the eastern, the strength of its magnetism fails, and the needle returns to the east. Captain John Ross illustrated this theory by an experiment. He placed two artificial magnets, one on each side of the needle. When the eastern one was covered, and the sun shone upon the western magnet, the compass moved towards the east. By shifting the screen to the other magnet, the needle moved towards the west." In 1855, Secchi published a careful discussion of the most approved magnetic observations; and he arrives at the conclusion that the sun does not produce the periodical variations in the elements of Terrestrial Magnetism by the influence of temperature, as was suggested by the too exclusive attention to the phenomena of declination merely. This conclusion he bases upon the fact, that, while the periodical changes in the *dip* and *intensity*, as well as in temperature, acknowledge a dependence upon the sun, they do not stand in such chronological relation to each other that solar heat can be considered as the secondary cause of the magnetic disturbances. Secchi concludes, on the contrary, that "all the phenomena hitherto known of the diurnal magnetic variation may be explained by supposing that the sun acts upon the earth as a very powerful magnet at a great distance.

In 1850, Faraday made the discovery that oxygen was a magnetic substance, and that oxygen holds the same magnetic position in the atmosphere that iron maintains in the solid earth. He also showed by experiment that it is affected by heat in the same way as iron is, in regard to its susceptibility to magnetic influence. Availing himself of the last and most approved results drawn from the British magnetic observatories and elsewhere, Faraday has labored to demonstrate that at least the periodical disturbances of the needle are produced by the variability in the magnetic energy of the oxygen of the atmosphere, as one or another part of it is most exposed to the sun's rays. Faraday does not regard the disturbance of the needle as the end, but as only the token of the changes which the magnetism of the atmosphere undergoes. He closes his memoir on the subject with this paragraph: "What is the final purpose in nature of this magnetic constitution of the atmosphere, and its liability to annual and diurnal variations, and its entire loss by entering into combination either in combustion or respiration? No doubt there is one or more; for nothing is superfluous there. We find no remainders or surplusage of action in physical forces. The smallest provision is as essential as the greatest. None are deficient, none can be spared."

A. De la Rive, about 1850, communicated to the French Academy a theory of diurnal variation in which he supposes currents of electricity to flow from the equator to the poles in the upper strata of air, and from the poles back to the equator again at the earth's surface, and to deflect the needle agreeably to Oersted's experiments with the galvanometer.

X.

The Magnetic Poles.*

The earth, like a great magnet, acts upon a magnetized needle with nearly a directive force. The two poles of the great terrestrial magnet which are situated in the vicinity of the poles of the earth's axis, are termed respectively the north magnetic pole and the south magnetic pole. In relation to the character and position of the earth's magnetic poles, Professor Lovering, in his exhaustive discussions of Terrestrial Magnetism, says:

"The *magnetic pole* is no longer the common-place point it was once supposed to be, but implies a complex mathematical conception. It was once thought by scientific men, and the world at

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*The Revolution of the Magnetic Pole.—We have received a paper read before the American Institute, by John A Parker, on "Polar Magnetism," which is, at all events, an ingenious and original discussion of a subject which possesses not only scientific but practical interest The main topic of the paper is the revolution of the magnetic pole around the north pole. The fact of this revolution is certainly established. In 1580, the magnetic pole was situated on a meridian forty-five degrees east of Greenwich. In 1658, it was on the meridian of Greenwich. In 1790, it was seventy degrees west of that point, and is now put by Mr. Parker at one hundred and eighteen degrees west of Greenwich.

Assuming, to account for this regular progress westward, that magnetism is a universal principle, Mr. Parker accounts for the revolution of the magnetic pole as caused "by magnetic attraction to the highest centre or system to which the earth in her various revolution is immediately related." The direction of the needle only indicates the line large is not probably wholly undeceived upon the subject, that if a great number of delicate compass needles were mounted upon their pivots at the same time, they would all swing round so as finally to point, though tremblingly, to the same spot of earth. This spot, on which this innumerable series of lines of direction is concentrated, in the magnetic pole. While one end of each needle points to the north magnetic pole, the other end points to the south magnetic pole. Moreover, it was concluded that if a magnetized needle were carried towards either pole, one or the other end of it would dip downwards until it reached the pole, when the needle would point directly to the earth's centre. Futhermore, in these positions the needle is directly over the poles, and nearer to them than when carried to any other place, so that the locality of the poles was characterized as the place, not only at which the local needle pointed downwards, and on which all other needles turned their regards, but also where the needle was fixed with the greatest force and determination. Finally, it was supposed that these favored localities were the geographical poles. Science discovered and corrected its mistake in regard to the position of the magnetic poles long before it had acquired correct ideas of the character of these poles. It was not necessary to go to the geographical poles to prove that the magnetic poles were missing. If the magnetic poles coincided in position with the geographical poles of the earth's rotation, every compass-needle, wherever found, if undisturbed, would direct itself northward.

When observations were limited to special localities, this might appear to be the fact. But commerce, which is circumscribed by no boundaries of longitude, and is making ever greater inroads among the smaller circles of latitude, soon recognized, if it did not discover, that the direction of the needle varied from the exact

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of attraction, and not an absolute magnetic pole. Mr. Parker regards polar magnetism as simply the result of a magnetic force, which is rendered active by revolution, and "identifies itself with that force which astronomers call the attraction of gravitation, a force known to exist, but for which no satisfactory cause has ever been assigned."

According to his theory, magnetic attraction, or the "attraction of gravitation," in revolving bodies, is the opposite of that centrifugal force created by their revolution, and always equal to it. The magnetic pole revolves around the polar axis of the earth in the same time in which the earth, together with the solar system, performs a complete revolution relatively to that system around which the sun itself revolves, and this period Mr. Parker estimates at six hundred and forty years.

Such is the theory of Mr. Parker, evidently the result of much reflection, and illustrated with great ability. Without diagrams it cannot be readily made clear, but we have given enough to indicate the bearing of his speculations.—[N. Y. Post.]

north, and that the magnetic poles were elsewhere, if indeed they were anywhere. Until men form correct ideas regarding the character of the magnetic poles, it is useless to trouble themselves about their position. As commonly regarded, they are nowhere. There is no single spot to which all compass-needles, with lines flanking lines, and rank fronting rank, direct their single aim. Some point to one place, others to a different place, so that this characteristic of the magnetic poles must be discarded, or else there is no such thing The other two properties of the magnetic poles are real, and belong to certain spots of the earth; but both of them do not belong to the *same* spots of the earth. There is one place, at least, in each hemisphere, possibly there are two, where the magnetized needle, if perfectly free to move, would point to the zenith and nadir. There is also a point in each hemisphere where the force exerted by the earth in directing such a needle is a *maximum*. Of the three properties originally ascribed to a magnetic pole, one has no existence anywhere, and the other two never unite upon any one point of earth. Which points, then, of the earth, are the magnetic poles,—those where the intensity prevails, or those where the dip prevails? Evidently, we must now acknowledge two kinds of magnetic poles, which are distinguishable from each other by property as well as position. One kind is called "Poles of Intensity," the other kind is called "Poles of Dip," and we must hereafter consider them as wholly distinct from each other.

The discovery of two kinds of magnetic poles was made by Col. Edward Sabine, during one of the Arctic expeditions in the years 1818–20. He observed that while navigating Baffin's Bay, the intensity of the magnetic force diminished while the vessel was sailing north. This fact showed that the place of the greatest magnetic energy was south of the ship, whereas the pole of dip was north of the ship. Hence it was suspected that the pole of dip was in a much higher latitude than the pole of intensity,—a suspicion which later observations have fully justified.

When Sabine made his report on Terrestrial Magnetism to the British Association for the Advancement of Science, in 1837, he assigned the pole of intensity in the northern hemisphere to the latitude of 52° and the longitude of 90° west, or only 5° north of Lake Superior. In 1843, Capt. J. H Lefroy started on an expedition to find the *exact position* of the *magnetic pole of intensity*, and having encircled it, he gave it a position differing but slightly from that which Col. Sabine had *presumptively* assigned to it.

"The *direction* of the earth's magnetic force was studied much earlier than its *intensity;* and the pole of dip was familiar to the world before it was imagined that there existed an independent pole of intensity; so that whenever we find the magnetic poles of the earth spoken of without qualification, we may understand the word as referring to the poles of dip, and not to the poles of intensity. The poles of dip have acquired this ascendency in the history of terrestrial magnetism; but in the theory of terrestrial magnetism, unless both classes of poles, as well as the affiliated lines which are related to them, can be spread out clearly before the mind, it is best to let the poles of dip go, and hold on to the poles of intensity. Nevertheless, the history of the poles of *dip* is not without interest. They were supposed at first to be also the points of convergence for the magnetic meridians, and were originally approached from that point of view. But I have already remarked that the poles of dip are not the points of common intersection of the magnetic meridians, and that there is no such place of general meeting anywhere. Much confusion, therefore, and considerable inaccuracy, must have grown out of the attempt to determine the position of the magnetic poles upon two irreconcilable principles. At an early period, observations indicated that there were at least two points in each hemisphere towards which the magnetic needles scattered over the earth seemed to converge. A general idea of the position of these points may be derived from their names. The principal one in the northern hemisphere is called the Hudson's Bay Pole. The principal one in the southern hemisphere is called the Australian Pole. The subordinate pole of the northern hemisphere is the Siberian Pole; and the subordinate one of the southern hemisphere is the Cape Horn Pole. These names indicate the longitudes rather than the latitudes in which we are to seek for these poles."

Hainsteen gave the magnetic poles the following positions for the year 1830:

Hudson's Bay,	69° 30′ N. Lat. and 87° 19′ W. Long.
Australian,	68° 44′ S. Lat. and 131° 47′ E. Long.
Siberian,	85° 6′ N. Lat. and 144° 17′ E. Long.
Cape Horn,	78° 29′ S. Lat. and 137° 45′ W. Long.

In 1831 the North American magnetic pole of dip was determined with the last degree of accuracy, by going to it, and observing its peculiarities on the spot. This was accomplished under the direction of Capt. John Ross, and found to be in the latitude of 70° 5′ 17″ N., and the longitude of 96° 45′ 48″ west from Greenwich. Here the dipping-needle wanted only half a minnte of being vertical. The large dip observed indicated that Ross and his companions were, at least, within half a mile of the pole of dip; and the place of the North American magnetic pole of dip may therefore be considered as known by observations made upon the spot, and as precisely as the purposes of practical or abstract science require. Captain Ross took possession of this pole, though it was nothing but an ideal point, in the name of Great Britain and William the Fourth, and raised the British flag upon it! A monument of earth was constructed upon the spot, and canisters filled with papers were buried underneath, in order that the place might be identified hereafter.

In 1839, James C. Ross, who, under the direction of his uncle, had already planted his standard upon the North American pole of dip, was dispatched in charge of two ships (Erebus and Terror), to survey in the neighborhood of the Antarctic Circle. This expedition was absent from England four years, wintering successively at Van Dieman's Land and Falkland Island. During this period Ross crossed, at a high southern point, two-thirds of all the meridians of longitude, and in 1845 the ship Padoga was sent from the Cape of Good Hope to complete the circle. Ross made his observations of magnetic elements partly afloat upon the ice, but mostly on board ship, and many of them were taken in latitudes never before reached by man. Besides discovering the Antarctic continent, Victoria, Ross sailed around the magnetic pole, and within one hundred and seventy-four miles of it, if he did not pass directly over it, and attained the extreme southern latitude of 78° 10′. Ross considered that he had come near enough to this pole to claim the privilege of naming it, and called it after Prince Albert!

The greatest dip actually observed at any one place was 88° 35′. This was in the latitude of 66° 23′ S. and 170° 12′ E. longitude. The greatest intensity observed was in the latitude of 60° 19′ S. and the longitude of 131° 20′ E. Hence we may infer a similar difference in the positions of the Australian poles of *dip* and of *intensity* to that which is now so notorious in the case of the North American poles. The magnetic pole of dip is now placed in south latitude 75° 5′ and east longitude 154°, and the magnetic pole of intensity in the latitude of 64° and the longitude of 137° 30′ E.

The line connecting the principal poles of dip in the northern and southern hemispheres is not the magnetic axis of the earth, and indeed has no scientific significancy at the present day.

Here it may be observed that, whenever two compass-needles are brought in proximity to each other, they will always be attracted by their opposite poles, and repelled by their similar poles; i. e. the north end of one needle will be attracted to the south end of the other. And since these contrary poles attract each other, a magnetic needle will turn its south pole to the north, and its north pole to the south. Hence, what we generally call the north pole of a needle is in reality its south pole, and its south pole is its north pole. If the ordinary compass be carried to either of the magnetic poles of the earth, it will lose its directive power and point indifferently in any direction. If it is carried beyond the magnetic pole, to any point between it and the true pole, the poles of the needle become reversed, the end called the north pole pointing to the south, and the south to the north.

Unless the needle is kept constantly in use or freely suspended on its pivot, its magnetism will in time become lessened or destroyed. It may then be renewed by being put between the opposite poles of two magnetic bars. While receiving the magnetism, it will be violently agitated, moving backward and forward as if it were animated; and when it has received as much magnetism as it can acquire in this way, it becomes quiescent. Or the needle may be retouched by means of the combined horseshoe magnet, from the centre of which draw that half of the needle which is to have the contrary pole; from a considerable distance draw the needle over it again. This repeated some twenty times or more, and the same for the other half, will sufficiently communicate the magnetic power.

Another, and perhaps the best, method of retouching the needle is to lay it flat upon a board with a notch or groove in it so as to admit the axis of the needle, its collar fitting nicely in the notch, and with the north end of the needle to your right, take two bar magnets, one in each hand, the left holding the marked or north end of the bar downwards, and the right holding the same mark upwards. Bring the two bars over the axis, about a foot above it (being careful that they shall not approach within two inches of each other), and then bring them down vertically on the needle—keeping the marks as directed—about an inch on each side of its axis; slide them outwards, with a slight pressure, to the ends of the needle, and repeating these upward and downward and lateral movements a number of times, the magnetic power will be amply imparted to it.

Although the magnetic needle is not that infallible guide which most people suppose, yet it is a very useful instrument, and, in the newer portions of our country, cannot be wholly dispensed with in land surveying; and the extensive use actually made of the compass in ordinary surveys, requires that the means of determining the variation of the needle should be known.

XI.

MERIDIANS.

To Determine the True Meridian.

As it is of great importance to the surveyor to be able to ascertain the direction of a true meridian line with which the direction of the needle, or magnetic meridian, may be compared, a few of the various methods which have been adopted for this purpose are here inserted.

Those which require the employment of the transit or theodolite are to be preferred, if one of these instruments is at hand. When the observations are performed with the proper care, and the instruments are to be depended on, the meridian may be run within a few seconds of its proper position. The most convenient and reliable method of obtaining the true direction of the meridian is by making observations on one or more of the circumpolar stars. The star which is most commonly used for this purpose, especially by surveyors, is the North Star, (*Polaris*), that star being in the meridian twice in 24 hours (or more precisely, 23h. 56m. 4s).

