United States Department of the Interior
General Land Office

Manual of Instructions
for the
Survey of the Public Lands of the United States

1930

Wm. H. Richards Jr.

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UNITED STATES DEPARTMENT OF THE INTERIOR
RAY LYMAN WILBUR, SECRETARY

GENERAL LAND OFFICE
C. C. MOORE, Commissioner

MANUAL OF INSTRUCTIONS
FOR THE
SURVEY OF THE PUBLIC LANDS OF THE UNITED STATES

1930

Prepared and published under the direction
of the Commissioner of the General Land Office

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The Superintendent of Documents, United States Government Printing Office, Washington, D. C., has on hand for sale to the public, at current cost of printing, the following publications of the General Land Office:

Manual of Instructions for the Survey of the Public Lands of the United States, edition of 1930.

Standard Field Tables (a supplement to the Manual of Surveying Instructions).

Ephemeris of the Sun and Polaris, and Tables of Azimuths and Altitudes of Polaris, published annually in advance (a supplement to the Manual of Surveying Instructions).

Wall map of the United States, scale 37 miles to 1 inch, and separate maps of the several public-land States, scale 12 miles to 1 inch, showing the developed rectangular surveys.

Copies of the approved field notes and plats of the public-land subdivisional surveys may be procured from the Commissioner of the General Land Office, Washington, D. C., at the current rates for such official copies.

Copies of the approved field notes and plats of the public-land, mineral-patent, and private-land-claim-patent surveys may be procured from the United States public survey offices or the appropriate State office indicated in the Manual, section 1, Chapter I. A charge is usually made for making copies of records furnished to the public, or provision is afforded to the public to make extracts from or copies of such records.

United States cadastral engineers and all others who may have occasion to use this volume are requested to report to the Commissioner of the General Land Office, Washington, D. C., any errors which may be found herein.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GENERAL LAND OFFICE

WASHINGTON, *June 14, 1930.*

The UNITED STATES SUPERVISOR OF SURVEYS.

SIR: This Manual of Instructions for the Survey of the Public Lands of the United States, published as the Manual of 1930, which is issued for the guidance of the cadastral engineering service of the General Land Office under the authority found in sections 453 and 2478 of the Revised Statutes, will supersede all previous manuals or circular instructions on the technical subjects contained therein.

C. C. MOORE,
Commissioner.

Approved June 14, 1930.
JOHN H. EDWARDS,
Assistant Secretary.

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CHAPTER I.

REGULATIONS IMPOSED BY LAW.

THE PUBLIC DOMAIN.

1. The survey of the public lands of the United States is inseparably associated with questions relating to the acquisition and disposal of proprietary title to the lands which have been added to the area included in the original thirteen States. The term "public domain" has been applied broadly to the entire aforementioned area in so far as the lands have been subject to survey and disposal by the United States, and of interest herein may be mentioned the 29 States and the District of Alaska surveyed or in progress of survey under the United States rectangular system, as follows:

Alabama.—Included in the territory of the original thirteen States and admitted into the Union December 14, 1819 (3 Stat. 608); surveys practically completed and original records transferred to the Secretary of State at Montgomery.

Arizona.—Included in the lands ceded by Mexico in 1848 and the Gadsden purchase in 1853 and admitted into the Union February 14, 1912 (36 Stat. 557, 37 Stat. 1728); surveys in progress; United States Public Survey Office at Phoenix.

Arkansas.—Acquired under the Louisiana Purchase in 1803 and admitted into the Union June 15, 1836 (5 Stat. 50); surveys practically completed and original records transferred to the Commissioner of State Lands at Little Rock.

California.—Ceded by Mexico in 1848 and admitted into the Union September 9, 1850 (9 Stat. 452); surveys in progress; United States Public Survey Office at ~~San Francisco.~~ Glendale

Colorado.—Acquired largely under the Louisiana Purchase in 1803, but including additional land, title to which was quieted through treaty with Spain in 1819, with other lands annexed with Texas in 1845, and lands ceded by Mexico in 1848, and admitted into the Union August 1, 1876 (18 Stat. 474, 19 Stat. 665); surveys in progress; United States Supervisor of Surveys at Denver.

Florida.—Ceded by Spain in 1819 and admitted into the Union March 3, 1845 (5 Stat. 742); surveys practically completed and original records transferred to the Commissioner of Agriculture at Tallahassee.

Idaho.—Acquired with the Oregon territory, title to which was established in 1846, and admitted into the Union July 3, 1890 (26 Stat. 215); surveys in progress; United States Public Survey Office at Boise.

Illinois.—Included in the territory of the original thirteen States and admitted into the Union December 3, 1818 (3 Stat. 536); surveys practically completed and original records transferred to the Auditor of State at Springfield.

Indiana.—Included in the territory of the original thirteen States and admitted into the Union December 11, 1816 (3 Stat. 399); surveys practically completed and original records transferred to the Auditor of State at Indianapolis.

Iowa.—Acquired under the Louisiana Purchase in 1803 and admitted into the Union December 28, 1846 (9 Stat. 117); surveys practically completed and original records transferred to the Secretary of State at Des Moines.

Kansas.—Acquired under the Louisiana Purchase in 1803 and with lands annexed with Texas in 1845 and admitted into the Union January 29, 1861 (12 Stat. 126); surveys practically completed and original records transferred to the Auditor of State and Register of State Lands at Topeka.

Louisiana.—Included in the Louisiana Purchase in 1803 and boundary extended to include additional lands, title to which was quieted through treaty with Spain in 1819, and admitted into the Union April 30, 1812 (2 Stat. 701); surveys practically completed and original records transferred to the Register of State Lands at Baton Rouge.

Michigan.—Included in the territory of the original thirteen States and admitted into the Union January 26, 1837 (5 Stat. 144); surveys practically completed and original records transferred to the Director, Department of Conservation, at Lansing.

Minnesota.—Included in the territory of the original thirteen States, and with lands acquired under the Louisiana Purchase in 1803, and admitted into the Union May 11, 1858 (11 Stat. 285); surveys practically completed and original records transferred to the Secretary of State at St. Paul.

Mississippi.—Included in the territory of the original thirteen States and admitted into the Union December 10, 1817 (3 Stat. 472); surveys practically completed and original records transferred to the Commissioner of State Lands at Jackson.

Missouri.—Acquired under the Louisiana Purchase in 1803 and admitted into the Union August 10, 1821 (3 Stat. 645, 3 Stat. Appendix II); surveys practically completed and original records transferred to the Secretary of State at Jefferson City.

Montana.—Acquired under the Louisiana Purchase in 1803 and with the Oregon territory, title to which was established in 1846, and admitted into the Union November 8, 1889 (25 Stat. 676, 26 Stat. 1551); surveys in progress; United States Public Survey Office at Helena.

Nebraska.—Acquired under the Louisiana Purchase in 1803 and admitted into the Union March 1, 1867 (14 Stat. 391, 820); surveys practically completed and original records transferred to the Commissioner of Public Lands and Buildings at Lincoln.

Nevada.—Ceded by Mexico in 1848 and admitted into the Union October 13, 1864 (13 Stat. 30, 749); surveys in progress; United States Public Survey Office at Reno.

New Mexico.—Included with lands annexed with Texas in 1845, with lands ceded by Mexico in 1848, and the Gadsden Purchase in 1853, and admitted into the Union January 6, 1912 (36 Stat. 557, 37 Stat. 1723); surveys in progress; United States Public Survey Office at Santa Fe.

North Dakota.—Included in the territory of the original thirteen States, and with lands acquired under the Louisiana Purchase in 1803, and admitted into the Union November 2, 1889 (25 Stat. 676, 26 Stat. 1548); surveys practically completed and original records transferred to the State Engineer at Bismarck.

Oklahoma.—Acquired under the Louisiana Purchase in 1803 and with lands annexed with Texas in 1845, and admitted into the Union November 16, 1907 (34 Stat. 267, 35 Stat. 2160); surveys practically completed and original records filed with the Commissioner of the General Land Office at Washington, D. C.

Ohio.—Included in the territory of the original thirteen States and admitted into the Union April 30, 1802 (2 Stat. 173); surveys practically completed and original records transferred to the Auditor of State at Columbus.

Oregon.—Included in the Oregon territory, title to which was established in 1846, and admitted into the Union February 14, 1859 (11 Stat. 383); surveys in progress; United States Public Survey Office at Portland.

South Dakota.—Included in the territory of the original thirteen States, and with lands acquired under the Louisiana Purchase in 1803, and admitted into the Union November 2, 1889 (25 Stat. 676, 26 Stat. 1549); surveys practically completed and original records transferred to the Commissioner of School and Public Lands at Pierre.

Utah.—Ceded by Mexico in 1848 and admitted into the Union January 4, 1896 (28 Stat. 107, 29 Stat. 876); surveys in progress; United States Public Survey Office at Salt Lake City.

Washington.—Included in the Oregon territory, title to which was established in 1846, and admitted into the Union November 11, 1889 (25 Stat. 676, 26 Stat. 1552); surveys in progress; United States Public Survey Office at Olympia.

Wisconsin.—Included in the territory of the original thirteen States and admitted into the Union May 29, 1848 (9 Stat. 233); surveys practically completed and original records transferred to the Commissioners of Public Lands at Madison.

Wyoming.—Included with lands acquired under the Louisiana Purchase in 1803, with lands annexed with Texas in 1845, with lands included in the Oregon territory, title to which was established in 1846, and with lands ceded by Mexico in 1848, and admitted into the Union July 10, 1890 (26 Stat. 222); surveys in progress; United States Public Survey Office at Cheyenne.

District of Alaska.—Ceded by Russia in 1867; surveys in progress; United States Public Survey Office at Juneau.

2. After the admission of the States into the Union the United States continued to hold title to the unappropriated lands and to administer its public-land laws with reference thereto, and it is expressly provided, as one of the conditions set forth in the various enabling acts, that the title to unappropriated lands within the State shall remain in the United States. The lands in the Territories not appropriated by competent authority before they were acquired are in the first instance the exclusive property of the United States, to be disposed of to such per-

sons, at such times, in such modes, and by such titles as the Government may deem most advantageous to the public. Congress alone has the power, derived from Article IV, section 3, of the Constitution, of disposing of the public domain and making all needful rules and regulations in respect thereto.

3. Under the laws of the United States the navigable waters have always been and shall forever remain common highways, and below mean high water the same are not subject to survey and disposal. This reservation includes all tidewater streams, and other important permanent bodies of water whose natural and normal condition at the date of the admission of a State into the Union was such as to classify the same as navigable water. (See sec. 2476, R. S.)

4. The act of Congress approved March 2, 1849 (9 Stat. 352), granted to the State of Louisiana all the swamp and overflowed lands within the limits of the State for the purpose of aiding in the reclamation of said lands, and the act of Congress approved September 28, 1850 (9 Stat. 519), extended the grant to the other public-land States then in the Union. The grant was also extended to the States of Minnesota and Oregon by the act of Congress approved March 12, 1860 (12 Stat. 3). The provisions of the aforementioned grants apply to the zone situated below the uplands wherein the lands are of such a character that without the construction of suitable levees and artificial drainage systems the same would be wet and unfit for agricultural purposes. The swamp-land grants apply to all swamp and overflowed lands within the beneficiary States which were unappropriated at the dates of the acts of Congress and whose character *at that time* would bring them within the provisions of said grants. A notable exception to the swamp-land laws is found in the Arkansas compromise act approved April 29, 1898 (30 Stat. 367), by virtue of which all right, title, and interest to the remaining unappropriated swamp and overflowed lands within the State of Arkansas reverted to the United States.

5. It comes within the province of the Department of the Interior to consider and determine what are public lands, what lands have been surveyed, what are to be surveyed, what have been disposed of, what remain to be disposed of, and what are reserved, and it is a well-settled principle of law that the United

States, through the Department of the Interior, has the right to extend the surveys as may be necessary to include lands omitted from earlier surveys. It is an important duty of the engineer in the field to discriminate between what are and what are not public lands of the United States, and to subdivide the former in accordance with the regulations imposed by law.

LAWS RELATING TO SURVEYS.

6. The rectangular surveying system is based upon existing law and was devised with the object of marking upon the ground and fixing for all time legal subdivisions for purposes of description and disposal of the public domain under the general land laws of the United States.

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

7. The rectangular system of survey of the public lands was inaugurated by a committee appointed by the Continental Congress. On the 7th of May, 1774, this committee reported "An ordinance for ascertaining the mode of locating and disposing of lands in the western territory, and for other purposes therein mentioned." The ordinance as finally passed on the 20th of May, 1775, provided for townships 6 miles square, containing 36 sections of 1 mile square. The first public surveys were made under this ordinance. The townships 6 miles square, were laid out in ranges extending northward from the Ohio

should be 20th of May, 1785

River, the townships being numbered from south to north, and the ranges from east to west. The region embraced by the surveys under this law forms a part of the State of Ohio. In these initial surveys only the exterior lines of the townships were surveyed, but the plats were marked by subdivisions into sections of 1 mile square, and mile corners were established on the township lines. The sections were numbered from 1 to 36, and the surveys were made under the direction of the geographer of the United States.

The act of Congress approved May 18, 1796, provided for the appointment of a surveyor general and directed the survey of the lands northwest of the Ohio River and above the mouth of the Kentucky River, "in which the titles of the Indian tribes have been extinguished." Under this law it was provided that "the sections shall be numbered, respectively, beginning with the number one in the northeast section and proceeding west and east alternately through the township, with progressive numbers till the thirty-sixth be completed." This method of numbering sections, as shown by the accompanying diagram, is still in use.

The act of Congress approved May 10, 1800, required the "townships west of the Muskingum, which * * * are directed to be sold in quarter townships, to be subdivided into half sections of three hundred and twenty acres each, as nearly as may be, by running parallel lines through the same from east to west and from south to north at the distance of one mile from each other, and marking corners at the distance of each half mile on the lines running from east to west and at the distance of each mile on those running from south to north. * * * And the interior lines of townships intersected by the Muskingum, and of all the townships lying east of that river, which have not been heretofore actually subdivided into sections shall also be run and marked. * * * And in all cases where the exterior lines of the townships thus to be subdivided into sections or half sections shall exceed, or shall not extend, six miles, the excess or deficiency shall be specially noted and added to or deducted from the western and northern ranges of sections or half sections in such townships, according as the error may be in running the lines from east to west or from south to north."

The act of Congress approved February 11, 1805, directs the subdivision of the public lands into quarter sections and provides that all the corners marked in the public surveys shall be established as the proper corners of sections, or subdivisions of sections, which they were intended to designate, and that corners of half and quarter sections not marked shall be placed as nearly as possible "equidistant from those two corners which stand on the same line." This act further provides that "The boundary lines actually run and marked * * * shall be established as the proper boundary lines of the sections or subdivisions for which they were intended; and the length of such lines as returned by * * * the surveyors * * * shall be held and considered as the true length thereof, and the boundary lines which shall not have been actually run and marked as aforesaid shall be ascertained by running straight lines from the established corners to the opposite corresponding corners; but in those portions of the fractional townships where no such opposite or corresponding corners have been or can be fixed, the said boundary lines shall be ascertained by running from the established corners due north and south or east and west lines, as the case may be, to the * * * external boundary of such fractional township."

The act of Congress approved April 25, 1812, provided "That there shall be established in the Department of the Treasury an office to be denominated the General Land Office, the chief officer of which shall be called the Commissioner of the General Land Office, whose duty it shall be, under the direction of the head of the department, to superintend, execute, and perform all such acts and things touching or respecting the public lands of the United States, and other lands patented or granted by the United States, as have heretofore been directed by law to be done or performed in the office of the Secretary of State, of the Secretary and Register of the Treasury, and of the Secretary of War, or which shall hereafter by law be assigned to the said office."

The act of Congress approved April 24, 1820, provides for the sale of public lands in half-quarter sections, and requires that "in every case of the division of a quarter section the line for the division thereof shall run north and south * * * and fractional sections, containing one hundred and sixty acres and upward, shall, in like manner, as nearly as practicable, be subdivided into half-quarter sections, under such rules and regulations as may be prescribed by the Secretary of the Treasury;

but fractional sections containing less than one hundred and sixty acres shall not be divided."

The act of Congress approved May 29, 1830 (secs. 2412, 2413, R. S.), provides for the fine and imprisonment of any person obstructing the survey of the public lands, and for the protection of surveyors, in the discharge of their official duties, by the United States marshal, with sufficient force, whenever necessary.

The act of Congress approved April 5, 1832, directed the subdivision of the public lands into quarter quarters; that in every case of the division of a half-quarter section the dividing line should run east and west; and that fractional sections should be subdivided under rules and regulations prescribed by the Secretary of the Treasury. Under the latter provision the Secretary directed that fractional sections containing less than 160 acres, or the residuary portion of a fractional section, after the subdivision into as many quarter-quarter sections as it is susceptible of, may be subdivided into lots, each containing the quantity of a quarter-quarter section as nearly as practicable, by so laying down the line of subdivision that they shall be 20 chains wide, which distances are to be marked on the plat of subdivision, as are also the areas of the quarter quarters and residuary fractions.

The last two acts above mentioned provided that the corners and contents of half-quarter and quarter-quarter sections should be ascertained, as nearly as possible, in the manner and on the principles directed and prescribed in the act of Congress approved February 11, 1805.

The act of Congress approved July 4, 1836, provided for the reorganization of the General Land Office, and that the executive duties of said office "shall be subject to the supervision and control of the Commissioner of the General Land Office under the direction of the President of the United States." The repealing clause is, "That such provisions of the act of the twenty-fifth of April, in the year one thousand eight hundred and twelve, entitled 'An act for the establishment of a General Land Office in the Department of the Treasury,' and of all acts amendatory thereof, as are inconsistent with the provisions of this act, be, and the same are hereby, repealed."

From the wording of this act it would appear that the control of the General Land Office was removed from the Treasury Department, and that the commissioner reported directly to the President; but, as a matter of fact, the Secretary of the Treasury still had supervisory control, for the act of Congress approved March 3, 1849, by which the Department of the Interior was established, provided, "That the Secretary of the Interior shall perform all the duties in relation to the General Land Office, of supervision and appeal, now discharged by the Secretary of the Treasury * * *." By this act the General Land Office was transferred to the Department of the Interior, where it still remains.

8. The following comprises so much of the general laws relating to the survey of the public domain as it is deemed necessary to incorporate in this volume, reference being made by chapter and section to the codification of the Public Land Laws, prepared pursuant to acts of Congress approved March 3, 1879, and June 16, 1880, and by section number to the Revised Statutes of the United States.

Duties of commissioner.

SEC. 32. The Commissioner of the General Land Office shall perform, under the direction of the Secretary of the Interior, all executive duties appertaining to the surveying and sale of the public lands of the United States, or in any wise respecting such public lands; and, also, such as relate to private claims of lands, and the issuing of patents for all grants of land under the authority of the Government. (R. S. 453.)

Power of commissioner to make regulations.

SEC. 61. The Commissioner, under the direction of the Secretary of the Interior, is authorized to enforce and carry into execution every part of the public land laws not otherwise specially provided for. (R. S. 2478.)

Rules of survey.

SEC. 99. First. The public lands shall be divided by north and south lines run according to the true meridian, and by others crossing them at right angles, so as to form townships of six miles square, unless where the line of an Indian reservation, or of tracts of land heretofore surveyed or patented, or the course of navigable rivers, may render this impracticable; and in that case this rule must be departed from no further than such particular circumstances require.

Second. The corners of the townships must be marked with progressive numbers from the beginning; each distance of a mile between such corners must be also distinctly marked with marks different from those of the corners.

Third. The township shall be subdivided into sections, containing as nearly as may be, six hundred and forty acres each, by running through the same, each way, parallel lines at the end of every two miles[1]; and by making a corner on each of such lines at the end of every mile. The sections shall be numbered, respectively, beginning with the number one in the northeast section, and proceeding west and east alternately through the township with progressive numbers till the thirty-six be completed.

Fourth. The deputy surveyors, respectively, shall cause to be marked on a tree near each corner established in the manner described, and within the section, the number of such section, and over it the number of the township within which such section may be; and the deputy surveyors shall carefully note, in their respective field books, the names of the corner trees marked and the numbers so made.

Fifth. Where the exterior lines of the townships which may be subdivided into sections or half sections exceed, or do not extend six miles, the excess or deficiency shall be specially noted, and added to or deducted from the western and northern ranges of sections or half sections in such townships, according as the error may be in running the lines from east to west, or from south to north; the sections and half sections bounded on the northern and western lines of such townships shall be sold as containing only the quantity expressed in the returns and plats, respectively, and all others as containing the complete legal quantity.

Sixth. All lines shall be plainly marked upon trees, and measured with chains, containing two perches of sixteen and

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[1] Authority for the establishment of section lines at intervals of 1 mile is found in the act of Congress approved May 10, 1800, previously quoted.

one-half feet each, subdivided into twenty-five equal links; and the chain shall be adjusted to a standard to be kept for that purpose.[2]

Seventh. Every surveyor shall note in his field book the true situations of all mines, salt licks, salt springs, and mill seats which come to his knowledge; all water courses over which the line he runs may pass; and also the quality of the lands.

Eighth. These field books shall be returned to the surveyor general, who shall cause therefrom a description of the whole lands surveyed to be made out and transmitted to the officers who may superintend the sales. He shall also cause a fair plat to be made of the townships and fractional parts of townships contained in the lands, describing the subdivisions thereof, and the marks of the corners. This plat shall be recorded in books to be kept for that purpose; and a copy thereof shall be kept open at the surveyor general's office for public information, and other copies shall be sent to the places of the sale and to the General Land Office. (Acts of May 18, 1796, and May 10, 1800, and R. S. 2395.)

Boundaries and contents of public lands, how ascertained.

SEC. 100. The boundaries and contents of the several sections, half sections, and quarter sections of the public lands shall be ascertained in conformity with the following principles:

First. All the corners marked in the surveys returned by the surveyor general shall be established as the proper corners of sections, or subdivisions of sections, which they were intended to designate, and the corners of half and quarter sections, not marked on the surveys, shall be placed as nearly as possible equidistant from two corners which stand on the same line.

Second. The boundary lines, actually run and marked in the surveys returned by the surveyor general, shall be established as the proper boundary lines of the sections or subdivisions for which they were intended, and the length of such lines as returned shall be held and considered as the true length thereof.

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[2] The superior results obtained by the use of modern steel ribbon tapes, in contrast with the obsolete link chain, have led to the abandonment of the latter, except that the "chain unit," which is peculiarly adapted to land surveying, has always been employed.

And the boundary lines which have not been actually run and marked shall be ascertained by running straight lines from the established corners to the opposite corresponding corners; but in those portions of the fractional townships, where no such opposite corresponding corners have been or can be fixed, the boundary lines shall be ascertained by running from the established corners due north and south or east and west lines, as the case may be, to the water course, Indian boundary line, or other external boundary of such fractional township.

Third. Each section or subdivision of section, the contents whereof have been returned by the surveyor general, shall be held and considered as containing the exact quantity expressed in such return; and the half sections and quarter sections, the contents whereof shall not have been thus returned, shall be held and considered as containing the one-half or the one-fourth part, respectively, of the returned contents of the section of which they may make part. (Act of Feb. 11, 1805, and R. S. 2396.)

Lines of division of half-quarter sections, how run.

SEC. 101. In every case of the division of a quarter section the line for the division thereof shall run north and south, and the corners and contents of half-quarter sections which may thereafter be sold shall be ascertained in the manner and on the principles directed and prescribed by the section preceding, and fractional sections containing one hundred and sixty acres or upwards shall in like manner, as nearly as practicable, be subdivided into half-quarter sections, under such rules and regulations as may be prescribed by the Secretary of the Interior, and in every case of a division of a half-quarter section, the line for the division thereof shall run east and west, and the corners and contents of quarter-quarter sections, which may thereafter be sold, shall be ascertained, as nearly as may be, in the manner and on the principles directed and prescribed by the section preceding; and fractional sections containing fewer or more than one hundred and sixty acres shall in like manner, as nearly as may be practicable, be subdivided into quarter-quarter sections, under such rules and regulations as may be prescribed by the Secretary of the Interior. (R. S. 2397.)

Extension of public surveys over mineral lands.

SEC. 106. The public surveys shall extend over all mineral lands, and all subdividing of surveyed lands into lots less than one hundred and sixty acres may be done by county and local surveyors at the expense of claimants; but nothing in this section contained shall require the survey of waste or useless lands. (R. S. 2406.)

Surveyors general to survey private land claims when confirmed, etc.

SEC. 118. Each surveyor general, when thereunto duly authorized by law, shall cause all confirmed private land claims within his district to be accurately surveyed, and shall transmit plats and field notes thereof to the Commissioner of the General Land Office for his approval. When publication of such surveys is authorized by law, the proof thereof, together with any objections properly filed, and all evidence submitted either in support of or in opposition to the approval of any such survey, shall also be transmitted to said commissioner. (R. S. 2447.)

Penalty for interrupting surveys.

SEC. 120. Every person who in any manner, by threat or force, interrupts, hinders, or prevents the surveying of the public lands, or of any private land claim which has been or may be confirmed by the United States, by the persons authorized to survey the same, in conformity with the instructions of the Commissioner of the General Land Office, shall be fined not less than fifty dollars, nor more than three thousand dollars, and be imprisoned not less than one nor more than three years. (R. S. 2412.)

Protection of surveyor by marshal of district.

SEC. 121. Whenever the President is satisfied that forcible opposition has been offered, or is likely to be offered, to any surveyor or deputy surveyor in the discharge of his duties in surveying the public lands, it may be lawful for the President to order the marshal of the State or district, by himself or deputy, to attend such surveyor or deputy surveyor with sufficient force to protect such officer in the execution of his duty, and to remove force should any be offered. (R. S. 2413.)

9. More recent legislation has brought about (*a*) authority for the purchase of metal or other equally durable monuments, to be employed in place of native material to mark public land corners; (*b*) penalty for the destruction of monuments of the public-land surveys; (*c*) authority for necessary resurveys; (*d*) authority for the employment of a permanent corps of United States cadastral engineers; (*e*) authority for the reorganization of the public survey offices; and (*f*) authority for the discontinuance of the public survey offices when no longer necessary, and transfer of certain records to the States.

Purchase of metal monuments.

The act of Congress approved May 27, 1908, provided "for the purchase of metal monuments to be used for public land survey corners wherever practicable." (35 Stat. 347.) This authority was amplified by the act of Congress approved June 25, 1910, making appropriation for sundry civil expenses for the fiscal year ended June 30, 1911, and has been continued from year to year to the present time.

Penalty for the destruction of survey monuments.

The act of Congress approved March 4, 1909, entitled "An act to codify, revise, and amend the penal laws of the United States," provides a penalty for the unauthorized alteration or removal of any Government survey-monument or marked trees, as follows:

"Whoever shall willfully destroy, deface, change, or remove to another place any section corner, quarter-section corner, or meander post, on any Government line of survey, or shall willfully cut down any witness tree or any tree blazed to mark the line of a Government survey, or shall willfully deface, change, or remove any monument or bench mark of any Government survey, shall be fined not more than $250, or imprisoned not more than six months, or both." (35 Stat. 1099, sec. 57.)

Resurvey of public lands.

The act of Congress approved March 3, 1909, entitled "An act authorizing the necessary resurvey of public lands," as amended by joint resolution approved June 25, 1910, provides as follows:

"That the Secretary of the Interior may, in his discretion, cause to be made, as he may deem wise under the rectangular system now provided by law, such resurveys or retracements of the surveys of public lands as, after full investigation, he may deem essential to properly mark the boundaries of the public lands remaining undisposed of: *Provided*, That no such resurvey or retracement shall be so executed as to impair the bona fide rights or claims of any claimant, entryman, or owner of lands affected by such resurvey or retracement: *Provided further*, That not to exceed 20 per centum of the total annual appropriation for surveys and resurveys of the public lands shall be used for the resurveys and retracements authorized hereby." (35 Stat. 845, 36 Stat. 884.)

The act of Congress approved September 21, 1918, entitled "An act authorizing the resurvey or retracement of lands heretofore returned as surveyed public lands of the United States under certain conditions" provides authority for the resurvey by the Government of townships heretofore held to be ineligible for resurvey under existing regulations of the Department of the Interior by reason of disposals in excess of fifty per centum of the total area thereof. The act provides:

"That upon the application of the owners of three-fourths of the privately owned lands in any township covered by public-land surveys, more than fifty per centum of the area of which township is privately owned, accompanied by a deposit with the United States surveyor general for the proper State, or if there be no surveyor general of such State, then with the Commissioner of the General Land Office, of the proportionate estimated cost, inclusive of the necessary (office) work, of the resurvey or retracement of all the privately owned lands in said township, the Commissioner of the General Land Office, subject to the supervisory authority of the Secretary of the Interior, shall be authorized in his discretion to cause to be made a resurvey or retracement of the lines of said township and to set permanent corners and monuments in accordance with the laws and regulations governing surveys and resurveys of public lands; that the sum so deposited shall be held by the surveyor general or commissioner when ex officio surveyor general and may be expended in payment of the cost of such survey, including field and office work, and any excess over the cost of such survey and the expenses incident thereto shall be repaid pro rata to the persons making said deposits or their legal representatives; that the proportionate cost of the field and office work for the resurvey or retracement of any public lands in such township shall be paid from the current appropriation for the survey and resurvey of public lands, in addition to the portion of such appropriation otherwise allowed by law for resurveys and retracements; that similar resurveys and retracements may be made on the application, accompanied by the requisite deposit, of any court of competent jurisdiction, the returns of such resurvey or retracement to be submitted to the court; that the Secretary of the Interior is authorized to make all necessary rules and regulations to carry this act into full force and effect." (40 Stat. 965.)

Selection of surveyors.

The act of Congress approved June 25, 1910 (36 Stat. 703, 740), making appropriation for sundry civil expenses for the fiscal year ended June 30, 1911, provided, under "Surveying the Public Lands": "The surveys and resurveys to be made by such competent surveyors as the Secretary of the Interior may select, * * *." This provision of law brought to a close the practice of letting contracts for the making of the public-land surveys, which had been followed from the beginning. The field work is now performed by a permanent corps of engineers who are employed under civil service regulations.

The act of Congress approved March 3, 1925, provided for the reorganization of the public survey offices as follows:

Administration, etc., transferred to Field Surveying Service.

"The office of surveyor general is hereby abolished, effective July 1, 1925, and the administration of all activities theretofore in charge of surveyors general, including the necessary personnel, all records, furniture, and other equipment, and all supplies in their respective offices, are hereby transferred to and consolidated with the Field Surveying Service, under the jurisdiction of the United States Supervisor of Surveys, who shall hereafter administer same in association with the surveying operations in his charge and under such regulations as the Secretary of the Interior may provide." (43 Stat. 1144.)

The act of Congress approved May 28, 1926, entitled "An act to provide for the transfer of certain records of the General Land Office to States, and for other purposes," provides as follows:

On abolishment of land offices in State records, etc., thereof may be transferred thereto.

"That whenever the last United States land office in any State has been or hereafter may be abolished the Secretary of the Interior be, and he is hereby, authorized to transfer to the State within which such United States land office was or is situated such transscripts, documents, and records of the office aforesaid as may not be required for use of the United States and which the State may desire to preserve.

Field notes, etc., of surveys, may be turned over to the State.

"SEC. 2. That when the public surveys in any State have been so far completed that in the opinion of the Secretary of the Interior it is no longer necessary to maintain a public survey office in said State, he may turn over to the State the field notes, maps, plats, records, and all other papers appertaining to land titles in such public survey office that may not be needed by the United States and which the State may elect to receive.

Provision for safekeeping required.

"SEC. 3. The transcripts, documents, records, field notes, maps, plats, and other papers mentioned in sections 1 and 2 of this act shall in no case be turned over to the authorities in any State until such State has provided by law for the reception and safekeeping of same as public records, and for the allowance of free access to the same by the authorities of the United States." (44 Stat. 672.)

The laws (1) in reference to the reorganization of the public survey offices (43 Stat. 1144, March 3, 1925, effective July 1, 1925), and (2) in reference to the transfer to the States of the field notes and plats on the completion of the surveys (44 Stat. 672, May 28, 1926), superseded certain long established and important provisions of the Public Land Laws, of which the following sections of the Revised Statutes are given here for the information bearing upon former practices:

Surveyor general, how and where appointed.

SEC. 77. There shall be appointed by the President, by and with the advice and consent of the Senate, a surveyor general for the States and Territories herein named, embracing, respectively, one surveying district, namely: Louisiana, Florida, Minnesota, Kansas, California, Nevada, Oregon, Nebraska and Iowa, Dakota, Colorado, New Mexico, Idaho, Washington, Montana, Utah, Wyoming, Arizona. (R. S. 2207.)

Transfer of papers and discontinuance of office in case of completed surveys.

SEC. 87. Whenever the surveys and records of any surveying district are completed the surveyor general thereof shall be required to deliver over to the secretary of state of the respective States, including such surveys, or to such other officer as may be authorized to receive them, all the field notes, maps, records, and other papers appertaining to land titles within the same; and the office of surveyor general in every such district shall thereafter cease and be discontinued. (R. S. 2218.)

Devolution of powers upon commissioner in case of discontinuance.

SEC. 88. In all cases of discontinuance, as provided in the preceding section, the authority, powers, and duties of the surveyor general in relation to the survey, resurvey, or subdivision of the lands therein, and all matters and things connected therewith, shall be vested in and devolved upon the Commissioner of the General Land Office. (R. S. 2219.)

Free access to public records delivered to States, and condition of such delivery.

SEC. 89. Under the authority and direction of the Commissioner of the General Land Office any deputy surveyor or other agent of the United States shall have free access to any such field notes, maps, records, and other papers for the purpose of taking extracts therefrom or making copies thereof without charge of any kind; but no transfer of such public records shall be made to the authorities of any State until such State has provided by law for the reception and safekeeping of such public records, and for the allowance of free access thereto by the authorities of the United States. (R. S. 2220, 2221.)

GENERAL RULES.

10. From the foregoing synopsis of congressional legislation it is evident—

First. That the boundaries and subdivisions of the public lands as surveyed under approved instructions by the duly appointed engineers, the physical evidence of which survey consists of monuments established upon the ground, and the record evidence of which consists of field notes and plats duly approved by the authorities constituted by law, are unchangeable after the passing of the title by the United States.

Second. That the physical evidence of the original township, section, quarter-section, and other monuments must stand as the true corners of the subdivisions which they were intended to represent, and will be given controlling preference over the recorded directions and lengths of lines.

Third. That quarter-quarter-section corners not established in the process of the original survey shall be placed on the line connecting the section and quarter-section corners, and midway between them, except on the last half mile of section lines closing on the north and west boundaries of the township, or on other lines between fractional or irregular sections.

Fourth. That the center lines of a regular section are to be straight, running from the quarter-section corner on one boundary of the section to the corresponding corner on the opposite section line.

Fifth. That in a fractional section where no opposite corresponding quarter-section corner has been or can be established, the center line of such section must be run from the proper quarter-section corner as nearly in a cardinal direction to the meander line, reservation, or other boundary of such fractional section, as due parallelism with section lines will permit.

Sixth. That lost or obliterated corners of the approved surveys must be restored to their original locations whenever it is possible to do so. Actions or decisions by surveyors, Federal, State, or local, which may involve the possibility of changes in the established boundaries of patented lands, are subject to review by the State courts upon suit advancing that issue.

THE MANUAL.

11. Various regions of the United States have been surveyed under different sets of instructions issued at periods ranging from 1785 to the present time. The earliest rules were given to surveyors in manuscript or in printed circulars. Regulations more in detail, improving the system for greater accuracy, permanency, and uniformity, were issued in book form in Manuals of 1855, 1881, 1890, 1894, and 1902. The current Manual will be known as the Manual of 1930. Advance sheets of the first six chapters of the Manual of 1930 were promulgated June 16, 1919; a manuscript edition of Chapter IX was put into effect March 1, 1928.

The Manual of Surveying Instructions has been revised with a view to harmonizing the printed instructions furnished to the engineers with recent legislation and current surveying practice. The use of iron-post corner monuments adds much to the permanency of the evidence of the surveys, but this has called for little change in rules except to outline the standard practice. A growing necessity for resurveys to identify and restore original surveys actually made, but poorly monumented, or to supersede grossly erroneous or fraudulent original surveys—"to properly mark the boundaries of the public land remaining undisposed of"—has demanded a full discussion of the subject in this revision of the Manual.

The change from the contract system, including the reorganization of the public-survey offices, has involved necessary changes in the administrative practice, but without departure from the established technical procedure. In this connection it will be noted throughout the Manual that references to the administrative practice are purposely stated in very general terms; this is done in order to avoid diverting the attention from a strictly technical treatment of the surveying subjects.

Modern methods have been made an integral part of the public-land surveying practice in so far as adaptable, for which purpose it has been necessary to include a full instructive text on the subjects of measurements of lines, field observations for the determination of time, latitude, and azimuth, and the running of the true latitudinal curve, an understanding of which is essential to the making of large-scale rectangular surveys.

Owing to many changes in the character of the work, there is much need for Manual treatment of the subjects of subdivision of sections, restoration of lost or obliterated corners, resurveys, the many types of special surveys, and the detail of the production of plats, which have not been included in any previous Manual. These subjects, by their growing importance, reflect the change in the character of the work from that principally of marking the original subdivisions to that which is largely concerned in the identification and perpetuation of the boundaries already created.

The instructions contained in this Manual are to be observed by every engineer engaged in the execution of the public-land surveys. All other surveyors, including those who have at times been employed in the surveying service of the General Land Office, should bear in mind that in their private capacities they are acting under somewhat different rules of law from those governing original surveys, and surveyors should discriminate between the provisions of the statute which control original surveys and those which apply to the retracement of lines that have been officially established and approved.

STANDARD FIELD TABLES.

12. There has been published by the General Land Office, in the shape of a pocket field book, a compendium of tables and formulas entitled "Standard Field Tables." The volume embraces the data peculiarly useful to engineers engaged in subdividing the public lands. The Standard Field Tables are issued as a supplement to the Manual, and as such the former are a part of the latter, with contents as follows:

1. Units of linear measure, units of area, expansion of steel tapes, and conversion tables, chains to feet and feet to chains.
2. Reduction in latitude to south boundary of township, and corrections for convergency within a township.
3. Traverse table, for the correction of random lines.
4. Traverse tables.

5. Correction of error in stadia wire interval.
6. Stadia coefficients, vertical rod.
7. Natural sines and cosines.
8. Natural tangents and cotangents.
9. Logarithmic sines, cosines, tangents, and cotangents.
10. Logarithms of numbers.
11. Convergency of meridians, and differences of latitude and longitude.
12. Azimuths of the tangent to the parallel.
13. Offsets from the tangent to the parallel.
14. Azimuths of the secant.
15. Offsets from the secant to the parallel.
16. Lengths of arcs of the earth's surface.
17. Apparent time of sunrise and sunset.
18. Conversion tables, degrees to time, and time to degrees.
19. Sidereal conversions, and reductions to the local mean time of upper culmination of Polaris.
20. Mean refractions in zenith distance.
21. Coefficients to apply to mean refractions for variations in barometer and temperature.
22. Coefficients for computing errors in azimuth due to small errors in declination or latitude.
23. Mean refractions in polar distance.
24. Trigonometric formulas for the solution of plane triangles.
25. Trigonometric formulas for the solution of stadia measurements, observations for time, latitude and azimuth, and problems in convergency.

EPHEMERIS OF THE SUN AND POLARIS, AND TABLES OF AZIMUTHS AND ALTITUDES OF POLARIS.

13. The above title has been given to a second supplement to the Manual which is published each year, a convenience which serves to supply the engineers with all necessary data relating to the daily positions of the sun and Polaris without requiring frequent revision of the text of the Manual or the Standard Field Tables. As a supplement to the Manual the data contained in the Ephemeris will be employed in preference to that contained in other publications over which the General Land Office has no control either as to accuracy or fitness for use in the public-land surveys.

on the subjects of [illegible] the determination of time, latitude, [illegible] ning of the true latitudinal curve, [illegible] is essential to the making of [illegible]

Owing to [illegible] much need for Manual treatment of [illegible] the many types of special surveys, and the details [illegible] tion of plats, which [illegible] Manual. These subjects [illegible] the change in the character of the [illegible] of marking the original [illegible] concerned in the identification and perpetuation of the boundaries already created.

[illegible] surveys. All other surveyors [illegible] times been employed in the surveying service of the [illegible] they are acting under somewhat different [illegible] lines between the provisions of the [illegible] that surveys and those [illegible] that have been [illegible]

12. There has been published by the General Land Office, [illegible] formulas entitled [illegible] The volume [illegible]

[illegible] corrections for [illegible]

3. Traverse table for the correction of random lines.

4. Traverse tables.

CHAPTER II.

INSTRUMENTS AND METHODS.

MEASUREMENTS.

14. The law prescribes the chain as the unit of linear measure for the survey of the public lands, and all returns of measurements are to be made in true horizontal distances, in miles, chains and links. The chain unit is known as the invention of Edmund Gunter, an English astronomer of the seventeenth century, and is especially convenient in computing areas in the unit of acres, one acre being equal to 10 square chains.

Units of linear measure.

1 chain=100 links.
=66 feet.
1 mile=80 chains.
=5,280 feet.

Units of area.

1 acre=10 square chains.
=43,560 square feet.
1 square mile=640 acres.

15. Each engineer will be provided with a standard and an assortment of 1, 2, 5 or 8-chain steel tapes. The standard tape will be employed for comparison with the field tapes, in order that errors in the latter may be noted and corrected. Before chainmen are intrusted with their actual duties they should be instructed by the chief of party, and required to measure over one or more trial lines of level and mountainous surface, to secure accuracy and uniformity of results.

16. It is essential to the record of a survey to state briefly at the beginning of the field notes, with every set of returns, the general manner of making measurements in the survey, and as topographical difficulties are encountered making it necessary to depart from the stated general method, it is desirable to record the plan of special measurement adopted. The field notes thus exhibit the manner of making all measurements, and the record should be such that another engineer retracing any line can substantially duplicate the exact procedure adopted in the original survey.

The following paragraphs are illustrative of the record to be made in the field notes:

"Unless otherwise specified all measurements are made with a Chicago 1-chain steel tape compared with a Chesterman standard steel tape and found correct."

"Unless otherwise specified all measurements are made with a Lallie 2-chain steel tape found correct by comparison with a Lufkin standard steel tape."

"Unless otherwise specified all measurements are made with a Lufkin steel tape 8 chains in length compared with a Chesterman standard steel tape and found correct. The measurements are made on the slope, the vertical angle determined, and the slope measurements properly reduced to true horizontal distances."

THE LONG STEEL TAPE.

17. The most approved method of measurement involves the use of steel ribbon tapes from 2 to 8 chains in length; in its use in the public-land surveys the tape is properly alined and stretched, and the measurements are made on the slope at any convenient distance up to the length of the tape as limited by the topography. The vertical angles of the lesser slopes are determined by the use of clinometers in the hands of the chainmen, while the vertical angles of the particularly sharp slopes are determined with the transit operated by the engineer. The slope distances are then reduced to true horizontal distances and the entire operation suitably recorded. It is not considered necessary to exhibit in the official field notes any but the true horizontal distances, omitting details, except where precise measurements are made of various bases for special use.

18. The following is an example of both field and final record for the use of the long steel tape and clinometer, and reductions by the use of the traverse tables (see Table 4, Standard Field Tables):

Field record.					Final field notes.	
Mean vertical angle.	Distance on slope.	True horizontal distance.	Intermediate measurement.	Difference in elevation.		
	Chains.	*Chains.*	*Chains.*	*Chains.*	*Chains.*	North, bet. secs. 19 and 24. Desc. 155 ft. over NW. slope, through scattering timber and dense undergrowth.
−12¼°	4.50	4.398		−0.95		
−17½°	2.20	2.098		− .66		
	6.70	6.496	3.80	− .75	10.30	Dry gulch, course W.; asc. 295 ft. over SW. slope.
				+ .75		
+ 8¼°	8.00	7.917		+1.15		
	14.70	14.413				
+19¾°	6.20	5.835		+2.10		
	20.90	20.248				
+ 7¾°	3.30	3.270		+ .44		
	24.20	23.518	0.00		23.50	Spur, slopes W.; desc. 185 ft. to 1/4 sec. cor., over NW. slope.
			1.20		24.70	Wagon road, bears E. and W.
			1.90		25.40	Leave undergrowth.
− 6½°	8.00	7.949		−0.91		
	32.20	31.467	1.15		32.60	Enter heavy timber, bears NW. and SE.
−10¼°	3.70	3.641		− .66		
	35.90	35.108				
−14 °	5.00	4.851		−1.21		
	40.90	39.959				
0 °	.04	.04				
	40.94	40.00				
	40.00	40.00			40.00	Set an iron post, etc.

19. A simplification of the reduction of measurements on the slope is obtained by the use of two diagrams constructed on cross-section paper, as follows: The first with the vertical lines representing intervals of 20 links measurement on the slope to 2, 5 or 8 chains to suit the length of tape used; the horizontal lines representing the correction in links to be made from the measurement on the slope to obtain the true horizontal distance; slanting lines are drawn to represent various degrees of slope scaled to the proper

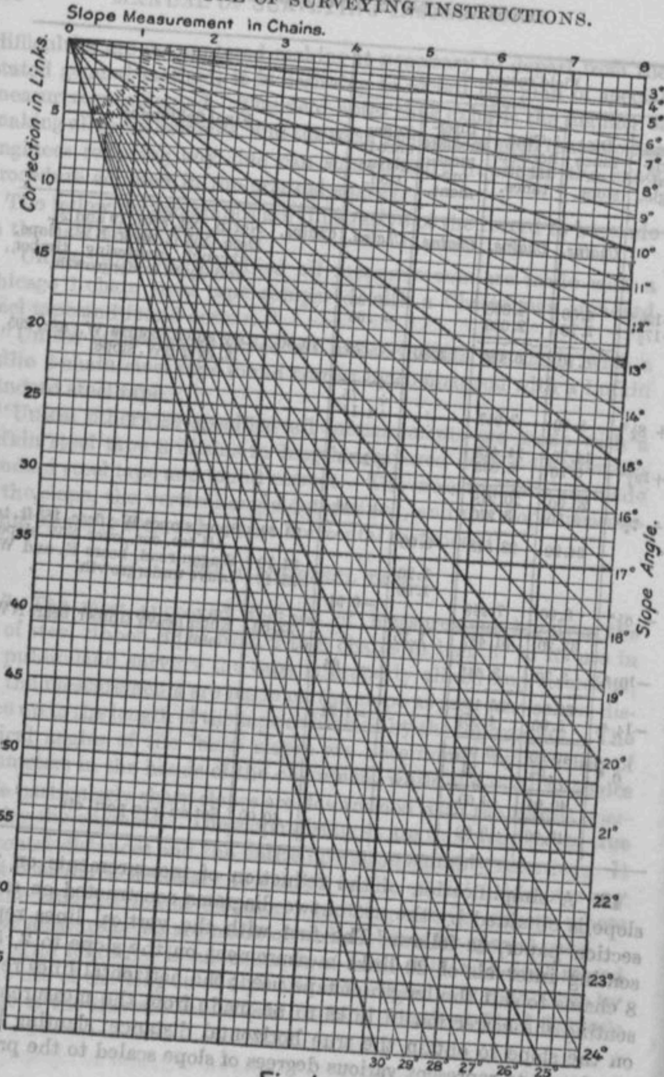


Fig. I.

Reduction from the slope to the horizontal.

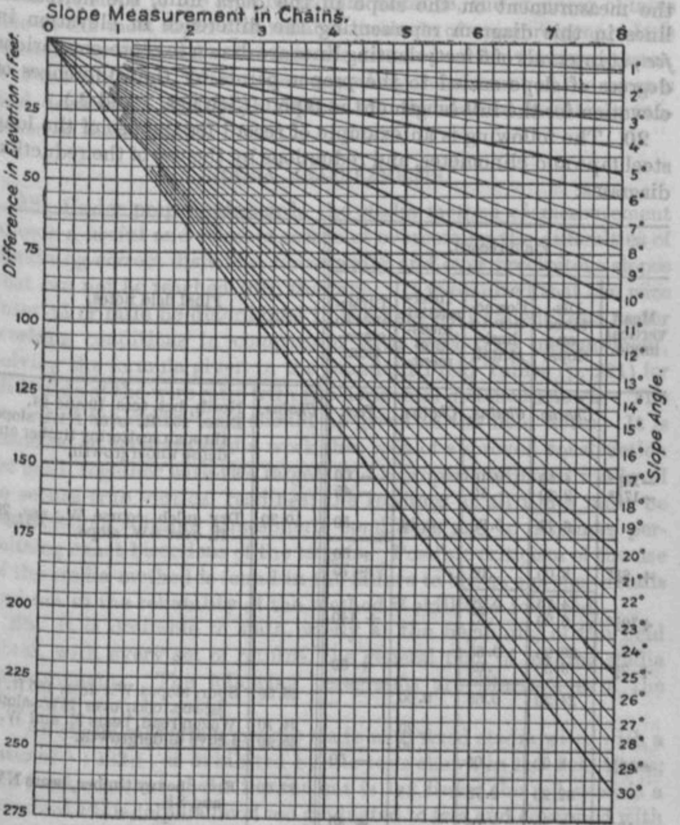


Fig. 2.

Reduction for difference of elevation.

points for the correction for the full length of the tape. The second diagram is constructed with the vertical lines representing similarly the measurement on the slope in the *chain* unit; the horizontal lines in this diagram representing the difference in elevation in *feet*, at intervals of 5 feet; slanting lines are drawn to represent various degrees of slope scaled to the proper points for the differences of elevation for the full length of the tape. (See figs. 1 and 2.)

20. The following is an example of record for the use of the long steel tape and clinometer, and reductions by the use of the reduction diagrams:

Field record.					Final field notes.	
Mean vertical angle.	Distance on slope.	Correction to horizontal.	Intermediate measurement.	Difference in elevation.		
	Chains.	*Chains.*	*Chains.*	*Feet.*	*Chains.*	North, bet. secs. 19 and 24. Desc. 155 ft. over NW. slope, through scattering timber and dense undergrowth.
−12¼°	4.50	0.10		− 60		
−17½°	2.20	.10		− 45		
	6.70	0.20	3.80	− 50	10.30	Dry gulch, course W.; asc. 295 ft. over SW. slope.
				+ 50		
+ 8¼°	8.00	.08		+ 75		
	14.70	0.28				
+19¾°	6.20	.37		+ 140		
	20.90	0.65				
+ 7¾°	3.30	.03		+ 30		
	24.20	0.68	0.00		23.50	Spur, slopes W.; desc. 185 ft. to ¼ sec. cor., over NW. slope.
			1.20		24.70	Wagon road, bears E. and W.
			1.90		25.40	Leave undergrowth.
− 6½°	8.00	.05		− 60		
	32.20	0.73	1.15		32.60	Enter heavy timber, bears NW. and SE.
−10¼°	3.70	.06		− 45		
	35.90	0.79				
−14 °	5.00	.15		− 80		
	40.90	0.94				
0 °	.04	.00				
	40.94	0.94				
	40.00	0.00			40.00	Set an iron post, etc.

21. By skillful use of the long steel tape on the slope, with correct determinations of the vertical angle, and proper reductions from the slope to the true horizontal distance, the engineer obtains one of the most rapid and reliable methods of measurement. It is essential to make all reductions for distance as the work progresses, but the additional information regarding the amount of the ascents and descents is readily obtainable from the record at the convenience of the engineer.

STADIA MEASUREMENTS.

22. Under proper safeguards the stadia method of measurement affords a useful and reliable means of overcoming the difficulties of obtaining correct distances across water and over precipitous slopes that can not be reached with the tape. It is required that the wire interval or ratio be determined in the field by frequent tests under working conditions in comparison with steel tape measurement, solving the formula given in the Standard Field Tables (p. 221) for the value of the wire ratio with the horizontal distance known. The record of the stadia tests should be given in the field notes. It is essential to accurate stadia work that rods of approved construction be used, together with two targets and a properly adjusted rod level to secure true vertical readings; the readings at all times must be restricted to suitable atmospheric conditions and to distances permitting exact bisections of the targets. Possible criticism of the use of the stadia method is found in the failure to observe proper details and not in the reliability of the method if skillfully followed.

23. It is desirable to state briefly at the beginning of the field notes, with every set of returns, the general plan of making stadia measurements. The following paragraphs are illustrative of the character of such record:

"All stadia measurements are made with fixed stadia wires with a ratio of 1 : 132±, as exhibited by the tests shown in the field notes; the focal constant of the instrument is 1.2 links; the rod used is a standard Philadelphia level rod graduated to feet and equipped with two targets and a rod level; all readings are made with a vertical rod."

"All stadia measurements are made with fixed stadia wires with a ratio of 1 : 100±, as exhibited by the tests shown in the field notes; the focal constant of the instrument is 1.2 links; the rod used is a standard Troy level rod graduated to feet and equipped with two targets and a rod level; all readings are made with a vertical rod."

24. Notation used in stadia measurements:

Hor. dist.: The true horizontal distance from the center of the instrument to the rod.

Diff. elev.: The true vertical distance from the height of the instrument to the center point between the two targets of the rod.

"r": Vertical rod reading.

"v": Observed vertical angle.

"K": The wire interval or ratio.

"c": Distance from the center of the instrument to the object glass.

"f": Distance from the plane of the cross-wires to the object glass.

Hor. dist. $= K\,r\,\cos^2 v + (c+f)\cos v$.

Diff. elev. $= K\,r\,\frac{1}{2}\sin 2v + (c+f)\sin v$.

Fig. 3

25. In Table 6, Standard Field Tables, the natural functions "$\cos^2 v$" and "$\frac{1}{2}\sin 2v$" are tabulated by intervals of 2′ for all angles from 0° 0′ to 28° 0′; these values become natural coefficients of the rod reading in the use of the vertical rod. In the same table are tabulated the natural products "$(c+f)\cos v$" and "$(c+f)\sin v$," for three values of "$(c+f)$" which may be considered as expressed in either the link or foot unit as convenient.

