Carnegie Institution of Washington

CONTRIBUTIONS FROM THE SOLAR OBSERVATORY
MT. WILSON, CALIFORNIA

NO. 2.

THE SOLAR OBSERVATORY OF THE CARNEGIE INSTITUTION OF WASHINGTON

BY
GEORGE E. HALE

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By GEORGE E. HALE, Director

In a report entitled "A Study of the Conditions for Solar Research at Mt. Wilson, California"[1] I have outlined the circumstances that have resulted in the establishment of a Solar Observatory on Mount Wilson[2] by the Carnegie Institution of Washington. At the recent annual meeting of the board of trustees, a grant of $150,000 was authorized, for use during 1905. It is expected that the first equipment will cost about twice this sum, and that important additions will result in the future from the operation of a large and well-appointed instrument and optical shop.

In April 1904 a grant of $10,000 was made by the executive committee of the Carnegie Institution for the purpose of bringing the Snow telescope to Mount Wilson from the Yerkes Observatory. An expedition for solar research was accordingly organized under the joint auspices of the University of Chicago and the Carnegie Institution, with the understanding that the funds granted by the Carnegie Institution would be used for the construction of piers and buildings, and for other expenses incidental to the work, while the University of Chicago would furnish the instrumental equipment, and pay the salaries of some of the members of the party. Messrs. Ritchey, Ellerman, and Adams, of the staff of the Yerkes Observatory, were to be associated with me in the work. While the executive committee of the Carnegie Institution indicated its intention of supplying further funds, if possible, for use during 1905, it was not supposed in April that provision could be made at present for the establishment of a large and fully equipped solar observatory. Nevertheless, it was agreed with the University of Chicago that if at any

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[1] See *Contributions from the Solar Observatory of the Carnegie Institution* No. 1; *Astrophysical Journal*, March 1905.

[2] The approximate geographical position of the Solar Observatory, as given (by triangulation) by the U. S. Coast and Geodetic Survey, is as follows:

Latitude, 34° 13′ 26″
Longitude, 118° 3′ 40″.

time the Carnegie Institution should decide to establish a solar observatory of its own, such an observatory would take the place of the Mount Wilson Station of the Yerkes Observatory, and the work of the Station would be continued under the sole auspices of the Carnegie Institution.

AIM OF THE SOLAR OBSERVATORY

It has been my privilege to outline the plan of research and to determine the equipment of two other observatories. The Kenwood Observatory (subsequently merged with the Yerkes Observatory) had for its prime purpose the development of the spectroheliograph, and its use in solar research. The equipment was consequently designed with this purpose in view. The Yerkes Observatory had its origin in the gift of a 40-inch refracting telescope to the University of Chicago by Mr. Charles T. Yerkes. In designing the Observatory building, and in preparing a plan of research, I felt that the obligation of securing the greatest possible return from this powerful telescope must be a paramount consideration. In the nature of the case, a thoroughly homogeneous scheme of investigation could hardly be adopted for the Observatory under these circumstances, since the lines of work for which the 40-inch telescope is peculiarly fitted are very diverse in character.[1] The various applications of the Yerkes telescope in micrometric observations by Professors Burnham and Barnard; in stellar spectroscopy by Professor Frost and Mr. Adams, and by Mr. Ellerman and myself; in lunar, nebular, and stellar photography by Professor Ritchey; in the photographic study of stellar parallaxes by Dr. Schlesinger; in stellar photometry by Mr. Parkhurst; and in solar research with the spectroheliograph by Mr. Ellerman, Mr. Fox, and myself, will suffice to indicate that a serious attempt has been made at the Yerkes Observatory to realize the full possibilities of this magnificent instrument. But while recognizing the special demands of the 40-inch telescope, I have constantly kept in mind the development of other departments of the Observatory's work. Without enumerating these,[2] I shall confine my remarks to a line of effort which is of importance in the present connection,

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[1] See "The Aim of the Yerkes Observatory," an address delivered at the formal inauguration of the work in 1897. *Astrophysical Journal*, **6**, 310, 1897.

[2] The results accomplished are epitomized in the *Reports of the Director*.

since it has defined the chief elements in the plan of research of the new Solar Observatory.

Both in the Kenwood and the Yerkes Observatories the instrument shop was regarded as of great importance, since it alone rendered possible the construction and frequent improvement of instruments of new type or special design. The Rumford spectroheliograph, the Bruce spectrograph, the two-foot reflecting telescope, and the Snow telescope are among the products of this shop. The operations of the shop were not confined to the construction of the mechanical parts of instruments; provision was also made for optical work on a large scale, under the direction of Professor G. W. Ritchey, who also succeeded Professor F. L. O. Wadsworth in the direction of the mechanical work.

In 1896, recognizing the great possibilities of the reflecting telescope for astrophysical research,[1] I engaged Professor Ritchey for the purpose of constructing a mirror of five feet aperture. An account of the methods employed in the grinding of this mirror has recently been given by Professor Ritchey.[2] My father's hope that he might be able to provide a suitable mounting for the five-foot mirror was frustrated by his death in 1898. At that time the fine grinding of the spherical surface had been completed, and the demands of other optical work rendered it advisable to discontinue further operations until funds for a mounting could be obtained. Many attempts were made to secure these funds, but they all proved ineffectual. Meanwhile, the success achieved by Keeler and Perrine with the three-foot Crossley reflector, and the remarkable results obtained by Ritchey with the two-foot reflector of the Yerkes Observatory, directed renewed attention to the possibilities of reflecting telescopes. It soon became clear that a five-foot mirror, if properly mounted, would give results entirely beyond the reach of existing instruments. The committee of the Carnegie Institution on the projects for southern and solar observatories accordingly felt that such a telescope should be included in the Solar Observatory equipment. The figuring and mounting of the five-foot mirror will therefore be undertaken as soon as possible.

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[1] "On the Comparative Value of Reflecting and Refracting Telescopes for Astrophysical Investigations," *Astrophysical Journal*, **5**, 119, 1897.

[2] *Smithsonian Contributions to Knowledge*, Vol. XXXIV.

It is a fortunate circumstance that the construction and use of a great reflecting telescope is a logical element in the general plan of research laid down for the Solar Observatory. In *Year Book* No. 2,[1] of the Carnegie Institution may be found a report on this subject, prepared at the request of Professors Boss and Campbell, my colleagues on the committee, and improved in many particulars as the result of their criticisms. The prime object of the Solar Observatory is to apply new instruments and methods of research in a study of the physical elements of the problem of stellar evolution. Since the Sun is the only star near enough the Earth to permit its phenomena to be studied in detail, special attention will be devoted to solar physics. It is hoped that the knowledge of solar phenomena thus gained will assist to explain certain stellar phenomena. Conversely, the knowledge of nebular and stellar conditions to be obtained through spectroscopic and photographic investigations with the five-foot reflector should throw light on the past and future condition of the Sun. All of the principal researches will thus be made to converge on the problem of stellar development. The name "Solar Observatory" is regarded as appropriate, since the spectroscopic study of stars and nebulæ, to be carried on in connection with the solar work, are essential elements in any attempt to determine the mode of origin, the development, and the decay of the Sun as a typical star.

