REPORT OF DIRECTOR

OF THE

Solar Observatory, Mount Wilson, California.

By George E. Hale, Director.

(Extracted from the Fourth Year Book of the Carnegie Institution of Washington, pages 56-77, plates 1 and 2.)

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BY GEORGE E. HALE, DIRECTOR.

I have the honor to present my first formal report on the Solar Observatory In view of the fact that the work of the Expedition for Solar Research from the Yerkes Observatory has been continued by the Solar Observatory, this report covers the entire period of our occupation of Mount Wilson, beginning with February 29, 1904.

The circumstances leading up to the establishment of the Solar Observatory have been stated elsewhere † and need not be repeated here. Suffice it to say that a grant of $10,000, made by the Executive Committee of the Carnegie Institution in April, 1904, rendered it possible to bring the Snow telescope of the Yerkes Observatory to Mount Wilson in the summer of 1904. As a study of the atmospheric conditions had given rise to belief that the site would prove a very advantageous one, warranting occupation for a considerable period of time, a lease of a large tract of land on the mountain was at once negotiated. The Carnegie Institution had not then decided to establish an observatory of its own, and the future was therefore uncertain. Accordingly the lease was taken by myself personally, but a new lease has since been executed in the name of the Carnegie Institution. The property belongs to the Pasadena and Mount Wilson Toll-road Company, and I desire to put on record my sense of obligation to the officers and controlling stockholders of this company, Messrs. J. H. Holmes and W. R. Staats, of Pasadena, to whom we are indebted for liberal and courteous treatment. The lease, which comprises a large tract (not yet completely surveyed) of the best land on Mount Wilson, not only involves no charge for the use of the property, but establishes restrictions of great importance on the adjoining land of the toll-road company. These restrictions, as fully set forth in the lease, seem to obviate completely such interference with the observations as might be caused by smoke, electric lights, vibrations from machinery, and other similar disturbances. The lease also contains other advantageous concessions, including one-half the water rights on Mount Wilson, free use of the toll trail to the valley, etc. The seemingly unique advantages of Mount Wilson, in atmosphere, topographical features, and proximity to an

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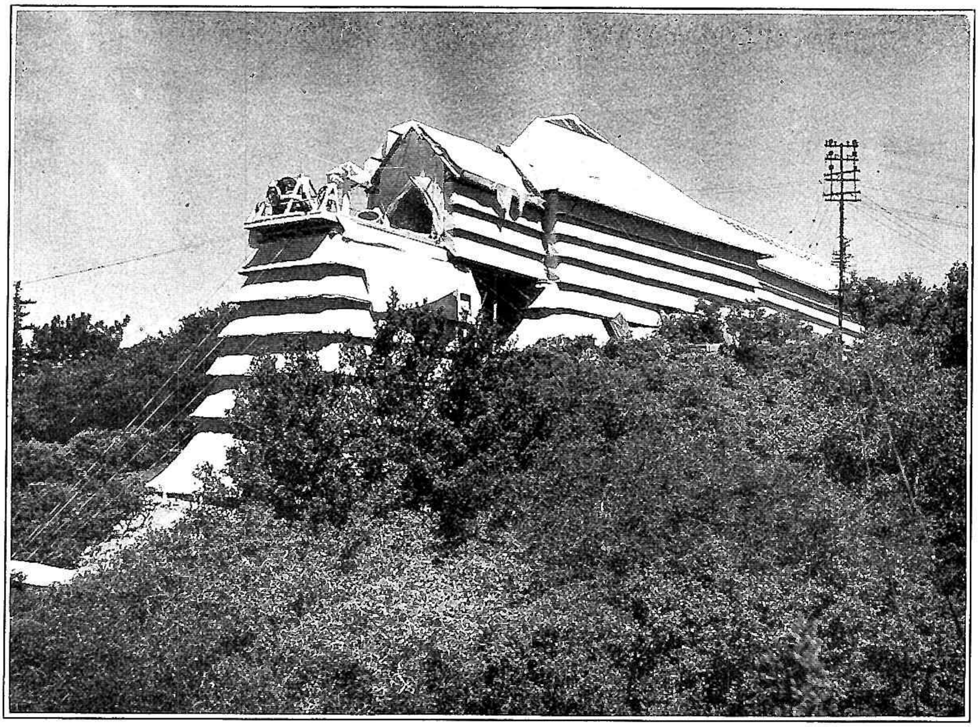
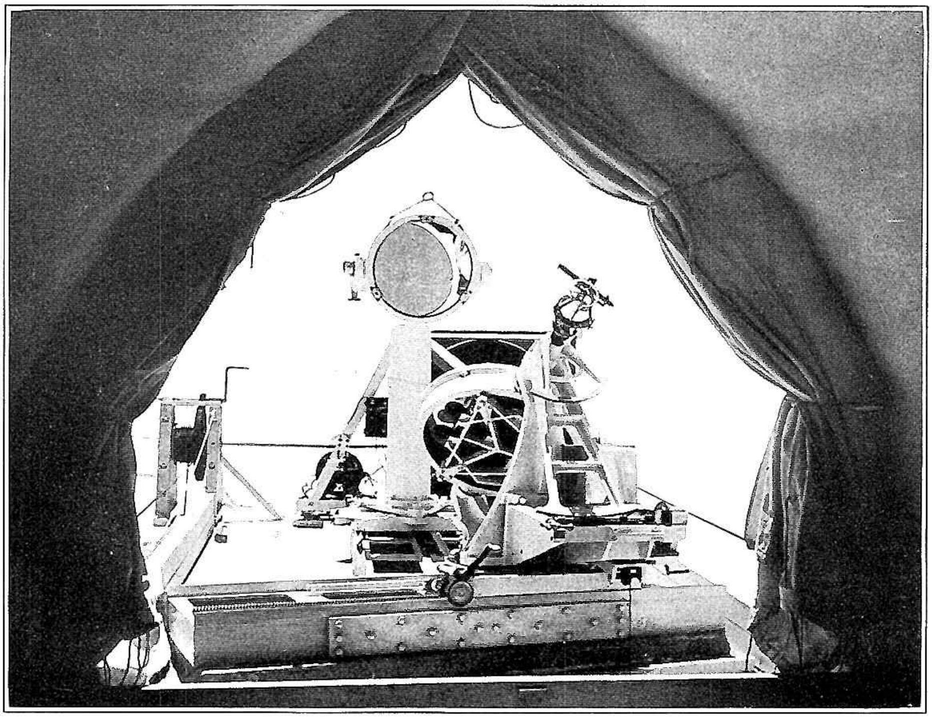
* Grant No. 217. $150,000 for building observatory and maintenance for 1905. (For preliminary report see Year Book No. 3, pp. 155-174.)

† Contributions from the Solar Observatory, Nos. 1 and 2.



SOUTH END OF SNOW TELESCOPE HOUSE.