26. In public-land surveying it is convenient to have fixed stadia wires with a ratio of 1:132, so that the sum of two rod readings in feet will be equivalent to a ratio of 1:66, or a reduced distance in chains; it is also convenient to reduce the error in the wire interval to the error in 10 chains,* and to eliminate the error by applying to the reduced distance the proper correction taken from the table of proportional parts (Table 5, Standard Field Tables).

27. Example of test of stadia wire interval, the approximate ratio being 1:132, and the focal constant 1.2 links:

Field record.				Final field notes.
Measurement of base by steel tape and clinometer.			Vertical rod reading.	
Mean vertical angle.	Distance on slope.	True horizontal distance.		
	Chains.	*Chains.*	*Feet.*	June 11, 1911, I make the following test of the stadia wire interval: Horizontal length of base =14.066 chs. Mean of 10 rod readings = 6.9985 ft. Vertical angle of of test = −0° 40′ K=132.551 Reduced error in 10 chs. =4.1 lks. All corrections to be added to the distances given by the stadia.
−4½°	3.90	3.888	6.992	
−1¼°	8.00	7.998	6.998	
+7¾°	2.20	2.180	7.002	
			6.995	
Total base		= 14.066	7.003	
Focal constant		= .012	7.004	
			6.997	
Stadia base		= 14.054 chs.	6.995	
			7.001	
" "		=927.564 ft.	6.998	
Mean rod reading		=	6.9985	
Coefficient for 0° 40′		=0.9999;		
0.0001×6.9985		=	.0007	
$r \cos^2 v$		=	6.9978	
$K=\frac{927.564}{6.9978}=132.551$				
Measured base			=14.066 chs.	
6.9985 6.9985	=mean rod reading.			
13.997	=equivalent 1:66.			
13.997 ×0.9999=13.996			14.008 chs.	
$(c+f)$ = .012				
Error in 14.008 chs. by stadia			= 0.058 chs.	
Error in 10.00 chs. by stadia			= 0.041 chs.	

28. The error of the wire interval having been determined for a distance of 10 chains, the proportional error for any distance from 1 to 20 chains may be taken from Table 5, Standard Field Tables, thus eliminating all complex steps from the ordinary reductions of field observations.

Emphasis is placed upon the necessity for the above tests for accurate stadia work, and attention is directed to the probability that successive tests will show slightly increasing or decreasing values of the wire interval. It is not considered necessary to record in the official field notes any but the basic elements of stadia observations, omitting the details of the reductions.

29. The following example of record, with reductions added, is adapted to the instrument showing the above test of the wire interval, ratio 1:132 with an error of 4.1 links in 10 chains, and focal constant 1.2 links.

Field record.	Final field notes.	
	Chains.	N. 0° 02′ W., bet. secs. 15 and 16. Descend gradually over mountainous land.
	12.60	Rim of canon, bears NW. and SE.; precipitous descent of 170 ft. Stadia to left bank of creek: 3.194 and 3.212 ft., −26° 44′. Stadia to right bank of creek: 3.448 and 3.432 ft., −24° 10′. Stadia to right rim of canon: 4.914 and 4.895 ft., +4° 58′.
3.194 3.212 6.406×0.7976=5.109 Error + .021 $(c+f)\cos v$ + .011 12.60 +5.14 chs. 6.406×0.4018=2.574 chs. Diff. elev. =170 ft.	=17.74	Left bank of creek, 62 lks. wide, course NW.
3.448 3.432 6.880×0.8324=5.727 Error + .024 $(c+f)\cos v$ + .011 12.60 +5.76 chs. 5.14 chs. Width of creek =0.62 chs.	=18.36	Right bank of creek; precipitous ascent of 225 ft. to rim of canon.
4.914 4.895 9.809×0.9925=9.735 Error + .040 $(c+f)\cos v$ .012 12.60 +9.79 chs. 9.809×0.0863=0.847 chs. = 56 ft. +170 ft. Diff. elev. =226 ft.	=22.39	Rim of canon, bears NW. and SE.; asc. gradually.

30. Attention is directed to the fact that in making the above reductions in the chain unit, wire ratio 1:132, the process is at once resolved into taking the sum of the two rod readings in feet multiplied by the proper coefficient for vertical angle, to which product are applied the corrections for the error in the wire interval and for the horizontal value of the focal constant. As two rod readings should always be taken, one as a check upon the other, the entire operation becomes very simple. It should also be noted that in computing the difference of elevation no correction has been made for the height of the instrument above the ground, nor for the mean height of the rod reading; these corrections are compensating and ordinarily may be neglected, but in precise reductions must be considered. Therefore, in ordinary work in computing differences of elevation by the stadia method it is permissible to neglect the height of the instrument above the ground, the mean height of the rod reading, the error in the wire interval, and the term "$(c+f)\sin v$."

31. Many engineers prefer the conventional stadia wire ratio 1:100 generally adopted in miscellaneous surveying practice, using a rod graduated to feet. With an instrument so fitted for public-land surveys, in which the chain unit of horizontal distance is stipulated by law, the reduction is simplified by ascertaining the logarithm of $\frac{\text{"}K\text{"}}{66}$, rod in feet and horizontal distance in chains, accomplishing the reduction of "$K r \cos^2 v$" by logarithmic functions.

32. Example of test of stadia wire interval, the approximate ratio being 1:100, and the focal constant 1.2 links:

Field record.				Final field notes.
Measurement of base by steel tape and clinometer.			Vertical rod reading.	
Mean vertical angle.	Distance on slope.	True horizontal distance.		
	Chains.	*Chains.*	*Feet.*	
− 3¾°	6.40	6.386 chs.	9.515	July 7, 1915, I made the following test of the stadia wire interval: Horizontal length of base = 14.160 chs. Mean of ten rod readings = 9.5200 ft. Vertical angle of test = +1°54′ K = 98.193 log $\frac{K}{66}$, rod in feet and horizontal distance in chains = 0.172537
− 4½°	2.70	2.692	9.518	
+12¼°	5.20	5.082	9.522	
			9.519	
Total base		= 14.160	9.527	
			9.513	
$(c+f)$		= .012	9.521	
			9.524	
Stadia base		= 14.148 chs.	9.521	
" "		=933.768 ft.	9.520	
Mean rod reading =			9.5200	
Coefficient for 1°54′ =0.9989;				
0.0011×9.5200 =			.0105	
$r \cos^2 v$=			9.5095	

$$K=\frac{933.768}{9.5095}=98.193$$

log K=1.992081

" 66=1.819544

" $\frac{K}{66}$=0.172537

33. The following example of record, with reductions added, is adapted to the instrument showing the above test of the wire interval, ratio 1:98.193 and focal constant 1.2 links.

Field record.	Final field notes.	
	Chains.	North, bet. secs. 31 and 36. Over level land.
	14.20	Commence gradual ascent of 40 ft. to base of cliff. Stadia to top of cliff: mean 8.472 ft., +16° 40′.
	24.50	Base of cliff, bears N. 65° W. and S. 65° E.; ascend 190 ft. to top.
$\log \frac{K}{66} = 0.172537$ " $8.472 = 0.927986$ " $\cos^2 16° 40' = \begin{cases} 9.981361 \\ 9.981361 \end{cases}$ $\overline{1.063245}$ nat $\frac{K}{66}r \cos^2 v = 11.568$		
$(c+f) \cos v = .012$ $14.20 \quad + \overline{11.58}$ chs.	25.78	Top of cliff; thence over level mesa.
$\log K = 1.992081$ " $8.472 = 0.927986$ " $0.2748 = 9.439017$ $\overline{2.359084}$		
Diff. elev. = 228 ft. To bluff = 40 Cliff $= \overline{188}$ "		

34. Most of the General Land Office surveying instruments are equipped with fixed stadia wires of the ratio 1:132, which has been found well adapted to all practical purposes for which used, and enables the use of standard double target level rods graduated to feet. A few instruments have been provided with fixed stadia wires of the ratio 1:100, at special request, but rods graduated to links can not be furnished except upon special order, and are not purchased because they are useless except for the one purpose. Engineers can not expect to accomplish the best results where they graduate their own rods to suit a particular instrument or personal equation.

In authorizing the use of the stadia method in the public-land surveys it is not contemplated that the same will be made a substitute for steel tape measurement where the latter is practicable, but rather that the stadia method may be used as an expedient where natural obstacles are encountered over which the distance may be more accurately measured by the stadia than otherwise, provided that every safeguard is duly observed.

TRIANGULATIONS.

35. In making all triangulations for the purpose of obtaining measurements across water or over precipitous slopes, the engineer is expected to exercise his best judgment in the selection of the measured base, and he is required to adopt the best possible geometric proportions of the sides and angles of the triangle. A complete record of the measurement of the base, the determination of the angles, the location and direction of the sides, and any other essential details of the problem will be required in the field notes, together with a small diagram to graphically represent the triangulation, but it is not considered necessary to include in the official field notes the process of the solution. The method of triangulation at all times must be sufficiently refined to produce reliable results, and when necessary to determine the value of an angle of a triangle with a precision of less than the least reading of the instrument, the method of repetitions will be employed.

36. In its simplest form the method of repeating an angle consists in sighting upon a station, A, with the vernier of the horizontal circle set at zero; the angle is then turned to the second station, B; the *lower clamp* is now loosened and the telescope again set upon station A with the lower tangent motion *without disturbing the angle first turned*, after which the *upper clamp* is loosened and the angle turned a second time to station B. The angle is thus "repeated" two, three, or more times, and finally the multiple angle is read, which, when divided by the repeating factor, gives a value for the angle much closer than the least reading of the instrument. For example, assume an instrument reading to single minutes of arc, and that a certain angle has been repeated five times with a resulting reading of 124° 32′; this gives a value of 24° 54′ 24″ for the angle, which if skillfully done is unquestionably closer than a single reading. In surveys which may require even greater precision both verniers are read and the angle is repeated as nearly as practicable to one complete turn of 360°, when both verniers are again read. The observer then reverses the telescope, and duplicates the process by turning the angle in the opposite direction, to eliminate instrumental errors, and finally takes a mean of the resulting four readings, which is divided by the proper factor. It is occasionally necessary in public-land surveying to repeat angles by the latter method, but the former method is of more general use and will be found dependable and quickly executed.

37. The base lines for triangulations are to be carefully measured, even to tenths of links if necessary, and the sum of the angles should be balanced to 180°, or redetermined if the disagreement is found to exceed 1′ of arc.

38. The following examples, with the reductions added, are designed to illustrate the form of record of triangulations best suited for the official field notes:

(*a*) Field record.

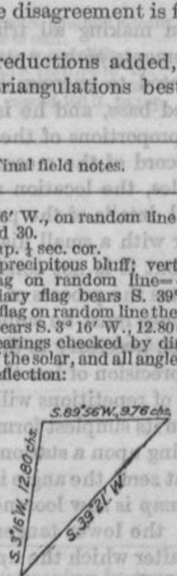
Angles.
50° 35′
93 20
36 05
180° 00′

Hor. meas. of base by one chain tape=12.80 chs.

$$\text{Dist.}=12.80\ \frac{\sin 36^\circ 05'}{\sin 50^\circ 35'}$$

log 12.80	=1.107210
" sin 36° 05′	=9.770087
	0.877297
" sin 50° 35′	=9.887926
" 9.76	=0.989371
Dist. by tri.	=9.76 chs.
log hor. dist.	=0.989371
" 66	=1.819544
" tan 32° 47′	=9.808916
" 415	=2.617831
Diff. elev.=415 ft.	

Final field notes.

Chains.	S. 89° 56′ W., on random line bet. secs. 19 and 30.
40.00	Set temp. ¼ sec. cor.
72.20	Top of precipitous bluff; vertical angle to flag on random line=−32° 47′; auxiliary flag bears S. 39° 21′ W.; from flag on random line the auxiliary flag bears S. 3° 16′ W., 12.80 chs. dist.; all bearings checked by direct reading of the solar, and all angles checked by deflection:
	
	Dist. on random line =72.20 chs. Dist. by triangulation = 9.76 81.96 Dist. by return meas. = 2.84 79.12
79.12	Intersect W. bdy. of Tp., 14 lks. S. of the cor. of secs. 19, 24, 25 and 30.
	Thence
	S. 89° 58′ E., on a true line bet. secs. 19 and 30.
	Ascend gradually in valley.
1.75	Base of bad-land bluff, bears N. and S.; precipitous ascent of about 400 ft.
6.92	Top of bad-land bluff, bears N. and S.; thence over level prairie.

(*b*) **Field record.**

NOTE.—Stadia wire ratio, 1:132.551; $(c+f)=1.2$ lks.

9.827
9.839

19.666
Error $=+.082$
$(c+f)=+.012$

Base $=19.76$

Angles.
79° 11′
33 03
67 46

180° 00′

$$\text{Dist.}=19.76\ \frac{\sin 67^\circ 46'}{\sin 33^\circ 03'}$$

log 19.76 = 1.295787
" sin 67° 46′ = 9.966447

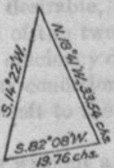
1.262234
" sin 33° 03′ = 9.736692

" 33.54 = 1.525542
Dist. by tri. = 33.54 chs.

Final field notes.

At the meander cor. at 57.30 chs. bet. secs. 16 and 17, a flag on Indian Island bears N. 18° 41′ W.; a point on a rock in the lake bears S. 82° 08′ W., stadia base to this point: 9.827 and 9.839 ft., level, measured base impracticable; from point on island, flag on rock in lake bears S. 14° 22′ W.; all bearings checked by direct reading of the solar, and all angles checked by deflection:

Length of base = 19.76 chs.
From meander cor. to island = 33.54 chs.



At the above point on Indian Island from which the meander cor. at 57.30 chs. bet. secs. 16 and 17, bears S. 18° 41′ E., 33.54 chs. dist.; I

Set a limestone, 28x10x6 ins., 21 ins. in the ground, for auxiliary meander cor. in sec. 8, mkd. S 8 on N., and A M C on S. face; from which

A spruce, 14 ins. diam., bears N. 42¼° E., 69 lks. dist., mkd. T 67 N R 43 W S 8 A M C B T.

A fir-balsam, 9 ins. diam., bears N. 14¼° W., 38 lks. dist., mkd. T 67 N R 43 W S 8 A M C B T.

(*c*) **Field record.**

Final field notes.

Chains.	
	5th Guide Meridian West, through T. 14 N., between Rs. 20 and 21 W.
	North, bet. secs. 13 and 18.
	Descend 225 ft. over NW. slope, through heavy timber and dense undergrowth.
	Difference between measurement of 27.80 chs., by two sets of chainmen, is 4 lks.; position of middle point by 1st set = 27.78 chs., by 2d " = 27.82 ", the mean of which is

(c) Field record, con.

$$\text{At } A = \frac{54^\circ\ 29'}{3} = 18^\circ\ 09'40''(-02'')$$

$$\text{“ } B = \frac{245^\circ\ 13'}{3} = 81^\circ\ 44'20''(-09'')$$

$$\text{“ } C = \frac{240^\circ\ 19'}{3} = \underline{80^\circ\ 06'20''(-09'')}$$

$$180^\circ\ 00'20''(-20'')$$

$$\text{Dist.} = 16.427\,\frac{\sin 80^\circ\ 06'\ 11''}{\sin 18^\circ\ 09'\ 38''}$$

$$\log 16.427 = 1.215558$$

$$\text{“ } \sin 80^\circ\ 06'\ 11'' = 9.993488$$

$$1.209046$$

$$\text{“ “ } 18^\circ\ 09'\ 38'' = 9.493710$$

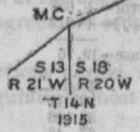
$$\text{“ } 51.92 = 1.715336$$

$$\begin{array}{r} 51.92 \\ +27.80 \\ \hline 79.72 \end{array}$$

Final field notes, con.

27.80 The south shore of Grand Lake, bears N. 62° E. and S. 48° W.

Set an iron post, 3 ft. long, 1 in. diam., 28 ins. in the ground, for meander cor. of frac. secs. 13 and 18, with brass cap mkd.



from which

A pine, 8 ins. diam., bears N. 84¾° E., 105 lks. dist., mkd. T 14 N R 20 W S 18 M C B T.

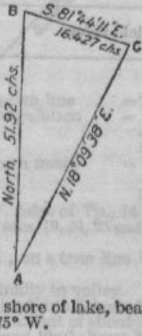
A pine, 10 ins. diam., bears S. 26½° W., 49 lks. dist., mkd. T 14 N R 21 W S 13 M C B T.

To make a triangulation across the lake I designate the above meander cor. point *A* and set a flag *B* at point for meander cor. on north shore of lake, also a flag *C* on the north shore which from point *A* bears N. 18° 09′ 38″ E.; the base *B C* bears S. 81° 44′ 11″ E., 16.427 chs. dist., the mean by two sets of chainmen,

by 1st set=16.425 chs.,
by 2d “ =16.429 “

longer base impracticable; the angle subtended at point *C*=80° 06′ 11″; all angles by three repetitions with error of 0′ 20″ balanced to 180°.

Distance across lake=51.92 chs.



79.72 The north shore of lake, bears S. 82° E. and N. 75° W.

39. In practical field work triangulations are made only to overcome physical difficulties of measurement, and under the conditions generally presented a right-angled triangle is likely to be less desirable than an oblique triangle as the latter may be selected to fit the best topography for the base line. A stadia base may likewise be superior to a measured base as, for example, in extremely rough mountainous regions where possibly no obstruction would interfere with a good stadia determination even though a steel tape measurement of the same base might be almost impossible, or involve great delay and expense. Under some conditions a double triangulation by independent bases may be highly desirable, one result as a check upon the other, whereby the mean of the two would be a better value than either result alone. True efficiency demands a choice of the best methods to suit the peculiar conditions encountered in each circumstance, and this must be left to the judgment of the engineer.

The subject of measurements is incomplete without a suggestion that each engineer should devise a system of signals by means of which numbers and directions may be readily communicated from one member of a party to another; such signals will be found especially useful in long steel tape and stadia measurements and triangulations.

INSTRUMENTS AND REQUIREMENTS AS TO THEIR ADJUSTMENT.

40. The direction of all lines of the public-land surveys will be determined with reference to the true meridian as defined by the axis of the earth's rotation. No departure from this rule is authorized. Beginning with the Manual of 1890 the use of the magnetic needle was prohibited except in subdividing and meandering, and then only in localities free from local attraction and with the use of suitably constructed needle instruments. The Manual of 1894 required that all surveys of the public lands of the United States, embracing all classes of lines, be made with reference to the true meridian, independently of the magnetic needle, and this prohibition against the use of the magnetic needle was even more pronounced in the Manual of 1902. In the modern instruments the length of the needle and other details relating to its construction are sacrificed in favor of the vastly more important details of design of the transit and solar attachment, and it is not presumed that the needle of the modern solar transit will give results even as reliable as those of a well-constructed needle compass. Many years' use of the solar transit and of the solar compass have proven that comparatively few localities are free from some local magnetic attraction. The needle has some value as a check and for approximate reference purposes under certain conditions, which need not be discussed in the Manual, but the use of the needle as a means of determining the direction of lines of the public-land surveys is now unqualifiedly prohibited.

41. Each engineer will be supplied with one or more instruments of approved construction suited to the conditions to be encountered in his field work. It is considered desirable to include in the record of every survey, at the beginning of the first book of field notes of every set of returns, a description of the instrument used and the general method by which the azimuth determinations were accomplished. The following paragraphs suggest the form of record to be made:

"Survey commenced August 1, 1915, and executed with a Buff 'Rocky Mountain Favorite' solar transit No. 9936, 1915 model, with U-shaped standards, 4½-inch horizontal circle, 4-inch vertical circle, and improved Smith solar attachment; all azimuth determinations are accomplished with the solar attachment except the special observations upon Polaris and the sun for meridian upon which to test the solar apparatus as stated in the field notes."

"Survey commenced July 28, 1909, and executed with a Young & Sons mountain transit, No. 8070, 1907 model; the instrument is equipped with a full vertical circle and the Smith solar attachment; unless otherwise specified all azimuth determinations are accomplished with the solar attachment."

"Survey commenced May 7, 1906, and executed with a Burt solar compass made by W. & L. E. Gurley, 1905 model; unless otherwise specified all azimuth determinations are accomplished with the solar compass. The Polaris observations in camp are made with a Keuffel & Esser mountain transit No. 9699, 1903 model."

42. The proper supervising officer will carefully examine all instruments to see that they are in first-class condition for field work, but the burden of the final test is placed upon the engineer who uses the instrument, as in every case the approval of an instrument will be made conditional upon satisfactory field test, the record of which will be stated in the field notes.

43. The record of the field test of the instrument should embrace a comprehensive statement of fact as to date, locality, and condition of the instrumental adjustments. The data relative to the independent observations for meridian should be included in the record, and the functions of apparent time, latitude and sun's declination will always be given in connection with the meridional tests of solar instruments. Various forms of record will be found in connection with the examples of observations and reductions given on the following pages.

44. When a transit without solar attachment is employed, Polaris observations, or direct altitude observations upon the sun, necessary to execute the work in accordance with existing law and the requirements of these instructions will be insisted upon. Observations upon Polaris, or direct altitude observations upon the sun, at frequent intervals, will be necessary to secure accuracy in the projection of transit reference lines, when solar apparatus is not used. The method of transferring the azimuth determined by the meridional observations to the surveyed lines will distinctly appear in the field notes.

45. Engineers using instruments with solar apparatus will be required to make azimuth observations on Polaris, or direct altitude observations upon the sun, at the beginning of every survey, to test the accuracy of the solar apparatus, and subsequent tests will be required at least at the beginning of the subdivision of every township.

46. A test at the conclusion of a survey is necessary in order to prove the continued proper projection of transit lines or the continued satisfactory adjustment of the solar apparatus during the survey. A book of field notes of the survey of standard lines, or of township exteriors, will therefore show preliminary and final azimuth observations for the projection of transit lines, or preliminary and final observations and tests for the adjustment of the solar apparatus, and intermediate tests to comply with the requirements of the preceding paragraphs. The satisfactory condition of the solar apparatus at the conclusion of the subdivision of a township executed with the solar apparatus may, if so desired, be shown by specific reference to the next succeeding test preliminary to commencing the subdivision of another township included in the same series of books of subdivisional notes. A careful engineer will make a sufficient number of tests to satisfy himself at all times of the accuracy of his alinement, but it is not intended to burden the engineer or the field notes with superfluous evidence in this particular matter.

GENERAL STATEMENT, TIME, LATITUDE, AND AZIMUTH.

47. When considering the following treatment of field methods of determination of time, latitude and azimuth, the engineer should bear in mind that a small error, either in assumed latitude or azimuth, produces only a slight effect in time, and when all are unknown the order of sequence in their determination should be that of time, latitude, and azimuth. Time may be readily determined by the engineer with an error not to exceed 10 seconds, while latitude and azimuth are readily determined with an error not to exceed 1′ 00″; the stated limits of error are not unreasonable where *any* of the methods herein described and authorized are employed; small errors in assumed longitude may be neglected in the determination of time, latitude, and azimuth.

The following methods are limited to observations upon the sun and the north star, Polaris, and are arranged to facilitate the engineer's work under all conditions encountered in the field without involving more than a practical understanding of astronomical technology. The tables and formulas published in the Standard Field Tables, and the complete daily ephemeris of the sun and Polaris and the tables of azimuths of Polaris, published in the "Ephemeris," are designed primarily for the convenience of the public-land engineers in the field, thus encouraging a general use of approved modern methods, consistent at all times with the engineer's clear understanding of underlying principles involved.

All reference to tables and formulas, or to the daily functions of the sun or Polaris, that follow herein, relate to the above supplements to the Manual, and when necessary to use conventional notation in the demonstrations that follow, the same agrees with that shown in detail in the Standard Field Tables.

With relation to the subject of records of observations as the same should appear in the official field notes of a survey, it must be granted that it is absolutely necessary to state all of the special basic functions of an observation, but it is quite unnecessary to include the process of reduction, except in unusual cases; thus the field notes should be complete in every respect, and it is the purpose to insist upon this requirement without involving that which is unessential to the record. In general also, no attempt is warranted by which the engineer may endeavor to make his results by analytical reduction appear to be more accurate than justified by the refinements of the observation upon which a determination is based; but it is good practice not to discard the various small elements, fractions or decimal parts of the record value of a function until the result is ascertained, whereupon the insignificant figures may be disposed of.

ANALYTICAL NOTATION, DECLINATION AND REFRACTION.

48. $\nless$: The symbol for approximation; this symbol signifies inequality, but it is used in a relation representing an inequality which approaches equality.

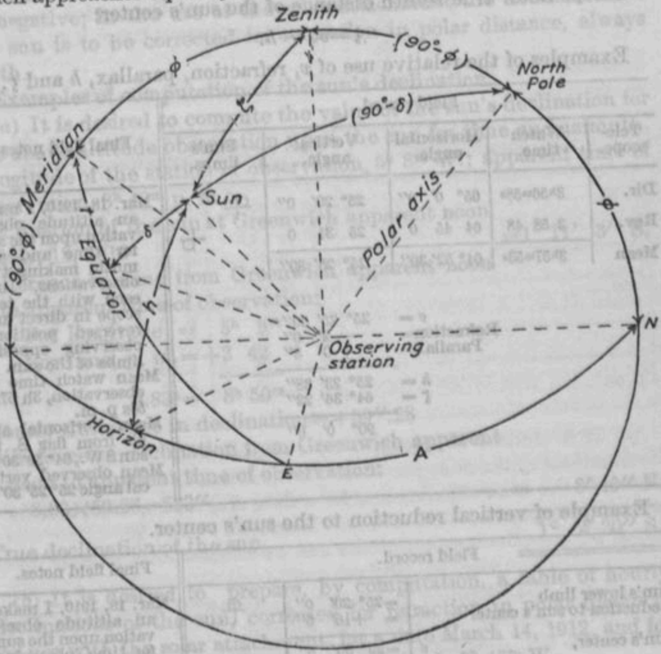


Fig. 4.

The "pole-zenith-sun" triangle as viewed from outside of the celestial sphere.

49. v: Observed vertical angle; in altitude observations on the sun, the reductions to the sun's center both vertically and horizontally, as well as instrumental errors, are eliminated by taking direct and reversed observations on the opposite limbs of the sun, and the mean observed vertical angle to the sun's center will be designated v in the notation. In single observations the vertical reduction to the sun's center=16′; a refinement is had by referring to the "Ephemeris" for the value of the sun's semi-diameter for the date of observation.

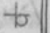
50. h: True vertical angle to the sun's center, or to Polaris, in altitude observations, after correction for refraction: $h=v-$refraction in zenith distance; a refinement is had in altitude observations on the sun by adding the value of the sun's parallax$=8''.9 \cos v$, opposite in effect to refraction, which results from the observer's position above the center of the earth.

51. ζ: Zeta: true zenith distance of the sun's center:

$$\zeta=90°-h.$$

Examples of the relative use of v, refraction, parallax, h and ζ.

Field record.

Telescope.	Watch time.	Horizontal angle.	Vertical angle.	Sun's limbs.
Dir.	$3^h 56^m 58^s$	65° 0′ 0″	25° 20′ 0″	
Rev.	3 58 48	64 45 0	25 31 0	
Mean	$3^h 57^m 53^s$	64° 52′ 30″	25° 25′ 30″	

v = 25° 25′ 30″
Refraction= − 2′ 0″
Parallax= + 0′ 8″
h = 25° 23′ 38″
ζ = 64° 36′ 22″
90° 0′ 0″

Final field notes.

Mar. 18, 1910, I make an altitude observation upon the sun for time and azimuth, making two observations, one each with the telescope in direct and reversed positions, observing opposite limbs of the sun.

Mean watch time of observation, 3h 57m 53s p. m.

Mean horizontal angle from flag S. to sun SW., 64° 52′ 30″.

Mean observed vertical angle 25° 25′ 30″.

Example of vertical reduction to the sun's center.

Field record.

Sun's lower limb Reduction to sun's center	=25° 20′ 0″ = +16′ 6″	
Sun's center, v	=25° 36′ 6″	

v =25° 36′ 6″
Refraction = − 2′ 0″
Parallax = + 0′ 8″
h =25° 34′ 14″
ζ =64° 25′ 46″
90° 0′ 0″

Final field notes.

Mar. 18, 1910, I make an altitude observation upon the sun for time, observing the sun's lower limb only; failing to observe the sun's upper limb in the reversal of the transit on account of clouds.

Watch time of observation, 3h 56m 58s p. m.

Observed vertical angle to sun's lower limb, 25° 20′ 0″, corrected to the sun's center=25° 36′ 6″.

52. ϕ: Phi: Latitude of the station of observation.

53. λ: Lambda: Longitude of the station of observation.

54. δ: Delta: Declination of the sun or Polaris; to be taken from the Ephemeris for the date of observation; the declination of the sun is to be corrected in hourly difference to the longitude of the station and to the time of observation; north declinations are treated as positive and south declinations as negative; a northerly hourly motion is treated as positive and a southerly hourly motion is treated as negative; in the use of the solar attachment the declination of the sun is to be corrected for refraction in polar distance, always north.

Examples of computation of the sun's declination.

(*a*) It is desired to compute the value of the sun's declination for the above altitude observation upon the sun for time and azimuth. Longitude of the station of observation, $5^h\ 8^m$ W.; apparent time of observation, $3^h\ 42^m$ p. m.:

Declination of the sun at Greenwich apparent noon
Mar. 18, 1910 =1° 11′ 3″ S.
Difference in time from Greenwich apparent noon
to apparent time of observation:
For longitude = $5^h\ 8^m$
For time, p. m. = +3 42
$8.83^h = 8^h\ 50^m$
Hourly difference in declination = +59″.28
Difference in declination from Greenwich apparent
noon to apparent time of observation:
8.83×59.28=523″ = 8′ 43″ N.
True declination of the sun 1° 2′ 20″ S.

(*b*) It is desired to prepare, by computation, a table of hourly declinations of the sun, corrected for refraction in polar distance, for use with the solar attachment, for a date March 14, 1912, and for a station in latitude 33° 10′ N., and longitude $7^h\ 47^m$ W.

2° 33′ 28″.6 S. = Declination of the sun at Greenwich apparent noon, Mar. 14, 1912.

Difference in time from Greenwich apparent noon to 7 a. m., local app. time:

For longitude = $7^h\ 47^m$

For time, a. m., $12^h - 7^h\ 0^m = (-)\ \underline{5\ \ 0}$

$2.78^h = 2^h\ 47^m$

Hourly difference in declinations = +59″.2.

2′ 44″.5 N. = Difference in declination from Greenwich apparent noon to 7 a. m., local apparent time: 2.78×59.2 = 164″.5.

2° 30′ 44″.1 S. = True declination of the sun, 7 a. m., local apparent time.

Local apparent time.	True declination.	Refraction.	Declination setting.
7 a. m.	2° 30′ 44″ S.	2′ 41″ N.	2° 28′ 3″ S.
7½	2 30 14	1 48	2 28 26
8	2 29 45	1 22	2 28 23
9	2 28 46	0 58	2 27 48
10	2 27 47	0 47	2 27 0
11 a. m.	2 26 48	0 43	2 26 5
Noon	2 25 49	0 41	2 25 8
1 p. m	2 24 50	0 43	2 24 7
2	2 23 51	0 47	2 23 4
3	2 22 52	0 58	2 21 54
4	2 21 53	1 22	2 20 31
4½	2 21 23	1 48	2 19 35
5 p. m.	2 20 54	2 41	2 18 13

(*c*) It is desired to prepare, by computation, a table of hourly declinations of the sun, corrected for refraction in polar distance, for use with the solar attachment, for a date August 12, 1912, and for a station in latitude 47° 10′ N., and longitude $7^h\ 24^m$ W.

15° 1′ 6″ N. = Declination of the sun at Greenwich apparent noon, Aug. 12, 1912.

Difference in time from Greenwich apparent noon to 6 a. m., local app. time:

For longitude = $7^h\ 24^m$

For time a.m.,

$12^h - 6^h\ 0^m = \underline{(-)6\ \ 0}$

$1.4^h = 1^h\ 24^m$

Hourly difference in declination = −45″.1.

1′ 3″ S. = Difference in declination from Greenwich apparent noon to 6 a. m., local apparent time: 1.4×45.1 = 63″.

15° 0′ 3″ N. = True declination of the sun, 6 a. m., local apparent time.

Local apparent time.	True declination.	Refraction.	Declination setting.
6 a. m.	15° 0′ 3″ N.	3′ 29″ N.	15° 3′ 32″ N
6½	14 59 40	2 22	15 2 2
7	14 59 18	1 46	15 1 4
8	14 58 33	1 9	14 59 42
9	14 57 48	0 52	14 58 40
10	14 57 3	0 42	14 57 45
11 a. m	14 56 18	0 39	14 56 57
Noon	14 55 33	0 37	14 56 10
1 p. m.	14 54 48	0 39	14 55 27
2	14 54 3	0 42	14 54 45
3	14 53 18	0 52	14 54 10
4	14 52 33	1 9	14 53 42
5	14 51 48	1 46	14 53 34
5½	14 51 26	2 22	14 53 48
6 p. m.	14 51 3	3 29	14 54 32

(*d*) A graphic method for ascertaining the changing declinations of the sun, corrected for refraction in polar distance, for use with the solar attachment, is obtained by the use of a diagram constructed on cross-section paper for each date, as follows:

The horizontal lines may be used to represent each hour of the day, and the vertical lines may represent intervals of 1′ in declination. It is convenient to use the right-hand side of the sheet to represent N., and the left-hand side of the sheet to represent S., or to have N. declinations increase numerically to the right-hand side of the sheet, and S. declinations increase numerically to the left-hand side of the sheet. The vertical lines are numbered to suit the range of declination of the sun for the date. Two points are marked on the diagram to agree with the true declination of the sun; the first point is marked with the argument of declination agreeing with the declination of the sun taken from the Ephemeris for Greenwich apparent noon and with the argument of time agreeing with the local apparent time corresponding to Greenwich noon; the second point is marked agreeing with the proper declination and time 10 hours later; the straight line determined by the two points agrees with the sun's true declination for the date for the local apparent time. The proper refractions in polar distance are then scaled from the straight line to the N. for each tabulated refraction, a. m. and p. m., taken from Table 23, Standard Field Tables, appropriate to the latitude of observation and declination of the sun; the locus of the latter points is a smooth curve representing graphically the declinations of the sun, corrected for refraction in polar distance, for use with the solar attachment. The scale of the refractions must equal the scale of the intervals of 1′ in declination, and the refractions are laid off along or parallel to the horizontal lines and *not* normal to the line of true declination. At any time throughout the day the proper declination for use with the solar attachment is obtained by reference to the curve at the point corresponding to the time of observation. To obtain any true value of the sun's declination for use in the reduction of *altitude observations* reference may be made to the straight line of true declination at the point corresponding to the time of observation.

The advantage of the diagram method is found in the practical elimination of errors of computation, and the ease with which it is checked, together with the fact that in the use of the diagram actual values are obtained at any time without any process of interpolation.

The following diagrams have been prepared to illustrate the method:

DIAGRAM OF THE SUN'S DECLINATIONS.

Date, Mar. 20, 1912.
Station: Lat.=37° 30′ N.
Long.=$7^h\ 30^m$ W.

Declination.

Greenwich noon=0° 11′ 14″ S.=$4^h\ 30^m$ a. m.
Diff. 10^h, +593″= 09 53 N.
0° 01′ 21″ S.=$2^h\ 30^m$ p. m.

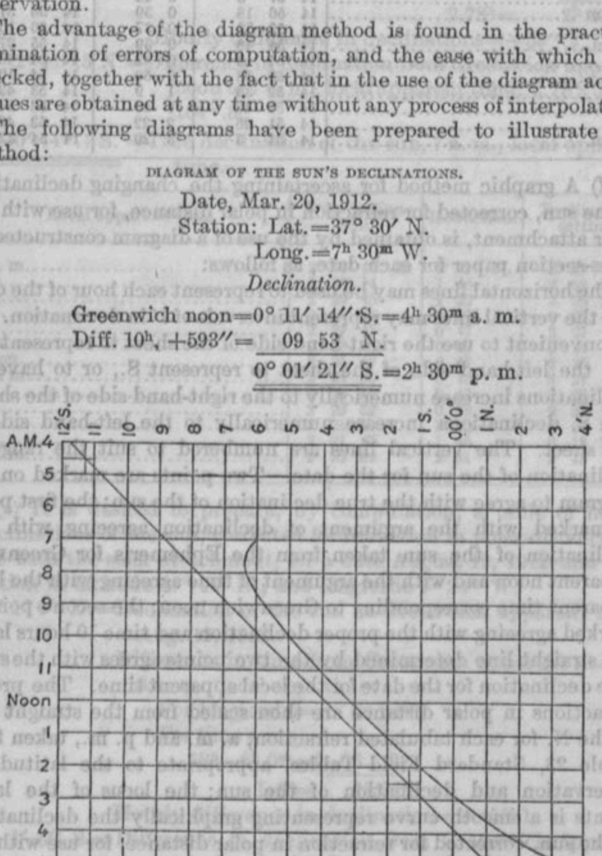


Fig.5.

DIAGRAM OF THE SUN'S DECLINATIONS.

Date, Sept. 23, 1913.
Station: Lat.=47° 30′ N.
Long.=6^h 18^m W.
Greenwich noon=0° 03′ 55″ N.=5^h 42^m a. m.
Diff. 10^h, −585″= 9 45 S.
0° 05′ 50″ S.=3^h 42^m p. m.

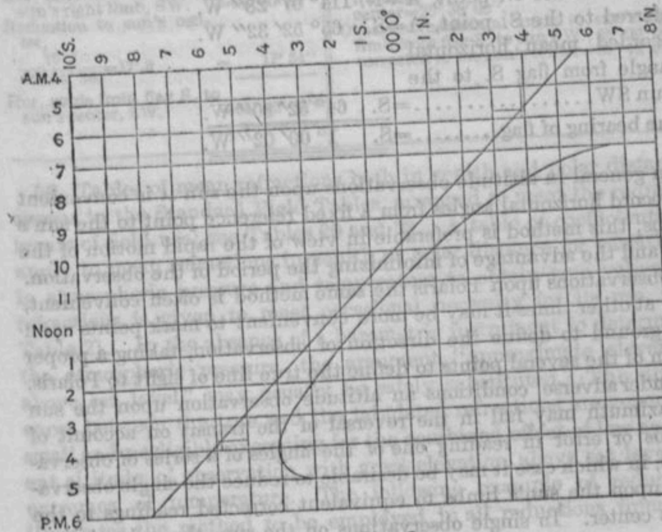


Fig. 6.

55. A: Azimuth angle from the true meridian to Polaris, or to the sun's center; in the following analytical examples A is referred to the north point unless otherwise noted, and the reductions are symmetrical either east or west of the meridian; all determinations for azimuth imply the recording of horizontal angles from a fixed reference point to Polaris or to the sun, or that a point has been marked on the ground to define the direction of observation; the mean horizontal angle in the first case, or the mean point in direction in the second instance, being used.

In the first of the foregoing examples of the relative use of v, h and ζ, is shown the record of certain observed horizontal angles from a fixed reference point to the sun's limbs, and now for the purpose of clearly stating the use of the notation A, the final reduction of that observation is here anticipated, in which the following result is obtained:

Sun's azimuth.

Referred to the N. point, A=N. 114° 07′ 28″ W.
Referred to the S. point, A=S. 65° 52′ 32″ W.
Recorded mean horizontal angle from flag S. to the sun SW..................=S. 64° 52′ 30″ W.
True bearing of flag.........=S. 1° 00′ 02″ W.

In general in altitude observations upon the sun it is convenient to record horizontal angles from a fixed reference point to the sun's limbs; this method is preferable in view of the rapid motion of the sun and the advantage of minimizing the period of the observation. In observations upon Polaris the same method is often convenient, and at other times it may be more convenient to mark points upon the ground to define the direction of observation, taking a proper mean of the several points to define the true line of sight to Polaris.

Under adverse conditions an altitude observation upon the sun for azimuth may fail in the reversal of the transit on account of clouds or error in reading one of the angles of a series of observations, in which case it may be desirable to reduce the single observation upon the sun's limbs to equivalent corrected readings to the sun's center. In single observations on the sun, the reduction to the sun's center in azimuth $=\frac{16'}{\cos v}$; a refinement in the value of the sun's semi-diameter is had by referring to the Ephemeris for the date of observation.

An example of reduction to the sun's center in both vertical and horizontal angles follows:

Field record.		Final field notes.
ꝗ Vertical angle to sun's lower limb	=25° 20′ 00″	Mar. 18, 1910, I make an altitude observation upon the sun for azimuth, observing the sun's lower and right limbs only; failing to observe the sun's upper and left limbs in the reversal of the transit on account of clouds: Apparent time of observation, 3h 42m p. m. Observed vertical angle to sun's lower limb, 25° 20′ 00″, corrected to the sun's center=25° 36′ 06″. Observed horizontal angle to sun's right limb from flag S. to sun SW., 65° 00′ 00″, corrected to the sun's center=64° 42′ 06″.
Sun's semi-diameter for reduction to center	= + 16′ 06″	
Sun's center, *v*	=25° 36′ 06″	
Hor. angle from flag S. to sun's right limb, SW.	=65° 00′ 00″	
Reduction to sun's center, $\frac{16'.1}{\cos 25^\circ 36'}=17'.9$	= 17′ 54″	
Hor. angle from flag S. to sun's center, SW.	=64° 42′ 06″	

56. Tables of mean refractions both in zenith and polar distance appear in the Standard Field Tables, arranged to meet the requirements of field use; see Tables 20 and 23. A table of coefficients to apply to mean refractions in zenith or polar distance for variations in atmospheric pressure and temperature to obtain true values of refractions is given to meet occasional necessity for its use, see Table 21. In the absence of a barometric instrument to determine the atmospheric pressure, the argument "approximate elevation above sea level" may usually be safely substituted. The differences between the true and the tabulated refractions are generally small and negligible excepting for the combined effect of low apparent altitude of observation with great elevation above sea level or extremes of temperature. The following example of reduction illustrates the method to be employed in all reductions from the tabulated refractions:

Tabulated refraction =6′ 45″=6′.75; elevation above sea level =10,000 feet, for which elevation the coefficient is 0.70; temperature at the time of observation =82° F., for which temperature the coefficient is 0.94; true refraction =0.70×0.94×6′.75=4′.44=4′26″.

TIME.

57. The element of time enters into all azimuth determinations to such an extent that the engineer should be able to arrive at the exact apparent time of all observations upon the sun and the exact local mean time of all observations upon Polaris. The sun's declination varies with the apparent time and the longitude west from

Greenwich, and enters directly into all observations upon the sun for azimuth; thus the apparent time and longitude should be known to a degree of accuracy commensurate with the refinement necessary in computing the sun's declination. The azimuth of Polaris varies with the local mean time of observation, which must be known to a degree of accuracy consistent with the result wanted in the determination of the true meridian. In observations upon Polaris at elongation precision in local mean time is unnecessary, but in hour angle observations upon Polaris it will be noted that at upper or lower culmination, in latitude 40° for example, Polaris varies 1′ in azimuth in about 2.5 minutes of time; this interval of time slowly increases toward elongation and in the latter position more than 30 minutes of time are required for a change of 1′ in azimuth.

58. Conversion of standard time into local mean time: watch reading ± watch error in standard time by comparison ± correction for longitude; the correction for longitude is additive east and subtractive west of the standard meridian of the time belt; the conversion table "degrees to time" (Table 18, Standard Field Tables) is convenient in this reduction.

Example of conversion of standard time into local mean time; longitude 77° 01′ 37″.5 W.:

Watch time of observation	$=6^h\ 26^m\ 40^s$ p. m.
Watch slow of 75th meridian standard time by comparison with a standard clock	$=\ +1^m\ 22^s$
Correction for longitude of station (77° 01′ 37″.5 W.$=5^h\ 08^m\ 06.5^s$)	$=\ -8^m\ 06^s$
Local mean time of observation	$=6^h\ 19^m\ 56^s$ p. m.

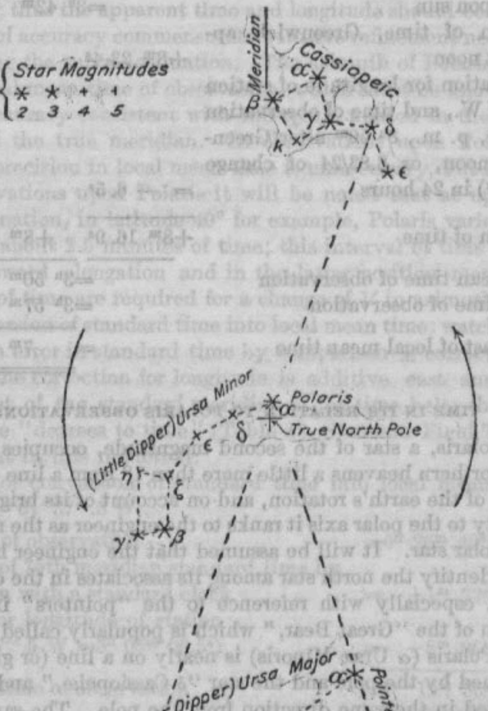
59. Conversion of apparent time into local mean time: apparent time of observation ± the equation of time; the equation of time is to be taken from the Ephemeris for the date of observation and corrected for the longitude and time of observation, conveniently interpolated as the interval from Greenwich noon to the time of observation; the watch error in local mean time is then found by taking the difference between the watch reading at the epoch of the observation and the reduced local mean time of observation.

Example of conversion of apparent time into local mean time; longitude 77° 01′ 37″.5 W.:

Mar. 18, 1910, apparent time of altitude observation upon sun		$=3^h\ 42^m\ 11^s$ p. m.
Equation of time, Greenwich apparent noon	$+8^m\ 23.4^s$	
Interpolation for longitude of station $5^h\ 08^m$ W., and time of observation $3^h\ 42^m$, p. m., $8^h\ 50^m$ after Greenwich noon, or 8.83/24 of change (17.64^s) in 24 hours	$= -6.5^s$	
Equation of time	$+8^m\ 16.9^s$	$+8^m\ 17^s$
Local mean time of observation		$=3^h\ 50^m\ 28^s$
Watch time of observation		$=3^h\ 57^m\ 53^s$
Watch fast of local mean time		$= 7^m\ 25^s$

TIME IN ITS RELATION TO POLARIS OBSERVATIONS.

60. Polaris, a star of the second magnitude, occupies a position in the northern heavens a little more than 1° from a line defined by the axis of the earth's rotation, and on account of its brightness and proximity to the polar axis it ranks to the engineer as the most useful circumpolar star. It will be assumed that the engineer has learned how to identify the north star among its associates in the clear starlit heavens, especially with reference to the "pointers" in the constellation of the "Great Bear," which is popularly called the "Dipper." Polaris (α Ursæ Minoris) is nearly on a line (or great circle) determined by the pole and the star "δ Cassiopeiæ," and both stars are located in the same direction from the pole. The same line (or great circle) passes near the star "ζ Ursæ Majoris" (another star of the "Dipper"), but the latter star is located on the *opposite* side of the pole. The engineer may note the relative position of the three stars aforementioned, if it is a clear night, and this will give an immediate indication of the approximate position of Polaris in its diurnal circle at such time of observation. The novice should secure field demonstration in these details from an experienced observer. The three stars named are all of about the same brightness. Instructions will follow (sec. 99) regarding the positive identification of Polaris by instrumental methods during the twilight period, before the star is visible to the naked eye, and the same process may



NAKED-EYE IDENTIFICATION OF POLARIS.

About noon March 23rd.
About 6 a. m. June 22nd.
About midnight September 22nd.
About 6 p. m. December 22nd.

be employed for verification of night observations, if there should be any doubt as in case the neighboring constellations are obscured by clouds.

A skillful engineer can readily observe Polaris at sunset or sunrise without artificial illumination, and with a very clear atmosphere can perform the observation when the sun is as much as 20 or 30 minutes above the horizon. At any time that Polaris is visible any one of the various methods of Polaris observation for meridian, properly followed, is superior to any form of observation upon the sun for the same purpose. In general, in public-land surveying, the best of all practices is found in the proper use of a solar instrument adjusted to the true meridian as established by Polaris observation.

Polaris has a diurnal circle about the earth's polar axis similar to the diurnal circle of other stars, though Polaris has the smallest circle of any naked-eye star. The daily circuit of Polaris is covered in one sidereal day of 24 sidereal hours, or an equivalent of 23 hours 56 minutes 4.09 seconds of mean solar time. In its diurnal circle Polaris crosses the meridian twice, once at upper culmination, or above the polar axis, and once at lower culmination, or below the polar axis.

The direction of the apparent motion of Polaris is suggested by the following diagram:

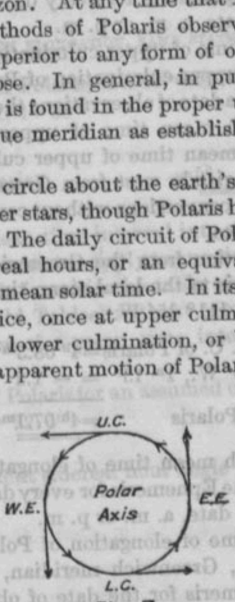


Fig. 7.

The pointings of the arrows on the above circle indicate the direction of the apparent motion of Polaris in its diurnal path, while the pointings of the arrows on the lines tangent to the circle show the direction of travel at the epochs of culmination and elongation. If the engineer has any doubt in regard to the quadrant occupied by Polaris in its diurnal circle at the time of an observation, he may set the intersection of the telescope cross-wires exactly upon the star, then, without moving the instrument, note the direction of the star's motion and compare with the diagram.

plify the text. By this means one confusing step in the problem relating to hour angles for positions of Polaris east of the meridian is avoided. Polaris crosses the meridian at lower culmination at an hour angle of $11^h\ 58^m\ 02^s$, and in the arrangement of the various examples, the observations west of the meridian have been referred to the last preceding upper culmination, and those east of the meridian have been referred to the next succeeding upper culmination, thus avoiding the introduction of any hour angles exceeding $11^h\ 58^m\ 02^s$.

Examples of computing hour angles of Polaris; all taken out for longitude 117° 15′ W.:

West of the meridian, p. m. obsn., U. C. in p. m.

L. M. T. of obsn., Feb. 18, 1911 $=5^h\ 20.1^m$ p. m.
Gr. U. C. same date $=3^h\ 36.5^m$ p. m.
Red. to long. 117° 15′ W.= $-\ 1.3$ $=3\ \ 35.2$ p. m.
Hour angle of Polaris, west $=1^h\ 44.9^m$

West of the meridian, p. m. obsn., U. C. in a. m.

L. M. T. of obsn., May 14, 1911 $=\left\{\begin{array}{l}+12\\ 7^h\ 12.4^m \text{ p. m.}\end{array}\right.$
Gr. U. C. same date $=10^h\ 02.1^m$ a. m.
Red. to long. 117° 15′ W.= -1.3 $=\ 10\ \ 0.8$ a. m.
Hour angle of Polaris, west $=\ 9^h\ 11.6^m$

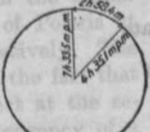
West of the meridian, a. m. obsn., U. C. in p. m.

L. M. T. of obsn., Nov. 3, 1911		$\begin{cases} +12 \\ = 6^h\ 31.6^m \text{ a. m.} \end{cases}$
Gr. U. C., Nov. 2	$=10^h\ 43.9^m$ p. m.	
Red. to long. 117° 15′ W.	−1.3	=10 42.6 p. m.
Hour angle of Polaris, west		$= 7^h\ 49.0^m$

West of the meridian, a. m. obsn., U. C. in a. m.

L. M. T. of obsn., Aug. 11, 1911		$= 5^h\ 05.9^m$ a. m.
Gr. U. C., same date	$=4^h\ 13.6^m$ a. m.	
Red. to long. 117° 15′ W.	−1.3	= 4 12.3 a. m.
Hour angle of Polaris, west		$= 0^h\ 53.6^m$

East of the meridian, p. m. obsn., U. C. in p. m.



Gr. U. C., Dec. 20, 1911	$= 7^h\ 34.8^m$ p. m.
Red. to long. 117° 15′ W.	= −1.3
L. M. T. of U. C., Dec. 20	= 7 33.5 p. m.
L. M. T. of obsn., same date	= 4 35.1 p. m.
Hour angle of Polaris, east	$= 2^h\ 58.4^m$

East of the meridian, p. m. obsn., U. C. in a. m.

Gr. U. C., Sept. 2, 1911 $= 2^h\ 47.4^m$ a. m.
Red. to long. 117° 15′ W. $= \quad -1.3$

L. M. T. of U. C., Sept. 2 $\begin{cases} = 2\ \ 46.1 \text{ a. m.} \\ +12 \end{cases}$

L. M. T. of obsn., Sept. 1 $= 6\ \ 34.0$ p. m.

Hour angle of Polaris, east $8^h\ 12.1^m$

East of the meridian, a. m. obsn., U. C. in p. m.

Gr. U. C., Mar. 19, 1911 $= 1^h\ 42.1^m$ p. m.
Red. to long. 117° 15′ W. $= \quad -1.3$

L. M. T. of U. C., Mar. 19 $\begin{cases} = 1\ \ 40.8 \text{ p. m.} \\ +12 \end{cases}$

L. M. T. of obsn., same date $= 6\ \ 06.6$ a. m.

Hour angle of Polaris, east $= 7^h\ 34.2^m$

East of the meridian, a. m. obsn., U. C. in a. m.