How, then, shall we attack in an effective manner the complex problem of stellar evolution? It goes without saying that I can offer no general answer to this question; I can only point out the three principal lines of attack which we hope to pursue at the Solar Observatory. These involve:

1. The more complete realization of laboratory conditions in astrophysical research, through the employment of fixed telescopes of the cœlostat type, and through the adoption of a *coudé* mounting for the five-foot reflector. This should permit: (*a*) the use of mirrors or objectives of great focal length, thus providing a large image of the Sun for study with spectroscopes and spectroheliographs; (*b*) the use of long focus grating spectroscopes, mounted in a fixed position in constant temperature laboratories, for the photography of stellar spectra requiring very long exposures; (*c*) the use of various labora-

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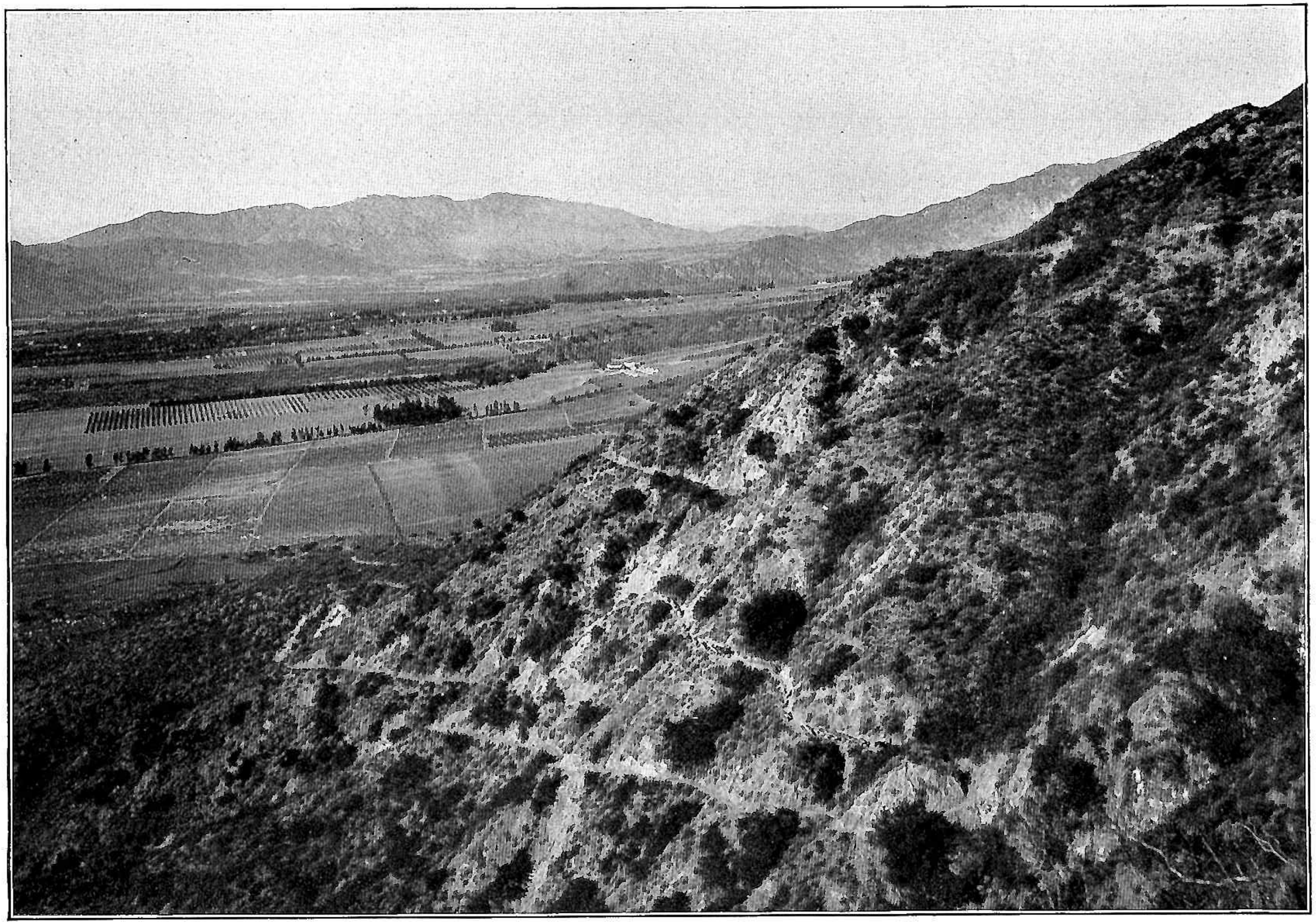
[1] Page 49.

PLATE I



Lower Part of Mount Wilson Trail, Showing Pack Animals Loaded with Lumber tory instruments, such as the radiometer, which cannot be employed in conjunction with moving telescopes.

2. The development of the spectroheliograph in the various directions suggested by recent work at the Yerkes Observatory, including the photography of the entire solar disk with dark lines of hydrogen, iron, and other elements; further application of the method of photographing sections of flocculi corresponding to different levels; special studies of sun-spots, etc.; and daily routine records of calcium and hydrogen flocculi and prominences.

3. The construction of a five-foot equatorial reflector, with *coudé* mounting, and its use in the photography of nebulæ, the study of stellar and nebular spectra, and the measurement of the heat radiation of the brighter stars.

It was originally intended that a prolonged series of determinations of the solar constant, extending over at least one sun-spot period, should be made an important feature of the Observatory's work. The plans outlined in *Year Book* No. 2 accordingly included an equipment at Mount Wilson for this purpose, and suggested, in harmony with Dr. Langley's view, that provision be made for two additional stations, one near the summit of a high mountain, at an elevation of about 12,000 feet, the other at a much lower level on the same mountain. The principal purpose of these two stations was to measure the atmospheric absorption, in order to eliminate it from the solar constant determinations. The recent developments of Dr. Langley's researches at Washington have led Mr. Abbot, who is associated with Dr. Langley in the work, to the conclusion that entirely satisfactory results can be obtained there by the method employed. The poor atmospheric conditions with which the Washington observers have so successfully contended, and the disturbances arising from ground tremors in the heart of a large city, would be largely eliminated at Mount Wilson. For this reason it seems probable that results of higher precision could be obtained at this site. I have accordingly offered Dr. Langley facilities for pursuing the investigation at Mount Wilson, which I trust he may find it possible to accept.

