of gradients; and then the contour lines, and the orthogonals also if required, are laid down.

VI. Geographical Reconnaissance.

When a traveller passes through an unknown or little known region the opportunity afforded him of acquiring some new geographical knowledge depends largely on the configuration and aspects of the ground, the condition of the atmosphere, the attitude of the inhabitants, and the time available. If hills are numerous and prominent and free from forest, and other conditions are favourable, a large area may be covered in a short time by reconnaissance from the stations of a chain of triangles carried along the line of route, fixing points in advance, some of which become stations of observation whence further points are fixed; and thus the continuity of the operations is maintained. But the ground may be flat and devoid of prominent points, the view circumscribed by forests and other obstacles, the atmosphere dense and unfavourable for distant vision, the inhabitants hostile, and the time short, and the traveller may be restricted to his line of route and unable to deviate from it; he must then endeavour to maintain a continuous traverse of the route, sketching in the ground in its immediate vicinity. Whenever breaks of continuity occur he must resort to astronomical observations to effect a connexion between the dissociated sections of his survey and to obtain an independent check on the general accuracy of the operations. He has therefore to be prepared to measure base-lines, to carry on a triangulation in some regions and a traverse in others, and to make any astronomical observations which may be wanted, and, if possible, to complete his mapping on the ground instead of postponing it to be done elsewhere. He should supply himself with some instruments suited for rough and rapid work and with others for better work when time and opportunity permit, and he should be careful to arrange beforehand the general character of the proposed operations and the scales and projections to be adopted for the mapping; he should also provide himself with blank sheets of paper duly graticulated to scale, for work in detail in the vicinity of the line of route and for general geography. For measures of base-lines and distances on the ground, chains, rolls of crinoline wire, long Assam canes, and perambulators may be employed, also omnimeters and subtense theodolites, to measure the angle subtended by a pole of known length, whence the distance may be deduced. For measures of angles and bearings, either theodolites,[1] or sextants, or prismatic compasses may be used, according as more or less accuracy is required. For the general survey the plane table is a most valuable instrument: it enables bearings to be at once laid down on the paper without previous measurement, and much detail to be sketched in on the spot, instead of being plotted subsequently from a field-book; then the only independent angular measurements which need be taken are those of the principal triangles and of very distant points beyond the range of the table. Rough and rapid route surveys may be made by pacing the distances, taking the magnetic bearings, and combining with the results of astronomical observation. Many thousand miles of itinerary through regions in Central Asia have been surveyed by Asiatic employés of the Indian Government in this way; the northings and southings were controlled by latitude observations, and the factors thus obtained were applied to the eastings and westings, longitudes being impracticable. The theodolite should be employed to fix points on very distant ranges, for it will give good results, even with short bases and very acute angles, provided the objects actually observed are well identified in each instance. Observations should be taken from three stations, giving two triangles with a common side, which will at once show up any mistake, whether of identity, circle reading, or calculation. Whenever a break of continuity occurs in the triangulation or the traversing, astronomical observations must be resorted to. Much may be done by a judicious introduction of latitudes and azimuths, more particularly where there is considerable northing and southing, for then differences of longitude may be obtained from the azimuths and differences of latitude. A prominent peak, visible from great distances all round, may be made to serve as a connecting link between regions which cannot be continuously connected, by measuring its azimuth and distance from a base-line in each region; the addition of latitudes at the azimuth stations will much strengthen the work.

Collateral Astronomical Determinations.—Determinations of azimuth, latitude, time, and longitude may all be required for geographical reconnaissance,—the first two more particularly, as they can be obtained readily with much accuracy; the fourth, being much the most troublesome to get and the least reliable when got, is only resorted to when it cannot be dispensed with.

The azimuth of an object may be determined without calculation by observing the angles between the object and a star at equal altitudes on opposite sides of the meridian; but it is generally found by observing the angle in one position of the star and applying thereto the azimuth of the star as obtained by calculation. In the spherical triangle PZS, in which P represents the pole, Z the zenith, and S the star, the angle PZS is the star's azimuth, which can be computed when any three parts of the triangle are given. PS, the polar distance of the star, is given by the tables, and PZ, the co-latitude, must be previously determined; then, for the third part, we may have either (1) PSZ, a right angle, by observing a circumpolar star at its maximum elongation, or (2) the hour angle P for any star, by taking the time of the observation, or (3) the zenith distance ZS, by measurement simultaneously with the horizontal angle. Of these three methods the first is the most accurate, but it is not always convenient; the second requires, in addition, special observations for time; the third is generally the most convenient, for it may be performed between sunset and dark, when the stars are coming into view, but when there is still sufficient light to illuminate the wires of the telescope and the referring mark, and thus enable lamps to be dispensed with.

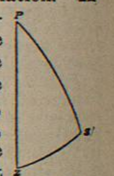

Fig. 7.

The latitude is most readily determined by measures of stars' zenith distances on the meridian, duly corrected for refraction; then, the polar distance being known, the latitude is at once ascertained. The stars should be observed in pairs of nearly equal zenith distance, north and south, for this eliminates all constant instrumental errors, as of index, excentricity, and graduation, and also errors in the adopted refractions. When a single star is employed, circum-meridian observations of zenith distance may be taken and reduced to the meridian by calculation; tables for the pole star are given in the *Nautical Almanac*, which enable an observation, taken at any known time in the 24 hours, to be reduced to the pole.