Observations not made at its elongations, i. e. at its greatest distance either east or west of the pole, make it necessary to have the time correctly—and for this a chronometer is needed. But the change of position of the stars nearest the pole is less, for a given time, than those most remote, and does not, perhaps, require that the time should be so very correct, as would otherwise be required. Polaris, on the whole, is the best star to observe; the astronomical data in regard to it, and other stars, are given in the American Ephemeris and Nautical Almanac, published at Washington.

Although observations upon the stars come more properly within the province of the astronomer than of the surveyor, yet, with a knowledge of the situation and movements of Polaris around the pole, and the relative situation of certain other stars in the constellations nearest the pole, the process of finding the meridian may be readily understood by any one qualified to engage in land surveying. All that is necessary to be known of the constellations made use of in these observations, may be obtained from Olmsted's, or Loomis' Astronomy, or from any of the published works on the subject.

Before proceeding to describe the constellations and the methods of determining the meridian, it may be proper to give a brief statement of the terms employed in astonomical calculations. [See Gurley on the "Solar Compass."]

THE SUN is the centre of the solar system, remaining constantly fixed in its position, though, for the sake of convenience, often spoken of as in motion around the earth.

THE EARTH makes a complete revolution around the sun in 365 days, 6 hours, very nearly.

It also rotates about an imaginary line passing through its centre, and termed its *axis*, once in 24 hours, turning from west to east.

THE POLES are the extremities of the axis; that in our own hemisphere, known as the north pole, if produced indefinitely towards the concave surface of the heavens, would reach the point situated near the polar star, and called the north pole of the heavens.

THE EQUATOR is an imaginary line passing around the earth equidistant from the poles, and at right angles with them. If the plane of the equator is produced to the heavens, it forms what is termed the equator of the heavens, or *celestial equator*.

THE ORBIT of the earth is the path in which it moves in making its yearly revolution.

If the plane of this orbit were extended to the heavens, it would form the *ecliptic*, or the sun's apparent path in the heavens.

The earth's axis is inclined to its orbit at an angle of about 23° 28′, making the angle between the earth's orbit and its equator, or between the celestial equator and the ecliptic of the same amount.

THE EQUINOXES are the two points in which the ecliptic and the celestial equator intersect each other.

THE DECLINATION of the sun is its angular distance north or south of the celestial equator; when the sun is at the equinoxes, that is about the 21st of March and the 21st of September of each year, his declination is 0, or he is said to be on the equator; from these points his declination increases from day to day, and from hour to hour, until, on the 21st of June and 21st of December, he is 23° 28′ distant from the equator.

It is the declination which causes the sun to appear so much higher in summer than in winter, his altitude in the heavens being in fact nearly 47° more on the 21st of June than it is on the 21st of December.

The Horizon of a place is the surface which is defined by a plane supposed to pass through the place at right angles to a vertical or plumb line, and to bound our vision at the surface of the earth.

The horizon or a horizontal surface is determined by the surface of any liquid when at rest, or by the spirit levels of an instrument.

The Zenith of any place is the point directly over head, at right angles to the horizon.

The Meridian of any place is a great circle passing through the zenith of the place, and the poles of the earth.

The Meridian Altitude of the sun is its angular elevation above the horizon, when passing the meridian of a place.

The Amplitude of the sun, or of any heavenly body, is its distance on the horizon, at the time of its rising or setting, from the prime vertical, or the true east and west points, to a vertical circle passing through the body; and the angle between the true amplitude and the magnetic amplitude is the variation of the needle for the place of observation.

The Latitude of a place is its distance north or south of the equator, measured on a meridian. At the equator the latitude is 0°, at the poles 90°.

The Longitude of a place is its distance in degrees or in time, east or west of a given place taken as the starting point or first meridian; it is measured on the equator or any parallel of latitude. In the American Almanac, the longitude of the principal places in the United States is reckoned from Greenwich, England, and expressed both in degrees and hours.

The Zenith Distance of any heavenly body, is its angular distance north or south of the zenith of a place, measured when the body is on the meridian.

Suppose a person situated on the equator at the time of the equinoxes, the sun, when on the meridian, would be in the zenith of the place, and the poles of the earth would, of course, lie in the plane of his horizon. Disregarding, for the present, the declination of the sun, let us suppose the person travels towards the north pole. As he passes to the north, the sun will descend from the zenith, and the pole rise from the horizon in the same proportion, until, when he arrives at the north pole of the earth, the sun will have declined to the horizon, and the pole of the heavens will have reached the zenith.

The altitude of the pole at any place, or the distance of the sun from the zenith, would in the case supposed, give the observer the latitude of that place.

If we now take into account the sun's declination, it would increase or diminish its meridian altitude, according as it passes north or south of the equator; but the declination of the sun at any time being known, its zenith distance, and therefore the latitude of the place, can be readily ascertained by an observation made when it is on the meridian.

TIME.—A solar day is the interval of time between the departure of the sun from the meridian of a place, and its succeeding return to the same position.

The length of a solar day, by reason of the varying velocities of the earth in its orbit, and the inclination of its axis, is continually changing. In order to have a uniform measure of time, we have recourse to what is termed a *mean solar day*, the length of which is equal to the mean or average of all the solar days in a year.

The time thus given is termed *mean time*, and is that to which clocks and watches are adjusted for the ordinary business of life. The sun is sometimes faster, and sometimes slower, than the clock, the difference being termed the *equation of time*.

The moment when the sun is on the meridian of any place is termed *apparent noon*, and this being ascertained, we can, by referring to the equation of time for the given day, and adding to, or substracting from, apparent noon, according as the sun is slow or fast, obtain the time of *mean noon*, by which to set the watch or chronometer.

DIFFERENCE OF LONGITUDE.—As the earth makes a complete rotation upon its axis once a day, every point on its surface must pass over 360° in 24 hours, or 15° in one hour, and so on in the same proportion. And as the rotation is from west to east, the sun would come to the meridian of every place 15° west of Geenwich, just one hour later than the time given in the Almanac, for apparent noon at that place.

To an observer situated at the State House, in Augusta, Me., the longitude of which is in time 4 hours 39 minutes 20 seconds, the sun would come to the meridian 4h. 39m. 20s. later than at Greenwich, and, therefore, when it was 12 M. at that place, it would be 7h. 20m. 40s. A. M. in Augusta.

Refraction.—By reason of the increasing density of the atmosphere from its upper regions to the earth's surface, the rays of light from the sun are bent out of their course, so as to make his altitude appear greater than is actually the case. The amount of refraction varies, according to the altitude of the body observed, and decreases until we come to the zenith, where it is nothing.

The following description of a few of the *Northern Constellations*, beginning with the North Pole, will be sufficient for our present purpose:

Ursa Minor (The *Little Bear*). The Pole-Star (Polaris) is in the extremity of the tail of the Little Bear. It is laid down in the Ephemeris as of the second magnitude, and being within less than a degree and a half of the North Pole of the heavens, it serves at present to indicate the position of the pole. It will be recollected, however, that on account of the precession of the equinoxes, the pole of the heavens is constantly shifting its place from east to west, revolving about the pole of the ecliptic, and will in time recede so far from the pole-star, that this will no longer retain its present distinction. When the earliest catalogues of the stars were made, this star was 12° from the pole. Its mean polar distance is now (1868) 1° 23′ 39″.6, and will approach still nearer; or, to speak more accurately, the pole will come still nearer to this star, after which it will leave it, and successively pass by others. Its distance is now diminishing at the rate of 19″.11 in a year, and will continue to do so till it approaches to within half a degree, when it will recede. Three stars in a straight line 4° or 5° apart, commencing with Polaris, lead to a trapezium of four stars, the whole seven together forming the figure of a *dipper*, the trapezium being the body, and the three first mentioned stars being the handle.

URSA MAJOR (The *Great Bear.*) This is one of the largest and most celebrated of the constellations. It is usually recognized by the figure of a larger and more perfect *dipper* than the one in the Little Bear—three stars, as before, constituting the handle, and four others, in the form of a trapezium, the body of the figure. The two western stars of the trapezium, ranging nearly with the North Star, are called the *Pointers*; and beginning with the northern of these two, and following round from left to right through the whole seven, they correspond in rank to the succession of the first seven letters of the Greek alphabet, *Alpha*, *Beta*, *Gamma*, *Delta*, *Epsilon*, *Zeta*, *Eta*. Several of them also are known by their Arabic names. Thus, the first in the tail, corresponding to Epsilon, is *Alioth*, the next, (Zeta) *Mizar*, and the last, (Eta) *Benetnasch*. These are all bright and beautiful stars, Alpha being of the first magnitude, Beta, Gamma, Delta, of the second, and the three forming the tail, of the third. But it must be remarked that this very remarkable figure of a dipper or laddle composes but a small part of the entire constellation, being merely the hinder half of the body and the tail of the Bear. The head and breast of the figure, lying about ten or twelve degrees west of the Pointers, contain a great number of minute stars in a triangular group. One of the fourth magnitude, *Omicron*, is in the mouth of the Bear. The feet of the figure may be looked for about 15° south of those already described, the two hinder paws consisting each of two stars very similar in appearance, and only a degree and a half apart. The two paws are distant from each other about 18°; and following westward about the same number of degrees, we come to another very similar pair of stars, which constitute one of the fore paws, the other foot being without any corresponding pair.

In a clear winter's night, when the whole constellation is above the pole, these various parts may be easily recognized, and the entire figure will be seen to resemble a large animal, readily accounting for the name given to this constellation from the earliest ages.

DRACO (*The Dragon*) is also a very large constellation, extending for a great length from east to west. Beginning at the tail, which lies half way between the Pointers and the Pole-Star, and winding round between the Great and the Little Bear, by a continued succession of bright stars from 5° to 10° asunder, it coils around under the feet of the Little Bear, sweeps round the pole of the ecliptic, and terminates in a trapezium formed by four conspicuous stars, from thirty to thirty-five degrees from the North Pole. A few of the members of this constellation are of the second, but the greater part of the third magnitude, and below it. With the constellations already described as general land-marks, we may now proceed with some few others, by stating their *boundaries*, as we do those of countries in geography; their relative situations being thus first learned from a map, or from a celestial globe, and then being severally traced out on the sky itself. Beginning with those which surround the North Pole:

Cepheus (*The King*) is bounded N. by the Little Bear, E. by Cassiopeia, S. by the Lizzard, and W. by the Dragon. The head lies in the Milky Way, and the feet extend towards the pole. It contains no stars above the third magnitude.

For our present purpose it is necessary to describe but one more of the constellations:

Cassiopeia is one of the constellations in the Milky Way, and is on the opposite side of the pole from the Great Bear, and nearly at the same distance from it. It is bounded N. and W. by Cepheus, E. by Camelopardalus, and S. by Andromeda. It is readily distinguished by the figure of a *chair* inverted, of which two stars constitute the back, and four, in the form of a square, the body of the chair.

This constellation is sometimes known as the "Lady in her chair," as the fabulous Cassiopeia was wife to Cepheus, king of Ethiopia; and consequently she now occupies a position near him in the heavens.

Method of determining the true Meridian by observing Polaris at its culmination either above or below the Pole.

If the North Star were situated precisely at the North Pole, the Meridian could be at once determined by sighting to it, or placing the eye at some distance behind a plumb-line so that this line should hide the star. But the North Star makes a circle round the pole in a sidereal day, making two transits across the meridian, one above and the other below the pole. It can therefore be *due north* only twice in that period; and that is within a very few minutes of the time, when the star called *Alioth*, in the constellation of Ursa Major, is directly over or under it. There is also another star nearly in an opposite direction from the pole, called *Gamma*, in the constellation of Cassiopeia. When these three stars are vertical, the north star is very near the meridian; and when they are horizontal it is at its greatest elongation either east or west of the pole, and on the same side of the pole as *Gamma Cassiopeiae.*

When Polaris comes to the Meridian at its upper transit, the position of the *three stars* above named will appear nearly in a vertical position as represented in the annexed Figure; (Fig. 1.); and when it comes to the Meridian below the pole, they will appear as represented in Figure 2.

Fig. 1.

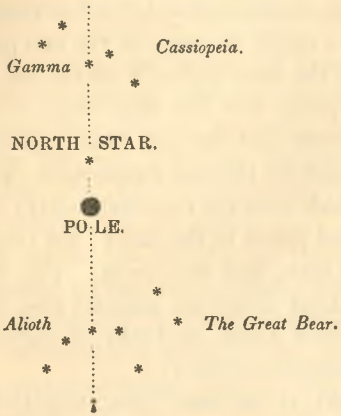

Fig. 2.

To determine the meridian by this method, select a position where a clear and unobstructed view of the northern constellations may be had, and let a small white plumb-line be suspened from the upper end of a pole about twenty feet in length, and raised in a slanting position to an elevation of 45° or 50°, the lower end of the pole being set in the ground and firmly supported in its place by means of shores or props. To the lower end of the line attach a plumb-bob, and let this pass downwards into a vessel of water to lessen its vibrations. About ten feet south of the plumb-line, erect two posts or crotches, about six feet in height, and four feet apart, placing them firmly in the ground, and nearly east and west of each other. On the top of these posts fasten a smooth rod or pole horizontally, and on this rod suspend a smaller plumb-line by a loop, so that the line may be slipped along the rod at pleasure, and let the plumb-bob swing in a vessel of water as before, that the line may not be agitated by the motion of the air. With this apparatus duly prepared in the daytime, we have only to wait for the proper time to make the observations of the star as it approaches the meridian.

The time at which the North Star comes to the meridian may be either taken from the table given below, or calculated by the rule as given in connection with the table. In making the observation it will be necessary to have the plumb-line lighted, which may be done by an assistant holding a lamp near it.

Having made the preliminary arrangements, as the time approaches for the North Star to be on the meridian, let the observer place himself a little to the south of the smaller or southern plumb-line, which must be slipped along on the horizontal rod or cross-bar till the North Star shall appear exactly in range of the two plumb-lines. Still watch the motion of the star, and as it moves one way, move the eye and the smaller plumb-line the other way, so as to constantly keep the two plumb-lines and the star exactly in range. At last *Alioth*, too, will be covered by the two plumb-lines ; and at that moment the eye and the plumb-lines are (approximately) in the meridian. The line thus obtained points to the east of the true line when the North Star is above Alioth, and *vice versa*. The North Star is exactly in the meridian about seventeen minutes after it has been in the same vertical plane with Alioth, and may be sighted to after that interval of time with perfect accuracy.

A lighted candle or lamp should, at the same time, be placed by a second assistant in an upright position at the distance of five chains or more to the north of the two plumb-lines, and in an exact range with them. Let the light be extinguished and left till morning, or with the compass take the bearing at once, and the reading is the variation. If instead of the compass and plumb-lines a Transit or Theodolite be used, the spider-lines must be illuminated either by a small lamp which sometimes accompanies the instrument, or by throwing the light of a common lamp into the telescope by its reflection from white paper.

The times of the upper transit of the North Star for every tenth day of the year are given in the following table. The calculation is made for the meridian of Augusta, the year 1870. As a change of six hours, or 90° of longitude, will only make a change of one minute in the time of the transit, the table is sufficiently correct for any place within the State.

Time of Polaris crossing the Meridian, above the Pole.