In addition to the above-mentioned observations, provision will be made at Mount Wilson for various laboratory investigations necessary in conjunction with solar research. In view of the importance of securing a complete record of solar phenomena when magnetic storms are in progress, suitable magnetic apparatus, recommended by Dr. L. A. Bauer, in charge of the Department of Terrestrial Magnetism of the Carnegie Institution, will be installed at a sufficient distance from the electrical machinery.

TRANSPORTATION OF MATERIAL

The first problem that confronts one in undertaking the construction of buildings and the erection of instruments on Mount Wilson is that of transportation over the trail from the valley. Two trails are available—the "Old Trail," from Sierra Madre, and the "New Trail," from the foot of Eaton Cañon, six and one-half miles from Pasadena. The New Trail, which is much the better of the two, is about nine miles long. At its narrowest points it is little over two feet in width, and in some of these places it had to be widened before the transportation of the heavy parts of the Snow telescope could be attempted. For ordinary packing with "burros" (donkeys) or mules the trail is well adapted. The loads brought up in this way range from 80 to 225 pounds per animal, and the charges from $1 to $1.35 per hundred pounds. On account of the expense of transportation over the trail, the best cement costs on the mountain more than twice as much as in the valley.

With a single exception, all parts of the 15-inch cœlostat, which was erected on Mount Wilson in April 1904,[1] were brought up on animals. The equatorial head of this instrument, which weighs about four hundred pounds, is too heavy to be carried in this way. A carriage was accordingly improvised for it from a two-wheel truck, such as is used by the railway companies for trunks. This served the purpose fairly well, though two days were required for the trip up the mountain. It was evident that a different arrangement would be required for heavier castings.

After provision had been made for the use of the Snow telescope on Mount Wilson, the carriage shown in Plate II was designed. The running gear consists of four automobile wheels, 28 inches (71 cm) in diameter, with 2½ inch (6.3 cm) rubber tires. The distance between the

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[1] See *Contributions from the Solar Observatory*, No. 1, *Astrophysical Journal*, March 1905.

PLATE II

Truck for Hauling Heavy Instruments on Mount Wilson Trail wheels was limited by the width of the trail to 24 inches (61 cm). The bed of the truck is hung by wrought-iron yokes from the running gear, the lower surface of the bed being at a height of 6 inches (15 cm) above the ground. Steering gear, of the type used on automobiles, is provided for both pairs of wheels. A man riding on the load steers the forward wheels with a hand wheel, while the rear wheels are steered with a tiller by a man walking behind the carriage. A single large horse pulls a load of a thousand pounds on this carriage without difficulty. With two horses, used in relays, the trip from the lower end of the trail to the summit and return (a total distance of about nineteen miles) is completed with such a load in less than two days (about fifteen hours on the trail). With loads not exceeding 700 pounds the round trip is completed in a single day. Up to the present time the truck has made fifty round trips, carrying all the mirrors, lenses, and heavy castings of the Snow and Bruce telescopes, the parts of a fifteen horse-power gas engine, and other heavy machines, as well as the four-inch pipe columns (some of them twelve feet long) used in constructing the steel skeleton of the telescope house (Plate IV). The lighter angle-iron and other parts of the telescope house were brought up on burros. The total weight of material carried over the trail for the present work amounts so far to about 175 tons.

As the steering and control of the carriage on the narrow mountain trail is a difficult and dangerous task, special mention should be made of the excellent work of Mr. C. O. Sparks, who has been in charge of the carriage on all of its trips. It is to the credit of Mr. Sparks that nothing has been lost or injured during transportation.

Before the heavy castings (some of them weighing as much as five tons) required for the mounting of the five-foot reflector can be taken up Mount Wilson, the trail must be widened or some other mode of transportation provided.

THE SNOW TELESCOPE

As no description of this instrument has been published, the present brief account may be prefaced by a statement regarding the construction of the telescope.

In designing the Yerkes Observatory in 1894, I provided a large heliostat room, 12 feet (3.66 m) wide and 104 feet (31.7 m) in length.[1] A small heliostat loaned by Professor Keeler was used in this room in 1897, and it was intended to mount permanently there, mainly for spectroscopic work, a combined heliostat and cœlostat designed by Professor Wadsworth.[2] When employed as a cœlostat, a second fixed mirorr was to be used with the instrument, so as to give the desired direction to the reflected beam.[2] Some of the patterns for this instrument were made, but the pressure of other work made it necessary to postpone the construction for some time.

In 1900, after Professor Ritchey had succeeded Professor Wadsworth as superintendent of instrument construction, a cœlostat with mirror of 15 inches (38 cm) aperture was made, from Professor Ritchey's designs, for the total solar eclipse of that year. This gave such satisfactory results that the plan of constructing a large cœlostat was again taken up. Unfortunately, however, no funds were available for this purpose. In 1901, during a visit to the Observatory of Professor Cross, chairman of the Rumford Committee, I showed him the details of the instrument, as worked out by Professor Ritchey. The design called for a cœlostat of 30 inches (76 cm) aperture, with second plane mirror of 24 inches (61 cm) aperture, the latter mounted so as to slide northeast and southwest on rails lying east of the cœlostat. The concave mirror, to which the light was reflected from the second plane mirror, had a focal length of 61 feet, and a second concave mirror, of 165 feet (50.3 m) focal length, was also to be used. For this reason the heliostat room, 104 feet (31.7 m) in length, was not long enough for our purpose, and the position of its axis, in the meridian, involved loss of light. It was accordingly necessary to erect a long wooden building, on the ground south of the Yerkes Observatory.

At the kind suggestion of Professor Cross, a grant of $500 was made by the Rumford Committee in aid of an investigation to be undertaken with this telescope. Subsequently, through the kindness of Professor Pickering, chairman of the Draper Committee, two other grants, of $500 each, became available. With these funds,

[1] See "The Yerkes Observatory of the University of Chicago," Part II, *Astrophysical Journal*, 5, 260, 1897.

[2] *Ibid.*, p. 261.

helped out by small amounts obtained from other sources, the work was begun.

An account will be published later of this cœlostat and its accessory apparatus. The long wooden house on the Observatory grounds which contained it was destroyed by fire on December 22, 1902, through the breaking down of the insulation of a high-voltage electric transmission line, which supplied the spark used for a comparison spectrum. A 24–inch plane mirror and some of the mirror supports were saved, but most of the apparatus was completely destroyed or rendered useless.