[1] In many respects a theodolite is more suitable than a sextant: (1) it measures horizontal angles directly, whereas the sextant measures oblique angles, which have to be reduced to the horizon; (2) it measures a round of several angles with much greater facility; (3) it measures all vertical angles with equal facility, including the small elevations and depressions of distant peaks which cannot be readily seen by reflexion from mercury for measurement with a sextant; (4) its telescopic power is usually far higher; (5) it may be so manipulated as to eliminate the effects, without ascertaining the magnitudes, of the constant instrumental errors,—excentricity, index, and collimation; and (6) when much accuracy is required the influence of graduation errors may be greatly reduced by systematic changes of the settings of the horizontal circle.

The time is usually best determined by measuring the zenith distances of stars situated not far from the prime vertical; then, the latitude and polar distance being known, the hour angle P of the spherical triangle is found by calculation. Time may also be determined by observing the transits of stars over the wires of the telescope of a theodolite set up in the meridian.

The longitude may be determined either absolutely, by purely astronomical methods, as by observations of the moon's motion, or differentially, with the aid of telegraph lines and travelling chronometers. Absolute longitude is the geographer's great difficulty; for much time must be devoted to the observations, and much more to their reduction, when undertaken with the object of fixing the relative positions of the stations of a survey. The observations are of various kinds,—(1) lunar distances, *i.e.*, the distance between the moon and the sun or one of the stars given for this purpose in the *Nautical Almanac*; (2) lunar zenith distances, observed at points of the moon's path where the conditions are favourable; (3) lunar transits over the meridian, observed with transits of the moon-culminating stars given in the *Nautical Almanac*; (4) lunar occultations of stars; (5) eclipses of the sun and moon; (6) eclipses of Jupiter's satellites. The first method requires the employment of a sextant or other reflecting instrument; the second may be accomplished with either a reflecting instrument or a theodolite; the third with a theodolite; for the last three a good astronomical telescope is wanted. The first, when carried out strictly, requires three observers,—one to measure the lunar distance, while the others are measuring the zenith distances of the moon and the star; but, as the last two are not wanted with great accuracy, the several observations may be taken in succession by one person, and the observed zenith distances afterwards adjusted to the time of the lunar distance.

The effects of errors of observation in these methods are as follows. In (1) an error in time produces the same error in the longitude, and an error of one second of arc in the distance produces two seconds in time in the longitude. In (2) an error of one second in time produces at least thirty seconds of time error in the longitude, and one second of arc in the zenith distance at least two seconds of time in the longitude. In (3) to (6) an error of time produces the same error in the longitude. The first method is preferred by seamen and travellers, who are more expert in the use of the sextant than of the theodolite. The second method is preferred by those who are more familiar with the theodolite, and who are equipped with one of good telescopic power. It gives very good results when the observations are made at the most favourable time, which occurs when the resultant of the moon's motion in right ascension and in declination lies in the direction of the observer's zenith; this time may be readily found by graphical projection on a chart of the heavens.

Differential longitude.

Differential longitude may be determined chronometrically, on land as at sea, by carrying about several well-rated chronometers and comparing their times with the local times deduced from observations of the sun and stars; or electro-telegraphically, by interchanging signals between two stations connected by a telegraph wire, and ascertaining the local times at which the signals are transmitted from and received at each station.

Hypsometry.—Determinations of height form a very necessary part of geographical reconnaissance. Whenever triangulation is possible, vertical angles may be measured and the heights ascertained in regular succession. But in a traverse this is scarcely practicable; breaks of continuity in the verticals are liable to be of frequent occurrence, and then recourse must be had to observations of the pressure and temperature of the atmosphere, or of the temperature of the vapour of boiling water, from either of which fairly correct heights may be deduced differentially under normal atmospheric conditions in settled weather. The instruments employed for this purpose are mercurial and aneroid barometers and boiling-point thermometers; descriptions of them, and the formulæ employed in reducing the observations, are given under Barometer (vol. iii. pp. 381-387). Here it is only necessary to add that the date and hour of every barometric observation should be recorded, and the observations referred for reduction to those taken at the same time at one or more of the nearest standard meteorological observatories; otherwise corrections should be given to the barometer readings for the hour of the day and the month of the year, in order to reduce them as nearly as may be to the local mean altitude of the mercury. The index errors of aneroid barometers, being liable to variations, should be determined from time to time by observations at stations of known altitude, or by comparisons with boiling-point thermometers.

VII. Nautical Surveying.

Nautical surveying.

Nautical surveying has for its object the determination of the configuration of land which is covered and concealed from view by water, more particularly along the foreshore of a coast-line, and wherever navigation is carried on in comparatively shallow waters and a knowledge of the depth of water is of great importance; it has likewise to lay down the positions of oceanic islands, shoals, and rocks, and generally to delineate whatever land exists immediately above or below the surface of the ocean. Its methods differ according as they are performed in or out of sight of land. When in the vicinity of land it is preceded by a survey of the coast-line and a belt of the country beyond, which must be of sufficient breadth to furnish suitable points of reference for the survey operations on the water, and may have to be extended inland to embrace those peaks of distant hill ranges which are prominent objects at sea for the guidance of mariners. This done, the nautical survey is carried on in boats, by taking soundings and determining the positions of the boats by observations to some of the points already fixed on land. The observations are necessarily made with sextants and magnetic compasses only. With the former the angles between conspicuous land-marks are measured, and, as the angle between any two points is half the magnitude of the angle between the same points at the centre of the circle which passes through them and through the boat, the measurement of two angles between three points enables two circles to be drawn on the chart, the intersection of which will generally indicate the position of the boat with sufficient accuracy. Occasionally, however, it happens that the positions of all three points on shore and the boat also lie actually, or very nearly, on the circumference of one and the same circle; then a bearing taken with the compass will fix the position of the boat on the circumference of the circle. Time is noted whenever soundings are taken, that due allowance may be made for the rise and fall of the tide. All the sounding stations are not fixed by observations to points on shore, as just indicated, but only a certain proportion, and between them straight lines of sounding are run, with intervals measured either by a patent log, or by time, or by counting the strokes of the oars; whenever possible the lines of sounding are carried parallel to each other. Sounding is the most important part of a nautical surveyor's duty and that on which his character mainly depends. It is essentially the work of the sailor, for in carrying it out the accidents of wind and water—the direction and force of the wind, the rise and fall of the tide, and the velocity of currents—must be duly taken cognizance of and the work managed to suit wind and weather; on the other hand, the work on land may be done by landsmen. Nautical surveying, out of sight of land, rests on astronomical determinations of latitude and time, chronometric longitudes, and dead reckoning by log.

When triangulation is resorted to, base-lines are measured sometimes with a patent log, sometimes by sound, by noting the interval in time between the flash and the report of a gun. The great length of modern ironclads presents a base-line which is occasionally very convenient: points are taken at each end of the ship, as far apart as possible, from which two observers can see each other; they are carefully marked, and the distances between them determined for future reference; then angles between moderately distant objects and observers standing at these points, taken simultaneously from each point, enable the required distances to be obtained. The magnetic variation is determined by observing the azimuth of the sun, when on or near the horizon, with a standard compass fixed amidship, care being taken beforehand to determine any deviation of the needle which may be due to the attraction of the surrounding ironwork, by observing the bearing of a distant mark as the ship is swung round and her head laid on different points of the compass. See also NAVIGATION (Practical), vol. xvii. p. 264.

VIII. Mapping.

Graticulation.—The sheets of paper on which the details of the survey of any large area of country are to be laid down must be furnished with a system of conventional lines, drawn with a view to assimilate the margins of contiguous sheets and to form a graticulation within which the details may be accurately inserted. The graticule is sometimes rectangular, sometimes spherical, sometimes a combination of both, as when points of which the latitude and longitude coordinates are given have to be plotted within rectangular marginal lines. Spherical graticules are constructed in various ways, usually in accordance with some specific method of projection; see GEOGRAPHY (Mathematical), vol. x. p. 197. The following convenient method is not referable to any demonstrated projection, but is generally employed on the Indian Survey. Suppose the intersection of two meridians by two parallels to form a small spherical quadrilateral, with sides of aliquot parts of a degree in latitude and in longitude; let m be the length of each of the meridional arcs, p, p' the lengths of the arcs on the upper and lower parallels, and let q be a diameter, then

$$q=\sqrt{m^2+p.p'};$$

thus, m, p, and p' being given, q is calculated. With these data, which are tabulated for different arcs and scales, the corner points of a number of quadrilaterals are laid off in succession on either side of an adopted meridian, and lines are drawn through the points to indicate the collateral meridians and the parallels of latitude. The latter are always curved, more or less sensibly; the former are also curved, though in a much less degree, being concave to their initial meridian, and the more so the farther they are from it. When the area is small and the scale large, the meridians are practically straight lines, and the several sheets of a map, each projected on its own meridian, will fit together closely when carried on in any direction. But, when the area is large—exceeding 8 or 10 square degrees—and the scale small, the sheets will not fit together continuously unless they are projected with reference to a single meridian for the whole map, to which the meridians on either side will be increasingly concave, or unless all the meridians are made straight lines, by slightly contracting each of the intermediate arcs of parallel to a length which is exactly proportioned to the lengths and relative distances of the upper and lower parallels of the map from it. There must be some distortion in either case: in the first, meridians which are actually straight lines are represented as being curved; in the second, straight meridians are obtained, but the distances between them are exact only on the upper and lower parallels, and are too small elsewhere, more particularly on the middle parallel, the length of which necessarily exceeds the mean length of the upper and lower parallels.[1] But distortion is inevitable whenever a spherical surface is projected on a plane.

When a map is constructed in rectangular sheets, some station is adopted as the origin and its meridian as the principal axis, to which the corner points of the sheets are to be referred; the coordinates of these points are given such dimensions as are most suitable for the size and scale of the map, and are equivalent to the rectangular spherical coordinates of imaginary points on the curved surface of the earth, at corresponding distances from the origin and its meridian. These being given, the distances of the points from the origin in latitude and longitude may be computed, as already shown (p. 706); thus data become available for projecting the graticulation of meridians and parallels within the rectangular marginal lines of each sheet, or for introducing the divisions of latitude and longitude on the marginal lines if preferred. Conversely, when the latitudes and longitudes are given, the rectangular spherical coordinates are computed and the marginal lines projected around the graticulation. Filling in is then commenced: the principal stations are laid down by their coordinates and the topographical details pencilled around them by copying or tracing the field sheets of the survey; the names and the outlines are then inked in; the shading for delineating the features and general configuration of the ground is usually done last of all. The manner in which the details are inked in and rendered permanent depends on whether the map is to be reproduced by hand only—as when it is to be engraved or lithographed—or whether in its reproduction photography is to be employed and the action of light invoked, either in entire supersession of or in partial co-operation with the labour of the draftsman. In the former case the map is made as perfect a pictorial representation of the surface of the ground as possible, the hill features being represented artistically in mezzotint shading with a brush or a chalk drawing, and a variety of colours used to facilitate discrimination of differences of topographical detail. In the latter no colours are used which will not photograph well, nor flat shades of any colour, nor—as a rule—mezzotint shading, but only some substitute therefor in pen and ink. This last condition is essential for the commonly employed processes of photo-zincography and photo-lithography; but endeavours have recently been made, with some degree of success, to reproduce mapping in middle tones by the processes of photo-collotype and photo-gravure.

Photography in mapping.

Photography is much employed as an auxiliary in mapping; for when a map is to be published on various scales the hand-drawn details of the largest scale edition may be reduced by its means as accurately as by the familiar pantagraph, and of course very much more rapidly. Thus in the Ordnance Survey town maps on the scale of $\frac{1}{500}$ are reduced to the scale of $\frac{1}{2500}$ for incorporation into the parish maps; the latter are reduced for insertion in the 6-inch maps, and they in turn for the 1-inch map. By limiting the dimensions of each sheet for reduction to 3 feet by 2, and by a judicious use of stops to lenses, the reductions are made without any error in scale or any distortion that can be detected by the most rigid examination. But photography reduces every part of the original alike, the printing of words and names as well as the topographical details, and it reproduces all the minor and less import-

[1] In Mr O'Farrell's pamphlet *On the Construction and Use of the Six Sheets of Marginal Lines for Maps of every part of the World*, published by the Ordnance Survey, tables are given of the lengths of meridional and longitudinal arcs, their versines and diagonals, for every ten minutes in latitude from the equator to 80° N. and 80° S.

ant as well as the more important features; hence a reduction is rarely suited for reproduction without intermediate modification, the printing being generally too small to be easily legible, and the mass of minor detail tending to confuse the principal sub-lines. The draftsman is therefore called in and the procedure so arranged as to obtain the best results with the least labour. Either he may construct a new map by tracing from a silver print of the photograph whatever topographical details are required for it and omitting the rest, or he may ink in such details at once with black ink on a blue print taken from a transfer of the photograph to stone or zinc, in both cases adding names and writing of appropriate sizes; either result may be reproduced by photography, as the unblackened details of the blue print will disappear in the process. This done, a transfer to stone or zinc may be made from the second photograph for the printing off. Prints from photographic reproductions to full scale exhibit all the blemishes of the hand drawing and somewhat exaggerate them, whereas prints from photo-reductions are freer from blemish, and often as clear and sharp as good hand lithographs. In employing a process of double photography, therefore, the first photo is usually made on a larger scale than that for publication; the lines of the printing and topographical detail are correspondingly exaggerated by the draftsman; and then the second photo is a reduction, which should be sharp, clear, and free from blemish.

IX. Map Printing.

Various processes are employed for the reproduction of maps in large numbers for general issue; some are purely manual, the map being redrawn by hand on copper, stone, or other substance presenting a suitable surface from which prints may be taken, or on paper specially prepared for transfer to such substance; others are carried out with the aid of photography, whereby an exact copy of the original can be obtained either directly upon, or for subsequent transfer to, the surface to be printed from. The former include the processes of copper-plate engraving and lithography, which are the oldest, and still in some respects the best of all, but slow and expensive; the latter include the processes of photo-lithography, photo-zincography, photo-gravure, and photo-collotype. Engraving on stone is much employed on the Continent for map work, being cheaper and quicker than engraving on copper. Electro-metallurgic processes are frequently employed in connexion with copper-plate engraving, either to protect and harden the surface of the plate with a facing of steel or to furnish duplicates to be printed from, instead of the plate itself being used; sometimes the wear of the plate is prevented by transferring a print from it to a lithographic stone or a zinc plate, from which the printing is done in its stead. By the anastatic process an old print of a map may be transferred to a zinc plate to be printed from.

Engraving.

Engraving may be performed on copper, wood, zinc, or stone; see vol. viii. p. 435. As done on copper plate for mapping, it is a combination of ploughing with the burin and etching with an acid, the former being used for the names and topographical outlines, the latter for the features of the ground. The system adopted in the Ordnance Survey of Great Britain—where it has been largely employed and carried to great perfection—is as follows. The 6-inch maps of the survey are engraved on copper plates measuring 36 by 24 inches within the marginal lines and weighing about 35 ℔; the 1-inch maps are 18 by 12 for England and 24 by 18 for Scotland. The corners of the maps, the prescribed marginal subdivisions, and the trigonometrical points are first marked on the plate by a scoring machine, in which it is laid, and which is provided with a travelling carriage holding a steel pricker. The carriage is moved along a graduated scale and the pricker along another scale at right angles to the former, and all points of which the rectangular coordinates are known are laid off by vernier-read measurements from the two scales. The plate is then removed from the scoring machine, heated, and given a thin coating of white wax, to form a surface on which the topographical details are plotted before the graving is commenced. This surface is divided into a number of rectangles by fine lines joining marginal subdivisions, the distances between which are usually so regulated as to introduce sixteen of the survey sheets on the $\frac{1}{2500}$ scale into one sheet on the 6-inch scale. The reductions to this scale are made by photography, and the subsequent reductions to the 1-inch scale either by the pantagraph or by photography. Tracings of the reductions in lamp-black, made to fit into the rectangles, are transferred to the wax ground by rubbing with a steel burnisher. The plate is then ready to be placed in the hands of the engravers, who complete first the outlines, then the printing and writing, and afterwards the ornament, each class of work being usually done by a different person. The figures of latitudes, longitudes, and altitudes, and various conventional symbols, are stamped with steel punches. Parks and sands are ruled with a dotting wheel, and buildings shaded in lines with a ruling machine. When a plate of the 1-inch map is being engraved, all the printing is completed, and line-engraving with the exception of the contour lines, and then an electrotype duplicate of the plate is taken. The contour-lines are engraved on the duplicate, and the hills are etched on the original plate; thus two editions of the map are obtained, one with contours but without hills, the other with hills but without contours, the topographical details and writing being the same in both. In etching, the surface of the plate is thinly coated with an acid-resisting substance composed of asphalt, Burgundy pitch, and virgin wax, forming an etching ground, on which the outlines of the hill features are traced, and then marked through with a needle which removes the ground where it passes, exposing the surface of the copper. Aquafortis is applied to bite in the finer lines and then poured off; the parts which are bitten sufficiently are painted over with "stopping varnish"; and acid is again applied. The processes of stopping out and biting in are alternately repeated until all the required tints from the lightest to the darkest are produced. In printing from a copper plate, a much more powerful press has to be used than in printing from stone or zinc, as the ink lies in the furrows that have been ploughed or bitten into the plate and not on its surface; the process of printing is also much slower. In engraving on stone or zinc, the surface is coated with a preparation of gum and lamp-black, and on it the detail is traced with red chalk and afterwards cut in with very fine steel or diamond points so as just to lay bare the surface of the ground without penetrating to any depth, as in copper-plate engraving. A little oil having been rubbed over the surface, the gummy composition is washed away and printing-ink applied; the printing is performed almost exactly in the same way as in ordinary lithography, except that the printing-ink is in the first instance spread over the stone or the zinc plate with a dabber instead of a roller.

Electrotyping.

Electrotyping is employed to conserve work engraved on copper, either by depositing a thin surface of steel over an engraved plate, which enables it to be printed from very much oftener without injury, or by producing a duplicate to be employed in its stead in the printing. In the latter case, a double process is gone through: first, a cast or matrix is produced in relief by the deposition of copper on the surface of the original plate, and then an intaglio of the matrix—which is therefore a duplicate of the original—is formed by depositing copper on the surface of the matrix. For details of these processes, see ELECTRO-METALLURGY, vol. viii. p. 114. In the Ordnance Survey electrotyping was first employed to obtain duplicates on which to make the corrections and additions necessary to show the growth of railroads and towns since the time of the original survey. The alterations are effected more easily when obsolete details are scraped off the electrotype matrix than when they are scooped out of an intaglio; the original plate is also preserved intact.[1] Electrotyping is further serviceable in producing the two editions of the general map, one with contour lines, the other with hill-shading, already mentioned, as well as editions for geological and other details. It is also serviceable in effecting a combination of portions of several plates: matrices of the different portions are riveted together to form a single plate; then an intaglio of this plate is taken, on which any details lost at the junction of the matrices are made good by hand. The dimensions of a full-sized plate are $38\frac{1}{2}$ by $26\frac{1}{2}$ inches; the weight of a matrix is 18 ℔, and of the duplicate 38 ℔.

Lithography.

There are two essentially distinct processes of lithography,—one in which the map is wholly drawn by hand on the stone, the other, a much quicker but coarser process, in which it is traced with greasy ink on specially prepared paper, which is then laid face downwards on the stone. When lithographs are to be produced by a single printing, all hill features, as well as topographical outlines and names, are drawn with a pen or fine camel-hair brush in ink of one colour. Double printing is necessary when the hills are drawn in chalk, two stones being required, one for the chalk work, the other for the pen-and-ink work; and in chromo-lithography a separate stone is required for the work in each colour. For full details, see LITHOGRAPHY, vol. xiv. p. 699.

Zincography has of late years largely taken the place of lithography for printing from hand-drawn transfers, though not for hand-drawing on the surface of the zinc, as on stone and copper. Zinc plates are less costly and bulky than lithographic stones, and are much more conveniently handled: thus a plate measuring about 43 by $28\frac{1}{2}$ inches and $\frac{3}{16}$ of an inch thick weighs 60 ℔, is easily carried by one man, and costs 16 shillings; a lithographic stone of the same surface is $4\frac{1}{2}$ inches thick, weighs 450 ℔, requires four men

[1] In the French and Austrian surveys corrections are made on fresh copper deposited by electricity over the faulty parts, which are scooped out.

to lift it, and costs about £7. Prints from transfers to a zinc plate are as satisfactory as prints from transfers to stone, and there is no liability of the plate being fractured in the press, which not unfrequently happens to the stone. The surface of the plate is prepared by scraping it evenly all over with a razor blade in parallel lines, until all irregularities are removed; the plate is then bent so as to present a slightly convex surface, which is ground with pumice-stone and water, and smoothed with a piece of steatite, and then given a grained surface with sand. It is flattened by being passed through a press, after which it is ready to receive the transfer. The subsequent procedure depends, as in lithography, on the circumstance that greasy substances do not mix with water and are repelled by gummy substances. The greasy ink lines of the transfer are readily absorbed by the surface of the plate; then a preparation of gum and decoction of gall nuts (to which a little phosphoric acid is added), applied to the entire surface of the plate, serves to etch the blank ground without affecting the lines of the transfer; but it prevents the ink from spreading, and also fills up the pores of the blank parts of the plate with a gummy substance, which repels a greasy ink. Printing ink, therefore, applied as usual with a roller to the entire surface of the plate adheres to the inked lines only and can be readily washed off the blank spaces, and then a print taken will show the inked lines only. The tracing for transfer is drawn on paper thinly coated with starch to prevent the graphic writing-ink from soaking into it; the ink is a mixture of Paris black, Castile soap, white wax tallow or sweet oil, and shellac, which being greasy is readily absorbed by the zinc. The tracing is laid face downwards on the plate and passed several times under the pressure of the roller of the printing press. It is then wetted and peeled off, the ink remaining on the zinc. The surface of the plate is again washed with the etching liquid, which removes stains from the blank spaces and renders them more susceptible of being equably wetted with water, and also—after a few drops of turpentine have been added—removes the unabsorbed writing-ink and helps to fix the lines. The plate is then ready to be printed from. The printing-ink is composed of lamp-black—with a little Prussian blue added—and linseed oil varnish of a thickness depending on the temperature and the subject. Small corrections on the plate can be made by removing the surface with a strong solution of hydrate of potash, and then preparing a new surface to be drawn on by applying dilute nitric acid and afterwards washing off the nitrate of zinc.

Anastatic printing.

Anastatic printing produces facsimiles of any inked print by transfer to a zinc plate, the inked lines on it being absorbed in a greater or less degree by the plate. The print is laid face downwards on blotting-paper, and brushed with a solution of nitric acid diluted with five times its bulk of water until thoroughly and evenly saturated; it is then placed face downwards on a zinc plate with a well-grained surface, and passed under the roller of a powerful copper-plate printing press. The grease of the ink, being set free by the acid, adheres to the surface of the plate; but, as the amount of ink absorbed is much less than in the case of an ordinary transfer, it is strengthened by working up with lithographic ink, oil, and gum water until the surface is sufficiently strong to bear etching with the usual preparation of gum, nut galls, and phosphoric acid. The plate is now ready to be printed from in the usual manner. If the original print is an old one, it must first have its ink softened by immersion in hot water containing half an ounce of caustic strontia for every pint of water, the time of immersion varying, with the condition of the print, from a few minutes to an hour. A print well worked up is often superior to the original.

Photography.

Photography having already been described in detail (see vol. xviii. p. 821), its application to mapping and map-printing need only be noticed here. The action of light can be employed either by placing the map in contact with a sheet of sensitized paper and against a glass plate in a printing frame, when the light will pass through the map and produce a picture of it on the paper, or by using a camera furnished with an object-glass, through which rays of light from the map are transmitted so as to produce a picture on a sensitized glass plate, which can afterwards be printed from. The best known of the processes in which the camera is not used is the "cyanotype"; the paper is sensitized with a mixture containing nearly equal proportions of solutions of ammonio-citrate of iron and the ferrid-cyanide of potassium; the prints give white lines on a dark-blue ground, and are very inexpensive. There are other processes of printing with the salts of iron, uranium, &c., which give an exact transcript of the original drawing with dark lines on a white ground. But they are only suitable for maps drawn in pen and ink not larger than the glass plate of the printing frame; being therefore only serviceable in special cases when few copies are wanted, they are little employed and may be regarded more as curiosities than as ordinary methods of map-printing. Photography is generally effected with the aid of a camera, and employed to obtain a negative of a map on glass, from which prints may be taken either for use *per se* or for transfer to a flat surface of zinc, stone, or other suitable material to print from. The map is usually attached to a board suspended vertically in an adjustable frame, while the camera is placed on an adjustable stand set at right angles to the map frame on a tramway, along which it can be moved to any desired distance from the map. The camera is furnished with a ground-glass focusing screen, on which is pencilled a rectangle whose dimensions are proportional to those of a corresponding rectangle on the map, in the ratio of the scale of the required photograph to that of the map. The map and the focusing screen are brought into parallelism at such a distance that the image of the rectangle on the map exactly coincides with the rectangle on the focusing screen. A sensitized collodion plate is then substituted for the screen and a negative taken, which is afterwards "fixed" and "intensified" so as to produce the greatest transparence in the lines and an almost opaque density of the ground. Printing from a negative is usually performed by the action of light when only a few copies are wanted, and mechanically when many are wanted; the prints are taken directly from the negative in the one instance, and from a transfer of the negative to the surface of a stone or metal plate in the other. Of the processes of printing directly from the negative, silver printing, the oldest, is as yet unsurpassed for the delicacy of its results, but it is expensive and perishable; the prints are taken on paper coated with albumen containing an alkaline chloride, such as common salt, floated on a bath of nitrate of silver, and allowed to dry in the dark. After exposure to light in a printing frame, the prints are washed, toned with a solution of gold, and then fixed in a bath of hyposulphate of soda, which dissolves all the remaining unaltered chloride of silver. At the Ordnance Survey office platinum printing is now (1887) largely used instead of silver printing for all purposes where only a few copies of a map are required. It is more expensive, but the prints are absolutely permanent and are produced more quickly than silver prints. Their rich velvety black colour and freedom from glaze render them peculiarly suitable. The paper is sensitized with a preparation of platinum and ferric oxalate. After exposure to light, the image is developed almost instantaneously by laying the print on a hot solution of potassic oxalate; it is then washed in successive baths of dilute acid to remove the soluble iron salts, and after that in a few changes of water. Various processes of "collo-chromate" printing are also most usefully employed in map-printing; they depend on the reaction of the salts of chromium—particularly the alkaline bichromates—on gelatin, gum, albumen, or other colloid substances, which, in proportion to the amount of the action of light upon them, become more or less insoluble in and unabsorbent of water, and acquire the property of taking up greasy ink and not attracting plumbago or other fine dry pigment in powder. When the subject is in line the print is taken on paper that is usually coated with a mixture of gelatin and bichromate of potash, coloured with Indian ink or any other suitable pigment; after a few minutes' exposure in the copying frame the paper is plunged into tepid water, which dissolves the unaltered gelatin in the blank parts of the print—they have been protected from the light under the dark parts of the negative—leaving a clear image in pigment on a white ground. When the subject is in half-tone, the gelatin film has to be detached from the paper that it may be developed by being washed on the unexposed side, a temporary support being employed to preserve the image from injury during the washing; the most delicate shades in the half-tones are thus perfectly preserved.

Photo-mechanical printing.

In the processes noticed above it is necessary to repeat the operation by exposure to light for every print produced; the rate of printing will therefore be more or less dependent on the sensitiveness of the paper, the strength of the light, and the condition of the atmosphere. In the processes about to be described these disadvantages are obviated by transferring the photographic image to a surface of stone or metal, from which prints may be made mechanically in any numbers independently of light or weather. The photo-mechanical processes are broadly divisible into two classes,—one comprising photo-lithography, photo-zincography, and photo-typography, for the reproduction of subjects in line only; the other, photo-collotype and photo-gravure, for subjects in mezzo-tint or half-tone as well as line.

Photo-lithography and the analogous photo-zincography are the processes which have hitherto been most extensively employed for map printing. They are the simplest to carry out; they allow the photographs of several sections of a map which may be too large to be reproduced as a whole to be combined; and additions and corrections may be readily made by hand on the stone or zinc plate. The prints for transfer from the negatives are taken on paper coated with a mixture of gelatin and potassium bichromate, as in the pigment printing process, except that the greasy ink or colouring matter is not mixed with the gelatin, but applied evenly over the surface of the prints after exposure to the light. The inked print is immersed for a few minutes in tepid water to soften the gelatin still remaining soluble in the parts not acted upon by light, and is then laid on a sloping plate and washed with a soft sponge until all the unaltered soluble gelatin and the ink overlying it are removed. The lines on which the light has acted remain insoluble and retain the ink, forming a clear image of the subject in a greasy

ink. When a map is photographed in several sections, as often happens, each section overlaps well all round to enable the transfers from the different negatives to be neatly joined together without showing lines of junction; if the whole is too large to be printed on a single sheet of paper, it is cut up into sections for printing separately.

The object of photo-typography is to obtain by photographic agency a surface block which may be set up with type and printed in the same way as a woodcut. The image may be obtained on a zinc plate by transfer in the same way as for photo-zincography, or it may be printed directly from a reversed negative. In the latter case the zinc plate is usually prepared with a thin coating of bitumen, a substance which has the property of becoming insoluble under the influence of light, so that, when after exposure the plate is washed with turpentine or benzole, the image remains on the zinc, while the ground is washed away. In both cases the image is strengthened by careful inking and by the application of powdered resin, which the plate is heated sufficiently to melt. The image is then etched with nitric acid. The operations of inking, applying resin, and biting with acid are repeated several times, until the plate is bitten sufficiently deeply to give clear prints. In another process, which is perhaps preferable for fine work, a mould is obtained by electrotyping a relief in swollen gelatin, the surface of which has been metallized with plumbago or bronze powder. These processes are largely used for producing small maps to illustrate books and newspapers, but not for maps of ordinary size.

The three mechanical processes just noticed are only applicable to maps drawn in line, and to get good prints every line should be of the same blackness, though of different breadth. Attempts have been made to reproduce brush-shaded drawings, exhibiting continuous gradations of shade, by photo-lithography and photo-zincography, but with very partial success, and only by breaking up and destroying the continuity of gradation. The following processes are specially suited for reproducing maps in half-tone.

Photo-collotype.

In photo-collotype, so-called from the printing surface being of gelatin, a plate with a perfectly smooth surface, usually of thick glass, either is coated with a sensitive mixture of gelatin and bichromate of potash, upon which the photographic image is produced by the action of light through a *reversed* negative, or is employed to support a gelatin film on which the image has been imprinted from an ordinary negative, and which is attached to the plate with suitable cement. The gelatin when properly moistened possesses the valuable property of receiving a greater or less amount of ink in different parts of the image in exact proportion to the intensity of the action of the light on each part; thus it is capable of reproducing the most delicate gradations of shade. The process is admirable for maps of small size, which only require a single plate, but is not suited for making a combination of sections to form a map of ordinary size; nor can additions or corrections be made on the gelatin film, which is, moreover, so tender that it does not readily permit of a large number of prints of uniform quality being taken, and is easily damaged.