Months.	1st Day.	11th Day.	21st Day.
	H. M.	H. M.	H. M.
January	6 26 P. M.	5 47 P. M.	5 7 P. M.
February	4 24 "	3 44 "	3 5 "
March	2 33 "	1 54 "	1 15 "
April	0 31 "	11 52 A. M.	11 13 A. M.
May	10 33 A M.	9 54 "	9 15 "
June	8 32 "	7 53 "	7 13 "
July	6 34 "	5 55 "	5 16 "
August	4 33 "	3 54 "	3 14 "
September	2 31 "	1 52 "	1 13 "
October	0 34 "	11 50 P. M.	11 11 P. M.
November	10 28 P. M.	9 48 "	9 9 "
December	8 30 "	7 50 "	7 11 "

If the time of the passage of POLARIS for any day not given in the table be desired, take out the time of its passage for the next preceding day given in the table, and from this time deduct four minutes for each day that elapses between the preceding date in the table and that for which the time of transit is required; or, more accurately, interpolate, thus:

Say, *As the number of days between those given in the table is to the number between the preceding date and that for which the time of transit is desired, so is the difference between the times of transit given in the table to the time to be subtracted from that corresponding to the earlier of the two days.*

The first term of the preceding proportion is always ten, except at the end of months having more or less than thirty days.

For example, let the time of transit, August 27th, be required:

	Time.
August 21.	3h. 14m.
September 1.	2 31
Difference.	43m.

From August 21st to September 1st being 11 days, and from August 21st to August 27th being 6 days, we have this proportion: As 11d. : 6d. : : 43m : 23 5-11m. Taking this from 3h. 14m. A. M. we get 2h. 50 6-11m. A. M. for the time of transit required.

The time of the lower transit may be obtained from the table by changing A. M. into P. M. and *diminishing* the minutes by two, or changing P. M. into A. M. and increasing the minutes by two; or it can be found by adding 11h. 58m. to the time of the upper transit, or by subtracting that interval from it.

Although the above table was calculated for the year 1870, yet it will serve for many years when the observations are made by means of the "plumb-lines," since the time of the meridian passage is determined, in that method, by the time when Polaris and Alioth are in the same vertical.

When the time is more accurately needed for determining the meridian, by other methods, the numbers in the table must be corrected for the years that elapse between 1870 and the current year. Polaris passes the meridian about 21 seconds—more accurately, 20 6 seconds—later every year than the preceding one, so that in 1880 the time will be 3m. 26s. later than those given in the table; in 1890, 6m. 52s.; and in 1900, 10 minutes 18 seconds later.

To determine the time the North Star is on the meridian, we have the following

RULE: "Take from the American Almanac, or other Ephemeris, the sun's right ascension, or sidereal time of mean noon, for the noon preceding the time for which the transit is wanted. The sidereal time is given in the American Almanac for mean noon at Greenwich for every day in the year, and may be calculated for any other meridian by interpolation, thus: The difference between the sidereal times for two successive days being 3 minutes 56.555 seconds, say, As 24 hours *is to* the longitude expressed in time, *so is* 3 minutes 56.555 seconds to the correction to be applied to the sidereal time at noon of the given day at Greenwich. This correction—added to the sidereal time taken from the almanac, if the longitude be west, but substracted if it be east—will give the sidereal time, at mean noon at the given place.

Having once determined the correction to be made for the given place, it will serve for all the calculations that may be wanted for that place. For example, let it be required to find the sidereal time at mean noon, at Augusta, Me., (its longitude, in time, being 4h. 39m. 20s. west from Greenwich), on the 14th of June, 1867.

The sidereal time at mean noon, Greenwich, June 14, is 5h. 29m. 15.46s., as taken from the Ephemeris of that year. And, to find the correction for the meridian of Augusta, say

As 24h. : 4h. 39m. 20s. : : 3m. 66.555s. : 44.71 seconds.

	h.	m.	s.
Then, sidereal time at Greenwich, mean noon,	5	29	15.46
Correction for difference of longitude,			44.71
Sidereal time at Augusta, mean noon,	5	30	0.17

Although the above table was calculated for the year 1870, yet it will serve for many years when the observations are made by means of the "plumb-lines," since the time of the meridian passage is determined, in that method, by the time when Polaris and Alioth are in the same vertical.

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Having once determined the correction to be made for the given place, it will serve for all the calculations that may be wanted for that place. For example, let it be required to find the sidereal time at mean noon, at Augusta, Me., (its longitude, in time, being 4h. 39m. 20s. west from Greenwich), on the 14th of June, 1867.

The sidereal time at mean noon, Greenwich, June 14, is 5h. 29m. 15.46s., as taken from the Ephemeris of that year. And, to find the correction for the meridian of Augusta, say

As 24h. : 4h. 39m. 20s. : : 3m. 66.555s. : 44.71 seconds.

	h.	m.	s.
Then, sidereal time at Greenwich, mean noon,	5	29	15.46
Correction for difference of longitude,			44.71
Sidereal time at Augusta, mean noon,	5	30	0.17

Next, from the same almanac, take the Right Ascension of the star, increasing it by 24 hours, if necessary to make the subtraction possible, and from this amount subtract the sidereal time above determined,—the remainder is the time of the transit expressed in sidereal hours. To convert these into solar hours, say, As 24 hours *is* to the number of hours in the above time, *so is* 3 minutes 55.909 seconds to the correction. This correction, subtracted from the sidereal time, will give the mean solar time of the upper transit. The time thus determined will be astronomical time.

The astronomical day begins at noon, the hours being counted from 0 to 24, commencing with the instant of the passage of the true vernal equinox over the upper meridian, and ending with its return to the same meridian. The first twelve hours, therefore, correspond with the hours in the afternoon of the same civil day; but the last twelve agree with the hours of the morning of the next succeeding day.

Thus, June 14, 5h. 30m., astronomical time, corresponds with June 14, 5h. 30m. P. M., civil time; but June 14, 16h. 30m., astronomical time, agrees with June 15, 4h. 30m. A. M., civil time.

If, therefore, the number of hours of a date expressed in astronomical time be greater than twelve, the days must be increased by *one* and the hours diminished by twelve to convert it into civil time.

The Right Ascension and Polar Distance of the North Star for the beginning of each decade for the last half of the present century, are given in the following table. For intermediate years they may be found, approximately, by interpolation.

Table, showing the Right Ascension and Polar Distance of the North Star, from 1850 to 1900.

Years.	Right Ascension.			Polar Distance.		
	h.	m.	s.	°	′	″
January 1, 1850	1	05	01.4	1	29	25
" 1860	1	08	02.8	1	26	17.7
" 1870	1	11	16.9	1	23	01
" 1880	1	14	45.1	1	19	50.4
" 1890	1	18	29.2	1	16	40.7
" 1900	1	22	31 0	1	13	32.2

SECOND METHOD.—*By observing a meridian passage with a transit or theodolite.*

Having accurately levelled the instrument, sight to Polaris when on the meridian. Then, depressing the telescope, set up an object in the line of sight: a line drawn from the instrument to that object will be a meridian. In the latitude of 50°, an error of five minutes in the time of the transit of Polaris will make an error of nearly 3′ in the bearing of the star, so that if the observation is not made near the proper time, it must be corrected. This may be done by the following

Rule. Deduct the star's polar distance from the complement of the latitude. Then say,

As sine of this difference is to the sine of the polar distance of the star (1° 23′ 39″ at present) *so is sine of the error in time* (expressed in degrees) *to the sine of the bearing of the star. East* if the time be too *early*, but *west* if it be too *late*.

The time is reduced to degrees by multiplying by 15; thus, 5 minutes = 1° 15′.

Example.

Required the bearing of Polaris at Fort Kent, in lat. 47° 15′ N., 5 minutes after the upper meridian passage.

Comp. of lat. 42° 45′ — 1° 23′ 39″ = 41° 21′ 21″.

As sine of 41° 21′ 21″ ar. co.,	.1799737
: sine of star's polar dist., 1° 23′ 39″,	8.3861421
: : sine of time, in degrees, 1° 15′,	8.3387529
: sine of star's bearing, 2′ 47″ W.,	6.9048687

Third Method. — *By an observation of Polaris at its greatest elongation.*

In the revolution of a circumpolar star, it gradually recedes from the meridian towards the west until it attains its most remote point; here it apparently remains stationary, or, at least, appears to move directly towards the horizon for a few minutes, and then gradually moves eastward towards the meridian which it crosses below the pole. Continuing its course, in about six hours it reaches its greatest eastern deviation, when it again becomes stationary. When most remote from the meridian, it is said to have its greatest elongation.

As the star is apparently stationary at the time of its greatest eastern or western elongation, this time is a very favorable one for observing it, since a variation of ten or fifteen minutes in the time will then make no appreciable error in the bearing of the line. The bearing of the star, or its angular distance east or west of the pole, is called its *azimuth*.

To obtain the true azimuth of the North Star, we have the following proportion:

As Cos. Lat. : Rad. : : Sin. Star's polar dist. : Sin. of Azimuth.

Example.

Required the azimuth of the North Star for the latitude of Augusta, 44° 18′ 43″ N.

Say, As Cos. Lat. 44° 18′ 43″ ar. co.	.1453617
: Rad. 90° 00′ 00″	10.0000000
: : Sin. Pol. dist. 1° 23′ 39″	8.3861421
: Sin. of azimuth, 1° 56′ 54″	8.5315038

Therefore, the azimuth, or *true* bearing of the North Star at Augusta, for the current year (1868) is 1° 56′ 54″ east or west of the true meridian, and whatever its magnetic bearing differs from this, is the variation of the needle, for that time and place.

It must be remembered, however, that when the *azimuth* of the star and its magnetic bearing are one *east* and the other west, the *sum* of the two is the *magnetic variation*, which is of the same name as the azimuth; that is, east, if that be east, and west if it be west. But when the azimuth of the star and its magnetic bearing are both east, or both west, their *difference* is the variation, which will be of the same name as the azimuth and bearing, if the azimuth be the greater of the two, or of the contrary name if the azimuth be the smaller.

The elongations of the star which answer the purpose of observation, are those which occur in the night. The times in which they occur, approximately at least, it is convenient to know beforehand. For this purpose the following tables have been computed. An examination of the tables will show that these times are later, by a small increment annually. The following general direction will insure the use of the correct table. Use Table for 1870 until 1880; then use Table for 1885 until 1892; thereafter use Table for 1900; or, more accurately, add to the times given in Table for 1870, one minute for every three years until 1882; then use Table for 1885; after 1885 add one minute for every two years until 1897, and thereafter use Table for 1900.

Times of Extreme Elongation of the North Star, calculated for the Latitude of 45°.

1870.

Month.	1st Day.		11th Day.		21st Day.	
	Eastern.	Western.	Eastern.	Western.	Eastern.	Western.
	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.
January	0 33 P. M.	0 24 A. M.	11 58 A. M.	11 40 P. M.	11 14 A. M.	11 01 P. M.
February......	10 31 A. M.	10 11 P. M.	9 51 "	9 38 "	9 12 "	8 59 "
March	8 40 "	8 27 "	8 01 "	7 48 "	7 21 "	7 08 "
April.........	6 38 "	6 25 "	5 59 "	5 46 "	5 20 "	5 07 "
May	4 40 "	4 27 "	4 01 "	3 48 "	3 22 "	3 09 "
June	2 39 "	2 26 "	2 00 "	1 47 "	1 20 "	1 07 "
July..........	0 41 "	0 28 "	0 02* "	11 49 A. M.	11 19 P. M.	11 10 A. M.
August	10 36 P. M.	10 27 A. M.	9 57 P. M.	9 48 "	9 17 "	9 08 "
September ...	8 34 "	8 25 "	7 55 "	7 46 "	7 16 "	7 07 "
October	6 37 "	6 28 "	5 57 "	5 48 "	5 18 "	5 09 "
November ...	4 35 "	4 26 "	3 55 "	3 46 "	3 16 "	3 07 "
December.....	2 37 "	2 28 "	1 57 "	1 48 "	1 18 "	1 09 "

1885.

Month.	1st Day. Eastern.	1st Day. Western.	11th Day. Eastern.	11th Day. Western.	21st Day. Eastern.	21st Day. Western.
January	0 37 P. M.	0 28 A. M.	11 57 A. M.	11 45 P. M.	11 18 A. M.	11 05 P. M.
February	10 34 A. M.	10 22 P. M.	9 55 "	9 42 "	9 15 "	9 03 "
March	8 44 "	8 31 "	8 04 "	7 52 "	7 25 "	7 13 "
April.........	6 42 "	6 29 "	6 03 "	5 50 "	5 23 "	5 11 "
May	4 44 "	4 32 "	4 05 "	3 52 "	3 25 "	3 13 "
June.	2 42 "	2 30 "	2 03 "	1 51 "	1 24 "	1 12 "
July	0 45 "	0 32 "	0 06 "	11 53 A. M.	11 23 P. M.	11 14 A. M.
August	10 39 P. M.	10 31 A. M.	10 00 P. M.	9 52 "	9 21 "	9 13 "
September.....	8 38 "	8 29 "	7 50 "	7 50 "	7 19 "	7 11 "
October	6 40 "	6 32 "	6 01 "	5 53 "	5 21 "	5 13 "
November	4 38 "	4 30 "	3 59 "	3 50 "	3 19 "	3 11 "
December. ..	2 40 "	2 32 "	2 01 "	1 52 "	1 21 "	1 13 "

1900.

Month.	1st Day. Eastern.	1st Day. Western.	11th Day. Eastern.	11th Day. Western.	21st Day. Eastern.	21st Day. Western.
January......	0 44 P. M.	0 37 A. M.	0 05 P. M.	11 53 P. M.	11 26 A. M.	11 14 P. M.
February	10 42 A. M.	10 30 P. M.	10 03 A. M.	9 51 "	9 23 "	9 12 "
March	8 52 "	8 40 "	8 12 "	8 01 "	7 33 "	7 21 "
April.........	6 50 "	6 38 "	6 10 "	5 59 "	5 31 "	5 20 "
May..........	4 52 "	4 40 "	4 13 "	4 01 "	3 33 "	3 22 "
June	2 50 "	2 39 "	2 11 "	1 59 "	1 32 "	1 20 "
July	0 52 "	0 41 "	0 13 "	0 02 "	11 30 P. M.	11 23 A. M.
August.......	10 47 P. M.	10 40 A. M.	10 08 P. M.	10 00 A. M.	9 29 "	9 21 "
September	8 46 "	8 38 "	8 07 "	7 59 "	7 27 "	7 20 "
October	6 48 "	6 40 "	6 09 "	6 01 "	5 29 "	5 22 "
November	4 46 "	4 39 "	4 07 "	3 59 "	3 27 "	3 20 "
December.....	2 48 "	2 40 "	2 09 "	2 01 "	1 29 "	1 21 "

* Also 11h. 58m. P. M.

To find the time of elongation of the North Star for other days than those given in the tables:

Take from the proper table (see direction above) the time for the day most nearly preceding the day desired, and subtract from this time four minutes for each day from the date given in the table to that of the required day; or, if greater accuracy be required, interpolate for the intervening days, according to the directions before given for finding the times of Polaris crossing the meridian. (See former Time Table, p. 47).