Gr. U. C., May 18, 1911	$= 9^h\ 46.4^m$ a. m.
Red. to long. 117° 15′ W.	$= \ \ -1.3$
L. M. T. of U. C., May 18	= 9 45.1 a. m.
L. M. T. of obsn.	= 4 42.9 a. m.
Hour angle of Polaris, east	$= 5^h\ 02.2^m$

67. By reference to the preceding diagram showing the direction of motion of Polaris in its diurnal circle, the motion at western elongation is shown to be vertically downward, and at eastern elongation the motion is shown to be vertically upward. At the epoch of either western or eastern elongation the motion of Polaris in azimuth is zero.

At the equator, if Polaris could be observed, the hour angle of Polaris at elongation would be 90° 0′ 0″$=6^h\ 0^m\ 0^s$ sidereal hour angle$=5^h\ 59^m\ 1.02^s$ mean time hour angle, but as stations of observation are occupied in the higher latitudes the hour angle of Polaris at elongation decreases progressively. The reason for this is found in the fact that all vertical planes intersect at the zenith, and the point of tangency of a vertical plane with the diurnal circle of Polaris occurs at points corresponding to decreasing hour angles with the higher latitudes. The "spread" of the two vertical planes intersecting Polaris at eastern and western elongation increases with the higher latitudes, giving increasing azimuths at elongation with the more northern latitudes.

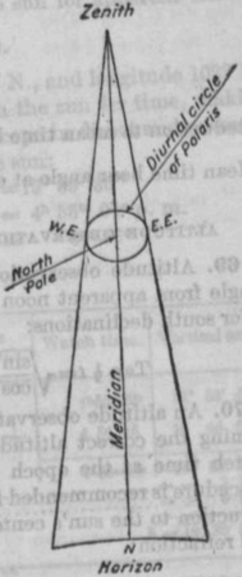


FIG. 8.—The meridian and vertical planes tangent to the diurnal circle of Polaris as viewed from inside of the celestial sphere.

68. Mean time hour angle of Polaris at elongation: t=the sidereal hour angle in angular measure; this converted into time measure, and this in turn converted from a sidereal time interval into a mean time interval gives the mean time hour angle of Polaris at elongation:

$$\text{Cos } t = \text{cotan } \delta \tan \phi$$

Example of computing the mean time hour angle of Polaris at elongation, April 3, 1915, in latitude 65° 0′ N., on which date the declination of Polaris=88° 51′ 20″ N.:

$\phi=65^\circ\ 0'$;	log tan ϕ	$=0.331327$
$\delta=88^\circ\ 51'\ 20''$;	" cotan δ	$=8.300530$
	" cos t	$=8.631857$
Sidereal hour angle		$=87^\circ\ 32'\ 41''$
		$87^\circ=5^h\ 48^m$
		$32'=\ 2^m\ 08^s$
		$41''=\ 3^s$
		$=5^h\ 50^m\ 11^s$
Reduction to mean time hour angle		$=-0^m\ 57^s$
Mean time hour angle at elongation		$=5^h\ 49^m\ 14^s$

ALTITUDE OBSERVATION OF THE SUN FOR APPARENT TIME.

69. Altitude observation of the sun for apparent time: t=hour angle from apparent noon in angular measure; reverse the signs of δ for south declinations:

$$\text{Tan } \tfrac{1}{2}\, t=\sqrt{\frac{\sin \frac{1}{2}(\zeta+\phi-\delta) \sin \frac{1}{2}(\zeta-\phi+\delta)}{\cos \frac{1}{2}(\zeta+\phi+\delta) \cos \frac{1}{2}(\zeta-\phi-\delta)}}$$

70. An altitude observation of the sun for time is made by determining the correct altitude of the sun's center and recording the watch time at the epoch of observation. The following order of procedure is recommended for the elimination of instrumental errors, reduction to the sun's center, and practical elimination of differential refraction:

A. M. OBSERVATION.

Thoroughly level the transit.

Observe the sun's upper limb, recording the watch time of observation and vertical angle.

Reverse the transit.

Observe the sun's lower limb, recording the watch time of observation and vertical angle.

The mean vertical angle is equivalent to the vertical angle to the sun's center corresponding to the mean epoch of the watch readings.

P. M. OBSERVATION.

Thoroughly level the transit.

Observe the sun's lower limb, recording the watch time of observation and vertical angle.

Reverse the transit.

Observe the sun's upper limb, recording the watch time of observation and vertical angle.

The mean vertical angle is equivalent to the vertical angle to the sun's center corresponding to the mean epoch of the watch readings.

Example of altitude observation of the sun for apparent time:

Final field notes.

August 24, 1909, in latitude 37° 16′ 50″ N., and longitude 102° 12′ W., I make an altitude observation upon the sun for time, making two observations, one each with the telescope in direct and reversed positions, observing opposite limbs of the sun:

Mean observed vertical angle $=19° 39' 30''$
Mean watch time of observation$=$ $4^h 56^m 04^s$ p. m.
Watch slow of local mean time $=$ $0^m 56^s$

Field record.

Telescope.	Sun's limbs.	Watch time.	Vertical angle.
Direct	$\underline{\odot}$	$4^h 55^m 22^s$	19° 33′ 00″
Reversed	$\overline{\odot}$	4 56 46	19 46 00
Mean		$4^h 56^m 04^s$	19° 39′ 30″$=v$
Refraction			$= -$ 2 40
Parallax			$= +$ 0 08
			$h = 19° 36' 58''$

$$\begin{array}{ll}
\text{True vertical angle} & = h = 19°37' \\
\text{Zenith distance} & = \zeta = 70°23' \\
\text{Sun's declination} & = \delta = 11°05'\text{N.}
\end{array}$$

$$\begin{array}{rlllrl}
\zeta = & 70°23' & & & \zeta = & 70°23' \\
\phi = & \underline{37\ 17} & & & \phi = & \underline{37\ 17} \\
(\zeta+\phi) = & 107°40' & & & (\zeta-\phi) = & 33°06' \\
\delta = & \underline{11°05'}\ (+) & & & \delta = & \underline{11°05'}\ (+) \\
 & & \tfrac{1}{2}\text{ values} = & & & \\
(\zeta+\phi+\delta) = & 118°45' & 59°22'30'' & 22°05'30'' & (\zeta-\phi+\delta) = & 44°11' \\
(\zeta+\phi) = & 107°40' & & & (\zeta-\phi) = & 33°06' \\
\delta = & \underline{11\ 05}\ (+) & & & \delta = & \underline{11\ 05}\ \ (+) \\
(\zeta+\phi-\delta) = & 96°35' & 48°17'30'' & 11°00'30'' & (\zeta-\phi-\delta) = & 22°01'
\end{array}$$

$$\begin{array}{llll}
\log \sin \tfrac{1}{2}(\zeta+\phi-\delta) = & & 9.873054 & \\
\text{“}\ \ \sin \tfrac{1}{2}(\zeta-\phi+\delta) = & & \underline{9.575291} & \\
\text{“}\ \ \cos \tfrac{1}{2}(\zeta+\phi+\delta) = & 9.707073 & 9.448345 & \\
\text{“}\ \ \cos \tfrac{1}{2}(\zeta-\phi-\delta) = & \underline{9.991934} & & \\
 & 9.699007 & \underline{9.699007} & 73° = 4^{h}52^{m} \\
\text{“}\ \ \tan^2 \tfrac{1}{2}t \quad = & & 9.749338 & 41' = \quad 2^{m}44^{s} \\
\text{“}\ \ \tan\ \tfrac{1}{2}t \quad = & & 9.874669 & 24'' = \quad \underline{\quad 2^{s}} \\
\tfrac{1}{2}t = 36°50'42'' & t = 73°41'24'' & & t = 4^{h}54^{m}46^{s}
\end{array}$$

$$\begin{array}{ll}
\text{Apparent time of observation} & = 4^{h}54^{m}46^{s}\text{ p. m.} \\
\text{Equation of time} & \quad \underline{+2\ 14} \\
\text{Local mean time of observation} & = 4^{h}57^{m}00^{s}\text{ p. m.} \\
\text{Watch time of observation} & = \underline{4\ 56\ 04}\text{ p. m.} \\
\text{Watch slow of local mean time} = & \quad 0^{m}56^{s}
\end{array}$$

MERIDIAN OBSERVATION OF THE SUN FOR APPARENT NOON.

71. *Meridian observation of the sun for apparent noon.*—With the telescope in the meridian elevated to the sun's altitude, the watch times of transit of the sun's west and east limbs are noted, the mean of which is the watch time of apparent noon; if the observation fails for either limb the reduction to the sun's center is accomplished by adding or subtracting 68 seconds; a refinement in the amount of this time is had by referring to the Ephemeris for the time of the sun's semi-diameter passing the meridian for the date of observation; the setting for the approximate altitude of the sun's center is:

$$v \nleq 90° - \phi \pm \delta$$

OBSERVING PROGRAM.

Determine the meridian by the best means at hand and compute the altitude setting for the sun.

Level the transit, place the instrument in the meridian, and elevate the telescope to the altitude of the sun's center.

Note the watch time of the sun's west limb tangent to the vertical wire.

Note the watch time of the sun's east limb tangent to the vertical wire.

Take the mean of the readings for the watch time of apparent noon from which to compute the watch error local mean time.

Example of meridian observation of the sun for apparent noon:

Final field notes.

August 14, 1909, in latitude 37° 16′ N., and longitude 102° 16′ W., with the telescope in the meridian and elevated to the sun's altitude, I observe the sun's transit for time, noting the watch time of transit of each limb:

Mean watch time of apparent noon $= 12^h\ 00^m\ 27^s$
Watch slow of local mean time $= 4^m\ 06^s$

Field record.

$$\begin{array}{lll} \text{Setting:} & & 90°\ 00' \\ & \phi \nleq & (-)\ 37°\ 16'\ \text{N.} \\ & \delta \nleq & (+)\ 14°\ 25'\ \text{N.} \\ \hline & v \nleq & 67°\ 09' \end{array}$$

◖| Watch time of transit, W. limb $= 11^h\ 59^m\ 22^s$
|◗ Watch time of transit, E. limb $= 12\ \ 01\ \ 32$

Watch time of apparent noon $= 12^h\ 00^m\ 27^s$

Apparent noon $= 12^h\ 00^m\ 00^s$
Equation of time $= +\ 4\ \ 33$

Local mean time of apparent noon $= 12\ \ 04\ \ 33$

Watch slow of local mean time $= 4^m\ 06^s$

The above form of meridian observation of the sun for apparent noon is by far the most convenient reliable method of time observation.

TIME FROM THE SOLAR ATTACHMENT.

72. Several of the approved forms of solar apparatus, including principally the Smith solar attachment and the Burt solar compass, have a graduated arc or circle mounted normal to the polar axis to indicate the apparent time of observation. The reading of the time arc is most conveniently checked by comparison with the above form of meridian observation of the sun for apparent noon. An error in the reading of the time arc or hour circle may be corrected by adjusting the circle, or allowed for as an index error. The reading of the hour circle may then be safely accepted as giving correct apparent time for use in computing or taking out required declinations of the sun for the various forms of solar observations. A proper reading of the hour circle may be safely accepted to indicate apparent time at which moment the watch reading may be noted, and the watch error *local mean time* determined as shown in the preceding example of conversion of apparent time into local mean time; this result derived for the *watch error local mean time* may then be safely used in observations on Polaris at *elongation*, but for observations upon Polaris by the *hour angle method* the time should be determined by one of the more refined methods already given.

LATITUDE.

73. It is absolutely necessary in the operation of any solar attachment to employ the correct latitude of the station, and in general in altitude observations upon the sun for azimuth or time the latitude must be well determined. In the public-land surveying practice all determinations of either time or latitude are an important part of the program of operations only so far as these functions finally enter into the establishment of the true meridian; all classes of observations given in the Manual have been arranged to facilitate the performance of solar instruments, and for this purpose a definite knowledge of the true latitude is highly important. No lack of reasonable precision should be allowed in the accepted latitude. The various forms of observations for latitude are very simple and a considerable series should be taken in every group of surveys, all reduced to the township boundaries for comparison, until a satisfactory mean has been obtained.

MERIDIAN ALTITUDE OBSERVATION OF THE SUN FOR LATITUDE.

74. *Meridian altitude observation of the sun for latitude.*—Reverse the sign of δ for south declinations:

$$\phi=90^\circ+\delta-h$$

The following observing program is recommended:

Thoroughly level the transit and place the telescope in the meridian elevated to the sun's approximate altitude at noon.

Observe the altitude of the sun's lower limb with the sun slightly east of the meridian.

Reverse the transit.

Observe the altitude of the sun's upper limb with the sun slightly west of the meridian.

Take the mean observed vertical angle for the altitude of the sun's center at apparent noon.

The following is an example of meridian altitude observation of the sun for latitude:

Final field notes.

October 5, 1909, in approximate latitude 37° 20′ N., and longitude 102° 04′ W., I make a meridian altitude observation of the sun for latitude, observing the altitude of the sun's lower limb with the telescope in direct position, reversing the transit and observing the sun's upper limb:

Apparent time of observation, noon	$=12^h\ 00^m\ 00^s$
Mean observed altitude	$=47°\ 59'\ 45''$
Reduced latitude	$=37°\ 19'.3$ N.

Field record.

Setting:		90° 00′
	$\phi \nleq (-)$	37° 20′ N.
	$\delta \nleq (-)$	4° 42′ S.
	$v \nleq$	47° 58′
Lower limb		47° 42′
Upper limb		48° 14′

$\underline{\odot}$ Observed alt., lower limb, tel. dir. $=47°\ 43'\ 00''$

$\overline{\odot}$ Observed alt., upper limb, tel. rev. $=48°\ 16'\ 30''$

Mean observed altitude, v	$=47°\ 59'\ 45''$
Refraction	$-\ 0\ 52$
Parallax	$+\ 0\ 06$
	$h=47°\ 58'\ 59''$
	$\delta=\ 4\ \ 41\ \ 42$ S.
$\phi=37°\ 19'.3$ N. $=90°-\delta-h$	$=37\ \ 19\ \ 19$
	$90°\ 00'\ 00''$

75. The above-described observation is conveniently combined with the meridian observation of the sun for time, by observing simultaneously the sun's lower and west limbs, recording the watch time and the vertical angle and reversing the transit in the interval of about 2 minutes, and then observing simultaneously the sun's upper and east limbs. The settings for the approximate altitudes of the sun's lower and upper limbs, respectively, are:

$$v \neq 90^\circ - \phi \pm \delta \mp 16'$$

Example of meridian observation of the sun for time and latitude:

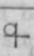
Final field notes.

June 8, 1910, in approximate latitude 38° 54′ N., and longitude 77° 01′.6 W., I make a meridian observation of the sun for time and latitude, observing simultaneously the altitude of the sun's lower limb and the transit of the sun's west limb, reversing the telescope and observing simultaneously the altitude of the sun's upper limb and the transit of the sun's east limb:

Mean observed altitude $=73^\circ\ 55'\ 30''$
Reduced latitude $=38^\circ\ 53'.7$ N.
Mean watch time of observation $=12^h\ 06^m\ 40^s$
Watch fast of local mean time $=\ 7^m\ 58^s$

Field record.

Setting: $90^\circ\ 00'$
$\phi \neq$ $(-)\ 38^\circ\ 54'$ N.
$\delta =$ $(+)\ 22^\circ\ 49'$ N.
$v \neq$ $73^\circ\ 55'$
Lower limb $73^\circ\ 39'$
Upper limb $74^\circ\ 11'$

Position of telescope.	Position of sun.	Watch time transit.	Observed vertical angle.
Direct		$12^h\ 05^m\ 37^s$	73° 42′ 30″
Reversed		12 07 42	74 08 30
Mean		$12^h\ 06^m\ 40^s$	73° 55′ 30″
Refraction			= −16
Parallax			= +02
h			= 73° 55′ 16″
$\delta = 22^\circ\ 49'\ 00''$; $90^\circ + \delta$			= 112 49 00
$\phi = 38^\circ\ 53'.7$ N. $= 90^\circ + \delta - h$			= 38° 53′ 44″

Watch time of apparent noon......$=12^h$ 06^m 40^s
Apparent noon.....$=12^h$ 00^m 00^s
Equation of time..$=$ $-$ 1 18

Local mean time of apparent noon.$=11$ 58 42

Watch fast of local mean time.....$=$ 7^m 58^s

The known latitude of the above station is 38° 53′ 40″, but it can not be assumed that any one altitude observation of the sun will always give a result so close to the true latitude. In general a better determination of the latitude by this method is possible only by making a series of observations on successive days, or by combining the result with Polaris observations for latitude.

For the purpose of a test as to the accuracy of the above time observation, the same watch was compared with a Western Union telegraph clock as follows:

75th meridian time of comparison.$=12^h$ 00^m 00^s
Correction for longitude 77° 1.6′...$=$ -08 06

Local mean time of comparison...$=11^h$ 51^m 54^s
Watch time of comparison........$=11$ 59 56

Watch fast of local mean time.....$=$ 8^m 02^s

ALTITUDE OBSERVATION OF POLARIS FOR LATITUDE.

76. *Altitude observation of Polaris at upper culmination for latitude:*

$$\phi=h+\delta-90^\circ$$

Altitude observation of Polaris at lower culmination for latitude: The mean time hour angle of Polaris at lower culmination is 11 hours 58 minutes 2 seconds:

$$\phi=h+90^\circ-\delta$$

The settings for the approximate altitude of Polaris at upper and lower culminations, respectively, are:

$$v\neq\phi\pm(90^\circ-\delta)$$

The following program is recommended in altitude observations of Polaris at culmination for latitude.

Compute the local mean time and watch time of culmination.

Thoroughly level the transit.

About four minutes before culmination observe the altitude of Polaris with the telescope in direct position.

Reverse the transit and observe the altitude of Polaris.

Again level the transit.

Observe the altitude of Polaris with the telescope in the reversed position.

Reverse the transit to the direct position of the telescope and again observe the altitude of Polaris.

Take the mean observed altitude to use in the reduction.

Example of altitude observation of Polaris at lower culmination for latitude:

Final field notes.

June 19, 1910, in approximate latitude 38° 54′ N., and longitude 77° 01′.6 W., I make an altitude observation on Polaris at lower culmination for latitude, making four observations, two each with the telescope in direct and reversed positions:

Watch fast of 75th meridian standard time by comparison = $0^m\ 24^s$

Mean watch time of observation = $7^h\ 44^m\ 37^s$ p. m.

Mean observed vertical angle = 37° 44′ 00″

Reduced latitude = 38° 53′.4 N.

Field record.

Setting: 90° 00′

$$\delta \approx 88°\ 49'$$

$$90° - \delta \approx 1°\ 11'$$

$$\phi \approx 38°\ 54'$$

$$v \approx 37°\ 43' = \phi - (90° - \delta)$$

Gr. U. C. of Polaris, June 19, 1910 = $7^h\ 39.7^m$ a. m.

Reduction to longitude 77° 1.6′ W. = −0.8

Reduction to lower culmination = +11 58.0

$7^h\ 36.9^m$ p. m.

L. M. T. of L. C. of Polaris, June 19 = $7^h\ 36^m\ 54^s$ p. m.

Watch fast of 75th meridian standard time by comparison with a Western Union telegraph clock = + 0 24

Correction for longitude 77° 01′.6 W. = + 8 06

Computed watch time of lower culmination = $7^h\ 45^m\ 24^s$ p. m.

Telescope.	Watch time.	Vertical angle.
Direct	$7^h\ 40^m\ 14^s$	37° 42′ 30″
Reversed	7 42 45	37 44 30
Reversed	7 46 39	37 45 30
Direct	7 48 50	37 43 30
Mean	$7^h\ 44^m\ 37^s$	37° 44′ 00″
Refraction		−1 15
		h=37° 42′ 45″
δ=88° 49′ 20″; 90°−δ		= 1 10 40
ϕ=38° 53′.4 N.=h+(90°−δ)		=38° 53′ 25″

76–A. To find the latitude by an altitude observation of Polaris at any hour angle, see section 133–A, page 131.

AZIMUTH.

THE SOLAR ATTACHMENT.

77. The solar attachment to the engineer's transit has been designed for instrumentally setting off the sides of the "pole-zenith-sun" triangle in agreement with their angular values at the station and time of observation. The sun's image may be brought into the line of collimation of an auxiliary telescope by orientation of the transit to the position where the instrumental parts are made parallel to the respective sides of the celestial triangle, whereupon the vertical plane of the "pole-zenith" arc of the solar attachment will coincide with the true meridian. Skillfully handled, the solar attachment will give at once close approximations to the true meridian comparing favorably for accuracy with direct observations. The advantage in the proper use of the solar attachment is found in its rapid and close determinations of the meridian in heavy timber, dense undergrowth, and strong wind, in low swamp or on high mountain ascents, and under nearly all other difficult physical situations encountered in the field, avoiding in its proper use accumulative errors incident to the prolongation and deflection of transit lines, and deviations in the azimuth of latitudinal lines. On the public-land surveys, the Smith solar attachment, designed in 1880 by Benjamin H. Smith, a United States surveyor of Colorado, has given the most general satisfaction. The later models, as perfected, have been adopted as the standard instrument of the General Land Office cadastral surveying service.

A description of the standard model of the Smith solar attachment is here given in order to preface a discussion of the theory, adjustment, test, and use of the instrument. A description of only one other solar instrument is included owing to the wide differences of design, and the impossibility of a general treatment of the adjustments, test, and use, without an elaboration of the subject beyond the purpose of the Manual. If nonstandard instruments are supplied to the engineers, the proper supervising officer will furnish suitable instructions regarding their adjustment and use.

DESCRIPTION.

78. The working parts of the Smith solar attachment consist of five fundamental features, each performing its own distinctive function. The principles involved have been adapted to various types of construction, and the efficiency of the different designs is related directly to the perfection which may be attained in making a proper adjustment in the field, the stability of the adjustments when made, and the compactness of the design, considering protection to the working parts and proper distribution of weight. The five fundamental working parts consist of:

1. An auxiliary telescope whose line of collimation is the polar axis of the solar attachment; the telescope may be revolved in collar bearings which are securely mounted on a vertical limb.
2. The vertical limb is mounted on a horizontal axis and has a graduated latitude arc in its vertical plane.
3. A plane mirror at the objective end of the auxiliary telescope with an axis normal to the line of collimation, and an arm leading to a graduated declination arc.
4. An hour circle on the auxiliary telescope mounted normal to the line of collimation.
5. A set of equatorial wires parallel to the axis of the reflector.

In all the forms of construction of the Smith solar attachment the auxiliary telescope is mounted in a vertical plane parallel to the transit telescope. Thus, if the instrument is in proper adjustment and oriented to the true meridian, the polar axis of the solar attachment may be made parallel to the earth's polar axis by setting off the true latitude of the station. The sun's rays are brought into the auxiliary telescope by means of the mirror, due allowance being

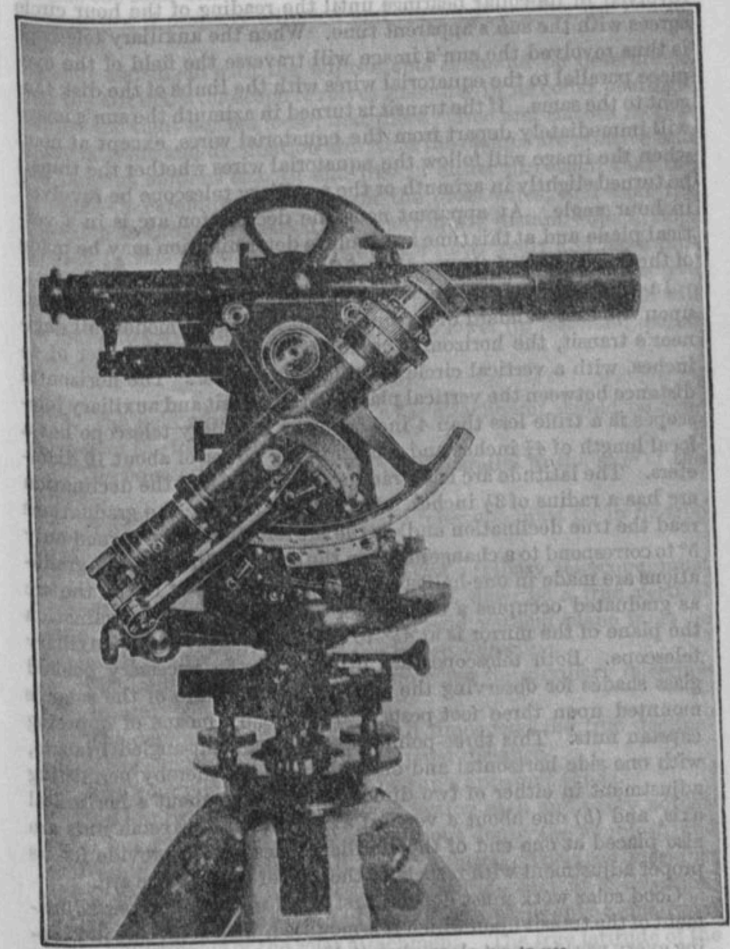


FIG. 9.—The solar transit as it appears in use.

made for the sun's declination north or south of the equator, but to bring the sun's image into the auxiliary telescope the latter must be revolved in its collar bearings until the reading of the hour circle agrees with the sun's apparent time. When the auxiliary telescope is thus revolved the sun's image will traverse the field of the eyepiece parallel to the equatorial wires with the limbs of the disk tangent to the same. If the transit is turned in azimuth the sun's image will immediately depart from the equatorial wires, except at noon when the image will follow the equatorial wires whether the transit be turned slightly in azimuth or the auxiliary telescope be revolved in hour angle. At apparent noon the declination arc is in a vertical plane and at this time an absolute determination may be made of the correctness of the reading of this arc.

In the modern construction the solar attachment is mounted upon the east standard of a regular light mountain model full engineer's transit, the horizontal circle of which has a diameter of 4½ inches, with a vertical circle of 4 inches diameter. The horizontal distance between the vertical planes of the transit and auxiliary telescopes is a trifle less than 4 inches. The auxiliary telescope has a focal length of 4¾ inches and a magnifying power of about 10 diameters. The latitude arc has a radius of 3 inches, and the declination arc has a radius of 3½ inches. Upon the latter arc the graduations read the true declination and, as the mirror needs to be turned only 5° to correspond to a change of 10° in the sun's declination, the graduations are made in one-half space, i. e., an interval of 10° on the arc as graduated occupies a segment of only 5°. At zero declination the plane of the mirror is at 45° to the line of sight of the auxiliary telescope. Both telescopes are fitted with the necessary colored glass shades for observing the sun. The base plate of the solar is mounted upon three foot posts, adjustable by means of opposing capstan nuts. This three-point base forms a right-angled triangle, with one side horizontal and one side vertical, thereby permitting adjustment in either of two directions: (*a*) One about a horizontal axis, and (*b*) one about a vertical axis. Suitable capstan nuts are also placed at one end of the auxiliary telescope to provide for its proper adjustment with respect to the axis of the latitude arc.

Good solar work must depend first of all upon the proper adjustment of the transit upon which it is mounted, with great care in keeping every working part cleaned, suitably oiled to work smoothly, and protected from adverse weather and injury. The same precautions are due the solar attachment. It will give very efficient meridional performance if properly adjusted and operated; nothing less can be conceded.

Before starting in with the adjustments it should be determined that the auxiliary telescope revolves smoothly in its collar bearings, neither too tight nor too loose; that there is free and smooth motion to the latitude and declination arcs; that the clamps are positive and the tangent motions smooth and free in either direction; that the eye-piece is carefully focused upon the cross wires; and that the objective is carefully focused upon any quite distant object, then secured in this position. The eye-piece turns freely and has a pin which travels in a guide slot; this pin is not a clamp. The objective may be moved by first loosening, then pushing the screw, which will be found to travel in a guide slot near the lower (or left hand) collar bearing.

ADJUSTMENT.

79. The field adjustments of the solar attachment should be considered in the following order:

1. The equatorial wires must be made parallel to the axis of the reflector.

2. The line of sight of the auxiliary telescope must lie in its true turning axis.

3. The polar axis, or line of sight of the auxiliary telescope, must be normal to the axis of the latitude arc, describe a true vertical plane when turning on said axis, and said vertical plane must be parallel to the vertical plane of the transit telescope.

4. The latitude arc should read zero when the auxiliary telescope is horizontal.

5. The declination arc should at all times read the true declination of the sun plus the refraction in polar distance.

6. The hour circle should read the sun's apparent time.

There are two or more methods of testing each and every adjustment, but those stated below are without doubt the simplest, and most rapid and reliable of all field methods. The true meridian should be established by Polaris or other independent observation, upon which to test the solar, but otherwise it plays only a small part in the adjustments of the solar attachment. The true latitude of the station must be definitely known. There should be a clear view to a distant object in the horizon, but if an object less than a mile away must be utilized due allowance may be made for the horizontal distance between the vertical planes of the transit and auxiliary telescopes.

1. *The equatorial wires.*—Set up the instrument as in a regular solar observation, setting off the known latitude, declination and apparent time, and bring the sun's image accurately between the equatorial wires by orienting the transit approximately to the meridian, in which position the instrument should be clamped. (See fig. 9.) Turn the auxiliary telescope in hour angle, causing the sun's image to travel across the field from side to side. If the image follows the equatorial wires accurately the latter are parallel to the axis of the reflector as required. If the sun's image departs materially from the equatorial wires, the capstan screws which hold the diaphragm should be loosened and the reticle may be rotated until the equatorial wires are made to agree with the path of the sun's image across the field, then return each capstan screw to a proper seat.

2. *Collimation of the auxiliary telescope.*—Swing the mirror to give a direct view through the auxiliary telescope. (See fig. 10.) Set the line of sight on a distant point and clamp the instrument. Revolve the auxiliary telescope 12 hours in hour angle. If the line of sight remains fixed on the distant point it agrees with the turning axis as required. If after revolution, the line of sight appears to be above or below, or to the right or left, of the distant point, one-half of the differences should be taken up with the capstan screws which control the diaphragm. The test should be repeated until the auxiliary telescope is in perfect collimation.

3. *The polar axis.*—Carefully level the transit and then sight the main telescope to the distant point and clamp the instrument; sight toward the same point with the auxiliary telescope, and place the striding level on the latitude axis. (See fig. 10.) The striding level should be reversed to see if there is any error in the level itself, and if so take the mean position for the true indication of the level. If the latitude axis is not horizontal it may be made so by adjusting the lower pair of capstan nuts on the base frame of the solar attachment. If the line of sight of the auxiliary telescope is not parallel to that of the main telescope it may be made parallel by means of the left-hand upper pair of capstan nuts on the base frame of the solar. After fulfilling the foregoing conditions turn the transit 180° in azimuth and reverse both telescopes so as to sight again to the same distant object,

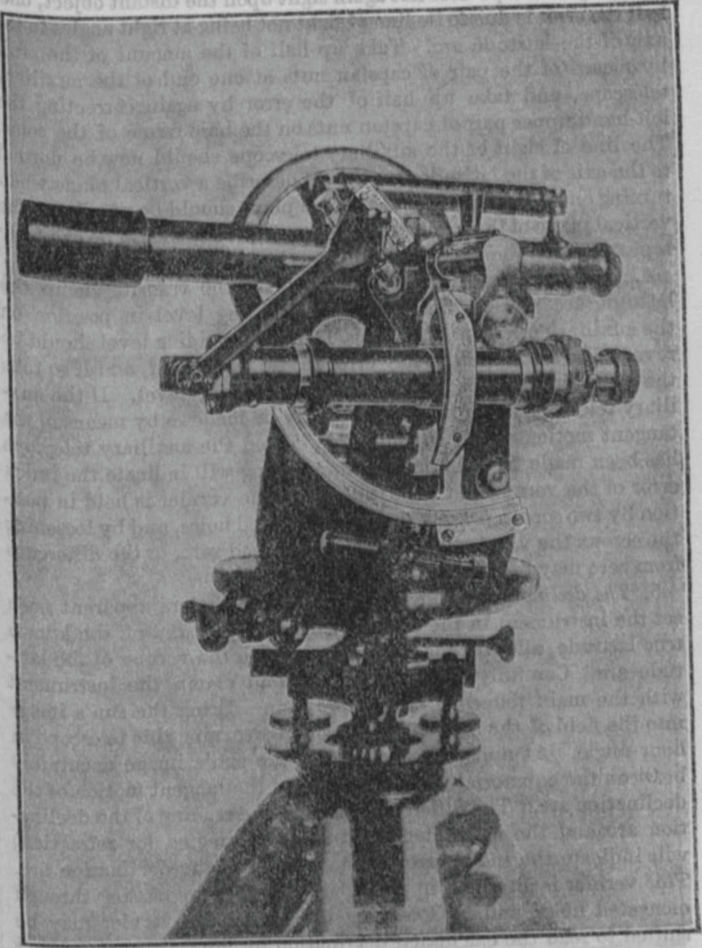


FIG. 10.—Direct sighting through the auxiliary telescope, with the mirror swung to a central position, and showing the striding level on the latitude axis.

setting the main telescope upon the object. (See fig. 11.) If the auxiliary telescope does not again sight upon the distant object, one-half the error is due to its line of sight not being at right angles to the axis of the latitude arc. Take up half of the amount of the error by means of the pair of capstan nuts at one end of the auxiliary telescope, and take up half of the error by again correcting the left-hand upper pair of capstan nuts on the base frame of the solar. The line of sight of the auxiliary telescope should now be normal to the axis of the latitude arc, should describe a vertical plane when turning on said axis, and said vertical plane should be parallel to the vertical plane of the transit telescope. The tests should be carefully repeated until the adjustments are perfected.

4. *The latitude vernier.*—Carefully level the transit, clamp the latitude arc at zero, and place the striding level in position on the auxiliary telescope. (See fig. 12.) The striding level should be reversed to see if there is any error in the level itself, and if so take the mean position for the true indication of the level. If the auxiliary telescope is not horizontal it may be made so by means of the tangent motion of the latitude arc. When the auxiliary telescope has been made truly horizontal the reading will indicate the index error of the vernier of the latitude arc. The vernier is held in position by two screws passing through elongated holes, and by loosening the screws the vernier may be shifted to read zero, or the difference from zero may be carried as an index error.

5. *The declination vernier.*—A few minutes before apparent noon set the instrument in the established meridian. Set off the known true latitude, allowing for any index error in the vernier of the latitude arc. Carefully level the transit and clamp the instrument with the main telescope in the meridian. Bring the sun's image into the field of the auxiliary telescope by turning this telescope in hour angle. At apparent noon bring the sun's image accurately between the equatorial wires by means of the tangent motion of the declination arc. The difference between the reading of the declination arc and the calculated declination (corrected for refraction) will indicate the index error of the vernier of the declination arc. This vernier is also held in position by two screws passing through elongated holes, and by loosening the screws the vernier may be shifted to read the calculated declination for apparent noon of that date, or the difference may be carried as an index error. This test should be made every day the instrument is used. If by some

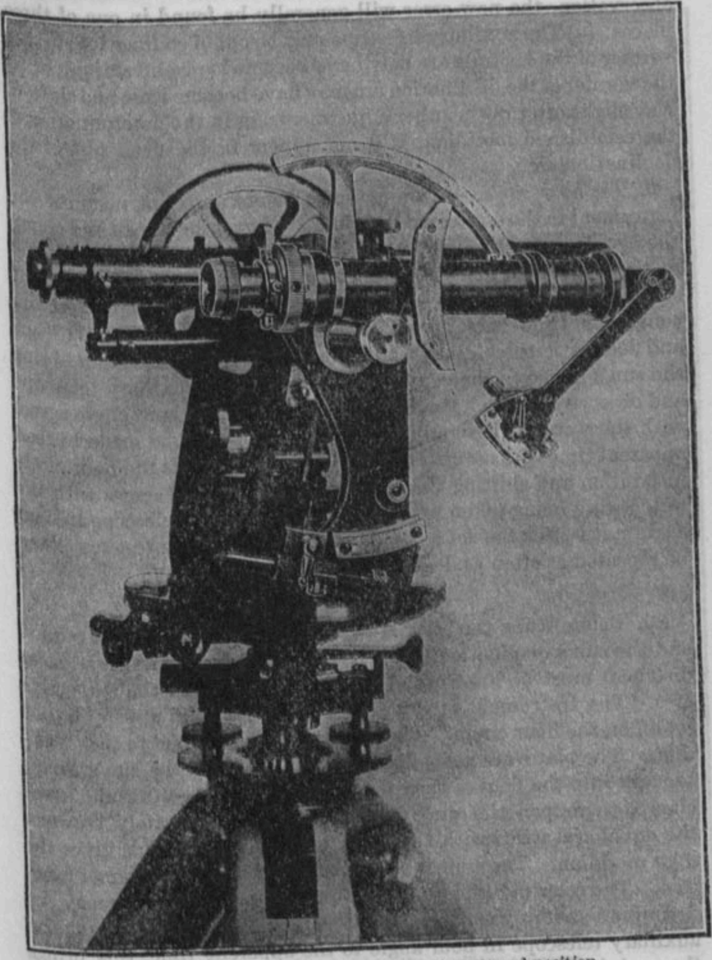


FIG. 11.—The auxiliary telescope in reversed position.

failure in the adjustments of the solar attachment a difference of as much as $30''$ from previous tests should be discovered in the noon observation, the new error will generally be found in one of three places: (*a*) The auxiliary telescope may be out of collimation; (*b*) the vernier of the latitude arc may have become loose and shifted; or (*c*) the vernier of the declination arc may have become loose and shifted. Any slight error in the other adjustments, or in the determination of the established meridian, will not appear in the noon test of the declination arc.

6. *The hour circle.*—A few minutes before apparent noon set the instrument in the established meridian. Level the transit and clamp the instrument with the main telescope in the meridian and elevated to the sun's altitude. Set your watch to read 12 o'clock as the sun's center crosses the vertical wire of the main telescope. At any convenient time thereafter set off the proper readings on the latitude and declination arcs, and with the instrument in the meridian, bring the sun's image to the center of the field of the auxiliary telescope and observe the watch time. If the reading of the hour circle agrees with the watch it is in adjustment; if not, it may be made to read apparent time by loosening the set screw which holds the hour circle in position and shifting the circle until the reading agrees with the watch, care being taken not to move the auxiliary telescope in hour angle until after the set screw is again seated. The test may then be repeated as often as desirable.

USE.

80. Before using the solar attachment the latitude of the station and the sun's declination (properly corrected for refraction in polar distance) must be known and accurately set off on the respective arcs. The instrument is carefully leveled and the apparent time set off on the hour circle. The transit is then oriented to the meridian. The plates are generally first set at zero and the sun's image brought into the field of the solar telescope before setting the lower clamp; thereupon the sun's image is brought accurately between the equatorial wires with the lower tangent motion; this gives the solar meridian. The transit may then be used for any normal function. The solar meridian may be tested as many times as may be desirable by simply setting the plates back to zero and turning the auxiliary telescope in hour angle to the apparent time; this brings the sun's image again to the center of the field. The sun's declination is constantly changing at a very slow rate, so that it is necessary

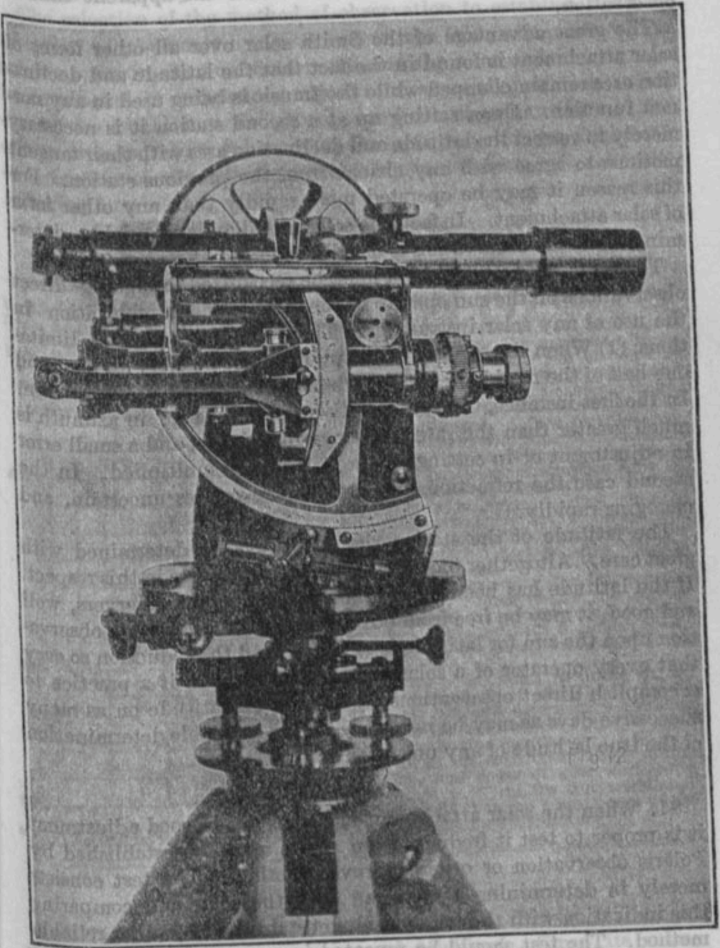


FIG. 12.—The striding level on the auxiliary telescope.

to correct the reading on the declination arc with its tangent motion to agree with the declination of the sun for the apparent time of observation.

The great advantage of the Smith solar over all other forms of solar attachment is found in the fact that the latitude and declination arcs remain clamped while the transit is being used in any normal function. Upon setting up at a second station it is necessary merely to correct the latitude and declination arcs with their tangent motions to agree with any change from the previous station. For this reason it may be operated more rapidly than any other form of solar attachment. In fact, the solar meridian is so quickly determined that the observation is usually repeated at every station.

The same restrictions which must be recognized in making direct observations on the sun operate in the same way as a prohibition in the use of any solar instrument. There are only two such limitations: (1) When the sun is within two hours, or possibly an hour and one-half of the meridian; and (2) when the sun is low in the horizon. In the first instance, the sun's relative rate of change in azimuth is much greater than the rate of change in altitude, and a small error in adjustment or in setting the arcs is greatly multiplied. In the second case the refractions are great, more or less uncertain, and changing rapidly.

The latitude of the station should always be determined with great care. Altogether too many maps are unreliable in this respect. If the latitude has been determined by competent observers, well and good, it may be free from error, but the direct altitude observation upon the sun for latitude is so simple and the reduction so easy that every operator of a solar transit should make it a practice to accomplish direct observations on the sun for latitude on as many successive days as may be necessary to give a reliable determination of the true latitude of any unknown station.

TEST.

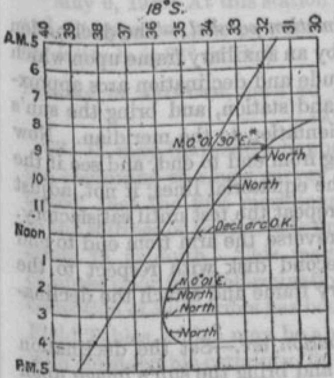
81. When the solar attachment has been put in good adjustment it is proper to test it frequently on a true meridian established by Polaris observation or other approved method. The test consists merely in determining a meridian with the solar and comparing this indication with the true meridian established by other reliable method. The test should be repeated in a. m. and p. m. hours at frequent intervals, and the noon observation should most certainly be taken every day that the solar is used.

The selection of the method of observation to establish the true meridian will be made by the engineer, the facts relative to which are to appear in the final field notes, and the solar attachment may be considered in satisfactory adjustment when all meridional tests during the usual hours of solar work are found to come within 1′ 30″ of the true meridian, whereupon the certificate of the engineer's examination of the adjustments of his instrument will take the following form:

Field record.

Buff Solar Transit No. 8028.
Sun's declination at Greenwich noon
$=5^h58^m$ a. m., local app. t. =18° 32′ 04″ S.
Diff. 10^h, −382″ = 6 22 S.

3^h58^m p. m. =18° 38′ 26″ S.



* Adjust auxiliary telescope for collimation.

Final field notes.

Nov. 16, 1911, at my station in Sec. 35, T. 11 N., R. 6 E., 5th Prin. Mer., Arkansas, in latitude 35° 32.9′ N., as determined by the mean of altitude observations on the sun on Sept. 26 and 29, 1911, heretofore described, and longitude 90° 25′ W., I examine the adjustments of the instrument and correct all errors. I then test the solar apparatus by comparing its indications hourly with the true meridian established by Polaris observation Sept. 26, 1911, heretofore described.

At 9^h20^m a. m., app.t., I set off 35° 33′ N., on the lat. arc; 18° 32′.5 S., on the decl. arc; and determine a meridian with the solar which I find to agree with the true meridian.

At app. noon, with the lat. arc unchanged, I observe the sun on the meridian; the resulting reading of the decl. arc is 18° 34′.5 S., which agrees with the computed declination of the sun.

At 3^h0^m p. m., app.t., with the lat. arc unchanged, I set off 18° 36′ S., on the decl. arc; and determine a meridian with the solar which I find to agree with the true meridian.

As all of the solar observations during the usual hours of solar work come within 1′ 30″ of the true meridian, I conclude that the adjustments of the instrument are satisfactory.

THE SOLAR COMPASS.

82. The first solar instrument was designed in 1836 by William A. Burt, a United States surveyor, of Michigan. Since its introduction the instrument has been extensively used in public-land surveying; the solar compass has given general satisfaction and is still used to some extent in the public-land surveys, but in recent years it has been largely superseded by the more complete instrument already described. The Burt solar apparatus is designed for mounting upon an open-sight compass, commonly used in the early public-land surveys. A polar axis is fitted in line with the terrestrial sights when the plate verniers are set at zero. The inclination of the polar axis is controlled by a latitude arc mounted in the same vertical plane. Normal to the polar axis there is a revolving arm upon which is mounted a declination arc and two solar lines of collimation, one for north declination of the sun, and one for south declination. Each line of collimation consists of a lens and silver plate or disk mounted upon opposite ends of the revolving arm; parallel equatorial lines are drawn upon each disk symmetrical with the axis of the opposite lens. Two adjustments are peculiar to the Burt solar compass, which are here given for the engineer's reference in the field; these adjustments should be made when the sun is within an hour of the meridian.

(1) *To make the solar lines of collimation parallel.*—The declination arm will be detached and replaced by an auxiliary frame upon which the arm will be laid. Set the latitude and declination arcs approximately correct for the hour, date and station, and bring the sun's image upon either disk as in an orientation to the meridian. Now turn the arm over, without reversing from end to end, and see if the sun's image again comes between the equatorial lines; if not, adjust the disk for half the difference and repeat the test until satisfactory. When this has been accomplished, reverse the arm from end to end for the purpose of adjusting the second disk with respect to the opposite lens. Remove the auxiliary frame and attach the declination arm in place.

(2) *To set the vernier of the declination arc.*—Set the declination vernier to read approximately zero, and bring the sun's image upon either disk as in an orientation to the meridian, changing the elevation of the polar axis as may be necessary to bring the solar line of collimation upon the sun. With the sun's image accurately between the equatorial lines, clamp all other motions and reverse the declination arm on the polar axis, thus bringing into use the second line of collimation. Note if the image of the sun is now squarely between the second pair of equatorial lines; if not, correct half the differ-

ence by movement of the tangent screw of the declination arc. Again orient in azimuth to bring the sun's image accurately between the equatorial lines, clamp and reverse as before, repeating the test until satisfactory. When the lines of collimation have thus been made truly at right angles to the polar axis, the vernier may be shifted to read zero in this position.

The general test of the Burt solar compass, by comparing its indications, resulting from solar observations made during a. m. and p. m. hours, with the true meridian determined by independent method, is similar to the test of the Smith solar attachment except in respect to the test of the latitude arc. No provision is made for independent adjustment of the latitude arc, and in the operation of the Burt solar compass the latitude is used as given by the instrument resulting from a meridian observation on the sun. In this respect therefore the noon observation with the Burt solar compass differs from the noon observation with the Smith solar attachment.

Example of noon observation with the Burt solar compass, in latitude 38° 53′ 40″ N., and longtitude 77° 01. 6′ W.:

"May 6, 1910: At this station I set off 16° 26′ N., on the decl. arc; and, at apparent noon, observe the sun on the meridian; the resulting latitude is 38° 54′ N."

ERRORS IN AZIMUTH, DUE TO SMALL ERRORS IN DECLINATION OR LATITUDE.

83. It may frequently happen with a solar transit, especially at the beginning of a new survey or with an instrument insufficiently tested, that the first meridional trials are made with slight errors in the settings of the latitude and declination arcs, resulting in small errors in azimuth. This may be particularly true with a solar compass prior to a determination of the instrumental latitude. The correction of such errors has been provided for in Table 22, Standard Field Tables, which may be applied to results of single observations with considerable certainty, but not so well to a series of observations as in ordinary line work owing to the changing values (for hours from noon) of the correction coefficients. The explanation with the table gives a key to the direction of the azimuth errors on account of small errors in setting the latitude and declination arcs.

For example, at $9^h 40^m$ a. m., app. t., at a station in latitude assumed to be 46° 20′ N., a test was made with a solar transit whereby the trial indication was found to fall 0° 05′ west of the true meridian. Subsequent determinations of the true latitude of the station and of the correctness of the vernier of the declination arc showed that the actual latitude of the station was 46° 21′.5 N., and that the vernier of the declination arc had an index error which gave readings 0° 00′.5 S. of the calculated declination (i. e. reading 15° 19′.5 N. for a calculated declination of 15° 20′ N.). Thus in the test the latitude arc was set 1′.5 S. of the correct latitude of the station, and the declination arc was actually set 0′.5 N. of the value that would have been set had the index error been known.

Table 22 is entered to obtain the correction coefficients:

Latitude.	Hours from noon.			
	$2^{h}\,0^{m}$.	$2^{h}\,20^{m}$.	$3^{h}\,0^{m}$.	
45° 00′	2.83	2.55	2.00	Declination coefficient.
46 21.5	....	2.62	....	
50 00	3.11	2.81	2.20	
45 00	2.45	2.10	1.41	Latitude coefficient.
46 21.5	....	2.16	....	
50 00	2.69	2.31	1.56	

The corrections are then applied as follows:

Indication of solar in test =S. 0° 05′.0 W.
Correction for declination = 0 01 .3 E.=(2.62×0.5)
Correction for latitude = 0 03 .2 E.=(2.16×1.5)

Corrected indication of solar=S. 0° 00′.5 W.

The above corrections will often serve to explain the apparent errors of the solar, but these are not intended for use in line work, and can not be accepted in lieu of satisfactory subsequent tests based on correct values.

In the above connection it should be explained that it is not deemed desirable to burden the official record with evidence of correction for index errors found in the verniers of the latitude and declination arcs, other than to state, when such are determined, that the same are forthwith removed or are allowed for in subsequent observations.

POLARIS AT ELONGATION.

84. The engineer having thoroughly considered the theory and use of the solar instrument in its relation to the public-land surveys, and presumably mastered its operation, his attention is now directed to the approved methods of observation to establish the true meridian with which to make comparisons of the indications of the solar apparatus as a necessary test of such an instrument, or without a solar instrument, the establishment of the true meridian from which to project transit lines and to test the calculated course thereof.

Of the various independent methods of observation to establish the true meridian, the simplest and most reliable is found in the observation upon Polaris at eastern or western elongation.

Azimuth of Polaris at elongation:

$$\text{Sin } A = \frac{\cos \delta}{\cos \phi}$$

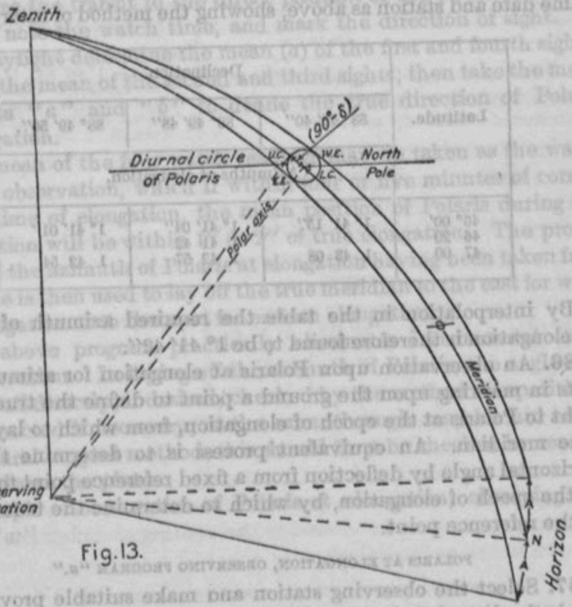


Fig. 13.

The meridian and vertical planes tangent to the diurnal circle of Polaris as viewed from outside of the celestial sphere.

Example of computing the azimuth of Polaris at elongation, October 20, 1910, in latitude 46° 20′ N., on which date the declination of Polaris=88° 49′ 48″ N.:

$$\log \cos \delta = 8.310033$$
$$\text{“} \quad \cos \phi = 9.839140$$
$$\text{“} \quad \sin A = \underline{\underline{8.470893}}$$

$$A = \text{Azimuth of Polaris at elongation} = 1^\circ\ 41'\ 41''.$$

85. A table of azimuths of Polaris at elongation for latitudes from 25° to 70° N., appears in the Ephemeris, arguments: declination of Polaris, and latitude of station.

Example in the use of the table of azimuths of Polaris at elongation, same date and station as above, showing the method of interpolation:

Latitude.	Declination.		
	88° 49′ 40″	88° 49′ 48″	88° 49′ 50″.
	Azimuths at elongation.		
46° 00′	1° 41′ 15″	1° 41′ 04″	1° 41′ 01″
46 20		1 41 42	
47 00	1 43 08	1 42 57	1 42 54

By interpolation in the table the required azimuth of Polaris at elongation is therefore found to be 1° 41′ 42″.

86. An observation upon Polaris at elongation for azimuth consists in marking upon the ground a point to define the true line of sight to Polaris at the epoch of elongation, from which to lay off the true meridian. An equivalent process is to determine the true horizontal angle by deflection from a fixed reference point to Polaris at the epoch of elongation, by which to determine the true bearing of the reference point.