The several methods of obtaining an incised image on a copper plate by means of photography are broadly divisible into the two groups of electrotyping and etching processes; one of each will be briefly noticed. (1) A positive pigment print, forming a relief in hardened gelatin, is developed on a silvered copper plate by the ordinary operations of the autotype or pigment printing process; it is then blackleaded and copper is deposited on it to form an electrotype intaglio, from which prints may be taken in the usual way, three to four weeks being required for the deposition of enough copper to produce a plate of sufficient thickness. (2) A negative pigment print is developed on a highly polished copper plate, upon which a very fine grain of powdered resin has been deposited and fixed by heat. The intaglio is obtained directly on the plate by biting in with a solution of perchloride of iron, which penetrates the gelatin film with comparative ease in those parts representing the shades and lines of a map, where there is little or no gelatin, and thus bites the copper to a considerable depth, while in the parts representing the blank spaces and ground of the map, where the gelatin is thicker, it penetrates with more and more difficulty as the thickness of the gelatin increases, and in the highest blanks should leave the copper untouched. The operation of biting takes only a few minutes, and the gravure is remarkable for its delicacy of gradation and richness of effect; there is, however, some difficulty in etching to the proper depth so that the plate may stand much printing without the loss of the finest tint. In both cases the copper plates have to be protected by a facing of steel before they can be printed from. The processes have not yet been used to any great extent for maps with half-tones, but they are very promising. For maps in line the first method gives excellent results, and is largely employed in the Austrian and Italian surveys.

X. Instruments.

The instruments employed in survey operations are broadly divisible into two classes, one for making the requisite linear and angular measurements on the ground, the other for plotting the data thus acquired on paper, and for measuring from the map, when completed, lengths and areas which it may not be convenient to calculate from the numerical data. As a rule different instruments are employed for the mensuration on the ground and for the plotting on paper; but to this rule there is a notable exception in the plane table, by means of which all bearings may be drawn directly on paper with a sight rule, without previous measurement of any kind, and thus a plot of the ground may be constructed without employing any other instrument.

Field Instruments.—These are of two classes,—linear, for determining distances directly by actual measurement along the surface of the ground, and angular, for determining the bearings of, or the angles between, any objects. Some instruments are automatic, as the needle, which points to the magnetic north, the plumb-line and the spirit-level, which indicate the direction of gravity, and hypsometers of various kinds, for measuring altitudes; others are entirely controlled by the manipulator. Some require to be rigidly supported on the ground, as measuring bars and theodolites; others are adapted for flexible supports, as reflecting and magnetic instruments, which may be employed either on land or on the oscillating deck of a ship at sea. Some, as magnetic compasses, measure angles in the horizontal plane only; others, as theodolites, in two planes,—one horizontal, the other vertical; others, as reflecting instruments, in all planes; others, as levelling instruments, measure nothing, but simply indicate a plane of reference. And there are certain instruments by which angles are measured in the ordinary way, and direct distances are determined by micrometric measures of the small angles subtended at a distance by objects of known dimensions.

Linear instruments.

Linear instruments are of two classes,—one for exact measurement of base-lines the lengths of which are required to be known with great precision, the other for ordinary and rough measurements. Among the former may be included the Colby apparatus of compensation bars and microscopes, described in sect. I., § 2 (p. 696 above), Bessel's apparatus, those of Struve and the United States Coast Survey, and Porro's (adopted by the Spaniards and the French in Algiers), which have already been described in EARTH (FIGURE OF THE), vol. vii. pp. 598, 600, and GEODESY, vol. x. pp. 163, 164. For less exact but still essentially accurate measures the instruments most commonly employed are the brass or steel chain of 100 links, the graduated metallic tape, and the offset pole.

For reconnaissance and rough measurement, perambulators, with wheels of known periphery and dials to indicate the number of revolutions, are largely used in India. Crinoline wire has been employed with advantage in Australia; it is so light that a length of 1000 feet or more may be easily carried, rolled on a drum, by one man, who pays it out as wanted; he is usually followed by another, who commences rolling it up at the opposite end when an entire length has been laid out on the ground. Air lines are sometimes measured by stretching the wire over the tops of trees in valleys obstructed with forest, also the breadths of rivers by resting the wire on logs anchored at suitable intervals to support it above water.

Angle-measuring instruments.

Angle-measuring instruments are of two classes, direct and reflecting. Both are provided with an aligner, usually a telescope, which is pivoted over the centre of the graduated circle or sector: in one the aligner is pointed in succession to any two objects the angle between which is being measured; in the other it is pointed to one object, while an image of the second is thrown on the first by double reflexion from a pair of mirrors. Reflecting instruments are largely employed in nautical surveys, as they can be held by the hand and do not require a rigid support; but they are very rarely used in land surveys. A description of them will be found under SEXTANT (vol. xxi. pp. 724-725). They give the angle in the plane in which they are held; and, whenever this plane is sensibly oblique to the horizon, the angle must be reduced by calculation to the plane of the horizon before it can be employed in the work of a land survey. The other instruments give the required horizontal angles, whatever the altitudes of the objects observed.

The circles of angle-measuring instruments are usually divided into 360 equal parts called degrees, and subdivided into spaces ranging downwards from thirty to five minutes of arc, according as the diameter of the circle is increased. Smaller arcs are measured by interpolation between the subdivisions, with the aid of a circle reader which moves with the aligner. All instruments except those of the simplest form are supplied with one or more circle readers and spirit-levels and a telescope; these important adjuncts, which are common to so many instruments, will therefore be first described, and afterwards the more important instruments which are employed in connexion with survey operations.

Circle readers are of two kinds,—the vernier and the microscope.