The method of observing the star at its elongation is similar to that already explained for observing it on the meridian. At fifteen or twenty minutes before the time of the elongation to be observed, as found in one or other of the tables above, let the instrument be placed at the point from which the line is to be drawn. Having levelled the instrument properly, the observer will next turn the telescope until the star appears directly behind the vertical wire, and will continue to follow the star until it has reached the point of greatest eastern or western elongation, as the case may be.

If the *eastern* elongation of Polaris be observed, its relative position, as connected with *Alioth* and *Gamma* Cassiopeiae, will appear as in Figure 3; but if the *western* be observed, the three stars will appear as in Figure 4, Polaris being always on the same side of Pole as Gamma Cassiopeiae.

FIG. 3.

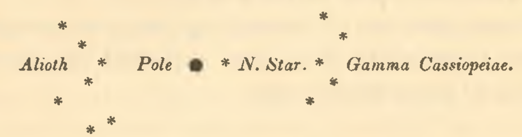
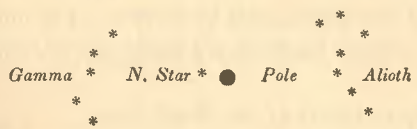


FIG. 4.



When the star has reached its extreme elongation, it will appear stationary for a time, and then gradually leave the wire of the telescope in a direction opposite to that in which it has been previously moving. The axis of the telescope will thus be left in the direction of the star at the observed elongation. To mark this direction, let an assistant hold a lighted candle at the distance of some thirty or forty rods in front of the telescope and at such a point that it shall appear to the observer directly behind the vertical wire of the telescope. This point being carefully marked, a line drawn to it from the center of the instrument, will be in the direction required.

In case a Transit instrument is not at hand, the direction of this line may be marked by using plumb-lines in the manner already described. Having thus ascertained the direction of the star at its elongation, it remains only to know the *azimuth of the star*, or its angular distance from the pole, in order to lay out the direction of the true meridian from the course of the line already obtained. For instance, if the magnetic bearing of the North Star at its greatest eastern elongation were found to be N. 18° 50′ E., and the azimuth known to be 2° 12′, then (18° 50′— 2° 12′= 16° 38′) the magnetic bearing of the true meridian would be N. 16° 38′ E., and 16° 38′ would be the amount of westerly variation, or declination of the needle. But if the magnetic bearing of the star at its *western* elongation had been N. 18° 50′ E., and its azimuth 2° 12′, then (18° 50′+ 2° 12′= 21° 2′) the magnetic bearing of the meridian would have been N 21° 2′ E., and 21° 2′ would have been the amount of the westerly variation.

Having established a meridian line, the variation of the needle is found by merely placing the compass upon the line and observing the angle which the needle makes with it.

Various other methods of determining the true meridian are employed, but those which have been explained are deemed amply sufficient for all practical purposes.

Latitude.

In order to calculate the azimuth of the North Star for any given place, the latitude of the place must be known. For obtaining the latitude of a place, various methods are made use of, among which are the following:

1st. By a meridian altitude of the North Star.

Since the altitude of the pole is equal to the latitude of the place, we may take the altitude of Polaris when on the meridian, and from the result make the proper deduction for refraction. When a celestial object is in the zenith, it has no refraction or parallax; but when in the horizon its refraction is 33′ 51″, and at an altitude of 45°, about one minute (more exactly 58″,) the natural cotangent of the altitude of a heavenly body expresses very nearly its refraction in minutes and decimal parts, which, reduced to minutes and seconds, may be deducted from the apparent altitude of the star as the allowance for refraction. Then increase or diminish the remainder by the polar distance of the star according as the lower or upper transit was observed, and the result will be the latitude required.

2d Method. Take the altitude of the star six hours before or after its meridian passage. The result, corrected for refraction, will be the latitude.

3d. Still another method of determining the latitude is by observing the meridional zenith distance of a circumpolar star, both at its upper and lower culmination; then, computing the refraction for each observation, the co-latitude will be equal to half the sum of the two zenith distances added to half the sum of the two refractions. The latitude thus obtained does not depend on a previous knowledge of the declination of the object observed.

Azimuth Table.

The azimuths as given in the following table are calculated for the first day of January of each year:

To find the azimuth of the North Star for other minutes (miles) of latitude than those given in the table, state thus:

Rule.—*As* five minutes (of latitude) *is to* the number of minutes between the next preceding number in the table and the desired number, *so is* the difference between the azimuths of the number of minutes next preceding and next following the desired number *to* the number of seconds additive to the azimuth of the number of minutes next preceding the number the azimuth of which is required.

Example.

Required the azimuth of the North Star in latitude 44° 19′ for January 1, 1868.

Solution. — As 5′ : 4′ :: 10″ : 8″. And 1° 56′ 48″ + 8″ = 1° 56′ 56″. Ans.

To find the azimuth of the North Star for other days in the year than January 1st.

Rule 1st.—*As* twelve months *is to* the number of months from the beginning of the proposed year to the time given, *so is* the difference between the azimuths (as found in the table) for the year proposed and the next year *to* the number of seconds to be subtracted from the azimuth of the proposed year; or, more accurately, thus:

Rule 2d. *As* 365 days (leap year 366) *is to* the number of days from January 1st to the proposed time, *so is* the difference between the azimuths for the year proposed and the next year *to* the number of seconds to be subtracted from the azimuth as given in the table for the proposed year.

EXAMPLE 1st.—Find the azimuth of the North Star in latitude 45° 40′ for July 15, 1870.

Solution.—As 12 months : $7\frac{1}{2}$ months : : 27″ : 16″.9. From 1° 58′ 48″ subtract 16″.9, and there remains 1° 58′ 31″. Ans.

EXAMPLE 2d.—Required the azimuth of the North Star in latitude 43° 45′ for September 24, 1875.

Solution. — As 365 days : 266 : : 26″ : 19″. From 1° 52′ 44″ take 19″, and there remains 1° 52′ 25″. Ans.

NOTE—Inspection of the Table shows that but a slight error would arise from using $2\frac{1}{4}$″ as the amount subtractive for each month. It may be convenient at times to use this number ($2\frac{1}{4}$″) as a multiple. It will be observed that the latitude in degrees and minutes, extending from 43° to 47° 55′, is given at the head and left hand column of the following table:

Table of Azimuths of the North Star (Polaris) calculated for the latitude of Maine, from A. D. 1868 to 1899, inclusive.

COMPUTED BY M. C. FERNALD.

1868.

′	43°	44°	45°	46°	47°
0	1° 54′ 24″	1° 56′ 18″	1° 58′ 19″	2° 00′ 26″	2° 02′ 41″
5	1 54 33	1 56 28	1 58 29	2 00 37	2 02 52
10	1 54 42	1 56 38	1 58 40	2 00 48	2 03 04
15	1 54 52	1 56 48	1 58 50	2 00 59	2 03 15
20	1 55 01	1 56 58	1 59 01	2 01 10	2 03 27
25	1 55 11	1 57 08	1 59 11	2 01 21	2 03 39
30	1 55 20	1 57 18	1 59 22	2 01 32	2 03 50
35	1 55 30	1 57 28	1 59 32	2 01 44	2 04 02
40	1 55 39	1 57 38	1 59 43	2 01 55	2 04 14
45	1 55 49	1 57 48	1 59 54	2 02 06	2 04 26
50	1 55 59	1 57 58	2 00 05	2 02 18	2 04 38
55	1 56 08	1 58 09	2 00 15	2 02 29	2 04 50

1869.

0	1° 53′ 57″	1° 55′ 52″	1° 57′ 52″	1° 59′ 59″	2° 02′ 12″
5	1 54 07	1 56 01	1 58 02	2 00 10	2 02 24
10	1 54 16	1 56 11	1 58 13	2 00 21	2 02 35
15	1 54 25	1 56 21	1 58 23	2 00 31	2 02 47
20	1 54 35	1 56 31	1 58 33	2 00 42	2 02 59
25	1 54 44	1 56 41	1 58 44	2 00 53	2 03 10
30	1 54 54	1 56 51	1 58 54	2 01 04	2 03 22
35	1 55 03	1 57 01	1 59 05	2 01 16	2 03 34
40	1 55 13	1 57 11	1 59 16	2 01 27	2 03 46
45	1 55 23	1 57 21	1 59 26	2 01 38	2 03 57
50	1 55 32	1 57 31	1 59 37	2 01 50	2 04 09
55	1 55 42	1 57 42	1 59 48	2 02 01	2 04 21

Table of Azimuths of the North Star (Continued).

1870.

′	43°	44°	45°	46°	47°
0	1° 53′ 31″	1° 55′ 25″	1° 57′ 25″	1° 59′ 31″	2° 01′ 44″
5	1 53 41	1 55 35	1 57 35	1 59 42	2 01 56
10	1 53 50	1 55 44	1 57 46	1 59 53	2 02 07
15	1 53 59	1 55 54	1 57 56	2 00 04	2 02 19
20	1 54 09	1 56 04	1 58 06	2 00 15	2 02 30
25	1 54 18	1 56 14	1 58 17	2 00 26	2 02 42
30	1 54 27	1 56 24	1 58 27	2 00 37	2 02 54
35	1 54 37	1 56 34	1 58 38	2 00 48	2 03 05
40	1 54 46	1 56 44	1 58 48	2 00 59	2 03 17
45	1 54 56	1 56 54	1 58 59	2 01 10	2 03 29
50	1 55 06	1 57 04	1 59 10	2 01 22	2 03 41
55	1 55 15	1 57 15	1 59 20	2 01 33	2 03 53

1871.

′	43°	44°	45°	46°	47°
0	1° 53′ 05″	1° 54′ 58″	1° 56′ 58″	1° 59′ 04″	2° 01′ 16″
5	1 53 14	1 55 08	1 57 08	1 59 14	2 01 28
10	1 53 24	1 55 18	1 57 18	1 59 25	2 01 39
15	1 53 33	1 55 28	1 57 29	1 59 36	2 01 51
20	1 53 42	1 55 38	1 57 39	1 59 47	2 02 02
25	1 53 52	1 55 47	1 57 49	1 59 58	2 02 14
30	1 54 01	1 55 57	1 58 00	2 00 09	2 02 25
35	1 54 11	1 56 07	1 58 10	2 00 20	2 02 37
40	1 54 20	1 56 17	1 58 21	2 00 31	2 02 49
45	1 54 30	1 56 27	1 58 32	2 00 43	2 03 01
50	1 54 39	1 56 38	1 58 42	2 00 54	2 03 12
55	1 54 49	1 56 48	1 58 53	2 01 05	2 03 24

1872.

′	43°	44°	45°	46°	47°
0	1° 52′ 39″	1° 54′ 32″	1° 56′ 31″	1° 58′ 36″	2° 00′ 48″
5	1 52 48	1 54 42	1 56 41	1 58 47	2 01 00
10	1 52 57	1 54 51	1 56 51	1 58 58	2 01 11
15	1 53 07	1 55 01	1 57 02	1 59 09	2 01 23
20	1 53 16	1 55 11	1 57 12	1 59 19	2 01 34
25	1 53 25	1 55 21	1 57 22	1 59 30	2 01 46
30	1 53 35	1 55 31	1 57 33	1 59 41	2 01 57
35	1 53 44	1 55 41	1 57 43	1 59 52	2 02 09
40	1 53 54	1 55 51	1 57 54	2 00 03	2 02 20
45	1 54 03	1 56 01	1 58 04	2 00 15	2 02 32
50	1 54 13	1 56 11	1 58 15	2 00 26	2 02 44
55	1 54 22	1 56 21	1 58 26	2 00 37	2 02 56

1873.

′	43°	44°	45°	46°	47°
0	1° 52′ 13″	1° 54′ 06″	1° 56′ 04″	1° 58′ 09″	2° 00′ 21″
5	1 52 22	1 54 15	1 56 14	1 58 20	2 00 32
10	1 52 31	1 54 25	1 56 24	1 58 30	2 00 43
15	1 52 41	1 54 35	1 56 35	1 58 41	2 00 55
20	1 52 50	1 54 44	1 56 45	1 58 52	2 01 06
25	1 52 59	1 54 54	1 56 55	1 59 03	2 01 17
30	1 53 09	1 55 04	1 57 06	1 59 14	2 01 29
35	1 53 18	1 55 14	1 57 16	1 59 25	2 01 41
40	1 53 27	1 55 24	1 57 27	1 59 36	2 01 52
45	1 53 37	1 55 34	1 57 37	1 59 47	2 02 04
50	1 53 46	1 55 44	1 57 48	1 59 58	2 02 16
55	1 53 56	1 55 54	1 57 58	2 00 09	2 02 28

Table of Azimuths of the North Star (Continued).

1874.

′	43°	44°	45°	46°	47°
0	1° 51′ 47″	1° 53′ 39″	1° 55′ 37″	1° 57′ 41″	1° 59′ 52″
5	1 51 56	1 53 49	1 55 47	1 57 52	2 00 04
10	1 52 05	1 53 58	1 55 57	1 58 03	2 00 15
15	1 52 14	1 54 08	1 56 07	1 58 13	2 00 26
20	1 52 24	1 54 18	1 56 18	1 58 24	2 00 38
25	1 52 33	1 54 27	1 56 28	1 58 35	2 00 49
30	1 52 42	1 54 37	1 56 38	1 58 46	2 01 01
35	1 52 52	1 54 47	1 56 49	1 58 57	2 01 12
40	1 53 01	1 54 57	1 56 59	1 59 08	2 01 24
45	1 53 10	1 55 07	1 57 10	1 59 19	2 01 36
50	1 53 20	1 55 17	1 57 20	1 59 30	2 01 47
55	1 53 29	1 55 27	1 57 31	1 59 41	2 01 59

1875.

′	43°	44°	45°	46°	47°
0	1° 51′ 21″	1° 53′ 12″	1° 55′ 10″	1° 57′ 14″	1° 59′ 25″
5	1 51 30	1 53 22	1 55 20	1 57 25	1 59 36
10	1 51 39	1 53 32	1 55 30	1 57 35	1 59 47
15	1 51 48	1 53 41	1 55 40	1 57 46	1 59 58
20	1 51 57	1 53 51	1 55 51	1 57 57	2 00 10
25	1 52 07	1 54 01	1 56 01	1 58 07	2 00 21
30	1 52 16	1 54 10	1 56 11	1 58 18	2 00 32
35	1 52 25	1 54 20	1 56 21	1 58 29	2 00 44
40	1 52 35	1 54 30	1 56 32	1 58 40	2 00 56
45	1 52 44	1 54 40	1 56 42	1 58 51	2 01 07
50	1 52 53	1 54 50	1 56 53	1 59 02	2 01 19
55	1 53 03	1 55 00	1 57 03	1 59 13	2 01 30

1876.

′	43°	44°	45°	46°	47°
0	1° 50′ 54″	1° 52′ 46″	1° 54′ 43″	1° 56′ 46″	1° 58′ 56″
5	1 51 04	1 52 56	1 54 53	1 56 57	1 59 08
10	1 51 13	1 53 05	1 55 03	1 57 08	1 59 19
15	1 51 22	1 53 15	1 55 13	1 57 18	1 59 30
20	1 51 31	1 53 24	1 55 24	1 57 29	1 59 42
25	1 51 40	1 53 34	1 55 34	1 57 40	1 59 53
30	1 51 50	1 53 44	1 55 44	1 57 51	2 00 04
35	1 51 59	1 53 54	1 55 54	1 58 02	2 00 16
40	1 52 08	1 54 03	1 56 05	1 58 12	2 00 27
45	1 52 18	1 54 13	1 56 15	1 58 23	2 00 39
50	1 52 27	1 54 23	1 56 25	1 58 34	2 00 50
55	1 52 37	1 54 33	1 56 36	1 58 45	2 01 02

1877.

′	43°	44°	45°	46°	47°
0	1° 50′ 29″	1° 52′ 19″	1° 54′ 16″	1° 56′ 19″	1° 58′ 29″
5	1 50 38	1 52 29	1 54 26	1 56 30	1 58 40
10	1 50 47	1 52 39	1 54 36	1 56 40	1 58 51
15	1 50 56	1 52 48	1 54 46	1 56 51	1 59 02
20	1 51 05	1 52 58	1 54 56	1 57 01	1 59 13
25	1 51 14	1 53 07	1 55 07	1 57 12	1 59 25
30	1 51 23	1 53 17	1 55 17	1 57 23	1 59 36
35	1 51 33	1 53 27	1 55 27	1 57 34	1 59 47
40	1 51 42	1 53 37	1 55 37	1 57 45	1 59 59
45	1 51 51	1 53 46	1 55 48	1 57 56	2 00 10
50	1 52 01	1 53 56	1 55 58	1 58 07	2 00 22
55	1 52 10	1 54 06	1 56 09	1 58 18	2 00 34

Table of Azimuths of the North Star (Continued).

1878.

′	43°	44°	45°	46°	47°
0	1° 50′ 03″	1° 51′ 53″	1° 53′ 49″	1° 55′ 52″	1° 58′ 01″
5	1 50 12	1 52 02	1 53 59	1 56 02	1 58 12
10	1 50 21	1 52 12	1 54 09	1 56 13	1 58 23
15	1 50 30	1 52 21	1 54 19	1 56 23	1 58 34
20	1 50 39	1 52 31	1 54 29	1 56 34	1 58 45
25	1 50 48	1 52 41	1 54 39	1 56 44	1 58 56
30	1 50 57	1 52 50	1 54 49	1 56 55	1 59 08
35	1 51 06	1 53 00	1 55 00	1 57 06	1 59 19
40	1 51 15	1 53 10	1 55 10	1 57 17	1 59 31
45	1 51 25	1 53 19	1 55 20	1 57 28	1 59 42
50	1 51 34	1 53 29	1 55 31	1 57 39	1 59 54
55	1 51 44	1 53 39	1 55 41	1 57 50	2 00 05

1879.

′	43°	44°	45°	46°	47°
0	1° 49′ 37″	1° 51′ 27″	1° 53′ 22″	1° 55′ 24″	1° 57′ 33″
5	1 49 46	1 51 36	1 53 32	1 55 35	1 57 44
10	1 49 55	1 51 45	1 53 42	1 55 45	1 57 55
15	1 50 04	1 51 55	1 53 52	1 55 56	1 58 06
20	1 50 13	1 52 04	1 54 02	1 56 06	1 58 17
25	1 50 22	1 52 14	1 54 12	1 56 17	1 58 28
30	1 50 31	1 52 24	1 54 22	1 56 28	1 58 40
35	1 50 40	1 52 33	1 54 33	1 56 38	1 58 51
40	1 50 49	1 52 43	1 54 43	1 56 49	1 59 02
45	1 50 58	1 52 53	1 54 53	1 57 00	1 59 14
50	1 51 08	1 53 02	1 55 03	1 57 11	1 59 25
55	1 51 17	1 53 12	1 55 14	1 57 22	1 59 37

1880.

′	43°	44°	45°	46°	47°
0	1° 49′ 11″	1° 51′ 00″	1° 52′ 55″	1° 54′ 57″	1° 57′ 05″
5	1 49 19	1 51 09	1 53 05	1 55 07	1 57 16
10	1 49 28	1 51 19	1 53 15	1 55 18	1 57 27
15	1 49 37	1 51 28	1 53 25	1 55 28	1 57 38
20	1 49 46	1 51 38	1 53 35	1 55 39	1 57 49
25	1 49 55	1 51 47	1 53 45	1 55 49	1 58 00
30	1 50 05	1 51 57	1 53 55	1 56 00	1 58 11
35	1 50 14	1 52 06	1 54 05	1 56 11	1 58 23
40	1 50 23	1 52 16	1 54 15	1 56 21	1 58 34
45	1 50 32	1 52 26	1 54 26	1 56 32	1 58 45
50	1 50 41	1 52 36	1 54 36	1 56 43	1 58 57
55	1 50 51	1 52 46	1 54 46	1 56 54	1 59 08

1881.

′	43°	44°	45°	46°	47°
0	1° 48′ 45″	1° 50′ 34″	1° 52′ 28″	1° 54′ 29″	1° 56′ 37″
5	1 48 53	1 50 43	1 52 38	1 54 40	1 56 48
10	1 49 02	1 50 52	1 52 48	1 54 50	1 56 59
15	1 49 11	1 51 02	1 52 58	1 55 01	1 57 10
20	1 49 20	1 51 11	1 53 08	1 55 11	1 57 21
25	1 49 29	1 51 21	1 53 18	1 55 22	1 57 32
30	1 49 38	1 51 30	1 53 28	1 55 32	1 57 43
35	1 49 47	1 51 40	1 53 38	1 55 43	1 57 54
40	1 49 57	1 51 49	1 53 48	1 55 54	1 58 06
45	1 50 06	1 51 59	1 53 58	1 56 04	1 58 17
50	1 50 15	1 52 09	1 54 09	1 56 15	1 58 29
55	1 50 24	1 52 19	1 54 19	1 56 26	1 58 40

Table of Azimuths of the North Star (Continued).

1882.

′	43°	44°	45°	46°	47°
0	1° 48′ 19″	1° 50′ 07″	1° 52′ 02″	1° 54′ 02″	1° 56′ 09″
5	1 48 27	1 50 17	1 52 11	1 54 12	1 56 20
10	1 48 36	1 50 26	1 52 21	1 54 23	1 56 31
15	1 48 45	1 50 35	1 52 31	1 54 33	1 56 42
20	1 48 54	1 50 45	1 52 41	1 54 44	1 56 53
25	1 49 03	1 50 54	1 52 51	1 54 54	1 57 04
30	1 49 12	1 51 04	1 53 01	1 55 05	1 57 15
35	1 49 21	1 51 13	1 53 11	1 55 15	1 57 26
40	1 49 30	1 51 23	1 53 21	1 55 26	1 57 38
45	1 49 40	1 51 32	1 53 31	1 55 37	1 57 49
50	1 49 49	1 51 42	1 53 42	1 55 47	1 58 00
55	1 49 58	1 51 52	1 53 52	1 55 58	1 58 12

1883.

0	1° 47′ 53″	1° 49′ 41″	1° 51′ 35″	1° 53′ 35″	1° 55′ 41″
5	1 48 01	1 49 50	1 51 45	1 53 45	1 55 52
10	1 48 10	1 49 59	1 51 54	1 53 55	1 56 03
15	1 48 19	1 50 09	1 52 04	1 54 06	1 56 14
20	1 48 28	1 50 18	1 52 14	1 54 16	1 56 25
25	1 48 37	1 50 28	1 52 24	1 54 27	1 56 36
30	1 48 46	1 50 37	1 52 34	1 54 37	1 56 47
35	1 48 56	1 50 47	1 52 44	1 54 48	1 56 58
40	1 49 04	1 50 56	1 52 54	1 54 58	1 57 10
45	1 49 13	1 51 06	1 53 04	1 55 09	1 57 21
50	1 49 22	1 51 15	1 53 14	1 55 20	1 57 32
55	1 49 32	1 51 25	1 53 25	1 55 31	1 57 43

1884.

0	1° 47′ 27″	1° 49′ 14″	1° 51′ 08″	1° 53′ 07″	1° 55′ 13″
5	1 47 35	1 49 24	1 51 18	1 53 18	1 55 24
10	1 47 44	1 49 33	1 51 27	1 53 28	1 55 35
15	1 47 53	1 49 42	1 51 37	1 53 38	1 55 46
20	1 48 02	1 49 52	1 51 47	1 53 49	1 55 57
25	1 48 11	1 50 01	1 51 57	1 53 59	1 56 08
30	1 48 20	1 50 10	1 52 07	1 54 10	1 56 19
35	1 48 29	1 50 20	1 52 17	1 54 20	1 56 30
40	1 48 38	1 50 29	1 52 27	1 54 31	1 56 41
45	1 48 47	1 50 39	1 52 37	1 54 41	1 56 52
50	1 48 56	1 50 49	1 52 47	1 54 52	1 57 04
55	1 49 05	1 50 58	1 52 57	1 55 03	1 57 15

1885.

0	1° 47′ 01″	1° 48′ 48″	1° 50′ 41″	1° 52′ 40″	1° 54′ 46″
5	1 47 10	1 48 57	1 50 51	1 52 50	1 54 56
10	1 47 18	1 49 06	1 51 00	1 53 00	1 55 07
15	1 47 27	1 49 16	1 51 10	1 53 11	1 55 18
20	1 47 36	1 49 25	1 51 20	1 53 21	1 55 29
25	1 47 45	1 49 34	1 51 30	1 53 32	1 55 40
30	1 47 54	1 49 44	1 51 40	1 53 42	1 55 51
35	1 48 03	1 49 53	1 51 50	1 53 52	1 56 02
40	1 48 12	1 50 03	1 52 00	1 54 03	1 56 13
45	1 48 21	1 50 12	1 52 10	1 54 14	1 56 24
50	1 48 30	1 50 22	1 52 20	1 54 24	1 56 36
55	1 48 39	1 50 31	1 52 30	1 54 35	1 56 47

Table of Azimuths of the North Star (Continued).

1886.

′	43°	44°	45°	46°	47°
0	1° 46′ 35″	1° 48′ 22″	1° 50′ 14″	1° 52′ 13″	1° 54′ 18″
5	1 46 44	1 48 31	1 50 24	1 52 23	1 54 29
10	1 46 52	1 48 40	1 50 34	1 52 33	1 54 39
15	1 47 01	1 48 49	1 50 43	1 52 43	1 54 50
20	1 47 10	1 48 59	1 50 53	1 52 54	1 55 01
25	1 47 19	1 49 08	1 51 03	1 53 04	1 55 12
30	1 47 28	1 49 17	1 51 13	1 53 15	1 55 23
35	1 47 37	1 49 27	1 51 23	1 53 25	1 55 34
40	1 47 46	1 49 36	1 51 33	1 53 35	1 55 45
45	1 47 54	1 49 46	1 51 43	1 53 46	1 55 56
50	1 48 04	1 49 55	1 51 53	1 53 57	1 56 07
55	1 48 13	1 50 05	1 52 03	1 54 07	1 56 19

1887.

′	43°	44°	45°	46°	47°
0	1° 46′ 09″	1° 47′ 55″	1° 49′ 47″	1° 51′ 45″	1° 53′ 50″
5	1 46 18	1 48 04	1 49 57	1 51 56	1 54 01
10	1 46 26	1 48 14	1 50 07	1 52 06	1 54 11
15	1 46 35	1 48 23	1 50 16	1 52 16	1 54 22
20	1 46 44	1 48 32	1 50 26	1 52 26	1 54 33
25	1 46 53	1 48 41	1 50 36	1 52 37	1 54 44
30	1 47 01	1 48 51	1 50 46	1 52 47	1 54 55
35	1 47 10	1 49 00	1 50 55	1 52 57	1 55 06
40	1 47 19	1 49 09	1 51 05	1 53 08	1 55 17
45	1 47 28	1 49 19	1 51 15	1 53 18	1 55 28
50	1 47 37	1 49 28	1 51 25	1 53 29	1 55 39
55	1 47 46	1 49 38	1 51 35	1 53 39	1 55 50

1888.

′	43°	44°	45°	46°	47°
0	1° 45′ 43″	1° 47′ 29″	1° 49′ 21″	1° 51′ 18″	1° 53′ 22″
5	1 45 52	1 47 38	1 49 30	1 51 28	1 53 33
10	1 46 00	1 47 47	1 49 40	1 51 38	1 53 43
15	1 46 09	1 47 56	1 49 49	1 51 48	1 53 54
20	1 46 18	1 48 05	1 49 59	1 51 59	1 54 05
25	1 46 26	1 48 15	1 50 09	1 52 09	1 54 16
30	1 46 35	1 48 24	1 50 19	1 52 19	1 64 27
35	1 46 44	1 48 33	1 60 28	1 52 30	1 54 38
40	1 46 53	1 48 43	1 50 38	1 52 40	1 54 49
45	1 47 02	1 48 52	1 50 48	1 52 50	1 55 00
50	1 47 11	1 49 01	1 50 58	1 53 01	1 55 11
55	1 47 20	1 49 11	1 51 08	1 53 12	1 55 22

1889.

′	43°	44°	45°	46°	47°
0	1° 45′ 17″	1° 47′ 03″	1° 48′ 54″	1° 50′ 51″	1° 52′ 55″
5	1 45 26	1 47 12	1 49 03	1 51 01	1 53 05
10	1 45 35	1 47 21	1 49 13	1 51 11	1 53 16
15	1 45 43	1 47 30	1 49 23	1 51 21	1 53 27
20	1 45 52	1 47 39	1 49 32	1 51 32	1 53 37
25	1 46 01	1 47 48	1 49 42	1 51 42	1 53 48
30	1 46 09	1 47 58	1 49 52	1 51 52	1 53 59
35	1 46 18	1 48 07	1 50 01	1 52 02	1 54 10
40	1 46 27	1 48 16	1 50 11	1 52 13	1 54 21
45	1 46 36	1 48 26	1 50 21	1 52 23	1 54 32
50	1 46 45	1 48 35	1 50 31	1 52 34	1 54 43
55	1 46 54	1 48 44	1 50 41	1 52 44	1 54 54

Table of Azimuths of the North Star (Continued).

1890.

′	43°			44°			45°			46°			47°		
0	1°	44′	51″	1°	46′	36″	1°	48′	27″	1°	50′	24″	1°	52′	27″
5	1	45	00	1	46	45	1	48	37	1	50	34	1	52	37
10	1	45	08	1	46	54	1	48	46	1	50	44	1	52	48
15	1	45	17	1	47	03	1	48	56	1	50	54	1	52	58
20	1	45	26	1	47	13	1	49	05	1	51	04	1	53	09
25	1	45	34	1	47	22	1	49	15	1	51	14	1	53	20
30	1	45	43	1	47	31	1	49	25	1	51	24	1	53	31
35	1	45	52	1	47	40	1	49	34	1	51	35	1	53	42
40	1	46	01	1	47	49	2	49	44	1	51	45	1	53	52
45	1	46	10	1	47	59	1	49	54	1	51	55	1	54	03
50	1	46	18	1	48	08	1	50	04	1	52	06	1	54	14
55	1	46	27	1	48	18	1	50	14	1	52	16	1	54	25

1891.