POLARIS AT ELONGATION, OBSERVING PROGRAM *“a.”*

87. Select the observing station and make suitable provision to mark the line defining the direction of Polaris at elongation; the flag point should be from 5 to 10 chains N. of the transit point, and should be cleared of all obstruction before dark. Determine the local mean and watch time of elongation of Polaris, provide suitable illumination for both the transit and flag point, and have everything in readiness as much as 15 minutes before the time of elongation.

Thoroughly level the transit.

About six minutes before elongation, with the telescope in direct position, bisect Polaris, note the watch time, and mark the direction of sight.

Reverse the transit, bisect Polaris, note the watch time, and mark the direction of sight.

Again level the transit.

With the telescope in the reverse position bisect Polaris, note the watch time, and mark the direction of sight.

Reverse the transit to the direct position of the telescope, bisect Polaris, note the watch time, and mark the direction of sight.

By daylight determine the mean (*a*) of the first and fourth sights, and (*b*) the mean of the second and third sights; then take the mean of points "*a*" and "*b*" to define the true direction of Polaris at elongation.

The mean of the four watch readings may be taken as the watch time of observation, which if within four or five minutes of correct watch time of elongation, the mean position of Polaris during the observation will be within 1″ or 2″ of true elongation. The proper value of the azimuth of Polaris at elongation having been taken from the table is then used to lay off the true meridian to the east for western elongation or to the west for eastern elongation.

The above program practically eliminates instrumental errors in observation. In laying off the azimuth of Polaris, the angle may be laid off directly, if desired, checked by the method of repetitions, and corrected if necessary; or the azimuth angle may be laid off by the natural tangent method; this should then be checked by reading the angle on the plates.

Example of observation of Polaris at elongation, observing program "*a*:"

Field record.

Sept. 10, 1911, Gr. E. E. of Polaris, lat. 40°	$=8^h 17.0^m$ p. m.
Red. to long. 111° 45′ W.	$= -1.2$
Red. to lat. 43° 22′ 30″ N.	$= +0.5$
L. M. T. of E. E. of Polaris.....	$=8^h 16.3^m$ p. m.
Watch slow of l. m. t.	$= -1.7$
Watch time of E. E.	$=8^h 14.6^m$ p. m.

Telescope.	Watch Time.
Direct..........................	$8^h 08^m 26^s$ p. m.
Reversed........................	8 11 20
Reversed........................	8 14 34
Direct..........................	8 16 46
Mean..............................	$8^h 12^m 46^s$ p. m.

Declination of Polaris=88° 49′ 54″ N.

Latitude.	Declination.		
	88° 49′ 50″	88° 49′ 54″	88° 49′ 60″
	Azimuth.		
43° 00′ 00″	1° 35′ 57″	1° 35′ 51″	1° 35′ 43″
43 22 30		1 36 27	
44 00 00	1 37 33	1 37 27	1 37 19

Final field notes.

Sept. 10, 1911, in camp at the standard cor. of Tps. 1 N., Rs. 39 and 40 E., Boise Mer., in latitude 43° 22′ 30″ N., and longitude 111° 45′ W., at $8^h 16.3^m$ p. m., l. m. t., I observe Polaris at eastern elongation, making four observations, two each with the telescope in direct and reversed positions, and mark the mean point in the line thus determined, on a peg driven firmly in the ground, 5 chs. N.

Azimuth of Polaris at eastern elongation=1° 36′ 27″.

Sept. 11: I lay off the azimuth of Polaris, 1° 36′ 30″, to the west, and mark the meridian thus determined, by a tack in a peg driven firmly in the ground, 5 chs. N.

The above program of observation of Polaris at elongation is the most convenient method where there is an opportunity to mark the direction of the line of sight. Occasionally conditions obtain where it is impossible to define or mark the direction of the observation; the program may then be altered to the reading of deflection angles as shown in the next method.

POLARIS AT ELONGATION, OBSERVING PROGRAM "*b*."

88. Select the observing station and mark a point by driving a tack in a peg driven firmly in the ground approximately in the true meridian as determined by the solar before sunset, or choose other suitable reference mark in any direction. The reference point should not be nearer to the transit than 5 chains distant. Determine the local mean and watch time of elongation of Polaris, provide suitable illumination for both the transit and flag point, and have everything in readiness as much as 10 minutes before the time of elongation.

Thoroughly level the transit.

About 6 minutes before elongation with the transit in direct position, read and note the deflection angle from the reference point to Polaris, noting also the watch time of observation.

Reverse the transit and read and note the deflection angle from the reference point to Polaris, noting also the watch time of observation.

Again level the transit.

With the transit in the reverse position again read and note the deflection angle from the reference point to Polaris and note the watch time of observation.

Reverse the transit to the direct position and again read and note the deflection angle from the reference point to Polaris, and note the watch time of observation.

As the position of Polaris remains within about 0° 00′ 01″ of true elongation for a period of about five or six minutes either side of the time of exact elongation, the observation may be considered satisfactory if all of the watch readings fall within the stated period.

The mean of the four horizontal deflection angles may be taken to which must be applied the value of the azimuth of Polaris at elongation taken from the table, to obtain the true bearing of the reference flag, from which the true meridian may be laid off, or the flag may be used as a reference point.

A reference point in any direction may be used in the above method; the direction of the deflection from the reference point to Polaris should always be clearly stated. The insignificant figures of the final result may be discarded if the value of the bearing angle does not enter into another determination that demands great precision. In the example below the true meridian may be laid off by accurately measuring a distance from the reference point, at right angles to the line of sight, found by multiplying the distance from the instrument to the reference point (660 ft.) by the tangent of the bearing angle (nat tan 0° 00′ 44″=0.00021) which gives 0.14 ft. After laying off the true meridian the angle from the reference point may be checked by the method of repetitions.

Example of observation of Polaris at elongation, observing program "*b*":

Field record.

Apr. 1, 1911, Gr. W. E. of Polaris, lat. 40° = 6^h 46.1^m p. m.
Red. to long. 104° 39′ W. = − 1.1
" " lat. 46° 13′ N. = − 1.0

L. M. T. of W. E. of Polaris. = 6^h 44.0^m p. m.
Watch slow of L. M. T. = − 2.9

Watch time of W. E = 6^h 41.1^m p. m.

Telescope.	Watch time.	Deflection angle.
Direct....................	6^h 37^m 22^s	1° 41′ 00″
Reversed..................	6 39 40	1 40 30
Reversed..................	6 43 14	1 40 00
Direct....................	6 45 30	1 40 30
Mean......................	6^h 41^m 26^s	1° 40′ 30″

Declination of Polaris = 88° 49′ 58″ N.

	Declination.		
Latitude.	88° 49′ 50″	88° 49′ 58″	88° 49′ 60″
	Azimuth.		
46° 00′	1° 41′ 01″	1° 40′ 50″	1° 40′ 47″
46 13		1 41 14	
47 00	1 42 54	1 42 42	1 42 39

Final field notes.

April 1, 1911, in camp at the cor. of Tps. 5 and 6 N., Rs. 56 and 57 E., Prin. Mer., Montana, in latitude 46° 13′ N., and longitude 104° 39′ W., at 6^h 44.0^m p. m., l. m. t., I observe Polaris at western elongation, making four observations, two each with the telescope in direct and reversed positions, reading the deflection angle from a tack in a peg driven firmly in the ground, 10 chs. N., west to Polaris:

Azimuth of Polaris at western elongation = 1° 41′ 14″
Mean deflection angle = 1 40 30
True bearing of mark = N. 0° 00′ 44″ W.

89. Both of the above observing programs require the engineer to compute in advance the correct watch time of elongation, and in so conducting the observation the minimum period is consumed in the observing program; every opportunity is also thus afforded for reversals to eliminate instrumental errors and otherwise to introduce creditable refinement. However, should the watch error be unknown, the observation may be conducted by following the motion of Polaris in azimuth during an ample period preceding elongation to insure that the epoch of the vertical motion of Polaris in its diurnal circle,

or zero motion in azimuth, is taking place, when the engineer marks the direction of sight thus defined.

The rate of horizontal motion for the hour preceding elongation rapidly diminishes, the change in azimuth being to the west for western elongation, or to the east for eastern elongation, when Polaris will follow the vertical cross-wire, after which the motion is reversed at an accelerating rate. This suggests a third, but less refined, observing program.

POLARIS AT ELONGATION, OBSERVING PROGRAM "c."

90. Select the observing station and make suitable provision to mark the line defining the direction of Polaris at elongation; provide suitable illumination for both the transit and flag point, and have everything in readiness as much as an hour before the time of elongation.

Thoroughly level the transit.

Bisect Polaris and note that the motion of the star carries it away from the vertical wire in the proper direction. As long as this motion is discernible continue the bisection of Polaris by the tangent movement. When it can not be discerned in a period of several minutes that the least lateral motion is taking place mark the direction of sight upon the ground.

Reverse and level the transit.

Again bisect Polaris and mark the direction of sight upon the ground.

Verify the position of Polaris in its diurnal circle by again bisecting the star and without changing the tangent motion note the movement of Polaris; the motion should still be nearly vertical, with a scarcely discernible movement in the opposite horizontal direction.

By daylight determine the mean of the sights, and establish the meridian by properly laying off the correct azimuth as described in observing program "*a*."

AZIMUTH OF POLARIS AT ANY HOUR ANGLE.

91. While no more reliable method is at the command of the engineer for the establishment of the true meridian than the observation upon Polaris at elongation, yet the epoch of elongation may occur at a very inconvenient time and should Polaris be obscured by clouds at the time of elongation the observation must fail. The "hour angle" method admits of observation upon Polaris for azimuth at any time that the star is visible; the precise watch error local mean time must be known, but if this has been determined, the hour angle method becomes at once the most convenient. The possible accuracy of the result compares favorably in every way with the refinement to be obtained in an observation at elongation.

The determination of the watch error local mean time and the calculation of hour angles having been fully treated on previous pages, it remains only to state that the record of the time observation should appear in the field notes with the record of all observations upon Polaris for azimuth by the hour angle method, as the azimuth observation is incomplete without the time determination. With the meridian observation of the sun for apparent noon, and the use of the azimuth tables contained in the Ephemeris, the entire process becomes so simple and yet so highly refined that the engineer should early become thoroughly familiar with the hour angle method.

92. *Azimuth of Polaris at any hour angle.*—"t"=sidereal hour angle in angular measure; in hour angles exceeding 90° the function "$-\sin\phi\cos t$" becomes positive by virtue of the cosine of an angle between 90° and 270° being treated as negative in analytical reductions:

$$\operatorname{Tan} A=\frac{\sin t}{\cos\phi\tan\delta-\sin\phi\cos t}$$

Example of computing the azimuth of Polaris, February 23, 1911, at a mean time hour angle of $2^{h}\,37.4^{m}$, in latitude 33° 20′ N., on which date the declination of Polaris=88° 50′ 08″ N.:

Mean time hour angle $=2^{h}37.4^{m}$

$=2^{h}37^{m}24^{s}$ $\quad 2^{h}=30^\circ$

$37^{m}=9^\circ15'$

Red. to sidereal hour angle$=\underline{+26^{s}}$ $\quad 50^{s}=\underline{12'\,30''}$

Sidereal hour angle $=\underline{\underline{2^{h}37^{m}50^{s}}}$ $\quad =\underline{\underline{39^\circ27'\,30''}}$

$\log\cos\phi=9.921940$ $\quad \log\sin\phi=9.739975$

" $\tan\delta=\underline{1.691944}$ $\quad$ " $\cos t=\underline{9.887666}$

" $\cos\phi\tan\delta=\underline{\underline{1.613884}}$ $\quad$ " $\sin\phi\cos t=\underline{\underline{9.627641}}$

nat $\cos\phi\tan\delta=41.104$ $\quad$ nat $\sin\phi\cos t=\underline{\underline{0.424}}$

nat $\sin\phi\cos t=\underline{0.424}\,(-)$

$\log\sin t=9.803127$

Algebraic sum$=\underline{\underline{40.680}}$ $\quad$ " $40.680=\underline{1.609381}$

" $\tan A=\underline{\underline{8.193746}}$

Azimuth of Polaris at above hour angle, $A=\underline{\underline{0^\circ\,53'\,42''}}$

93. A table of azimuths of Polaris at all hour angles, for latitudes from 30° to 50° N., appears in the Ephemeris, arguments: declination of Polaris, mean time hour angle, and latitude of station. For other than the latitudes given in the table the engineer will be required to solve the above equation.

Example in the use of the table of azimuths of Polaris at any hour angle, same date, hour angle and station as above, showing the method of interpolation:

Mean time hour angle.	Azimuth of Polaris.			Correction subtractive for declination +88° 50′ 10″
	Mean declination. +88° 50′ 05″			
	Latitude.			
	32°	33° 20′	34°	
2^h 29.6^m	50′.7	51′.5	51′.9	0′.1
37.4		53 .8		0 .1
39.6	53 .5	54 .4	54 .8	0 .1

By interpolation in the table the required azimuth of Polaris is therefore found to be 0° 53′.8 − 0′.1 = 0° 53′ 42″.

94. Example of computing the azimuth of Polaris, Sept. 11, 1911, at a mean time hour angle of 7^h 25.1^m, in latitude 42° 54′ N., on which date the declination of Polaris = 88° 49′ 54″ N.:

Mean time hour angle...............	$=7^h\ 25.1^m$	7^h	$=105°$
	$=7^h\ 25^m\ 06^s$	$26^m=$	$6°30′$
Reduction to sidereal hour angle....	$=\ +1^m\ 13^s$	$19^s=$	$4′\ 45″$
Sidereal hour angle................	$=7^h\ 26^m\ 19^s$		$=111°\ 34′\ 45″$
log cos ϕ	$=9.864833$	log sin ϕ	$=9.832969$
" tan δ	$=1.690496$	" cos t	$=9.565596$
" cos ϕ tan δ	$=1.555329$	" sin ϕ cos t	$=9.398565$
nat cos ϕ tan δ	$=35.919$	nat sin ϕ cos t	$=\ .250$
" sin ϕ cos δ	$=\ .250(+)$	log sin t	$=9.968441$
Algebraic sum	$=36.169$	" 36.169	$=1.558337$
		" tan A	$=8.410104$
Azimuth of Polaris at above hour angle, A			$=1°28′22″$

95. Example in the use of the table of azimuths of Polaris at any hour angle, same date, hour angle and station as above:

Mean time hour angle.	Azimuth of Polaris.			Correction additive for declination +88° 49′	
	Mean declination. +88° 50′ 05″				
	Latitude.				
	42°	42° 54′	44°	60″	50″
7^h 18.8^m	87′.9	89′.2	90′.7	0′.1	0′.3
25.1		88 .2		0 .1	0 .3
28.8	86 .3	87 .6	89 .1	0 .1	0 .3

By interpolation in the table the required azimuth of Polaris is therefore found to be 1° 28′.2+0′.2=1° 28′ 24″.

96. An observation upon Polaris for azimuth by the hour angle method consists in marking upon the ground a point to define the true line of sight to Polaris at any convenient epoch, the watch error local mean time being known, from which line to lay off the true meridian. An equivalent process is to determine the true horizontal angle by deflection from a fixed reference point to Polaris at any convenient epoch, the watch error local mean time being known, by which to determine the true bearing of the reference point.

HOUR ANGLE OBSERVATION OF POLARIS, OBSERVING PROGRAM "*a*."

97. Select the observing station and make suitable provision to mark the line defining the direction of Polaris; the flag point should be from 5 to 10 chains north of the transit point; provide suitable illumination for both the transit and flag point.

Thoroughly level the transit.

With the telescope in the direct position, bisect Polaris, note the watch time, and mark the direction of sight.

Reverse the transit, bisect Polaris, note the watch time, and mark the direction of sight.

Again level the transit.

With the telescope in the reverse position bisect Polaris, note the watch time, and mark the direction of sight.

Reverse the transit to the direct position of the telescope, bisect Polaris, note the watch time, and mark the direction of sight.

By daylight determine the mean (*a*) of the first and fourth sights, and (*b*) of the second and third sights; then take the mean of points "*a*" and "*b*" to define the true direction of Polaris at the epoch of the average of the watch times of observation.

Treat the reduction as one observation, applying the watch error to the average watch time of observation to obtain the correct local mean time of observation.

Enter the table in the Ephemeris or make the computation to determine the value of the azimuth of Polaris at the epoch of the observation with the stated arguments: declination of Polaris, mean time hour angle and latitude; this value is then used to lay off the true meridian, to the east if Polaris is observed west of the meridian or to the west if Polaris is observed east of the meridian.

Example of hour angle observation of Polaris, observing program "*a*":

Field record.

Meridian observation of the sun for apparent noon:

$\phi=37° 18' $ N.	$90° 00'$
$\delta=$ 4 36 S.	41 54
$\phi+\delta=41° 54'$	$v=48° 06'$
	Watch time.
Sun's W. limb 	$=12^{h}\ 00^{m}\ 18^{s}$
" E. " 	=12 02 26
Watch time of app. noon	$=12^{h}\ 01^{m}\ 22^{s}$
App. noon $=12^{h}\ 00^{m}\ 00^{s}$	
Equation of time = −11 25	
L. M. T. of apparent noon	=11 48 35
Watch fast of l. m. t.	$12^{m}\ 47^{s}$

Hour angle observation of Polaris:

Telescope.	Watch time.
Direct	$5^{h}\ 48^{m}\ 40^{s}$ p. m.
Reversed	5 49 49
Reversed	5 51 36
Direct	5 52 54
Mean	$5^{h}\ 50^{m}\ 45^{s}$ p. m.
Watch fast of l. m. t.	− 12 47
L. M. T. of obsn.	$5^{h}\ 37^{m}\ 58^{s}$ p. m. $5^{h}\ 38.0^{m}$ p. m.

Final field notes.

Oct. 5, 1910, in camp at the cor. of secs. 5, 6, 31, and 32, on the S. bdy. of T. 31 S., R. 42 W., 6th Prin. Mer., Colo., in latitude 37° 17′.6 N., and longitude 102° 11′ W., I make a meridian observation of the sun for apparent noon:

Watch time of obsn. $=12^{h}\ 01^{m}\ 22^{s}$.

Watch fast of l. m. t. $=12^{m}\ 47^{s}$.

At the same station, at $5^{h}\ 38.0^{m}$ p. m., l. m. t., I make an hour angle observation on Polaris east of the meridian, making four observations, two each with the telescope in direct and reversed positions, and mark the mean point in the line thus determined, on a peg driven firmly in the ground, 8 chs. N.

Field record, con.

Gr. U. C. of Polaris, Oct. 6, 1910 $=0^h\ 32.7^m$ a. m.
Red. to long. 102° 11′ W. $= -\ 1.1$

L. M. T., U. C. of Polaris, Oct. 6 $=\ 0^h\ 31.6^m$ a. m.
$+12$
L. M. T. of obsn., Oct. 5 $=\ 5\ \ 38.0$ p. m.

Hour angle of Polaris east of the meridian $=\ 6^h\ 53.6^m$

Declination of Polaris = 88° 49′ 42″ N.

Mean time hour angle.	Azimuth of Polaris.			Correction additive for declination +88° 49′ 40″
	Mean declination. +88° 49′ 45″			
	Latitude.			
	36°	37° 18′	38°	
$6^h\ 48.9^m$	84′.5	85′.9	86′.7	0′.1
53.6		85 .4		0 .1
58.9	83 .5	84 .9	85 .7	0 .1

Azimuth of Polaris = 1° 25′.4 + 0′.1 = 1° 25′ 30″

Final field notes, con.

Watch time of obsn., mean of four readings $= 5^h\ 50^m\ 45^s$ p. m.

Oct. 6, I lay off the azimuth of Polaris, 1° 25′ 30″, to the west, and mark the meridian thus determined, by a tack in a peg driven firmly in the ground, 8 chs. N.

HOUR ANGLE OBSERVATION OF POLARIS, OBSERVING PROGRAM "b."

98. Select the observing station and choose a suitable reference mark in any direction. The reference point should be at least 5 chains distant.

Thoroughly level the transit.

With the telescope in the direct position, read and note the horizontal angle from the reference point to Polaris, noting the watch time at the moment Polaris is properly bisected.

Reverse the transit and read and note the horizontal angle from the reference point to Polaris, noting the watch time at the moment Polaris is properly bisected.

Again level the transit.

With the telescope in the reverse position again read and note the horizontal angle from the reference point to Polaris, noting the watch time at the moment Polaris is properly bisected.

Reverse the transit to the direct position of the telescope and again read and note the horizontal angle from the reference point to Polaris, noting the watch time at the moment Polaris is properly bisected.

Treat the reduction as one observation, applying the watch error to the average watch time of observation to obtain the correct local mean time of observation.

The mean of the four horizontal deflection angles may be taken, to which must be applied the proper value of the azimuth of Polaris at the mean epoch of the observation, to give the true bearing of the reference flag, from which the true meridian may be laid off, or the flag may be used for a reference point.

Example of hour angle observation of Polaris, observing program "*b*":

Field record.

Hour angle observation on Polaris:

Telescope.	Horizontal angle from flag to Polaris.	Watch time.
Direct..........	177° 34′ 30″	6^h 22^m 37^s p. m.
Reversed......	177 34 30	6 25 29
Reversed......	177 34 00	6 28 17
Direct..........	177 34 00	6 30 17
Mean...	177° 34′ 15″	6^h 26^m 40^s p. m.

Watch slow of 75th mer. standard time + 1 22

Correction for longitude.......... − 8 6

L. M. T. of obsn. Mar. 21, 1910= 6^h 19^m 56^s

6^h 19.9^m p. m.

Gr. U. C. of Polaris, same date.....=1^h 33.0^m p. m.

Red. to long. 77° 1.6′ W......= − 0.9 = 1 32.1 p.m.

Hour angle of Polaris west of the meridian =4^h 47.8^m

Declination of Polaris =88° 49′ 41″ N.

Mean time hour angle.	Azimuth of Polaris.			Correction additive for declination +88° 49′ 40″
	Mean declination. +88° 49′ 45″			
	Latitude.			
	38°	38° 54′	40°	
4^h 39.2^m	84′.2	85′.3	86′.7	0′.1
47.8		86 .3		0 .1
49.2	85 .4	86 .5	87 .9	0 .1

Azimuth of Polaris=1° 26′.3+0′.1=1° 26′ 24″

Final field notes.

March 21, 1910, at a transit point in Washington, D. C., in latitude 38° 53′ 40″ N., and longitude 77° 1′.6 W., I find by comparison with a Western Union telegraph clock that my watch is 1^m 22^s slow of 75th meridian standard time.

At the same station at 6^h 19.9^m p. m., l. m. t., I make an hour angle observation on Polaris, west of the meridian, two each with the telescope in direct and reversed positions, reading the horizontal deflection angle from a flag pole about 20 chs. S., in the direction S-W-N to Polaris.

Watch time of obsn.=6^h 26^m 40^s p. m.

Mean horizontal angle from Polaris to flag =177° 34′ 15″ N-W-S

Azimuth of Polaris= 1 26 24 W.

True bearing of flag = N. 179° 00′ 39″ W.

= S. 0° 59′ 21″ W.

POLARIS AT SUNSET OR SUNRISE.

99. Polaris is conveniently observed for azimuth by the hour angle method at sunset or sunrise without artificial illumination. The preparation for the observation consists in computing in advance the approximate settings in azimuth and altitude in order to find Polaris, and the plan contemplates an approximate reference meridian: With the time of sunset or sunrise assumed as the time of observation, the hour angle "*t*" and azimuth "*A*" are ascertained in order to find the position of Polaris in azimuth; the position in altitude is found by the method indicated in section 133–A, the vertical angle being equal to the latitude of the station *plus* the primary adjustment when Polaris is above the pole, or *subtractive* when below, taking this value from the tabulation given in the Ephemeris.

Example of computation of the position of Polaris at sunset, May 6, 1911, at a station in latitude 47° 20′ N., and longitude 102° 40′ W.:

From the Ephemeris the declination of the sun is found to be 16° 18′ N., and by entering Table 17, of the Standard Field Tables, the apparent time of sunset is found to be $7^h\ 15^m$ p. m.

Assumed time of obsn., May 6, 1911		= $7^h\ 15^m$ p. m.
Gr. U. C. of Polaris, May 6	= $10^h\ 33.5^m$ a. m.	+12
Red. to long. 102° 40′ W.	−1.1	= 10 32.4 a. m.
Assumed hour angle of Polaris west of the meridian		= $8^h\ 42.6^m$
Azimuth of Polaris, W.		≠ 1° 17′
Latitude of station	=47° 20′	
Primary adjustment to the vertical angle elevation of Polaris, from the table	= 46(−)	
	v≠46° 34′	

Example of computation of the position of Polaris at sunset, November 6, 1911, at a station in latitude 47° 20′ N., and longitude 102° 40′ W.:

From the Ephemeris the declination of the sun is found to be 15° 44′ S., and by entering Table 17, of the Standard Field Tables, the apparent time of sunrise is found to be $7^h\ 12^m$ a. m., or of sunset $4^h\ 48^m$ p. m.

Gr. U. C. of Polaris, Nov. 6, 1911 $=10^h\ 28.2^m$ p. m.
Red. to long. 102° 40′ W. $= -1.1$

L. M. T. of U. C. of Polaris $=10^h\ 27.1^m$ p. m.
Assumed time of observation $=4\ \ 48$ p. m.

Assumed hour angle of Polaris east of the meridian $=5^h\ 39.1^m$
Azimuth of Polaris, E. ≠ 1° 43′
Latitude of station =47° 20′
Primary adjustment to the vertical angle elevation of Polaris, from the table = 06 (+)
v≠47° 26′

Example of computation of the position of Polaris at sunrise, November 7, 1911, and same station as above:

Assumed time of obsn., Nov. 7, 1911 $=\begin{cases} 7^h\ 12^m \text{ a. m.} \\ +12 \end{cases}$
L. M. T. of U. C. of Polaris, Nov. 6 = 10 27.1 p. m.

Assumed hour angle of Polaris west of the meridian $=8^h\ 44.9^m$
Azimuth of Polaris, W. ≠ 1° 16′
Latitude of station =47° 20′
Primary adjustment to the vertical angle elevation of Polaris, from the table = 46 (−)
v≠46° 34′

Thus at the above station in latitude 47° 20′ N., and longitude 102° 40′ W., to observe Polaris by the daylight method an approximate meridian should be established with the solar before sunset, then to *find* Polaris the following angles are set off:

	Horizontal angle.	Vertical angle.
Sunset May 6, 1911	1° 17′ W.	46° 34′
Sunset Nov. 6, 1911	1° 43′ E.	47° 26′
Sunrise Nov. 7, 1911	1° 16′ W.	46° 34′

The above "settings" are merely approximations, but sufficiently close, however, to bring Polaris reasonably near the center of the field of the telescope where the star will be found in plain view; the telescope should be focused upon a distant object, otherwise, though Polaris may be practically at the center of the field, it might be out of focus and therefore not observable during daylight. When Polaris has been found the above settings have answered their purpose and the observation may proceed in accordance with either observing program "*a*" or "*b*" of the hour angle method, the final reductions to be based upon the precise details of the observation. During the reversals of the transit the settings should be made each time. The daylight hour angle method is particularly desirable because the observation, including all instrumental work, marking of points upon the ground, etc., is accomplished without artificial illumination, and sunset is usually a convenient time to devote to this field duty.

To recapitulate, the following general program will be found best adapted to the requirements of public-land surveying practice, and will be used most extensively:

Time: By meridian observation of the sun for apparent noon.

Latitude: By meridian altitude observation of the sun.

Azimuth, true meridian upon which to test the solar apparatus: By hour angle observation on Polaris at sunset.

Azimuth, on line: By the solar transit properly adjusted to the true meridian.

ALTITUDE OBSERVATION OF THE SUN FOR AZIMUTH.

100. While the methods of observation upon Polaris for azimuth are unquestionably the most desirable in their relation to the theory and practice of public-land surveying, yet a very efficient alternative is found in direct altitude observations upon the sun for azimuth, with a number of equations at the disposal of the engineer to suit his convenience. During the shorter days of the year and even quite often at any season the engineer finds himself at a loss for time and suitable daylight hours in which to make the required tests of his solar attachment; conditions obtain making the required tests impossible if limited to a Polaris meridian in camp, without involving unreasonable delay. It is in such cases that a direct altitude observation upon the sun for azimuth, on the actual line of the survey, finds its most useful application. Presuming the engineer at work with a standard instrument with solar attachment, the accuracy of its adjustments can, by this method, be readily tested at work on line at any suitable morning or afternoon hour, without appreciable loss of time. Under working conditions any line determined with the solar attachment may be used for reference purposes, while vertical and horizontal angles are recorded to the sun to obtain the necessary data for computing the true bearing of the established solar line. A series of three altitude observations upon the sun, each with the telescope in direct and reversed positions, are required to guard against error; these are readily made in 10 or 12 minutes, while the reductions may be made in the evening without loss of time from the line work.

Other difficulties in the nature of temporary disability of the solar attachment, and cloudy nights preventing Polaris observations, or other adverse conditions may sometimes obtain, during which periods, even for a few days, if the engineer is familiar with the method of direct altitude observation upon the sun for meridian, he can thus establish his lines and possibly realize a saving of the entire time of his party until the trouble is removed. To the engineers who have used this method little more needs to be said in its favor, but to those unfamiliar with it the suggestion is made to practice the observations and reductions until proficiency is attained, and in its application the reward will come many times during an average season's work.

Referring to the description of the standard instrument adopted by the General Land Office it will be noted that it is equipped with a full vertical circle, a colored glass shade in the dust shutter of the eye-piece, and a prismatic eye-piece; these are essential to rapid and accurate altitude observations upon the sun.

101. An altitude observation of the sun for azimuth consists in the simultaneous determination of the true vertical and horizontal angles to the sun's center, the horizontal angle being referred to a fixed point. With the true vertical angle to the sun's center, the declination of the sun, and the latitude of the station all known, one of the following equations is entered and a calculation made of the azimuth of the sun's center at the epoch of observation, as referred to the true meridian; the relation between the sun's calculated azimuth and the recorded angle to the sun's center gives the true bearing of the fixed reference point.

102. *Altitude observation of the sun for azimuth.*—Reverse the signs of "δ" for south declinations:

$$\text{Tan } \tfrac{1}{2} A = \sqrt{\frac{\cos \frac{1}{2} (\zeta+\phi+\delta) \sin \frac{1}{2} (\zeta+\phi-\delta)}{\cos \frac{1}{2} (\zeta-\phi-\delta) \sin \frac{1}{2} (\zeta-\phi+\delta)}}$$

The spherical angles "ζ", "ϕ", and "δ" appear in this equation combined as in the formula for the reduction of an altitude observation of the sun for apparent time, and when it is desired to reduce for both time and azimuth, the above equation for azimuth is to be preferred to any that follow.

103. *Altitude observation of the sun for azimuth.*—For south declinations the function "sin δ" becomes negative by virtue of the sine of a negative angle being treated as negative in analytical reductions: If the algebraic sign of the result is positive the azimuth "A" is referred to the north point, but if negative, the azimuth "A" is referred to the south point:

$$\text{Cos } A = \frac{\sin \delta}{\cos \phi \cos h} - \tan \phi \tan h$$

The above equation is very convenient in reducing for azimuth only.

104. *Altitude observation of the sun for azimuth.*—To many surveyors the following equation is familiarly expressed directly in terms of the spherical triangle "pole-zenith-sun:" Reverse the sign of "δ" for south declinations:

Pole to zenith $=90° - \phi =$ colat.;
Pole to sun $=90° - \delta =$ codecl.;
Zenith to sun $=90° - h =$ coalt.;
$S = \frac{1}{2}$ sum of the three sides:

$$\text{Cos } \tfrac{1}{2} A = \sqrt{\frac{\sin S \sin (S - \text{codecl.})}{\text{sin colat. sin coalt.}}}$$

OBSERVING PROGRAM, MORNING.

105. Thoroughly level the transit.

With the telescope in direct position observe and record the horizontal deflection angle from a fixed reference point to the sun's right limb, and the vertical angle to the sun's upper limb; these observations must be simultaneous, at the epoch of which the sun will appear as indicated; note the watch time at the epoch of the observation:

Reverse the transit.

Observe and record the horizontal deflection angle from the fixed reference point to the sun's left limb, and the vertical angle to the sun's lower limb; these observations must be simultaneous, at the epoch of which the sun will appear as indicated; note the watch time at the epoch of the observation: 

The mean observed vertical and horizontal angles, and the mean watch time are to be used in the reduction; this program constitutes one complete altitude observation, which is repeated until a series of three complete direct and reversed observations are made.

OBSERVING PROGRAM, AFTERNOON.

106. In the afternoon the program is modified only as to the order in which the sun's limbs are observed, which is as follows:

First observation, telescope direct, observe the sun's right and lower limbs: 

Second observation, telescope reversed, observe the sun's left and upper limbs: 

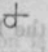
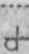
107. By the above observing programs the horizontal and vertical angles in the direct positions of the telescope will be found of about the same numerical values as in the reversed position of the telescope, by reason of the sun passing in a direction that will carry it across the field of the telescope during the time taken in the reversal and second setting. Differential refraction is therefore practically eliminated, and it is desirable that the corresponding angles in the direct and reversed positions of the telescope be about the same rather than as far apart as would result in any other observing program.

The most suitable hour for this observation is when the sun is moving rapidly in altitude as compared with a relatively small change in azimuth. When the sun has been brought into about the proper position in the field of the telescope the observer by lateral motion of the horizontal tangent screw on the plates keeps the vertical wire tangent to the sun's right or left limb while the upper or lower limb of the sun by the direction of its motion gradually approaches the horizontal wire; at the epoch of proper tangency of the two limbs to the two wires the observation is completed by calling "time" and stopping all motion until the angles are recorded. It is very helpful for an assistant to read the time and to enter all records.

108. Example of direct altitude observation of the sun for azimuth, sun north declination, and both north and south of an east and west line:

Final field notes.

Aug. 2, 1909, at the cor. of Tps. 31 and 32 S., Rs. 43 and 44 W., 6th Prin. Mer., Colo., in latitude 37° 17′.5 N., and longitude 102° 18′.6 W., at 7h 30m. a. m., app. t., I set off 37° 17′ 30″ N., on the lat. arc; 17° 52′ N., on the decl. arc; and determine a meridian with the solar, whence I turn 90° to the east and set a flag, about 20 chs. dist.; then to test this indication of the solar I make a series of three altitude observations of the sun for azimuth, each with the telescope in direct and reversed positions, observing opposite limbs of the sun, and reading the horizontal deflection angles from the flag to the sun:

Observation.	Telescope.	Sun.	Watch time.	Vertical angle.	Horizontal angle from flag to sun.
1st	Direct		$7^h\ 36^m\ 54^s$	30° 05′	0° 08′ 30″ to N.
"	Reversed		7 38 15	29 48	0 33 00 " "
	Mean			29° 56′ 30″	0° 20′ 45″ to N.
2nd	Direct		$7^h\ 41^m\ 20^s$	30° 58′ 00″	0° 32′ 00″ to S.
"	Reversed		7 43 00	30 46 30	0 12 30 " "
	Mean			30° 52′ 15″	0° 22′ 15″ to S.
3rd	Direct		$7^h\ 52^m\ 00^s$	33° 05′ 00″	2° 11′ 00″ to S.
"	Reversed		7 53 48	32 53 30	1 50 00 " "
	Mean		$7^h\ 52^m\ 54^s$	32° 59′ 15″	2° 00′ 30″ to S.

By 1st obsn. flag bears	N. 89° 58′ 57″ E.
By 2nd obsn. flag bears	N. 89 58 26 E.
By 3rd obsn. flag bears	N. 89 58 38 E.
Mean true bearing of flag	N. 89° 58′ 40″ E.
Indicated error of solar attachment	1′ 20″

Field record.

The declination of the sun for the mean period of the three observations=17° 51′ 04″ N.

The following reductions are made to obtain the true vertical angles of the above observations:

	1st obsn.	2nd obsn.	3rd obsn.
v	=29° 56′ 30″	30° 52′ 15″	32° 59′ 15″
Refraction =	−1 40	−1 36	−1 28
Parallax =	+ 8	+ 8	+ 8
h	=29° 54′ 58″	30° 50′ 47″	32° 57′ 55″

The following examples of reduction are all by the equation:

$$\text{Cos } A=\frac{\sin\delta}{\cos\phi\cos h}-\tan\phi\tan h$$

log cos ϕ=9.900674 log sin δ=9.486493(+) log tan ϕ=9.881708
" cos h=9.937897 " tan h=9.759970
9.838571 9.838571 log 9.641678
log 9.647922 nat(−) .43821
nat (+) .44455
(−) .43821
cos A=(+) .00634

A=True bearing of sun =N. 89° 38′ 12″ E.
Angle from sun to flag =(+) 0 20 45
True bearing of flag =N. 89° 58′ 57″ E.

log cos ϕ=9.900674 log sin δ=9.486493(+) log tan ϕ=9.881708
" cos h=9.933763 " tan h=9.776132
9.834437 9.834437 log 9.657840
log 9.652056 nat(−) .45482
nat(+) .44880 (+) .44880
cos A=(−) .00602

A=True bearing of sun =S. 89° 39′ 19″ E.
Angle from sun to flag =(+) 0 22 15
True bearing of flag =S. 90° 01′ 34″ E.
=N. 89° 58′ 26″ E.

log cos ϕ=9. 900674	log sin δ=9. 486493(+)	log tan ϕ=9. 881708
" cos h=9. 923762		" tan h=9. 811941
9. 824436	9. 824436	log 9. 693649
	log 9. 662057	nat (−) . 49391
	nat (+) . 45926	(+) . 45926
		cos A=(−) . 03465

A=True bearing of sun =S. 88° 00′ 52″ E.
Angle from sun to flag =(+) 2 00 30
True bearing of flag =S. 90° 01′ 22″ E.
=N. 89° 58′ 38″ E.

The particular convenience of the above equation is noted in the fact that the functions "cos ϕ", "tan ϕ", and "sin δ" are constant throughout the entire reduction, the function "h" being the only variable.

109. The third of the above series is selected for an example of reduction by the equation:

$$\text{Cos}\ \tfrac{1}{2}A=\sqrt{\frac{\sin S \sin (S-\text{codecl.})}{\sin \text{colat.} \sin \text{coalt.}}}$$

$90°-\phi=90°-37°\ 17'\ 30''$ $=52°\ 42'\ 30''$=colat.
$90°-\delta=90°-17°\ 51'\ 04''(+)$=72 08 56 =codecl.
$90°-h=90°-32°\ 57'\ 55''$ =57 02 05 =coalt.

$2\,S$=181° 53′ 31″

S= 90° 56′ 45″
codecl.=$90°-\delta$= 72 08 56

$S-$codecl.= 18° 47′ 49″

log sin S	=	9. 999941
" sin ($S-$codecl.)	=	9. 508146
" sin colat.	=9. 900674	9. 508087
" sin coalt.	=9. 923762	
	9. 824436	9. 824436
" cos² ½A	=	9. 683651
" cos ½A	=	9. 841825
½A	=	45° 59′ 35″

A=True bearing of sun =N. 91° 59′ 10″ E.
Angle from sun to flag =(−) 2 00 30
True bearing of flag =N. 89° 58′ 40″ E.

The above equation is as good as any for the reduction of one observation, but the reduction becomes laborious for a series of three observations.

110. The third of the above series is also selected for an example of reduction by the equation:

$$\operatorname{Tan} \tfrac{1}{2} A = \sqrt{\frac{\cos \frac{1}{2}(\zeta+\phi+\delta) \sin \frac{1}{2}(\zeta+\phi-\delta)}{\cos \frac{1}{2}(\zeta-\phi-\delta) \sin \frac{1}{2}(\zeta-\phi+\delta)}}$$

$$\begin{array}{rl}
h = & 32^\circ\ 57'\ 55'' \\
\hline
\zeta = & 57^\circ\ 02'\ 05'' \\
\phi = & 37\ \ 17\ \ 30 \\
\hline
\zeta+\phi = & 94^\circ\ 19'\ 35'' \\
\delta = & 17\ \ 51\ \ 04\ (+) \\
\hline
\zeta+\phi+\delta = & 112^\circ\ 10'\ 39'' \\
\frac{1}{2}(\zeta+\phi+\delta) = & 56^\circ\ 05'\ 20'' \\
\hline\hline
\zeta+\phi = & 94^\circ\ 19'\ 35'' \\
\delta = & 17\ \ 51\ \ 04\ (+) \\
\hline
\zeta+\phi-\delta = & 76^\circ\ 28'\ 31'' \\
\frac{1}{2}(\zeta+\phi-\delta) = & 38^\circ\ 14'\ 15'' \\
\hline\hline
\end{array}
\qquad
\begin{array}{rl}
\zeta = & 57^\circ\ 02'\ 05'' \\
\phi = & 37\ \ 17\ \ 30 \\
\hline
\zeta-\phi = & 19^\circ\ 44'\ 35'' \\
\delta = & 17\ \ 51\ \ 04\ (+) \\
\hline
\zeta-\phi+\delta = & 37^\circ\ 35'\ 39'' \\
\frac{1}{2}(\zeta-\phi+\delta) = & 18^\circ\ 47'\ 50'' \\
\hline\hline
\zeta-\phi = & 19^\circ\ 44'\ 35'' \\
\delta = & 17\ \ 51\ \ 04\ (+) \\
\hline
\zeta-\phi-\delta = & 1^\circ\ 53'\ 31'' \\
\frac{1}{2}(\zeta-\phi-\delta) = & 0^\circ\ 56'\ 45'' \\
\hline\hline
\end{array}$$

$$\begin{array}{rll}
\log \cos \frac{1}{2}(\zeta+\phi+\delta) = & & 9.746561 \\
\text{``}\ \sin \frac{1}{2}(\zeta+\phi-\delta) = & & 9.791636 \\
\cline{3-3}
 & & 9.538197 \\
\text{``}\ \cos \frac{1}{2}(\zeta-\phi-\delta) = & 9.999941 & \\
\text{``}\ \sin \frac{1}{2}(\zeta-\phi+\delta) = & 9.508152 & \\
\cline{2-2}
 & 9.508093 & 9.508093 \\
\hline\hline
\log \tan^2 \frac{1}{2}A = & & 0.030104 \\
\text{``}\ \tan \frac{1}{2}A = & & 0.015052 \\
\hline\hline
\frac{1}{2}A = & & 45^\circ\ 59'\ 34''
\end{array}$$

A=True bearing of sun =N. 91° 59′ 08″ E.

Angle from sun to flag = (−)2 00 30

True bearing of flag =N. 89° 58′ 38″ E.

111. The above equation is as good as any for the reduction of one observation, but the reduction becomes laborious for a series of three observations. However, the advantage in using the above equation is found when it becomes desirable to reduce the observations for both time and azimuth.

Let it be required to reduce the third observation of the above series for time, making the reduction by the following equation:

$$\text{Tan } \tfrac{1}{2}\, t = \sqrt{\frac{\sin \frac{1}{2}(\zeta+\phi-\delta) \sin \frac{1}{2}(\zeta-\phi+\delta)}{\cos \frac{1}{2}(\zeta+\phi+\delta) \cos \frac{1}{2}(\zeta-\phi-\delta)}}$$

$$\begin{array}{llll}
\log \sin \frac{1}{2}(\zeta+\phi-\delta) & = & & 9.791636 \\
\text{“} \ \ \sin \frac{1}{2}(\zeta-\phi+\delta) & = & & \underline{9.508152} \\
 & & & \overline{9.299788} \\
\text{“} \ \ \cos \frac{1}{2}(\zeta+\phi+\delta) & = & 9.746561 & \\
\text{“} \ \ \cos \frac{1}{2}(\zeta-\phi-\delta) & = & \underline{9.999941} & \\
 & & \overline{9.746502} & \underline{9.746502} \\
\text{“} \ \ \tan^{2} \frac{1}{2}\, t & = & & 9.553286 \\
\text{“} \ \ \tan \frac{1}{2}\, t & = & & 9.776643 \\
\frac{1}{2}\, t & = & 30^\circ\, 52'\, 34'' & \\
t & = & 61^\circ\, 45'\, 08'' & = 4^h\, 07^m\, 01^s
\end{array}$$

Apparent time of observation $=7^h\ 52^m\ 59^s$ a. m.
Equation of time $= +6\ \ 05$

Local mean time of observation $=7^h\ 59^m\ 04^s$ a. m.
Watch time of observation $=7\ \ 52\ \ 54$

Watch slow of l. m. t. $=\ 6^m\ 10^s$

112. Example of direct altitude observation of the sun for azimuth, sun south declination:

Final field notes.

March 18, 1910, at a transit point in Washington, D. C., in latitude 38° 53′ 40″ N., and longitude 77° 01′.6 W., at $3^h\ 42^m$ p. m., app. t., I make a series of three altitude observations upon the sun for azimuth, each with the telescope in direct and reversed positions, observing opposite limbs of the sun, and reading the horizontal deflection angle from a flag pole about 20 chs. to the S., SW. to the sun:

Observation.	Telescope.	Sun.	Watch time.	Vertical angle.	Horizontal angle flag to sun.
1st.....	Direct........	◴	$3^h\ 56^m\ 58^s$	25° 20′	65° 00′ to SW.
" ...	Reversed....	◶	3 58 48	25 31	64 45 " "
	Mean .	....	$3^h\ 57^m\ 53^s$	25° 25′ 30″	64° 52′ 30″ " "
2nd....	Direct.......	◴	$4^h\ 01^m\ 48^s$	24° 28′	65° 56′ " "
" ...	Reversed....	◶	4 03 10	24 44	65 36 " "
	Mean .	....	....	24° 36′ 00″	65° 46′ 00″ " "
3rd....	Direct.......	◴	$4^h\ 05^m\ 58^s$	23° 44′	66° 44′ " "
" ...	Reversed....	◶	4 07 30	23 57	66 26 " "
	Mean .	....	....	23° 50′ 30″	66° 35′ 00″ " "

By 1st obsn. flag bears S. 1° 00′ 02″ W.
" 2nd " " " S. 1 00 20 W.
" 3rd " " " S. 0 59 50 W.

Mean true bearing of flag=S. 1° 00′ 04″ W.

Field record.

The declination of the sun for the mean period of the three observations=1° 02′ 16″ S.

The following reductions are made to obtain the true vertical angles of the above observations:

	1st obsn.	2nd obsn.	3rd obsn.
v=	25° 25′ 30″	24° 36′ 00″	23° 50′ 30″
Refraction=	−2 00	−2 06	−2 10
Parallax=	+ 08	+ 08	+ 08
h=	25° 23′ 38″	24° 34′ 02″	23° 48′ 28″

113. The first of the above series is selected for an example of reduction by the equation:

$$\text{Tan}\ \tfrac{1}{2}A=\sqrt{\frac{\cos\frac{1}{2}(\zeta+\phi+\delta)\ \sin\frac{1}{2}(\zeta+\phi-\delta)}{\cos\frac{1}{2}(\zeta-\phi-\delta)\ \sin\frac{1}{2}(\zeta-\phi+\delta)}}$$

$$h=25^\circ\ 23'\ 38''$$

$$\begin{array}{rlrl}
\zeta= & 64^\circ\ 36'\ 22'' & & \\
\phi= & 38\ \ 53\ \ 40 & \zeta= & 64^\circ\ 36'\ 22'' \\
 & & \phi= & 38\ \ 53\ \ 40 \\
\hline
\zeta+\phi= & 103^\circ\ 30'\ 02'' & \zeta-\phi= & 25^\circ\ 42'\ 42'' \\
\delta= & 1\ \ 02\ \ 16\ (-) & \delta= & 1\ \ 02\ \ 16\ (-) \\
\hline
\zeta+\phi+\delta= & 102^\circ\ 27'\ 46'' & \zeta-\phi+\delta= & 24^\circ\ 40'\ 26'' \\
\frac{1}{2}(\zeta+\phi+\delta)= & 51^\circ\ 13'\ 53'' & \frac{1}{2}(\zeta-\phi+\delta)= & 12^\circ\ 20'\ 13'' \\
\hline\hline
\zeta+\phi= & 103^\circ\ 30'\ 02'' & \zeta-\phi= & 25^\circ\ 42'\ 42'' \\
\delta= & 1\ \ 02\ \ 16\ (-) & \delta= & 1\ \ 02\ \ 16\ (-) \\
\hline
\zeta+\phi-\delta= & 104^\circ\ 32'\ 18'' & \zeta-\phi-\delta= & 26^\circ\ 44'\ 58'' \\
\frac{1}{2}(\zeta+\phi-\delta)= & 52^\circ\ 16'\ 09'' & \frac{1}{2}(\zeta-\phi-\delta)= & 13^\circ\ 22'\ 29'' \\
\hline\hline
\end{array}$$

$$\begin{array}{lrr}
\log\cos\frac{1}{2}(\zeta+\phi+\delta)= & & 9.796697 \\
\text{“}\ \ \sin\frac{1}{2}(\zeta+\phi-\delta)= & & 9.898118 \\
\cline{3-3}
 & & 9.694815 \\
\text{“}\ \ \cos\frac{1}{2}(\zeta-\phi-\delta)= & 9.988058 & \\
\text{“}\ \ \sin\frac{1}{2}(\zeta-\phi+\delta)= & 9.329724 & \\
\cline{2-2}
 & 9.317782 & 9.317782 \\
\cline{3-3}
\log\tan^2\frac{1}{2}A\ = & & 0.377033 \\
\text{“}\ \ \tan\frac{1}{2}A\ = & & 0.188516 \\
\frac{1}{2}A\ = & & 57^\circ\ 03'\ 44''
\end{array}$$

A=True bearing of sun=N. 114° 07′ 28″ W.

Angle from sun to flag=(+)64 52 30

True bearing of flag=N. 178° 59′ 58″ W.

=S. 1° 00′ 02″ W.

114. Let it also be required to reduce the first observation of the above series for time, making the reduction by the following equation:

$$\text{Tan}\ \tfrac{1}{2}\,t=\sqrt{\frac{\sin\frac{1}{2}(\zeta+\phi-\delta)\ \sin\frac{1}{2}(\zeta-\phi+\delta)}{\cos\frac{1}{2}(\zeta+\phi+\delta)\ \cos\frac{1}{2}(\zeta-\phi-\delta)}}$$

$$\begin{array}{lll}
\log\sin\frac{1}{2}(\zeta+\phi-\delta)= & & 9.898118\\
\text{“}\ \sin\frac{1}{2}(\zeta-\phi+\delta)= & & \underline{9.329724}\\
 & & 9.227842\\
\text{“}\ \cos\frac{1}{2}(\zeta+\phi+\delta)= & 9.796697 & \\
\text{“}\ \cos\frac{1}{2}(\zeta-\phi-\delta)= & \underline{9.988058} & \\
 & \underline{\underline{9.784755}} & \underline{9.784755}\\
\log\tan^2\frac{1}{2}\,t= & & 9.443087\\
\text{“}\ \tan\frac{1}{2}\,t= & & 9.721544\\
\frac{1}{2}\,t=27^\circ\ 46'\ 29'' & & \underline{\underline{}}\\
t=55^\circ\ 32'\ 58''=3^h\ 42^m\ 12^s & &
\end{array}$$

Apparent time of obsn.	$=3^h\ 42^m\ 12^s$ p. m.
Equation of time	$=\ +8\ \ 17$
Local mean time of obsn.	$=3^h\ 50^m\ 29^s$ p. m.
Watch time of obsn.	$=3\ \ 57\ \ 53$
Watch fast of l. m. t.	$=\ \ 7^m\ 24^s$

75th meridian time of comparison with a Western

Union telegraph clock	$=4^h\ 30^m\ 00^s$ p. m.
Correction for longitude	$=-08\ \ 06$
L. M. T. of comparison	$=4\ \ 21\ \ 54$
Watch time of comparison	$=4\ \ 29\ \ 20$
Watch fast of l. m. t	$=\ \ 7^m\ 26^s$

115. The second observation of the above series is selected for an example of reduction by the equation:

$$\text{Cos}\ A=\frac{\sin\delta}{\cos\phi\ \cos h}-\tan\phi\ \tan h$$

$$\begin{array}{llll}
\log\cos\phi=9.891149 & \log\sin\delta=8.257958\ \ (-) & \log\tan\phi= & 9.906733\\
\text{“}\ \cos h=\underline{9.958790} & & \text{“}\ \tan h= & \underline{9.660053}\\
\underline{\underline{9.849939}} & \underline{9.849939} & \log & 9.566786\\
\log & 8.408019 & \text{nat}\ (-) & .36880\\
\text{nat}\ (-) & .02559 & (-) & \underline{.02559}\\
 & & \cos A=(-) & .39439
\end{array}$$

A=True bearing of sun	=S. 66° 46′ 20″ W.
Angle from sun to flag	=(−)65 46 00
True bearing of flag	=S. 1° 00′ 20″ W.