Confident that the necessary funds could be obtained from some source, I decided to construct at once a new and better instrument, and to provide for it a more suitable house. Two important changes were made in the design. In the tests of the telescope, made by Mr. Adams and myself, the definition was poor, both in the case of the Sun and the stars. I attributed this in part to the fact that the cœlostat was mounted on a pier, the surface of which was only a few inches from the ground. This led me to observe distant objects at various heights above the ground with the naked eve, with field glasses and small telescopes, and finally with the 12-inch refractor, which stands on a pier about 40 feet (12.2 m) high. I soon reached the conclusion that the cœlostat must be mounted as far as possible above the ground, and that a site shaded by low trees or bushes would be much better than unshaded soil.

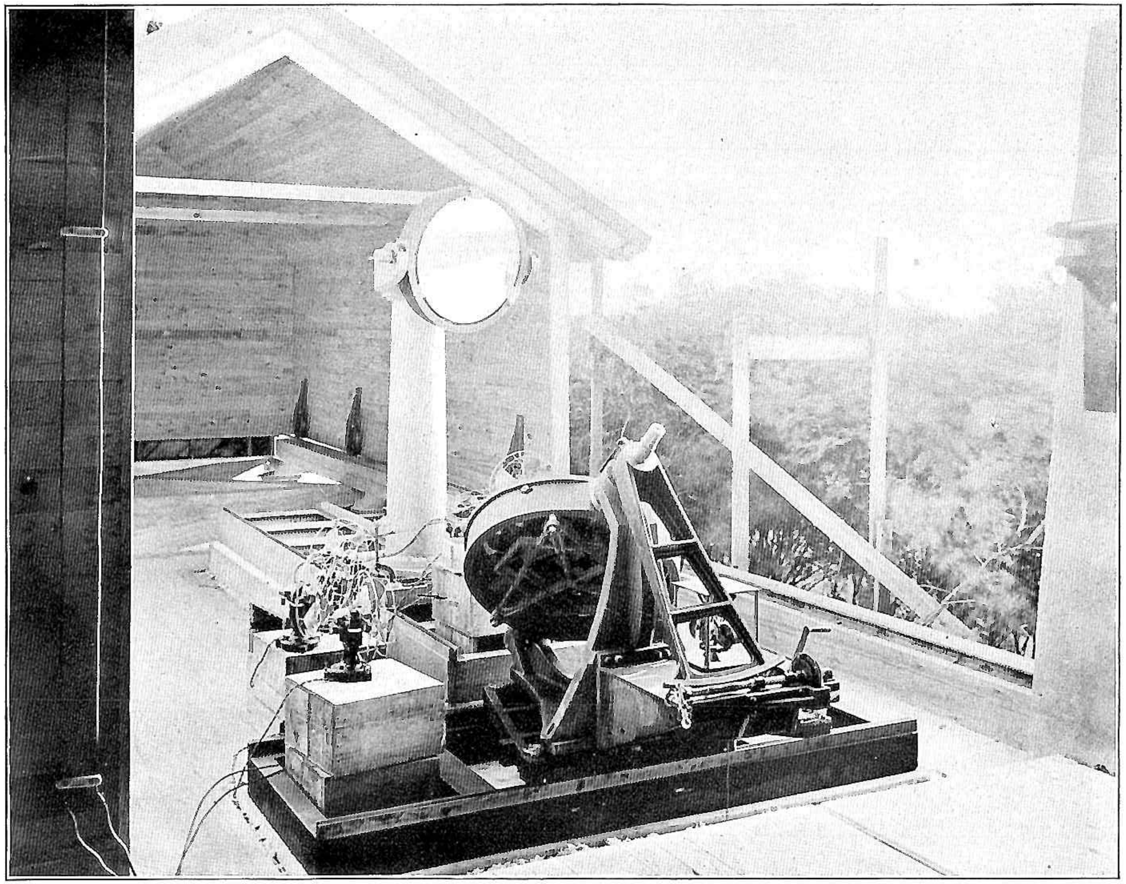
A gift of $10,000 from Miss Helen Snow, of Chicago, in memory of her father, the late George W. Snow, provided sufficient funds to complete the telescope and to instal it in a suitable house. The cœlostat was mounted on a brick pier, at a height of 15 feet (4.57 m) above the ground. In Professor Ritchey's design of the previous instrument the rays were reflected in a northeasterly direction from the cœlostat mirror to a second plane mirror, which sent them toward the southwest to one or the other of the concave mirrors. In designing the Snow telescope, a new arrangement of the second mirror was adopted by Professor Ritchey, at the suggestion of Mr. C. G. Abbot. As Plate III indicates, thelight is reflected upward and to the south from the cœlostat mirror to a second plane mirror, mounted in a fork at the upper extremity of an iron column, on a carriage which can be moved along heavy iron rails. The position of this carriage on the rails depends upon the declination of the observed object: with a low Sun the second mirror stands close to the cœlostat, but with a high Sun it must be moved away in order to intercept the reflected beam. The cœlostat itself may be moved east or west on its own rails, so that a low object near the meridian may not be hidden by the second mirror or its support.

With the exception of the solar and stellar spectroscopes, for which suitable gratings could not be obtained, the Snow telescope was practically completed in the autumn of 1903. On October 3 of that year it was formally presented to the University of Chicago by Miss Snow, in the presence of a number of guests. Dr. George S. Isham, on behalf of Miss Snow, made the presentation address. The address of acceptance was made by Dean R. S. Salisbury, of the Ogden Graduate School of Science. The manner of using the telescope was afterward demonstrated.

The tests of the telescope made at this time seemed to indicate a decided improvement in definition, which I attributed to the greater elevation of the cœlostat. The Sun's image was frequently well defined, in spite of the change of focus due to the heating of the mirrors. Of this change more will be said later. At present I wish to refer especially to the definition as affected by the design of the telescope house.

The parallel beam from the second mirror was reflected due north through a spectroscopic laboratory into a long, narrow room, at the end of which the concave mirror stood on a massive brick pier. After striking the mirror, the beam was reflected back, so as to form an image of the Sun or a star in the spectroscopic laboratory a short distance from the axis of the parallel beam. The walls and floor of the house are of wood, and the question arises whether their radiation may not heat the air in the house, and thereby affect the definition. In general, the temperature of the air within such a house must differ in some degree from that of the air outside. Hence, some effect on the definition might be expected. The warm air rising about the cœlostat, due in part to the heating of the wooden walls which surround the pier, may also cause some disturbance of the image.

PLATE III



The Snow Telescope when Mounted at the Yerkes Observatory

Rayleigh has shown that in a telescope tube only 12 cm long, a stratum of air in the upper part of the tube, occupying only a moderate fraction of the entire volume, would produce a sensible effect on the definition if heated 1° C.[1] In a tube 60 feet (18.3 m) long, through which the beam passes twice, the difference in temperature of a stratum, required to produce a similar effect, would be only about one three-hundredth of a degree. The assumed retardation is one-quarter of a wave, and the change of temperature from one side of the beam to the other is supposed not to be uniform.