′	43°			44°			45°			46°			47°		
0	1°	44′	25″	1°	46′	10″	1°	48′	00″	1°	49′	56″	1°	51′	59″
5	1	44	34	1	46	19	1	48	10	1	50	06	1	52	09
10	1	44	42	1	46	28	1	48	19	1	50	16	1	52	20
15	1	44	51	1	46	37	1	48	29	I	50	26	1	52	31
20	1	45	00	1	46	46	1	48	38	1	50	36	1	52	41
25	1	45	08	1	46	55	1	48	48	1	50	47	1	52	52
30	1	45	17	1	47	04	1	48	57	1	50	57	1	53	03
35	1	45	26	1	47	13	1	49	07	1	51	07	1	53	13
40	1	45	34	1	47	23	1	49	17	1	51	17	1	53	24
45	1	45	43	1	47	32	1	49	27	1	51	28	1	53	35
50	1	45	52	1	47	41	1	49	37	1	51	38	1	53	46
55	1	46	01	1	47	51	1	49	46	1	51	48	1	53	57

1892.

′	43°			44°			45°			46°			47°		
0	1°	44′	00″	1°	45′	44″	1°	47′	34″	1°	49′	29″	1°	51′	31″
5	1	44	08	1	45	53	1	47	43	1	49	39	1	51	42
10	1	44	17	1	46	02	1	47	52	1	49	49	1	51	52
15	1	44	25	1	46	11	1	48	02	1	49	59	1	52	03
20	1	44	34	1	46	20	1	48	11	1	50	09	1	52	13
25	1	44	42	1	46	29	1	48	21	1	50	19	1	52	24
30	1	44	51	1	46	38	1	48	31	1	50	29	1	52	35
35	1	45	00	1	46	47	1	48	40	1	50	40	1	52	46
40	1	45	08	1	46	56	1	48	50	1	50	50	1	52	56
45	1	45	17	1	47	06	1	49	00	1	51	00	1	53	07
50	1	45	26	1	47	15	1	49	10	1	51	10	1	53	18
55	1	45	35	1	47	24	1	49	19	1	51	21	1	53	29

1893.

′	43°			44°			45°			46°			47°		
0	1°	43′	34″	1°	45′	18″	1°	47′	07″	1°	49′	02″	1°	51′	04″
5	1	43	42	1	45	26	1	47	16	1	49	12	1	51	14
10	1	43	51	1	45	35	1	47	26	1	49	22	1	51	24
15	1	43	59	1	45	44	1	47	35	1	49	32	1	51	35
20	1	44	08	1	45	53	1	47	45	1	49	42	1	51	46
25	1	44	16	1	46	02	1	47	54	1	49	52	1	51	56
30	1	44	25	1	46	11	1	48	04	1	50	02	1	52	07
35	1	44	34	1	46	21	1	48	13	1	50	12	1	52	17
40	1	44	42	1	46	30	1	48	23	1	50	22	1	52	28
45	1	44	51	1	46	39	1	48	33	1	50	33	1	52	39
50	1	45	00	1	46	48	1	48	42	1	50	43	1	52	50
55	1	45	09	1	46	57	1	48	52	1	50	53	1	53	01

Table of Azimuths of the North Star (Continued).

1894.

′	43°	44°	45°	46°	47°
0	1° 43′ 08″	1° 44′ 51″	1° 46′ 40″	1° 48′ 35″	1° 50′ 36″
5	1 43 16	1 45 00	1 46 49	1 48 45	1 50 46
10	1 43 25	1 45 09	1 46 59	1 48 55	1 50 57
15	1 43 33	1 45 18	1 47 08	1 49 05	1 51 07
20	1 43 42	1 45 27	1 47 18	1 49 15	1 51 18
25	1 43 50	1 45 36	1 47 27	1 49 25	1 51 28
30	1 43 59	1 45 45	1 47 37	1 49 35	1 51 39
35	1 44 08	1 45 54	1 47 46	1 49 45	1 51 49
40	1 44 16	1 46 03	1 47 56	1 49 55	1 52 00
45	1 44 25	1 46 12	1 48 06	1 50 05	1 52 11
50	1 44 34	1 46 22	1 48 15	1 50 15	1 52 22
55	1 44 42	1 46 31	1 48 25	1 50 26	1 52 33

1895.

′	43°	44°	45°	46°	47°
0	1° 42′ 42″	1° 44′ 25″	1° 46′ 14″	1° 48′ 08″	1° 50′ 08″
5	1 42 51	1 44 34	1 46 23	1 48 18	1 50 19
10	1 42 59	1 44 43	1 46 32	1 48 27	1 50 29
15	1 43 07	1 44 52	1 46 42	1 48 37	1 50 39
20	1 43 16	1 45 01	1 46 51	1 48 47	1 50 50
25	1 43 24	1 45 10	1 47 00	1 48 57	1 51 00
30	1 43 33	1 45 19	1 47 10	1 49 07	1 51 11
35	1 43 42	1 45 28	1 47 20	1 49 17	1 51 22
40	1 43 50	1 45 37	1 47 29	1 49 27	1 51 32
45	1 43 59	1 45 46	1 47 39	1 49 38	1 51 43
50	1 44 08	1 45 55	1 47 48	1 49 48	1 51 54
55	1 44 16	1 46 04	1 47 58	1 49 58	1 52 05

1896.

′	43°	44°	45°	46°	47°
0	1° 42′ 16″	1° 43′ 59″	1° 45′ 47″	1° 47′ 41″	1° 49′ 41″
5	1 42 25	1 44 08	1 45 56	1 47 50	1 49 51
10	1 42 33	1 44 17	1 46 05	1 48 00	1 50 01
15	1 42 42	1 44 25	1 46 15	1 48 10	1 50 12
20	1 42 50	1 44 34	1 46 24	1 48 20	1 50 22
25	1 42 58	1 44 43	1 46 34	1 48 30	1 50 33
30	1 43 07	1 44 52	1 46 43	1 48 40	1 50 43
35	1 43 16	1 45 01	1 46 53	1 48 50	1 50 54
40	1 43 24	1 45 10	1 47 02	1 49 00	1 51 04
45	1 43 33	1 45 19	1 47 12	1 49 10	1 51 15
50	1 43 41	1 45 29	1 47 21	1 49 20	1 51 26
55	1 43 50	1 45 38	1 47 31	1 49 30	1 51 36

1897.

′	43°	44°	45°	46°	47°
0	1° 41′ 51″	1° 43′ 33″	1° 45′ 20″	1° 47′ 13″	1° 49′ 13″
5	1 41 59	1 43 41	1 45 29	1 47 23	1 49 23
10	1 42 07	1 43 50	1 45 39	1 47 33	1 49 34
15	1 42 16	1 43 59	1 45 48	1 47 43	1 49 44
20	1 42 24	1 44 08	1 45 57	1 47 53	1 49 54
25	1 42 32	1 44 17	1 46 07	1 48 02	1 50 05
30	1 42 41	1 44 26	1 46 16	1 48 12	1 50 15
35	1 42 49	1 44 35	1 46 26	1 48 22	1 50 26
40	1 42 58	1 44 44	1 46 35	1 48 32	1 50 36
45	1 43 07	1 44 53	1 46 45	1 48 42	1 50 47
50	1 43 15	1 45 02	1 46 54	1 48 53	1 50 57
55	1 43 24	1 45 11	1 47 04	1 49 03	1 51 08

Table of Azimuths of the North Star (Concluded).

1898.

′	43°	44°	45°	46°	47°
0	1° 41′ 25″	1° 43′ 06″	1° 44′ 54″	1° 46′ 46″	1° 48′ 45″
5	1 41 33	1 43 15	1 45 03	1 46 56	1 48 56
10	1 41 41	1 43 24	1 45 12	1 47 06	1 49 06
15	1 41 50	1 43 33	1 45 21	1 47 16	1 49 16
20	1 41 58	1 43 42	1 45 31	1 47 25	1 49 26
25	1 42 07	1 43 50	1 45 40	1 47 35	1 49 37
30	1 42 15	1 43 59	1 45 49	1 47 45	1 49 47
35	1 42 24	1 44 08	1 45 59	1 47 55	1 49 58
40	1 42 32	1 44 17	1 46 08	1 48 05	1 50 08
45	1 42 41	1 44 26	1 46 18	1 48 15	1 50 19
50	1 42 49	1 44 35	1 46 27	1 48 25	1 50 29
55	1 42 58	1 44 44	1 46 37	1 48 35	1 50 40

1899.

′	43°	44°	45°	46°	47°
0	1° 40′ 59″	1° 42′ 40″	1° 44′ 27″	1° 46′ 19″	1° 48′ 18″
5	1 41 07	1 42 49	1 44 36	1 46 29	1 48 28
10	1 41 16	1 42 58	1 44 45	1 46 39	1 48 38
15	1 41 24	1 43 06	1 44 54	1 46 48	1 48 48
20	1 41 32	1 43 15	1 45 04	1 46 58	1 48 59
25	1 41 41	1 43 24	1 45 13	1 47 08	1 49 09
30	1 41 49	1 43 33	1 45 22	1 47 18	1 49 19
35	1 41 57	1 43 42	1 45 32	1 47 28	1 49 30
40	1 42 06	1 43 51	1 45 41	1 47 38	1 49 40
45	1 42 15	1 44 00	1 45 51	1 47 47	1 49 51
50	1 42 23	1 44 09	1 46 00	1 47 57	1 50 01
55	1 42 23	1 44 18	1 46 10	1 48 08	1 50 12

XII.

Earliest accounts of observations made on the Variations of the Magnetic Needle in the United States, a part of which fall within the present limits of Maine.

In an article on the Variation and Dip of the Magnetic Needle in the United States, by Prof. Loomis, communicated to the Connecticut Academy of Arts and Sciences, and read April 28, 1840, the writer says:

"The earliest information on the subject I have been able to obtain is contained in the journal of Hudson's third voyage, in 1609, when he discovered Hudson River. The journal is contained in the third volume of Purchas' Pilgrims, from which the following extract was furnished me by Prof. Jared Sparks of Cambridge.

Hudson came to the Grand Bank of Newfoundland, and proceeded along the coast to the thirty-fifth degree of latitude. He does not mention his longitude, but was commonly in sight of land.

July 3, 1609.	Bank of Newfoundland,	lat. 44°,	varia.	17° W.
" 4, "	" "	uncertain,	"	15 "
" 5, "	" "	lat. 44° 10′,	"	13 "
" 10, "	Near Cape Sables,		"	17 "
" 25, "	Mouth of Penobscot River,	44° 01′,	"	10 "
" 26, "	At Sunset,	43° 56′,	"	10 "
" 28, "	Farther S. towards Cape Cod,		"	6 "
" 29, "	Sunset, near Cape Cod,		"	5½ "
Aug. 11, "	Near the coast,	39° 11′,	"	11¼ "
" 12, "	At noon,	38° 13′,	"	10 "
" 13, "	At noon,	37° 45′,	"	7½ "
" 15, "		37° 25′,	"	7 "
" 22, "		about 36°	"	4 "
Sept. 13, "	A few miles up Hudson's River,		"	13 "
Oct. 4, "	At noon, on the coast,	39° 30′,	"	6 "

On the 2d of September, when he was near the Jersey shore, a little below the mouth of Hudson's River, he says: 'This night I found the land to haul the compass eight degrees. Far to the northward of us we saw high hills. For the day before we found not above two degrees variation.'

Most of the preceding observations were of course made on shipboard, and perhaps all, with the exception of that of September 13th. The iron of the vessel would necessarily influence the needle to an amount which we have, perhaps, no means of estimating.

The observation of Sept. 13th, it is presumed, was made on shore, and may be compared with subsequent observations at New York City. The variation here in 1686, according to Mr. Welles, was 8° 45′, showing a decrease of 4° 15′ in seventy-seven years, or about three and a third minutes per year. This accords very well with subsequent observations at the same place."

[See Am Jour. of Science, Vol. 39, p. 42.]

In Williamson's History of Maine, Vol. I, page 11, the author refers, in a note, to a "table of variation of the compass at Boston, Portland and Penobscot, from A D. 1672 to 1800, by Professor John Winthrop." This table may be found in Silliman's Journal of Science, Vol. XVI, page 63, as follows:

TABLE exhibiting the variation of the Compass in Boston, and parts adjacent, from the earliest accounts of it to the end of the 18th century, agreeable to actual observations, by John Winthrop, Esq., *Hollis Professor of Mathematics, at Harvard College, in Cambridge.*

Years.	Variations at Boston	Difference.	Variations at Falmouth	Difference.	Variations at Penobscot *	Difference.	Mean annual diff between each.
1672	11° .15′	0° .00′	12° .00′	0° .00′	12° . 8′	0° .00′	00′
78	11 .00	.15	11 .45	.15	11 .53	.15	15
89	10 .30	.30	11 .15	.30	11 .23	.30	30
1700	10 .00	.30	10 .45	.30	10 .53	.30	30
5	9 .45	.15	10 .31	.14	10 .39	.14	14 1-3
10	9 .32	.13	10 .12	.19	10 .25	.14	15 1-3
15	9 .18	.14	10 . 3	. 9	10 .11	.14	12 1-3
20	9 . 5	.13	9 .50	.13	9 .58	.13	13
1725	8 .57	. 8	9 .36	.14	9 .41	.14	12
30	8 .37	.20	9 .22	.14	9 .30	.14	16
35	8 .23	.14	9 . 8	.14	9 .16	.14	14
1742	8 .00	.23	8 .45	.23	8 .53	.23	23
45	7 .56	. 4	8 .41	. 4	8 .49	. 4	4
1750	7 .42	.14	8 .27	.14	8 .32	.17	15
57	7 .20	.22	8 . 5	.22	8 .13	.19	21
61	7 . 7	.13	7 .52	.13	8 .00	.13	13
1763	7 .00	. 7	7 .45	. 7	7 .53	. 7	7
70	6 .45	.15	7 .31	.14	7 .39	.14	14 1-3
75	6 .32	.13	7 .17	.14	7 .25	.14	13 2-3
1780	6 .18	.14	7 . 3	.14	7 .11	.14	14
85	6 . 4	.14	6 .49	.14	6 .57	.14	14
1790	5 .50	.14	6 .35	.14	6 .43	.14	14
95	5 .35	.15	6 .21	.14	6 .29	.14	14 1-3
1800	5 .22	.13	6 . 7	.14	6 .15	.14	15 1-3

128 yrs. diff. 5° .53′ — 5° .53′ — 5° .53′

Mean annual difference, 0° 2′. 45″. 28‴. 7⁗. 3‴″. — the same. — the same.
or 0° 2′ 7578125

From 1672 to 1700	the mean annual difference is		2′.67871428,	which in 11½ years amounts to		30.48	Mean of all the periods, 31′ .43″.
1700 to 1725	do	do	2 52	do	do	28.59	
1725 to 1750	do	do	3.	do	do	34.30	
1750 to 1775	do	do	2,8	do	do	32.12	
1775 to 1800	do	do	2.8	do	do	32.12	

* Now Castine.—Ed.