116. The third observation of the above series is selected for an example of reduction by the equation:

$$\cos \tfrac{1}{2} A = \sqrt{\frac{\sin S \sin (S - \text{codecl.})}{\sin \text{colat.} \sin \text{coalt.}}}$$

$$\begin{array}{llll}
90^\circ - \phi = 90^\circ - 38^\circ\ 53'\ 40'' & & = 51^\circ\ 06'\ 20'' & = \text{colat.} \\
90^\circ - \delta = 90^\circ - \ \ 1\ \ 02\ \ 16 & (-) & = 91\ \ 02\ \ 16 & = \text{codecl.} \\
90^\circ - h = 90^\circ - 23\ \ 48\ \ 28 & & = 66\ \ 11\ \ 32 & = \text{coalt.} \\
\hline
 & & 2\,S = 208^\circ\ 20'\ 08'' & \\
 & & S = 104^\circ\ 10'\ 04'' & \\
 & \text{codecl.} = 90^\circ - \delta = & 91\ \ 02\ \ 16 & \\
\hline
 & S - \text{codecl.} = & 13^\circ\ 07'\ 48'' &
\end{array}$$

$$\begin{array}{lll}
\log \sin S \quad = & & 9.986585 \\
\text{“} \ \sin (S - \text{codecl.}) \ = & & 9.356334 \\
\hline
 & & 9.342919 \\
\text{“} \ \sin \text{colat.} & = 9.891149 & \\
\text{“} \ \sin \text{coalt.} & = 9.961376 & \\
\hline
 & 9.852525 & 9.852525 \\
\hline
\log \cos^2 \tfrac{1}{2} A = & & 9.490394 \\
\text{“} \ \cos \tfrac{1}{2} A = & & 9.745197 \\
\tfrac{1}{2} A = & & 56^\circ\ 12'\ 35''
\end{array}$$

$$\begin{array}{ll}
A = \text{True bearing of sun} & = \text{N. } 112^\circ\ 25'\ 10''\ \text{W.} \\
\text{Angle from sun to flag} & = (+)\ 66\ \ 35\ \ 00 \\
\hline
\text{True bearing of flag} & = \text{N. } 179^\circ\ 00'\ 10''\ \text{W.} \\
 & = \text{S. } \ 0^\circ\ 59'\ 50''\ \text{W.}
\end{array}$$

EQUAL ALTITUDE OBSERVATIONS OF THE SUN FOR MERIDIAN.

117. The true meridian may be established by the method of equal altitude observations of the sun. The observation is not well adapted to line work, but it possesses a certain usefulness in camp, in that the engineer may thus determine the true meridian by the sun with mere approximations as to time and latitude.

The fixation of the true meridian by this method depends upon the theory that the sun's center at equal altitudes occupies symmetrical positions in azimuth east and west of the meridian in the morning and in the afternoon except for the correction necessary to be applied due to the change in the sun's declination in the interval between the a. m. and p. m. observations:

"dA_δ": Correction in azimuth in minutes of angular measure to be applied to the mean position in azimuth to obtain the true south point; the correction is to be applied to the east with a northerly hourly change in declination, or to the west with a southerly hourly change.

"$d\delta$": Change in declination of the sun from the a. m. to the p. m. observation, expressed in minutes of angular measure.

"(t_1+t_2)": The sum of the hour angles from apparent noon, or the total watch time from the a. m. to the p. m. observation, expressed in angular measure.

$$dA_\delta=\frac{\frac{1}{2}d\delta}{\cos\phi\sin\frac{1}{2}(t_1+t_2)}$$

The symmetry of the equal altitude observation is maintained by observing opposite limbs in azimuth in the a. m. and p. m. observations, in connection with the same limb in vertical angle in both observations.

With "$\frac{1}{2}d\delta$" and "$\frac{1}{2}(t_1+t_2)$" calculated, the computation can be concluded by applying to "$\frac{1}{2}d\delta$" the declination coefficient obtained by entering Table 22 of the Standard Field Tables, which gives coefficients for computing errors in azimuth due to small errors in declination, arguments: "ϕ" and "$\frac{1}{2}(t_1+t_2)$."

118. An equal altitude observation of the sun for azimuth consists in reading the horizontal deflection angles from a fixed reference point to opposite right or left limbs of the sun in a. m. and p. m. observations simultaneously with the same upper or lower limb at the epoch of equal vertical angle in both observations, from the record of which a calculation is made of the bearing of the reference point as referred to the true meridian. To guard against error the engineer is required to make a series of three equal altitude observations, taking the resulting mean. The most suitable a. m. and p. m. hours for this observation obtain when the sun is moving rapidly in altitude as compared with a relatively small change in azimuth.

EQUAL ALTITUDE OBSERVATIONS OF THE SUN, OBSERVING PROGRAM.

119. Select the observing station, or transit point, and a reference point preferably to the south, and not nearer than 5 or 10 chains distant.

Thoroughly level the transit for the a. m. observation.

Observe and record the horizontal deflection angle from the fixed reference point to the sun's right limb, and the vertical angle to the sun's lower limb; these observations must be simultaneous, at the epoch of which the sun will appear as indicated; note the watch time at the epoch of the observation: 

Thoroughly level the transit for the p. m. observation.

With the same vertical angle set off for the p. m. observation follow the sun's left limb until the sun's lower limb becomes tangent, as indicated, recording the watch time and horizontal deflection angle from the reference point: 

The above program constitutes one observation. A series of three observations are taken by three successive a. m. settings at intervals of about four or five minutes of time. In the p. m. the settings are of course made in the inverse order.

Consider each equal altitude observation separately and subtract the lesser horizontal angle from the greater and divide by two.

The mean of the three half-differences is then taken to determine the horizontal angle from the reference point to an *uncorrected* south point, this angle to be applied in a direction to equalize the south point between the two observed positions of the sun.

Compute the differential azimuth correction due to the change in the sun's declination from the mean period of the a. m. to the mean period of the p. m. observations, and apply this angle to the mean of the half-differences as stated above; the differential azimuth correction is to be applied to the east when the hourly change in the sun's declination is northerly or to the west when the hourly change in the sun's declination is southerly; the computed resultant angle indicates the bearing of the reference point referred to the true meridian.

The correct apparent times of the observations do not need to be known, as the function "$\frac{1}{2}(t_1+t_2)$" equals one-half the time in hours and minutes, by the engineer's watch, from the a. m. to the p. m. observation.

The equal altitude observation may be modified by taking a p. m. observation one day followed by an a. m. observation the next, in which case the functions "$\frac{1}{2}d\,\delta$" and "$\frac{1}{2}(t_1+t_2)$" are to be computed for the period from the p. m. to the a. m. observation; and the differential azimuth correction, "$d\ A_\delta$", is then applied in the *opposite* direction.

120. Example of equal altitude observation of the sun for azimuth:

Final field notes.

May 3, 1913, at a transit point in Washington, D. C., in latitude 38° 53′ 40″ N., and longitude 77° 1′.6 W., at 9^h27^m a. m. and 2^h33^m p. m., app. t., I make a series of three equal altitude observations upon the sun for azimuth, reading the horizontal deflection angle from a flag-pole about 20 chs. to the S., SE. in the a. m. to the sun's right limb, and SW. in the p. m. to the sun's left limb; equal vertical angles being taken to the sun's lower limb.

Observation.	Sun.	Watch time.	Vertical angle.	Horizontal angle flag to sun.	
1st a. m.	◵	$9^h29^m25^s$	48°28′00″	67°20′00″	to SE.
3d p. m.	◶	2 41 40		65 28 30	to SW.
				1°51′30″ (Diff.)	
2d a. m.	◵	$9^h32^m50^s$	49°05′00″	66°29′30″	to SE.
2d p. m.	◶	2 38 15		64 38 00	to SW.
Sum of hour angles		$5^h05^m25^s$		1°51′30″ (Diff.)	
Mean hour angle		$2^h32^m42^s$			
3d a. m.	◵	$9^h36^m30^s$	49°43′00″	65°34′30″	to SE.
1st p. m.	◶	2 34 45		63 45 30	to SW.
				1°49′00″ (Diff.)	

One-half differences, or bearing angles from uncorrected south point to flag:

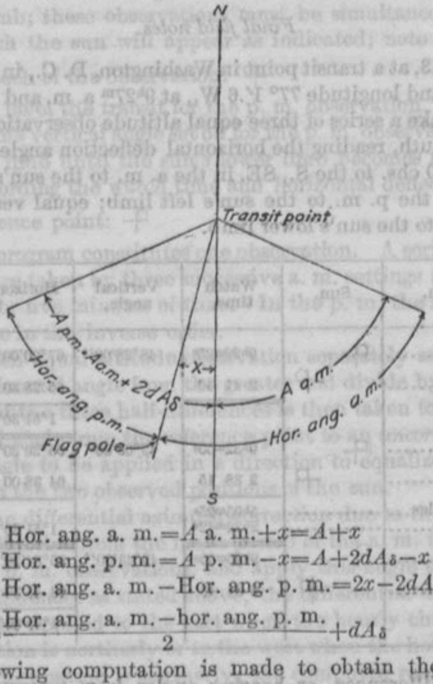
By 1st obsn. = S. 0° 55′ 45″ W.
" 2d " = S. 0 55 45 W.
" 3d " = S. 0 54 30 W.

Mean = S. 0° 55′ 20″ W.
Differential azimuth correction = (+) 3′ 53″

Mean true bearing of flag = S. 0° 59′ 13″ W.

Field record.

The hourly change in the sun's declination=44″.3 N.



$$\text{Hor. ang. a. m.} = A\ \text{a. m.} + x = A + x$$

$$\text{Hor. ang. p. m.} = A\ \text{p. m.} - x = A + 2dA_\delta - x$$

$$\text{Hor. ang. a. m.} - \text{Hor. ang. p. m.} = 2x - 2dA_\delta$$

$$x = \frac{\text{Hor. ang. a. m.} - \text{hor. ang. p. m.}}{2} + dA_\delta$$

The following computation is made to obtain the differential azimuth correction for the above series:

$$\begin{array}{lrr}
\tfrac{1}{2}\,d\delta = \tfrac{1}{2} \times 5.08 \times 44.3 = 112''; \ \log \tfrac{1}{2}d\delta & & = 2.049218 \\
\phi = 38^\circ\ 53'\ 40''\ \text{N.}; \ \log \cos \phi & = 9.891149 & \\
\tfrac{1}{2}(t_1 + t_2) = 2^\text{h}\ 32^\text{m}\ 42^\text{s} & & \\
\quad = 38^\circ\ 10'\ 30'' & & \\
\log \sin \tfrac{1}{2}(t_1 + t_2) & = 9.791034 & \\
\hline
 & 9.682183 & 9.682183 \\
\hline\hline
 & \log d\,A_\delta & = 2.367035 \\
d\,A_\delta = \text{Differential azimuth correction} & & = 233'' \\
 & & = 3'\ 53''
\end{array}$$

121. The following reduction to obtain the value of the differential azimuth correction for the above series is made with the use of Table 22 of the Standard Field Tables:

Latitude.	$\frac{1}{2}(t_1+t_2)$, or hours from noon.		
	2^h	$2^h\ 33^m$	3^h
35° 00′	2.44	2.05	1.73
38 54		2.16	
40 00	2.61	2.19	1.85

Declination coefficient $=2.16$

$d\ A_\delta=2.16\times\frac{1}{2}\ d\delta=2.16\times112''$ $=242''$

$d\ A_\delta$=differential azimuth correction$=4'\ 02''$

The small difference (09″) in the computation of "$d\ A_\delta$" in the two processes of reduction is due to the error in adopting a coefficient obtained by linear interpolation in Table 22 of the Standard Field Tables, the tabular interval of which is large. Ordinarily the equal altitude method would be used when the latitude of the station is uncertain, and the slight error in using the declination coefficient taken by linear interpolation from Table 22 is small enough to be negligible.

122. The second a. m. and p. m. observations of the above series are selected for an example of reduction to the sun's center and direct computation of the sun's azimuth, and true bearing of the flag, by the equation:

$$\text{Cos } A=\frac{\sin\delta}{\cos\phi\cos h}-\tan\phi\tan h$$

Vertical angle to sun's lower limb	$=49°\ 05'\ 00''$
Reduction to sun's center	$=+\ \ 15'\ 54''$
Refraction	$=-\ \ 49''$
Parallax	$=+\ \ 06''$
Sun's center, h	$=49°\ 20'\ 11''$

Declination of the sun at Greenwich apparent noon =15° 34′ 37″ N.
Diff. in time to a. m. obsn.:
For longitude = 5^h08^m
For time, a. m. = −2 33
2.58 ^{h} = 2^h35^m
Diff. in declination to app. t. of a. m. obsn.:
2.58×44″.3=114″ = 1′ 54″ N.
Sun's decl. a. m. obsn. =15° 36′ 31″ N.
Diff.to p.m.obsn.,already computed(2×112″=224″)= 3′ 44″ N.
Sun's decl. p. m. obsn. =15° 40′ 15″ N.

	a. m. obsn.	p. m. obsn.
log cos ϕ=9.891149	log sin δ=9.429856(+)	log sin δ=9.431541(+)
" cos h=9.813992		
9.705141	9.705141	9.705141
" tan ϕ =9.906733	log 9.724715	log 9.726400
" tan h =0.065991	nat (+) .53054	nat (+) .53260
log 9.972724		
nat (−) .93913	(−) .93913	(−) .93913
cos A =	(−) .40859	(−) .40653
A=true bearing of sun	=S. 65° 53′ 02″ E.	S. 66° 00′ 47″ W.
Horizontal angle from flag to sun's right and left limbs	= 66° 29′ 30″ to SE.	64° 38′ 00″ to SW.
Reduction to sun's center=$\frac{15.9'}{\cos 49° 20'}$	= (+) 24′ 24″	(+) 24′ 24″
Hor. ang. to sun's center	= 66° 53′ 54″ to SE.	65° 02′ 24″ to SW.
Sun's azimuth as computed above	=S. 65° 53′ 02″ E.	S. 66° 00′ 47″ W.
True bearing of flag	=S. 1° 00′ 52″ W.	S. 0° 58′ 23″ W.
Mean true bearing of flag	=S. 0° 59′ 37″ W.	

The discrepancy between the a. m. and p. m. results suggests a systematic instrumental error ordinarily eliminated by taking direct and reversed observations, which in this instance is of opposite effect in a. m. and p. m. hours and apparently eliminated in the mean result.

123. One additional fact should be noted relative to the several reductions of the above equal altitude observations:

By above direct computation, A p. m. $=66° \ 00' \ 47''$

A a. m. $=65° \ 53' \ 02''$

$$\text{Difference}=2dA_\delta = 7' \ 45''$$

$$dA_\delta = 3' \ 53''$$

This value for $dA\delta$ ($3' \ 53''$) agrees with same function as first computed.

124. Upon concluding the subject of azimuth determinations it will be of interest to note that the weighted mean of a large number of observations gives a value of S. 0° 59′ 25″ W. for the azimuth of the line from the Washington, D. C., transit point to the flag pole heretofore described. A comparison of the methods and results of the various observations as given on the preceding pages suggests that the engineer should seldom be without means by which accurately to determine time, latitude, and azimuth at any place in the field, however remote, and should doubt arise as to his results a "check" by independent method is nearly always available and a certain guide as to the accuracy of the determinations. It might be added that a careful engineer will not fail to surround his methods with adequate verification to insure the accuracy required in the execution of the public-land surveys.

THE TRUE PARALLEL OF LATITUDE.

125. The base lines and standard parallels of the rectangular system are established on the true parallel of latitude; the random latitudinal township boundary lines are also projected on the same curve; this curve is defined by a plane at right angles to the earth's polar axis cutting the earth's surface on a small circle. At every point on the true parallel the curve bears due east and west, the direction of the line being at right angles to the meridian at every point along the line. Two points at a distance of 20 chains apart on the same parallel of latitude may be said to define the direction of the curve at either point, without appreciable error, but the projection of a line so defined in either direction, easterly or westerly, would describe a great circle of the earth gradually departing southerly from the true parallel. The great circle tangent to the parallel at any origin or reference point along the parallel is known as the "tangent to the parallel," and it is coincident with the true latitude curve only at the point of origin. The rate of the change of the azimuth of the tangent is a function of the latitude on the earth's surface. The azimuth of the tangent varies directly as the distance from the origin, and the offset distance from the tangent to the parallel varies as the square of the distance from the point of tangency. A great circle connecting two distant points on the same latitude curve has the same angle with the meridian at both points and the azimuth of such a line at the two points of intersection is a function of one-half the distance between the points.

There are three general methods of establishing a true parallel of latitude which may be employed independently to arrive at the same result: (1) The solar method; (2) the tangent method; and, (3) the secant method.

SOLAR METHOD.

126. The solar instruments are capable of following the true parallel of latitude without substantial offsets. If such an instrument, in good adjustment, is employed, the true meridian may be determined by observation with the solar at each transit point. A turn of 90° in either direction then defines the true parallel, and if sights are taken not longer than from 20 to 40 chains distant, the line so established does not appreciably differ from the theoretical parallel of latitude. The locus of the resulting line is a succession of points each one at right angles to the true meridian at the previous station. However, during a period each day the solar is not available, and during this time, also whenever the sun may be obscured by clouds, or on account of a disturbance of the adjustments of the solar attachment, and whenever an instrument without solar attachment is employed, reference must be made to a transit line from which to establish the true latitude curve by one of the following methods.

TANGENT METHOD.

127. The tangent method of determination of the true latitude curve consists in establishing the true meridian at the point of beginning, from which a horizontal deflection angle of 90° is turned to the east or west, as may be required, and the projection of the line thus determined is called the tangent. The tangent is projected 6

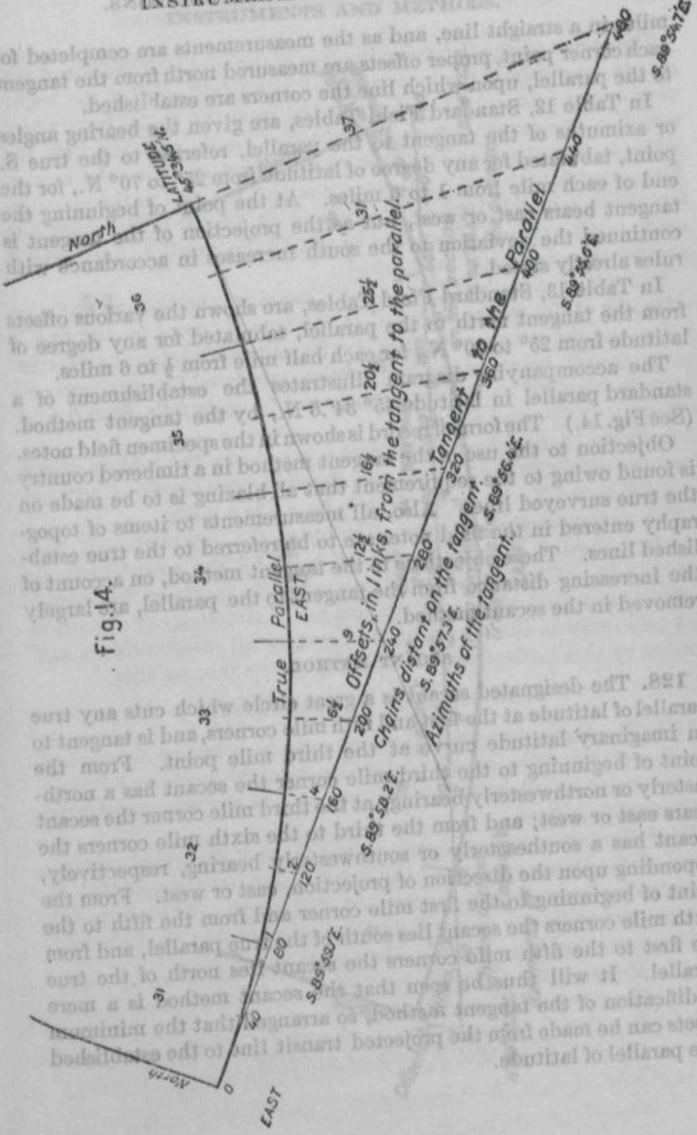

North
LATITUDE 45°34.5' N.
North
EAST
True Parallel
EAST
Offsets, in links, from the tangent to the parallel.
Chains distant on the tangent.
Azimuths of the tangent.
Tangent to the Parallel
31
32
33
34
35
36
0
40
80
120
160
200
240
280
320
360
400
440
480
1
2
4
6¼
9
12¼
16¼
20¼
25¼
31
37
S.89°59.5'E.
S.89°58.2'E.
S.89°57.3'E.
S.89°56.4'E.
S.89°55.6'E.
S.89°54.7'E.

Fig. 14.

miles in a straight line, and as the measurements are completed for each corner point, proper offsets are measured north from the tangent to the parallel, upon which line the corners are established.

In Table 12, Standard Field Tables, are given the bearing angles or azimuths of the tangent to the parallel, referred to the true S. point, tabulated for any degree of latitude from 25° to 70° N., for the end of each mile from 1 to 6 miles. At the point of beginning the tangent bears east or west, but as the projection of the tangent is continued the deviation to the south increases in accordance with rules already stated.

In Table 13, Standard Field Tables, are shown the various offsets from the tangent north to the parallel, tabulated for any degree of latitude from 25° to 70° N., for each half mile from ½ to 6 miles.

The accompanying diagram illustrates the establishment of a standard parallel in latitude 45° 34′.5 N., by the tangent method. (See Fig. 14.) The form of record is shown in the specimen field notes.

Objection to the use of the tangent method in a timbered country is found owing to the requirement that all blazing is to be made on the true surveyed lines. Also, all measurements to items of topography entered in the field notes are to be referred to the true established lines. These objections to the tangent method, on account of the increasing distance from the tangent to the parallel, are largely removed in the secant method.

SECANT METHOD.

128. The designated secant is a great circle which cuts any true parallel of latitude at the first and fifth mile corners, and is tangent to an imaginary latitude curve at the third mile point. From the point of beginning to the third mile corner the secant has a northeasterly or northwesterly bearing; at the third mile corner the secant bears east or west; and from the third to the sixth mile corners the secant has a southeasterly or southwesterly bearing, respectively, depending upon the direction of projection, east or west. From the point of beginning to the first mile corner and from the fifth to the sixth mile corners the secant lies south of the true parallel, and from the first to the fifth mile corners the secant lies north of the true parallel. It will thus be seen that the secant method is a mere modification of the tangent method, so arranged that the minimum offsets can be made from the projected transit line to the established true parallel of latitude.


North
31
Offsets, in links,
5
12
0
40
80
120
160
200
240
280
320
360
400
440
480
Chains distant
from the secant
to the parallel.
N.89°57.3'E.
N.89°58.2'E.
Azimuths of
32
N.89°59.1'E.
33
EAST
Secant
34
S.89°59.1'E.
35
36
True Parallel
EAST
on the secant.
S.89°58.2'E.
the secant.
S.89°57.3'E.
North
LATITUDE 45°34.5'N.

Fig. 15

The secant method of determination of the true latitude curve consists in establishing the true meridian at a point south of the beginning corner a measured distance taken from the table, from which meridian the proper horizontal deflection angle, as taken from the table, is turned to the northeast or northwest to define the secant. The secant is projected 6 miles in a straight line, and as the measurements are completed for each corner point, proper offsets are measured, north or south, from the secant to the parallel, upon which parallel the corners are established.

In Table 14, Standard Field Tables, are given the bearing angles or azimuths of the secant, referred to the true N. point for the first 3 miles, and the same symmetrical bearing angles or azimuths referred to the true S. point for the last 3 miles, tabulated for any degree of latitude from 25° to 70° N., for the end of each mile from 0 to 6 miles.

In Table 15, Standard Field Tables, are shown the various offsets from the secant to the parallel, tabulated for any degree of latitude from 25° to 70° N., for each half mile from 0 to 6 miles.

The accompanying diagram illustrates the establishment of a standard parallel in latitude 45° 34′.5 N. by the secant method. (See Fig. 15.) The form of record is shown in the specimen field notes.

The secant method is recommended for its simplicity of execution and proximity to the true latitude curve, as all measurements and cutting by this method are substantially on the true parallel.

CONVERGENCY OF MERIDIANS.

129. The linear amount of the convergency of two meridians is a function of their distance apart, of the length of the meridian between two reference parallels, of the latitude, and of the spheroidal form of the earth's surface.

The following equation is convenient for the analytical computation of the linear amount of the convergency on the parallel, of two meridians any distance apart, and any length. The correction for convergency in any closed figure is proportional to the area, and may be computed from an equivalent rectangular area:

"m_λ": Measurement along the parallel.
"m_ϕ": Measurement along the meridian.
"a": Equatorial radius of the earth=3963. 3 miles.
"e": Factor of eccentricity, $\log e=8.915\ 2515$.

"dm_λ": Linear amount of the convergency on the parallel, of two meridians distance apart "m_λ," and length "m_ϕ" along the meridian: "dm_λ", "m_λ", "m_ϕ" and "a" to be expressed in the same linear unit:

$$dm_\lambda = \frac{m_\lambda \, m_\phi}{a} \tan \phi \sqrt{1-e^2 \sin^2 \phi}$$

Example of computation of the convergency of two meridians 24 miles long and 24 miles apart in a mean latitude of 43° 20′:

nat 1	=	1. 0000000
log e	=8. 915 2515	
" "	=8. 915 2515	
" sin 43° 20′	=9. 836 477	
" " " "	=9. 836 477	
" $e^2 \sin^2 \phi$	=7. 503 457	
nat " " "	=	0. 0031875
" $(1-e^2 \sin^2 \phi)$ =		0. 9968125
log " " "	9. 998 614	
" $\sqrt{1-e^2 \sin^2 \phi}$	=9. 999 307	
" tan 43° 20′	=9. 974 720	
" 24	=1. 380 211	
" "	=1. 380 211	
" 80*	=1. 903 090	
" product	=4. 637 539	
" 3963. 3	=3. 598 057	
" dm_λ	=1. 039 482	
nat "	10. 9517	chs.

The convergency, measured on the parallel, of two meridians 24 miles apart and 24 miles long, in a mean latitude of 43° 20′, is therefore found to be 10.95 chains. The convergency of the east and west boundaries of a regular township in the same latitude would be equal to one-sixteenth of the convergency of the east and west boundaries of the quadrangle as computed above, or 68.44 links, which agrees with the value taken from Table 11 of the Standard Field Tables.

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*This factor is introduced here for the purpose of conversion from the unit expressed in miles to the unit expressed in chains.

See letter 1742005 E 11/21/38 to O.E. [illegible] Canal Zone, Panama.

130. In Table 11, Standard Field Tables, are tabulated the linear amounts of the convergency of meridians, 6 miles long and 6 miles apart, for each degree of latitude from 25° to 70° N., together with the angle of convergency of the same meridians. These amounts of linear convergency are at once the proper corrections to apply to the north boundary of a regular township in the computation of the closing error around a township, or other computation by which a theoretical length of a north or south boundary of a township is compared with the length of the opposite boundary; the tabulated linear amounts of convergency are equal to double the amounts of the offsets from a tangent to the parallel at 6 miles for the same latitudes. Simple interpolation may be made for any intermediate latitude, and the amount of the convergency for a fractional township or other figure may be taken in proportion to the tabulated convergency as the fractional area is to 36 square miles.

The tabulated angle of convergency represents at once the deviation in azimuth of the tangent from the parallel at 6 miles; and 1/6, 1/3, 1/2, 2/3, and 5/6 of the tabulated angles of convergency represent at once the amounts of the correction in the bearing of meridional section lines to compensate for convergency within a township.

In the same table are given the differences of longitude for 6 miles in both angular and time measure, also the differences of latitude, for 1 or 6 miles, in angular measure, in the various tabulated latitudes.

131. In the plan of subdivision of townships the meridional section lines are established parallel to the east boundary or other governing line; this necessitates a slight correction on account of the angular convergency of meridians. Meridional section lines west of the governing line are deflected to the left of the bearing of the governing line the amount shown in the second part of Table 2, Standard Field Tables, which is entered under two arguments: (1) Latitude, and (2) distance from the governing line. Meridional section lines east of a governing boundary are given the same amount of correction for bearing, but the deflection is made to the right.

LENGTHS OF ARCS OF THE EARTH'S SURFACE.

132. All computations involving a difference of latitude for a given measurement along a meridian or the converse calculation, or other computations involving a difference of longitude for a given measurement along a parallel or a similar converse calculation, are readily accomplished by the use of the values given in Table 16, Standard Field Tables; this table gives the lengths in miles and decimal part of a mile of one degree of longitude measured on the parallel, and the lengths in miles of one degree of latitude measured on the meridian, for any latitude from 25° to 70° N.

The above tabulated values may be reduced to miles and chains, or to chains or feet, as convenient. In taking out lengths of degrees of longitude measured on the parallel an exact linear interpolation may be made, and in taking out lengths of degrees of latitude measured on the meridian the value should be taken out for the mean position in latitude of that portion of the meridian whose length it is desired to compute.

133. The first part of Table 2, Standard Field Tables, has been arranged for the reference of the latitude of any point within a township to the south boundary, the only argument being the miles and chains distant from the south boundary. Thus with the use of this table all observations for latitude within a township may be reduced to the south boundary; and conversely, given the latitude of the south boundary of a township, the latitude of any station within the township may readily be obtained by applying the difference given in the table for the known distance north.

HOUR ANGLE OBSERVATION OF POLARIS FOR LATITUDE.

133–A. Continuing subjects included in sections 73 to 76, inclusive, and sections 91 to 98, inclusive. The latitude may be determined by an altitude observation of Polaris at any hour angle. By this method the vertical angles are read in pairs, or double pairs, with reversals of the position of the telescope, and watch time noted at each setting. The watch correction is required, which will be applied to the mean (or average) of the watch readings to obtain the correct local mean time of observation for the pair or double pairs of settings. The mean time hour angle of Polaris at the epoch of observation is then taken out as in observations for azimuth, and the declination of Polaris for the date will be ascertained in the Ephemeris.

With the two values, mean time hour angle and declination, the latitude may be computed or there may be derived from the table in the Ephemeris the vertical angle equivalent for the position of Polaris above or below the earth's polar axis at the epoch of observation. The latter value is applied to the observed vertical angle, corrected for refraction, to secure the true elevation of the pole, or the *latitude* of the station. The method may be combined with the observation for azimuth, or it may be used independently.

The vertical angle reduction is tabulated in the Ephemeris in a simplified form in which the two principal arguments are employed to secure a primary adjustment to the elevation of the pole, subtractive when Polaris is above the pole and additive when below; a small supplemental correction is then secured from the table, with the arguments of mean time hour angle and observed altitude.

Example of hour angle observation of Polaris for latitude, making use of the table given in the Ephemeris:

Final field notes.

May 23, 1929, at station No. 1, in longitude 100° 00′ W., I make an hour angle observation of Polaris for latitude, reading two vertical angles, one each with the telescope in direct and reversed positions:

Mean observed vertical angle	35° 39′ 30″
Mean watch time of observation, p. m.	$7^{h}\ 41^{m}\ 12^{s}$
Watch fast of l. m. t., determined by setting with a Western Union clock reading central standard time	$40^{m}\ 00^{s}$
Reduced latitude	36° 29′ 48″

Field record.

Hour angle observation of Polaris for latitude:

Telescope.	Vertical angle.	Watch time.
Direct..........................	35° 39′ 00″	$7^{h}\ 40^{m}\ 44^{s}$ p. m.
Reversed........................	35 40 00	7 41 40
Mean....................	35° 39′ 30″	$7^{h}\ 41^{m}\ 12^{s}$ p. m.

Watch fast of local mean time.............. 40 00

L. M. T. of observation, May 23, 1929 = $7^{h}\ 01^{m}\ 12^{s}$ p. m.

= $7^{h}\ 01.2^{m}$ p. m.

+12

Gr. U. C. of Polaris, same date =$9^{h}\ 33.2^{m}$ a. m.

Red. to longitude 100° 00′ = −1.1 = 9 32.1 a. m.

Hour angle of Polaris west of the meridian = $9^{h}\ 29.1^{m}$

Declination of Polaris +88° 55′ 15″

Mean time hour angle.	Primary adjustment, additive, Polaris below the pole.		
	Declination.		
	+88° 55′ 00″	+88° 55′ 15″	+88° 55′ 20″
9h 22.5m	0° 50′ 46″	0° 50′ 34″	0° 50′ 30″
29.1		0 51 42	
34.4,	0 52 48	0 52 36	0 52 32

Mean obs^d. v. ang., v $=35° 39′ 30″$
Corr. for refraction $= \quad -1 \quad 20$
$h=35° 38′ 10″$
Primary adjustment to elev. of pole. $+ 0° 51′ 42″$
Supplemental corr. $- 0 \quad 0 \quad 04$
Latitude of station. $=36° 29′ 48″$

In order to proceed with the analytical reduction, it is convenient to begin with an angle α, computed from the equation:

$\text{Tan } \alpha=\frac{\tan \delta}{\cos t}$, in which equation the factor "$\cos t$" becomes negative for hour angles exceeding 90°, whereupon α will exceed 90°.

The latitude may then be derived from the equation:

$$\text{Cos } (\phi-\alpha)=\frac{\sin \alpha \sin h}{\sin \delta}$$

The above example of a field observation is reduced as follows:

Mean time h. a. $9^h\ 29.1^m$
Red. to sidereal h. a. $+1.6$
Sidereal h. a. $9^h\ 30.7^m$

Same, red. to ang. meas., $t=142° 40′ 30″$

log tan $\delta=1.7249827$
" cos $t=9.9004813$ (−)
" tan $\alpha=1.8245014$ (−)
$\alpha=$ 90° 51′ 30″

log sin $\alpha=9.9999513$
" " $h=9.7653968$
9.7653481
" " $\delta=9.9999230$
log cos $(\phi-\alpha)=9.7654251$

By inspection it will be seen that $\phi-\alpha$ is a negative angle.
$\phi-\alpha=-54° 21′ 40″$
$\alpha=+90° 51′ 30″$
Latitude of station............$\phi=$ 36° 29′ 50″

CHAPTER III.

SYSTEM OF RECTANGULAR SURVEYS.

GENERAL SCHEME.

134. In the preceding chapters there has been outlined the system of nomenclature and procedure relating, in general terms, to the survey of the public domain. It is confidently assumed that the United States surveyor has become impressed with the purpose of his task and the stability and dignity which should be attached to a work so great and important, commensurate with its broad foundation in law and science.

For the purpose of disposal of the public domain the law provides, in general terms, for its description, subdivision and identification in conformity with the following general scheme:

1st. The township, 6 miles square, containing 36 sections, each 1 mile square.

2d. The numbering of the townships meridionally into a range and latitudinally into a tier, from which the necessity at once appears for the selection of independent initial points, each to serve as an origin for the extension of surveys synchronously needed in somewhat widely separated localities, to provide for which, principal or governing meridians and base lines have been established, to which might be related the surveys executed in each of such localities.

3d. The establishment of guide meridians and correction lines or standard parallels at intervals sufficiently near each other to maintain a practical workable adherence to the legal definition of the primary unit, the township 6 miles square, and at the same time to reduce to a minimum the number of corners required.

4th. The placing of fractional sections on the north and west boundaries of the township.

5th. The subdivision of the townships into 36 sections by running parallel lines through the township from south to north and from east to west at distances of 1 mile.

6th. The inflexible declaration of the integrity of the corners marked in the public surveys as the proper legal corners of the sections or of the subdivisions of the sections which they were intended to designate, together with the equally important provisions (*a*) that the boundary lines actually run and marked shall be and remain the proper boundary lines of the sections or subdivisions for which they were intended: (*b*) that the length of such lines as returned by the surveyors shall be held as the true length thereof; and (*c*) that the sections shall be subdivided by running straight lines from the established quarter-section corners to the opposite established quarter-section corners.

135. The townships will be numbered to the north or south commencing with number 1 at the base line, and with range numbers to the east or west beginning with number 1 at the principal meridian.

The 36 sections into which a township is subdivided are numbered commencing with number 1 in the northeast section of the township, proceeding thence west to section 6, thence south to section 7, thence east to section 12, and so on, alternately, to number 36 in the southeast section. In the case of fractional townships, the sections will bear the same numbers they would have had if the townships were full, that is to say the section numbers should be employed which are the proper section numbers relating to the sides which are the governing boundaries, leaving any deficiency to fall on the opposite sides.

136. The specimen field notes will serve to illustrate the method of running lines to form quadrangles 24 miles square; the method of running the exterior lines of townships; and the method of subdividing regular townships. The methods here presented are designed to insure a full compliance with every practicable requirement, meaning and intent of the surveying laws.

137. By the terms of the original law and by general practice section lines are surveyed from south to north and from east to west, in order uniformly to place excess or deficiency of measurement on the north and west sides of the townships. For convenience the exterior lines on which subdivisions are based are called the governing boundaries. In unusual cases the north and west boundaries may be employed to govern the subdivision of a township, and in extreme cases an irregular township may be without even a single governing boundary.

INITIAL POINTS.

138. Initial points from which the lines of the public surveys are to be extended will be established whenever necessary, under such special instructions as may be prescribed in each case by the Commissioner of the General Land Office. The initial points are to be selected with a view to their control of extensive agricultural areas within reasonable geographical limitations. Upon the establishment of an initial point, the position of the point in latitude and longitude is to be determined by accurate field astronomical methods.

During the period since the organization of the system of rectangular surveys numbered and locally named principal meridians and base lines have been established as shown by the accompanying tabular exhibit. These bases and meridians may be found by examining the large wall map of the United States published by the General Land Office; they are also shown upon the various official State maps, and upon a special map entitled "United States, Showing Principal Meridians, Base Lines and Areas Governed Thereby."

139. The latitudes and longitudes given in the following table are based upon the best obtainable information, but in some cases the values shown are only approximately correct owing to the fact that many of the initial points were fixed in position and the surveys therefrom largely completed before the same importance was attached to the matter of accurate latitudes and longitudes as at the present time. It may also be noted, by way of explanation, that present-day facilities for accurate field astronomical determinations were not available to the early surveyors. It is not expected that the values of the latitudes given in the table will be used as the basis of the calculation of the latitude of an unknown station, in lieu of a field determination thereof, except as an approximate value may satisfy all requirements. The coördinates of the earliest surveys in Ohio can not be conveniently tabulated, but they are shown upon the maps as stated above.

PRINCIPAL MERIDIAN.

140. This line shall conform to the true meridian and will be extended from the initial monument, either north or south, or in both directions, as the conditions may require; regular quarter-section and section corners will be established alternately at intervals of 40 chains, and regular township corners at intervals of 480 chains; meander corners will be established at the intersection of the line with all meanderable bodies of water.

141. In the survey of the principal meridian and the other *standard lines* (base lines, standard parallels and guide meridians), hereinafter described, two independent sets of measurements will

MERIDIANS AND BASE LINES OF THE UNITED STATES RECTANGULAR SURVEYS.

Meridians.	Governing surveys (wholly or in part) in States of—	Longitude of principal meridians west from Greenwich.			Latitude of base lines north from Equator.		
		°	′	″	°	′	″
Black Hills	South Dakota	104	03	00	44	00	00
Boise	Idaho	116	24	15	43	22	31
Chickasaw	Mississippi	89	15	00	34	59	00
Choctaw	....do	90	14	45	31	54	40
Cimarron	Oklahoma	103	00	00	36	30	00
Copper River	Alaska	145	18	42	61	49	11
Fairbanks	Alaska	147	38	33	64	51	49
Fifth Principal	Arkansas, Iowa, Minnesota, Missouri, North Dakota, and South Dakota.	91	03	42	34	44	00
First Principal	Ohio and Indiana	84	48	50	41	00	00
Fourth Principal	Illinois [1]	90	28	45	40	00	30
Do	Minnesota and Wisconsin	90	28	45	42	30	00
Gila and Salt River	Arizona	112	18	24	33	22	33
Humboldt	California	124	07	11	40	25	04
Huntsville	Alabama and Mississippi	86	34	45	35	00	00
Indian	Oklahoma	97	14	30	34	30	00
Louisiana	Louisiana [2]	92	24	15	31	00	00
Michigan	Michigan and Ohio	84	22	24	42	26	30
Mount Diablo	California and Nevada	121	54	48	37	51	30
Navajo	Arizona and New Mexico	108	32	45	35	45	00
New Mexico Principal	Colorado and New Mexico	106	53	40	34	15	25
Principal	Montana	111	38	50	45	46	48
Salt Lake	Utah	111	54	00	40	46	04
San Bernardino	California	116	56	15	34	07	10
Second Principal	Illinois and Indiana	86	28	00	38	28	20
Seward	Alaska	149	21	53	60	07	26
Sixth Principal	Colorado, Kansas, Nebraska, South Dakota, and Wyoming.	97	23	00	40	00	00
St. Helena	Louisiana	91	09	15	31	00	00
St. Stephens	Alabama and Mississippi	88	02	00	31	00	00
Tallahassee	Florida	84	16	42	30	28	00
Third Principal	Illinois	89	10	15	38	28	20
Uintah	Utah	109	57	30	40	26	20
Ute	Colorado	108	33	20	39	06	40
Washington	Mississippi	91	09	15	31	00	00
Willamette	Oregon and Washington	122	44	20	45	31	00
Wind River	Wyoming	108	48	40	43	01	20

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[1] The numbers are carried to fractional township 29 north in Illinois, and are repeated in Wisconsin, beginning with the south boundary of the State; the range numbers are in regular order.

[2] Latitude doubtful; is to be verified.

MEMO.: The east boundary of the State of Ohio, known as "Ellicott's Line," in longitude 80° 32′ 20″, was employed as the first reference meridian, with township numbers counting from the Ohio River and range numbers in regular order. The township and range numbers within the United States military land in Ohio are counted from the south and east boundaries of the tract.

122° 44′ 35.4 – 45° 31′ 14.00″
1911 1914

be employed, unless subdivisional closings thereon are provided in the same assignment with the standard line, in which case the closings will furnish a satisfactory verification of the length of the lines thus surveyed. Where such closings are not to be made during the progress of the same survey, the proper supervising officer will provide suitable instructions for the employment of a second set of chainmen, or for the duplication of the measurement by the one set of chainmen. In either case, where two independent sets of measurements are employed, the distance to the mean point, and the difference between the measurements to each corner established, will be shown in the field notes; a form of record is given in the specimen field notes.

142. Should the difference between the two sets of measurements of any standard line, as above provided, exceed 20 links per 80 chains, it is required that the line be remeasured to reduce the difference, the final measurement of the line only to be shown in the field notes. Should the successive independent tests of the alinement of any standard line, or the average tests of the solar attachment employed in the projection thereof, indicate that the line has deflected from the true cardinal course to exceed 3′ 00″, the necessary corrections will be made to reduce the deviation in azimuth, the field notes of the true line only being shown. Every reasonable effort will be exercised to insure the accuracy of both the alinement and the measurement of the standard lines, and the stated discrepancies are the maximum that will be allowed in new surveys; corrective steps will be required where the differences are beyond the maximum.

BASE LINE.

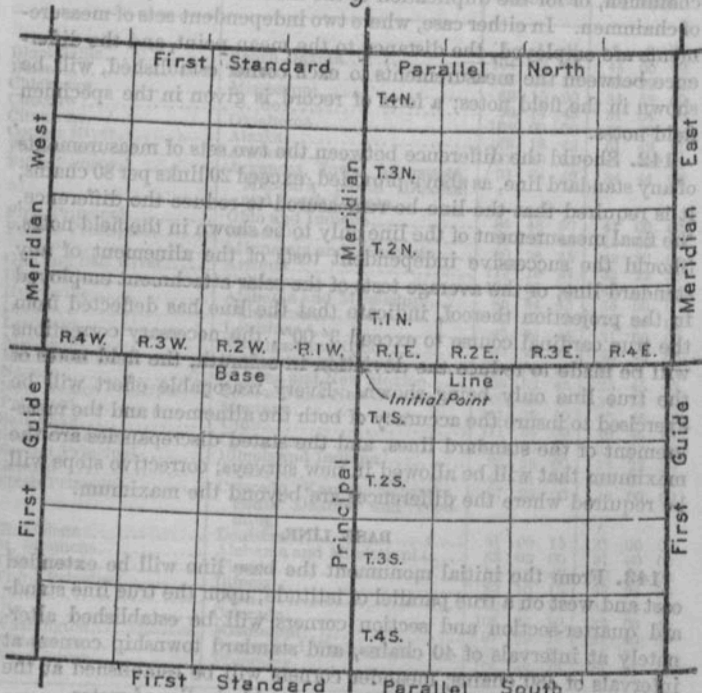
143. From the initial monument the base line will be extended east and west on a true parallel of latitude; upon the true line standard quarter-section and section corners will be established alternately at intervals of 40 chains, and standard township corners at intervals of 480 chains; meander corners will be established at the intersection of the line with all meanderable bodies of water.

The manner of making the measurement of the base line and the accuracy of both the alinement and measurement will be the same as required in the survey of the principal meridian. Any one of the methods heretofore set forth for the determination of the alinement of the true latitude curve may be used as existing conditions may require and the detailed process will be fully stated in the field notes.

STANDARD PARALLELS.

144. Standard parallels, which are also called correction lines, are extended east and west from the principal meridian, at intervals of 24 miles north and south of the base line, in the manner prescribed for the survey of the base line.

Fig. 16.



Illustrating the survey of quadrangles each embracing 16 townships bounded by standard lines, and showing the coördinate system of numbering the townships.

145. Where standard parallels have been placed at intervals of 30 or 36 miles, under practice then permissible, and present conditions require additional standard lines from which to initiate new, or upon which to close the extension of old surveys, an intermediate correction line should be established to which a local name may be given, e. g., "Fifth Auxiliary Standard Parallel North," or "Cedar Creek Correction Line," etc., and the same will be run, in all respects, like a regular standard parallel.

GUIDE MERIDIANS.

146. Guide meridians are extended north from the base line, or standard parallels, at intervals of 24 miles east and west from the principal meridian, in the manner prescribed for running the principal meridian. Under all conditions the guide meridians will be terminated at the points of their intersections with the standard parallels; the guide meridian is to be projected on the true meridian and the fractional measurement is to be placed in the last half mile. At the true point of intersection of the guide meridian with the standard parallel a closing township corner is to be established; the parallel will be retraced between the first standard corners east and west of the point for the closing corner, in order to determine the exact alinement of the line closed upon, and the distance will be measured and recorded to the nearest corner on said standard parallel.

147. When existing conditions require that such guide meridians shall be run south from the base or correction lines, they will be initiated at the theoretical point for the closing corner of the guide meridian, which will be calculated on the basis of the survey of the line from south to north initiated at the proper standard township corner. At the theoretical point of intersection a closing township corner will be established.

148. Where guide meridians have been placed at intervals exceeding the distance of 24 miles, and new governing lines are required in order to limit the errors of the old or to control new surveys, a new guide meridian will be established, and a local name may be assigned to the same, e. g., "Twelfth Auxiliary Guide Meridian West," or "Grass Valley Guide Meridian," etc. These auxiliary guide meridians will be surveyed in all respects like regular guide meridians.

149. The above scheme covers the controlling lines contemplated under the rectangular system, and results regularly in the survey of quadrangles bounded on the north and south by true parallels of latitude, and on the east and west by true meridians, 24 miles apart. One exception may now be noted which will be found to depart from former practice, that is, where a guide meridian is carrie forward at a time when uncertainty exists as to how the exterior an subdivisional surveys to the east may close upon it, the corners upo the same will be marked only for the surveys to the west.

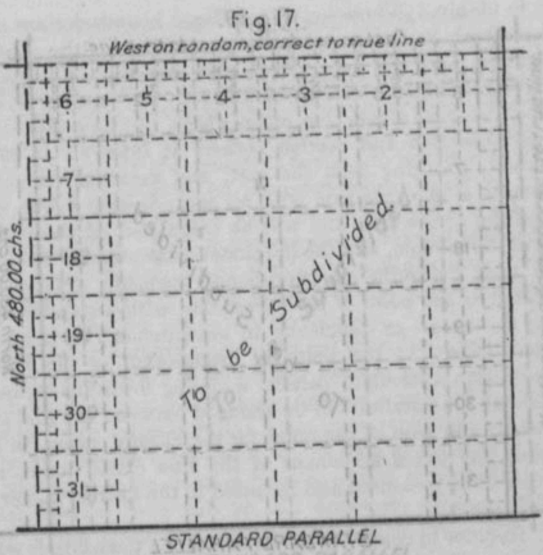
TOWNSHIP EXTERIORS.

REGULAR ORDER.

150. The controlling factors to be recognized in the establishment of new township boundary lines are found in the relation of these lines to the new subdivisional surveys which are to be executed. The south and east boundaries are normally the governing lines of the subdivisional surveys. Defective conditions which may be found in previously established exteriors can not be eliminated where subdivisional lines have been initiated from or closed upon an old boundary, but the errors of the former surveys are not to be incorporated into the new, and where the previously established south and east boundaries can not on that account be used to govern the subdivision of the adjoining township, other controlling lines known as the sectional correction line and the sectional guide meridian, hereinafter described, will be employed as expedient. A new meridional township exterior is normally the governing boundary of the township to the west, and a new latitudinal township exterior is normally the governing boundary of the township to the north; any new boundary should therefore be established with full consideration for its control upon the subdivisional surveys thereafter to be executed.

151. Whenever practicable the township exteriors will be surveyed successively through a quadrangle in ranges of townships, beginning with the townships on the south. The meridional boundaries of the townships will have precedence in the order of survey and will be run from south to north on true meridians; quarter-section and section corners will be established alternately at intervals of 40 chains, and meander corners at the intersection of the line with all meanderable bodies of water; a temporary township corner will be set at a distance of 480 chains, pending a determination of the controlling factor upon which its final position will be governed, whereupon the temporary point will be replaced by a permanent corner in proper latitudinal position. The latitudinal township boundary will be run first as a random line, setting temporary corners, on a cardinal course, from the old toward the new meridional boundary, and corrected back on a true line if ideal conditions are

Fig. 17.


West on random, correct to true line
North 480.00 chs.
6
5
4
3
2
7
18
19
30
31
To be Subdivided
STANDARD PARALLEL

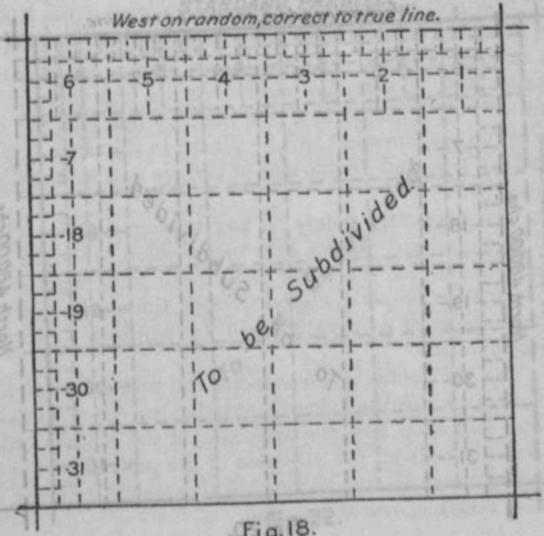
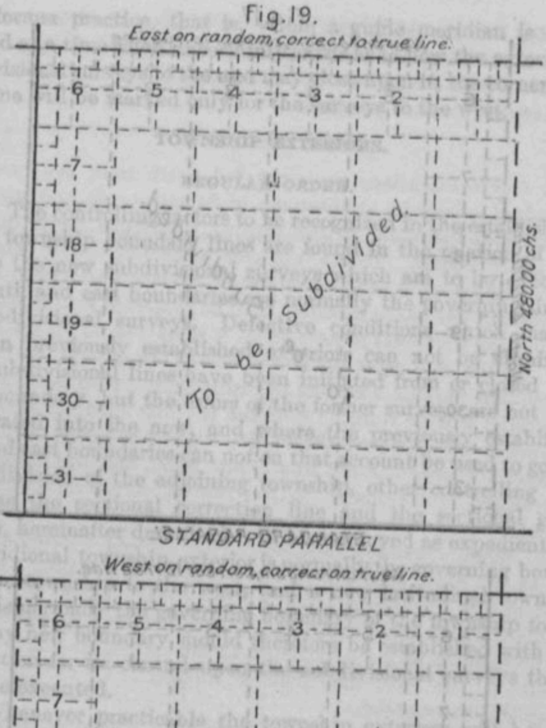

West on random, correct to true line.
6
5
4
3
2
7
18
19
30
31
To be Subdivided

Fig. 18.

Fig. 19.


East on random, correct to true line.
6
5
4
3
2
7
18
19
30
31
To be Subdivided.
North 480.00 chs.
STANDARD PARALLEL

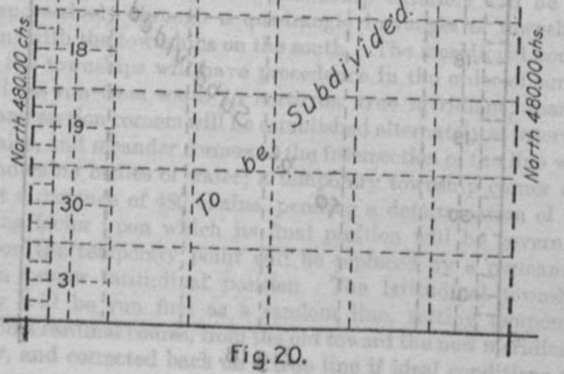
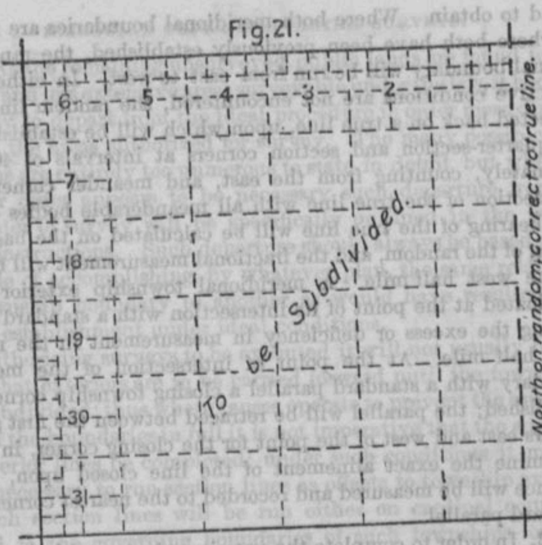

West on random, correct on true line.
6
5
4
3
2
7
18
19
30
31
To be Subdivided.
North 480.00 chs.
North 480.00 chs.

Fig. 20.

Fig. 21.


6
5
4
3
2
7
18
19
30
31
To be Subdivided.
North on random, correct to true line.