To the practical observer such a result may seem to have little meaning. I have repeatedly seen the solar image beautifully defined with the 40-inch (102 cm) Yerkes refractor, when the air within the tube had become greatly heated—and certainly not uniformly so—after hours of continuous observation. Indeed, it is difficult to understand how such excellent definition can be obtained under these conditions. For in the optical testing-room Rayleigh's conclusions are easily verified. The great difficulty of securing a satisfactory test of a mirror by the Foucault test is well known; with a focal length as great as 145 feet (44.2 m) our opticians have waited for weeks to obtain a satisfactory test, even in the quiet air of the long testing-room in the basement of the Yerkes Observatory. The trouble resulting from stratification of the air, and the disturbance caused by the proximity to the beam of a person's hand, are familiar to all opticians. With these difficulties in mind, the problem of obtaining really good images of the Sun appears very serious. Yet the fact remains that good images are sometimes obtained. The great height of the 40-inch objective above the ground is probably an important advantage of this telescope, though the radiation of the dome on each side of the shutter-opening must produce some disturbance. The mere heating of the cell of the objective by the Sun would seem to be a sufficient cause for serious disturbance of the definition. Of course it is extremely probable that with sufficiently good atmospheric conditions all of these heating effects are actually perceptible in some degree, and that if they could be eliminated the seeing would

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[1] *Collected Papers*, Vol. I, p. 434.

be much better than it is now. A skeleton tube, with a simple device for shading the cell, would probably be advantageous.[1]

During the tests of the Snow telescope at the Yerkes Observatory, Langley's plan of stirring the air along the path of the beam was tried. The beam was made to pass through a tube of thick building paper, supported on a light wooden frame of square section, about 36 inches (91 cm) square. Electric fans were mounted at openings cut in the walls of the tube. When running at high speed, they kept the air within the tube in constant motion. At times the image of the Sun was distinctly improved in definition soon after the fans were started; but in other cases no improvement whatever resulted. It nevertheless seemed probable that a modified method of stirring the air might advantageously be employed for the Snow telescope house on Mount Wilson, and a tentative design was prepared. But further tests, made at my request by Professor Ritchey, indicated that we could not hope for satisfactory results without much more experimenting than we could afford to undertake. I accordingly abandoned this plan, and designed the cœlostat house described below.

CŒLOSTAT HOUSE ON MOUNT WILSON

In designing the new cœlostat house, I was influenced by two principal considerations:

1. The importance of placing the cœlostat as far as possible above the ground, which had been indicated by observations made with a telescope in a tree at elevations ranging from twenty to seventy feet.

2. The importance of constructing the house in such a way as to reduce to a minimum the heating and the radiation of the floor, walls, and ceiling, with the purpose of keeping the air within the house at the same temperature as the outer air.

In plan (Fig. 1), the building resembles the Snow telescope house at Williams Bay. The cœlostat stands on a carriage, which

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[1] The case of the 40-inch telescope tube is doubtless hardly comparable with that of the Snow telescope house. The 40-inch tube is sealed by the objective at the upper end, and there is little mixture of the heated air of the tube with the cooler air outside. For this reason it would be interesting to close the end of the telescope house (near the cœlostat) with an objective, and try the definition under such conditions, i. e., without the concave mirror.

can be moved east or west along the rails, *a a*. On account of the configuration of the ground, which falls rapidly toward the north, it was necessary to make the long axis of the building run fifteen degrees east of north, instead of being exactly in the meridian. For the same reason this axis is not horizontal, but inclines downward five degrees toward the north. Without these modifications of the original plan, the height of the northern part of the building would have been very great, involving serious increase of expense. The rails *b b*, on which the carriage bearing the second mirror slides, are parallel to the optical axis.

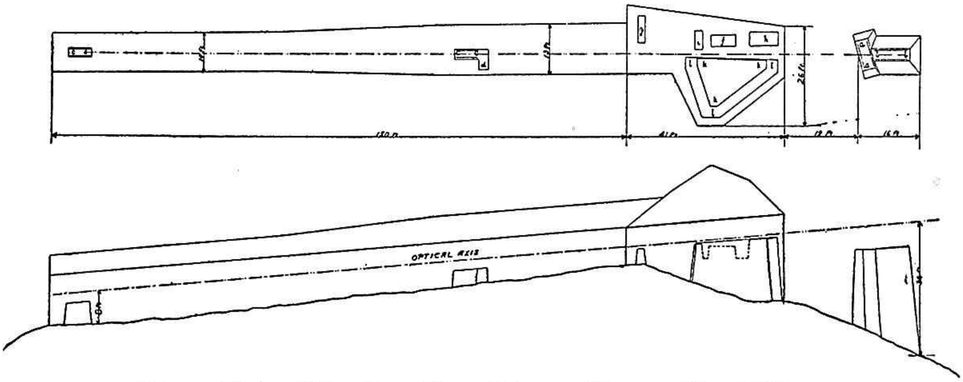


FIG. 1.—Plan and Elevation of Snow Telescope House on Mount Wilson.

Two concave mirrors, each of 24 inches (61 cm) aperture, are to be used. Of these, the mirror of 60 feet (18.3 m) focal length is mounted on its carriage so that it can be moved (for focusing), along the rails *c c*. The mirror of 145 feet (44.2 m) focal length is to be similarly mounted on the rails *e e*. When the long-focus mirror is to be used, the mirror of 60 feet focus is moved to one side, on the extension of its pier at *d*.

In designing the spectroscopic apparatus for the telescope, I have had the benefit of valuable suggestions from all members of the staff. The instruments are to be five in number, as follows:

1. A spectroheliograph with portrait lenses of 8 inches (20.3 cm) aperture, and 60 inches (152 cm) focal length, provided with four dense flint prisms. This instrument is to be carried on the pier *f*, where it will be floated in mercury (to reduce the friction of steel balls

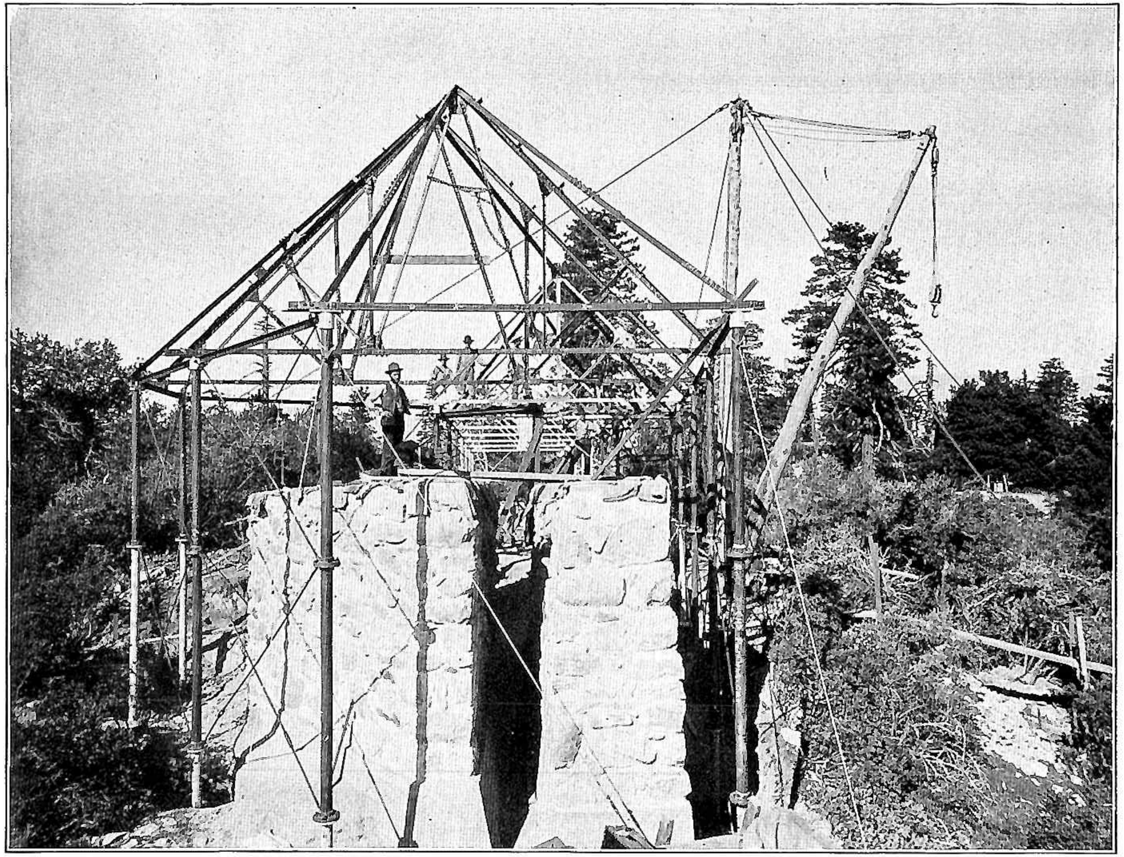
running in V rails), and moved as a whole across the 6.7 inch (17 cm) solar image given by the mirror of 60 feet focal length. The principal purpose of the instrument is to secure daily photographs of the entire solar disk with the calcium and hydrogen lines.

2. A spectroheliograph with lenses of 5 inches (12.7 cm) aperture, and 30 feet (9.14 m) focal length, provided with three light flint prisms of 50° angle. The first and second slits of this spectroheliograph are to stand on the pier *g*, while the collimator and camera lenses and the prism train will be carried by the pier *h*. The spectroheliograph will be fixed in position, and the 16-inch (41 cm) solar image given by the mirror of 145 feet focal length will be moved across the slit by a slow motion of rotation, about a vertical axis, of the 145 foot mirror. At the same time, the photographic plate will be moved synchronously across the second slit. The principal purpose of this instrument is to photograph zones about 4 inches (10 cm) wide of the large solar image, using the lines of iron and other elements which are too narrow to be employed with spectroheliographs of small dispersion. The instrument will also be employed with a plane grating, as a spectroscope for the study of the spectra of sun-spots, etc.

3. A Littrow spectrograph of 18 feet (5.49 m) focal length, with large plane grating. The single objective (on pier *h*), that serves for collimator and camera, will form an image of the spectrum just above the slit (on pier *j*). This spectrograph will be used with the 60-foot mirror, mainly for a study of the solar rotation and the spectra of sun-spots.

4. A concave grating stellar spectrograph, of about 15 feet (4.57 m) equivalent focal length, mounted on the massive pier *k k k* in the constant-temperature room *l l l*. A collimating lens of 5 inches (12.7 cm) aperture will be used with the grating, in order to avoid astigmatism. For the present, until a suitable concave grating can be obtained, a plane grating will be used with a camera lens of 5 inches aperture, and about 13 feet (3.96 m) focal length. This spectrograph is to be employed with the 60-foot mirror in an attempt to photograph, with high dispersion, the spectra of some of the brightest stars. The fixed position of the spectrograph on a massive stone pier, and the possibility of maintaining the grating at a constant temperature, should render very long exposures feasible.

PLATE IV



House for Snow Telescope on Mount Wilson
Looking North from Cœlostat Pier

5. A prism spectrograph, with collimator lens of 1½ inches (3.8 cm) aperture and 45 inches (114.5 cm) focal length, dispersion of from one to four prisms, and camera lenses of various focal lengths, all of ultra-violet glass. The optical parts of the spectrograph will be mounted in such a way that they can be used on the large pier in the constant-temperature room, in conjunction with the slit of the concave grating spectrograph. The prism spectrograph will be used for special studies of stellar spectra, especially in the ultra-violet region.

It is to be understood that instruments 1, 2, and 3 are to be so supported, at different levels, that they will not interfere with one another, and will always be ready for use. The prism spectrograph, however, must be moved to one side when the concave grating spectrograph is to be employed.

The arrangement of the apparatus having thus been explained, let us consider more particularly the construction of the building. As Plates IV and V show, the structure is of steel, as light as due regard for occasional high winds will permit. Steel guy ropes, anchored to large masses of concrete, afford the additional strength required in the heavy storms of winter. Since the parallel beam from the cœlostat to the concave mirror passes through a closed tube, it is not essential that this part of the building should stand high above the ground. Where the rays of the Sun fall upon the cœlostat itself, however, there can be no protection of the beam, and consequently it is desirable that the cœlostat should stand at a considerable elevation. After many tests of the seeing had been made at various points on the mountain, a site was finally selected which seemed to meet the required conditions. The cœlostat pier stands on a south slope, commanding a practically unobstructed horizon. At its south end this pier rises 29 feet (8.8 m) above the ground; hence, as the center of the second mirror is 74 inches (1.88 m) above the pier, the optical axis of the telescope is at this point about 35 feet (10.7 m) above the ground. At the north end of the pier the rising slope of the hill decreases this height to about 25 feet (7.6 m). When not in use, the cœlostat and second mirror are covered by a house on wheels, closed at both ends by double walls of heavy canvas. These may be opened, so that when the house is moved to the north, the cœlostat stands completely exposed. The movable shelter then fits closely against the south wall of the spectroscopic laboratory, and thus forms a part of the tube through which the beam passes. When in this position the shelter has a canvas floor, so that the beam is completely protected from ascending currents after it leaves the north end of the cœlostat pier.