Since the foregoing table has often been referred to by men of science, as well as by historians, and is, on the whole, rather a literary curiosity, I have thought proper to insert it, although I am aware that its authenticity is now considered doubtful.

In the 34th Volume of Silliman's Journal (page 298), Prof. Loomis treats on the facts connected with the table as follows:

"This table professes to give the variation of the needle at intervals generally of five years, from 1673 to 1800, for Boston, Falmouth and Penobscot.

I have rejected the table, because I am satisfied it is a *calculated* table. This assertion will sound strange to some, for I have more than once been referred to it by men of science, as a repository of exceedingly valuable observations, and they seem never to have suspected that the observations were not genuine. But there is no room for the shadow of a doubt, that those numbers were mostly *calculated.* The evidence is as follows: The table is a very old one, being found in the Almanac for 1771, by Nathaniel Ames. A copy of this Almanac is now (1838) in possession of Mr. William Lyon of New Haven. There is also in the possession of Mr. Adam Winthrop of Louisiana, grandson of Prof. Winthrop of Harvard University, a small printed sheet, in the form of a handbill, containing the same table. It is without date, but bears marks of age, and was found among the papers of Prof. Winthrop. It is my opinion that this is the original from which the table in the Almanac was copied, and as it is a document to which circumstances have given considerable consequence, I have here transcribed it verbatim.

A table exhibiting the variation of the compass in Boston and parts adjacent, from the earliest accounts of it to the end of the 18th century, agreeable to the actual observations distinguished by Obs., by John Winthrop, Esq., Hollis Professor of Mathematics at Harvard College, in Cambridge, in New England:

Years.	Variation at Boston			Falmouth.		Penobscot.	
1673	11°	15′		12°	00	12°	08′
1678	11	0		11	45	11	53
1689	10	30		11	15	11	23
1700	10	0	Obs.	10	45	10	53
1705	9	46		10	31	10	39
1710	9	32		10	17	10	25
1715	9	18		10	3	10	11
1720	9	5		9	50	9	58
1725	8	51		9	36	9	44
1730	8	37		9	22	9	30
1735	8	23		9	8	9	16

Variation of the Compass in Boston, &c., (Continued).

Years.	Variation at Boston	Falmouth.	Penobscot.
1742..................	8° 0′ Obs.	8° 45′	8° 53′
1745..................	7 56	8 41	8 49
1750..................	7 42	8 27	8 35
1757..................	7 20 Obs.	8 5	8 13
1761..................	7 7	7 52	8 0 Obs.
1763..................	7 0 Obs.	7 45 Obs.	7 53
1770..................	6 46	7 31	7 39
1775..................	6 32	7 17*	7 25
1780..................	6 18	7 3	7 11
1785	6 4	6 49	6 57
1790..................	5 50	6 35	6 43
1795..................	5 36	6 21	6 29
1800.	5 22	6 7	6 15

* See Coast Survey Report for 1859, p. 302, showing an actual obs. = 8° 30′ W.

The table which is given in Ames' Almanac for 1771, is exactly like the preceding, with six exceptions, viz: the variations for Boston are given 9° 45′ for 9° 46′; 8° 57′ for 8° 51′; 6° 45′ for 6° 46′; and 5° 35′ for 5° 36′. In the column for Falmouth is given 10° 12′ for 10° 17′; and in the column for Penobscot 8° 32′ for 8° 35′. I have no doubt that these were typographical errors in the Almanac, and that the sheet in the possession of Mr. Adam Winthrop, which was doubtless printed under the eye of Prof. Winthrop, is the correct copy. It is evident that the preceding table was entirely *computed*, with the exception of those numbers marked Obs. For (1) the table was published before 1771. One-quarter of the numbers were then certainly computed. (2) The variations for Falmouth are constantly 45′ greater than those for Boston, and those for Penobscot 8′ greater than those for Falmouth.

To one who has ever made magnetic observations, this will amount to an absolute demonstration that those numbers were never observed. (3) The observations from 1700 to 1800, with the exceptions of those marked Obs., all occur at intervals of five years, and the change of declination for this period is constantly 14′ or 15′.

The observations of 1742 and 1763, showing a change of one degree in twenty-one years, or somewhat more than 14′ in five years, doubtless furnished the data for the table. (4) Penobscot and Falmouth, during the first years contained in the table, were small settlements. Penobscot [now Castine] was little more than a military post, and Falmouth was devastated by the Indians in

1692,* and the town entirely broken up. The inhabitants did not return until about 1708.

Who then was this indefatigable observer, that, with clock-like regularity, at the expiration of every five years, returns to measure the magnetic variation; and how does his zeal reprove the sluggishness of the scientific institutions in our country, at many of which the variation of the needle has not been even once observed? (5) The table does not purport to be *a table of observations*, but to be '*agreeable* to the actual observations distinguished by obs.' The numbers marked obs. were then observed, and the others were computed from them, so that six observations were the foundation of the whole table. The matter appears to me so plain, that it seems useless to argue the question further. The table has copied the errors of Ames' Almanac, and thus, by introducing a little irregularity into the numbers, has given them more of the air of actual observations.

The table is still further disguised by omitting the *obs.* which mark certain numbers in the original table. If now I have succeeded in showing that this 'interesting document,' as Mr. DeWitt terms it, contains but six actual observations, I shall consider that I have effected no small object; for it certainly is a fact not very creditable to American science, that a table which Prof. Winthrop, nearly three-quarters of a century ago, computed for his own amusement, should now be referred to as composed of genuine observations. I have taken the more pains to expose this imposition, (for imposition I think it may be called, although a perfectly honest one on the part of Prof. Winthrop), because it is necessary to be particularly on our guard against confounding *calculations* with observations, and because in the progress of my investigations I have met with other tables similar to the preceding one of Prof. Winthrop."

The materials for the following table of declination, as observed in Maine, have been collected from various sources, and may, as a whole, be regarded reliable; especially those which have been taken from the Coast Survey. It is probable, however, that some few of the observations inserted in the table were erroneous, and should be so regarded. That the reader may be enabled to judge of the weight and importance to be attached to these observations, the *authority* for each is inserted in the table.

*Williamson says 1690.

Tabular View of the Declination of the Magnetic Needle as observed at various places in Maine from 1609 to 1865.

Places.	Lat. N.	Lon. W.	Years.	Declination W.	Authority.
Mouth of Penobscot River	44° 01′	-	1609,	10° 00′	Capt. H. Hudson.
Penobscot (Castine)	44 22.5	68° 45′	1761,	8 00	Prof. J. Winthrop.
Pownalborough	43 51	70 10	"	8 00	Same.
Falmouth	43 39	70 19	1763,	7 45	Same.
Kittery	43 06	70 35	1771,	7 46	Helland.
Portland	43 41	70 20.5	1775,	8 30	J. F. De Barre
Piscataqua Harbor	-	-	1781,	6 00	Belknap Hist. N. H.
Mouth St Croix River	45 05	67 12	1797,	12 19	Chart. Pub. Doc.
Hampden	44 40	68 55	1805,	11 15	Jed. Herrick.
Source of St. Croix	45 55*	67 55	1817,	14 00	John Johnson, Am. Sur.
Madawaska	47 12	68 10	1818,	16 45	Same
Temiscouata Lake	47 38	69 00	"	16 31	Same.
N. E. Angle of Maine	48 01	67 55	"	17 45	Same.
Forks of Penobscot River	45 30	68 30	1825,	14 45	Jed Herrick.
Waterville	44 28	69 32	1835,	12 68	3d Geological Report.
Hampden	44 40	68 55	1837,	13 04	Jed. Herrick
N. E. Angle of Maine	48 00	67 37	1838,	19 12	State Commissioners.
Greenville	45 24	69 35	"	11 00	3d Geological Report
Farmington	44 42	70 04	"	11 20	Same.
Umbagog Lake	44 42	70 53	"	13 00	Same.
Dixfield	44 32	70 14	"	12 00	Same.
Rumford	44 30	70 26	"	11 00	Same.
Raymond	43 57	70 24	"	9 45	Same.
West Thomaston	43 56	69 05	"	12 00	Same.
Belfast	44 18	68 54	"	13 00	Same.
Fort Kent	47 15	68 35.6	1843,	17 30	Maine and Massachusetts Survey.
Portland	43 41	70 20.5	1845,	11 28.3	Smithson Cont. to Kno.
Greenwood	44 23.6	70 44	"	12 08	Same.
Bethel	44 27.8	70 51	"	11 50	Same.
York	43 13.4	70 41.2	1847,	10 09.8	U. S. Coast Survey.
Allagash River	46 40	69 25	"	16 38	Pub Survey, Me. and Mass.

Falmouth	43 45 5	70 18.9	1849,	11 46.4	U. S. Coast Survey.
Richmond Island	43 32.6	70 14.1	1850,	12 18.1	Same.
Mouth Saco River	43 26.8	70 20.2	"	11 17.5	Same.
Kittery Point	43 04.8	70 42.7	"	10 30.2	Same.
Canada Boundary	46 25	70 03	"	15 45	Pub Survey, Me. and Mass.
Cape Neddick	43 11.6	70 36.1	1851,	11 09	U. S. Coast Survey.
Portland (Bowdoin Hill)	43 38.8	70 16.2	"	11 41.1	Same.
Kennebunkport	43 21.4	70 27.8	"	11 23.6	Same.
Phipsburg (Cape Small)	43 46.7	69 50.4	"	12 05.5	Same.
Denmark	44 01 6	70 49	"	14 32.1	Same.
Wales (Mt. Sebattis)	44 09.1	70 04.5	1853,	12 53.5	Same.
Camden Village	44 12	69 05	1854,	13 57.1	Same.
Ragged Mountain	44 12.7	69 08.7	"	14 16.8	Same.
Dixmont (Mt. Harris)	44 39.9	69 08.5	1855,	14 34.6	Same.
Fremont Plantation	46 39	67 50	1856,	18 00	State Survey.
Falmouth (Mt. Ind.)	43 45.5	70 18.9	1857,	12 27	U. S. Coast Survey.
Phipsburg (Cape Small)	43 46.7	69 50.4	"	12 36	Same.
Portland (Bowdoin Hill)	43 38.8	70 16.2	"	12 23	Same.
Richmond Island	43 32.4	70 14	"	12 54	Same.
Mouth Saco River	43 26.8	70 20.2	"	11 55	Same.
Seguin Light	43 42.4	69 45.2	"	12 41	Same.
Kennebunkport	43 21.4	70 27.8	"	12 06	Same.
York (Mt. Agamenticus)	43 13.4	70 41.2	"	11 02	Same.
Cape Neddick	43 11.6	70 36.1	"	11 51	Same.
Kittery Point	43 04.8	70 42.7	"	11 06	Same.
St. John River, N. E. Angle of Me. by Treaty of Wash	47 04	67 47.5	1859,	19 30	State Survey.
Kittery Point	43 04.8	70 42.7	"	11 15	Coast Survey.
Eastport	44 54	66 56	1860,	17 57.1	Same.
"	"	"	1861,	17 59.2	Same.
"	"	"	1862,	18 00.6	Same.
"	"	"	1863,	18 02.3	Same.
"	"	"	1864,	18 03.7	Same.
"	"	"	1865,	18 06.1	Same.

* According to Maj. Graham, in 1840, Lat. 45° 56′ 38′ and Lon. 67° 47′.

An inspection of the foregoing table will show that, in several instances, observations are recorded for the same place in different years. These observations furnish the data by which we may calculate, with some degree of accuracy, perhaps, the *annual change* of declination at the places where these repeated observations were made.

For example, we find the declination at Falmouth, in 1763, to have been by observation, 7° 45′, and according to the "old table" calculated by Prof. Winthrop, the declination in 1800 had slackened to 6° 07′. Again, in 1849, the declination at Falmouth had increased to 11° 46′.4, and assuming the minimum to have occurred in 1800 (which was doubtless within a very few years of the time), we have a change in 49 years of 5° 39′.4, or 6′.9 annually. And again, we have the declination at the same place in 1857, 12° 27′, being a change in eight years from 1849 of 40′.6, or 5′.07 annually.

In the reëstablishment of old lines, the annual changes in declination are of far greater importance to the surveyor than its absolute amount. And by having the results of different observations at the same place, tables of reference may be constructed as follows :

Places.	Date.	Declination.	Date	Declination.	Total change.	Mean annual change.
Falmouth	1849,	11° 46′.4	1857,	12° 27′	0° 40′.6	5′ .07
Kittery Point..............	1850,	10 30.2	"	11 06	0 35.8	5 .1
Portland	1845,	11 28.3	1851,	11 41.1	0 12.7	2 .1
Mouth of Saco River........	1850,	11 17.5	1857,	11 55	0 37.5	5 .3
Bowdoin Hill, Portland......	1851,	11 41.1	"	12 23	0 41.9	6 .9
N. E Angle of Maine.......	1818,	17 45	1838,	19 12	1 27.0	4 .35
Same	1838,	19 12	1840,	19 29.6	0 17.6	8 .8
Phipsburg..................	1851,	12 05	1857,	12 36	0 31	5 .1
Houlton....................	1818,	–	1840,	–	–	5 .25
Richmond Island	1850,	12 18	1857,	12 54	0 36	5 .1
Linneus....................	1830,	–	1864,	–	–	5 .29
Umbagog Lake.............	1858,	–	1866,	–	0 32	4 .
Kennebunkport.............	1851,	11 23.6	1857'	12 06	0 42.4	7 .
Andover, west line	1797,	–	1867,	–	4 30	
York	1847,	10 09.8	1857,	11 02	0 52.2	5 .2
Cape Neddick..............	1851,	11 09	"	11 51	0 42	7
Seguin Light................	–	–	"	–	–	4 .8
Penobscot Forks............	1825,	14 45	1840,	15 25		
Farmington................	1838,	11 20	"	11 30		
Hampden.	1837,	13 04	"	13 22		
Dixfield....................	1838,	12 00	"	12 10		
Rumford	"	11 00	"	11 10		
West Thomaston	"	12 00	"	12 11		
Belfast............	"	13 00	"	13 11		
Waterville..................	1835,	12 08	"	12 36		

Table of Variations of the Needle at Portland, as taken from Gillespie's Land Surveying, p. 414, *and may be found in the U. S. Coast Survey Report*, 1859.

Years.	Variation.	Years.	Variation.
1770	8° 6′	1830	10° 36′
1780	8 18	1840	11 12
1790	8 30	1850	11 48
1800	8 54	1860	12 18
1810	9 24	1870	12 42
1820	10 00		

To Re-Establish Old Lines.

In the renewal of old lines, it should be remembered that *bearings must yield to monuments*, whenever these are to be found.

It is a rule in practical surveying which prevailed in this country before the Revolution, and has since been, and still is, considered obligatory, that when there is found in the location of the premises described in a deed, or any other instrument, a disagreement in the course of a given line, and the bearing of a natural object or monument called for as its termination, the given course must be made to yield to the given object, and the line closed at the object, in a direction corresponding, as nearly as practicable, to the course prescribed, upon the principle that the natural object furnishes evidence of the true intention of the parties, which may be relied upon with more safety than the course, errors in which constantly occur, from the imperfection of the instruments used, or the want of knowledge of those in whose hands they may have been placed.

To succeed in retracing old lines which were originally run and described by magnetic courses, due allowance must be made for the change in the declination of the needle since the date of the original survey.

That date being known, and also the annual change, the *amount* of change to be allowed for may be obtained by simply multiplying the annual change by the time that has elapsed between the original survey and the renewal of it. When the amount and direction of the change have been accurately ascertained, the bearings may be corrected thus:

When the north end of the needle has been moving westerly, as it has in Maine for the last sixty years or more, the *present bearings* will be the *sums* of the *change* and the *old bearings* which were north-easterly or south-westerly; and the *differences* of the change and the old bearings which were north-westerly or south-easterly.

If the change were *easterly* instead of westerly, the preceding rules must be reversed, subtracting where it is directed to add, and adding where it is directed to subtract. The lines may then be run with the bearings thus corrected.

If the compass has a Vernier, it can be adjusted for the change once for all, and then the courses can be run as given in the deed, the correction being made by the instrument.

CONCLUSION.—In closing this report, it may not be improper to call attention to the fact that "the various litigations and disputes about boundaries, which our courts of justice are constantly called upon to decide, are most of them either directly or indirectly the result of the present loose and imperfect method of conducting land surveys. This evil is not, however, it must be acknowledged, confined exclusively to the surveyors. Many of our lawyers, who are entrusted with the drafting of instruments of conveyance, are often deficient in the knowledge requisite to render their descriptions of land correct and to place them beyond the possibility of a misconstruction.

As landed property is constantly increasing in value, greater accuracy will be required in the execution of the surveys, and we cannot, in consequence, too soon commence upon an improved system, for the longer the change is delayed, the more firmly shall we be established in error, and a reformation, if effected, will bring with it but a portion of its benefits."

Since the establishment of our State Land Office in 1824, these evils have been in a great measure remedied so far as regards the surveys of our public lands, by adopting the method of making all the lines of the surveys conform to the *true* cardinal points. But prior to that time, the surveys in the earlier settled portions of the State were, in most cases, conducted very loosely, and with but little regard to the variations of the needle.

As the only complete remedy for the disputes, and the uncertainty of bounds, resulting from the continued change in the variation, Prof. Gillespie, in his Treatise on Land Surveying, suggests the following:

"Let a Meridian, i. e. a true North and South line, be established in every town or county, by the authority of the State; monuments, such as stones set deep in the ground, being placed at each end of it.

Let every surveyor be obliged by law to test his compass by this line, at least once in each year. This he could do as easily as in taking the Bearing of a fence, by setting his instrument on one monument, and sighting to a staff held on the other.

Let the variation thus ascertained be inserted in the notes of the survey and recorded in the deed. Another surveyor, years or centuries afterwards, could test his compass by taking the Bearing of the same monuments, and the difference between this and the former Bearing would be the change of variation. He could thus determine with entire certainty the proper allowance to be made in order to retrace the original line, no matter how much, or how irregularly, the variation may have changed, or how badly adjusted was the compass of the original survey. Any permanent line employed in the same manner as the meridian line, would answer the same purpose, though less conveniently, and every surveyor should have such a line at least, for his own use." Prof. Smyth recommends the same remedy in his work on Surveying, (page 171). Edwin F. Johnson, also, as early as 1831, treats on the same subject in his "Remarks upon the present mode of conducting Land Surveys in the United States," which were published at the time in Silliman's Journal. With the following quotation from that able article I close the subject:

"It has hitherto been too much the case that our Legislators instead of proposing and adopting those measures by which many of the disputes and difficulties which affect and vex society, might be avoided, have contented themselves with merely prescribing the means of equitably settling such disputes when they do occur. Certainly the first object is of equal importance with the second, and in most cases the advantages on the side of the prevention of an evil are decidedly superior to those of the best remedy which can be proposed."

APPENDIX.

As the following letter, from an able pen, throws much additional light on the variations of the magnetic needle along the eastern boundary of our State, and at the same time defines the meaning of certain terms used in deeds, and by land surveyors, (concerning which there has recently been a long and expensive controversy in the courts of a neighboring State), it is deemed proper that so important a document should, in this connection, be preserved entire, and is accordingly inserted:

"MIDDLETOWN, Conn., April 25, 1866.

NOAH BARKER, ESQ.,—*Dear Sir*,—You desire my opinion of the meaning of the terms *due north*, *due west*, &c., as used by land surveyors. *Due north* means the *true north* as distinguished from the *magnetic north*, or north as pointed out by the magnetic needle. The latter is variable. The former is a line formed at the earth's surface by a plane passing through its axis. A *due* north or south line conforms in direction to the true or astronomical meridian, and a *due* east or west line is a line at right angles thereto, which, if properly prolonged, will describe a parallel of latitude.

In the fifth article of the Treaty of Ghent the eastern boundary of your State is described as a due north line from the source of the St. Croix River to the highlands, &c. I was employed as an assistant in the first surveys of that boundary, and I do not remember to have heard a doubt expressed by commissioners, agents or surveyors, on either side, as to the meaning of the words *due north* being as I have stated.

The magnetic variation at the point of starting on the line, at the St. Croix monument, was, in 1817, fourteen degrees, nearly, west, and at the northern extremity of the line, in lat. 48° 1′ N., 147 miles distant, it was, in 1818, seventeen and three-fourth degrees west, showing an increase in the variation of nearly one and a half minutes per mile on the average, an increase which was not uniform, nor was it constant in the same place for any length of time. The extreme diurnal variation at any one point reached the very unusual amount of one-third of a degree on the Mempticook branch of the Ristigouche as appears by the record.

To have attempted to trace a north line as pointed out by the magnetic needle, would have been a vain effort. If practicable, it would have been a curved or irregular and not a straight line, departing more and more from the true meridian drawn through the point of starting, towards the west, and meeting the St. John River probably thirty miles above where the due north line meets the same river. To trace such a line would have been as impossible as to trace the outline of a moveable shadow, and hence the demarcation, if attempted, would have been in nowise fit or suited to constitute a proper or reliable boundary to property. Even if by any process so remarkable as that of the daguerrotype, monuments could be set upon it at intervals *simultaneously* throughout its whole extent, before the rising of another sun the line would be found to occupy another position, and the monuments would be simply monuments of folly.

In 1838 your State Commissioners found the variation of the needle at the northern extremity of the due north line 19° 12′ west, or one degree and twenty-seven minutes more than it was in 1818, and you found, it appears, a still greater increase or difference in 1856, at a point a little north of Mars Hill where the variation then was eighteen degrees west, and further north you found it greater still.

In the case of the eastern boundary of Maine had there been any plausible pretext for construing *due north* to mean *magnetic north*, it certainly would not have escaped the notice of the ingenious men who represented the British interest in the settlement of the boundary, and who claimed that the St. John was not an Atlantic river in the language of the Treaty, because forsooth, it emptied into the Bay of Fundy, which in their view was not a part of the Atlantic ocean!

In all my experience, which has been quite extensive for the last half century, embracing surveys in almost every State from Maine to Minnesota, I do not remember any other construction to have been put on the term *due north* than the one I have given above, and from your quotation from the description of Sargent's Purchase in New Hampshire, I am obliged to conclude that the words *due* *north*, as used in that description, are not an exception, and that the words *due west* and *due east*, in the same description, mean lines parallel to the equator or lines of latitude.

EDWIN F. JOHNSON,
Civil Engineer and Surveyor."

Although personally unacquainted with Mr. Johnson, yet from his high reputation as a scientific and practical civil engineer, I thought proper to address him by letter, to which he responded as above.

Since Mr. J. is so widely known, it is perhaps needless for me to say that he has been connected, either as chief or consulting engineer, with the location of most of the important railroads in this country, and having surveyed the chain of the great American lakes with a view to improve their navigation, by the construction of ship canals, he is now in charge of the survey of the route of the Northern Pacific Railroad, which is to connect the navigation of these lakes with that of Puget Sound.

The relation of Sidereal Time to Mean Solar Time.

The sidereal day is the interval of time which elapses between two successive culminations of a star. The length of this interval appears to be invariable, whatever star is observed, or in whatever season or year the observation is made. On this account, the sidereal day is regarded as the true period of the earth's rotation on its axis.

The mean solar day is the mean interval between two successive culminations of the sun. These intervals vary throughout the year. As the sun, by the annual motion, is advancing eastward continually among the stars, the solar day must always be longer than the sidereal day. For, if the sun and a star were on the meridian of a place together, then, while that place passes around eastward till the meridian meets the star again, the sun has advanced eastward nearly a degree, and the place must revolve nearly a degree more than one revolution before its meridian will reach the sun. This will require nearly four minutes of time; for, in the diurnal motion, 15° correspond to one hour and therefore 1° to one-fifteenth of an hour—that is, four minutes.

As the sun, in its apparent annual motion, describes 360° in 365.24 days, it will, in one day, on an average, pass over 360° ÷ 365.24 = 59′ 8.35″, or nearly 1°, as before stated. But, by the diurnal motion, a given place on the earth in one solar day describes 360° plus the above arc. Therefore, as 360° 59′ 8.35″ : 59′ 8 35″ : : 24h. : 3m. 55.9s. of solar time. This is the excess of the mean solar day above a sidereal day. And the ratio of one sidereal hour, minute or second is to one solar hour, minute or second as 360° : 360° 59′ 8 35″,—that is, as 1 : 1.0027379. Therefore, to reduce a given period of time from the mean solar to the sidereal reckoning, multiply by 1.0027379; and to reduce sidereal time to mean solar time, divide by the same number.*

TABLE I.

For converting Intervals of Sidereal into corresponding Intervals of Mean Solar Time.

Hours.			Minutes.						Seconds.					
h.	m.	s.	m.	s.	m.	s.	m.	s.	s.	s.	s.	s.	s.	s.
1	0	9.830	1	0.164	21	3.440	41	6.717	1	0.003	21	0.057	41	0.112
2	0	19.659	2	0.328	22	3.604	42	6.881	2	0.005	22	0.060	42	0.115
3	0	29 489	3	0.491	23	3.768	43	7.044	3	0.008	23	0.063	43	0.118
4	0	39.318	4	0.655	24	3.932	44	7.208	4	0.011	24	0.066	44	0.120
5	0	49.148	5	0.819	25	4.096	45	7.372	5	0.014	25	0.068	45	0.123
6	0	58.977	6	0.983	26	4.259	46	7.536	6	0.016	26	0.071	46	0.126
7	1	8.807	7	1.147	27	4.423	47	7.700	7	0.019	27	0.074	47	0.128
8	1	18.636	8	1.311	28	4.587	48	7.864	8	0.022	28	0.076	48	0.131
9	1	28.466	9	1.474	29	4.751	49	8.027	9	0.025	29	0.079	49	0.134
10	1	38.296	10	1.638	30	4.915	50	8.191	10	0.027	30	0.082	50	0.137
11	1	48.125	11	1.802	31	5.079	51	8.355	11	0.030	31	0.085	51	0.140
12	1	57.955	12	1.966	32	5.242	52	8.519	12	0.033	32	0.087	52	0.142
13	2	7.784	13	2.130	33	5.406	53	8.683	13	0.036	33	0.090	53	0.145
14	2	17.614	14	2.294	34	5.570	54	8.847	14	0.038	34	0.093	54	0.148
15	2	27.443	15	2.457	35	5.734	55	9.010	15	0.041	35	0.096	55	0.150
16	2	37.273	16	2.621	36	5.898	56	9.174	16	0.044	36	0.098	56	0.153
17	2	47.103	17	2.785	37	6.062	57	9.338	17	0.047	37	0.101	57	0.156
18	2	56.932	18	2.949	38	6.225	58	9.502	18	0.049	38	0.104	58	0.159
19	3	6.762	19	3.113	39	6.389	59	9.666	19	0.052	39	0.106	59	0.161
20	3	16.591	20	3.277	40	6.553	60	9.830	20	0.055	40	0.109	60	0.164
21	3	26.421												
22	3	36.250												
23	3	46.080												
24	3	55.909												

The quantities taken from this Table must be subtracted from a sidereal interval, to obtain the corresponding interval in mean solar time.

* Olmsted's Astronomy, page 48.

TABLE II.

For converting Intervals of Mean Solar into corresponding Intervals of Sidereal Time.

Hours.			Minutes.						Seconds.					
h.	m.	s.	m.	s.	m.	s.	m.	s.	s.	s.	s.	s.	s	s.
1	0	9.856	1	0.164	21	3.450	41	6.735	1	0.003	21	0.057	41	0.112
2	0	19.713	2	0.329	22	3.614	42	6.900	2	0.005	22	0.060	42	0.115
3	0	29.569	3	0.493	23	3.778	43	7.064	3	0.008	23	0.063	43	0.118
4	0	39.426	4	0.657	24	3.943	44	7.228	4	0.011	24	0.066	44	0.120
5	0	49 282	5	0.821	25	4.107	45	7.392	5	0.014	25	0.068	45	0.123
6	0	59.139	6	0.986	26	4.271	46	7.557	6	0.016	26	0.071	46	0.126
7	1	8.995	7	7.150	27	4.436	47	7.721	7	0.019	27	0.074	47	0.128
8	1	18.852	8	1.314	28	4.600	48	7.885	8	0.022	28	0.076	48	0.131
9	1	28.708	9	1.478	29	4.764	49	8.050	9	0.025	29	0.079	49	0.134
10	1	38.565	10	1.643	30	4.928	50	8.214	10	0.027	30	0.082	50	0.137
11	1	48.421	11	1.807	31	5.092	51	8.378	11	0 030	31	0.085	51	0.140
12	1	58.278	12	1.971	32	5.257	52	8.542	12	0.033	32	0.087	52	0.142
13	2	8.134	13	2.136	33	5.421	53	8.707	13	0.036	33	0.090	53	0.145
14	2	17.991	14	2.300	34	5.585	54	8.871	14	0.038	34	0.093	54	0.148
15	2	27.847	15	2.464	35	5 750	55	9.035	15	0.041	35	0.096	55	0.150
16	2	37.704	16	2.628	36	5.914	56	9.199	16	0.044	36	0.098	56	0.153
17	2	47.560	17	2.793	37	6.078	57	9.364	17	0.047	37	0.101	57	0.156
18	2	57.416	18	2.957	38	6.242	58	9.528	18	0.049	38	0.104	58	0.159
19	3	7.273	19	3.121	39	6.407	59	9.692	19	0.052	39	0.106	59	0.161
20	3	17.129	20	3 285	40	6.571	60	9.856	20	0.055	40	0.109	60	0.164
21	3	26.986												
22	3	36.841												
23	3	46.699												
24	3	56.555												

The quantities taken from this Table must be added to a mean interval, to obtain the corresponding interval in sidereal time.

The foregoing tables will be found to be of great practical utility; since they obviate the necessity of making the arithmetical computation required by the "Rule" given on page 48th of this report, which is respectfully submitted.

NOAH BARKER.

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GENERAL REPORT.

APPENDIX.