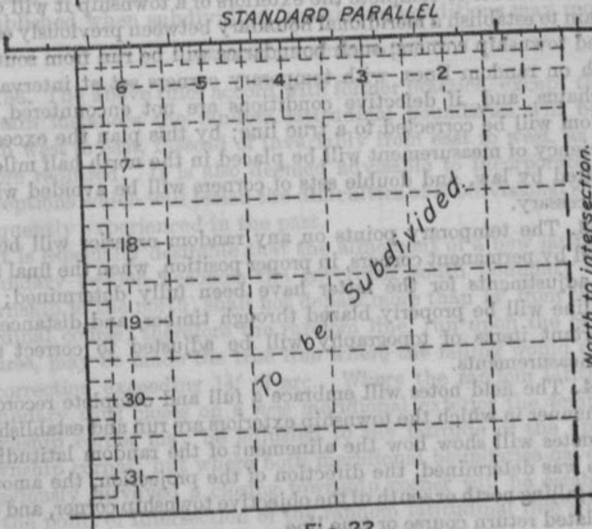

STANDARD PARALLEL
6
5
4
3
2
7
18
19
30
31
To be Subdivided.
North to intersection.

Fig. 22.

found to obtain. Where both meridional boundaries are new lines or where both have been previously established, the random latitudinal boundary will be run from east to west. In either case, if defective conditions are not encountered, the random line will be corrected back on a true line, upon which will be established regular quarter-section and section corners at intervals of 40 chains, alternately, counting from the east, and meander corners at the intersection of the true line with all meanderable bodies of water. The bearing of the true line will be calculated on the basis of the falling of the random, and the fractional measurement will be placed in the west half mile. A meridional township exterior will be terminated at the point of its intersection with a standard parallel, placing the excess or deficiency in measurement in the northernmost half mile. At the point of intersection of the meridional boundary with a standard parallel a closing township corner will be established; the parallel will be retraced between the first standard corners east and west of the point for the closing corner, in order to determine the exact alinement of the line closed upon, and the distance will be measured and recorded to the nearest corner on said standard parallel.

152. In order to complete the exteriors of a township it will often remain to establish a meridional boundary between previously established township corners; such boundaries will be run from south to north on random lines, with temporary corners set at intervals of 40 chains, and, if defective conditions are not encountered, the random will be corrected to a true line; by this plan the excess or deficiency of measurement will be placed in the north half mile, as required by law, and double sets of corners will be avoided where unnecessary.

153. The temporary points on any random exterior will be replaced by permanent corners, in proper position, when the final true line adjustments for the latter have been fully determined; the true line will be properly blazed through timber, and distances to important items of topography will be adjusted to correct true line measurements.

154. The field notes will embrace a full and complete record of the manner in which the township exteriors are run and established. The notes will show how the alinement of the random latitudinal curve was determined, the direction of the projection, the amount of the falling north or south of the objective township corner, and the calculated return course or true line.

IRREGULAR ORDER AND PARTIAL SURVEYS.

155. As the remaining unsurveyed public lands are found to contain less and less extensive areas surveyable under the law, it becomes necessary to depart from the ideal procedure in order more directly to reach the areas authorized for survey. The many possible combinations are entirely too numerous to state in detail, but where an irregular order appears to be necessary such departure from the ideal order of survey will be specifically outlined in the written special instructions. Such departure should always be based on the principle of accomplishing, by whatever plan, the same relation of one township boundary to another as would have resulted from regular establishment under ideal conditions.

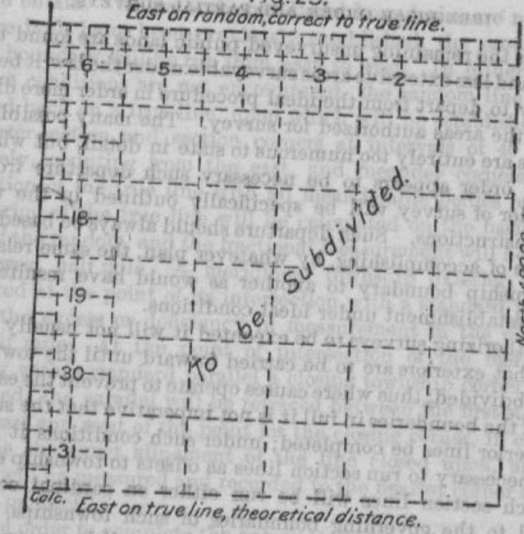
In authorizing surveys to be executed it will not usually be provided that exteriors are to be carried forward until the township is to be subdivided; thus where causes operate to prevent the establishment of the boundaries in full it is not imperative that the survey of the exterior lines be completed; under such conditions it may be found necessary to run section lines as offsets to township exteriors and such section lines will be run either on cardinal courses or parallel to the governing boundaries of such townships, or even established when subdividing, as existing conditions may require.

GENERAL EXCEPTIONS.

156. The above rules accord with former practice, except that in certain instances the random latitudinal boundaries will be run from west to east, instead of invariably from east to west, as heretofore required. It is also deemed advisable to incorporate other exceptions which will lessen the difficulties of subdivisional surveys frequently experienced in the past.

It is especially desirable that the alinement of a new latitudinal boundary (which becomes the governing south boundary of the township to the north) shall not depart more than 14′ from the true cardinal course; therefore the random line, run upon the cardinal course, may be made the true line where the falling would require a correction exceeding 14′ of arc. Where the random latitudinal boundary thus closes on a *new* meridional exterior the temporary township corner may be adjusted to the latitude of the opposite township corner; but where both meridional boundaries have been previously surveyed a closing township corner will be established at the point of intersection of the random latitudinal line with the

Fig. 23.


East on random, correct to true line.
6
5
4
3
2
7
18
19
30
31
To be Subdivided.
North 480.00 chs.
Calc.
East on true line, theoretical distance.

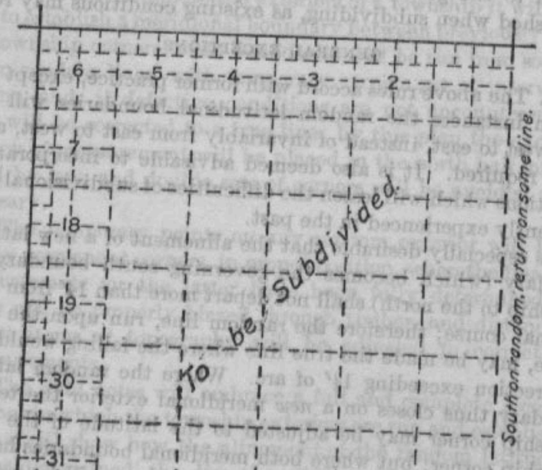
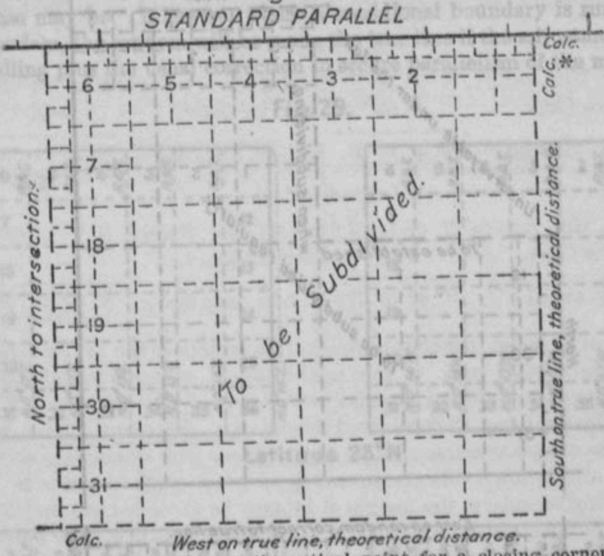

6
5
4
3
2
7
18
19
30
31
To be Subdivided.
South on random, return on same line.
East on random, return on same line.

Fig. 24.

Fig. 25.



* Exteriors initiated at a theoretical point for a closing corner.

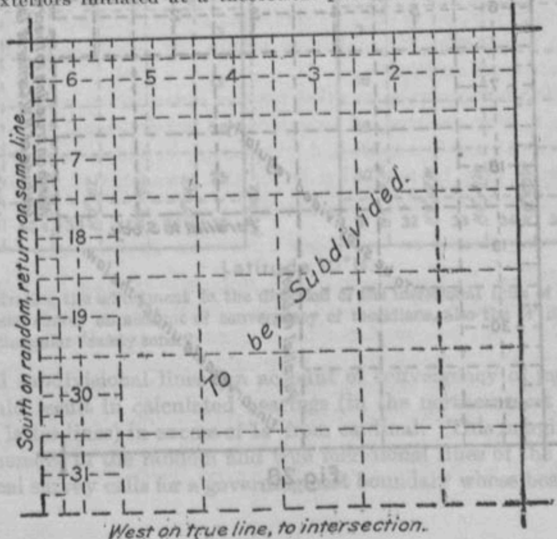
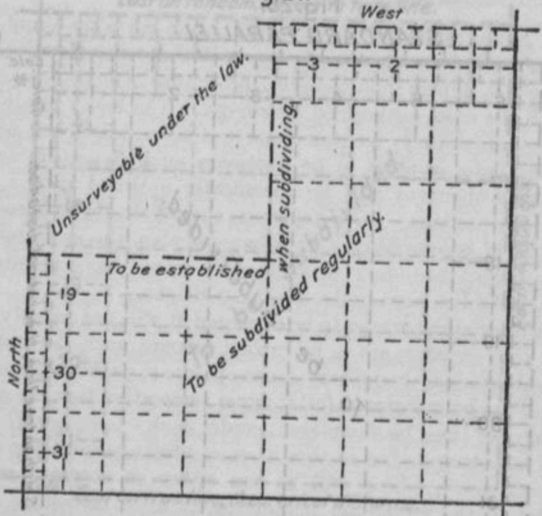


Fig. 26.

Fig. 27.


West
3
2
Unsurveyable under the law.
To be established
when subdividing
To be subdivided regularly.
North
19
30
31

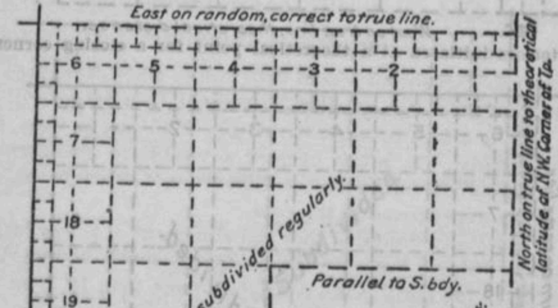
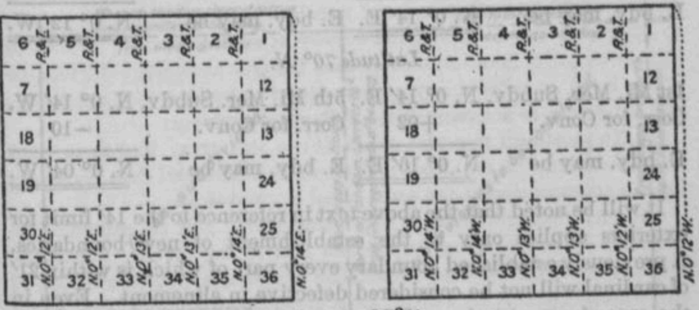

East on random, correct to true line.
6
5
4
3
2
7
18
19
30
31
To be subdivided regularly.
Parallel to S. bdy.
Parallel to E. bdy.
Unsurveyable under the law.
North on true line to theoretical latitude of N.W. Corner of Tp.

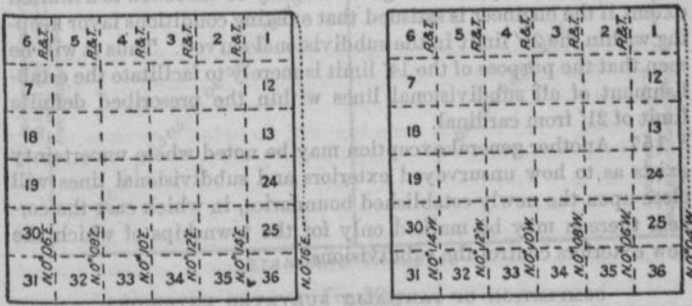
Fig. 28.

meridional boundary, or its projection to the north or south as the case may be. Likewise, where a meridional boundary is run as a random, the random will be made the true line if the adjustment for falling plus the usual correction to secure parallelism of the meridi-

Fig. 29.



Latitude 25°N.



Latitude 70°N.

Illustrating the adjustment in the direction of the meridional lines of a subdivisional survey on account of convergency of meridians, also the 14′ limit of the rectangular "safety zone."

onal subdivisional lines (on account of convergency of meridians) would result in calculated bearings (in the northernmost miles of the latter lines) in excess of 14′ from cardinal. This margin for the alinement of the random and true meridional lines of the subdivisional survey calls for a governing east boundary whose bearing will fall within certain extremes suited to the latitude of the township, as for example (see second part of Table 2, Standard Field Tables):

Latitude 25° N.

1st Mi. Mer. Subdv.	N. 0° 14′ E.	5th Mi. Mer. Subdv.	N. 0° 14′ W.
Corr. for Conv.	+00	Corr. for Conv.	−02
E. bdy. may be	N. 0° 14′ E.	E. bdy. may be	N. 0° 12′ W.

Latitude 70° N.

1st Mi. Mer. Subdv.	N. 0° 14′ E.	5th Mi. Mer. Subdv.	N. 0° 14′ W.
Corr. for Conv.	+02	Corr. for Conv.	−10
E. bdy. may be	N. 0° 16′ E.	E. bdy. may be	N. 0° 04′ W.

It will be noted that the above text in reference to the 14′ limit for exteriors applies only to the establishment of new boundaries. A previously established boundary every part of which is within 21′ of cardinal will not be considered defective in alinement. Even in the case of new exteriors, where the engineer who establishes such line is also to subdivide the township of which such exterior is a governing boundary, the margin of 14′ may be exceeded to a limited extent if the engineer is satisfied that existing conditions favor keeping within the 21′ limit in the subdivisional survey. Thus it will be seen that the purpose of the 14′ limit is merely to facilitate the establishment of all subdivisional lines within the prescribed definite limit of 21′ from cardinal.

157. Another general exception may be noted where uncertainty exists as to how unsurveyed exteriors and subdivisional lines will close upon the newly established boundaries, in which case the corners thereon may be marked only for the townships of which the new exteriors control the subdivisions.

COMPLETION OF PARTIALLY SURVEYED EXTERIORS.

158. Where the end portions of a township exterior have been previously surveyed and closed upon, the fractional unsurveyed middle part will be completed by random and true line, without offset regardless of the deviation from cardinal; the fractional measurements will be placed as a general rule in the north and west half miles, thereby permitting the subdivisional lines to be extended as usual from the south to the north and from the east to the west. In the case of a fractional part of an exterior remaining unsurveyed at either end of the line, the boundary will be completed by random line, initiated at the previously established terminal monument, which will be projected on a cardinal course in the direction of the objective township corner. The random will be corrected to a true line where the calculated bearing of any subdivisional line, governed by such exterior, comes within 14′ from cardinal, and the

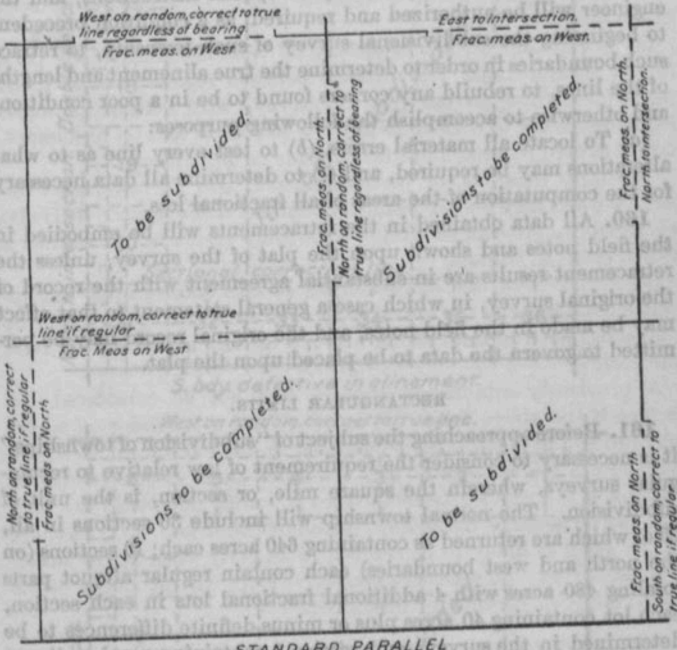


Fig. 30.

fractional measurement will be placed generally in the north or west half miles. However, should irregularity be developed, or in the absence of a previously established objective township corner, the partially surveyed exteriors will be completed on cardinal courses beginning as above; and in either case the fractional measurements will generally be placed in the north and west half miles.

RETRACEMENTS BEFORE SUBDIVIDING.

159. If any part or all of the boundaries of a township which is to be subdivided have been previously surveyed, and the proper supervising officer has reason to question the accuracy of any portion of such exteriors, or the condition of the corner monuments thereon, the fact will be stated in the written special instructions, and the engineer will be authorized and required, as a condition precedent to beginning the subdivisional survey of such township, to retrace such boundaries in order to determine the true alinement and lengths of the lines, to rebuild any corners found to be in a poor condition, and otherwise to accomplish the following purposes:

(*a*) To locate all material errors, (*b*) to test every line as to what alterations may be required, and (*c*) to determine all data necessary for the computation of the areas of all fractional lots.

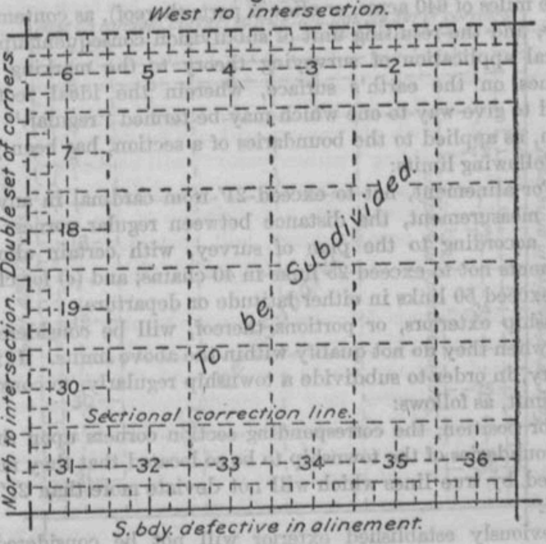
160. All data obtained in the retracements will be embodied in the field notes and shown upon the plat of the survey, unless the retracement results are in substantial agreement with the record of the original survey, in which case a general statement to that effect may be made in the field notes, and the original record may be permitted to govern the data to be placed upon the plat.

RECTANGULAR LIMITS.

161. Before approaching the subject of "subdivision of townships" it is necessary to consider the requirement of law relative to rectangular surveys, wherein the square mile, or section, is the unit of subdivision. The normal township will include 36 sections in all, 25 of which are returned as containing 640 acres each; 10 sections (on the north and west boundaries) each contain regular aliquot parts totaling 480 acres with 4 additional fractional lots in each section, each lot containing 40 acres plus or minus definite differences to be determined in the survey; and, section 6 containing regular aliquot parts totaling 360 acres with 7 additional fractional lots each containing 40 acres plus or minus certain definite differences to be determined in the survey, all as contemplated by law. The aforementioned aliquot parts of 640 acres may be termed "regular or legal subdivisions of a section," as a quarter section, a half-quarter section, or a quarter-quarter section, the legal minimum of which, for purposes of disposal under the general land laws, is 40 acres.

162. In the administration of the surveying laws it has been necessary to establish a definite relation between rectangularity

Fig. 31.


West to intersection.
North to intersection. Double set of corners
6
5
4
3
2
7
18
19
30
To be Subdivided.
Sectional correction line.
31
32
33
34
35
36
S. bdy. defective in alinement.

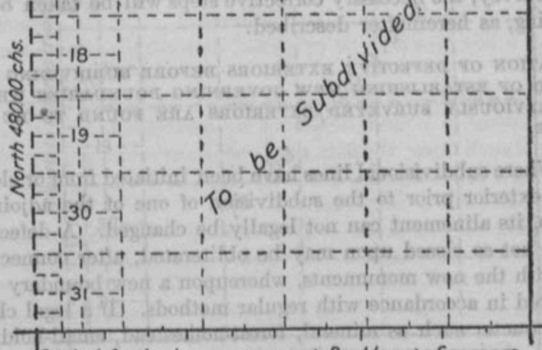

West on random, correct to true line.
North 48.00 chs.
6
5
4
3
2
7
18
19
30
31
To be Subdivided.
S. bdy defective in measurement. Double set of corners.

Fig. 32.

(square miles of 640 acres, or aliquot parts thereof), as contemplated by law, and the resulting unit of subdivision consequent upon the practical application of surveying theory to the marking out of the lines on the earth's surface, wherein the ideal section is allowed to give way to one which may be termed "regular." Such relation, as applied to the boundaries of a section, has been placed at the following limits:

(*a*) For alinement, not to exceed 21′ from cardinal in any part; (*b*) for measurement, the distance between regular corners to be normal according to the plan of survey, with certain allowable adjustments not to exceed 25 links in 40 chains; and (*c*) for closure, not to exceed 50 links in either latitude or departure.

Township exteriors, or portions thereof, will be considered defective when they do not qualify within the above limits. It is also necessary, in order to subdivide a township regularly, to consider a fourth limit, as follows:

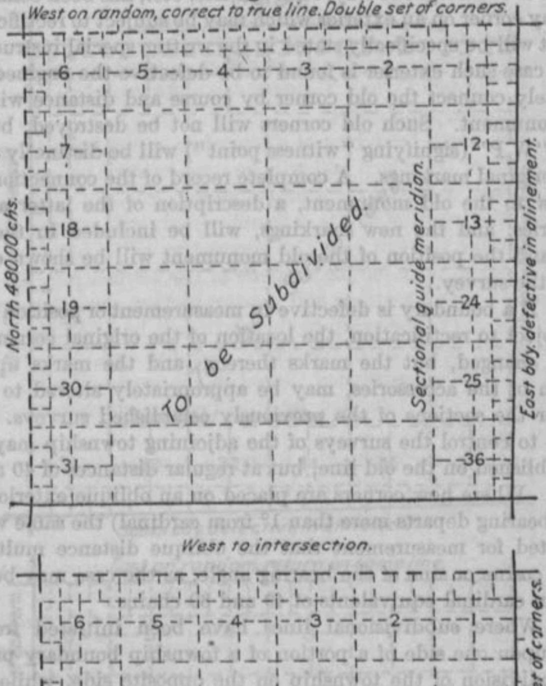
(*d*) For position, the corresponding section corners upon the opposite boundaries of the township to be so located that they may be connected by true lines which will not deviate more than 21′ from cardinal.

A previously established exterior will not be considered defective if the above limits are satisfied, and a *subdivisional survey* may proceed in safety if the rectangular limits (in such subdivisional survey) are not exceeded. On the other hand, if the conditions relating to the previously established *governing boundaries* are such that the rectangular limits have already been exceeded or that the danger point is likely to be reached at an early stage in the subdivisional survey, the necessary corrective steps will be taken before subdividing, as hereinafter described.

RECTIFICATION OF DEFECTIVE EXTERIORS BEFORE SUBDIVIDING AND METHOD OF ESTABLISHING NEW GOVERNING BOUNDARIES WHERE THE PREVIOUSLY SURVEYED EXTERIORS ARE FOUND TO BE DEFECTIVE.

163. Where subdivisional lines have been initiated from or closed upon an exterior prior to the subdivision of one of the adjoining townships, its alinement can not legally be changed. A defective boundary not so closed upon may be obliterated, after connecting the old with the new monuments, whereupon a new boundary will be projected in accordance with regular methods. If a legal claim of any character such as mineral, forest-homestead, small-holding,

Fig. 33.


West on random, correct to true line. Double set of corners.
North 480.00 chs.
Sectional guide meridian.
East bdy. defective in alinement.
To be Subdivided.
6
5
4
3
2
7
12
18
13
19
24
30
25
31
36

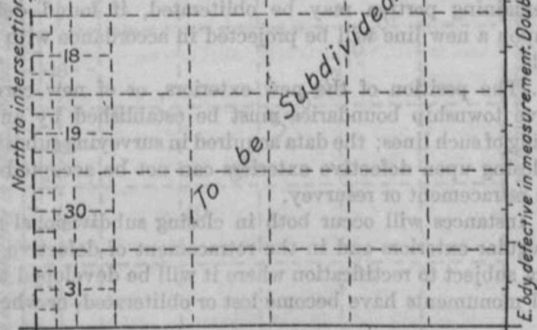

West to intersection.
North to intersection.
E. bdy. defective in measurement. Double set of corners.
To be Subdivided.
6
5
4
3
2
1
7
18
19
30
31

Fig. 34.

railroad or canal right-of-way, reservoir site, etc., has been connected with any corner on an exterior which may be subject to rectification, the fact will be specifically stated in the written special instructions, and in case such exterior is found to be defective the engineer will accurately connect the old corner by course and distance with the new monument. Such old corners will not be destroyed, but the letters "W P" (signifying "witness point") will be distinctly added to the original markings. A complete record of the connection from the new to the old monument, a description of the latter and its accessories, and the new markings, will be included in the field notes, and the position of the old monument will be shown on the plat of the survey.

164. If a boundary is defective in measurement or position and is not subject to rectification, the location of the original corners will not be changed, but the marks thereon, and the marks upon or position of the accessories, may be appropriately altered to stand only for the sections of the previously established surveys. New corners to control the surveys of the adjoining township may then be established on the old line, but at regular distances of 40 and 80 chains. Where new corners are placed on an oblique exterior (one whose bearing departs more than 1° from cardinal) the same will be so located for measurement that the oblique distance multiplied by the cosine or sine of the bearing angle, as the case may be, will result in cardinal equivalents of 40 and 80 chains.

165. Where subdivisional lines have been initiated from or closed upon one side of a portion of a township boundary prior to the subdivision of the township on the opposite side, while upon the remaining portion of the same such conditions do not interfere, said remaining portion may be obliterated, if found defective, whereupon a new line will be projected in accordance with regular methods.

166.. The position of the new exteriors, or of new corners on defective township boundaries must be established by an actual rerunning of such lines; the data acquired in surveying subdivisional lines closing upon defective exteriors can not be accepted in lieu of such retracement or resurvey.

167. Instances will occur both in closing subdivisional surveys upon regular exteriors and in the retracement of defective boundaries not subject to rectification where it will be developed that the original monuments have become lost or obliterated, or where such

Fig. 35.


East on random, return on same line.
6
5
4
3
2
7
18
19
30
31
32
33
34
35
36
Double set of corners.
North to intersection.
To be Subdivided.
Sectional correction line.
South bdy. defective in alinement.

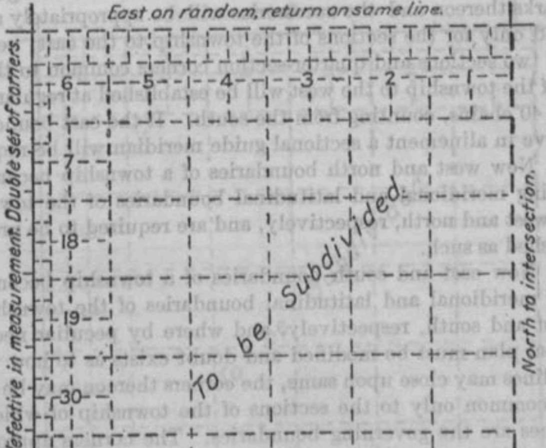

East on random, return on same line.
6
5
4
3
2
7
18
19
30
31
W. bdy. defective in measurement. Double set of corners.
North to intersection.
To be Subdivided

Fig. 36.

corners may be identified in an advanced state of deterioration. All such exterior corners will be reestablished and remonumented in their correct original positions in strict accordance with the provisions of Chapters IV and V, and a complete record thereof will be embodied in the field notes.

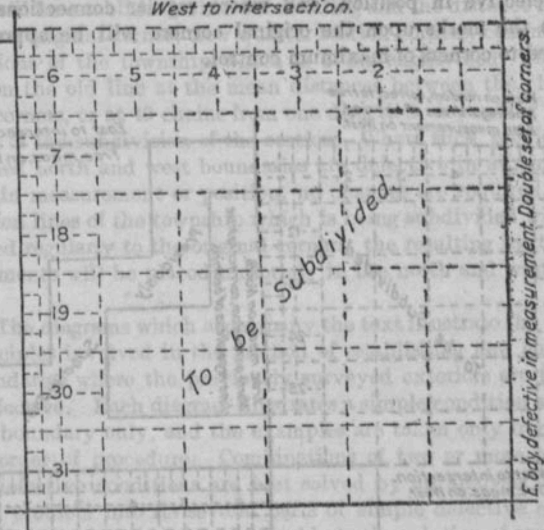
168. The south boundary of a township is regularly the governing latitudinal boundary and will be used as such unless defective in alinement; if defective in measurement, and not subject to rectification, the position of the original corners will not be changed, but the marks thereon and the accessories will be appropriately altered to stand only for the sections of the township to the south; new corners of two sections and quarter-section corners common to the sections of the township to the north will be established at regular intervals of 40 chains, counting from the east, and the excess or deficiency in measurement placed in the west half mile. If the south boundary is defective in alinement, a sectional correction line will be required.

169. The east boundary of a township is regularly the governing meridional boundary and will be used as such unless defective in alinement; if defective in measurement, and not subject to rectification, the position of the original corners will not be changed, but the marks thereon and the accessories will be appropriately altered to stand only for the sections of the township to the east; new corners of two sections and quarter-section corners common to the sections of the township to the west will be established at regular intervals of 40 chains, counting from the south. If the east boundary is defective in alinement a sectional guide meridian will be required.

170. New west and north boundaries of a township become the governing meridional and latitudinal boundaries of the townships to the west and north, respectively, and are required to be properly established as such.

171. New east and south boundaries of a township become the closing meridional and latitudinal boundaries of the townships to the east and south, respectively, and where by peculiar necessity the ideal plan must be modified and doubt exists as to how unsurveyed lines may close upon same, the corners thereon may be established common only to the sections of the township of which the new lines are the governing boundaries. The corners appropriate to the sections upon the opposite side will be duly established as closing corners at the time of the survey of the subdivisional lines

Fig. 37.


West to intersection.
6
5
4
3
2
7
18
19
30
31
To be Subdivided
E. bdy. defective in measurement. Double set of corners.

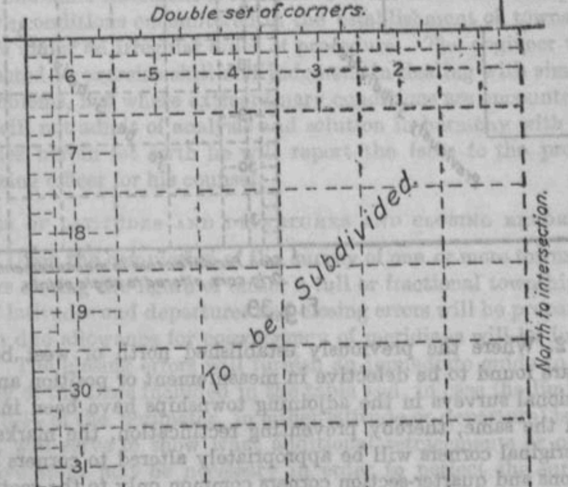

Double set of corners.
6
5
4
3
2
7
18
19
30
31
To be Subdivided.
North to intersection.
S. bdy. defective in measurement. Double set of corners.

Fig. 38.

of the adjoining townships if the original corners are then found to be defective in position, and where regular connections can be made the marks upon the original corners will be appropriately altered to corners of maximum control.

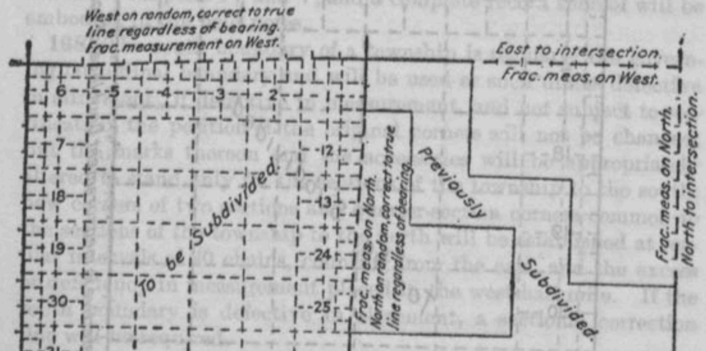


Fig. 39.

172. Where the previously established north or west boundaries are found to be defective in measurement or position and subdivisional surveys in the adjoining townships have been initiated upon the same, thereby preventing rectification, the marks upon the original corners will be appropriately altered to corners of two sections and quarter-section corners common only to the sections of the townships to the north or west, respectively. Closing section corners will be established when subdividing and the distance measured to an original corner; new quarter-section corners, common to the sections of the township which is being subdivided, will be placed on the old line at the mean distances between the closing section corners, or at 40 chains from one direction, depending upon the plan of the subdivision of the section. Where such previously established north and west boundaries are defective in alinement, but not in measurement or position, no changes are required, and the section lines of the township which is being subdivided will be connected regularly to the original corners; the resulting fractional measurements will be placed uniformly in the north and west half miles.

173. The diagrams which accompany the text illustrate the guiding principles involved in the method of establishing new governing boundaries where the previously surveyed exteriors are found to be defective. Each diagram illustrates a simple condition affecting one boundary only, and the examples are taken only from the regular order of procedure. Combinations of two or more of the simple defective conditions are best solved by an analysis of the complex problem into its several parts of simple defective conditions. The same statement is applicable to the solution of complex defective conditions encountered in the establishment of township exteriors under an irregular order of procedure. The engineer will be expected to exercise skill and judgment in dealing with similar field problems, but where extraordinary conditions are encountered which will not admit of analysis and solution in harmony with the principles herein set forth he will report the facts to the proper supervising officer for his counsel.

TABLES OF LATITUDES AND DEPARTURES AND CLOSING ERRORS.

174. Upon the completion of the survey of one or more township exteriors closing the figure of either a full or fractional township, a table of latitudes and departures and closing errors will be prepared, wherein due allowance for convergency of meridians will be introduced. The closing errors will furnish an immediate guide to the accuracy of the lines included in the table and, in case the limit of closure ($\frac{1}{640}$ of the perimeter, in either latitude or departure) is exceeded, will serve to show what additional retracements or other corrective steps may be necessary in order to perfect the survey before leaving the field. The table of latitudes and departures and closing errors, including every part of any closed figure embracing township exteriors, based upon final field determination after all necessary retracements and final true lines have been completed, will be filed with the field tablets and computation sheets. The general subject of "limits of closure" will be amplified hereinafter.

SUBDIVISION OF TOWNSHIPS.

REGULAR BOUNDARIES.

175. The boundaries of a township will be considered within satisfactory governing limits from which to control the subdivisional survey when the calculated position of the latter lines may be theoretically projected from said boundaries without invading the danger zone in respect to rectangular limits as previously described. The danger zone has already been placed at theoretical bearings exceeding 14′ from cardinal, and the corresponding zone in respect to lengths of lines may be placed at theoretical adjustments exceeding 33 links per mile.

176. The direction of the east boundary may qualify anywhere within the governing limits set forth under the subject of "township exteriors," and where this boundary is broken in alinement, but otherwise within the governing limits, its mean course will be adopted when considering the control upon the direction of the meridional subdivisional lines.

177. The subdivision of a township may proceed in the normal order, where the above conditions are satisfied, as follows:

The meridional section lines will be initiated at the regularly established section corners on the south boundary of the township and will be run from south to north parallel to the governing east boundary, or, in case the east boundary is within limits, but has been found by retracement to be imperfect in alinement, the meridional section lines will be run parallel to the mean course of such east boundary. Regular quarter-section and section corners will be established alternately at intervals of 40 chains, as far as the northernmost interior section corner. The last miles of the meridional section lines will be continued as random lines, each successive line being run parallel to the true east boundary of the section to which it belongs; a temporary quarter-section corner will be set at 40 chains, the distances will be measured to the points of intersection of the random lines with the north boundary of the township, and the fallings of the random lines east or west of the objective section corners will be noted. The randoms will then be corrected to true lines by returning to accomplish the required markings between the section corners, including the permanent establishment of the quarter-section corners on the true lines at distances of 40 chains from the south, thus placing the fractional measurements in the north half miles. The bearings of the true lines will be calculated on the basis of the fallings of the randoms (see Table 3, Standard Field Tables). Where the north boundary of the township is a base line or standard parallel, the last miles of the meridional section lines will be continued as true lines parallel to the east boundary of the township, setting permanent quarter-section corners at 40 chains from the south and closing section corners at the points of intersection of the several lines with the base or standard or correction line, where the distances will be measured to the nearest corners on said line. The adjustment of the bearing of all meridional section lines on account of convergency of meridians has already been explained in Chapter II.

178. The latitudinal section lines, except in the west range of sections, will normally be run from west to east on random lines parallel to the south boundaries of the respective sections, setting temporary quarter-section corners at 40 chains; the distances will be measured to the points of intersection of the random lines with the north and south lines passing through the objective section corners, and the fallings of the random lines north or south of said corners will be noted. Each random will be corrected to a true line by returning to accomplish the required markings between the section corners, including the permanent establishment of quarter-section corners at the *mid-points* on the true lines. The bearings of the true lines will be calculated on the basis of the fallings of the randoms (see Table 3, Standard Field Tables). In the west range of sections the random latitudinal section lines will be run from east to west, parallel to the south boundaries of the respective sections, and on the true lines the permanent quarter-section corners will be established at 40 chains from the east, thus placing the fractional measurements in the west half miles.

179. Meander corners will be established at the points of intersection of the several true lines with all meanderable bodies of water.

180. The meridional section lines will have precedence in the order of execution, and these will be surveyed successively, beginning with the first meridional section line counting from the east. A meridional section line will not be continued beyond a section corner until after the connecting latitudinal section line has been surveyed, and in the case of the fifth meridional section line, both latitudinal section lines connecting east and west will be surveyed before continuing with the meridional line beyond a section corner. The successive meridional lines may be taken up at the convenience of the engineer at any time in order as previously stated, but none will be carried beyond uncompleted sections to the east. The field notes will be compiled in ranges of sections beginning with the easternmost, and the west two ranges will be compiled by alternating with the adjoining east and west sections. The specimen field notes exemplify the usual order of survey and the prescribed method of arranging the field notes.

181. Thus, to recapitulate, the subdivisional survey will be commenced at the corner of sections 35 and 36, on the south boundary of the township, and the line between sections 35 and 36 will be run parallel to the east boundary of the township, or to the mean course thereof, if it is imperfect in alinement, but within limits, establishing the quarter-section corner at 40 chains, and at 80 chains, the corner of sections 25, 26, 35 and 36. From the last-named corner, a random line will be run eastward, without blazing, parallel to the south boundary of section 36, to its intersection with the east boundary of the township, placing at 40 chains from the point of beginning, a post for temporary quarter-section corner. If the random line intersects said township boundary exactly at the corner of sections 25 and 36, it will be blazed back and established as the true line, the permanent quarter-section corner being established thereon, midway between the initial and terminal section corners. If the random intersects said township boundary to the north or south of said corner, the falling will be carefully measured, and from the data thus obtained, the true return course will be calculated, and the true line blazed and established, and the position of the quarter-section corner determined, as directed above. The meridional section line will be continued on the same plan, likewise the successive latitudinal section lines except that each random will be run parallel to the true south boundary of the section to which it belongs. After having established the west and north boundaries of section 12, the line between sections 1 and 2 will be projected northward, on a random line, parallel to the east boundary of the township, or to its mean course, as the case may be, setting a post for temporary quarter-section corner at 40 chains, to its intersection with the north boundary of the township. If the random intersects said north boundary exactly at the corner of sections 1 and 2, it will be blazed back and established as the true line, the quarter-section corner being established permanently in its original temporary position, and the fractional measurement thrown into that portion of the line between the permanent quarter-section corner and the north boundary of the township. If, however, said random intersects the north boundary of the township, to the east or west of the corner of sections 1 and 2, the falling will be carefully measured, and from the data thus obtained the true return course will be calculated and the true line established, the permanent quarter-section corner being placed upon the same at 40 chains from the initial corner of the random line.

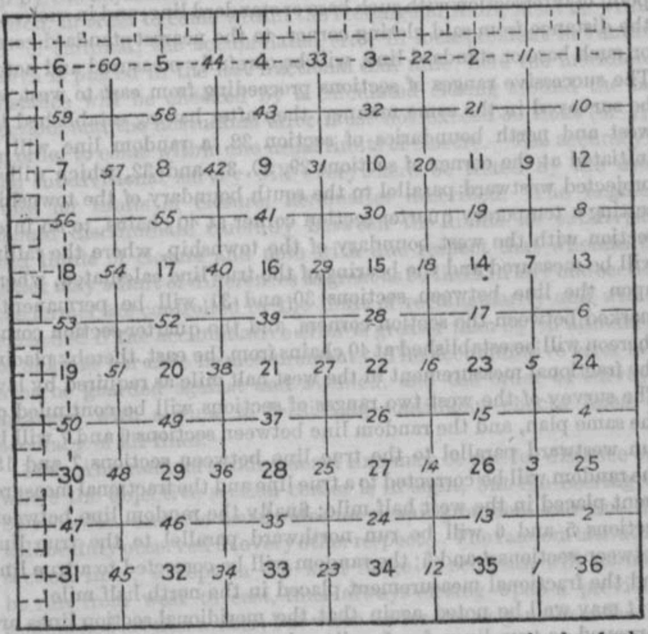


FIG. 40.—The numbers on the section lines indicate the normal order of subdivision and arrangement of the field notes.

thereby throwing the fractional measurement in that portion lying between the quarter-section corner and the north boundary of the township. When the north boundary of a township is a base line or standard parallel, the line between sections 1 and 2 will be run as a true line parallel to the east boundary of the township, or to its mean course, as the case may be; the quarter-section corner will be placed at 40 chains, and a closing corner will be established at the point of intersection with such base or standard line; and in such case, the distance from said closing corner, to the nearest standard corner on such base or standard line, will be carefully measured and noted. The successive ranges of sections proceeding from east to west will be surveyed in the same manner; then after having established the west and north boundaries of section 32, a random line will be initiated at the corner of sections 29, 30, 31 and 32, which will be projected westward parallel to the south boundary of the township, setting a temporary quarter-section corner at 40 chains, to an intersection with the west boundary of the township, where the falling will be measured and the bearing of the true line calculated, whereupon the line between sections 30 and 31 will be permanently marked between the section corners, and the quarter-section corner thereon will be established at 40 chains from the east, thereby placing the fractional measurement in the west half mile as required by law. The survey of the west two ranges of sections will be continued on the same plan, and the random line between sections 6 and 7 will be run westward parallel to the true line between sections 7 and 18; the random will be corrected to a true line and the fractional measurement placed in the west half mile; finally the random line between sections 5 and 6 will be run northward parallel to the true line between sections 4 and 5; the random will be corrected to a true line and the fractional measurement placed in the north half mile.

It may well be noted again that the meridional section lines are surveyed as true lines for 5 miles, i. e., the lines are surveyed and permanently monumented in the first instance without later adjustment. Every means is placed at the disposal of the engineer by which he is expected to accomplish accurate results, and the system of survey provides amply for the adjustment of all reasonable closing errors. Thus, a slight error in the alinement of the meridional section lines is taken up in the measurement of the latitudinal lines which, in order to come within the rectangular limit, must be within 50 links of 80 chains in length, except in the west range of sections where the convergency of the meridional lines is regularly provided for; the accumulated error in alinement for the 5 miles of true meridional line is taken up in the sixth mile, which is run random and true; here the true line must be within 21′ of cardinal in order to come within the rectangular limit. The slight, ordinary errors in the measurement of the meridional section lines are taken up by the adjustment of the bearings of the latitudinal section lines which, in order to come within the rectangular limit, must be within 21′ of cardinal; the accumulated error in measurement in running north is placed in the last fractional half mile; here the meridional distance will be checked by a calculated closing around the last section, and the latitudinal error must not exceed 50 links (or $\frac{1}{640}$) in order to come within the usual limits of closure. The accuracy of the subdivisional survey will everywhere be tested by the usual rules for limits of closure, hereinafter described. The engineer should discriminate carefully between the limits for subdivision and limits of closure and note with due respect that whereas the latter may admit of differences as great as 50 links in any one section, the former are controlled by the limit of rectangularity and will be exceeded if the accumulative error is greater than 3½′ in alinement, or 8⅓ links per mile in measurement. The accumulative error must ever be guarded against and avoided, and the order of survey is arranged with a view to furnishing continuous checks upon the accuracy of all lines.

182. Any random subdivisional line may be run for distance only where the objective section corner is in sight, but the bearing will be recorded, and the usual rules for running random and true lines will be duly observed in every other respect. The random latitudinal section lines, except in the west range of sections, will normally be run from west to east, thus always closing upon a previously established section corner; but when under the exigencies of the field work, in order to economize the time of his party, the engineer may elect to project the random from east to west (always parallel to the south boundary of the section), a temporary section corner (if the permanent corner has not already been established) will be set at 80 chains, and the true point for the section corner will be determined as usual at the 80-chain point on the meridional section line, whereupon the connection of the random latitudinal line and the permanent marking of the true line will be completed as regularly provided. Examples of the authorized rules for running subdivisional lines will be found in the specimen field notes.

IRREGULAR BOUNDARIES.

183. Where either of the governing boundaries of a township is disqualified as a controlling line upon which to initiate a subdivisional survey, the necessary retracements and resurveys or alterations will be accomplished before subdividing as previously explained under the subject of township exteriors; thus may be assured every possible provision for a correct subdivisional survey except as either the south or the east boundary may be defective in alinement and not subject to rectification.

SECTIONAL GUIDE MERIDIAN.

184. If the east boundary of the township is defective in alinement, and can not be rectified, and the north boundary is thus made defective in position, the first meridional section line will be projected on a true meridian to an intersection with the north boundary of the township where a closing section corner will be established and the distance measured to the nearest regular corner. The intermediate quarter-section and section corners will be established alternately at regular intervals of 40 chains, counting from the south, unless the south boundary of the township is itself defective in alinement. Where the north boundary is not defective in position (nor within the danger zone) with reference to the section corners on the south boundary (by reason of the errors in the alinement of the east boundary being compensating), the first meridional section line will be projected 5 miles as a true line on a bearing calculated to intersect the objective section corner on the north boundary, and the last mile will be run as a random line on the same course and corrected to a true line after the falling has been measured. The remaining meridional section lines will be run parallel to the one first established, in the usual manner, to closing section corners on the last mile or random and true as the case may be.

The fractional measurements of the latitudinal section lines in the first range of sections will be placed in the east half mile; elsewhere, unless the south boundary is defective in alinement, the latitudinal section lines will be run in the usual manner.

SECTIONAL CORRECTION LINE.

185. If the south boundary of the township is defective in alinement, and can not be rectified, and the west boundary is thus made defective in position, a sectional correction line will be surveyed

Fig. 41.


N. bdy. defective in position.
6
5
4
3
2
7
12
18
13
19
24
30
25
31
36
Sectional guide meridian.
North to intersection.
E. bdy. defective in alinement.

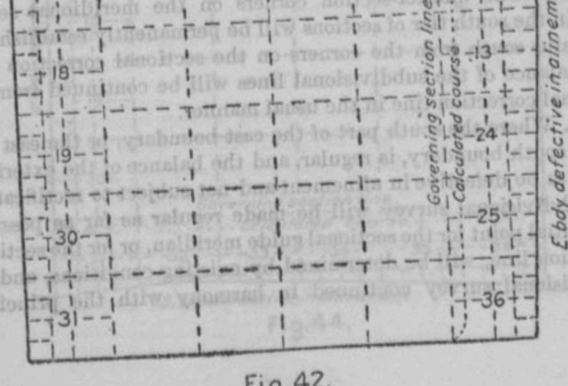

N. bdy. regular.
6
5
4
3
2
R. & T.
7
12
18
13
19
24
30
25
31
36
Governing section line.
Calculated course.
E. bdy. defective in alinement.

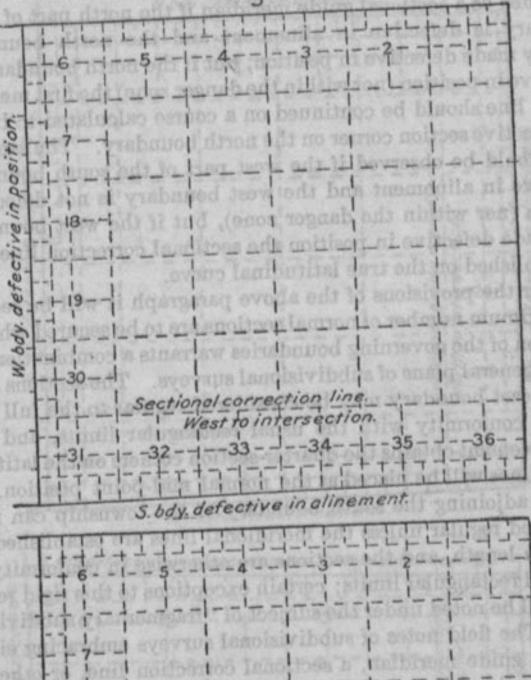
Fig. 42.

as a permanent line on a true latitudinal curve initiated at the first regular section corner on the east boundary and projected to an intersection with the west boundary of the township where a closing section corner will be established and the distance measured to the nearest regular corner. The intermediate quarter-section and section corners will be marked as temporary points at regular intervals of 40 chains, alternately, counting from the east. Where the west boundary is not defective in position (nor within the danger zone) with reference to the section corners on the east boundary (by reason of the errors in alinement of the south boundary being compensating), the first latitudinal section line will be projected 5 miles as a permanent line on a bearing calculated to intersect the objective section corner on the west boundary; temporary quarter-section and section corners will be marked at regular intervals of 40 chains, alternately, counting from the east.

The section corners on the sectional correction line will be established at the several points of intersection of the meridional section lines alined in the normal manner. Thereafter the quarter-section corners on the sectional correction line will be established at the usual mid-point positions except in the east and west ranges of sections. The quarter-section corner between sections 25 and 36 will be established at 40 chains from the west if the east boundary is defective in alinement; otherwise it will be fixed at the usual mid-point position. The quarter-section corner between sections 30 and 31 will be placed at 40 chains from the east, and if the sectional correction line has not been terminated at a closing section corner on the west boundary of the township (as previously provided), the line between sections 30 and 31 will be run random and true in the normal manner. The quarter-section corners on the meridional section lines in the south tier of sections will be permanently established at 40 chains south from the corners on the sectional correction line. The balance of the subdivisional lines will be continued from the sectional correction line in the usual manner.

186. Where the south part of the east boundary, or the east part of the south boundary, is regular, and the balance of the exterior is found to be defective in alinement and not subject to rectification, the subdivisional survey will be made regular as far as possible. The initial point for the sectional guide meridian, or for the sectional correction line, will be determined by existing conditions, and the subdivisional survey continued in harmony with the principles

Fig. 43.


6
5
4
3
2
7
18
19
30
W. bdy. defective in position.
Sectional correction line.
West to intersection.
31
32
33
34
35
36
S. bdy. defective in alinement.

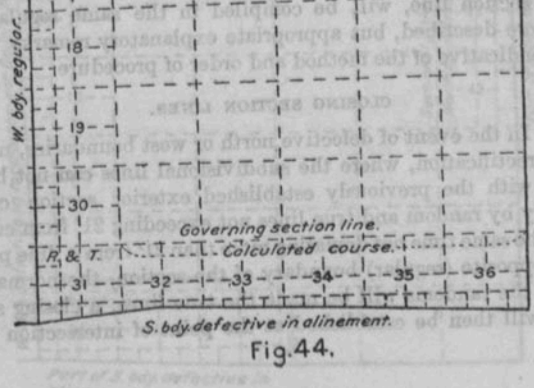

6
5
4
3
2
7
18
19
30
W. bdy. regular.
Governing section line.
Calculated course.
R. & T.
31
32
33
34
35
36
S. bdy. defective in alinement.

Fig. 44.

already outlined. Thus the first meridional section line would be continued as a sectional guide meridian if the north part of the east boundary is defective in alinement and the north boundary is thereby made defective in position, but if the north boundary is not defective in position (nor within the danger zone) the first meridional section line should be continued on a course calculated to intersect the objective section corner on the north boundary. The same principle would be observed if the west part of the south boundary is defective in alinement and the west boundary is not defective in position (nor within the danger zone), but if the west boundary is thus made defective in position the sectional correction line should be established on the true latitudinal curve.

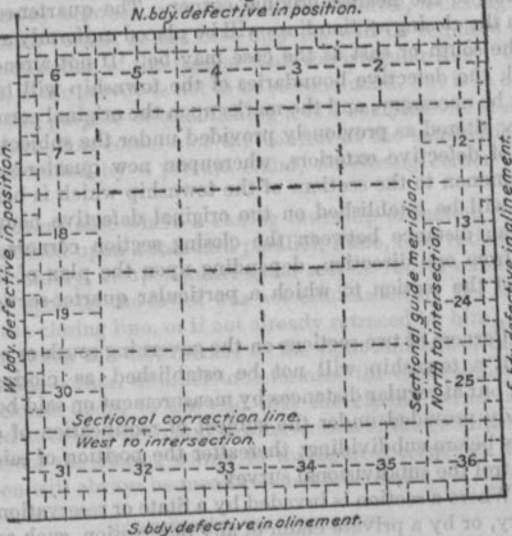
Under the provisions of the above paragraph it will be seen that the maximum number of normal sections are to be secured where the condition of the governing boundaries warrants a combination of the several general plans of subdivisional surveys. The sections adjoining the east boundary may be considered regular to the full extent of their conformity with the usual rectangular limits, and where such agreement obtains the quarter-section corners on the latitudinal section lines will be placed at the normal mid-point position. The sections adjoining the south boundary of the township can not be considered regular unless the meridional lines are established at 80 chains in length, and the sections are otherwise in conformity with the usual rectangular limits; certain exceptions to this rigid requirement will be noted under the subject of "fragmentary subdivision."

187. The field notes of subdivisional surveys embracing either a sectional guide meridian, a sectional correction line, or other governing section line, will be compiled in the same regular order heretofore described, but appropriate explanatory remarks will be added indicative of the method and order of procedure.