COELOSTAT AND SECOND MIRROR OF NEW TELESCOPE.

important base of supplies like Los Angeles, will indicate the value of this lease to the Solar Observatory.

In Contributions from the Solar Observatory No. 1, I have given a detailed account of the systematic tests of the atmospheric conditions at Mount Wilson made prior to January 1, 1905. Since the telescopic tests of this period were necessarily limited to solar observations with a refractor of 3¼ inches aperture, they might perhaps be considered inconclusive, especially as they related entirely to sharpness of definition, and took no account of transparency of the atmosphere. At present, however, any doubts that might have existed on this score have been removed, for extensive tests with powerful instruments have fully confirmed, and even strengthened, the favorable opinion previously entertained. The large aperture and great focal length of the Snow telescope have rendered the tests of the solar definition very severe, and the number of days of fine seeing recorded under such conditions is most gratifying. The transparency and uniformity of the sky by day have been fully proven by Mr. Abbot's precise measures of the solar radiation with the pyrheliometer and spectro-bolometer, and these conditions, with the long stretches of unbroken clear weather, have left no doubt of the advantages to be gained from a continuation on Mount Wilson of the important research instituted here by the Smithsonian Expedition. Professor Barnard's remarkable photographs of the southern Milky Way, including many star clouds and extended nebulæ not previously recorded, and showing numerous stars to exist in regions heretofore supposed to be devoid of stars, testify to the transparency and purity of the night sky, and his systematic tests of the seeing by night have shown it to be very fine. These tests, made with the 5-inch guiding telescope of the Bruce telescope, have been amply confirmed with the large aperture of the Snow telescope. In photographing stellar spectra with the high dispersion of a powerful grating spectroscope, the observer has the star's image constantly under observation for many hours at a time. In this work it has been found that the average night-seeing is exceedingly good, while the low wind-velocity, coupled with the transparency of the atmosphere, afford additional advantages which should render Mount Wilson an ideal site for the 5-foot reflector.

PLAN OF RESEARCH.

Before proceeding to describe the work so far accomplished, it is desirable to call attention to the plan of research prepared for the observatory. This plan has been set forth in Contributions from the Solar Observatory No. 2, but the developments of the last few months have cleared up some points of uncertainty, especially as regards the desirability of including a systematic study of the solar radiation in our observational program. Furthermore, the question recently raised by the editor of the Popular Science Monthly, as to the wisdom of establishing the Solar Observatory in a State already so well represented by the Lick Observatory, indicates that the purpose of the Solar Observatory is not yet clearly apprehended by some men of science. The Carnegie Institution would certainly run counter to its well-defined principles by duplicating the work of the Lick Observatory, and the Solar Observatory would not accomplish its purpose if this were done.

The purpose of the Solar Observatory may be defined as follows:

(1) The investigation of the sun (*a*) as a typical star, in connection with the study of stellar evolution; (*b*) as the central body of the solar system, with special reference to possible changes in the intensity of its heat radiation, such as might influence the conditions of life upon the earth.

(2) The choice of an effective mode of attack, involving (*a*) the application of new methods in solar research; (*b*) the investigation of stellar and nebular phenomena, especially such as are not within the reach of existing instruments; and (*c*) the interpretation of these celestial phenomena by means of laboratory experiments.

(3) The design and construction of a large reflecting telescope and of new types of instruments peculiarly adapted for the purposes in view, with special reference to the possibilities of research through the study of celestial objects under laboratory conditions.*

4) The accomplishment of the foregoing purposes at a site where the atmospheric conditions have been shown to be exceptionally favorable: Mount Wilson (5,886 feet), in southern California (lat. + 34° 13′ 26″, long. W. 118° 3′ 40″).

(5 The furtherance of international coöperation in astrophysical research through the invitation to Mount Wilson, from time to time, of investigators specially qualified to take advantage of the opportunities afforded by the Solar Observatory.

STAFF.

My principal associates on Mount Wilson are Ferdinand Ellerman and Walter S. Adams, assistant astronomers. Mr. Charles S. Backus is a general assistant. At the Pasadena office and instrument shop

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* See The Development of a New Observatory, Publications of the Astronomical Society of the Pacific, Vol. XVII, p. 41. 1905.

the work of construction is carried on under the supervision of Prof. G. W. Ritchey, astronomer and superintendent of instrument construction.

Prof. Winslow Upton, Director of the Ladd Observatory of Brown University, and Prof. L. H. Gilmore, of Throop Polytechnic Institute, were engaged in special work at the Solar Observatory during the summer of 1905.

During 1905 the following expeditions have conducted observations on Mount Wilson in coöperation with the Solar Observatory:

Hooker Expedition: Edward E. Barnard, astronomer of the Yerkes Observatory, in charge.

Smithsonian Expedition: Charles G. Abbot, aid acting in charge of the Smithsonian Astrophysical Observatory, in charge; Leonard R. Ingersoll, University of Wisconsin, assistant.

INVESTIGATIONS IN PROGRESS.

Although the program of observations must naturally be a restricted one until the completion of the instrumental equipment, it has nevertheless been possible to commence systematic work in four departments: (1) daily photography of the sun with the photoheliograph; (2) daily photography of the sun with the spectroheliograph; (3) photography of the spectra of sun-spots and flocculi; (4) photography of stellar spectra with a grating spectrograph of high dispersion. Since the Snow telescope has been employed in all of this work, an account of the tests of this instrument should precede a description of the investigations named.

The Snow telescope was set up on Mount Wilson in January, 1905, but the extremely wet weather of the rainy season rendered it inadvisable to put the mirrors in place until about March 15, 1905. On the return of favorable weather, tests of the telescope were at once undertaken. It was found that the heating of the mirrors by the sun produced marked changes of focal length, together with such evidences of astigmatism as would be expected to follow from the distortion of the plane mirrors. The focal distance lengthened rapidly after the mirrors had been exposed to the solar rays for a short time, but soon reached a maximum, where it remained fairly constant. Speaking approximately (as the results varied considerably at different times), the change from normal to maximum, with the mirror of 60 feet focal length, was from 3 inches to 1 foot. It was soon noticed that the change became more marked as the silvered surfaces grew older and more tarnished, on account of the greater absorption of heat. For a time it seemed probable that the use of the telescope would be seriously handicapped by these changes of focal length, not only because of the poor definition caused by astigmatism, but also because the long exposures required with the spectroheliograph would be impracticable under such conditions. Attention was therefore concentrated on two objects: (1) the provision of a remedy for the difficulty experienced with the mirrors; (2) the reduction of exposure time in the spectroheliograph.

The solar definition at Mount Wilson is best about an hour after sunrise. At this time the mirrors, after being cooled by the night air, might be supposed to give most trouble on account of the rapid change of temperature after sunrise. It was accordingly thought that it might be desirable to maintain the mirrors during the night at a temperature approximating that attained during the day after exposure to the sun. Experiment soon led, however, to a different solution of the problem. At the time of best definition the radiation from the low sun undergoes considerable absorption in the earth's atmosphere. Although this makes necessary an increased exposure in the spectroheliograph, it is nevertheless very advantageous in preventing rapid heating of the mirrors. In fact, if the exposure time is made as short as possible and the mirrors shielded from the sun between exposures by an adjustable canvas screen, the change of focus can be so reduced as to become of small importance during the period of best definition, which lasts about an hour.

The experiment has been tried of cooling the mirrors with a blast of air after they have been exposed for some time to the sun. The good effect of this treatment was shown by a considerable change of focus toward the normal position. Electric fans are accordingly being installed to blow each of the three mirrors while they are exposed to the sun during the adjustment of the spectroheliograph, and between exposures, when the mirrors are also shielded by a canvas screen. The success attained in decreasing the exposure time with the spectroheliograph is described below. The result of the combined efforts was to yield photographs of the sun equal, if not superior, to the best obtained with the 40-inch Yerkes telescope and the Rumford spectroheliograph. When it is remembered that the spectroheliograph employed in the present work is an instrument of the simplest construction, extemporized for use until the permanent spectroheliographs can be completed, it will be seen that such results are to be regarded as satisfactory.

It should be added that photographs of the sun suitable for most classes of work can be made with the Snow telescope at almost any hour of the day. Advantage is taken, however, of the fine definition soon after sunrise and before sunset to secure the daily record, so that the plates may be suitable for investigations of the more minute solar phenomena.

Images of the stars and of the moon given by the Snow telescope are frequently very fine, but after the mirrors have become distorted through heating by the sun they sometimes do not return to their normal figure for many hours. The images observed at such times are greatly distorted and usually multiple in character.

The special form of house designed for the Snow telescope has proved very satisfactory. The louvres and ventilated roof undoubtedly accomplish their purpose, as the air within the house remains cool even at midday.

QUARTZ MIRRORS.

The above remarks emphasize the importance of carrying to a successful issue the experiments on the use of fused quartz for mirrors undertaken last year and reported upon in Year Book No. 3 (p. 127). Professor Gilmore, of Throop Polytechnic Institute, who has carried on the experiments this year in conjunction with Professor Ritchey, succeeded in making quartz disks decidedly better than any obtained in the earlier work. The method of heating the quartz crystals to about 500° C. before dropping them into the white hot electric furnace proved more successful than other methods, in that the disks thus produced contain fewer bubbles. Nevertheless the bubbles still remaining are too numerous to permit a satisfactory optical surface to be given the quartz disks, and experiments in remelting the surface in the electric arc have not succeeded, as was hoped, in removing the bubbles from a superficial layer of sufficient thickness for figuring. The molten quartz is far too viscous to permit the bubbles to be removed by stirring, but it is hoped that melting the crystals under pressure may accomplish the purpose.

Meanwhile there is reason to hope that materials other than ordinary glass or fused quartz may prove suitable for mirrors. Schott, of Jena, has produced an opal glass having a coefficient of expansion about one-third that of ordinary glass. Other glass-makers will be induced, if possible, to make special experiments in the hope of producing glass of low expansion coefficient.

There is reason to think that speculum metal, on account of its high conductivity of heat, may not undergo in sunlight such surface distortion as glass exhibits. We are preparing similar mirrors of glass and speculum metal for a careful comparative test to decide this question.

DIRECT PHOTOGRAPHY OF THE SUN (MESSRS. HALE AND ELLERMAN).

Photographs of the sun on a scale of 6.7 inches to the solar diameter are taken daily with the Snow telescope. With the present exposing shutter the aperture of the 60-foot mirror must be reduced to about 3 inches when Process plates are used. A separate photoheliograph will be provided later, so that the Snow telescope may be used exclusively for work with the spectroheliograph during the hours of best definition. Many of the direct photographs already obtained are very sharp and have been of great service in comparisons (with the stereocomparator) of faculæ with H_1 photographs of the flocculi.

WORK WITH THE SPECTROHELIOGRAPH (MESSRS. HALE AND ELLERMAN).

The temporary spectroheliograph, built for use with the Snow telescope pending the construction of the 5-foot spectroheliograph, is a simple but very efficient instrument. A heavy wooden base (saturated with melted paraffin to prevent change of shape in moist and dry weather) carries two iron rails of V section. Four steel balls run in these V's and in the inverted V's of two iron rails on the lower side of the wooden platform that bears the slits and optical parts. The first slit, the collimator, and the camera are from the old Kenwood spectroheliograph. The two prisms, of 64° refracting angle, were made for the Bruce spectrograph of the Yerkes Observatory, but had to be replaced in that instrument because of their imperfect definition. This is sufficiently good, however, for spectroheliographic work, where the requirements in this particular are less severe than in stellar spectroscopy. In the absence of a suitable mirror, to give the required deviation of 180°, the silvered face of a third prism is employed. The second slit and plate-holder support belonged to a spectroheliograph of the type suggested by Newall, which was built for experimental purposes at the Yerkes Observatory. The solar image and plate are fixed and the spectroheliograph is moved across them by means of a small electric motor. This is belted to a large wooden pulley on a screw supported by the wooden base and running in a nut attached to the moving platform.

The optical parts in this simple instrument are small, and therefore only a narrow zone of the 6.7-inch solar image can be photographed. For special studies of spot regions and of interesting flocculi, however, no better instrument could be desired. The great advantages of a spectroheliograph mounted on a pier over one attached to an equatorial telescope have made themselves evident from the first. It has been easy to change the exposure time by the use of a cone pulley on the motor and by the provision of a worm gear for very slow speeds. The convenience of experimentation thus afforded has rendered possible a long series of tests involving considerable variations in slit-width, speed, and plate sensitiveness. These experiments will be completed with the 5-foot spectroheliograph, which offers many additional advantages. It may be said, however, that the most satisfactory results (for H_2) have been obtained with Process plates, high speeds (from 0.2 to 0.3 inch per second), and wide slits. It must not be forgotten, as Newall has pointed out, that very wide slits can not be used without producing an astigmatic effect in the direction of dispersion, unless an even number of reflections (or no reflections) occur in the optical train. The 5-foot spectroheliograph, when used with two prisms, is designed to give either one or two reflections, as desired.

In my discussion of the results obtained with the Rumford spectroheliograph, I adopted a working hypothesis which assumes that photographs taken with the second slit set on the broad dark band H_1 represent the low-lying, dense calcium vapor in the flocculi, while those taken with H_2 show the less dense calcium vapor at a higher level. Mr. Evershed has advanced good arguments in favor of his view that the H_1 photographs represent the faculæ proper, the increased contrast being due to the dark background afforded by the dark band. This assumes that the level of the faculæ is above that of the denser calcium vapor, but photographs of the spectrum of the faculæ taken on Mount Wilson show that the bright band representing their continuous spectrum is greatly reduced in intensity near the middle of H_1 and K_1. The strength of this counter-argument, however, is lessened by the fact that this same evidence conclusively shows the absence of such reversals of H_1 and K_1 as my working hypothesis would seem to require. It is evident that further advance must depend in large measure upon a series of careful comparisons of faculæ near the sun's limb (taken direct or with a spectroheliograph having its second slit set on the continuous spectrum) and of the same objects photographed nearly simultaneously with a spectroheliograph set on H_1.

A Zeiss stereocomparator (not available in the work at the Yerkes Observatory) has afforded the means of comparing photographs with the necessary precision. Numerous plates of the recent large spot groups have supplied excellent material for the tests. Though the comparisons are not yet completed, it may be said that they now seem more favorable to Mr. Evershed's view than to my own. In continuing the work special care will be taken (1) to obtain photographs with H_1 and with the continuous spectrum without change of slit-width (in the temporary spectroheliograph a change of slit-width has been necessary in order to compensate for the difference in brightness); (2) to increase the contrast in photographs of the faculæ proper, so that the comparisons may be made nearer the center of the disk, as well as near the limb.

Mr. Evershed's alternative view that the H_1 photographs may be due to H_2 light reflected from the slit jaws has been rendered untenable. The beveled edges of the jaws in the temporary spectroheliograph are turned toward the plate, so as to reduce the possibility of reflection; but in any event the differences in form of H_1 and H_2 images are such as to preclude this view.

H_1 photographs undoubtedly represent a lower level than H_2 photographs; there is no question on this point. The doubt is whether H_1 photographs show the faculæ themselves or the calcium vapor in or above the faculæ, and whether the level represented depends upon the position of the second slit on the H_1 band. The Rumford spectroheliograph results formed the basis of my working hypothesis, but in some respects they were less suitable for this purpose than the photographs recently taken on Mount Wilson. Now that the 5-foot spectroheliograph is completed, it should be possible to settle the matter in a short time.

A description of this large instrument is reserved until the completion of the tests now in progress. With its large aperture (8 inches) and focal length (5 feet); the possibility of using a dispersion of from one to four prisms with an odd or even number of reflections; the wide range of speed afforded by the electric driving mechanism; the convenient means provided for focusing on the solar image, setting on the spectral lines, and attaching slits of various curvatures—this spectroheliograph may reasonably be expected to yield results surpassing those hitherto obtained.

A spectroheliograph of 8 inches aperture and 30 feet focal length, with three prisms of 50°, is now under construction. This instrument is designed especially for the photography of limited regions of the solar disk with Fraunhofer lines other than those of calcium and hydrogen, including the lines affected in and near sun-spots.

A method of measuring the heliographic latitude and longitude of points on photographs of the solar disk by projection upon the surface of a ruled globe has been successfully employed by Mr. Fox and myself at the Yerkes Observatory. A modified form of the apparatus, which I have more recently devised, is now under construction in our instrument shop and will soon be mounted in the laboratory on Mount Wilson. It will also be suitable for the measurement of the position angle, height, and heliographic latitude of prominences, as well as for the monocular comparison of two photographs in a manner similar to that employed in the stereocomparator. A measuring machine, recently completed for us by William Gaertner & Co., after the designs of Dr. Frank Schlesinger, furnishes the means of determining rectangular coördinates on solar or stellar photographs, when it is desired to employ the ordinary methods of measurement and reduction. A special micrometer for the stereocomparator, designed for use with a réseau, is also under construction by the Zeiss Company.

SPECTRA OF SUN-SPOTS AND FLOCCULI (MESSRS. HALE AND ADAMS).

The plan of research prepared for the Solar Observatory lays special stress on the simultaneous study of solar phenomena from several points of view. To obtain adequate knowledge of the nature of sun-spots, for example, it is not enough to make direct or monochromatic photographs of the spots, or to devote all our attention to a study of their spectra. Direct photographs are useful in giving the heliographic position and general character of the spots and the details of their structure. They tell nothing, however, of the forms and motions of the invisible vapors surrounding them, or of those peculiarly characteristic vapors within the spots that are represented by the widened lines. To study these forms we must employ spectroheliographs, of moderate dispersion for high and low level photographs with the calcium lines, of great dispersion when it is desired to study the distribution of the rarest and most lofty vapors of calcium or the luminous clouds revealed with the aid of the narrow lines of other substances. In the interpretation of these photographs, however, and for other purposes as well, we must have the assistance of high-dispersion photographs of spectra. The spectroheliograph plates themselves furnish the means of studying the motions of the luminous vapors parallel to the solar surface, but the distortions and displacements of the spectral lines, as determined by the most precise measurements, supply the only available means of measuring the velocities of ascent or descent. For the interpretation of the phenomena of widened lines and for an explanation of the causes which bring about the disappearance or complete reversal of Fraunhofer lines over spots, recourse must be had to such laboratory experiments as are referred to elsewhere in this report.

Finally, to mention only some of the principal modes of attack, without going further into detail, the bolometer or radiometer furnishes the necessary means of measuring the radiation energy of the spots and photosphere in various parts of the spectrum, thus supplementing in an important way the instruments already mentioned. All of these modes of solar observation have been brought into use on Mount Wilson, thanks to the Snow telescope, which supplies the first requisite—a large and well-defined solar image within a laboratory.

The photographs of spectra obtained with this instrument well illustrate its advantages over an equatorial telescope. The long and powerful Littrow spectrograph, having a combined collimator and camera lens of 18 feet focal length, could not possibly be attached to such a telescope as the 40-inch Yerkes refractor. The photographs obtained with this spectrograph are naturally far superior to the best we were able to make with the 40-inch, and the precision with which they can be measured is in proportion to the respective focal lengths of the spectrographs used in the two cases—42 inches at Lake Geneva and 216 inches at Mount Wilson. The third-order spectrum of the same grating (the one formerly used in the Kenwood spectroheliograph) was employed in both cases. A great number of widened lines are shown in the spot spectra and the reversals of H and K are admirably brought out. Systematic work with this instrument has been going on since the latter part of August and will be continued regularly.

Certain conclusions, of importance in their bearing on future work, have resulted from the experiments already made. These are (1) the advantage of using a large solar image, in the present case 6.7 inches in diameter, produced by the mirror of 60 feet focal length; (2) the advantage of very high resolving power and linear dispersion in the spectrograph; (3) the importance of providing for a simultaneous attack on the same solar phenomena with a suitable battery of independent instruments. I have accordingly designed a cœlostat telescope of 60 feet focal length and a powerful spectrograph especially for work on the spectra of sun-spots, flocculi, and the chromosphere, and the study of the solar rotation. It is hoped that this instrument, which is to be erected next year, will combine a high degree of efficiency with moderate cost. A special merit of this telescope lies in the fact that it will set free the Snow telescope for uninterrupted work with the spectroheliograph during the early morning hours of fine definition, and at the same time permit the various spectroscopic phenomena to be simultaneously recorded.

STELLAR SPECTROSCOPY (MESSRS. HALE AND ADAMS).

One of the principal objects of the Solar Observatory is to secure photographs of the spectra of certain bright stars with a long focus grating spectrograph on a scale comparable with that of Rowland's photographs of the solar spectrum. It is hardly necessary to say that such photographs, if sharply defined, would be of the greatest service in an investigation of the physical condition of various types of stars and their relationship with the sun and with one another. On account of the great length and weight of suitable grating spectrographs and their liability to flexure, it is impossible to attach them to equatorial telescopes. Consequently, in the absence of powerful horizontal telescopes, such investigations as that here described have not previously been undertaken.

Evidently the principal difficulty to overcome is the extreme faintness of the star's light as compared with that of the sun. The importance of using a telescope of large aperture is therefore obvious, but in any case the exposure of the photographic plate must be very long. Hence the spectrograph must be rigidly mounted on a heavy pier in a room where the temperature can be kept nearly constant throughout the exposure. If no change occurs in the relative positions of slit, lenses, grating, and plate, and if the grating itself is maintained at a constant temperature within very narrow limits, the spectral lines should occupy precisely the same positions on the plate whenever the star is on the slit. In extreme cases the orbital and diurnal motions of the earth must be taken into account, but these need cause no trouble. Thus the exposure may be prolonged until the feebly luminous image has registered itself on the plate.

The spectrograph used in the work with the Snow telescope has collimating and camera lenses of 5 inches aperture and 13 feet focal length, mounted rigidly, with the slit, grating-mount, and plate-holder, on a single massive stone pier. The large plane grating, for the use of which we are indebted to the kindness of Professor Ames, of Johns Hopkins University, was ruled on Rowland's engine many years ago. Although fairly bright in the first order, the spectra are much less brilliant than those of the best gratings of recent years. However, as no other large grating could be had, we were very glad to be favored with the use of this one. The grating is mounted in the front of a cubical brass box and its rear surface is bathed by water, which is constantly stirred by paddles revolved at slow speed by a small electric motor, supported on the wall of the room. Special precautions are taken to prevent vibration of the grating from the motor or its connections. A bulb containing saturated ether vapor is immersed in the water, which is heated by two small incandescent lamps controlled through a relay. If the temperature rises too high the current is cut off by the expansion of the ether vapor, which moves a column of mercury and thus breaks contact in the relay circuit. In the preliminary work on Arcturus described below, the grating showed no variations of temperature equal to 0.1° C., as measured by a thermometer immersed in mercury in contact with the grating. Further improvements in this apparatus will undoubtedly give all necessary constancy of temperature.

An automatic arrangement is now being installed to control the temperature of the entire spectrograph, as the variations of several degrees from minimum night to maximum day temperature, which occur in extreme cases, are greater than can be allowed. Under ordinary circumstances the range within the room is very small and probably inappreciable in effect.

One photograph of the blue region of the first-order spectrum of Arcturus required an exposure of fourteen hours on three successive nights. Another, made when the mirrors were badly tarnished, required twenty-four hours on five successive nights. The guiding was done with the aid of electric slow motions attached to the mounting of the 60-foot concave mirror of the Snow telescope, supplemented by cords (kept taut by weights) with which the cell can be sprung slightly without danger of distorting the mirror. The good definition and the uniform succession of clear nights make Mount Wilson an excellent place for such work.

The photographs are good, but they are not equal to solar spectra taken in the same apparatus with short exposure. It is expected that improved temperature control will remedy this difficulty. The value of the spectra is well shown by the fact that the measures of a large number of lines made by Mr. Adams show the linear error of setting to be as small as in the case of the best Bruce spectrograph plates. As the scale of the present photographs is nearly three times as great, the increase of precision should be in the same ratio.

These experiments with the Snow telescope should be of special service in their bearing on the design and use of the large grating spectrograph for the five-foot reflector. As this instrument will give six times as much light as the Snow telescope, it is already evident that valuable results may be expected from its application to high-dispersion stellar spectroscopy.

HOOKER EXPEDITION.

As the result of a special gift made by Mr. John D. Hooker, of Los Angeles, for this purpose, Professor Barnard was enabled to bring the Bruce telescope from the Yerkes Observatory to Mount Wilson in December, 1904, and to carry on photographic work with it until the completion of his program in September, 1905. Although the work is to be considered as that of the Yerkes Observatory, I may be permitted to say a few words regarding it in the present report. Professor Barnard's special object was to photograph the southern part of the Milky Way, in the region that can not be reached from the latitude of Williams Bay. He has accomplished this purpose in a most satisfactory manner, with the same untiring zeal that he has shown in all his undertakings. The perfection of the photographs, testifying at once to the skill of the observer, the excellence of his instruments, and the purity of the sky, must be seen to be appreciated. They include not only the large plates made with the 10-inch Brashear lens, but also three complete series of smaller plates, made with a powerful battery of lenses, all working simultaneously. In addition to his photographic observations in the southern heavens, Professor Barnard has made many valuable plates of northern objects. It is hoped that provision will be made for the early publication of these results, as they constitute a most important contribution to our knowledge of the structure of the Milky Way and of the remarkable nebulæ within it.

SMITHSONIAN EXPEDITION.

The inception of the Solar Observatory was due to a suggestion made by Secretary Langley, of the Smithsonian Institution, regarding the desirability of providing for systematic observations of the solar radiation at a mountain station. The work of the Smithsonian Observatory during the last few years has emphasized this suggestion by indicating the probability that the solar constant has undergone considerable variations. Furthermore, these variations nearly coincide in time with apparent changes in the absorbing power of the solar atmosphere and in the mean temperature of the earth's atmosphere. So important a conclusion deserves the most complete investigation, such as might result from a simultaneous attack with similar apparatus from Washington and Mount Wilson. As Mr. Langley had planned to send an expedition to some mountain station for this purpose, it was a special pleasure to place at his disposal all the facilities that could be offered by the Solar Observatory. He accordingly decided to send an expedition to Mount Wilson under his own direction and under the auspices of the Smithsonian Institution. Mr. C. G. Abbot, aid acting in charge of the Smithsonian Astrophysical Observatory, was placed at the head of the party, and Mr. Leonard R. Ingersoll, of the University of Wisconsin, came as his assistant. The usual work at Washington is being continued by Mr. Fowle. Although conducted under the auspices of the Smithsonian Institution, the work of this expedition bears so important a relationship to that of the Solar Observatory that a brief statement regarding it may not be inappropriate.

As is well known, the direct measurement of the solar radiation received at the surface of the earth is much less difficult than the determination of the amount of heat lost by absorption in our atmosphere. Although it has attacked both phases of the subject in a most thorough manner, the Smithsonian Observatory enjoys special distinction from the fact that the bolometer used there permits the relative amount of the atmospheric absorption to be automatically recorded for each wave-length of the spectrum. In short, it furnishes the information essential in determining the true value of the solar constant.

The fine weather experienced by the Smithsonian party since the installation of their instruments on Mount Wilson has permitted a great amount of excellent work to be done. The collection of bolographs and pyrheliometer readings is so great that months will be required for their complete discussion. In addition to all of these observations, much time has been devoted to frequent determinations of the absorption in the apparatus, experimental work with a new and promising form of recording pyrheliometer devised by Mr. Abbot, and bolographic observations of the radiation of sun-spots and the absorption of the solar atmosphere, made with the 6.7-inch image given by the Snow telescope. As all the results indicate that Mount Wilson is an ideal site for investigations of the solar radiation, Secretary Langley has been invited by President Woodward to continue the work of the expedition, at least during another summer. If for any reason he shall not be able to accede to this request, arrangements will be made for the Solar Observatory to carry forward the observations in coöperation, it is hoped, with the work of the Smithsonian Astrophysical Observatory in Washington. The Solar Observatory has profited greatly by the visit of Messrs. Abbot and Ingersoll, and all the members of the staff would be glad to see it repeated another year.

BUILDINGS AND EQUIPMENT ON MOUNT WILSON.

In the present report it is unnecessary to refer at length to the design and construction of buildings, as they will be fully described in other publications. For the sake of completeness, however, a brief account will be given of the work of construction hitherto accomplished.

Temporary Building for 15-inch Cœlostat Telescope.—This inexpensive structure was erected in the spring of 1904 and served admirably for the experiments with the small cœlostat and 6-inch objective of 60-foot focal length brought out from the Yerkes Observatory. This work was of special value in determining the design of the permanent building for the Snow telescope.

The "Casino."—An old log cabin, used many years ago for the entertainment of visitors at Strain's Camp, now belonging to the Pasadena and Mount Wilson Toll-road Company, was made habitable and occupied until December, 1904, by the members of the staff on Mount Wilson. It was also used during all last season and a part of this for the workmen's mess.

Snow Telescope Building.—This building has been described in Contributions from the Solar Observatory No. 2. It was completed in the summer of 1905, including all electric wiring, plumbing for dark-rooms, fire protection, etc. The framework is of steel and the canvas covering, chosen because it heats but little in the sun, is painted with fireproof paint, found by our tests to be very effective. As stated elsewhere in this report, the louvres and roof ventilation of this building have answered their purpose admirably.

Mount Wilson Shop and Power-house.—This building, described in No. 2 of the "Contributions," contains the gasoline engine, dynamo, and switchboard of the electric plant, as well as the tools needed for work of construction and repair on the mountain. The storage battery of thirty cells, installed here temporarily, has now been placed, with a second battery of sixty cells, in a separate building. The operation of the engine, using distillate in place of gasoline, has shown that electric power can be generated at very low cost on Mount Wilson, in spite of the heavy expense of "packing" the distillate to the summit. The power plant, though originally designed for the purpose of the expedition for solar research, may possibly serve, with some additions, for the much heavier demands of the Solar Observatory.

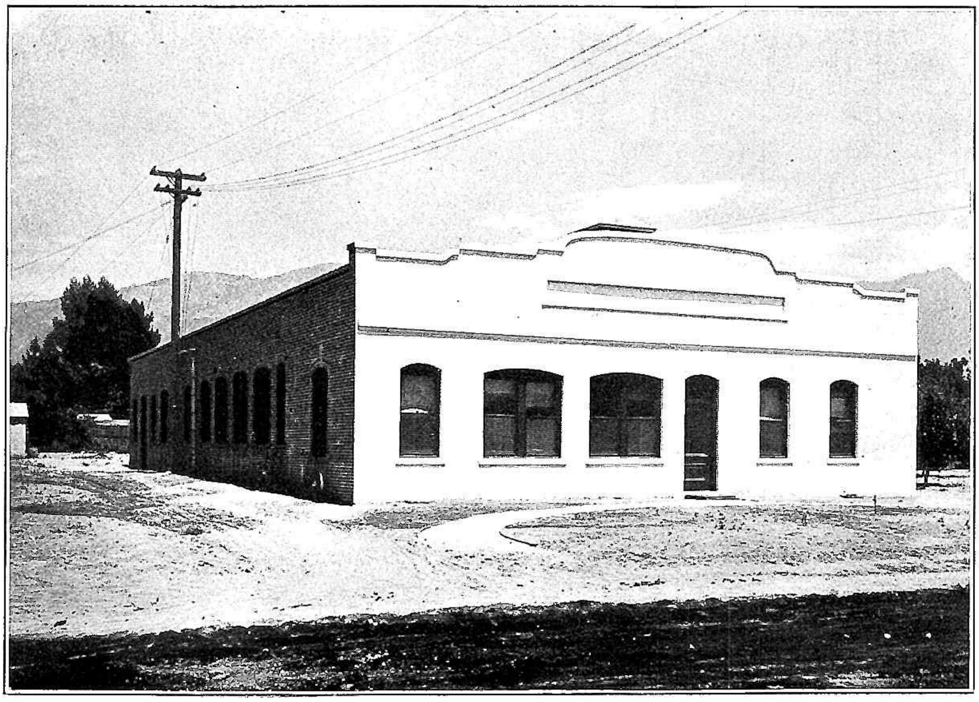
Storage-Battery House.—The intense heat experienced for a period of several days last summer and the limited space available in the small power-house led me to design an underground building of concrete for the enlarged storage battery. This building, 13 by 13 feet in size, with cement floor and ventilated roof at the level of the ground, is large enough to contain a storage battery that seems ample for the purposes of the observatory. The number of plates in each of the sixty new cells may be increased from seven, the present number, to fifteen, when more storage capacity is needed. The thirty smaller cells of the former installment are used for special purposes, such as supplying power for the spectroheliograph motors, where great constancy of voltage is necessary to give photographs free from lines or bands due to irregular motion. The Snow telescope-house, laboratories, "Monastery," guest house, and shop are supplied with electric lights.

Pumping Plant.—The water system was installed during the past summer. A small house built of cement blocks, situated at Strain's Camp, contains a Deane triplex pump, connected with a 3½ K. W. direct current motor driven by the dynamo at the power-house. The water is raised about 325 feet and carried to a concrete reservoir of 30,000 gallons capacity, situated near the north end of the Snow telescope-house, about 2,100 feet from the well. All the buildings are supplied with water from the reservoir.

Fire Protection.—The danger from forest fires on Mount Wilson has led me to take special precautions to protect our buildings. During the past summer the Solar Observatory has coöperated with the U. S. Bureau of Forestry in the construction of an extensive system of fire-breaks, guarding Mount Wilson at the most vulnerable points. It is hoped that this system may be extended next year, as it protects both the observatory and the important station of the Bureau of Forestry at Henniger's Flats. In this connection I wish to express our appreciation of the interest in the observatory shown by Mr. Gifford Pinchot, Forester, and by Mr. T. P. Lukens, in charge of the station at Henniger's Flats, under whose supervision the work has been done. I may add that the extensive work of tree-planting on Mount Wilson, so successfully inaugurated by Mr. Lukens, is likely to prove of great future benefit to the observatory.

A fire-pump, driven by an electric motor, has been established in a small house of cement blocks near the large reservoir. This pump will supply a special fire-extinguishing fluid, or water from the reservoir, to the main system of pipes connected with each building and also to a line of pipes surrounding the Snow telescope-house. Fire hose is available where needed and fire-extinguishers are placed in each building.

COURT OF "MONASTERY."



PASADENA OFFICE AND LABORATORY

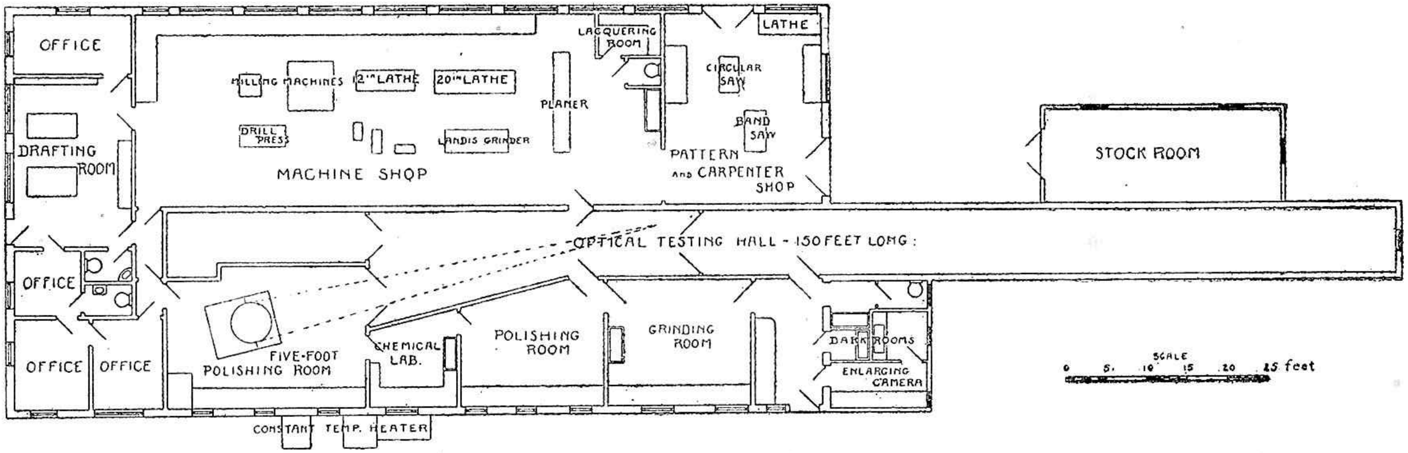


FIG. 1.—Plan of Pasadena Office and Instrument Shop.

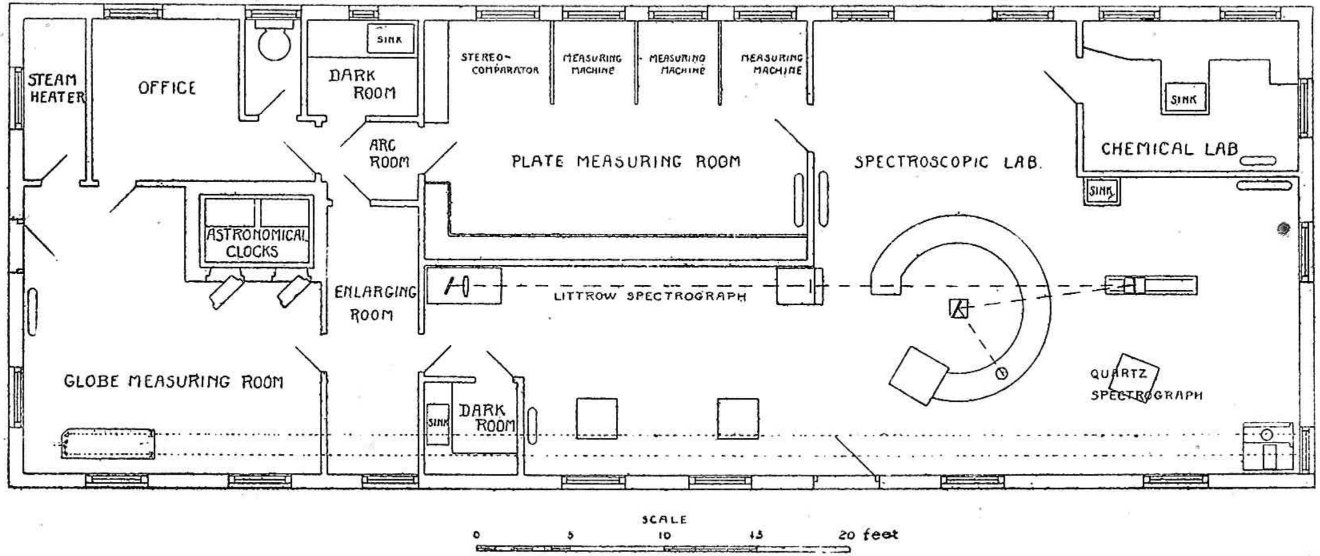


FIG. 2.—Plan of Laboratory at Mount Wilson.

The "Monastery."—The offices and living quarters provided for the members of the staff in this building (described in Contribution No. 2) have proved very satisfactory. The library and current journals are also kept here. All the members of the staff, with the members of the visiting expeditions, meet regularly at meals in the common dining-room. The opportunity thus afforded for the informal discussion of scientific questions is one of the most attractive features of life at the observatory.

Guest-House.—The need of suitable accommodations for visiting men of science has been recognized by Mr. John D. Hooker, to whom we were already indebted for meeting the expenses of the Hooker Expedition. The guest-house, recently erected and furnished at Mr. Hooker's expense, contains two bed-rooms and a large living room, with broad piazzas extending the entire length of the building on the east and west sides. It has already proved of the greatest service in the entertainment of guests, thus serving as an important adjunct of the " Monastery."

General Laboratory.—The prompt and accurate interpretation of the results of astrophysical research is a matter of the first importance in planning the work of an observatory. On the one hand, if the observations, as in the present case, are made for the most part by photographic means, the problem of providing suitable devices for the measurement and reduction of the plates presents itself. In some instances the measures must be of the highest possible precision, while in others simple devices for measurement or computation may save a great amount of time and expense without in any wise detracting from the value of the results. Special attention has been devoted to these considerations. But it is not enough to accumulate a vast series of measures without undertaking such experiments as may be required for their interpretation. Accordingly, a laboratory has been built on Mount Wilson for the measurement and reduction of the photographs and the comparative study of the radiations emitted by various substances under widely different conditions of temperature, pressure, strength of surrounding magnetic field, etc. In order to provide against the destruction by fire of the collection of photographs, the building is constructed of cement blocks, with cement floor and partitions, metal ceiling, and metal-sheathed roof. It is 27 by 70 feet in size, and thus of sufficient length to contain the special globe apparatus for measuring solar photographs, already referred to in this report. Other measuring machines have also been mentioned in the discussion of the solar investigations. The chief apparatus in the spectroscopic laboratory is a collection of light sources, including spark and arc in liquids or in gases at any desired pressure, electric furnace, Michelson tubes and mercury arc, Du Bois magnet for the Zeeman effect, etc., so arranged on a circular pier that by setting a mirror at the proper angle the light from any source may be focused on the slit of (1) a Fuess quartz spectrograph, giving nearly the whole spectrum on a single plate; (2) a Littrow grating spectrograph of 18 feet focal length; (3) a Pérot-Fabry interferometer, by Jobin, with auxiliary spectroscope; (4) a Michelson echelon spectroscope, by Hilger. It is hoped that this apparatus will be of great service in the interpretation of solar and stellar spectra. The laboratory also contains rooms for chemical experiments, photographic enlargement by electric and sky light, and developing rooms. It is heated by steam, lighted by electricity, and has ample electrical connections with the power-house and storage battery.

Warehouse.—A wooden building, 18 by 36 feet in size, has been erected near the power-house for storing building materials, etc. At present it is also used as a mess-house for the workmen.

Telephone Line.—A private telephone line, extending from the summit of Mount Wilson to the foot of the new trail, was constructed in the early spring of 1905. It connects with the lines of the Home Telephone Company, which were brought out to the foot of the trail for this purpose. All of the observatory buildings, including the pump-house at Strain's Camp, are in telephonic communication with one another, but instruments of the telephone company, connected with Pasadena, are installed only in the "Monastery" and the Snow telescope-house. The service is so good that letters can be dictated without difficulty to the stenographer at the Pasadena office.

Library.—A good working library is being purchased and installed in the "Monastery." It already includes complete sets of the Astronomische Nachrichten, Zeitschrift für Instrumentenkunde, Bulletin Astronomique, The Observatory, and Astrophysical Journal, and partial sets, extending back far enough to include the literature most needed in our work, of the Philosophical Magazine and the Annalen der Physik. Various standard treatises have been received, and the private library of the director, including sets of the Comptes Rendus, Proceedings of the Royal Society, Monthly Notices of the Royal Astronomical Society, Nature, and other journals, and a large collection of papers on astrophysical subjects, is also available. We are indebted to many individuals and to the directors of various observatories for the gift of books, pamphlets, and sets of publications.

PUBLICATIONS.

The publications of the Solar Observatory will include: (1) Contributions from the Solar Observatory, consisting of octavo papers printed also in the Astrophysical Journal (Nos. 1 and 2 have been distributed); (2) quarto volumes, forming part of the regular series of publications of the Carnegie Institution; (3) annual report of the director, from the Year Book of the Carnegie Institution, and (4) a series of reproductions of photographs, issued separately from time to time.

PASADENA OFFICE AND SHOP.

The Solar Observatory has no department more important than its instrument and optical shop in Pasadena, of which Mr. Ritchey is superintendent. When instruments of special design are needed in astrophysical research they are best constructed under the immediate observation of those whose ideas they embody. This fact, together with the saving of time and the facility of improvement or repair also afforded, has made a well-equipped instrument shop an essential part of a modern astrophysical observatory. Since the successful performance of the instruments constructed depends in large measure on the quality of the machine tools with which they are made, I have thought it wise to equip the shop with the best tools obtainable. These are enumerated in Contribution No. 2.

The shop, when first established in connection with the expedition for solar research (September, 1904), occupied rented quarters in Pasadena. The danger from fire and the necessity of having more space and special arrangements for optical work led to the construction of a substantial brick building in the spring of 1905. I wish to express our great obligations to the Board of Trade of Pasadena, which secured through public subscription funds sufficient to pay for two of the three adjoining lots (each 50 feet wide and 208 feet deep) occupied by the shop. I wish also to thank each of the contributors to the fund raised by the Board of Trade. The hearty interest shown by the citizens of Pasadena and Los Angeles in the Solar Observatory has helped us very materially. We hope that the observatory may ultimately prove of considerable public benefit. The space still available on the shop site (Santa Barbara street, near Lake avenue) will give ample room for the temporary erection of the 5-foot reflector mounting, the construction of a small building for the staff of computers, etc.

The new shop building, which is briefly described in Contribution No. 2, was first occupied in May, 1905. The machine and pattern shops were immediately fitted up and brought into use, and the optical shop, which required special fittings, has been in operation since July. A 24-inch concave mirror of 143 feet focal length and a 20-inch plane mirror have been nearly completed, and work on the 5-foot mirror is in progress.

In addition to the large amount of work done in fitting up the shop and making special tools, etc., the following instruments have been nearly or quite completed:

Spectroheliograph of 8 inches aperture and 60 inches focal length, with several sets of curved slits and various accessories.
Stellar spectrograph of 5 inches aperture and 13 feet focal length, with constant-temperature case and support for large plane grating.
Solar spectrograph (Littrow type) of 6 inches aperture and 18 feet focal length.
Spectroheliograph temporarily used with the Snow telescope.
Electric slow motions for 24-inch concave mirror of Snow telescope.
Globe-measuring machine for solar photographs.
Apparatus for removing the mirrors of Snow telescope from their cells when silvering.

All the patterns for the above work and much special furniture for the offices and laboratories have been made in the pattern shop.

FIVE-FOOT REFLECTOR.

The 5-foot mirror, which will form the principal optical part of the largest and most powerful telescope of the Solar Observatory, was brought out from the Yerkes Observatory last spring. It was packed with special precautions, under the personal supervision of Mr. Ritchey, in a double case, supported by two systems of spiral springs. The mirror arrived safely in Pasadena and is now being polished. Detailed drawings for the heavy mounting are being made by our draftsmen, under Mr. Ritchey's direction, and are so far completed as to enable the Union Iron Works Company of San Francisco to undertake work on the large castings. Several of these are finished and the nickel-steel forging for the polar axis has also been machined. There is every reason to hope that the mounting will carry the mirror with the high degree of precision necessary for the most refined photographic work.