All parts of the building, including the movable shelter, the spectroscopic laboratory, and the long, narrow house extending north from the spectroscopic laboratory, have an inner wall and ceiling of canvas, and an outer wall composed of canvas louvres, very completely ventilated. The roof is also ventilated, by wooden louvres at the ridge, thoughout the entire length of the movable shelter and the north extension, and at the peak of the laboratory. Rain and snow are prevented from entering the roof louvres by means of canvas curtains, which can be raised or lowered at will. The house extending north from the laboratory has a floor of canvas, with an air-space below, through which the air may pass freely.

In traversing the spectroscopic laboratory, the beam necessarily passes very close to the wall of the constant-temperature room. To diminish the effect of radiation from this wall, a covering of sheet metal is arranged so that a constant current of air may be drawn between the sheet metal and the wall by means of an exhaust fan. Outer air is brought in from the west side of the laboratory, and no internal drafts are created, as the connections between the air-space and the supply and exhaust tubes are perfectly tight. It is hoped that any evil effects of radiation from the stone piers and the wooden floor of the spectroscopic laboratory can be eliminated by similar devices.

The louvres surrounding the cœlostat pier are intended to protect the pier from vibration caused by the wind, and from heating by the Sun. The steel structure does not touch the pier at any point, and is therefore made rigid enough to support itself in high winds.

The cœlostat, and the supports for the plane mirror and the 60-foot concave mirror, are now in place on the piers, but heavy storms have prevented the mirrors from being mounted. The concave grating stellar spectrograph is nearly ready to be set up, and work is well advanced on the smaller of the two spectroheliographs. The ultraviolet glass prisms and lenses for the stellar spectrograph have been

PLATE V

House for Snow Telescope on Mount Wilson
Showing Cœlostat Pier and Movable Shutter

completed by the Carl Zeiss Company, and orders have been placed for the optical parts of the 30-foot spectroheliograph and the Littrow spectrograph. Through the courtesy of the president and trustees of the University of Chicago, the Snow telescope and some of its accessories will be used by the Solar Observatory for some time. It will subsequently be replaced by a similar telescope constructed in our own instrument shop.

THE HOOKER EXPEDITION

As the result of a gift of $1,000, made by Mr. John D. Hooker, of Los Angeles, the Bruce photographic telescope of the Yerkes Observatory has been brought to Mount Wilson by Professor Barnard, for use during a period of several months, after which it will be returned to Williams Bay. A full description of this telescope has recently been published by Professor Barnard in the *Astrophysical Journal.*[1] The house built for the Bruce telescope on Mount Wilson has a sliding roof, which leaves the entire sky free when it is pushed back. Professor Barnard has already obtained some excellent photographs of *Orion* and other constellations. Their quality is such as to give promise of important results, as soon as the stormy weather of the rainy season abates sufficiently to permit long exposures to be given.

THE "MONASTERY"

In the original estimates for the Solar Observatory, made by the committee of the Carnegie Institution, $52,500 was set apart for the construction of dwelling houses on Mount Wilson for the families of the staff, and $51,000 for a large building, containing offices for all the members of the staff, and rooms for laboratories and instrument shops. In these particulars the report simply adopted the plan followed by the Lick and Yerkes Observatories. A residence of six months in a log cabin on Mount Wilson, under conditions which rendered necessary the greatest economy of expenditure, convinced me that a better use could be made of the Institution's funds. In the first place, it is by no means desirable to confine families, and especially children deserving every educational advantage, within the narrow limits of an isolated observatory colony. Furthermore,

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[1] **21**, 35–48, 1905.

the work of an instrument shop, and much routine computing as well, can be done at much less expense and to better advantage in a town, where foundries and various sources of supply are at hand, and better workmen and computers can be employed. Finally, a great economy can be effected by using funds for instruments, machinery, and books—the tools of the investigator—that would otherwise be spent for mere buildings. In short, I believe the principle should be recognized that the mountain site is valuable for *observations*, and that most other classes of work can be better done elsewhere. These considerations strike one most forcibly in a place where the cost of building materials is doubled by transportation over the trail.

The isolation of most mountain sites, however, might seem to demand that the staff of such an observatory should be composed only of celibates, or that its members must be content to experience long periods of separation from their families. In this particular Mount Wilson is most fortunately situated. The city of Pasadena, which is hardly to be surpassed as a place of residence, lies at the very foot of the mountain, and can easily be reached in two and one-half hours. Los Angeles, with its large machine shops, foundries, and supply houses, is also near at hand. It is thus perfectly feasible to have the families of the observers live in Pasadena, where members of the staff can spend Sundays, and go on business at other times. We are following this plan, and find it is as satisfactory as could be expected under the circumstances.

I consider it very desirable that each member of an observatory staff, if engaged in work requiring concentrated attention, such as computing or measuring, should have a workroom of his own. The space occupied may be very small, but it should certainly be set apart for individual use. This requirement, together with the necessity of supplying living accommodations for the astronomers, determined the design of the "Monastery."

As shown in plan in Fig. 2, the building has two wings; one containing the dining-room, kitchen, pantries, two bedrooms, woodshed, etc.; the other, the bedrooms and offices of the astronomers, guest-room, bathroom, etc., opening on a long, narrow hall. Each astronomer has a small bedroom and an adjoining office. The convenience of this arrangement, and the satisfaction it has given to all the members of the staff, indicate that a great saving in expense, without loss of efficiency, will be effected. The large room, with stone fireplace, which unites the two wings, serves as a general library. The "Monastery" stands at the extreme end of a narrow point with precipitous walls, and commands a fine view of the neighboring mountains, the San Gabriel Valley, the cities of Pasadena and Los Angeles, and the Pacific Ocean. It was designed, after our plans, by Messrs. Hunt & Gray, architects.

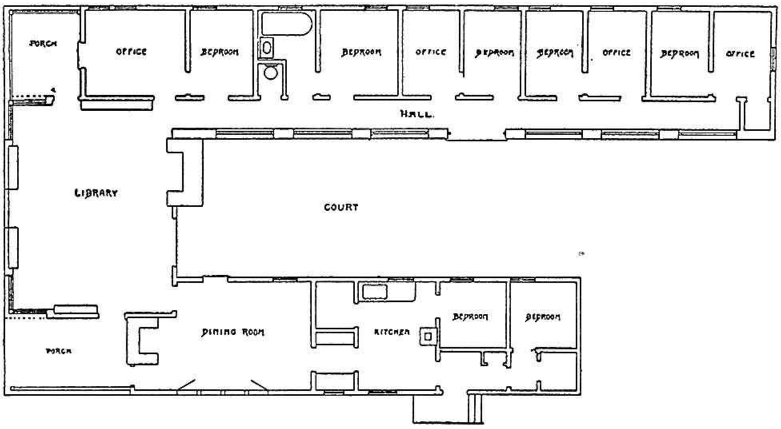

FIG. 2.—Plan of the "Monastery."

Through a recent gift from Mr. John D. Hooker, a small guest-house, containing two bedrooms and a living-room, will soon be erected near the Monastery.

POWER HOUSE AND REPAIR SHOP

A one-story building, 15×35 feet (4.57×10.67 m), situated between the Snow telescope and the "Monastery," is equipped as a small power-house and repair shop. It contains a 15 horse-power Witte gasoline engine; $7\frac{1}{2}$ K. W. dynamo, giving either alternating or direct current; storage battery of thirty cells, small screw-cutting lathe; Rivett milling machine; sensitive drill; emery grinder; Oliver trimmer; forge and anvil; and a good assortment of small tools needed for repairs and for a certain amount of construction work.

Although our large instrument shop in Pasadena is prepared to undertake any class of work, I regard a small shop on the mountain as indispensable. The engine, dynamo, and storage battery furnish current for arc and spark discharges, and for temperature control required in spectroscopic work, power to run the spectroheliographs, exhaust fan, etc., and light for the offices and laboratories.

A line for transmitting electric power from the San Gabriel Valley will be installed later, since much more power will be required for the 5-foot reflector and other purposes. The present power plant was provided before it was known that a large Solar Observatory would be established by the Carnegie Institution.

It was originally intended to supply water to the various buildings from a well at Strain's Camp, about 325 feet (99 m) below the summit of Mount Wilson; but as the well yielded almost no water last autumn (after an unusually dry period), it is likely that a more reliable source will be chosen.

GENERAL LABORATORY

A small laboratory building, probably of fire-proof construction, will be erected near the Snow telescope in the spring. This will contain a large grating spectrograph, with various accessory apparatus, such as a Du Bois half-ring electromagnet for the Zeeman effect, an arc in pressure chamber, a transformer and condenser for studies of spark discharges, etc. The equipment will also include a Pulfrich stereocomparator, principally for the study of spectroheliograph plates; an Abbe spectrometer; an interferometer, for the measurement of absolute wave-lengths; measuring machines for spectra and for stellar photographs; globe for the measurement of heliographic positions, etc. In addition to the spectroscopic laboratory, the building will contain a small chemical laboratory, an enlarging room, photographic dark-rooms, rooms for the storage of negatives, etc. A visible recording variometer and magnetic storm detector will be established in a separate building, for use in connection with the solar observations.

PASADENA OFFICES AND LABORATORIES

With the invaluable assistance of the Pasadena Board of Trade, a piece of land, on Santa Barbara Street, 150 feet (45.7 m) front by

208 feet (61 m) deep, has been secured for the Pasadena offices and instrument shop. The building, which is now under construction, was designed by Professor Ritchey. It is 50×100 feet (15.2×30.5 m) in size, with an optical testing-room, 150 feet (45.7 m) long, extending 68 feet (20.7 m) beyond it in the rear. The walls are of brick, and the floor of cement. Pains will be taken to make the structure throughout as nearly fire-proof as the available funds will permit, since the optical and mechanical parts of instruments under construction will be very valuable.

The building will contain offices for Professor Ritchey and myself, and a stenographer; drafting-room, machine shop, instrument shop, pattern shop, lacquering-room, constant-temperature room, room for 5-foot (1.5 m) grinding machine, room for 40-inch (1 m) grinding machine, long optical testing-room, photographic dark-rooms, enlarging-room, etc. The equipment includes a No. 2 Brown & Sharpe Universal milling machine, 24×24-inch (61×61 cm) Gray planer, 20-inch (51 cm) Hendey-Norton engine lathe, 12-inch (30.5 cm) Hendey-Norton tool maker's lathe, No. 4 Rivett bench lathe, No. 2 Landis Universal grinding machine, drill press, pattern-maker's lathe, circular saw, band-saw, Oliver trimmer, automatic hack-saw, emery grinder, etc. The supply of small tools is very complete. The optical laboratory will contain all necessary machinery for grinding, polishing, and testing mirrors, with apertures as great as 5 feet (1.5 m), and focal lengths as great as 150 feet (45.7 m).

Most of the above machine tools are now in use at the instrument shop temporarily occupied in the Seward Building, between Colorado and Union Streets. At present, two draftsmen, one instrument-maker, three machinists, and two pattern-makers are at work there, under the direction of Professor Ritchey. No optical work can be done until the new shop is completed.

It is probable that offices for a staff of computers will ultimately be provided adjoining the instrument shop.

EXPERIMENTS WITH FUSED QUARTZ

As already stated, glass mirrors are subject to change of figure when exposed to the Sun's rays. At the independent suggestion of Dr. Billings and Dr. Elihu Thomson, experiments have been undertaken with the object of using fused quartz instead of glass for the mirrors, since its coefficient of expansion is only about one-tenth as great. The work has been done by Professor Ritchey and Mr. Wingren, with the aid of a grant given last spring for this purpose by the Carnegie Institution. The quartz is easily fused in an electric furnace, but the fused mass is filled with fine bubbles, which increase in number and size as the temperature of the furnace is increased. An attempt is being made to eliminate the bubbles, in order to secure fused quartz for prisms and lenses. For mirrors, as Professor Ritchey suggests, blocks like those already obtained will probably serve very well, if the bubbles at one surface can be gotten out by remelting with the flame of an electric arc.

STAFF

The staff of the Solar Observatory is at present constituted as follows:

George E. Hale, Director.

G. W. Ritchey, Astronomer, and Superintendent of Instrument Construction.

Ferdinand Ellerman, Assistant Astronomer.

Walter S. Adams, Assistant Astronomer.

There is a post-office on Mount Wilson, about a mile from the Observatory, but the delivery of mail is so infrequent and irregular, that I conduct my correspondence from the Observatory Office in Pasadena, where letters for me should be addressed. Letters and printed matter for Professor Ritchey should be sent to the same address, but printed matter intended for me should be addressed to Mount Wilson, Cal., as my scientific library is at the Observatory. Printed matter for the Solar Observatory, and both letters and printed matter for Mr. Ellerman and Mr. Adams, should be addressed to Mount Wilson.

Books and papers, especially on astrophysical subjects, will be gladly received for the library of the Solar Observatory. Sets of observatory publications, which are greatly needed, may be forwarded from abroad, free of expense, through the International Bureau of Exchanges of the Smithsonian Institution, which has offices in the principal cities of Europe. It is hoped that some return for such contributions may ultimately be made in the form of our own publications.

Mount Wilson, Cal.,
February 8, 1905.