CLOSING SECTION LINES.

188. In the event of defective north or west boundaries, not subject to rectification, where the subdivisional lines can not be connected with the previously established exterior section corners, regularly by random and true lines not exceeding 21′ from cardinal and at the same time not deviating more than 21′ from a line parallel to the opposite (regular) boundary of the section, the normal positions of the randoms will be made the true lines; a closing section corner will then be established at the point of intersection of the

Fig. 45.


N.bdy. defective in position.
6
5
4
3
2
12
7
13
18
24
19
25
30
W.bdy. defective in position.
Sectional guide meridian.
North to intersection.
E.bdy. defective in alinement.
Sectional correction line.
West to intersection.
31
32
33
34
35
36
S.bdy. defective in alinement.

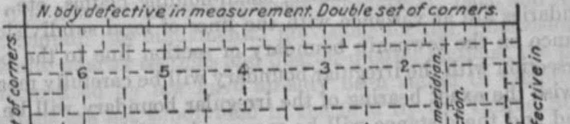

N.bdy. defective in measurement. Double set of corners.
6
5
4
3
2
12
7
13
18
19
30
W.bdy. defective in measurement. Double set of corners.
Sectional guide meridian.
North to intersection.
Part of E.bdy. defective in alinement.
Sectional correction line.
West to intersection.
31
32
33
Regular
Part of S.bdy. defective in alinement.

Fig. 46.

section line with the original boundary, and the distance will be measured to the nearest original corner. The quarter-section corners on the closing section lines will be placed uniformly at 40 chains from the south or east as the case may be. If not already accomplished, the defective boundaries of the township will be retraced as may be necessary, and the marks upon the original corners appropriately altered as previously provided under the subject of rectification of defective exteriors, whereupon new quarter-section corners, common to the sections of the township which is being subdivided, will be established on the original defective boundaries at the mean distance between the closing section corners, or at 40 chains from one direction, depending upon the plan of the subdivision of the section to which a particular quarter-section corner belongs.

189. Corners of two sections on the governing south or east boundaries of a township will not be established as closing section corners, but at regular distances by measurement on said boundaries as already provided under the subject of rectification of defective exteriors before subdividing; thereafter the position of said corners will control the subdivisional survey.

190. Where a section is invaded by a State or reservation or grant boundary, or by a private claim of any description, such as mineral claims, forest-homestead claims, small-holding claims, etc., whose boundaries are at variance with the lines of legal subdivision, the distance on the township boundary or section line to the point of intersection with the irregular boundary will be carefully measured, likewise the exact bearing of the irregular boundary will be determined and the distance will be measured to the nearest corner on such irregular boundary. Where a private claim is located entirely within the limits of a section, a connection will be made from a regular corner on one of the boundaries of the section to a corner of the claim, and the bearing and length of the connecting line will be carefully determined. In the latter case a connecting traverse line will be recorded, if one is run, but it will also be reduced to the equivalent direct course and distance, all of which will be stated in the field notes, and the course and length of the direct connecting line will be shown upon the plat of the survey.

191. If a survey is to be concluded upon an irregular boundary at variance with the lines of legal subdivision, or if the survey is to be continued on a blank line to acquire a definite location upon the opposite irregular boundary, but without monumenting the rectangular survey between such irregular boundaries, a closing township or section corner, as the case may be, will be required at the point of intersection of the regular with the irregular line. On the other hand, if the survey is not to be so concluded, but is to be continued for the purpose of establishing a full complement of section and quarter-section corners for the control of the subdivision of a section so invaded by a private claim, no closing corner will be required.

192. In every case where a closing township or section corner is to be established upon a standard parallel, State, reservation, grant, or claim boundary, or upon an irregular section line or exterior, the line closed upon (if the latter was not established by the engineer who runs the closing line, or if not already retraced by him), will be retraced between the first corners to the right and left of the point for the closing corner, in order to determine the exact alinement of the line closed upon, to the end that the closing corner may be established at the precise point of intersection of the two lines. The distance from the closing corner to the nearest corner on the line closed upon will always be measured and recorded.

SUBDIVISION OF SECTIONS.

193. The acts of Congress approved February 11, 1805, and April 5, 1832, contain the fundamental provisions for the subdivision of sections into quarter sections and quarter-quarter sections; the principles recognized by law have already been stated in Chapter I. The sections are not subdivided in the field by the United States surveyors unless provision therefor is specifically mentioned in the written special instructions, but certain subdivision-of-section lines are always protracted upon the official plats, and the local surveyor who may be employed by entrymen to run said lines in the field is compelled to correlate the conditions as found upon the ground with those shown upon the approved plat. The United States surveyor is required to so establish the official monuments that a proper foundation is laid for the subdivision of the section, whereby the officially surveyed lines may be identified and the subdivision of the section controlled as contemplated by law.

194. The rectangular system provides for the unit of disposal under the general land laws, broadly, the quarter-quarter section of 40 acres, upon a plan in which the square mile, or section of 640 acres, is the unit of subdivision, while the unit of survey is the township of 36 sections. All agricultural entries are based upon descriptions in accordance with legal subdivisions shown upon the official plat. The plats are constructed in harmony with the official field notes returned by the engineer. The land included in an entry is identified on the ground by fixed monuments established by the engineer. A United States land patent grants to the entryman a title of ownership to a tract defined by certain fixed monuments on the ground and related by description and outline to the official plat. The function of the United States surveyor has been fulfilled when he has properly executed and monumented his survey and returned an official record thereof in the shape of complete detailed field notes and a plat. The function of the local surveyor begins when he is employed as an expert to identify the lands which have passed into private ownership; this may be a simple or a most complex problem, depending largely upon the condition of the original monuments as affected principally by the lapse of time since the execution of the official survey. The work of the local surveyor usually includes the subdivision of the section, already mentioned as the official unit of subdivision, into the fractional parts shown upon the approved plat. In this capacity the local surveyor is performing a function contemplated by law, and he can not properly serve his client or the public unless he is familiar with the legal requirements concerning the subdivision of sections. In the event that the original monuments have become lost the surveyor can not hope effectively to recover said corners without a full understanding of the record concerning their original establishment, nor can the surveyor hope legally to restore the same until he has mastered not only the principles observed in the execution of the original survey, but the principles upon which the courts having jurisdiction over such matters have based their rulings.

195. The General Land Office assumes no control or direction over the acts of local and county surveyors in the matters of subdivision of sections and reestablishment of lost corners of original surveys where the lands have passed into private ownership, nor will it issue instructions in such cases. It follows the general rule that disputes, arising from uncertain or erroneous location of corners, originally established by the United States, are to be settled by the proper local authorities or by amicable adjustment, and the office desires that the rules controlling the acts of its own surveying service be considered by all other surveyors as merely advisory and explanatory of the principles which should prevail in performing such duties.

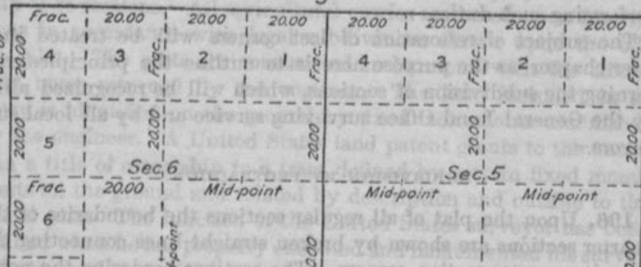
The subject of restoration of lost corners will be treated in a later chapter, as the purpose here is to outline the principles concerning the subdivision of sections, which will be recognized alike by the General Land Office surveying service and by all local surveyors.

SUBDIVISION BY PROTRACTION.

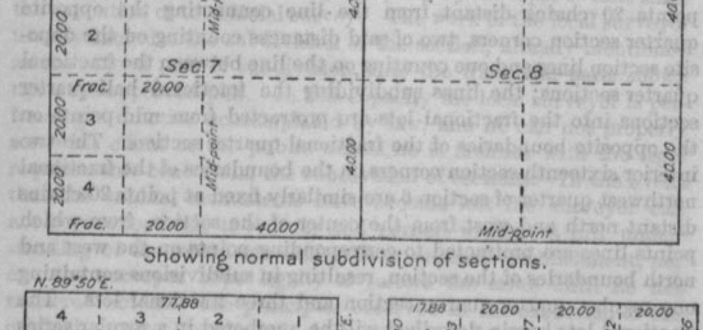
196. Upon the plat of all regular sections the boundaries of the quarter sections are shown by broken straight lines connecting the opposite quarter-section corners. The sections bordering the north and west boundaries of a normal township, excepting section 6, are further subdivided by protraction into parts containing two regular half-quarter sections and four lots, the latter containing the fractional areas resulting from the plan of subdivision of normal townships; the lines of the half-quarter sections are protracted from three points 20 chains distant from the line connecting the opposite quarter section corners, two of said distances counting on the opposite section lines and one counting on the line between the fractional quarter sections; the lines subdividing the fractional half-quarter sections into the fractional lots are protracted from mid-points on the opposite boundaries of the fractional quarter section. The two interior sixteenth-section corners on the boundaries of the fractional northwest quarter of section 6 are similarly fixed at points 20 chains distant north and west from the center of the section, from which points lines are protracted to corresponding points on the west and north boundaries of the section, resulting in subdivisions containing one regular quarter-quarter section and three fractional lots. The fractional lots herein described will be numbered in a regular series progressively from east to west or from north to south, in each section. As section 6 borders on both the north and west boundaries of the township, the fractional lots in the same will be numbered commencing with No. 1 in the northeast, thence progressively west to No. 4 in the northwest, and south to No. 7 in the southwest fractional quarter-quarter section.

Entrymen are allowed, under the law, to acquire title to any regular quarter-quarter section, but as such subdivisions are aliquot parts of quarter sections based upon mid-point protraction, it is not deemed necessary to indicate these lines upon the official plat.

Fig. 47.



Showing normal subdivision of sections.

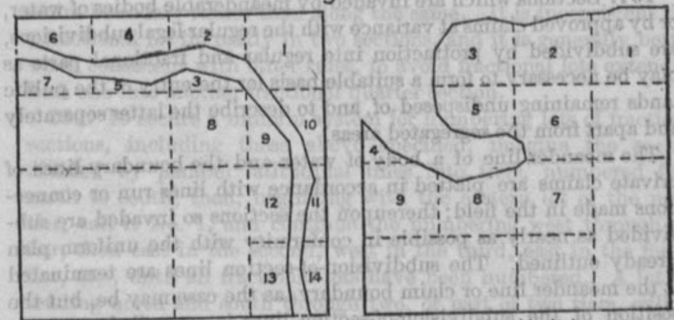


Showing areas.

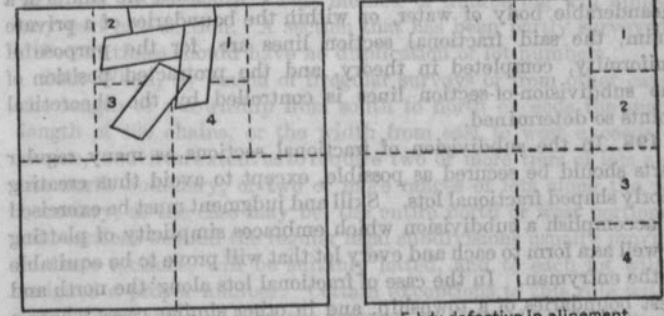
Showing calculated distances.

Examples of subdivision by protraction.

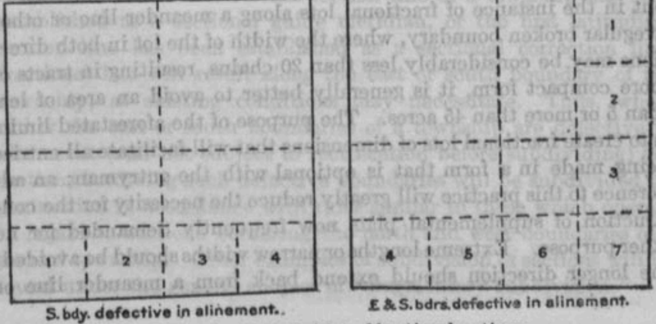
Fig. 48.



Meanderable River. Meanderable Lake.



Mineral Claims. E. bdy. defective in alinement.



S. bdy. defective in alinement.. E & S. bdrs. defective in alinement.

Examples of subdivision of fractional sections.

197. Sections which are invaded by meanderable bodies of water, or by approved claims at variance with the regular legal subdivisions, are subdivided by protraction into regular and fractional parts as may be necessary to form a suitable basis for the entry of the public lands remaining undisposed of, and to describe the latter separately and apart from the segregated areas.

The meander line of a body of water and the boundary lines of private claims are platted in accordance with lines run or connections made in the field; thereupon the sections so invaded are subdivided as nearly as possible in conformity with the uniform plan already outlined. The subdivision-of-section lines are terminated at the meander line or claim boundary, as the case may be, but the position of the subdivision-of-section lines is controlled precisely as though the section had been completed regularly. In the case of a section whose boundary lines are in part within the limits of a meanderable body of water, or within the boundaries of a private claim, the said fractional section lines are, for the purpose of uniformity, completed in theory, and the protracted position of the subdivision-of-section lines is controlled by the theoretical points so determined.

198. In the subdivision of fractional sections as many regular parts should be secured as possible, except to avoid thus creating poorly shaped fractional lots. Skill and judgment must be exercised to accomplish a subdivision which embraces simplicity of platting as well as a form to each and every lot that will prove to be equitable to the entryman. In the case of fractional lots along the north and west boundaries of a township, and in other similar cases where a lot has a full normal width of 20 chains in one direction, it is generally advisable to avoid areas of less than 10 or more than 50 acres, but in the instance of fractional lots along a meander line or other irregular broken boundary, where the width of the lot in both directions may be considerably less than 20 chains, resulting in tracts of more compact form, it is generally better to avoid an area of less than 5 or more than 45 acres. The purpose of the aforestated limits is to create fractional lots of dimensions that will facilitate all entries being made in a form that is optional with the entryman; an adherence to this practice will greatly reduce the necessity for the construction of supplemental plats now frequently demanded for no other purpose. Extreme lengths or narrow widths should be avoided; the longer direction should extend back from a meander line or claim boundary rather than along the same. It is inconsistent that a fractional lot lie partly in two sections, and it is generally better, when consistent with other rules, to avoid fractional lots extending from one into another fractional quarter section.

199. To secure a uniform system for numbering lots of fractional sections, including those above specified, imagine the section divided by parallel latitudinal lines into tiers, numbered from north to south; then, beginning with the eastern lot of the north tier, call it No. 1, and continue the numbering west through the tier, then east in the second, west in the third, east in the fourth tier, etc., until all fractional lots have been numbered. A lot extending north and south through two, or part of two tiers, will be numbered in the tier containing its greater area. In case any tier is without numbered lots, the numbering will be continued in the next tier to the south. This method of numbering will apply to any part of a section. A section that has been partly surveyed at different times should have no duplication of lot numbers.

200. When, by reason of irregular surveys or from other causes, the length of a township from south to north exceeds the regular length of 480 chains, or the width from east to west exceeds 480 chains, to such an extent as to require two or more tiers of lots along the north boundary, or two or more ranges of lots along the west boundary, as the case may be, the entire north or west portions of said sections beyond the regular legal subdivisions usually provided in these sections, will be suitably lotted, and to each lot will be assigned a proper number. Certain exceptions to this rule will be found in Chapter VII, in the instance of townships which possess abnormal dimensions in one or both directions.

201. If the first meridional section line of a township has been established as a sectional guide meridian, or the first latitudinal section line has been established as a sectional correction line, fractional lots will result along the east or south boundary of the township, as existing conditions may necessitate. Thus, where either the east or south boundaries of a township are defective in alinement (and not subject to rectification before subdividing) the sections bordering such defective boundaries will be subdivided by protraction in accordance with rules similar to those which operate in regard to sections bordering the north and west boundaries of a normal township. Other examples of subdivision ot sections will be found under the general subject of "fragmentary subdivision."

SUBDIVISION BY SURVEY.

202. The rules for subdivision of sections by actual survey in the field are based upon the laws governing the survey of the public lands. When cases arise which are not covered by these rules, and the advice of the General Land Office in the matter is desired, the letter of inquiry should, in every instance, contain a description of the particular tract or corner, with reference to township, range and section of the public surveys, to enable the office to consult the record; also a diagram showing conditions found, giving distances in chains and links and not in feet.

203. Preliminary to subdivision it is essential to know the actual boundaries of the section, as it can not be subdivided legally until the section corners and quarter-section corners have either been found or restored by proper methods, and the resulting courses and distances determined by survey. The practice of entering a section to survey a tract from only one or two corners, and those perhaps unreliable, is unlawful.

204. The order of procedure is: First, identify or reestablish the boundary corners; next, fix the lines of quarter sections; then, form smaller tracts by equitable and proportionate division, according to the following rules:

205. *Subdivision of sections into quarter sections.*—Under the provisions of the act of Congress approved February 11, 1805, the course to be pursued in the subdivision of sections into quarter sections is to run straight lines from the established official quarter-section corners to the opposite corresponding corners. The point of intersection of the lines thus run will be the corner common to the several quarter sections, or, in other words, the legal center of the section.

Upon the lines closing on the north and west boundaries of a regular township the quarter-section corners are established by the United States surveyors at 40 chains to the north or west of the last interior section corners, and the excess or deficiency in the measurement is thrown into the half mile next to the township or range line, as the case may be.

Where there are double sets of section corners on township and range lines the quarter-section corners for the sections south of the township lines and east of the range lines have not always been established in the field by the United States surveyors, but in subdividing such sections said quarter-section corners should be so placed as to suit the calculations of the areas of the quarter sections adjoining the township boundaries as expressed upon the official plat, adopting proportionate measurements where the new measurements of the north or west boundaries of the section differ from the original measurements.

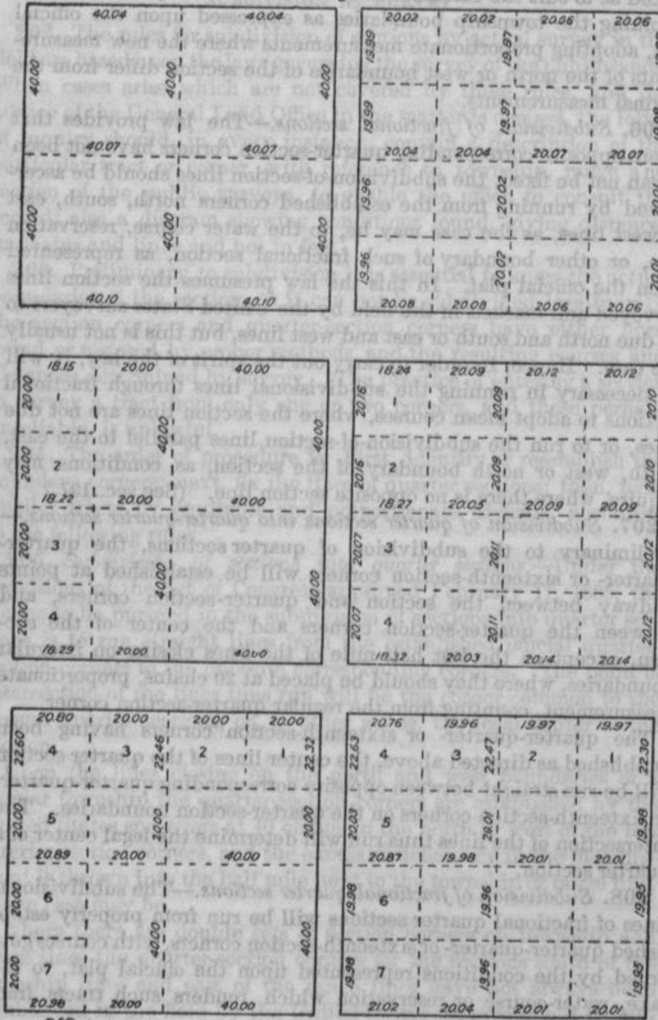
206. *Subdivision of fractional sections.*—The law provides that where opposite corresponding quarter-section corners have not been or can not be fixed, the subdivision-of-section lines should be ascertained by running from the established corners north, south, east or west lines, as the case may be, to the water course, reservation line, or other boundary of such fractional section, as represented upon the official plat. In this the law presumes the section lines surveyed and marked in the field by the United States surveyors to be due north and south or east and west lines, but this is not usually the case. Hence, in order to carry out the spirit of the law, it will be necessary in running the subdivisional lines through fractional sections to adopt mean courses, where the section lines are not due lines, or to run the subdivision-of-section lines parallel to the east, south, west or north boundary of the section, as conditions may require, where there is no opposite section line. (See sec. 197.)

207. *Subdivision of quarter sections into quarter-quarter sections.*—Preliminary to the subdivision of quarter sections, the quarter-quarter- or sixteenth-section corners will be established at points midway between the section and quarter-section corners, and between the quarter-section corners and the center of the section, except on the last half mile of the lines closing on irregular boundaries, where they should be placed at 20 chains, proportionate measurement, counting from the regular quarter-section corner.

The quarter-quarter- or sixteenth-section corners having been established as directed above, the center lines of the quarter section will be run straight between opposite corresponding quarter-quarter- or sixteenth-section corners on the quarter-section boundaries. The intersection of the lines thus run will determine the legal center of a quarter section.

208. *Subdivision of fractional quarter sections.*—The subdivisional lines of fractional quarter sections will be run from properly established quarter-quarter- or sixteenth-section corners, with courses governed by the conditions represented upon the official plat, to the lake, water-course or reservation which renders such tracts fractional. (See sec. 197.)

Fig. 49.



Official measurements.

Remeasurements.

The above examples of subdivision by survey show the relation of the official measurements and calculated distances to the remeasurements, and indicate the proportional distribution of the differences.

209. By "proportionate measurement" is meant a measurement having the same ratio to that recorded in the original field notes as the length of the line by re-measurement bears to its length as given in the record. Reasonable discrepancies between former and new measurements may generally be expected. Errors may occur through many causes and should be as carefully avoided in re-measurements as in original surveys. Instead of the old practice of "adjusting the chain" to suit the former measure, the distance obtained by a precise method is compared with that of the record, and the shortage or surplus is computed by proportion, producing the same result in a more reliable manner. For example: The length of the line from the quarter-section corner on the west boundary of section 2 to the north line of the township, by the United States surveyor's measurement was reported as 43.40 chains, and by the county surveyor's measurement was found to be 42.90 chains; then the distance which the quarter-quarter- or sixteenth-section corner should be located north of the quarter-section corner would be determined by proportion as follows: As 43.40 chains, the official measurement of the whole distance, is to 42.90 chains, the county surveyor's measurement of the same distance, so is 20 chains, original measurement, to 19.77 chains by the county surveyor's measurement, showing that by proportionate measurement in this case the quarter-quarter- or sixteenth-section corner should be set at 19.77 chains north of the quarter-section corner, instead of 20 chains north of said corner, as represented on the official plat. In this manner the discrepancies between original and new measurements are equitably distributed.

210. By way of recapitulation it should be emphasized that when entrymen have acquired title to certain legal subdivisions they have become the owners of the identical ground area represented by the same subdivisions upon the official plat. It is a matter of expert or technical procedure to mark out the legal subdivisions called for in a patent, and entrymen are advised that a competent surveyor should be employed. The surveyor must necessarily identify the section boundaries and locate the legal center of the section in order to determine the boundaries of a quarter section. Then, if the boundaries of quarter-quarter sections, or fractional lots, are to be determined on the ground, the boundaries of the quarter section must be measured, and the sixteenth-section corners thereon should be fixed in accordance with the proportional distances represented upon the approved plat, thereupon the legal center of the quarter section may be duly located. Thus will be produced in the field the figure represented upon the plat, every part of the former in true proportion to the latter, where the elements of absolute distance and area have given away to corresponding proportional units as defined by fixed monuments established in the original survey.

FRAGMENTARY SUBDIVISION OF TOWNSHIPS.

211. In the preceding articles covering the subject of subdivision of townships every assumption was based upon initiating the subdivisional survey upon regularly established exteriors, or, when necessary, a sectional guide meridian or a sectional correction line, or both, were to be established, upon which rested the control of the subdivision of the township. The subdivision of every full township may always be governed by the aforestated rules, but many other factors operate in determining the method and order of procedure to be adopted in the instance of fractional townships which have no linear south or east boundary, or in the case of continuing with the survey of partially subdivided townships, where one or more of the previously established section lines may be found to be defective in respect to the rectangular limit, or where partially surveyed sections, or sections containing outlying areas protracted as surveyed, are to be completed. The engineer can not hope to master the subject of fragmentary subdivision of townships until he has become thoroughly familiar with every question relating to the subdivision of sections, nor is it possible to give in the Manual an example of every intricate problem which may be encountered in the field; thus the following discussion deals primarily with the principles, which must be considered in the field, operating to control the engineer's method and order of procedure. It is possible, however, that cases may arise so complex in their character as to produce a feeling of doubt relative to the proper solution of the problem; in which case the engineer will at once communicate with the proper supervising officer, submitting information, by letter and diagram, of the exact condition as found by him, and the necessary instructions will be forwarded as soon as practicable.

FRACTIONAL TOWNSHIPS.

212. Where by reason of the presence of a large meanderable body of water, impassable objects, a State or reservation or grant boundary, or for other similar reasons a township is made fractional

Fig. 50.


6
5
4
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Auxiliary base
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Auxiliary base
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32
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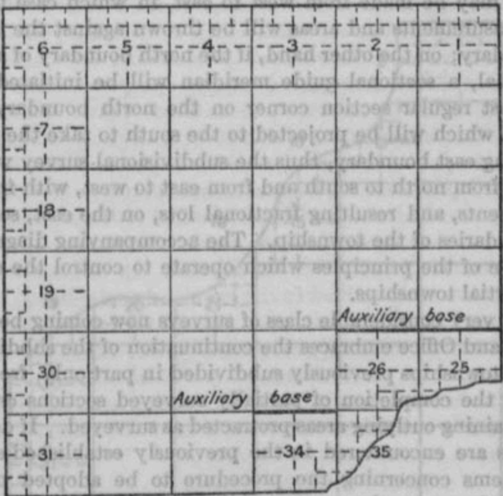

6
5
4
3
2
1
7
18
19
Auxiliary base
30
26
25
Auxiliary base
31
34
35

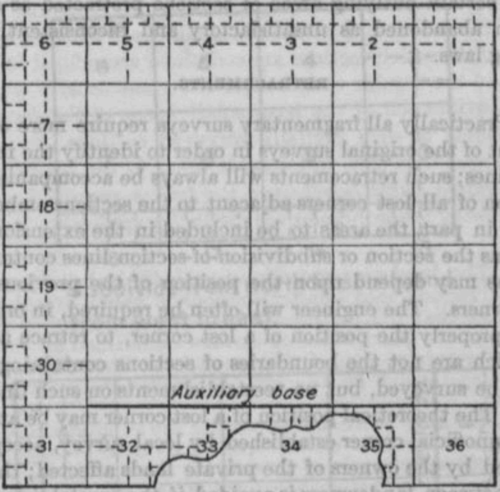
Fig. 51.

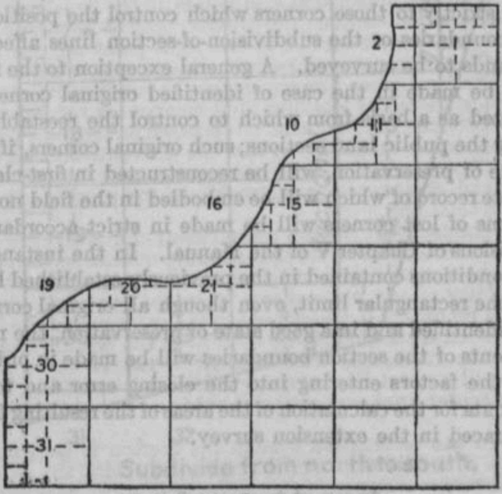
and is without a full linear south or east boundary, and it has been found advisable to run section lines as offsets to the township exteriors, the fractional section lines south and east of said controlling lines will be projected opposite to the usual direction; the fractional measurements on said lines and the resulting fractional lots will be placed against the irregular boundary. If similar conditions obtain throughout the north or west part of a fractional township no departure from the regular order of subdivision becomes necessary; in all such cases the fractional measurements on the exterior and subdivisional lines, and the resulting fractional lots, will be placed to the north and west against the irregular boundary.

213. Where on account of impassable objects or for other reasons no part of the south boundary of a township can be regularly established, the subdivision thereof may proceed from north to south and from east to west, thereby throwing all fractional measurements and areas against the west boundary and the meanderable stream or other boundary limiting the township on the south; if the east boundary is without regular section corners and the north boundary has been run eastwardly as a true line, with section corners at regular intervals of 80 chains, the subdivision of the township may be made from west to east, in which case the fractional measurements and areas will be thrown against the irregular east boundary; on the other hand, if the north boundary of section 6 is fractional, a sectional guide meridian will be initiated at the easternmost regular section corner on the north boundary of the township, which will be projected to the south to take the place of a governing east boundary, thus the subdivisional survey would be projected from north to south and from east to west, with fractional measurements, and resulting fractional lots, on the east, south and west boundaries of the township. The accompanying diagrams are illustrative of the principles which operate to control the subdivision of partial townships.

214. A very considerable class of surveys now coming before the General Land Office embraces the continuation of the subdivisional survey of townships previously subdivided in part only, frequently including the completion of partially surveyed sections or of sections containing outlying areas protracted as surveyed. If defective conditions are encountered in the previously established surveys, the problems concerning the procedure to be adopted multiply rapidly and require the greatest skill on the part of the engineer.

Fig. 52.





Subdivide Regularly.

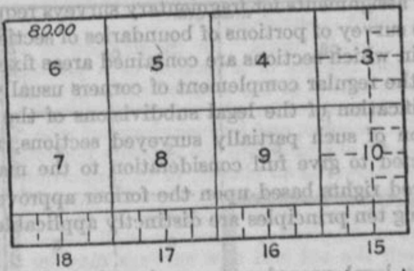
Fig. 53.

In the construction of new township plats the former practice of showing certain outlying areas of sections protracted as surveyed has been abandoned as unsatisfactory and inconsistent with the surveying laws.

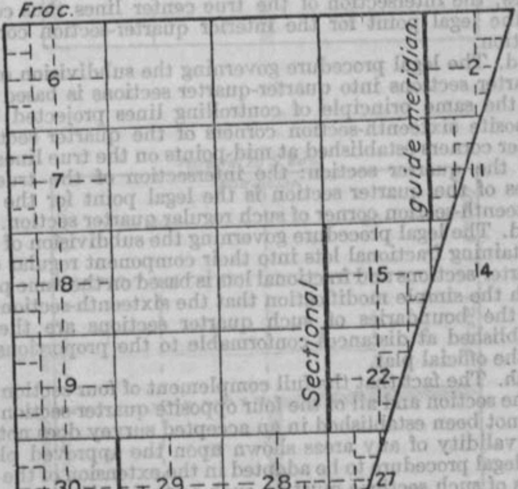
RETRACEMENTS.

215. Practically all fragmentary surveys require more or less retracement of the original surveys in order to identify the initial and closing lines; such retracements will always be accompanied by the restoration of all lost corners adjacent to the sections embracing, in whole or in part, the areas to be included in the extension survey, in-so-far as the section or subdivision-of-section lines controlling the new areas may depend upon the position of the previously established corners. The engineer will often be required, in order to determine properly the position of a lost corner, to retrace additional lines which are not the boundaries of sections containing the new areas to be surveyed, but no reestablishments on such lines are required. The theoretical position of a lost corner may be at variance with an unofficial corner established by local survey, accepted and recognized by the owners of the private lands affected; thus much trouble between landowners is avoided if the reestablishments are confined strictly to those corners which control the position of the section boundaries or the subdivision-of-section lines affecting the public lands to be surveyed. A general exception to the foregoing rule will be made in the case of identified original corners which are adopted as a basis from which to control the reestablishments bordering the public land sections; such original corners, if not in a good state of preservation, will be reconstructed in first-class order, a complete record of which will be embodied in the field notes. All restorations of lost corners will be made in strict accordance with the provisions of Chapter V of the Manual. In the instance of defective conditions contained in the previously established lines, exceeding the rectangular limit, even though all original corners may be fully identified and in a good state of preservation, the necessary retracements of the section boundaries will be made in order to determine the factors entering into the closing error and to furnish suitable data for the calculation of the areas of the resulting fractional lots embraced in the extension survey.

Fig. 54.



Subdivide from north to south, and from west to east.



Subdivide from north to south, and from east to west.

Fig. 55.

COMPLETION OF PARTIALLY SURVEYED SECTIONS.

216. Many assignments for fragmentary surveys require the completion of the survey of portions of boundaries of sections heretofore unsurveyed, in which sections are contained areas fixed in position by less than the regular complement of corners usually established for the identification of the legal subdivisions of the section. In the completion of such partially surveyed sections, the engineer will be expected to give full consideration to the manner of protecting acquired rights based upon the former approved plats.

The following ten principles are distinctly applicable to the subject:

1st. The legal procedure governing the subdivision of any normal section into quarter sections is based broadly on the principle that the partition lines may be definitely fixed by four opposite quarter-section corners established on its boundaries; the intersection of the true center lines thus controlled is the legal point for the interior quarter-section corner of a section.

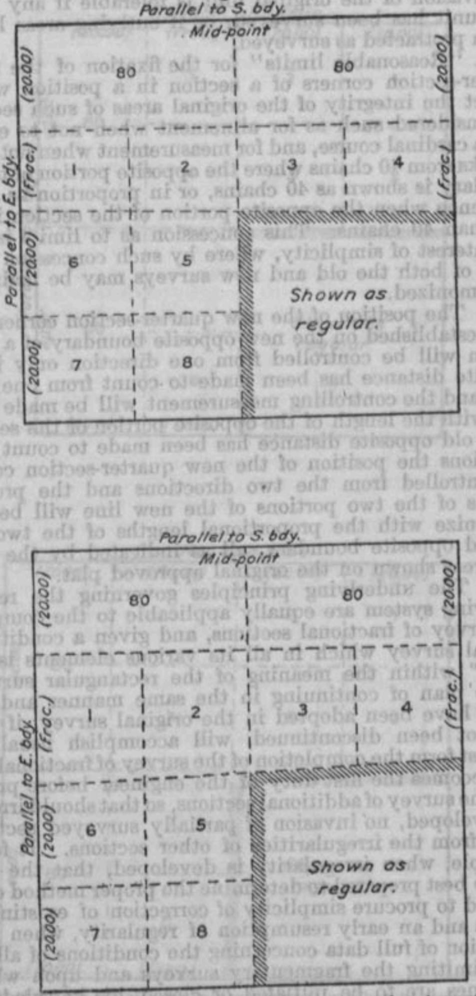
2d. The legal procedure governing the subdivision of regular quarter sections into quarter-quarter sections is based broadly on the same principle of controlling lines projected between opposite sixteenth-section corners of the quarter section, the latter corners established at mid-points on the true lines bounding the quarter section; the intersection of the true center lines of the quarter section is the legal point for the interior sixteenth-section corner of such regular quarter section.

3d. The legal procedure governing the subdivision of sections containing fractional lots into their component regular quarter-quarter sections and fractional lots is based on the same principle with the simple modification that the sixteenth-section corners on the boundaries of such quarter sections are themselves established at distances conformable to the proportions shown on the official plat.

4th. The fact that the full complement of four section corners of the section and all of the four opposite quarter-section corners has not been established in an accepted survey does not impair the validity of any areas shown upon the approved plat, and the legal procedure to be adopted in the extension of the boundaries of such sections must be such as to fix, within reasonable limits, the remaining quarter-section corners in a position which will protect the integrity of the original areas by controlling center lines connecting the old and new quarter-section corners.

5th. In the rectangular system the section is recognized as the unit of subdivision, and in proceeding with the extension of fragmentary surveys first consideration must necessarily be

Fig.56.



East boundary of section out of limits in measurement; southeast quarter protracted as surveyed; and section to be completed.

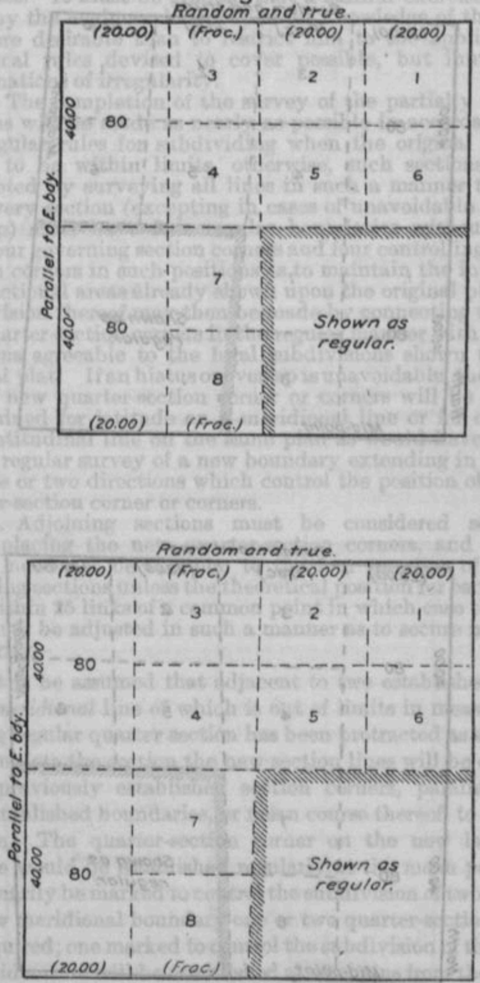
given to the completion of the survey of fractional sections. No invasion of the original unit is tolerable if any portion of such unit has been surveyed, or if outlying areas have been shown protracted as surveyed.

6th. "Reasonable limits" for the fixation of the remaining quarter-section corners of a section in a position which will protect the integrity of the original areas of such section may be considered such as for alinement when not to exceed 21′ from a cardinal course, and for measurement when not to exceed 25 links from 40 chains where the opposite portion of the section boundary is shown as 40 chains, or in proportion as a limiting difference when the opposite portion of the section is more or less than 40 chains. This concession as to limits is made in the interest of simplicity, where by such concession rectangularity of both the old and new surveys may be maintained if so harmonized.

7th. The position of the new quarter-section corner which is to be established on the new opposite boundary of a fractional section will be controlled from one direction only if the old opposite distance has been made to count from one direction only, and the controlling measurement will be made to harmonize with the length of the opposite portion of the section, but if the old opposite distance has been made to count from two directions the position of the new quarter-section corner will be controlled from the two directions and the proportional lengths of the two portions of the new line will be made to harmonize with the proportional lengths of the two parts of the old opposite boundary, all as indicated by the distances and areas shown on the original approved plat.

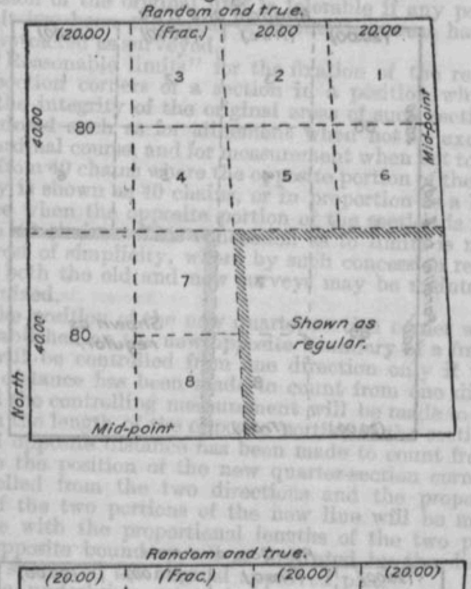
8th. The underlying principles governing the rectangular surveying system are equally applicable to the completion of the survey of fractional sections, and given a condition in an original survey which in all its various elements is "within limits" within the meaning of the rectangular surveys, the simple plan of continuing in the same manner and order as would have been adopted in the original survey, if the same had not been discontinued, will accomplish usually in its simplest form the completion of the survey of fractional sections; this becomes the first duty of the engineer before proceeding with the survey of additional sections, so that should irregularity be developed, no invasion of partially surveyed sections can result from the irregularities of other sections. It follows in principle, when irregularity is developed, that the engineer will be best prepared to determine the proper method of survey adapted to procure simplicity of correction of existing irregularities and an early resumption of regularity, when he is in possession of full data concerning the conditions of all the old lines limiting the fragmentary surveys and upon which the new lines are to be initiated or closed, his knowledge being based upon the results of actual retracement of such irregular

Fig. 57.



South boundary of section out of limits in measurement; southeast quarter protracted as surveyed; and section to be completed.

Fig. 58.



East boundary of section out of limits in alinement; southeast quarter protracted as surveyed; and section to be completed.

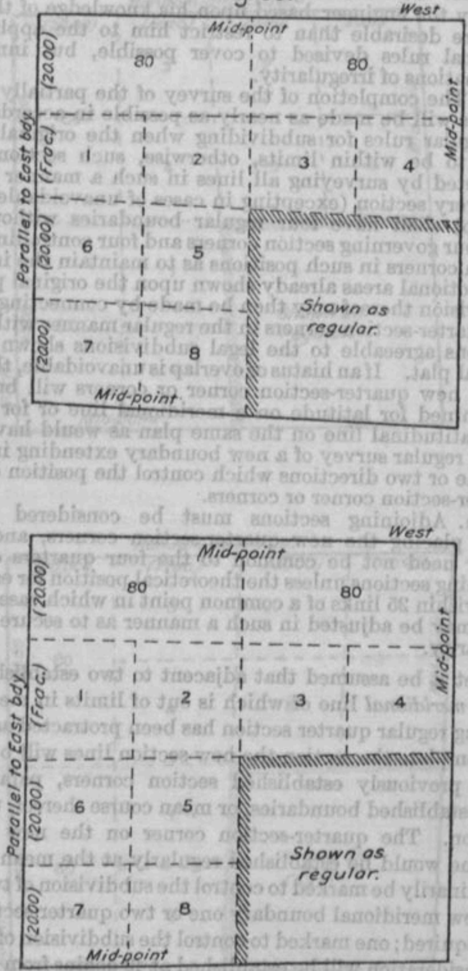
old lines. It must be granted that a skillful exercise of judgment by the engineer based upon his knowledge of the facts is far more desirable than to restrict him to the application of empirical rules devised to cover possible, but innumerable combinations of irregularity.

9th. The completion of the survey of the partially surveyed sections will be made as nearly as possible in accordance with the regular rules for subdividing when the original lines are found to be within limits, otherwise, such sections will be completed by surveying all lines in such a manner that each and every section (excepting in cases of unavoidable hiatus or overlap) shall have four regular boundaries without offsets, with four governing section corners and four controlling quarter-section corners in such positions as to maintain the integrity of the fractional areas already shown upon the original plat. The subdivision thereof may then be made by connecting the opposite quarter-section corners in the regular manner with resulting locations agreeable to the legal subdivisions shown upon the original plat. If an hiatus or overlap is unavoidable, the position of the new quarter-section corner or corners will be carefully determined for latitude on a meridional line or for departure on a latitudinal line on the same plan as would have resulted in the regular survey of a new boundary extending in full from the one or two directions which control the position of the new quarter-section corner or corners.

10th. Adjoining sections must be considered separately when placing the new quarter-section corners, and the new corner need not be common to the four quarters of the two adjoining sections unless the theoretical position for each section falls within 25 links of a common point in which case the difference may be adjusted in such a manner as to secure maximum regularity.

217. Let it be assumed that adjacent to two established section lines, the *meridional* line of which is out of limits in measurement, an outlying regular quarter section has been protracted as surveyed; then to complete the section the new section lines will be extended from the previously established section corners, parallel to the opposite established boundaries, or mean course thereof, to a mutual intersection. The quarter-section corner on the new latitudinal section line would be established regularly at the mean point, and would ordinarily be marked to control the subdivision of two sections. On the new meridional boundary one or two quarter-section corners may be required; one marked to control the subdivision of the section under consideration will be established at 40 chains from the original section corner; the same quarter-section corner would be marked to control the subdivision of the adjoining section if the fractional

Fig. 59.

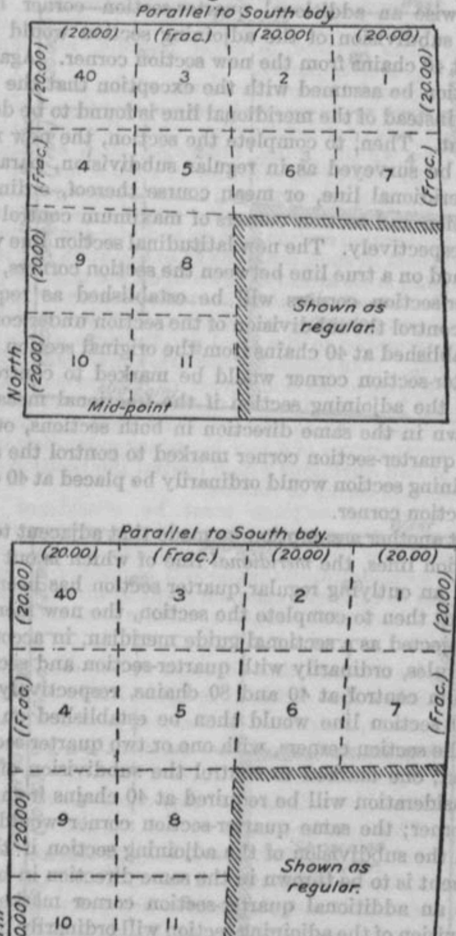


South boundary of section out of limits in alinement; southeast quarter protracted as surveyed; and section to be completed.

measurement is to be thrown in the same direction in the two sections, otherwise an additional quarter-section corner marked to control the subdivision of the adjoining section would ordinarily be placed at 40 chains from the new section corner. Again, let the same condition be assumed with the exception that the *latitudinal* section line instead of the meridional line is found to be defective in measurement. Then, to complete the section, the new meridional line would be surveyed as in regular subdivision, parallel to the opposite meridional line, or mean course thereof, ordinarily with quarter-section and section corners of maximum control at 40 and 80 chains, respectively. The new latitudinal section line would then be established on a true line between the section corners, and one or two quarter-section corners will be established as required; one marked to control the subdivision of the section under consideration will be established at 40 chains from the original section corner; the same quarter-section corner would be marked to control the subdivision of the adjoining section if the fractional measurement is to be thrown in the same direction in both sections, otherwise an additional quarter-section corner marked to control the subdivision of the adjoining section would ordinarily be placed at 40 chains from the new section corner.

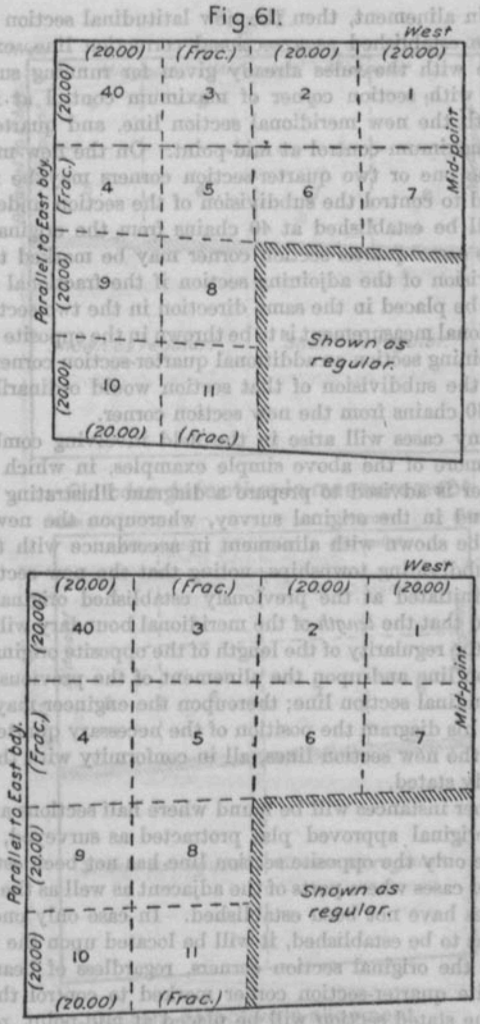
218. Let another assumption be made that adjacent to two established section lines, the *meridional* line of which is out of limits in alinement, an outlying regular quarter section has been protracted as surveyed; then to complete the section, the new meridional line will be projected as a sectional guide meridian, in accordance with the usual rules, ordinarily with quarter-section and section corners of maximum control at 40 and 80 chains, respectively. The new latitudinal section line would then be established on a true line between the section corners, with one or two quarter-section corners as required; one marked to control the subdivision of the section under consideration will be required at 40 chains from the original section corner; the same quarter-section corner would be marked to control the subdivision of the adjoining section if the fractional measurement is to be thrown in the same direction in both sections; otherwise an additional quarter-section corner marked to control the subdivision of the adjoining section will ordinarily be established at 40 chains from the new section corner. On the other hand, if the same conditions be assumed with the exception that the original *latitudinal* section line instead of the meridional line is found to be

Fig. 60.



East boundary of section out of limits in alinement and measurement; southeast quarter protracted as surveyed; and section to be completed.

Fig. 61.



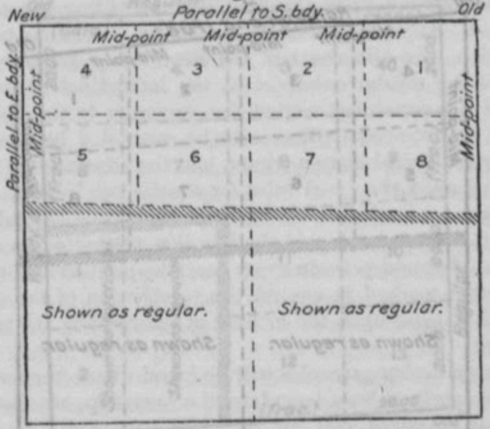
South boundary of section out of limits in alinement and measurement; southeast quarter protracted as surveyed; and section to be completed.

defective in alinement, then the new latitudinal section line will have to be established as a sectional correction line, exactly in accordance with the rules already given for running such lines, ordinarily with section corner of maximum control at its intersection with the new meridional section line, and quarter-section corner of maximum control at mid-point. On the new meridional section line one or two quarter-section corners may be required; one marked to control the subdivision of the section under consideration will be established at 40 chains from the original section corner; the same quarter-section corner may be marked to control the subdivision of the adjoining section if the fractional measurement is to be placed in the same direction in the two sections, but if the fractional measurement is to be thrown in the opposite direction in the adjoining section an additional quarter-section corner marked to control the subdivision of that section would ordinarily be required at 40 chains from the new section corner.

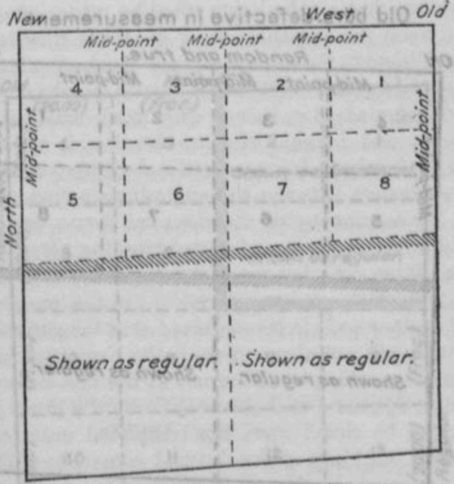
219. Many cases will arise in the field involving combinations of two or more of the above simple examples, in which instance the engineer is advised to prepare a diagram illustrating the conditions found in the original survey, whereupon the new section lines may be shown with alinement in accordance with the usual rules for subdividing townships, noting that the new section lines are to be initiated at the previously established original section corners, and that the *length* of the meridional boundary will depend both upon the regularity of the length of the opposite original meridional section line and upon the alinement of the previously established latitudinal section line; thereupon the engineer may at once show upon his diagram the position of the necessary quarter-section corners on the new section lines, all in conformity with the simple rules already stated.

220. Other instances will be found where half sections are shown upon the original approved plat protracted as surveyed, in some cases where only the opposite section line has not been established and in other cases where parts of the adjacent as well as the opposite section lines have not been established. In case only one section line remains to be established, it will be located upon the true line connecting the original section corners, regardless of bearing; the new opposite quarter-section corner marked to control the subdivision of the stated section will be placed at mid-point, regardless of the length of the new section line; the position of the quarter-

Fig. 62.



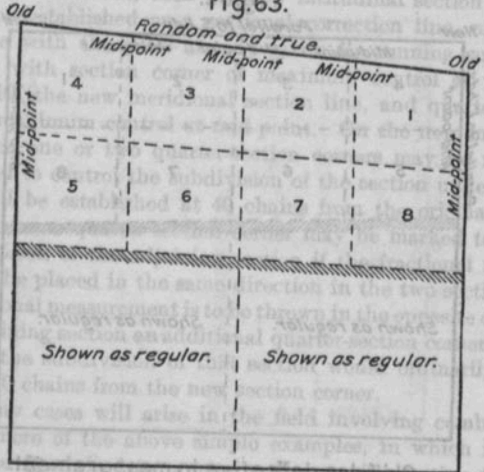
Old bdrs. defective in measurement.



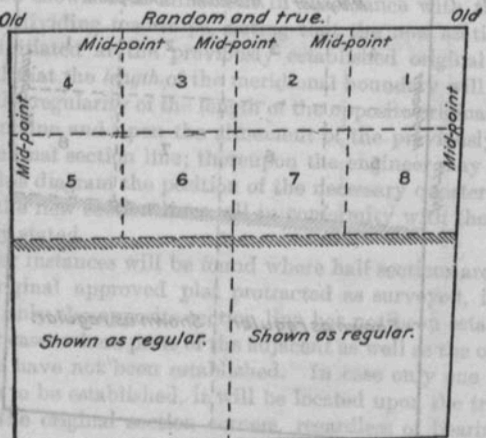
Old bdrs. defective in alinement.

South half protracted as surveyed, and section to be completed.

Fig.63.



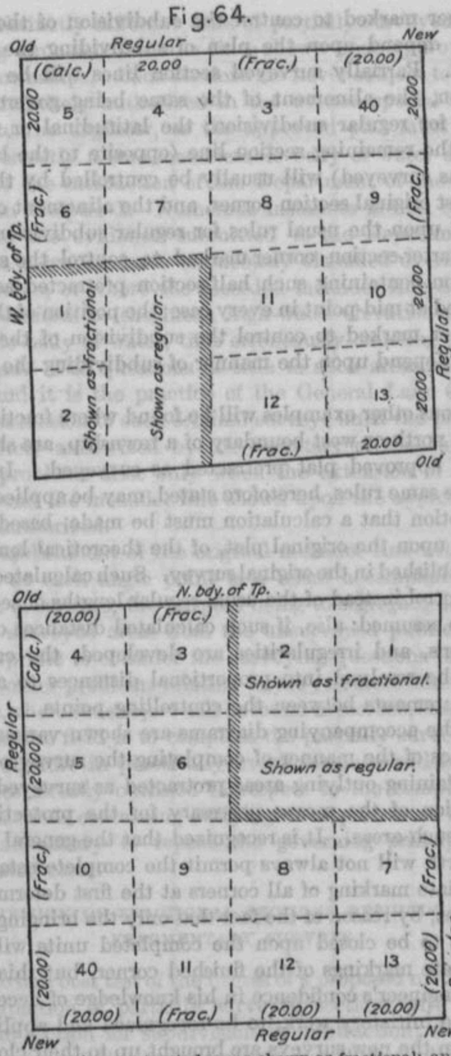
Old bdrs. defective in measurement.



Old bdrs. defective in alinement.

South half protracted as surveyed, and section to be completed.

Fig. 64.



Old surveys irregular; protracted areas shown as fractional; and section to be completed.

section corner marked to control the subdivision of the adjoining section will depend upon the plan of subdividing the remaining public land. Partially surveyed section lines will be completed by extension, the alinement of the same being governed by the usual rules for regular subdivision; the latitudinal or meridional position of the remaining section line (opposite to the half section protracted as surveyed) will usually be controlled by the position of the nearest original section corner, and the alinement of the same will depend upon the usual rules for regular subdivision; the new opposite quarter-section corner marked to control the subdivision of the section containing such half section protracted as surveyed will be placed at mid-point in every case; the position of the quarter-section corner marked to control the subdivision of the adjoining section will depend upon the manner of subdividing the remaining public land.

221. Various other examples will be found where fractional areas, as along the north or west boundary of a township, are shown upon the original approved plat protracted as surveyed. In all such instances the same rules, heretofore stated, may be applied, with the single exception that a calculation must be made, based upon the areas shown upon the original plat, of the theoretical lengths of all lines not established in the original survey. Such calculated distances will then control instead of the usual regular lengths of section lines as heretofore assumed; also, if such calculated distances count from two directions, and irregularities are developed, the calculations must again be resolved into proportional distances to agree with actual measurements between the controlling points.

222. On the accompanying diagrams are shown various exaggerated examples of the manner of completing the survey of irregular sections containing outlying areas protracted as surveyed, showing the application of the means necessary for the protection of the integrity of such areas. It is recognized that the general principles above set forth will not always permit the complete establishment and appropriate marking of all corners at the first determination of their locations, by reason of the fact that only the bringing up of the new surveys to be closed upon the completed units will develop the appropriate markings of the finished corner, but this need not impair the engineer's confidence in his knowledge of necessary procedure in the initiatory work, to be recognized and applied appropriately when the new surveys are brought up to their closings.

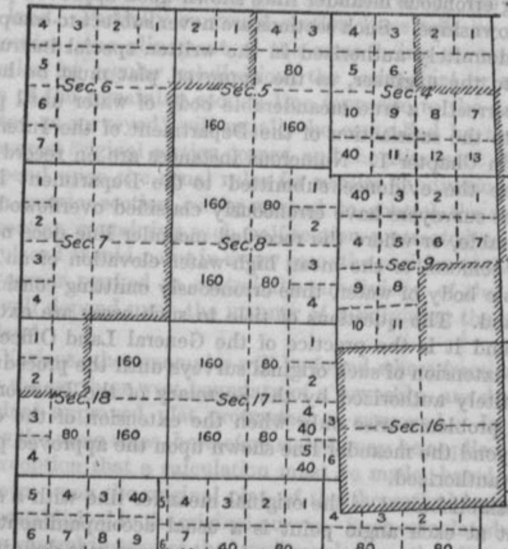
223. A distinctly different class of partially surveyed sections is found along erroneous meander lines shown upon approved plats of fractional townships. Such sections are never subject to completion except as definitely authorized in the written special instructions furnished to the engineer, as the approved plat must be held to represent correctly a true meanderable body of water until proven otherwise to the satisfaction of the Department of the Interior, as intimated in Chapter I. Numerous instances are on record, however, where the evidence submitted to the Department is conclusive that surveyors have erroneously classified overflowed lands as meanderable, or where the recorded meander line does not and never did conform to the mean high-water elevation of an actual meanderable body of water, thus erroneously omitting considerable areas of land. The questions of title to such areas are extremely intricate, and it is the practice of the General Land Office not to allow any extension of such original surveys until the procedure has been definitely authorized by the Secretary of the Interior. The surveying problems arise only when the extension of the original survey beyond the meander line shown upon the approved plat has been duly authorized.

The reestablishment of the original meander line with a suitable monument at each angle point is a usual accompaniment of the above class of surveys, the purpose being to segregate definitely the previously surveyed areas from the unsurveyed public lands; it is more appropriate to consider the surveying questions thus involved along with other problems relating to the reestablishment of broken boundaries, where the subject will be found in sec. 380, Chapter V. The next step in the field is to complete the partially surveyed sections and the procedure in practically every instance will be controlled by the rules already outlined in respect to the completion of the survey of sections containing outlying areas protracted as surveyed; it seems unnecessary to repeat the governing principles in such closely related cases.

SUBDIVISION OF FRACTIONAL SECTIONS RESULTING FROM FRAGMENTARY SURVEYS.

224. The one best test of the fitness of a proposed method incident to the completion of partially surveyed sections will be found in platting the section for subdivision by protraction; thereupon the regular rules for subdivision of sections should be applicable. Thus

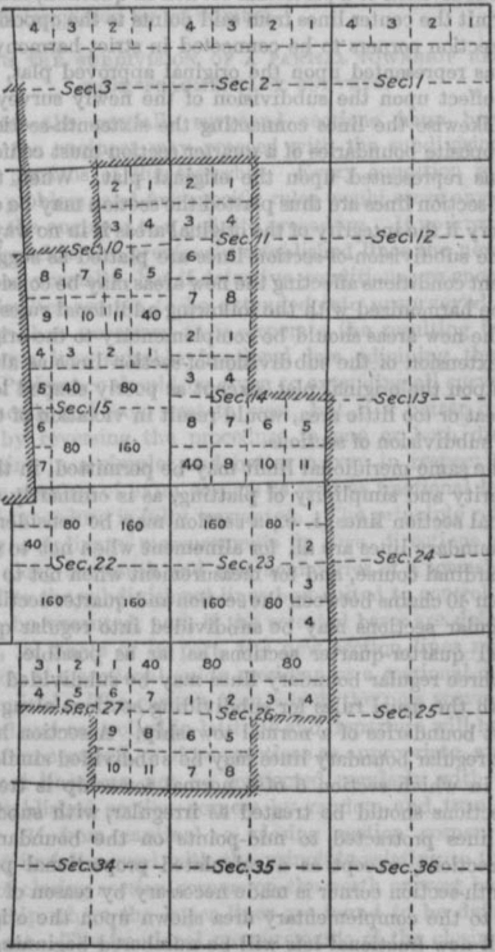
Fig. 65 (West half)



Example showing the completion of partially surveyed sections, the subdivision of

resulting from

Fig. 65 (East half)



fractional sections, and the completion of the subdivisional lines of a partial township fragmentary surveys.

the position of the new quarter-section corners, established to control the subdivision of a particular section in question, must be such as to permit the center lines from said points to the opposite original quarter-section corners to be connected in strict harmony with the conditions represented upon the original approved plat, disregarding the effect upon the subdivision of the newly surveyed public land. Likewise the lines connecting the sixteenth-section corners on the opposite boundaries of a quarter section must conform to the conditions represented upon the original plat. When the subdivision-of-section lines are thus platted the section may be considered satisfactory if the integrity of the original areas is in no way violated. When the subdivision-of-section lines are platted as suggested, the permanent conditions affecting the new areas may be considered, and should be harmonized with the following additional rules:

1st. The new areas should be complementary to the original areas by the extension of the subdivision-of-section lines as already protracted upon the original plat, except as poorly shaped lots, or lots of too great or too little area, would result in violation of the regular rules for subdivision of sections.

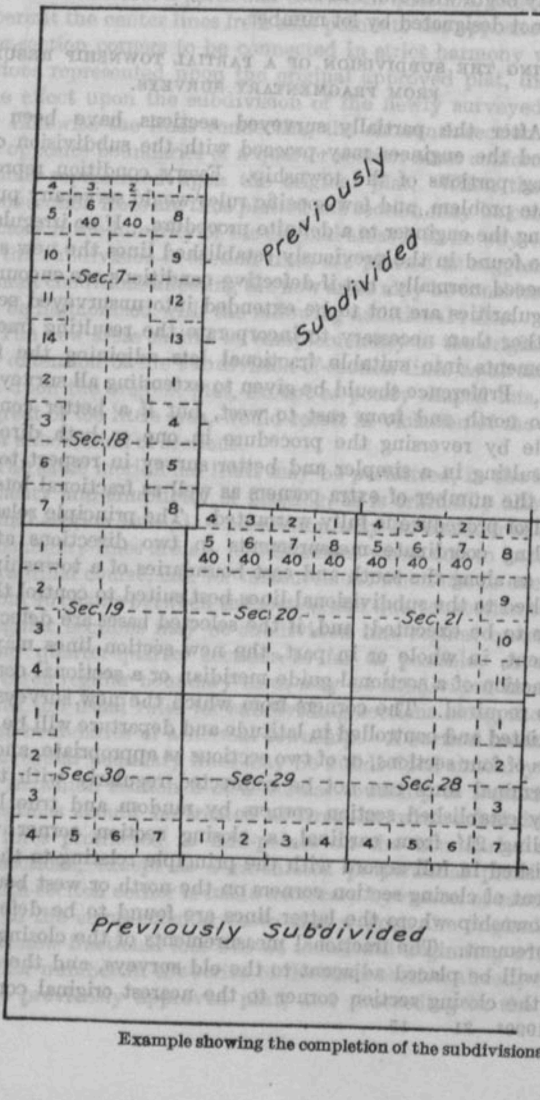
2d. The same meridional limit may be permitted, in the interest of regularity and simplicity of platting, as is ordinarily allowed in latitudinal section lines; i. e., a section may be considered regular whose boundary lines are all for alinement when not to exceed 21′ from a cardinal course, and for measurement when not to exceed 25 links from 40 chains between the section and quarter-section corners. Such regular sections may be subdivided into regular quarter sections and quarter-quarter sections as far as possible. A section having three regular boundary lines may be subdivided in accordance with the usual rules for subdividing sections along the north and west boundaries of a normal township. A section having two adjacent regular boundary lines may be subdivided similarly to the manner in which section 6 of a normal township is treated. All other sections should be treated as irregular, with subdivision-of-section lines protracted to mid-points on the boundaries of the quarter sections, except as a calculated proportional position for a sixteenth-section corner is made necessary by reason of conditions relating to the complementary area shown upon the original plat.

3d. All new fractional lots will be numbered beginning with the next higher number in the series of the same section already begun upon the previously approved plat, and proceeding in the usual order in which fractional lots are normally numbered. The new series may begin with No. 1 in case the fractional parts of the original area are not designated by lot number.

COMPLETING THE SUBDIVISION OF A PARTIAL TOWNSHIP RESULTING FROM FRAGMENTARY SURVEYS.

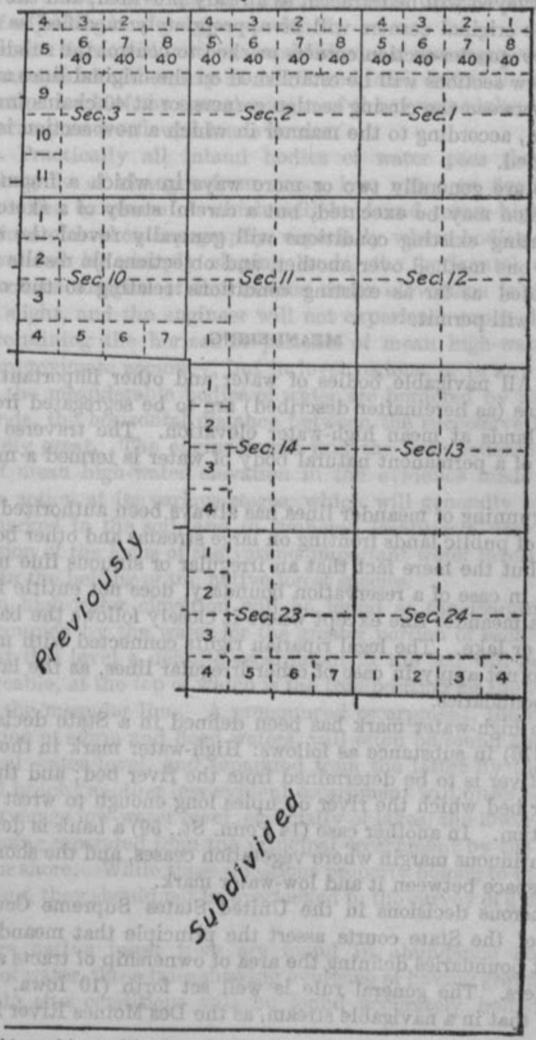
225. After the partially surveyed sections have been fully completed the engineer may proceed with the subdivision of the remaining portions of the township. Every condition represents a separate problem, and few specific rules would serve any purpose in guiding the engineer to a definite procedure. If no irregularities are to be found in the previously established lines the new survey may proceed normally, but if defective conditions are encountered the irregularities are not to be extended into unsurveyed sections any farther than necessary to incorporate the resulting fractional measurements into suitable fractional lots adjoining the former surveys. Preference should be given to extending all surveys from south to north and from east to west, but if a better control is available by reversing the procedure in one or both directions, thus resulting in a simpler and better survey in respect to minimizing the number of extra corners as well as fractional lots, such reversal of procedure is fully warranted. The principle relating to controlling coördinate measurements in two directions at right angles, as along the south and east boundaries of a township, may be applied to the subdivisional lines best suited to control the new surveys to be executed; and, if the selected bases are defective in alinement, in whole or in part, the new section lines may serve the function of a sectional guide meridian or a sectional correction line as required. The corners from which the new surveys are to be initiated and controlled in latitude and departure will be termed corners of four sections, or of two sections as appropriate, and where the terminal lines can not be connected regularly with the previously established section corners by random and true line not exceeding 21′ from cardinal, a closing section corner will be established in full accord with the principle relating to the establishment of closing section corners on the north or west boundaries of a township where the latter lines are found to be defective in measurement. The fractional measurements of the closing section lines will be placed adjacent to the old surveys, and the distance from the closing section corner to the nearest original corner will

Fig. 66 (West half)



Example showing the completion of the subdivisional lines

Fig. 66 (East half)



of a partial township resulting from fragmentary surveys.

be measured; the original lines forming the boundary of the lands to be surveyed will be retraced, as already provided, and the marks upon the original corners will be appropriately modified as necessary; new quarter-section corners marked to control the subdivision of the new sections will be established on the original lines at midpoints between the closing section corners, or at 40 chains from one direction, according to the manner in which a new section is to be subdivided.

There are generally two or more ways in which a fragmentary subdivision may be executed, but a careful study of a sketch plat representing existing conditions will generally reveal the superiority of one method over another, and objectionable results should be avoided as far as existing conditions relating to the original surveys will permit.

MEANDERING.

226. All navigable bodies of water and other important rivers and lakes (as hereinafter described) are to be segregated from the public lands at mean high-water elevation. The traverse of the margin of a permanent natural body of water is termed a meander line.

The running of meander lines has always been authorized in the survey of public lands fronting on large streams and other bodies of water, but the mere fact that an irregular or sinuous line must be run, as in case of a reservation boundary, does not entitle it to be called a meander line except where it closely follows the bank of a stream or lake. The legal riparian rights connected with meander lines do not apply in case of other irregular lines, as the latter are strict boundaries.

Mean high-water mark has been defined in a State decision (47 Iowa, 370) in substance as follows: High-water mark in the Mississippi River is to be determined from the river bed; and that only is river bed which the river occupies long enough to wrest it from vegetation. In another case (14 Penn. St., 59) a bank is defined as the continuous margin where vegetation ceases, and the shore is the sandy space between it and low-water mark.

Numerous decisions in the United States Supreme Court and many of the State courts assert the principle that meander lines are not boundaries defining the area of ownership of tracts adjacent to waters. The general rule is well set forth (10 Iowa, 549) by saying that in a navigable stream, as the Des Moines River in Iowa, high-water mark is the boundary line. When by action of the water the river bed changes, high-water mark changes and ownership of adjoining land progresses with it.

Meander lines will not be established at the segregation line between upland and swamp or overflowed land, but at the ordinary high-water mark of the actual margin of the river or lake on which such swamp or overflowed lands border.

227. Practically all inland bodies of water pass through an annual cycle of changes from mean low water to flood stages, between the extremes of which will be found mean high water. In regions of broken topography, especially where bodies of water are bounded by sharply sloping lands, the horizontal distance between the margins of the various water elevations is comparatively slight, and the engineer will not experience much difficulty in determining the horizontal position of mean high-water level with approximate accuracy; but in level regions, or in any locality where the meanderable bodies of water are bordered by relatively flat lands, the horizontal distance between the successive levels is relatively great. The engineer will find the most reliable indication of mean high-water elevation in the evidence made by the water's action at its various stages, which will generally be found well marked in the soil, and in timbered localities a very certain indication of the locus of the various important water levels will be found in the belting of the native forest species.

Mean high-water elevation will be found at the margin of the area occupied by the water for the greater portion of each average year; at this level a definite escarpment in the soil will generally be traceable, at the top of which is the true position for the engineer to run the meander line. A pronounced escarpment, the result of the action of storm and flood waters, will often be found above the principal water level, and separated from the latter by the storm or flood beach; another less evident escarpment will often be found at the average low-water level, especially of lakes, the lower escarpment being separated from the principal escarpment by the normal beach or shore. While these questions properly belong to the realm of geology, they should not be overlooked in the survey of a meander line.

Where native forest trees are found in abundance bordering bodies of water, those trees showing evidence of having grown under favorable site conditions will be found accurately belted along contour lines; thus a certain class of mixed varieties common to a particular region will be found only on the lands seldom if ever overflowed; another group of forest species will be found on the lands which are inundated only a small portion of the growing season each year, and indicate the area which should be included in the classification of the uplands; other varieties of native forest trees will be found only within the zone of swamp and overflowed lands. All timber growth normally ceases at the margin of permanent water.

228. At every point where either standard, township or section lines intersect the bank of a navigable stream, or any meanderable body of water, corners at such intersections will be established at the time of running these lines. Such monuments are called meander corners. In the survey of lands bordering on tide waters, meander corners may be temporarily set at the intersection of the surveyed lines with the margin of mean high tide, but no monument should be placed in a position exposed to the beating of waves and the action of ice in severe weather. In all such cases a witness corner on the line surveyed, at a secure point near the true point for the meander corner, will be established. The crossing distance between meander corners on the same line will be ascertained by triangulation or direct measurement, and the full particulars will be given in the field notes.

229. Inasmuch as it is not practicable in public-land surveys to meander in such a way as to follow and reproduce all the minute windings of the high-water line, the United States Supreme Court has given the principles governing the use and purpose of meandering shores in its decision in a noted case (R. R. Co. *v.* Schurmeir, 7 Wallace, 286–287) as follows:

"Meander lines are run in surveying fractional portions of the public lands bordering on navigable rivers, not as boundaries of the tract, but for the purpose of defining the sinuosities of the banks of the stream, and as the means of ascertaining the quantity of land in the fraction subject to sale, which is to be paid for by the purchaser. In preparing the official plat from the field notes, the meander line is represented as the border line of the stream, and shows to a demonstration that the water-course, and not the meander line as actually run on the land, is the boundary."

230. The engineer will commence the meander line at one of the meander corners, follow the bank or shore line, and determine the true bearing and measure the exact length of each course, from the beginning to the next meander corner. All meander courses are to be taken or counted from the true meridian and will be determined with precision; "transit angles" showing only the amount of the deviation from the preceding course are not acceptable in field notes of meanders. For convenience the courses of meander lines should be adjusted to the exact quarter degree; meander lines are not strict boundaries and this method will give approximate agreement with the minute sinuosities of mean high-water elevation. Again, for convenience of platting and computation, the engineer is required to adopt turning points at distances of whole chains, or multiples of 10 links, with odd links only in the final course.

In cases where the engineer finds it impossible to carry his meander line along mean high-water mark, his notes should state the distance therefrom and the obstacles which justify the deviation. A table of latitudes and departures of the meander courses should be computed before leaving the vicinity, and if misclosure is found, indicating error in measurement or in reading courses, the lines should be rerun.

All streams flowing into a river, lake or meanderable bayou will be noted, and the width at their mouths stated; also, the position, size and depth of springs, whether the water be pure or mineral; also, the heads and mouths of all bayous, all rapids and bars, will be noted, with intersections to the upper and lower ends of the latter, to establish their exact situation. The elevation of the banks of lakes and streams, the height of falls and cascades, and the length and fall of rapids, will be recorded in the field notes.

The field notes of meanders will show the corners from which the meanders commenced and upon which they closed, and will exhibit the meanders of each fractional section separately; following, and composing a part of such notes, will be given a description of the adjoining land, soil and timber, and the depth of inundation to which the bottom land is subject. The utmost care will be taken to pass no object of topography, or change therein, without giving a particular description thereof in its proper place in the notes of the meanders.

RIVERS.

Facing

231. Proceeding downstream, the bank on the left hand is termed the left bank and that on the right hand the right bank. These terms will be universally used to distinguish the two banks of a river or stream. Navigable rivers and bayous, as well as all rivers not embraced in the class denominated "navigable," the right-angle width of which is 3 chains and upwards, will be meandered on both banks, at the ordinary mean high-water mark, by taking the general courses and distances of their sinuosities. Rivers not classed as navigable will not be meandered above the point where the average right-angle width is less than 3 chains, except that streams which are less than 3 chains wide and which are so deep, swift and dangerous as to be impassable may be meandered, where good agricultural lands along the banks require their separation into fractional lots for the benefit of settlers.

Shallow fresh-water streams, without any well-defined channel or permanent banks, will not be meandered. Tidewater streams, whether more or less than 3 chains wide, should be meandered at ordinary high-water mark, as far as tidewater extends.

LAKES.

232. The meanders of all lakes of the area of 25 acres and upwards, will be commenced at a meander corner and continued, as above directed for navigable streams; from said corner, the courses and distances of the entire margin of the same, and the intersections with all meander corners established thereon, will be noted.

In the case of lakes which are found to be located entirely within the boundaries of a section, a quarter-section line, if one crosses the lake, will be run from one of the quarter-section corners, on a theoretical course to connect with the opposite quarter-section corner, to the margin of the lake, and the distance will be measured; then at the point thus determined a "special meander corner" will be established. If a meanderable lake is found to be located entirely within a quarter section, an "auxiliary meander corner" will be established at some suitable point on its margin, and a connecting line will be run from said monument to a regular corner on the section boundary. A connecting traverse line will be recorded, if one is run, but it will also be reduced to the equivalent direct connecting course and distance, all of which will be stated in the field notes, and the course and length of the direct connecting line will be shown on the plat of the survey.

The meander line of a lake lying within the interior of a section will be initiated at the established special or auxiliary meander corner, as the case may be, and continued around the margin of the normal lake at its mean high-water level, to a closing at the point of beginning. All proceedings are to be fully entered in the field notes.

Artificial lakes and reservoirs are not to be segregated from the public lands, unless specially provided in the instructions, but the true position and extent of such bodies of water will be determined in the field and shown on the plat.

ISLANDS.

233. In the progress of the regular surveys every island above the mean high-water elevation of any meanderable body of water, excepting only those islands which may have formed in navigable bodies of water after the date of the admission of a State into the Union, will be definitely located by triangulation or direct measurement or other suitable process, and will be meandered and shown upon the official plat.

In the survey of the mainland fronting on any non-navigable body of water, any island opposite thereto, above mean high-water elevation, is subject to survey. Also, even though the United States may have parted with its title to the adjoining mainland, an island in any meandered body of water, navigable or non-navigable, known or proven to have been in existence at the date of the admission of a State into the Union, and at the date of the survey of the mainland, if omitted from said original survey, remains public land of the United States, and as such the island is subject to survey.

The survey of islands not shown upon the original approved plats of subdivided townships is authorized by the Department only upon the receipt of formal application, and subject to the approval thereof. The proof of the time of the formation of such islands is often more or less difficult, and it is the practice of the Department to make a careful examination of the history of an island in relation to the question of its legal ownership before approving the application for its survey.

Any township boundary or section line which will intersect an island will be extended as nearly in accordance with the plan of regular surveys as conditions will permit, and the usual township, section, quarter-section and meander corners will be established on the island. If an island falls in two sections only, the line between those particular sections should be established in its proper theoretical position based upon suitable sights and calculations

If an island falls entirely in one section, and is large enough to be subdivided (over 50 acres in area), a suitable sight or calculation will be made to locate on the margin of the island an intersection with the theoretical position of any suitable subdivision-of-section line, and at the point thus determined a "special meander corner" will be established. In the case of an island falling entirely in one section and found to be too small to be subdivided, an "auxiliary meander corner" will be established at any suitable point on its margin, which will be accurately connected with any regular corner on the mainland. The direct course and length of the connecting line will be given in the field notes, together with all sights, measurements, triangulations and traverse lines upon which the calculation may be based. The course and length of the direct connecting line will be shown on the plat.

The meander line of an island will be surveyed in harmony with principles and rules heretofore stated; all township and section lines crossing the island will be shown on the plat; and, if the island is large enough to be subdivided, the subdivision will be accomplished by the protraction of suitable subdivision-of-section lines in their correct theoretical position.

Agricultural upland within the limits of swamp and overflowed lands should be so classified and shown upon the plat accordingly, but such land will not be meandered as an island.

LIMITS OF CLOSURE.

234. Under the general subjects of "township exteriors" and "subdivision of townships" certain definite limits were prescribed beyond which previously established surveys are classed as "defective," or in the case of new surveys corrective steps are required. Such limits constitute the standard of accuracy of the United States rectangular surveys, and, for convenience, have been variously referred to as the "rectangular limit," "limit for the control of new surveys," "limit relating to defective exteriors and section lines," "limits for subdivision," etc., each expression having been formed to suit the descriptive exigency of the text. A more general requirement known as the "limit of closure" will be applied as a test of the accuracy of the alinement and measurement of all classes of lines embraced in any closed figure incident to the public-land surveys, and corrective steps will be required wherever this test discloses an error beyond the allowable limit.

The "error of closure" of a survey may be defined, in general terms, as the ratio of the length of the line representing the equivalent of the errors in latitude and departure (as found by a table of latitudes and departures) to the length of the perimeter of the figure constituting the survey; but, with due regard for the controlling coördinate governing lines of a rectangular survey, pronounced accuracy in latitude will not be permitted to offset gross error in departure, or vice versa, and, in order to be consistent with this fundamental theory, a double test must be applied in place of the one expressed in general terms. The "limit of closure" fixed for the United States rectangular surveys may be expressed by the fraction $\frac{1}{452}$ provided that the limit of closure in neither latitude nor departure exceeds $\frac{1}{640}$, and where a survey qualifies under the latter limit the former is bound to be satisfied; thus an accumulative error of 12½ links per mile of perimeter, in either latitude or departure, will not be exceeded in an acceptable survey. The limit of closure as thus expressed may be applied to various specific conditions as heretofore stated.

The latitudes and departures of a normal section shall each close within 50 links; of a normal range or tier of sections, within 175 links; and of a normal township, within 300 links. The boundaries of each fractional section including irregular claim lines or meanders, or the meanders of an island or lake in the interior of a section, should close within a limit to be determined by the fraction $\frac{1}{640}$ when the error in either latitude or departure is considered separately; the same rule will be applied to all broken or irregular boundaries.

Engineers are required to compute all doubtful closings while in the field in the immediate vicinity of a particular line, or series of lines, in question, and to accomplish all necessary corrective work before concluding a survey.

MARKING LINES BETWEEN CORNERS.

235. The marking of a survey upon the ground in such a manner as to fix forever the position of the legal lines in relation to the earth's surface is the final step in the field work, and is accomplished in three ways, which, if well executed, will individually or collectively furnish the means of the identification of the survey at even remote future dates. Careful attention to these details is one of the most important phases of the engineer's field work. (*a*) The regular corners of the public-land surveys are marked by fixed monuments of specified character as described in Chapter IV; (*b*) the relation of the officially surveyed lines to natural topographical features is recorded in much detail as hereinafter outlined, and again exemplified in the specimen field notes; and, (*c*) the locus of the legal lines, wherever living timber is encountered, is plainly marked upon the forest trees, which is accomplished by the process of "blazing" and by "hack" marks.

A "blaze" is an ax mark which is made upon a tree trunk at about breast height, in which a flat scar is left upon the tree surface. The bark and a very small amount of the live wood tissue are removed, leaving a smooth surface which forever brands the tree. The size of the blaze depends somewhat upon the size of the tree, but is never made larger than the surface of an ax blade; a blaze 5 or 6 inches in height and from 2 to 4 inches in width is ample to mark any tree.

A "hack" is also an ax mark which is made upon a tree trunk at about breast height, in which a horizontal notch is cut into the surface of the tree. The notch is made "V-shaped," and is cut through the bark and well into the wood. Two hacks are cut in order to distinguish those made in the survey from accidental marks resulting from other causes; a vertical section of the completed official hack mark resembles a "double-V" ($\substack{<\\<}$) extending across a tree from 2 to 6 inches in length, depending upon the diameter of the tree. The "hack" and "blaze" marks are equally permanent, but so different in character that one mark should never be mistaken for the other.

The marking of trees along the surveyed lines was required by law as positively as the erection of monuments, by the act of 1796, which is still in force. All lines on which are to be established the legal corners will be marked after this method, viz: Those trees which may be intersected by the line will have two hacks or notches cut on each of the sides facing the line, without any other marks whatever. These are called sight trees or line trees. A sufficient number of other trees standing within 50 links of the line, on either side of it, will be blazed on two sides quartering toward the line, in order to render the line conspicuous, and readily to be traced in either direction, the blazes to be opposite each other coinciding in direction with the line where the trees stand very near it, and to approach nearer each other toward the line the farther the line passes from the blazed trees.

Due care will ever be taken to have the lines so well marked as to be readily followed, and to cut the blazes plainly enough to leave recognizable scars as long as the trees stand. This can be accomplished by blazing just through the bark into the live wood tissue. Where trees 2 inches or more in diameter occur along a line, the required blazes will not be omitted. Where trees have branches growing to the ground, the blazes will be omitted unless it is necessary to remove the branches to permit sighting.

Lines are also to be marked by cutting away enough of the undergrowth to facilitate correct sighting of instruments. Where lines cross deep wooded valleys, by sighting over the tops, the usual blazing of trees in the low ground when accessible will be performed; that settlers may find their proper limits of land and timber without special survey. The undergrowth will be especially well cut along all lines within distances of 5 chains of corner monuments and within 2 chains of arteries of travel, to enable other surveyors and settlers to locate the survey readily, but the cutting of the undergrowth may be omitted in deep untraveled ravines unless necessary for accurate sighting or measurement.

Line trees and blazing will be marked only with reference to the established true line, and where lines are run by the "random and true" line method, the marking of line trees and the blazing will be accomplished by returning over the line after all corrections or adjustments to the final line are definitely known. A sufficient number of temporary stakes should be set along a random line to render it generally unnecessary to rerun the true line instrumentally merely for the purpose of blazing the line through timber, as this can usually be accomplished by properly estimating the distance from the temporary stakes, but intersections with line trees will be made with precision, and distances thereto accurately measured.

SUMMARY OF OBJECTS TO BE NOTED, AND SKETCHES.

236. The field notes and plat of a survey are designed to furnish not only a technical record of the procedure, but also of equal importance a report upon the character of the land, soil and timber traversed by the survey, and a detailed schedule of the topographical features along every line, with accurate connections showing the relation of the rectangular surveys to other surveys, to natural objects and to improvements. A triple purpose is thus served: (*a*) the technical procedure is made a matter of official record; (*b*) general information relating to a region is gathered; and, (c) the "calls" of the field notes and the representations of the plat in respect to objects along the surveyed lines furnish important evidence by which the locus of the survey becomes practically unchangeable as contemplated by law.

The specimen field notes and plats are intended to standardize the form of record, and many special matters relating to these subjects are brought together in Chapters VIII and IX, but before concluding the special questions concerning rectangular surveys it is deemed expedient to outline the technical and topographical features which are to be carefully observed and recorded in the field during the progress of the public-land surveys:—

1. The precise course and length of every line run, noting all necessary offsets therefrom, with the reason for making them, and method employed.

2. The kind and diameter of all bearing trees, with the course and distance of the same from their respective corners, and the markings; all bearing objects and marks thereon, if any; and the precise relative position of witness corners to the true corners.

3. The kind of material of which corners are constructed, their dimensions and markings, depth set in the ground, and their accessories.

4. Trees on line. The name, diameter and distance on line to all trees which it intersects, and their markings.

5. Intersections by line of land objects. The distance at which the line intersects the boundary lines of every reservation, townsite, or private claim, noting the exact bearing of such boundary lines, and the precise distance to the nearest boundary corner; the center line of every railroad, canal, ditch, electric transmission line, or other right-of-way across public lands, noting the width of the right-of-way and the precise bearing of the center line; the change from one character of land to another, with the approximate bearing of the line of demarcation, and the estimated height in feet of the ascents and descents over the principal slopes typifying the topography of the country traversed, with the direction of said slopes; the distance to and the direction of the principal ridges, spurs, divides, rim rock, precipitous cliffs, etc.; the distance to where the line enters or leaves heavy or scattering timber, with the approximate bearing of the margin of all heavy timber, and the distance to where the line enters or leaves dense undergrowth.

6. Intersections by line of water objects. All unmeandered rivers, creeks and smaller water-courses which the line crosses; the distance measured on the true line to the center of the same in the case of the smaller streams, and to both banks in the case of the larger streams, the course downstream at points of intersection, and their widths on line, if only the center is noted. All intermittent water-courses, such as ravines, gulches, arroyos, draws, dry-drains, etc.

7. The land's surface; whether level, rolling, broken, hilly or mountainous.

8. The soil; whether rocky, stony, gravelly, sandy, loam, clay, etc., and also whether first, second, third or fourth rate.

9. Timber; the several kinds of timber and undergrowth, in the order in which they predominate.

10. Bottom lands to be described as upland or swamp and overflowed, as contradistinguished under the law, noting the extent and approximate position of the latter, and depth of overflow at seasonal periods. The segregation of lands fit for cultivation without artificial drainage, from the swamp and overflowed lands, where the latter are subject to selection by the States, is always accomplished by legal subdivision, and any smallest legal subdivision is classified as all upland or all swamp and overflowed land accordingly as more than half of the same may be of the character of the one or of the other class of lands; bottom lands will be classified with special consideration to these matters.

11. Springs of water, whether fresh, saline, or mineral, with the course of the stream flowing therefrom. The location of all streams, springs, or water-holes, which because of their environment may be deemed to be of value in connection with the utilization of public grazing lands, and which may be designated as public watering places, will be specially noted.

12. Lakes and ponds, describing their banks, tributaries and outlet, and whether the water is pure or stagnant, deep or shallow.

13. Improvements; towns and villages; post offices; Indian occupancy; houses or cabins, fields, or other improvements, with owner's name; mineral claims; mill-sites; United States mineral monuments, and all other official monuments not belonging to the system of rectangular surveys; will be located by bearing and distance or by intersecting bearings from given points.

14. Coal banks or beds, all ore bodies, with particular description of the same as to quality and extent; all mining surface improve-

ments and underground workings; and salt licks. All reliable information that can be obtained respecting these objects, whether they be on the line or not, will appear in the general description.

15. Roads and trails, with their directions, whence and whither.

16. Rapids, cataracts, cascades, or falls of water, in their approximate position and estimated height of their fall in feet.

17. Stone quarries and ledges of rocks, with the kind of stone they afford.

18. Natural curiosities, petrifactions, fossils, organic remains, etc.; also all archaeological remains, such as cliff dwellings, mounds, fortifications, or objects of like nature.

19. The general average of the magnetic declination in the township, with maximum known range of local attraction and other variations, will be stated in the general description, and the general average for the township, subject to local attraction, will be shown upon the plat.

20. *General description.*—The above information will be summarized by townships in a general description which will be made the concluding part of the field notes of every survey. The general description will be made to embrace many more comprehensive details in regard to the characteristics of the region than is feasible to cover as an intimate part of the technical record of the survey, as follows:—

Land.—A general outline of the drainage and topographical features of the township and approximate range of elevation above sea level.

Soil.—The prevailing and characteristic soil types. (See special reference to soil classification, Chap. VII.)

Timber.—The predominant forest species, age, size, condition, etc.

Evidence of mineral.—All known bodies of mineral, and lands whose formation suggests mineral-bearing characteristics, especially with reference to lands of volcanic or igneous origin, will be listed by appropriate legal subdivision, with brief description of the mineral indications. On the other hand, if the engineer finds no apparent indication of mineral deposits, a report to that effect will be embodied in the general description.

Watering places.—The areas embracing all streams, springs, or water holes as may be of special value as public watering places, in connection with the utilization of public grazing lands, will be listed by appropriate legal subdivision, with brief description of the nature of such water supply.

Settlement.—The extent of the settlement at the time of the survey.

Industry.—The industrial possibilities of the township, especially as to the adaptability of the region to agricultural pursuits, stock raising, lumbering, mining, or other profitable enterprise.

Special.—All exceptional steps in the technical process of the survey, and other special matters required in paragraphs Nos. 1 to 19, inclusive, of the above summary, not otherwise suitably recorded will be reported in the general description.

In addition to the field notes the engineers are required to prepare, as the work progresses, an outline diagram showing the course and length of all established lines with connections, and a topographical sketch embracing all features usually shown upon the completed official township plat. These maps will be made to scale, drawn in pencil only, if desired, and will be kept up with the progress of the field work. The interiors of the sections will be fully completed; the topographical features will be sketched with care while in the view of the engineer, and the position within the section of the various details which are to be shown on the completed plat will be located with an accuracy commensurate with their relative importance. The design of the specimen township plat will be followed closely in the preparation of the outline diagram and topographical sketch plat, except that it will generally be desirable to employ a separate sheet for each of the two purposes. These maps will then form the basis of the official plat, the ultimate purpose of which is a true and complete graphic representation of the public lands surveyed.

[illegible]

level.

Soil.—The prevailing and characteristic soil types. (See special reference to soil classification, Chap. VII.)

Timber.—The predominant forest species, age, size, condition, etc.

Evidence of mineral.—All known bodies of mineral, and lands whose formation suggests mineral-bearing characteristics, especially with reference to lands of volcanic or igneous origin, will be listed by appropriate legal subdivision, with brief description of the mineral indications. On the other hand, if the engineer finds no apparent indication of mineral deposits, a report to that effect will be embodied in the general description.

Watering places.—The areas embracing all streams, springs, or water holes as may be of special value as public watering places, in connection with the utilization of public grazing lands, will be listed by appropriate legal subdivision, with brief description of the nature of each water supply.

CHAPTER IV.

CORNER MONUMENTS.

THE LEGAL SIGNIFICANCE OF A CORNER MONUMENT.

237. It is one of the fundamental principles of the surveying laws that absolute permanency be attached to the public-land surveys when the lines have been officially established. The "survey" embraces certain definite technical procedure, heretofore described, also the marking of certain fixed points, as will be described in this chapter, though the establishment of a survey may not be termed "completed" until the field notes and plat and every detail of the technical operation constituting the survey have been finally accepted by the Commissioner of the General Land Office, all as contemplated by law. The law provides that the original corners established during the process of the survey shall forever remain fixed in position, even to disregarding technical errors in the execution of the survey—where discrepancies may have passed undetected prior to the acceptance of the survey and the opening of the lands to entry—and, as an aid to the matter of permanency, the Congress provides for the purchase of durable material for the corner monuments, also a penalty for the defacing of any marks relating to the locus of the survey. If it were possible to carry out the full intent of the surveying laws in regard to the aforementioned particulars, the most intricate of all technical and legal problems relating to surveys—the questions pertaining to the reestablishment of lost corners—would be avoided.

The courts attach major importance to authentic evidence relating to the original position of an official corner monument, such evidence being given far greater weight than the technical record relating to bearings and lengths of lines, and it is assumed in the first instance that the original corners shall serve every necessary purpose for the identification of the survey delineated upon the official approved plat, and of the lands which have passed into private ownership. The legal significance of the original monuments, as thus briefly outlined, makes it mandatory upon the engineer to exercise constant diligence in the workmanlike construction of lasting corners, and alertness in skillfully connecting the same with natural objects or improvements, to the end that the greatest possible permanency may be secured for the public-land surveys.

238. Accordingly, if an engineer is called upon to alter the condition of a previously established point, the utmost regard should be shown for the evidence of the original location of the monument, and the corner will be carefully reconstructed by such additional means as may be appropriate, without destroying the evidence which served to identify its legal position. A complete record will be kept of the description of the old monument as identified, and all alterations and additions thereto.

239. Regulation monuments are employed to mark permanently the position of the quarter-section, section, township and meander corners, appropriate to the subdivision of the public lands, as described in Chapter III; also at such sixteenth-section corners as the requirements of the written special instructions or the exigencies of the survey of fractional sections may demand; also at all angle points along an irregular boundary line, and at intermediate intervals of 40 and 80 chains along such limiting boundary. A more extended discussion of the subject of "angle points" and other monuments to be established upon irregular boundaries will be found in Chapter VII.

240. The position of every corner monument will be "evidenced" by the best of such accessories as may be available, and where the corner point itself can not be marked in the usual manner an appropriate "witness corner" will be established. A "witness meander corner" will be established upon secure ground wherever the intersection of a surveyed line with the mean high-water elevation of a meanderable body of water falls at a point where the monument would be liable to destruction.

241. The field notes relating to the establishment of a corner monument will be introduced into the technical record of the survey at the logical place in the record where the true position for the corner is indicated as having been attained. The record of the monument itself will embrace a description of:

(*a*) The corner material, including its dimensions, in the order of length and diameter of an iron post; or length, width and breadth of a stone; or the breast height diameter of a tree; (*b*) the depth set in the ground, with mention of additional support if any; (*c*) the significance of its position; (*d*) the markings upon the monument; and (*e*) the nature of the accessories, including character, size, position, and markings.

CORNER MATERIAL.

242. The General Land Office has adopted a model iron post for monumenting the public-land surveys, which will be generally used unless exceptional circumstances warrant a departure from this rule. This practice is deemed so important that the engineer is not authorized to exercise an option in the matter, but he may refer the question to the proper supervising officer, who may grant authority for the use of other suitable material, provided the reasons for departing from the general rule are sufficient, in which case a brief statement of the facts will be given in the field notes, in the form of an explanation as to why the model iron posts were not employed.

The model iron post is made from commercial iron pipe, from 1 to 3 inches in diameter, which is cut into lengths of about 36 inches; one end of the pipe is split for a distance of about 4 or 5 inches, and the two halves are spread (when heated) to form flanges or foot plates, at right angles to the axis of the pipe; a brass cap is securely riveted to the opposite end of the pipe; and finally the pipe is filled with concrete. Unless otherwise provided in the written special instructions, the iron posts will be employed as follows: 3-inch, for standard and closing township corners, corners of one, two or four townships, and as required for mile corners and angle points of special boundary surveys; 2-inch, for standard and closing section corners, and corners of one, two or four sections; and, 1-inch, for quarter-section and meander corners, and as required for miscellaneous angle points, sixteenth-section corners and corners of special tract surveys. All witness corners are to be of the same size as would be used for the true corner.

243. The caps of the iron posts are to be suitably and plainly marked with steel dies at the time when used; the posts will be set in the ground about three-fourths of their length; and earth and stone, if the latter is at hand, will be tamped into the excavation to give the post a solid anchorage.

244. Durable native stone may be substituted for the model iron post, if the procedure has been duly authorized, but no stone will be used which measures less than 20 inches in length, or less than 6 inches in either of its minor dimensions, or less than 1,000 cubic inches in volume. A stone should always be selected with regard to its durability when exposed to the usual weathering influences. Stone will not be used as a corner monument where its position falls among large quantities of loose surface stone or slide rock.

245. A stone will be suitably and legibly marked with a steel chisel or punch with such letters, figures, grooves or notches, as may be required, and will be set firmly in the ground about three-fourths of its length.

246. Both iron post and stone monuments will always be set the usual depth in the ground unless it is impossible to complete the excavation, in which case the monument will be planted as deep as conditions will permit, and the necessary support will be secured by a stone mound.

247. Where the corner point falls upon solid surface rock, preventing excavation, a cross (×) will be cut at the exact corner point, and, if feasible, the monument will be erected in the same position, supported by a large stone mound of broad base, so well constructed that it will possess thorough stability.

248. Where the corner point falls exactly at the position occupied by a sound living tree, which is too large to be removed, the tree will be appropriately marked for the corner.

WITNESS CORNERS.

249. Where the true point for a corner falls within a roadway in such a place as to interfere with travel, a marked (×) stone will be deposited in the ground at the true corner point and a witness corner will be established at some suitable point, preferably on a surveyed line, outside of the roadway.

250. Where the true point for a corner falls upon insecure ground, or in an inaccessible place, such as within an unmeandered stream, lake or pond, or in a marsh, or upon a precipitous slope or cliff, a witness corner will be established at some suitable point, preferably on a surveyed line, where the monument may be permanently constructed.

251. The engineer will be expected to exercise his best judgment in selecting the position for a witness corner, with a view to affording a definite and convenient connection from the witness corner to the true point for the monument, for use in subsequent surveys to recover the legal position of the true corner. Extra effort will be exerted to accomplish the permanent establishment of a monument at its true corner point, wherever this is feasible, in order to avoid as much as possible the confusion to settlers and others caused by witness corners.

252. Only one witness corner will be established in each instance, and the same will be placed upon any one of the surveyed lines leading to a corner, if a suitable place, within a distance of 10 chains, is available, but if there is no secure place to be found on a surveyed line within the stated limiting distance, the witness corner may be located in any direction within a distance of 5 chains. On the other hand, if there is no suitable place within the latter radius, one or more legal subdivisions will be eliminated from the survey as provided in Chapter VII.

253. All of the lines of a survey will be completed in the regular manner, if the true point for a corner is accessible, but where the true point can not be attained, a line connecting therewith may be returned as surveyed if the same has been completed by the projection and measurement of a suitable offset or traverse, resulting in a closed figure which approaches the true point for a monument within the limit prescribed for the establishment of witness corners.

254. The field notes will show every detail of the relation of a witness corner to the true point for a monument, and the direct connecting course and distance will be shown upon the plat of the survey.

MARKING CORNERS.

255. All classes of corner monuments are to be marked in accordance with a system hereinafter described which has been devised to furnish a ready identification of the character and position of the monument which bears the marks. Capital letters and Arabic figures are employed to mark iron post and tree corners, while upon stone corners certain additional marks termed "notches" and "grooves" are employed to convey the same information, but to lessen the labor incident to the marking process. The letters and figures upon a monument are designed to relate to the township, range and section to which the corner belongs; the notches and grooves upon a stone monument relate—in the case of an exterior corner—to the normal number of miles from the monument to the adjoining township corners, and—in the case of a subdivisional corner—to the normal number of miles from the monument to the township boundary lines, as hereinafter described, thus furnishing the means of ascertaining the appropriate section numbers.

256. All markings should be accomplished neatly, distinctly and durably; and the marks are to be carefully arranged. An assortment of steel dies, chisels, punches and timber scribes, in perfect condition for use, should always be at hand.

257. A witness corner and its accessories will be constructed and marked similarly to a regular corner for which it stands, with the additional letters "W C" to signify "witness corner."

258. The following schedule is an index of the ordinary markings common to all classes of corners and accessories:—

Marks.	To indicate.	Marks.	To indicate.
A M C	Auxiliary meander corner.	R	Range.
		S	Section.
A P	Angle point.	S	South.
B O	Bearing object.	S C	Standard corner.
B T	Bearing tree.	SE	Southeast.
C	Center.	S M C	Special meander corner.
C C	Closing corner.	SW	Southwest.
E	East.	T	Township.
M	Mile.	TR	Tract.
M C	Meander corner.	W	West.
N	North.	W C	Witness corner.
NE	Northeast.	W P	Witness point.
NW	Northwest.	$\frac{1}{4}$	Quarter section.
P L	Public land (unsurveyed).	$\frac{1}{16}$	Sixteenth section.

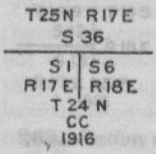
MARKS ON IRON POST MONUMENTS.

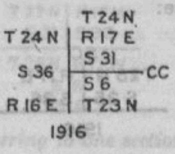
259. The markings upon the brass cap of an iron post should always be made to read from the south side of the monument, and all iron posts will be marked with the year number at the date when established.

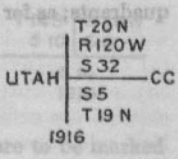
260. *Standard township corners* are to be marked "S C" and the township on the north half, and the ranges and sections in the proper quadrants; as for example:

SC
T 25 N
R 17 E | R 18 E
S 36 | S 31
1916

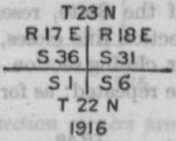
261. *Closing township corners* are to be marked "C C" on the half from which the closing line approaches the monument, with the township (or range) on the same half, and the ranges (or townships) and sections in the proper quadrants; also (as far as known at the time) the township, range and section, or the initials or abbreviation of the State, reservation, grant or private claim, upon which the township exterior closes; as for example:



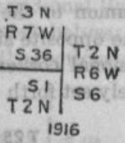


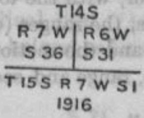


262. *Corners common to four townships* are to be marked with the townships on the north and south halves, the ranges on the east and west halves, and the sections in the four quadrants; as for example:

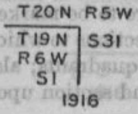


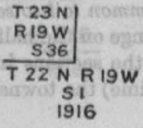
263. *Corners common to two townships only* are to be marked with the township (or range) common to both on the proper half, and the ranges (or townships) and sections in the proper quadrants; also (as far as known at the time) the township, range and section upon the opposite half; as for example:

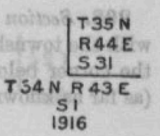




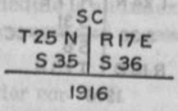
264. *Corners referring to one township only* are to be marked with the township, range and section in the particular quadrant which is concerned; also (as far as known at the time) the township, range and section upon the opposite part; as for example:



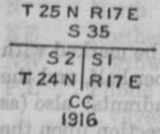


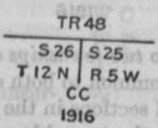


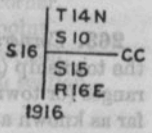
265. *Standard section corners* are to be marked "S C" and the township and range on the north half, and the sections in the proper quadrants; as for example:



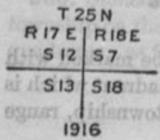
266. *Closing section corners* are to be marked "C C" and the township and range on the half from which the closing line approaches the monument, and the sections in the proper quadrants; also (as far as known at the time) the township, range and section, or the initials or abbreviation of the State, reservation, grant or private claim, upon which the section line closes, with the exception that in the case of an interior closing section corner, the township and range numbers will not be repeated; as for example:

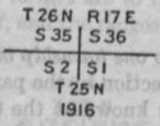


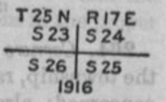




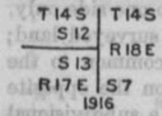
267. *Corners common to four sections* are to be marked: (*a*) On an exterior, with the township (or range) common to the adjoining townships, the ranges (or townships) upon the opposite sides of the exterior, and the sections; and (*b*) a subdivisional corner, with the township, range and sections; all appropriately set forth as follows:

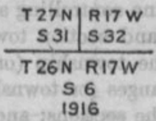


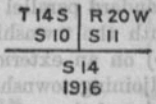




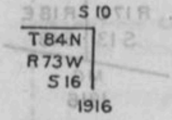
268. *Section corners common to two sections only* are to be marked with the township and range on the half facing the sections to which the corner belongs, and the sections in the proper quadrants; also (as far as known at the time) the township, range and section upon the opposite half, except that in the case of an interior corner, the township and range numbers will not be repeated; as for example:

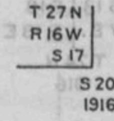


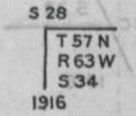




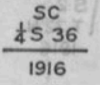
269. *Section corners referring to one section only* are to be marked with the township, range and section in the particular quadrant which is concerned; also (if known at the time) the section upon the opposite part; as for example:



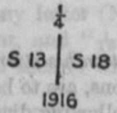


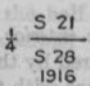


270. *Standard quarter-section corners* are to be marked "S C ¼" and the section, all on the north half; as for example:



271. *Quarter-section corners of maximum control* are to be marked (*a*) on a meridional line, "¼" on the north, and the sections on the east and west halves; and, (*b*) on a latitudinal line, "¼" on the west, and the sections on the north and south halves; as for example:





272. *Quarter-section corners of minimum control* are to be marked "¼" and the section, all on the half toward the particular section which is concerned; as for example: