MOUNT WILSON OBSERVATORY

George E. Hale, Honorary Director
Walter S. Adams, Director
Frederick H. Seares, Assistant Director

The death of Dr. Albert A. Michelson on May 9, 1931, brought to a close a relationship between this great scientist and the work of the Observatory which has been productive of notable advances in knowledge and has influenced in many ways the objects and methods of our research. Dr. Michelson was appointed Research Associate of the Carnegie Institution of Washington in 1919 and during the periods of his visits to the Observatory carried on three major investigations, in all of which his remarkable genius in optical problems played a most important part. The first of these was the application of the interferometer to the measurement of stellar diameters and of very close double stars, which resulted in the first successful determination of a star’s diameter and confirmed in a striking way theoretical studies of stellar luminosities. The second investigation, conducted in collaboration with Mr. Pearson and Dr. Pease, was a repetition of the Michelson-Morley experiment with new apparatus operated under the most favorable conditions. The precision attained was very high and the results bore out fully Michelson’s earlier conclusion that no measurable displacements of the interference fringes occurred in different orientations of the instrument. Finally, Dr. Michelson returned to the problem with which his name will always be most intimately associated, the measurement of the velocity of light. In 1925–1927 he secured with the aid of Mr. Pearson a series of admirable determinations over a distance of 21 miles between Mount Wilson and Mount San Antonio which yielded a value of 299,796 km./sec. with an astonishingly small probable error. The difference of about 60 km./sec. between this value and that previously accepted made him most desirous of repeating the measurements under conditions which could be controlled accurately. For this purpose he designed a pipe line which could be exhausted of air to provide the finest observing conditions, and through which the light could be sent back and forth by multiple reflections. Through the financial aid of the Rockefeller Foundation and the Carnegie Corporation the necessary apparatus was secured and installed, and the measurements were undertaken as a joint investigation by the Observatory and the University of Chicago. Dr. Michelson personally made some of the earliest observations, and the successful outcome of the work under the care of Dr. Pease and Mr. Pearson was fully assured at the time of his death. Although his loss is felt most deeply by the members of our staff, with whom he has been associated intimately for many years, it is a source of great satisfaction that the Observatory was able to contribute so extensively to the investigations which Dr. Michelson had most at heart during the latter years of his life.

Especially noteworthy among the events of the year were the visits of Professor Einstein to the California Institute of Technology and the Observatory during the months of January and February, and of Sir James Jeans,

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Research Associate of the Carnegie Institution, to the Observatory during May. Both of these eminent scientists visited Mount Wilson during their stay and through lectures and discussions took an intimate part in the researches in progress. Their wide knowledge of physical processes and their suggestive criticisms can not fail to influence in many important ways the problems under investigation at the Observatory.

The General Meeting of the American Association for the Advancement of Science in June brought many astronomers, physicists and other scientists to Pasadena and afforded numerous opportunities for discussion and formation of plans for cooperative studies. Of three technical sessions of the Astronomical Society of the Pacific and Section D of the American Association, one was held in the 100-inch telescope dome on Mount Wilson, one in the library of the Observatory in Pasadena, and the third as a joint meeting with the American Physical Society at the California Institute. Immediately preceding and during these meetings Professor R. H. Fowler of Cambridge University delivered before the members of the staff and others interested a short series of most valuable lectures on the theory of stellar atmospheres and the interior of stars.

In cooperation with the California Institute of Technology, the Observatory has continued its assistance on plans relating to the 200-inch telescope, and Dr. Hale, Dr. Anderson, Dr. Pease and Dr. Smith have all given a part of their time to this work. Since the development of accessory apparatus and improved methods of observation forms an integral part of this project, it has been most fortunate that Dr. Ross of the Yerkes Observatory and Dr. Stebbins of the Washburn Observatory could visit Mount Wilson during the year. Dr. Ross has made further tests on his lens for extending the field of the reflecting telescope, and Dr. Stebbins has utilized his photo-electric photometer on the 60-inch reflector in studies of the surface brightness of extended nebulae.

One of the most interesting results of the year is the further confirmation of the fundamental relationship between distance and amount of red-shift found by Dr. Hubble and Mr. Humason in the spectra of the extra-galactic nebulae. The most recent observation of this character is of a faint nebula in a cluster in the constellation of Leo, the distance of which is estimated by Hubble at 105 million light-years. The red-shift on a spectrogram obtained by Humason amounts to about 300 angstroms, which would correspond to a radial velocity of +19,700 km./sec., by far the largest displacement ever observed in the spectrum of any object. The “velocity”-distance relationship has now been established from observations of over 50 nebulae, 31 of which occur in clusters. Whether these huge red-shifts are to be interpreted directly as motions of recession, which would imply a rapidly expanding universe, is as yet uncertain, although no other adequate explanation has as yet been offered. In any event this relationship between distance and red-shift must remain an observational result of profound significance in its bearing on the nature and development of the stellar universe.

The support system originally installed beneath and at the edges of the 100-inch mirror was necessarily experimental in the case of a disk of such great weight and size. During recent years it has been suspected that some of the distortions observed in the figure of the mirror, at first ascribed
to the effect of temperature variations, might arise from local strains, and in the course of the past winter a new support system has been designed and constructed in our instrument shop. The principle of multiple lever support is retained, but ball races have been inserted between the lever arms and the supporting plates on both the back and the edges of the mirror. The position of the mirror is defined very closely by the edge-arc, but within the narrow limits allowed for temperature variations the mirror is very free and can be moved by a push of the hand. This support system has performed extremely well and has improved greatly the character of the images, especially in certain positions of the telescope. Our experience in this connection should be of great value in its bearing on the methods of support for the mirror of the 200-inch telescope.

**STAFF**

Dr. George E. Hale, Honorary Director of the Observatory, has divided his time between solar observations with the spectrohelioscope at the Solar Laboratory and the consideration and discussion of plans for the 200-inch telescope. Dr. Walter S. Adams, Director, has carried on the administrative work of the Observatory and has been engaged in investigations in stellar spectroscopy. Dr. Frederick H. Seares has shared in the administrative duties and has continued his studies on stellar distribution. In addition he has remained in charge of the editorial supervision of the Observatory publications.

Dr. John A. Anderson has given much of his time to the detailed plans relating to the 200-inch telescope and has carried on further experimental work in the laboratory on various optical problems and on the spectra of high-tension discharges. Dr. Arthur S. King, Superintendent of the Physical Laboratory, has been engaged mainly in studies of rare-earths and has completed the measurement of wave-length and the estimation of intensity for great numbers of lines in these most complex spectra. Dr. Edwin P. Hubble has continued his investigations of extra-galactic nebulae with especial reference to their distribution and distances and has further confirmed the relationship established by him between red-shift and distance. Dr. Paul W. Merrill has extended his work on bright-line O- and B-type stars, studying the spectra throughout a wide range of wave-length and tracing the variations of intensity of some of the lines in certain of these interesting objects. Mr. Harold D. Babcock has devoted considerable time to problems connected with the ruling machine and has made further studies of the infra-red solar spectrum and of the spectra of the isotopes of oxygen in the earth's atmosphere. Professor Alfred H. Joy, Secretary of the Observatory, has investigated the spectra of many variable stars including the fainter Cepheids and those of the Algol and cluster types. Dr. Seth B. Nicholson has given most of his time to solar observations, the measurement of sun-spot polarities and the compilation and examination of the material. With the assistance of Mr. Mayall he has also computed an orbit of the planet Pluto and derived a value of its mass from the perturbations of Neptune. Dr. Francis G. Pease, in addition to work on the 200-inch telescope, has made many of the measurements required in the investigation of the velocity of light and has observed with the 50-foot
interferometer on Mount Wilson. Dr. Adriaan van Maanen has continued his measures of the parallaxes and proper motions of selected stars on photographs taken with the two reflectors and has also investigated the proper motions of several nebulae from negatives made a considerable number of years apart. Dr. Edison Pettit has made regular observations of the ultra-violet solar radiation and has undertaken new investigations dealing with the energy-curve of the sun in the ultra-violet and with the relative forms of prominences in calcium and hydrogen light. Dr. Roscoe F. Sanford has devoted his time to stellar spectroscopy with especial reference to stars of variable radial velocity and spectroscopic binaries. Dr. Gustaf Strömberg has been engaged in computations relating to the luminosity distribution among stars of types A to M and to a mathematical investigation of the motion of a particle in a system of varying density. Dr. Theodore Dunham has given much attention to the development of methods of standardizing spectrograms and deriving line contours and has employed them in connection with stellar spectra of high dispersion. Mr. Milton Humason has continued his spectrographic observations of faint extra-galactic nebulae, with most interesting and important results. Dr. Sinclair Smith has devoted a portion of his time to work at the Seismological Laboratory and to problems connected with the 200-inch telescope. In addition to other investigations he has designed and used at the coudé focus of the 60-inch reflector a highly sensitive photoelectric photometer of special type. Mr. Ferdinand Ellerman has carried on solar observations on Mount Wilson, and much of the general photographic work of the Observatory has been under his charge. Dr. Robert S. Richardson has been engaged in solar investigations, giving especial attention to the study of bands in the spectra of sun-spots. Mr. Joseph Hickox has continued as regular solar observer on Mount Wilson and has done much work on the testing of photographic emulsions.

In the Computing Division, Miss Louise Ware has used the large registering microphotometer for a variety of investigations on the contours and intensities of spectral lines and has measured and reduced many of Dr. Pettit's photographs of solar prominences. Miss Elizabeth Sternberg has continued her measurements of the positions and areas of sun-spots and has compiled and discussed much of the material on sun-spot polarities. Mr. Edward F. Adams has been engaged principally in the measurement of solar spectra and the determination of the solar rotation. Miss Myrtle L. Richmond has carried on the reduction of the observations of the ultra-violet radiation of the sun and of the radiation of the moon and planets. Miss Richmond and Miss Brayton have also assisted Dr. Strömberg in the preparation of the material used in his studies of absolute-magnitude distribution among the stars. Miss Mary C. Joyner has cooperated with Dr. Sears in photometric investigations and studies of stellar distribution. Mr. Howard C. Willis was appointed to the staff on July 1, 1930, and has been assisting in the observation and reduction of parallaxes and proper motions of stars. Miss Cora G. Burwell has continued her studies of the spectra of bright-line O- and B-type stars under investigation by Dr. Merrill. Miss Elizabeth MacCormack has given her time to the measurement and reduction of stellar and nebular spectrograms and computations of stellar motions.
Mr. Nicholas Mayall has taken part in the spectroscopic and direct photographic observations on Mount Wilson and has measured radial velocities as well as stellar magnitudes from photometric plates. Miss Ada M. Brayton has assisted in the reduction of the spectrograms of rare-earths and has given much time to computations of the absolute magnitudes of stars. Mr. William H. Christie has carried on photographic and spectroscopic observations and has measured many of the stellar spectrograms. Mr. Wendell P. Hoge has assisted Mr. Babcock in the Physical Laboratory and has shared in spectroscopic observations on Mount Wilson. Miss Elizabeth Connor has remained in charge of the library and has assisted in editing the Observatory publications.

Dr. Albert A. Michelson, Research Associate of the Carnegie Institution, returned to Pasadena from Chicago late in the summer of 1930 and remained until his death in May 1931. During this time he carried on with the assistance of Mr. Pearson and Dr. Pease his investigation on the velocity of light. Sir James Jeans, Research Associate, visited the Observatory in May 1931, and gave several interesting and suggestive informal lectures before the members of the staff. Dr. Henry Norris Russell, Research Associate, spent two months in Pasadena during the autumn of 1930 and devoted especial attention to a study of the results of an analysis of the line-spectrum of sun-spots made by Miss Moore. Dr. Charles E. St. John, Research Associate, has continued his measurements of the solar rotation and of the contours and intensities of solar spectrum lines. Dr. Toshio Takamine, of the Institute of Physical and Chemical Research of Tokyo, spent most of the past winter as Research Associate at the Physical Laboratory in Pasadena. His principal research was on the absorption of the ultra-violet lines of hydrogen of the Balmer series.

Many astronomers and other scientists have visited the Observatory during the year and several have undertaken definite research investigations during the periods of their stay. Dr. Fred E. Wright, of the Geophysical Laboratory of the Carnegie Institution, was engaged in lunar studies and preparations for the construction of a new map of the moon during several weeks in the autumn of 1930. Dr. Frank E. Ross, of the Yerkes Observatory, was at Mount Wilson between August and October 1930, and, in addition to making further tests of his correcting lens for the field of the 60-inch reflector, he obtained a number of photographs of the Milky Way with a special lens of his own design. Dr. Ross returned to Pasadena for additional work on June 1, 1931. Dr. Joel Stebbins, Director of the Washburn Observatory, carried on observations of stars and extra-galactic nebulae with his photoelectric photometer during August and September 1930. Dr. Giorgio Abetti, Director of the Royal Astrophysical Observatory at Arcetri, spent the months of August and September in Pasadena and engaged in solar observations with the spectrohelioscope and in studies of the chromospheric spectrum. Dr. C. D. Shane, of the University of California, continued during the summer months his investigation of the intensities of solar spectrum lines by his interference method. Dr. Otto Struve, of the Yerkes Observatory, made observations of the spectra of B-type stars during June and July 1930. Dr. John C. Duncan, Director of the Whitin Observatory, spent the months of July and August 1930 at Mount Wilson and took part
in the direct photographic work. Dr. Duncan returned to Pasadena in April 1931. Dr. B. W. Sitterly, of Wesleyan University, after spending eight months at the Observatory in photometric investigations returned to Middletown in August 1930. Mr. R. v. d. R. Woolley, Commonwealth Research Fellow at Mount Wilson since September 1929, after completing several studies of spectral line contours returned to England in March 1931. Miss Charlotte E. Moore, of the University Observatory at Princeton, was in Pasadena between July 1930 and January 1931 engaged in a study of several thousand lines in the sun-spot spectrum on the Mount Wilson photographs.

Among astronomers who visited the Observatory for briefer periods, but in many cases carried on observations with the instruments, were Dr. Harlow Shapley, Miss Cecilia Payne, Dr. Frank S. Hogg, and Miss Henrietta Swope of the Harvard College Observatory, Dr. John A. Miller of Swarthmore College Observatory, Dr. E. A. Fath of Goodsell Observatory and Dr. P. ten Bruggencate of the University Observatory at Göttingen.

The members of the staff of the Observatory took an active part in the meetings of the National Academy of Sciences held in Pasadena in October 1930, and of the American Association for the Advancement of Science in June 1931. Many technical papers were contributed to these meetings, and Merrill, Babcock, Joy and others devoted much time to the plans of organization for the various sessions. The representatives of the Observatory at the annual meeting of the Carnegie Institution at Washington in December were Adams and Hubble. On this occasion Hubble gave one of the lectures in the regular Institution series on the subject of The Exploration of Space. The local series of lectures in Pasadena and Los Angeles under the auspices of the Astronomical Society of the Pacific and the Carnegie Institution which has been maintained for several years past was given during the winter months, mainly by members of the Observatory staff.

**SUMMARY OF THE YEAR’S WORK**

Solar activity, as measured by the number of sun-spot groups, has decreased, the average daily number during 1930 being 3.8, as compared with 6.0 in 1929. The phase of the spot-cycle at present is about half-way between maximum and minimum. The polarities of 221 groups have been observed, 80 per cent being regular, 6 per cent irregular, and 14 per cent unclassified. Two small bipolar groups in high latitudes had polarities opposite to those of the present cycle, but can not be regarded with certainty as forerunners of the next cycle.

Direct photographs of the sun were made on 302 days between July 1, 1930, and June 30, 1931, by Ellerman, Hickox, Nicholson and Richardson; and 1052 calcium and hydrogen spectroheliograms were obtained with the 60-foot tower telescope. Estimates of the areas of the flocculi, also an index of solar activity, have been sent regularly to the Solar Physics Committee of the International Astronomical Union and to Terrestrial Magnetism and Atmospheric Electricity. Spectroheliograms have also been supplied to the Kodaikanal and Meudon Observatories, and sun-spot numbers to Science Service of Washington.
Observations with the spectrohelioscope have been continued regularly by Hale at the Solar Laboratory and by the observers on Mount Wilson. Hale has designed a simplified form of instrument primarily for amateurs, and an attachment for quickly converting a spectrohelioscope into a spectroheliograph. Twenty-five observatories and other institutions distributed all over the earth are cooperating in Hale's plan to observe the sun systematically with this instrument.

Special observations of prominences have been made by Pettit with the Yerkes and Mount Wilson spectrohelioiographs in a study of internal motions and velocities of eruption. Prominences in hydrogen (Hα) and calcium (Kα) light photographed at Mount Wilson and observed simultaneously with the spectrohelioscope at Pasadena show the same structure, even to many of the details, thus indicating a thorough mixture of the two kinds of atoms. Occasional exceptions are the streamers which often appear as broad ribbons in Kα and thin lines in Hα. If confirmed, this result might be interpreted as indicating the electrical nature of prominences, since the ionized calcium atom has an external electrical field, while neutral hydrogen has none. In this connection Pettit measured the height of the chromosphere in Hα by observing the change in the diameter of the solar image when the line was thrown on and off the second slit of the spectrohelioscope. Measures in March and April gave a value of 8000 km.

Measures of the integrated ultra-violet radiation of the sun by Pettit gave the lowest monthly averages since 1924. Since a change of nearly 1000° in the temperature of the sun would be required to produce the observed variation, a partial explanation is perhaps to be found in some atmospheric variant, itself controlled by ultra-violet light. Pettit has also measured at Tucson, Arizona, the ultra-violet energy-curve of the sun's disk, using a 12-inch fused silica objective to form an image. Between $\lambda$ 0.385 $\mu$ and $\lambda$ 0.325 $\mu$ the solar energy is nearly constant, the rapid fall observed at the earth's surface being due mainly to atmospheric scattering.

Observations of the solar rotation by St. John indicate a slow increase in the linear velocity since 1928. According to other observers, the velocity decreased between 1905 and 1912. Since the velocity derived from long-lived spots has remained practically constant for 30 years, the results for the reversing layer indicate a reversal of flow relative to spots after the cycle 1901-1913. A correlation of linear velocity with the double spot-cycle and the direction of whirl in the spot-forming vortex would be of great interest. A somewhat similar though smaller change has been found in the velocity of the high-level chromosphere given by Hα.

Babcock has nearly completed his measurements of solar wave-lengths between $\lambda$ 7330 and $\lambda$ 9100 and is continuing his observations toward the present photographic limit at $\lambda$ 11934. He has also studied the faintest lines visible on some of the original negatives made by Jewell with Rowland's apparatus at Baltimore. Of 4709 lines having intensity $-3$ in Rowland's Table, 29 per cent have been identified with more or less certainty, but the reality of many of the others seems very doubtful.

Theoretical developments based on a study of molecular dissociation by Dr. Russell account for many observational results on band spectra in solar and stellar atmospheres. The abundance of hydrogen and oxygen ex-
plains why most of the recognized compounds are hydrides and oxides. The maximum of intensity shown by the cyanogen and hydrocarbon bands near spectral type G5 may be due to the fact that CO is the most firmly bound carbon compound. When there is considerably more oxygen than necessary to combine with the carbon, an increasing proportion of the carbon goes into CO at the expense of CN, CH and C2, if the temperature is low, while at high temperatures which dissociate all compounds, the CN and CH bands reach a maximum. When carbon is in excess, the CN, CH and C2 bands should increase steadily in strength as the temperature falls. Dissociation of the molecules and ionization of the metallic atoms account for the rapid weakening of the titanium oxide bands with rising temperature, as well as for the occurrence of the bands of the hydrides of magnesium, calcium and aluminum in the spectrum of sun-spots, but not of the disk. The compounds of the non-metals persist at higher temperatures than those of the metals because the non-metals are harder to ionize. Considerations of the influence of differences in temperature and pressure upon the dissociation of compounds indicate that band-spectra in general should show no conspicuous absolute-magnitude effects.

Richardson has measured wave-lengths and intensities of lines in the solar hydrocarbon bands with a view to determining the temperature of the reversing layer and any departure from thermodynamic equilibrium for molecules. During the investigation, he has identified three new CH bands in the spectrum of the disk. Intensity measurements by Mr. Woolley show that the weaker lines of multiplets in the solar spectrum are relatively much stronger than in emission spectra and indicate a marked divergence from the values obtained from the calibration of Rowland’s Table by Russell and Adams. The widening of the lines by the finite resolving power and by the Doppler effect appears to be insufficient to account for the observed departure. The possibility that Unsöld’s method for determining the number of atoms that perform the transitions falls in the case of weak lines has been tested by measures of atmospheric oxygen lines. Their widths are found to be proportional to the three-eighths rather than the one-half power of the number of atoms. During a study of selected multiplets in the solar spectrum, St. John has found a similar divergence of the weaker diagonal lines from their theoretical intensities.

Miss Moore investigated the intensities of over 6000 atomic lines in the sun-spot spectrum, of which 956 have been identified as faint predictable members of multiplets. She has also measured 396 new lines which appear only in the spot spectrum and has identified 193 of them. The temperature of spots based on a comparison of lines of different excitation potentials for six elements is found to be 4720° absolute, the temperature of the photosphere being taken as 5740°. The relative intensities of the arc and the enhanced lines give an effective electron-pressure above the spot 0.60 times that above the disk, the reduction being due to the lower ionization. The corresponding effective amount of absorbing matter per unit area above the spot is 1.7 times that over the disk. The ratios calculated from Russell’s data for the composition of the solar atmosphere and Gaunt’s formula for the opacity coefficient are 0.55 for the electron-pressure and 1.35 for the absorbing material. The theoretical intensities of sun-spot lines cal-
culated from these data are in good agreement with observation, the average discordance being ±1 on Rowland's scale.

Lunar and planetary investigations include the completion of apparatus for Dr. Wright's photographic map of the moon on a standard line of sight, further spectrographic observations of the polarization of light reflected from surface features on the moon by Adams, and photographs of the faint satellites of Jupiter by Nicholson. The most probable mass of Pluto, as determined by Nicholson and Mayall from the perturbations of Neptune, is about two-thirds that of the earth. Visual observations of Pluto with the 100-inch reflector have so far shown no evidence of a measurable disk. An attempt to derive a mass for the satellite of Neptune has been made by van Maanen, Nicholson and Willis. From measurements made on 14 nights when the planet was nearly stationary, the most probable value is between 0.04 and 0.1 the mass of the earth.

Observations of Mars made near aphelion by Nicholson and Pettit with a thermocouple substantially corroborate the theoretical difference between aphelion and perihelion of 27° C. in temperature for the sub-solar point. The mean maximum temperature on Mars throughout the Martian year is approximately 14° lower than that based on measurements at perihelion.

From a study of some 20,000 nebulae north of −30°, Hubble finds a zone of avoidance along the galactic plane which appears to represent the distribution of obscuring clouds. In the general direction of the center of the system, partial obscuration extends to galactic latitudes ±40°, but toward the anticenter it is very limited. In latitudes greater than ±40°, the surface distribution of nebulae is approximately random with occasional clusters scattered at wide intervals; and the increase in numbers with exposure-time indicates an approximately uniform distribution in depth. The resulting mean density is one nebula per 6 × 10^{16} cubic parsecs or 5 × 10^{31} gm./c.c., on the assumption of a mean nebular mass of 5 × 10^{8} suns. Two new clusters of faint nebulae near the Virgo cluster have been discovered on photographs by Mayall, and Christie has found in Leo a cluster of some 300 nebulae, apparently the most distant cluster now known.

Measurements of 12 spiral nebulae by van Maanen on photographs separated by intervals of from 9.9 to 14 years give absolute proper motions ranging from 0'002 to 0'014 in right ascension, and from 0'000 to 0'019 in declination. These are so distributed that all the nebulae are apparently moving away from the poles of the galaxy. The alternative of a motion of the comparison stars toward the poles is not supported by measures of the faint stars in several fields centered on Boss stars. These stars show no such effect, but the question is still under investigation. From measures of six points in Messier 101, van Maanen obtains a mean annual rotational component of 0'015±0'003, in good agreement with his earlier results.

Humason has determined the apparent radial velocities of 15 extragalactic nebulae, 11 of which are in nebular clusters. One of these, in the Leo cluster discovered by Christie, shows a red-shift of nearly 300 angstroms, corresponding to a radial velocity of +19,700 km./sec. Hubble and Humason have used all their results to extend the velocity-distance relationship, which is now based upon 85 nebulae ranging over a distance of
105 million light-years. Except for a revision of the unit of distance, the relation, velocity = (distance in parsecs)/1790, remains unchanged. Hubble, using all available data, including Shapley's revision of the zero-point of the period-luminosity curve for Cepheids, finds $-13.8$ for the photographic and $-14.9$ for the photovisual mean absolute magnitudes of extra-galactic nebulae.

Among other investigations of the year dealing with extra-galactic nebulae are: spectrographic observations of rotation by Pease; measurements of brightness with a photo-electric cell by Smith, which indicate the possibility of observing objects as faint as the seventeenth magnitude; a study by Hubble of the relation between size and surface-brightness of threshold images, important for deriving the total magnitudes of faint nebulae; and a comparison by Strömgberg of the aberration coefficient of light from the Ursa Major cluster of nebulae with that from nearby stars, which shows the velocity of light from the two sources to be the same within the errors of measurement.

Trigonometric parallaxes have been determined by van Maanen for 19 stars, six of which have photographic absolute magnitudes fainter than $-10$. Among 60,000 stars in 42 Selected Area fields, 122 with magnitudes between 6.7 and 20 are found by van Maanen and Willis to have proper motions between $0\deg 041$ and $0\deg 925$. The percentage of stars having such motions increases from 0.07 in galactic regions to 1.02 in high latitudes. The mean motion decreases with magnitude but seems to be independent of galactic latitude, while the mean parallaxes depend little on the magnitude but are strongly correlated with proper motion. The calculated position of the antapex of the motions is $A = 6^h 43^m$; $D = -28^\circ$.

Strömgberg has investigated the orbit of a particle in a system having spherical symmetry and a density decreasing outward according to an exponential law. In general the orbit is not periodic but consists of a succession of loops around the center. Corresponding results are found for a greatly flattened system. These types of orbits may be expected for stars in the galactic system moving under the gravitational influence of the system as a whole.

Excellent progress has been made by Seares and Miss Joyner on the program of photovisual magnitudes in the Selected Areas. The color of the stars in Area 40, near the edge of an obscuring cloud, is striking. At least one-fourth of 760 stars brighter than magnitude 15.7 show a color excess of about 0.7 mag. Spectral types observed by Humason check the zero-point of the color indices and indicate a distance for the absorbing cloud of the order of a thousand parsecs. The Mount Wilson photovisual scale used in these investigations has been found to be in close agreement with visual measures of polar stars recently published at Potsdam.

Magnitudes and colors of 374 stars along the path of Eros by Seares, Sitterly, and Miss Joyner, besides affording standards of brightness, provide material for studies of the relation between spectrum and color and of the scales and color equations of various catalogues. Mayall has observed a long-period variable found by him which has an exceptional color index of about 5 magnitudes; and also van Gent's faint variable, the period of which is only 100 minutes.
Seares has studied the relation between the true space-density function of stars and that found by ignoring the effects of absorption. Tests made with different coefficients indicate that the absorption now known to occur in low latitudes is not constant either in longitude or for any great distance in the galactic plane; otherwise, the true space density would increase with increasing distance from the sun.

For questions involving space density, a numerical method devised by Seares for determining the density function should be useful. It makes no assumption as to the form of the density function, admits the use of a luminosity function which changes with the distance, and is applicable at all distances, except in so far as the inherent uncertainty of the problem sets a limit.

The adjustment and operation of the 50-foot interferometer have been continued by Pease, who has observed fringes with mirror-separations up to 44 feet. Measurements of α Orionis give an angular diameter of about 0.040 and of β Andromedae, 0.016.

In the field of stellar spectroscopy, instrumental additions include a three-prism spectrograph for use in the ultra-violet and a 15-foot concave-grating spectrograph for the coude focus of the 100-inch telescope. These instruments, together with a plane-grating spectrograph used principally in the red and infra-red, have added greatly to our knowledge of stellar spectra in these important regions.

About 1200 stellar spectrograms have been obtained during the year. Among the chief results of their study are: the determination of the radial velocities of about 100 stars; the derivation by Joy of orbits, masses and absolute dimensions for the eclipsing variables TT Aurigae, RS Canum Venaticorum, and RT Lacertae; the completion by Sanford of the orbits of the spectroscopic binaries H.D. 73619, 75767, 206546 and 214686; and further results by Sanford on the variable radial velocities of the interesting stars AC Herculis and Boss 1074. Joy has completed approximate velocity-curves for 10 Cepheids and has under investigation the spectra of many other variables of different classes. For 10 stars of type N and two of type R, Sanford finds a velocity difference of 23 km./sec. between the emission lines of hydrogen and the absorption lines of other elements.

Since 1924 more than 90 bright-line B-type stars have been discovered by Merrill, Humason and Miss Burwell, and a catalogue of all such stars now known is in preparation. The complexity of the spectra of certain stars of this type and their remarkable variations are well illustrated by Merrill's detailed study of H.D. 50138. The spectrum of P Cygni has been photographed by Adams and Dunham with the 15-foot coude spectrograph and shows double absorption lines of hydrogen, as well as other interesting details of structure.

Spectrograms in the yellow and red regions have been studied by Merrill with especial reference to the detached D lines of sodium, Hα, the forbidden Ω multiplet near λ 7325, and the oxygen and ionized calcium triplets farther to the red. Miss Burwell finds a marked absolute-magnitude effect for the red neutral calcium lines near λ 6100, and Sanford is utilizing this region in his work on N-type spectra.
The three-prism spectrograph has been used by Adams and Joy in further investigations of the H and K lines in late-type spectra. Bright lines have been discovered in several additional stars, and especial attention is being given to their relative behavior in giants and dwarfs.

Humason has completed the observations required for the spectral classification of faint stars in the Selected Areas, and about 90 per cent of the stars have been classified. Ten or more stars fainter than photographic magnitude 11.0 are included in each of 115 Areas; the total classified will be approximately 3000. Dunham has developed a useful method for standardizing stellar spectra in which the intensity of the standardizing spectrum varies logarithmically in a direction perpendicular to the dispersion. The method has been applied to many of the stellar spectrograms and is being used to measure the contours of absorption lines traced with a Zeiss microphotometer. Dunham has also investigated extensively the Eberhard effect and the influence of plate-grain on the micro-photometer tracings.

Smith has devised a method for observing radiometer deflections from stellar spectra which increases greatly the precision. Light from a slightly overdamped radiometer is brought to focus on a photographic film, the intensity being such that a relatively long exposure is required to record an image. The wandering of the spot of light due to Brownian movement is thus averaged out, and the image represents with high accuracy the mean position of the spot. The method has been used successfully at the coude focus of the 60-inch reflector.

Spectroscopic absolute magnitudes for about 1500 giant stars of types G0 to K5 have been determined by Adams from new reduction tables based upon recent determinations of mean absolute magnitude. A comparison with Strömgren's values and with mean trigonometric results shows differences of the order of 0.1 mag. Strömgren has completed for types A2 to M his computations of the distribution of absolute magnitudes based on the distributions of peculiar and parallactic motions and of radial velocities among stars brighter than 6.0. The striking features of his results are the existence of clearly separated supergiants in all types, and the great concentration of normal giants within narrow limits of absolute magnitude, especially among stars of types G, K and M.

In the Physical Laboratory King has completed a preliminary spectroscopic survey of 13 of the rare-earths and in nine cases has carried out a temperature classification. Many new lines have been measured in the spectra of ytterbium and lutecium, and further work has been done on neodymium and samarium. The more prominent lines of the very rare element thulium have been identified. Fully half of the lines of lutecium have hyperfine structure, a feature shown by King to occur in the spectra of all rare earths of odd atomic number, with the possible exception of thulium. Columbium has been studied extensively in cooperation with Dr. Meggers, with especial view to a term analysis of the spectrum. King has recently succeeded in obtaining in the electric furnace a considerable number of the lines of tungsten, the most refractory metal known.

Anderson is using the large condenser to study quantitatively the energy distribution in the continuous spectrum given by a high-current vacuum tube of fused silica. Spectral changes during the discharge are recorded
with a rotating-mirror camera, and the energy is measured with a vacuum thermocouple at the focus of a quartz monochromator. The large condenser was also used by Dr. Takamine in an attempt to produce the Balmer lines of hydrogen in absorption by passing white light through a suitably excited hydrogen-neon tube. Only the first five members of the Balmer series were obtained, and these were abnormally wide.

Further studies by Babcock of the atmospheric band spectra of the isotopes of oxygen give results of especial interest as bearing on the “packing effect,” or the difference between the mass of an atomic nucleus and the sum of the masses of its constituent alpha-particles and protons, which in turn provides an independent test of Einstein’s fundamental equation connecting mass and energy. Babcock and Birge have found that when O\textsuperscript{16} is taken as 16 exactly, the mass of O\textsuperscript{18} is 18.0065, with a probable error of 1 in 100,000. The mass of O\textsuperscript{17}, although subject to a large probable error, can also be used to test Einstein’s equation. The relative proportions of O\textsuperscript{16}, O\textsuperscript{17} and O\textsuperscript{18} which enter into the mixture usually called oxygen are under investigation.

Other laboratory investigations have included tests of photochemical cells by Smith, who finds their fluctuations too erratic and their sensitivity in general too low for astronomical use; further trials by Anderson of a cylindrical lens in a microscope to reduce the effect of plate grain, which show the method to be most useful in the case of emission lines, but of doubtful value for absorption spectra on account of the production of spurious lines from silver grains; the successful use by Pettit of a simple convex cylindrical lens behind the slit of a concave-grating spectrograph to eliminate astigmatism; and tests of numerous photographic emulsions by Dunham, who has developed methods for defining the characteristics of plates most useful in practical work.

Several improvements have been made in the large ruling machine, including a new diamond carriage of light construction. All the 4-inch and 6-inch gratings ruled during the year have been of a quality suitable for observing, and a few give nearly theoretical resolving power. The design of the new machine of medium size is completed, and construction is well advanced.

Measurements of the velocity of light through the one-mile pipe line, with the air-pressure reduced to about 2 mm. over the path traversed by the light, have been continued by Pease and Pearson since Dr. Michelson’s death early in May. The base-line was measured with a remarkable degree of precision by Commander Garner of the U. S. Coast and Geodetic Survey. Thus far five sets of observations have been made, each consisting of 60 or more groups of 20 micrometer readings each. The first two sets are of low weight because of a slight drift in the image, and one of these gives a systematically low value. The other four sets are, however, closely accordant.

**Observing Conditions**

Observing conditions during the year were well above the normal of those recorded during the last 19 years. Solar observations were made on 302 days and stellar observations on 298 nights. The 60-inch reflector was
in use during 2454 hours as compared with an average of 2260 hours, or during nearly 70 per cent of the total estimated hours of darkness.

In contrast to the preceding season, the winter was mild and the total snowfall was only 19 inches. Much of the precipitation, which amounted to 27.62 inches for the year, about 3.5 inches below the normal, occurred during a few storms. A single rainstorm near the end of April gave a precipitation of 7.9 inches. The highest temperature during the year was 92° F. on August 29, 1930, and the lowest 24° F. on January 6, 1931. Meteorological records for the use of the Weather Bureau have been maintained regularly, and additional observations have been made during certain hours of the day and night to assist in the operation of the air-mail service.

The accompanying table compiled from the records of the 60-inch telescope gives the observational data for this instrument throughout the months of the year.

<table>
<thead>
<tr>
<th>Month</th>
<th>Hours of darkness</th>
<th>Hours of observation</th>
<th>No. observations</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>All night</td>
</tr>
<tr>
<td>1930:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>255</td>
<td>221</td>
<td>34</td>
<td>26</td>
</tr>
<tr>
<td>August</td>
<td>260</td>
<td>261</td>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td>September</td>
<td>295</td>
<td>291</td>
<td>94</td>
<td>23</td>
</tr>
<tr>
<td>October</td>
<td>336</td>
<td>247</td>
<td>89</td>
<td>23</td>
</tr>
<tr>
<td>November</td>
<td>330</td>
<td>200</td>
<td>130</td>
<td>16</td>
</tr>
<tr>
<td>December</td>
<td>346</td>
<td>275</td>
<td>71</td>
<td>24</td>
</tr>
<tr>
<td>1931:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>346</td>
<td>144</td>
<td>202</td>
<td>9</td>
</tr>
<tr>
<td>February</td>
<td>308</td>
<td>116</td>
<td>192</td>
<td>7</td>
</tr>
<tr>
<td>March</td>
<td>324</td>
<td>231</td>
<td>93</td>
<td>18</td>
</tr>
<tr>
<td>April</td>
<td>286</td>
<td>193</td>
<td>93</td>
<td>13</td>
</tr>
<tr>
<td>May</td>
<td>266</td>
<td>207</td>
<td>59</td>
<td>22</td>
</tr>
<tr>
<td>June</td>
<td>230</td>
<td>158</td>
<td>72</td>
<td>17</td>
</tr>
<tr>
<td>Total</td>
<td>3591</td>
<td>2454</td>
<td>1137</td>
<td>228</td>
</tr>
<tr>
<td>Mean 19 years</td>
<td>2260</td>
<td>1334</td>
<td>196</td>
<td>90</td>
</tr>
</tbody>
</table>

Public use of the 60-inch telescope for visual observations has been continued on Friday evenings throughout the year, and there has been a large increase in the number of visitors to Mount Wilson on these evenings. More than 8200 persons used the instrument during the year, among whom were many high school and college students. Mr. W. P. Hoge has given the public lectures on these occasions and has supervised the observations with the telescope.

The 100-inch telescope was made available for visual use by the members of the National Academy of Sciences at the time of their meeting in October 1930, and also for the astronomers attending the meeting of the American Association for the Advancement of Science in June of the present
year. This instrument and the exhibit of astronomical photographs are open daily to inspection by the public, and many thousands of visitors have availed themselves of the opportunity.

SOLAR RESEARCH

Sun-spot activity showed a marked decrease in 1930 and the first half of 1931 as compared with that of the two preceding years. The classification of all sun-spot groups and the daily measurement of the polarity and intensity of their magnetic fields have been continued with the 75-foot spectrograph at the 150-foot tower telescope. Regular observations have been made with the spectroheliograph at the 60-foot tower telescope, supplemented by visual observations with the spectrohelioscope on Mount Wilson and with those at the Physical Laboratory and the Solar Laboratory in Pasadena. Daily measurements of the ultra-violet radiation of the sun have also been made, and the spectral distribution of energy from different portions of the solar disk has been studied. Continuous records of the variations in the declination and in the horizontal intensity of the earth's magnetic field have been obtained throughout the year.

Spectroscopic investigations have included further work on the infra-red spectrum of the sun; measurements of the solar rotation and the displacements of lines at the center and limb of the sun; researches on the Zeeman effect and the wave-lengths and identification of lines in sun-spot spectra; and several studies of the contours and intensities of groups of lines in the solar spectrum. Special attention has been given to the investigation of certain of the molecular band spectra.

SOLAR PHOTOGRAPHY

Direct photographs of the sun were made at the 60-foot tower telescope on 302 days between July 1, 1930, and June 30, 1931, by the solar observers, Ellerman, Hickox, Nicholson and Richardson. The following spectroheliograms have been obtained at the same telescope with the 13-foot spectroheliograph:

<table>
<thead>
<tr>
<th>Ha image</th>
<th>Prominences in K light</th>
<th>K2 image</th>
<th>Sun-spot groups, etc., in Ha light</th>
</tr>
</thead>
<tbody>
<tr>
<td>311</td>
<td>348</td>
<td>300</td>
<td>93</td>
</tr>
</tbody>
</table>

Spectroheliograms have been sent regularly to the Kodaikanal Observatory in accordance with the plan for cooperative investigations of solar activity, and special series of photographs have been forwarded to Meudon and other observatories as requested.

SUN-SPOT ACTIVITY

Solar observations were made at Mount Wilson on 316 days during the calendar year 1930. Spots were present on all these days except December 8, 1930, when none could be seen. The monthly means of the numbers of groups observed daily are as follows:

The present phase of the sun-spot cycle may be ascertained approximately by comparing the total number of groups observed last year with those observed in previous years. The total number of sun-spot groups observed each year since 1890 is given below, arranged in columns according to the spot cycle. The year 1930 apparently occupies a position in the
present cycle somewhat earlier than that of 1920 in the last cycle, which was three years after maximum and three years before the following minimum.

<table>
<thead>
<tr>
<th>Month</th>
<th>Daily number</th>
<th>Month</th>
<th>Daily number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1929</td>
<td>1930</td>
<td>1931</td>
</tr>
<tr>
<td>January</td>
<td>5.2</td>
<td>6.7</td>
<td>1.8</td>
</tr>
<tr>
<td>February</td>
<td>5.9</td>
<td>6.2</td>
<td>4.0</td>
</tr>
<tr>
<td>March</td>
<td>3.7</td>
<td>3.4</td>
<td>3.0</td>
</tr>
<tr>
<td>April</td>
<td>4.7</td>
<td>4.0</td>
<td>3.8</td>
</tr>
<tr>
<td>May</td>
<td>5.4</td>
<td>3.3</td>
<td>2.7</td>
</tr>
<tr>
<td>June</td>
<td>8.0</td>
<td>3.3</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The number of groups in the northern hemisphere decreased from 174 in 1929 to 124 in 1930, and in the southern hemisphere from 172 in 1929 to 97 in 1930. The mean distance of the spot zones from the equator decreased from 11°1 in 1929 to 10°4 in 1930. These decreases are characteristic of this phase of the sun-spot cycle.

In cooperation with the Perkins, Yerkes and Harvard Observatories, Mount Wilson has supplied observations on 34 days to supplement the records of areas and positions of sun-spots published by the Naval Observatory in the Monthly Weather Review.

Character figures which serve as an index of solar activity have been sent regularly to Zürich in accordance with the plan formulated by the Solar Physics Committee of the International Astronomical Union. Estimates for the calcium flocculi have been made on 282 days and for hydrogen flocculi on 274 days. This series of character figures was begun in January 1928, but the Solar Physics Committee plans to extend the series as far back as the contributing observatories have spectroheliograms available. The character figures from Mount Wilson for the five years 1923-1927 inclusive have been completed and forwarded to Zürich. Estimates of the calcium flocculi were made for 1355 days and of hydrogen for 1249
days during this interval. The solar character figures, a similar index for the terrestrial magnetic activity, and the number of sun-spot groups observed daily are published regularly in Terrestrial Magnetism and Atmospheric Electricity.

The numbers of sun-spots and spot groups observed at Mount Wilson have been communicated daily to Science Service in Washington, D. C., which, in cooperation with the American Section of the International Scientific Radio Union, broadcasts them daily with other cosmic data.

**SUN-SPOT POLARITIES**

Records of the direction of polarity and the intensity of the magnetic field in sun-spots were made on 289 days in 1930, with the results indicated in the accompanying table. "Regular" groups in the northern hemisphere have S (south-seeking), or negative, polarity for the preceding spots, and N polarity for the following spots, while in the southern hemisphere the reverse is true. Complex groups, unipolar spots for which there was no indication whether they were preceding or following members of a group, and all groups for which the polarity observations were incomplete are given in the last column.

<table>
<thead>
<tr>
<th>Hemisphere</th>
<th>Polarity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regular</td>
</tr>
<tr>
<td>North</td>
<td>98</td>
</tr>
<tr>
<td>South</td>
<td>78</td>
</tr>
<tr>
<td>Whole Sun</td>
<td>176</td>
</tr>
<tr>
<td>Total</td>
<td>....</td>
</tr>
</tbody>
</table>

Two small bipolar groups which had polarities opposite to those of the present cycle were observed in high latitudes, one in April at $+28^\circ$, the other in November at $-26^\circ$. The first spots of the next cycle will be characterized by high latitudes and polarities like those of these groups, but the phase of this cycle is hardly far enough advanced to allow of calling them forerunners of the next spot cycle.

**THE SPECTROHELIOSCOPE**

The further development of cooperative research with the spectrohelioscope has occupied much of Hale's time during the year. The first two articles in his series on *The Spectrohelioscope and its Work* were mentioned in the last Annual Report. Part III, *Solar Eruptions and their Apparent Terrestrial Effects*, and Part IV, *Methods of Recording Observations*, have since been completed. The last-named paper contains a description of a photographic attachment for the standard spectrohelioscope, built and tested in the Solar Laboratory during the year. This enables the instrument to be instantly transformed into a spectroheliograph, thus permitting active phenomena in the solar atmosphere to be photographed with any part of the Ha line as soon as they have been detected and analyzed.
visually. A rapid means of velocity analysis, which is a prime requisite in studying and recording such phenomena, is afforded by the spectrohelioscope.

In cooperative work this instrument can be used most advantageously for the detection and study of those sudden eruptions near the sun’s central meridian which are generally regarded as the cause of bright auroras and terrestrial magnetic storms. As stated in the last Annual Report, a chain of spectrohelioscopes at stations well distributed around the earth is needed for an adequate investigation of this problem, and much progress has been made in securing the cooperation of observers for this purpose. Twenty-five standard spectrohelioscopes have now been ordered for various observatories, and in most cases the instruments have already been installed. Much valuable work has been done with some of these spectrohelioscopes, and it is hoped that most of them may soon be employed in a cooperative plan under the auspices of the International Astronomical Union.

Several amateur astronomers are also building ccelostat telescopes and spectrohelioscopes, but others have expressed a wish for even simpler apparatus. Hale has accordingly designed a very inexpensive outfit, which can be made without machine tools. This consists of a small ccelostat telescope and spectroheliograph for photography of the solar atmosphere with the calcium line K. One of these instruments, built by Hitchcock at the Solar Laboratory, gives images adequate to show eruptions on the disk. In addition to institutions previously listed, the following are adding spectrohelioscopes to their equipment: Solar Physics Observatory, Cambridge, England; Federal Observatory, Zürich, Switzerland; Solar Physics Observatory, Kodaikanal, South India; Department of Terrestrial Magnetism of the Carnegie Institution of Washington at Watheroo, Australia, and Huancayo, Peru; Dominion Observatory, Wellington, New Zealand; Griffith Planetarium, Los Angeles; Bell Telephone Laboratories, New York; Massachusetts Institute of Technology, Cambridge; the Franklin Institute, Philadelphia; and the private observatory of G. W. Cook, Wynnewood, Montgomery County, Pennsylvania.

SOLAR PROMINENCES

During August, Pettit spent three weeks at the Yerkes Observatory photographing prominences with the Rumford spectroheliograph. One eruptive prominence yielded a velocity-curve which corroborated previous observations, showing the motion to be uniform, with an occasional sudden increase, as if suddenly accelerated. A disturbed prominence studied with exposures at intervals of five minutes over a period of several hours showed occasional wave-like filaments, the first of the kind thus far observed with the Rumford spectroheliograph. A large quiescent prominence was observed with exposures at short intervals to study the internal motions. These plates were measured on the blink comparator by Miss Ware. The plots show interesting internal motions demonstrating turbulence in prominences.

During the fall and winter a systematic comparison of prominences in the light of Ha and Kβ was undertaken. A spectrohelioscope with a 6-inch grating mounted in the Littrow form in the Pasadena Laboratory was used with a 6-inch projecting lens of 30 feet focal length to form an image of
the sun. Drawings of prominences made with this instrument were afterward compared with spectroheliograms in $K_3$ light made simultaneously on Mount Wilson in accordance with plans arranged by telephone. So far only quiescent and active prominences have been obtained. These show the same form, even in many of the details, thus indicating a fairly thorough mixture of the atoms of hydrogen emitting $H_α$ and of calcium emitting $K_3$. Such exceptions as occur seem to be confined to the streamers. These are very prominent in active prominences in $K_3$ and often appear as broad ribbons pouring into areas of attraction on the chromosphere, while in $H_α$ they appear as thin lines or not at all. The same difference was noted in a cloud-like form driven away from an active prominence. This behavior might be interpreted as indicating the electrical nature of prominences and of the areas of attraction, a result perhaps to be expected since the ionized calcium atom emitting $K_3$ has an external electrical field, while the neutral hydrogen atom emitting $H_α$ has no such field. It is not impossible that the spread of light in the spectrohelioscope so far reduces the intensity that these comparisons are not conclusive. It is expected that they will be checked in the near future by observations made with the visual spectroscopic and spectroheliograph at the Yerkes Observatory. An examination of Fényi’s daily charts of prominences observed with a visual spectroscope at the Haynal Observatory shows, however, that streamers of the kind here studied are infrequent, and this fact confirms the observations with the spectrohelioscope.

HEIGHT OF THE CHROMOSPHERE IN $H_α$

Because of the added thickness of the chromosphere, the radius of the solar image as seen in the spectrohelioscope in the center of the $H_α$ line is greater than that seen in light just off the line. Hence it is possible to measure the thickness of the chromosphere by measuring the change in the radius of the sun as the line-shifter is used to move the line off and on the second slit of the spectrohelioscope. Pettit has used a projecting system in front of the second slit to form a solar image in the field of a filar micrometer. Fine guiding in right ascension was done by tilting a plane parallel plate placed in front of the first slit. The change in diameter of the image was measured directly with the micrometer as the line, centered on the second slit, was quickly shifted back and forth. Several measures made in March and April under good conditions of seeing gave a value of 8000 km. for the height of the chromosphere at that time.

ULTRA-VIOLET SOLAR RADIATION

Measurements of the ratio of ultra-violet solar radiation at $\lambda 0.32 \mu$ to green radiation at $\lambda 0.50 \mu$ have been continued by Pettit, who has now completed seven years of observations. Although considerable correlation with the fluctuations of sun-spot numbers was noted, the two curves ran counter to each other during the year June 1928 to June 1929. The highest monthly averages were 1.57 in November 1925, 1.51 in February and April 1927, and 1.52 in January 1930. The lowest values were 1.00 in June 1924, 1.12 in September 1928, 1.10 in July 1930, and 1.00 in May 1931. The monthly average is now at its lowest point since 1924 and has the same value as at the beginning of the observations.
Were we to attribute the observed variation to a temperature change in the sun, a range of nearly 1000° would be required, in case the energy-curve behaves like that of a black body. It is possible that some atmospheric variant like the white haze which often appears toward noon on Mount Wilson may contribute largely to the observed variations and may itself in turn be controlled by ultra-violet light from the sun. The general effects of the atmosphere, and of ozone in particular, have been investigated, but so far without affording any explanation of the observed variation.

ENGY-CURVE OF THE SUN IN THE ULTRA-VIOLET

The energy-curve of the sun in the ultra-violet was measured by Pettit at the Research Laboratory of the Desert Sanatorium at Tucson, Arizona, in May 1931. The 12-inch tellurite soderstat of this Laboratory was used to feed sunlight into a pair of Bausch and Lomb quartz monochromators having a common straight slit, the first acting as a filter to eliminate scattered light from the second. The vacuum thermopile was used to measure the radiation between \( \lambda 0.7 \mu \) and \( \lambda 0.30 \mu \), and a quartz photoelectric cell that between \( \lambda 0.292 \mu \) and \( \lambda 0.325 \mu \). The coefficients of atmospheric absorption were obtained by successive measurements at various zenith distances. Measurements of radiation from the center of the disk were made with a 12-inch fused quartz projecting lens of 6 feet focal length belonging to the Laboratory. One of the interesting results of these measurements is that the solar energy between \( \lambda 0.385 \mu \) and \( \lambda 0.325 \mu \) is nearly constant, the rapid fall observed at the earth's surface being due mostly to the rapid increase in atmospheric scattering toward the violet. The energy-curve may be described briefly as follows: From the maximum at approximately \( \lambda 0.47 \mu \), the energy gradually falls to about 80 per cent at \( \lambda 0.4 \mu \), from which it drops suddenly to 45 per cent at \( \lambda 0.38 \mu \). It then falls gradually with small variations to 44 per cent at \( \lambda 0.325 \mu \), from which it falls rapidly to about 20 per cent at \( \lambda 0.30 \mu \). The energy-curve for the center of the disk follows closely that of integrated light down to \( \lambda 0.325 \mu \), but, for some reason not yet explained, it falls below that of integrated light for shorter wave-lengths.

SOLAR ROTATION

It has become increasingly evident that the rotation of the sun as determined from spectroscopic observations of the reversing layer is not constant. Observations by Halm at Edinburgh and Adams at Mount Wilson gave a velocity of 2.07 km./sec. and a minimum period of 24.75 days for 1905.5, while a smaller velocity was indicated by observations at Ottawa, Allegheny and Kodaikanal for the epoch of 1912. In 1914 a program of observations with the 75-foot spectrograph was begun at Mount Wilson by St. John and Miss Ware in which the instrumental equipment should remain the same for at least one sun-spot cycle. During twelve years the linear velocity decreased consistently from the value previously indicated. For the ten years 1919-1929 the linear velocity averaged 1.90 km./sec., and the period two days longer than in 1905.5. Since 1928 the linear velocity has slowly increased, while the period has decreased by 0.6 day. On the other hand, the velocity derived from long-lived spots has remained practically constant at 2.02 km./sec. for the last thirty years. The lower reversing layer is 200 to 500 km. above the photosphere (level
of spots). In 1905.5 its linear velocity was 0.06 km./sec. greater than that of the photosphere, and in 1918, 0.10 km./sec. less, thus indicating a streaming of the lower reversing layer relative to the photosphere from east to west during the spot cycle 1901-1912 and from west to east during the following cycle. If connected with the direction of whirl in the spot-forming vortex, this systematic difference would indicate a counter-clockwise rotation of the vortex in the northern hemisphere during the cycle 1901-1913 and a clockwise rotation during the following cycle. For the cycle beginning in 1923, the linear velocity of the reversing layer might have been expected to increase, and apparently it has increased; but whether it will continue to do so remains to be determined. A correlation between linear velocity of the reversing layer and direction of whirl in the spot-forming vortex would be of great interest in its bearing on the sign of the charge in the spot vortex.

The linear velocity of the high-level chromosphere (Hα) follows, in a lessened degree, the changes in the reversing layer. For Hα Adams found 2.11 km./sec. in 1907; the Mount Wilson observations for epoch 1919 gave 2.00. Evershed obtained 2.07 km./sec. in 1923, and Abetti and Novakova 2.07 in 1929.

It is evident that the changes in the observed rotation of the reversing layer are not correlated with a single spot cycle, but may be related to the double cycle.

INFRA-RED SOLAR SPECTRUM

Babcock has continued his investigation of the solar spectrum between \( \lambda 7330 \) and \( \lambda 11634 \), giving especial attention to the fixing of the scale of wave-lengths by means of overlapping spectra observed with the 21-foot concave-grating spectograph. Photographs supplementing the Pasadena observations over a portion of the region have been obtained by Babcock and Dr. Duncan with the Snow telescope and 30-foot spectrograph on Mount Wilson. These have proved especially useful in the separation of solar from telluric lines through the effects of solar rotation. Measurements have been nearly completed for the region \( \lambda 7330 \) to \( \lambda 9100 \) and are satisfactorily accordant. As indicating the detail shown on the photographs, it is of interest to note that the most recent bolometric measurements of the water-vapor band at \( \lambda 11300 \) show only 50 lines in a region where 150 lines have been measured on the spectrograms.

FAINTEST LINES LISTED IN ROWLAND'S TABLE OF THE SOLAR SPECTRUM

It has often been remarked that in spite of improvements in photographic materials, modern instruments fail to show many of the weakest lines listed in the Rowland Table. It has been possible for Babcock to study during the past year a few spectrograms made by Jewell with Rowland's apparatus, following the same technique that was used in preparing the Table, although these plates are probably not among those actually used for the Table. We are indebted to Dr. C. E. K. Mees, Director of the Eastman Laboratory, for the privilege of working with these plates. Although our examination of them is not complete, we find in selected regions that they do not show as many lines as are visible on the best plates made at Mount Wilson, and that many of the tabulated lines are too uncertain.
for measurement. A count by Hoge of all the lines listed with intensity —3 in Rowland’s Table gives a total of 4709. Of these 19 per cent are identified without question in the Revision of Rowland’s Table, and 10 per cent are identified with question. In view of this comparison of old and modern solar spectrograms, it is possible that many of the remaining two-thirds of these lines may be illusory.

BANDS IN THE SOLAR SPECTRUM

Dr. Russell has commenced a study of the dissociation of molecules in solar and stellar atmospheres. The data regarding dissociation potentials derived from band spectra, while still scanty, are enough to show that a theory can be developed along lines similar to those followed by Milne in studying the lines of the elements. The principal qualitative results are as follows:

1. The majority of the compounds recognized in the solar atmosphere are hydrides, and most of the rest are oxides. This may be attributed to the preponderance of hydrogen in the solar atmosphere and the abundance of oxygen.

2. In stars of the G—K—M sequence the cyanogen and hydrocarbon (G) bands show a definite maximum of intensity near type G5. This can be explained by the fact that CO (which shows no bands in the accessible region of the spectrum) is the most firmly bound carbon compound. At low temperatures, the equilibrium shifts so that an increasing proportion of the carbon goes into this compound, at the expense of CN, CH and C2. At high temperatures, all the compounds are dissociated. Hence the intensity of the CN and CH bands reaches a maximum, much as in the case of a subordinate line of a neutral element. All this happens when there is a considerable excess of oxygen above that necessary to combine with the carbon.

3. If carbon is in excess, the C2, CN and CH bands should increase steadily in strength as the temperature falls, thus fully confirming R. H. Curtiss’s explanation of the difference between the M and N stars.

4. The rapid weakening of the TiO bands with rising stellar temperature arises partly from dissociation of the molecules, but also from ionization of the metallic atoms. This greatly diminishes the number of neutral atoms, which alone can enter into combination with the oxygen. The same explanation applies to the appearance of the bands of MgH, CaH, and AIH in sunspots but not in the normal solar spectrum. The non-metals are harder to ionize; hence their compounds persist at higher stellar temperatures than those of the metals. Only roughly approximate quantitative results can yet be obtained. These indicate that the differences in temperature and pressure between giant and dwarf stars should affect the dissociation of compounds in very much the same way as the ionization of metals, so that band spectra in general should show no conspicuous absolute-magnitude effects. The sensitiveness of the cyanogen bands to absolute magnitude is not yet accounted for. For stars with a large excess of oxygen the computed maximum intensity of the CN bands falls at about the right temperature. The absolute intensities of the band lines in the solar and spot spectra are of the order of magnitude theoretically to be expected.
An investigation is being made by Richardson of the wave-lengths and intensities of lines in the hydrocarbon (CH) bands in the solar spectrum. The lines in the CH band at $\lambda$ 4300 (Fraunhofer's band G) are of sufficient strength to enable their intensities to be measured from microphotometer tracings. From these intensities it is expected that a much more accurate determination of the temperature of the reversing layer can be made than that obtained from the $\lambda$ 5165 Swan band, which is very weak in the spectrum of the disk. The line-intensities should also reveal any noticeable deviation from thermal equilibrium for molecules, if such exists.

Three new CH bands have been identified in the disk spectrum: at $\lambda$ 3900, at $\lambda$ 3143, and the Raffety band at $\lambda$ 4050. Twenty-four lines in the table of the strongest unidentified solar lines in the Revised Rowland Table can be attributed to these new CH bands with an average difference in wave-length of 0.007 A.

**SPECTROPHOTOMETRIC OBSERVATIONS OF SOLAR LINES**

During his stay at the Observatory, Mr. Woolley carried on several investigations of the intensities and contours of solar spectrum lines with the large registering microphotometer. In the first of these the widths of the lines in a titanium multiplet were measured and compared with the theoretical intensities given by the quantum theory, which are themselves in agreement with the observations of laboratory emission spectra. A marked divergence was found in the solar spectrum, the weaker lines appearing with relatively greater intensity than theory would allow. A survey was then made of all the solar spectrum lines in the region $\lambda$ 4500—$\lambda$ 4600 with Rowland intensities 1 or greater. When these are grouped according to Rowland intensities, the square of the mean width, which gives the number of atoms concerned in the formation of the line, shows a similar marked divergence from the values found by Russell and Adams, who calibrated the Rowland intensities on the basis of theoretical multiplet intensities. The conclusion is that multiplet intensities in the solar spectrum differ widely from intensities in emission spectra, the weaker lines being relatively of greater strength.

Mr. Woolley has given further consideration to possible explanations of this discordance in the case of weak solar spectrum lines and has discussed the legitimacy of inferring the number of atoms from observations of line-width or of equivalent breadth. He has calculated the effect on the observations of finite resolving power and of the widening of lines by the Doppler effect and concludes that neither cause can affect seriously deductions from measurements of lines whose Rowland intensity is greater than 2. The possibility of a failure in the postulate underlying Unsöld’s method for determining the number of atoms that perform the transitions in the formation of a weak line from measurements of its width or equivalent breadth is considered, and the theoretical possibility of such an effect is suggested. An observational test of the widths of the oxygen lines in the B band of the solar spectrum at different solar zenith distances shows a definite departure from Unsöld’s formula. Instead of being proportional to the one-half power of the number of atoms, the widths, according to these observations, are approximately proportional to the three-eighths power.

St. John is continuing an investigation on a selected list of lines of widely
different intensities in several regions of the solar spectrum, measuring the
total absorption in all cases and the contours wherever possible. The most
important result so far found, which is well illustrated by the iron multi-
plet $\lambda 5269 - 5506$, is the relatively great intensity of the theoretically
weak lines of the side diagonals in the multiplets. This also raises the
question whether the Fraunhofer lines follow the same intensity laws as
emission lines.

Dunham has used an auxiliary grating spectrograph as a monochromator
with the 75-foot spectrograph in photographing solar absorption lines. A
region of the spectrum two angstroms in length can be isolated conveniently,
and practically all the errors introduced by ghosts and scattered light
into the measurement of contours of absorption lines are eliminated. Sev-
eral methods of correcting for the finite resolving power of the instrument
have been studied.

**SPECTRUM OF SUN-SPOTS**

Miss Moore, while holding a Lick Observatory Fellowship, spent several
months at Mount Wilson in a study of the atomic lines in the sun-spot
spectrum. In connection with this work she re-examined the identifica-
tions of all atomic lines between $\lambda 2975$ and $\lambda 6635$ in the spectrum of the
disk, and between $\lambda 3894$ and $\lambda 6635$ in that of the spot.

Of the faint lines not previously identified, 935 in the spectrum of the
disk and 21 which appear only in spots have been recognized as faint
members of multiplets not yet observed in the laboratory but are accurately
predictable. Among these, 437 are due to Fe, 122 to Cr, 89 to Ni, 73 to Cr$^+$,
67 to Ti, 50 to Fe$^+$, 43 to Ti$^+$, 21 to Co, 20 to Zn, 12 to V, 8 to V$^+$,
7 to Sc$^+$, and 7 to Mn. Miss Moore has measured 396 new atomic lines
which appear only in the spot spectrum and has identified 193 of these. A
quantitative study of the atmosphere above spots has been made with the
aid of the calibration of Rowland's intensity scale. There is good reason
to believe that the composition of the gases is the same in the spots and
above the photosphere. The relative numbers of atoms engaged in the
production of a given spectral line in the two cases will, however, depend,
first, on the opacity of the gas above the spot, which may permit the light
to come from greater or less depths; second, on the degree of ionization
of the element considered; and third, on the excitation potential for the
line in question. By comparison of lines of different excitation potentials
belonging to six elements, the temperature of the spots is found to be
4720° K., that of the photosphere being taken as 5740°. From the relative
strengths of the arc and enhanced lines of seven elements for which both
are available, it is found that the effective electron-pressure above the spot
is 0.60 times that which prevails over the disk. This diminution is due to
the lower ionization. When the effective amount of absorbing matter per
unit area was computed (which could be done for 19 elements in the neutral
and 11 in the ionized state) it was found that this quantity was 1.7 times
greater above the spot than over the disk, thus indicating increased trans-
aparency of the gases.

The ionization and transparency for a temperature of 4720° can be pre-
dicted with the aid of Russell’s data for the composition of the solar atmos-
phere and Gaunt’s formula for the opacity coefficient. The calculated
electron pressure is 0.55 times, and the calculated quantity of material 1.35 times, that above the disk. In view of the uncertainty of Gaunt's formula, the agreement is quite satisfactory.

With these data, theoretical intensities for the lines of the spot spectrum may be calculated. Computations have been made for a number of the most difficult cases (H, O, Si, Si⁺, Mg, Mg⁺), and for all the lines in four typical regions in the red, where the difference between the spectra of spot and disk is most marked. The computed intensities agree with the observed with an average discordance of ±1 unit of Rowland's scale, except for a few very strong lines and certain lines which are very faint in the disk and greatly strengthened in the spot. In both instances errors in the Rowland calibration (which is here weakest) may be responsible. Apart from this the whole series of differences in intensity between the lines in the spectra of the disk and of sun-spots can be accounted for quantitatively on a basis of pure thermodynamic theory with but three constants derived from observation.

**TIME OF A SOLAR ECLIPSE FROM A SOUND FILM**

The position of the Mount Wilson station for the solar eclipse of April 28, 1930, at Honey Lake, California, as determined by a careful survey with instruments loaned by the astronomical department of the University of California, was longitude W 120° 15’ 30”, latitude N 40° 8’ 20”, elevation 4000 feet.

During the eclipse, moving pictures with sound records were made by the Fox Movietone News. This film gives a continuous record of the eclipse near totality with 24 pictures per second, and also shows the time-counts which were made for the convenience of the observers at ten-second intervals during the minute preceding totality.

A determination of the time of mid-totality from this film gave $19^h 5^m 51^{1/4}$ G.C.T. The predicted time was $19^h 5^m 53^{1/1}$. The predicted duration was 1.4 sec., while the observed value was 1.2 sec. Thus it appears that the eclipse occurred 1.7 seconds earlier than predicted and that the duration was about 0.2 sec. less.

**LUNAR AND PLANETARY INVESTIGATIONS**

Dr. F. E. Wright, Chairman of the Committee on the Study of the Surface Features of the Moon, spent several weeks on Mount Wilson during September and October 1930 in experimental work relating to his proposed large-scale photographic map of the moon and other lunar problems. A meeting of the Committee was held on Mount Wilson during Dr. Wright's visit.

Two small houses were constructed north of the 100-inch telescope building, one containing a powerful light-source, the adjustable frame holding the lunar negative, a 15-inch globe coated with magnesia, and the photographic plate on which the image of the globe is projected. At a distance of 135 feet, which is the equivalent focal length of the telescope with which the negatives were obtained, is a second building containing the two concave mirrors which reflect the light from the negative to the globe and from the globe to the photographic plate. The second mirror may be
moved along a track to a distance corresponding to an angle as great as $12^\circ$ as seen from the globe. This provides for projection of all the negatives on a common line of sight.

An examination of the projected image on the globe showed remarkably fine detail and excellent contrast, but the image was in almost constant vibration and could not be photographed. This effect was without doubt due to the effect of air currents across the beam of light over the long path of 540 feet close to the surface of the ground. Accordingly, during the present summer the entire path has been enclosed by a long double-walled house of simple construction, and it is hoped that with the arrival of Dr. Wright successful work may be undertaken on the proposed lunar map.

Several additional spectrograms of the walls and floors of craters and other features of the surface of the moon have been made by Adams with the small quartz spectrograph and Wollaston prism. These photographs have been standardized and examined with reference to the amount of polarized light at different wave-lengths. It is clear that the effect is small, and the investigations will be extended farther into the ultra-violet where it may be more marked. Microphotometer tracings will be used for quantitative measurements of the spectrograms.

**PHOTOGRAPHS OF SATELLITES**

During the opposition of 1930 and 1931, Nicholson secured a number of photographs of the faint satellites of Jupiter. The Eighth Satellite, which had not been observed since 1923, was found by using an ephemeris communicated by Dr. Numerov.

**PLUTO**

Positions of Pluto were obtained by Nicholson and Mayall from plates taken on several nights at the 100-inch and 60-inch reflectors. Comparisons on a single night with stars of the North Polar Sequence gave provisional values of 15.5 and 14.5 for the photographic and photovisual magnitudes, respectively.

The orbit of Pluto previously determined by Nicholson and Mayall was revised by them to include the perturbations of the other planets and observations made in 1930 after Pluto's conjunction with the sun.

The perturbations of Pluto on Neptune were used by Nicholson and Mayall in an attempt to determine Pluto's mass. The solution based on observations since Neptune's discovery in 1848 is nearly indeterminate. The value derived for the mass depends, therefore, on the pre-discovery position by Lalande in 1795. A least-squares solution for the mass of Pluto in units of the earth's mass, based on both modern observations and Lalande's position, all with equal weight, gave $0.94 \pm 0.25$. For $m = 0$ the residual in Lalande's observation is $-6''2$; for $m = 1.5$ the residual is $+3''5$.

If the mass of Pluto is more than two-thirds that of the earth, its density must be higher, or its albedo lower, than any yet determined in the solar system. A consideration of its magnitude, therefore, favors values less than 0.9, and until further evidence becomes available it may be accepted as probable that the mass of Pluto is not greater than two-thirds that of the earth.
Attempts were made with the 100-inch telescope on several nights to ascertain whether Pluto had a visible disk. The image of the planet could not be distinguished from that of a star of the same magnitude. As a check on the size of disk, which one might expect to see with the 100-inch telescope, the satellite of Neptune, an object of the same order of magnitude, was also examined. Although nearly a magnitude brighter than Pluto, no disk could be seen. If the albedo of the satellite is the same as that of Neptune, the disk would be about 0'3 in diameter.

**MASS OF NEPTUNE'S SATELLITE**

An attempt was made to determine the mass of Neptune's satellite from its perturbations on Neptune. On 14 nights, when Neptune was nearly stationary, 27 exposures were made at the 80-foot focus of the 60-inch reflector by van Maanen, Willis and Nicholson. The first two observers measured the plates differentially on the stereocomparator to determine the motion of Neptune. The discussion of this material and a least-squares solution for the mass of the satellite was undertaken by Nicholson. The ephemeris of Neptune given in the American Ephemeris and Nautical Almanac was corrected by means of plates taken in March, May and June and used to compute the relative motion of the center of mass of Neptune's system. The differences between the observed motions of Neptune and the computed motions of the center of mass were used to compute the mass of the satellite. The result from all the measures, expressed in units of the earth's mass, is 0.06±0.024. If two poor plates are omitted, the value is 0.09±0.026. The mass of the satellite is therefore probably not greater than one-tenth or less than four one-hundredths that of the earth.

The positions of Neptune in right ascension and declination, referred to *Astrographic Catalogue* standards, were also determined from several of the plates by Nicholson and Miss Richmond. The mean corrections to the ephemeris given in the American Ephemeris and Nautical Almanac are $-1'3$ and $+1''2$, respectively.

**TEMPERATURE OF MARS**

Theory shows that the temperature of the sub-solar point on Mars should be 27° C. lower at aphelion than at perihelion. Heretofore all measurements of Martian temperature have been made near perihelion. At the opposition of 1931, the planet was near aphelion, and Pettit and Nicholson attempted observations with the thermocouple. The small apparent diameter of the planet increased the difficulties, but a thermocouple with receivers 0.1 mm. in diameter was constructed and used successfully with the 100-inch telescope. The determination of the effective area of the small receivers gave some trouble, and seeing conditions proved to be of vital importance in the case of the comparison stars used to calibrate the deflections; but the results substantially corroborate the theoretical temperature. A check was obtained by comparing the ratios of the deflections due to planetary heat and to reflected light. The ratio at aphelion is the same as that found at perihelion, which indicates that the radiated planetary heat must vary with the reciprocal square of the radius vector of the planet, a result also true for the incident solar radiation which is the
basis of the theoretical temperature. It follows that the mean maximum
temperature on Mars throughout the Martian year is approximately 14°
C. lower than that based on measurements at perihelion.

**RESEARCHES ON NEBULÆ**

**DISTRIBUTION OF NEBULÆ**

An investigation by Hubble of the distribution of nebulae based on counts
of some 20,000 nebulae on 900 plates with the 100-inch and 60-inch reflectors
scattered over the three-fourths of the sky north of declination —30° has
been completed. The results may be summarized as follows:

1. No nebulae are found in low galactic latitudes, and the zone of avoid-
ance 10° to 40° wide appears to represent the distribution of obscuring
clouds in the galactic system.

2. The zone of avoidance is bordered by partial obscuration which ex-
tends to latitudes ±40° in the general direction of the center of the
galactic system but is very limited in the direction of the anticenter.

3. In latitudes greater than ±40° (and less in the direction of the anti-
center) the distribution is approximately uniform or random with occa-
sional clusters scattered at wide intervals (possibly one cluster per 30
square degrees). The frequency distribution of the counts from point to
point in the sky, reduced to an hour's exposure on Eastman 40 plates with
the 100-inch telescope, approximates an error-curve with a total range of
about 1.0 in log N and a probable error of 0.15 for a single plate. The
mean log N per square degree for exposures of one hour with the 100-inch
reflector is 2.375. The corresponding value with the 60-inch is 2.036.

4. In the higher latitudes and for exposures ranging from 20 minutes to
3 hours, the counts are correlated with the exposure times in a manner
closely approximating that to be expected on the assumption of uniform
distribution in depth. The scatter about the correlation-curve decreases as
the exposures increase.

5. The limiting photographic magnitude of the counts on exposures of
one hour with the 100-inch telescope is estimated as 19.8, whence the
number of nebulae per square degree is

$$\log N = 0.6 m - 9.5$$

This value, combined with —13.8, the value for the absolute magnitude,
gives a density of one nebula per $6 \times 10^{16}$ cubic parsecs. For a mean mass
of $5 \times 10^8$ suns, the mean density of nebular matter in the observable region
of space appears to be of the order of

$$5 \times 10^{-31} \text{ gm./c.c.}$$

In connection with Hubble's investigation of the Virgo cluster of nebulae,
Mayall obtained a series of about 50 photographs, each of one hour's ex-
posure with the 60-inch reflector, using the Ross zero-power correcting lens.
Counts of nebulae on these plates indicate the presence of two new clusters
of faint nebulae, distinct from the larger and brighter cluster superposed
upon them. Mayall also made a series of photographs with the 10-inch
photographic telescope covering the region south of the Virgo cluster. Pro-
visional counts indicate another grouping of bright nebulae to the south and
east of the main cluster, but further evidence is required to decide whether the two groups are distinct. Similar photographs have been made of the region between the galactic pole and galactic latitude $+75^\circ$, but counts of the nebulae have not yet been completed.

A cluster of faint extra-galactic nebulae centered about right ascension $10^h 23^m$, declination $+11^\circ 0'$ (1900) was discovered by Christie on photographs made by him of the planet Neptune during a search for additional satellites. This has proved to be the most distant cluster of nebulae yet investigated. Hubble assigns to it a distance of 32 million parsecs, and the apparent velocity of the brightest nebula in the cluster as determined by Humason is the largest so far observed. More than 300 nebulae are visible on the photographs.

**Absolute Magnitudes of Extra-Galactic Nebulae**

A review by Hubble of the material previously available, together with new data on stars involved in nebulae and Shapley's revision of the zero-point of the period-luminosity curve for Cepheids, has led to $-13.8$ photographic and $-14.9$ photovisual as revised values for the mean absolute magnitudes of extra-galactic nebulae. The luminosity function approximates an error-curve with a probable error of the order of 0.8 mag. for a single object.

**Velocity-Distance Relation**

In collaboration with Humason, Hubble has reexamined the velocity-distance relation. The 85 velocities now available, 32 of which refer to nebulae in 8 clusters or groups, extend the range of the relation to about 32 million parsecs, or 18 times the distance covered by the first formulation. The relation, $v = (d - 1790)$, remains unchanged except for a revision of the unit of distance. The uncertainty is estimated to be of the order of 10 per cent. In addition to its cosmological significance, the relation furnishes a method of deriving distances of individual isolated nebulae, and hence opens new fields for investigation.

**Proper Motions Measured in Spiral Nebulae**

Reference was made in last year's Report to the proper motions measured by van Maanen for the two spiral nebulae N.G.C. 4051 and 5194. He has added results for 10 others from photographs taken at the 80-foot focus of the 60-inch reflector. The relative motions have been reduced to absolute values by means of Oort's results for the proper motions of the comparison stars. For the 12 nebulae observed, the number of pairs of plates measured ranges from 1 to 9, the mean interval in years between the plates from 9.9 to 14.0, and the galactic latitude from $-52^\circ$ to $+89^\circ$. The absolute motions range in right ascension between 0"002 and 0"014, and in declination between 0"000 and 0"019. The probable errors are between 0"002 and 0"003 for a single pair of plates, and about 0"001 when five or more pairs are measured.

When these motions are plotted on a sphere, the remarkable result is found that all of these nebulae are apparently moving away from the poles of the Milky Way. The alternative explanation of a motion of the comparison stars toward the pole seems at present to be excluded. At least the faint stars in fields centered on certain Boss stars show no such systematic
effect. Willis is investigating this question and has measured 44 fields of Boss stars during the year in order to determine the direction and amount of the motions of the comparison stars of magnitudes 12 to 15, as well as the correction to Boss's proper motions.

In one of the spirals, N.G.C. 5457 (Messier 101), van Maanen has been able to measure not only the nucleus but 6 points which presumably form parts of the nebula. These show a decided internal motion in the same direction as was found in his original measures of this nebula. The mean annual rotational component of these 6 points is $0^\circ 015 \pm 0^\circ 003$, as compared with $0^\circ 019 \pm 0^\circ 002$ from the old measures. The linear displacement on the new plates is 0.022 mm. as against 0.004 mm. on the old plates, which were taken at the 25-foot focus of the 60-inch reflector with an interval of only 5 years.

**NEBULAR SPECTROSCOPY**

During the year Humason has obtained with the 100-inch reflector apparent radial velocities for 15 extra-galactic nebulae. Eleven of these are in the Pisces group and in the Cancer, Leo and Coma Berenices clusters. The remaining four are isolated nebula and include N.G.C. 7217, the spectrogram for which was obtained by Pease.

The largest velocity, $+19,700$ km./sec., is for the brightest nebula in the Leo cluster discovered by Christie. Its photographic magnitude, the faintest so far observed, is $16.8 \pm$. Hubble estimates the distance of the cluster as about 105 million light years. The small dispersion used, 875 angstroms per millimeter at $\lambda 4350$, and the displacement of the H and K lines of calcium well toward the region most active photographically made it possible to photograph the spectrum in $13\frac{1}{2}$ hours. This observation gives striking evidence of the efficiency and power of the 100-inch reflector and the short-focus Rayton spectrograph objective.

Velocities have also been obtained for the nucleus and two emission patches in N.G.C. 5457 (Messier 101). These are in fair agreement with the $+215$ km./sec. previously found for the brightest emission patch. The mean velocity is now $+280$ km./sec.

The problem of the rotation of spiral nebulae is being taken up again by Pease, who is using the three-prism spectrograph designed for work in the violet portion of the spectrum. As in previous observations, an occulting bar with a considerable number of windows is placed in front of the slit to provide for the use of a comparison spectrum at points along the diameter of the nebula. Measures by Humason of the H and K lines on a spectrogram of N.G.C. 4594 taken with this instrument give values for the nucleus accordant with earlier observations.

**NEBULAR PHOTOMETRY**

Smith has investigated the possibilities of work on faint nebulae with a photo-electric cell. A cell borrowed from Dr. Stebbins showed sufficient sensitivity and stability for the purpose. This indicated that the problem was not hopeless, provided suitable means could be found for measuring the very feeble currents involved. Preliminary experiments with a Hoffman electrometer showed promise and suggested certain changes in the moving parts of the electrometer, which led to the construction of an extremely light moving system having the proper electrical characteristics for the cell.
Insulation difficulties and local ionization produced by cosmic rays and similar causes were overcome by encasing all important leads in evacuated tubes. The instrument is now in satisfactory form and has been installed at the coudé focus of the 60-inch telescope. Measures of a number of nebulae in the Coma cluster ranging from 13.8 to 16.3 show that it should be possible to make precise determinations of magnitudes and color indices for objects as faint as the seventeenth magnitude. Even a nineteenth-magnitude object should show a small deflection.

**RELATION BETWEEN SIZE AND SURFACE-BRIGHTNESS OF THRESHOLD IMAGES**

An investigation by Hubble of threshold images on photographic plates of uniform exposure with the 100-inch and 60-inch reflectors has shown a correlation between the diameter and the surface brightness (magnitude per square second of arc) of the faintest images perceptible to the eye, with or without the aid of magnification. The observations range from the smallest focal images photographed under excellent conditions, through larger images registered in poor seeing, to extra-focal images of various dimensions.

For the smallest images (0.04 to 0.10 mm.), the perceptibility depends almost wholly on total luminosity rather than on surface brightness, i.e., the limiting magnitude is essentially independent of the size of image and hence of seeing conditions. For images 8 mm. and larger, the perceptibility depends essentially on surface brightness rather than on size. The transition between the two extremes is smooth, and the correlation simulates that found in the visual perception of faint luminous sources. The surface brightness of threshold images ranges through some four magnitudes as the diameters vary from 0.04 mm. to 4 mm. The correlation is important in the determination of total magnitudes of faint nebulae on focal exposures. Analogous results are found with smaller cameras (apertures 10, 5 and 2 inches) having comparable focal ratios. The efficiency appears to increase slightly as the apertures decrease.

**DETERMINATION OF THE VELOCITY OF LIGHT FROM EXTRA-GALACTIC NEBULÆ IN URSÆ MAJOR**

Strömbärg has determined the velocity of light from the cluster of extra-galactic nebulae in Ursa Major by finding the difference in the values of the aberration coefficient for the nebulae and nearby stars. Comparison of two plates taken when the aberration was near maximum and near zero, respectively, gave, for the difference nebulae minus stars, $-0.006 \pm 0.050$. From this the ratio of the velocity of light from the nebulae to that from the stars is found to be $0.9997 \pm 0.0024$. The two velocities are the same within the errors of measurement. In spite of having traveled a distance of about 70 million light-years the velocity of nebular light is not changed. This is in accordance with modern theories of light.

**MISCELLANEOUS STELLAR INVESTIGATIONS**

**TRIGONOMETRIC PARALLAXES**

In continuation of his work on trigonometric parallaxes, van Maanen has obtained 105 plates with 181 exposures at the Newtonian focus of the 100-inch reflector and 136 plates with 237 exposures at the Cassegrain focus of the 60-inch reflector. Nineteen fields have been finished during the year.
Most of the observations are on faint stars of large proper motion, six of which are found to have absolute photographic magnitudes fainter than −10.

**PROPER MOTIONS**

For the measurement of proper motions, van Maanen has taken 47 plates with 49 exposures at the 100-inch reflector, and with the assistance of Willis has obtained 180 plates with 266 exposures at the 60-inch reflector. In addition, Christie has reobserved several of the Selected Areas in connection with van Maanen’s search for very faint stars of large proper motion. The results of the measurements during the year by van Maanen and Willis of 21 Selected Area fields, when added to previous results by van Maanen on 21 other fields, may be summarized briefly: Among about 60,000 stars examined in the 42 Selected Area fields, 122, ranging in magnitude from 6.7 to 20, are found to have annual motions between 0"041 and 0"0925. The percentage of stars having a considerable motion increases from 0.07 in galactic regions to 1.02 in high galactic latitudes. The amount of the mean motion of the fainter stars decreases with magnitude but seems to be independent of galactic latitude. Three methods have been used to determine the antapex of the motions, the final result being: A = 6h 43m; D = −28°. The mean parallaxes have been calculated from the peculiar motions for groups of different magnitudes and proper motions, and are found to depend very little on the magnitude but to be correlated strongly with the proper motion.

**MOTION OF A PARTICLE IN A SYSTEM WHOSE DENSITY DECREASES OUTWARD**

Strömbäck has studied the types of motion to be expected in a system whose density decreases from the center outward. The potential of a particle at a distance r from the center was determined for a system having spherical symmetry and a density decreasing according to the law $\sigma = \sigma_0 e^{-kr^2}$. A particle in this system having a velocity higher than that of escape which passes near the center moves in an orbit similar to a hyperbola, but the angle between the asymptotes is much greater for a given distance from the center than in the case in which all the attracting mass is concentrated in a point. For particles having velocities less than that of escape the radius vector has definite maximum and minimum values which do not change with time. The angle between these radii lies between 180° and 90°. For the limit of 180°, $hr$ remains large, and the motion is a Keplerian ellipse; for the 90° limit, $hr$ remains small, and the motion is a central ellipse. In the general case the orbit is not periodic but consists of a number of loops around the center.

In an extremely flat system the potential for a particle moving in the equatorial plane has another form, which can be expressed in Bessel functions. The orbits, however, are of the same general type as for a spherical system. (See Publications Astronomical Society of the Pacific, 43, 263, 1931.)

These results show the types of orbits to be expected for stars moving in the galactic system under the gravitational action of the system as a whole.

**STELLAR PHOTOMETRY**

Seares and Miss Joyner have continued the reductions for photovisual magnitudes in 43 of the Selected Areas of Kepteyn. Results for the zones at declinations +45°, +30°, 0°, and −15°, including the final zero-point
adjustment, are now complete. With the exception of the long-exposure plates, the zone at +15° is also finished.

A discussion of the results for 760 stars in Selected Area 40, near α Cygni, extending down to photovisual magnitude 15.7, shows that about one-fourth of all these objects are redder than normal M-type stars; of the 150 stars brighter than 14.0, 15 per cent are likewise redder than M-type stars. Since the zero-points are checked by three different methods of determination, a large percentage of the stars certainly have a large color excess. This undoubtedly is to be attributed to selective absorption produced by the obscuring clouds which are numerous in this part of the sky. Spectra by Humason are available for 32 of the stars, mostly brighter than 13.0 photovisual. For 18 of these the colors are normal; 3 are doubtful, and 11 show a mean color excess of 0.66 mag. The stars of normal color are at a mean distance of about 400 parsecs, while those showing selective absorption range in distance from 1200 to 2800 parsecs.

The scale of photovisual magnitudes used in these investigations depends partly on the Mount Wilson scale of the Polar Sequence and partly on special determinations in each of the Selected Areas. The scale at the Pole is now well checked by the extension of the Potsdam visual measures published in the Potsdam Polar Catalogue. A detailed comparison of results made by Seares, with allowance for color equations, is now in press. Between the second and twelfth magnitudes, the mean scale difference averages 0.02 to 0.03 mag., with a total systematic range of about 0.04 mag. The comparison also determines the relation of the zero-point of the Potsdam catalogues to that of the international system.

The determination of magnitudes and colors for the southern comparison stars of Eros by Seares, Sitterly and Miss Joyner was referred to in last year’s Report. Results were obtained for 300 Eros stars (mags. 7–10) and 74 brighter stars (mags. 5–7). More than a hundred of the stars have also been observed by Ross and Zug at the Yerkes Observatory. The two series of measures give practically the same relation between spectral types from the Draper Catalogue and color index on the international system. The colors for F, G and K stars are, however, appreciably less than those found by King, Parkhurst and Seares for other, and in general brighter, stars. The greater percentage of dwarfs among the Eros stars will account for part but not all of the difference. Comparisons with Harvard magnitudes of these stars give general indications as to the scale and the color equations of Pickering, Wendell and Bailey—data which are essential for the reduction of the Harvard visual magnitudes to the international system.

Mayall has measured the magnitudes of the remarkable variable star (8h 10m 36s, –18° 44’9, 1900) recently discovered by van Gent at the Union Observatory, which has a period of slightly more than 100 minutes. Provisional results show a range from 14.5 to 15.75 photographic. The photovisual measures are fragmentary, but suggest a maximum of about 14.0. The color index at maximum appears therefore to be of the order of +0.5 mag.

Mayall has also made photometric measures of an interesting variable (5h 56m 14s, +39° 38’, 1930) discovered by him on a red-sensitive objective-prism plate taken with the 10-inch Cooke triplet. Attention was first
attracted by the bright Hα line and the practical absence of the violet end of the spectrum, which seems to be of type Se. Data from early Harvard plates kindly supplied by Dr. Shapley confirm the variability, and, together with the Mount Wilson photographs, indicate a period of about 417 days. The amplitude of variation is still uncertain, but the photographic range is from magnitude 12 to 17 at least. Rough comparisons with neighboring Selected Areas on March 28, 1931, gave photographic and photovisual magnitudes of 16 and 11, respectively, and the exceptional color index of 5 mags.

Comparisons with Selected Areas have been made by Hubble and Mayall for 8 nebular fields in which standards of brightness were required for photometric observations of extra-galactic nebulae.

**EFFECT OF ABSORPTION ON THE SPACE DENSITY OF STARS**

Globular clusters and extra-galactic nebulae indicate that space outside the galactic system is highly transparent. On the other hand, the dark clouds scattered along the Milky Way show that the light of great numbers of stars must be much reduced in intensity by absorbing material within the system. Measures such as those in Selected Area 40 described above, and others made at other observatories, show that the absorption, in part at least, is selective in character. The effect on photographic and photovisual magnitudes will therefore be different. The data are still too fragmentary to afford more than general indications as to the amount of the absorption, which seems to be appreciable only within a thin stratum close to the Milky Way. For the galactic plane itself, Dr. Trumpler's discussion of open clusters indicates an average effect on photographic light amounting to 0.67 mag. per 1000 parsecs. If this value is maintained over any considerable distance, the effect on the apparent magnitudes of the remote stars will be large, and calculations of the space density of stars will be seriously modified. Seares has investigated the matter with the aid of a general relation connecting the true density, the absorption function, and the fictitious distribution of density found by ignoring the existence of absorption. Acceptance of Trumpler's coefficient means, in general, an increase in the true density in all directions outward from the sun. The value at 6000 parsecs in the direction of the center of the system in Sagittarius would be 5 or 6 times that near the sun. An increase in this direction, although perhaps not of this amount, is rather to be expected. For the opposite direction also the results are not wholly decisive; but the three-fold increase indicated for directions perpendicular to those toward the center and anti-center seems to be wholly inadmissible. The general indications are that the absorption is not constant in longitude or for any great distance in the galactic plane. This statement refers to the general trend in the average values, for the obvious irregularities in the obscuring clouds of course imply large local fluctuations in the absorption.

**A NUMERICAL METHOD OF CALCULATING THE SPACE-DENSITY FUNCTION**

None of the formulæ hitherto used for the space-density function are capable of representing the observed data throughout their entire range, even when the irregularities of stellar distribution are eliminated by using counts of stars averaged over many square degrees; and none of them gives even a first approximation to the density distribution of the galactic star clouds. To meet this difficulty Seares has developed a numerical solution
of the fundamental integral equation which represents all the data satisfactorily, even when the density undergoes marked fluctuations. Since the method is wholly numerical, no assumption need be made as to the form of the luminosity function or of the frequency function for the star counts. The method is flexible in that a luminosity function which depends on the distance may be used if necessary; further, the effect of absorption is easily included in the calculation, provided the absorption function is known. Finally, the method is objective in that the calculations show how the counts of stars of each apparent magnitude are distributed in distance and how the stars fainter than the limit of the counts affect the calculated densities. In spite of these advantages, the method does not of course overcome the inherent uncertainty of the problem arising from the fact that a sharp narrow maximum in the density distribution appears in the star counts as a very broad flat maximum extending over a range of about 20 magnitudes in apparent brightness. In general it should be possible to locate the beginning of one or more aggregations of stars; but it will be difficult to tell what lies beyond—whether a succession of minor clouds or a single large cloud.

STELLAR INTERFEROMETERS

The difficult work of adjusting and using for measurement the 50-foot interferometer has been carried on by Pease from time to time during the year, but the demands of other investigations, especially that on the velocity of light, have interrupted the regular use of the instrument. Fringes have been observed with separations of the mirrors as great as 44 feet, and considerable experience has been gained in the ability to locate the fringes and estimate their visibility. Measurements of α Orionis by Pease have given an angular diameter of about 0\'040, and of β Andromedae, 0\'016.

Attempts were made by Pease and Nicholson to measure the diameter of Eros near opposition with the 20-foot interferometer on the 100-inch telescope. Due principally to the faintness of the object, however, no results of value were obtained.

STELLAR SPECTROSCOPY

A three-prism spectrograph of light flint glass for use in the H and K region of the spectrum and near the head of the Balmer series of hydrogen lines has been completed and placed in operation during the year. The collimator and camera lenses were designed by Ross and have focal lengths of 24 and 15 inches, respectively. The instrument is planned for use at the Cassegrain focus of either the 60-inch or the 100-inch reflector and operates at the focal ratio of 1 to 16. It is attached directly to the plateholder frame, and the observer may use either the cross-slides of the plateholder or the slow-motion motors of the telescopes for guiding purposes. Provision is also made for tilting the spectrograph about a horizontal axis in order to leave the field of the telescope free for the identification of faint stars. A camera consisting of a Rayton lens with a focal ratio of 0.6 may be used interchangeably with the 15-inch camera. The linear scale of the spectrograms made with the longer camera is about 17 angstroms to 1 mm. at H and K, and the definition is excellent over a long range of spectrum.

An interesting development in connection with the coudé spectrograph of the 100-inch reflector has been its adaptation for use with a concave
grating. The grating is one by Jacomini with a ruled surface 6×4.5 inches and a radius of 30 feet. It gives a remarkably bright spectrum in the first order on one side, and the definition is of fair quality, although not excellent, the strongest lines of the comparison spectrum showing a fringe on the red side. Since the spectrograph is used in the stigmatic form with a 6-inch collimating lens of 15 feet focal length, the focal length of the grating is also 15 feet. The linear scale on the spectrograms is slightly more than 3.5 angstroms to the millimeter. Exposure times are only about two-thirds as long as with the same spectrograph when the large prism is used, even in the region of the spectrum near λ 4400 where the linear scale is the same. In the violet region the gain is, of course, very much greater. Although the spectra obtained with this grating can not be used for quantitative work of the highest precision, they are of great value for qualitative studies and the resolution of close lines, especially in the violet and red regions. The efficiency of the instrument is so unexpectedly great that it is of the highest importance that a first-quality grating be secured for it as soon as possible.

A second lens of the type designed by Dr. Rayton of the Bausch and Lomb Company, with an aperture of 2 inches and a focal length of 1.2 inches, has been obtained for observations of faint nebular and stellar spectra. It may be used either with the small one- and two-prism spectrograph employed mainly by Humason, or with the three-prism ultra-violet spectrograph already described. In designing this lens Dr. Rayton has dispensed with the extra element employed to correct the lens for infinite distance of object.

A plane-grating spectrograph for use at the Cassegrain focus of the 100-inch reflector was completed a few years ago and especially during the past year has been utilized by Merrill and Sanford in studies of the red and infra-red regions of stellar spectra. The optical parts consist of a 2.5-inch telephoto collimating lens of 40 inches equivalent focal length, a plane grating by Jacomini with 600 lines to the millimeter, and interchangeable camera lenses of various focal lengths. The main casting of aluminum alloy is supported by a tubular steel frame in such a way as to avoid cramping and flexure. The instrument was designed by Nichols and built in our instrument shop and has given excellent results with exposures of as much as six hours.

A total of 1054 spectrograms has been obtained during the year with the regular one-prism spectrographs at the Cassegrain focus of the two reflectors, 772 with the 60-inch and 282 with the 100-inch telescope. Most of the spectrograms taken with the 100-inch reflector are of stars of visual magnitudes between 8 and 12. In addition 89 spectrograms of bright stars have been obtained with the coude spectrograph and many others with the three-prism ultra-violet instrument, the plane-grating and the small spectrographs of low dispersion. The members of the staff who have taken part in the observations are Adams, Christie, Dunham, Joy, Mayall, Merrill, Sanford and Strömberg.

**RADIAL VELOCITIES**

Observations for radial velocity have been continued on selected lists of stars, including many from Boss's *Preliminary General Catalogue*, the Selected Areas, and Russell's catalogue of dynamical parallaxes; variable
stars of different classes; bright-line B stars and many others. The velocities of about 90 stars have been determined from three or more spectrograms in addition to those of several N-type stars observed by Sanford.

In continuation of his spectroscopic observations of eclipsing variable stars, Joy has derived orbits and values of the absolute dimensions for RS Canum Venaticorum, TT Aurigae and RT Lacertae, all of which show double lines in their spectra. The masses of the components in the case of RS Canum Venaticorum are each about 1.8 times that of the sun. The primary star has the spectral type F4 and a radius 5.3 times that of the sun, while the secondary of type G8 seems to be intermediate in absolute magnitude between the giants and the dwarfs and has a radius 1.6 that of the sun.

Photometric observations of TT Aurigae made at Princeton by Joy and discussed by Dr. Sitterly have been combined with the spectroscopic orbits to give the absolute dimensions. Both stars have the spectral type B3 and are distinctly elongated toward each other. The longer radii in terms of the sun's radius are 4.5 and 4.0, and the masses 6.7 and 5.3 times that of the sun. The H and K lines of interstellar calcium show faintly in the spectra of both stars, along with the stellar calcium lines.

The components of RT Lacertae are among the coolest of the eclipsing stars, having spectral types G9 and K1. They are of nearly the same size, with radii 5.0 times that of the sun and masses 1.0 and 1.9 that of the sun. The star of type G9 has the greater luminosity but the lesser mass, a condition previously unknown in stars of this class. The absolute magnitudes of both stars seem to be intermediate between those of giants and dwarfs.

Joy has completed approximate velocity-curves for 10 Cepheids and has under investigation the spectra of several variables of the RV Tauri type and the peculiar variables UU Herculis and DF Cygni. Sanford is collaborating in some of these observations.

Among the interesting stars showing variable radial velocities which have been under investigation by Sanford is AC Herculis with a period of light variation of 75 days. The velocity-curve has the same period and shows double maxima and minima which follow the minima and maxima of light with a lag of about seven days. If the star is considered as a spectroscopic binary, both the velocity of the center of mass and the velocity-amplitude appear to vary. The enhanced lines give algebraically higher velocities than those due to the neutral atom. At certain phases of the period, pairs of emission lines border the absorption lines of hydrogen, and, since the components vary in relative intensity and perhaps in position as well, the velocities given by the absorption lines differ from those given by the lines of other elements. These differences form a curve with double maxima and minima. The sequence of spectral changes explains adequately the fact that the amplitude of the photographic light-curve is much greater than that of the visual light-curve.

The orbits of four spectroscopic binaries with the Henry Draper Catalogue numbers 73619, 75767, 206546 and 214686 have been calculated by Sanford. With the exception of H.D. 75767, all show double lines in their spectra. H.D. 73619 is a member of the Praesepe cluster, and the velocity of its center of mass, +32.1 km./sec., is in close agreement with the mean...
value, +32.4 km./sec., given by about 20 other stars in the cluster which appear to have constant velocities. The two components of H.D. 214686 have orbits with an eccentricity of 0.38 and are so oriented that the lines are resolved only near periastron. The minimum masses for the three spectroscopic binaries with double lines are all only slightly larger than that of the sun.

The bright star Boss 1074 has been observed spectroscopically at Mount Wilson since 1918. A comparison by Sanford of these observations with those obtained at the Lick Observatory in 1906-1909 and in 1921 indicates a period of 17 years. If the star is regarded as a spectroscopic binary, the orbit would have an eccentricity of 0.45; and on the assumption that the primary is three times as massive as the secondary, it would have a mass at least 48 times as great as the sun.

Sanford has continued his observations of the interesting variable star U Monocerotis and has completed the velocity-curve for UU Cassiopeiae. The velocity-curves of the Algol variables TT Hydæ, RW Corœæ, TT Herculis, AK Herculis and WZ Ophiuchi are still under observation. The spectrum of RR Herculis, classified in the Draper Catalogue as K5p, is found to show emission lines of hydrogen. Sanford has also determined the radial velocities of ten stars of type N and two of type R, both from the hydrogen lines in emission and from the absorption lines of other elements. The difference, emission — absorption, is 23 km./sec., a value with the same sign but larger than that found by Merrill for the Me and Se variables. In the case of two stars, U Aurigæ and T Draconis, the presence of emission lines of hydrogen had apparently not been observed previously.

**B-TYPE STARS WITH EMISSION LINES**

Observations during the year have increased the total number of bright-line stars discovered since 1924 by Merrill, Humason and Miss Burwell to about 90. In addition to these an excellent objective-prism photograph by Mayall of the region surrounding the double cluster in Perseus shows a large number of stars of the ninth magnitude or fainter which have a bright Hα line. Merrill and Miss Burwell have begun the preparation of a catalogue of all known bright-line stars of type B.

A detailed description of the interesting spectral variations of the B8e star H.D. 50138 has been prepared for publication by Merrill. Bright hydrogen lines were discovered at Mount Wilson in 1920. Hβ has two strong emission components separated by about 4.2 A. The red component maintains its position and intensity practically without change, but the violet component exhibits striking variations. Helium, magnesium and iron lines are wholly dark. The forbidden OⅠ lines λλ 6300, 6363, known in gaseous nebulae, are present as emission lines of low intensity. The displacements of the well-defined absorption centers of Hγ and Hδ vary, but appear not to correspond to a simple orbit. The displacements of other lines fail to agree with those of Hγ and Hδ. The phenomena are complicated and difficult to interpret. The changes in intensity of the violet emission component of Hβ can not be caused by absorption of the same type as that which produces the central dark lines of the Balmer series. Explanation by the occultation of the approaching limb of a rotating star
seems too artificial to be convincing. The general behavior of the hydrogen lines resembles that observed by Joy in the companion to o Ceti (Mira).

Observations of the well-known B-type star P Cygni by Adams and Dunham with the coudé spectrograph show interesting details of structure in the hydrogen lines. The absorption lines on the violet side of the emission bands are clearly double, with the stronger component to the violet and a weaker component between this and the edge of the emission band. The effect is most plainly shown in the case of H α, but may also be seen in some of the other hydrogen lines and resembles the effect seen at certain stages of the spectra of novae.

YELLOW AND RED REGIONS OF STELLAR SPECTRA

The plane-grating spectrograph and, in the case of bright stars, the coudé spectrograph, have been used to excellent advantage in the study of the less refrangible portion of the spectrum. The development of highly sensitive photographic emulsions for this region, especially by Dr. Mees of the Eastman Company, has greatly facilitated such work. Merrill has given especial attention to the detached D lines of sodium, bright H α, the (nebular) forbidden OⅡ multiplet near λ 7325, the OⅠ triplet λλ 7772, 7774 and 7775, and the strong CaⅡ triplet λλ 8498, 8542 and 8662. In the course of these investigations he has discovered bright sodium D lines in the spectrum of H.D. 190073, which is the first star apart from novae in which these familiar lines have been observed in emission. The structure of the H and K lines is very peculiar. Bright hydrogen and iron lines were found several years ago.

Miss Burwell has examined the spectra of some of the K- and M-type stars in the less refrangible region and finds a marked absolute-magnitude effect in the case of the red calcium lines. Sanford has made use of the fact that N-type stars show a great relative concentration of light in the yellow-red portion of the spectrum, and has added to the number already observed through the use of the plane-grating spectrograph with a 6-inch camera which is very efficient in this region. The addition of these stars will bring the number of N-type stars for which radial velocities may be obtained to about 85. Sanford has also obtained with the 15-foot coudé spectrograph a spectrum of the bright N-type star Y Canum Venaticorum on a scale of 3.5 angstroms to the millimeter. The photograph shows a wealth of detail which it is difficult on superficial examination to reconcile with the view that the spectrum is wholly one of absorption.

BRIGHT H AND K LINES IN LATE-TYPE SPECTRA

The new three-prism spectrograph has been used by Adams and Joy in a continuation of their investigation of the bright H and K lines of calcium in stellar spectra. Bright lines have been found in several additional stars, and especial attention is being given to a comparison of these lines in giant and dwarf stars. The bright H and K lines in the spectrum of 61 Cygni, discovered at Mount Wilson several years ago, have been photographed with considerably higher dispersion than heretofore.

SPECTRAL CLASSIFICATION OF STARS IN THE SELECTED AREAS

At the request of Dr. van Rhijn in 1922, the Observatory undertook to observe and classify the spectra of 10 or more stars fainter than photographic magnitude 11.0 in each of 115 of Kapteyn's Selected Areas. The
areas to be observed included those on and north of the celestial equator. The observing part of the program, carried on by Humason with the 60-inch reflector, has been completed, and about 90 per cent of the spectra have been classified. The total number of stars classified, including those brighter than 11.0, will be approximately 3000.

** STELLAR SPECTROPHOTOMETRY **

A most satisfactory method of standardizing stellar spectra by means of a raster, cylindrical lens and plane-grating spectrograph has been developed by Dunham and applied to 59 spectrograms of bright stars obtained by him during the year with the coude spectrograph. He has constructed two new rasters of improved design, the one now in regular use having the form of a logarithmic curve. This gives a standardizing spectrum whose intensity varies logarithmically in a direction perpendicular to the dispersion. Extensive measurements of the contours of absorption lines are in progress.

The instrument used for tracing the curves of these spectrograms is the Zeiss microphotometer of the Astrophysical Laboratory of the California Institute. Dunham has investigated for this instrument the electrical lag in response, which is of sufficient importance to introduce errors into the measurement of line-contours.

When photography is employed in an attempt to secure quantitative measurements of large variations in the intensity of light occurring within a small part of a millimeter, as in the case of stellar spectra, serious difficulties arise. The most important of these is the Eberhard effect, which distorts the contours of spectral lines. The grain of photographie plates also introduces considerable uncertainty into determinations of line-contours from microphotometer tracings. In examining both of these effects Dunham has compared various methods of development and the graininess of different emulsions. Using a slit 0.5 mm. long and 5μ wide, he has found that on a typical fast plate, blackened uniformly to a density of 0.3, the average deviations from the mean line drawn by the microphotometer amount to 1.5 per cent of the total deflection from clear film to complete opacity.

Dunham has also studied the applicability of a photoelectric amplifier to our stellar microphotometer. With the use of the FP-54 tubes recently developed by the General Electric Company it is possible to obtain excellent stability and great speed with a short-period galvanometer. An amplifier using two of these tubes in a balanced circuit appears to meet the requirements for recording the contours of solar lines directly without the intervention of photography, and the method will be tried in the near future.

** RADIOMETRIC MEASURES OF STELLAR SPECTRA **

Smith has made further tests of his radiometers on stellar spectra at the coude focus of the 60-inch telescope. These show that precise spectral-energy curves of the brighter stars can be derived with the aid of the radiometer, and preparations are under way to carry out these measurements at the coude focus of the 100-inch reflector. A suitable spectrometer and other necessary accessories are being built.

A new method of measuring radiometer deflections has been developed which has greatly increased the effective sensitivity of these instruments.
Heretofore it has been thought that the deflections due to Brownian movement set a natural limit to the accuracy with which star deflections can be determined. The following technique, however, enables one to determine deflections with an uncertainty which is many times less than the mean Brownian movement deflections.

A beam of light from the mirror of a slightly over-damped radiometer is brought to a focus on a photographic film, the intensity of the light being fixed at such a value that a relatively long time is required to record the image on the film. Hence, when the film is exposed, even though the spot of light continually wanders about its mean position in building up the photographic image, the various excursions are automatically averaged out, and the center of the image very accurately represents the mean position of the spot.

When a measurement is made, the instrument is allowed to assume its zero position, and the recording light is then turned on for a definite time-interval. At the end of this interval the recording light is cut off, the starlight is allowed to fall on the radiometer, and after the instrument has had sufficient time to come to "rest," the recording light is again turned on for the chosen time interval. The actual deflection is measured on a comparator after the film is developed.

SPECTROSCOPIC DETERMINATIONS OF ABSOLUTE MAGNITUDE AND PARALLAX

Adams has continued throughout the year the classification of stellar spectra and the determination of absolute magnitudes from the intensities of spectral lines. Special attention has been given to giants and supergiants of types G0 to K5.

In the Annual Report for last year reference was made to the completion of a revised table of reductions for dwarf stars of types F0 to K8 to provide for the inclusion of additional lines used in the estimates. Similar tables have now been completed for giants and supergiants, and the absolute magnitudes of about 1500 stars of types between G0 and K5 have been calculated on this system. The reduction tables are based mainly on smoothed values of the absolute magnitudes calculated by Strömgren from radial velocities and peculiar and parallactic motions, and on mean trigonometric values derived from the material contained in Schlesinger's General Catalogue of Stellar Parallaxes, 1924. A comparison of the results for the list of 1500 stars is of interest as showing not only the degree of accordance of the spectroscopic mean absolute magnitudes with those derived by other methods, but also the agreement of the mean trigonometric values with those calculated by Strömgren. The comparison of the trigonometric values is limited to stars with parallaxes measured at the Allegheny, McCormick and Mount Wilson Observatories.

Mean Absolute Magnitudes of Giant Stars of Types G0 to K5

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strömgren (about 2100 stars)</td>
<td>+0.26</td>
</tr>
<tr>
<td>Spectroscopic (1310)</td>
<td>+0.27</td>
</tr>
<tr>
<td>Trigonometric (231)</td>
<td>+0.37</td>
</tr>
</tbody>
</table>

19 Supergiants: Spectroscopic −2.4; Trigonometric −2.5

The mean absolute magnitudes in the case of the stars with trigonometric parallaxes have been calculated by the formula which provides for the
inclusion of negative parallaxes and on the assumption of a dispersion of 0.8 mag. for the giants, and 1.2 mag. for the supergiants.

A limited group of stars with absolute magnitudes of about $+2.5$, intermediate between giants and dwarfs, which is indicated by the calculations of Strömgberg and also by the trigonometric parallaxes, is clearly shown in the spectroscopic values. Most of these stars are of spectral type G.

**LUMINOSITY DISTRIBUTION AMONG STARS OF TYPES A2 TO M**

Strömgberg has applied to stars with apparent magnitudes brighter than 6.0 the method which he has developed for calculating the distribution in absolute magnitude from the distributions of peculiar and parallactic motions and of radial velocities. The investigation began with the M-type stars and has been continued through the spectral sequence to type A2. The analysis for the B- and early A-type stars has not yet been completed. The accompanying table gives the results, the figures in parentheses showing the percentage of the total number of stars in each group.

<table>
<thead>
<tr>
<th>Spectrum (H.D.)</th>
<th>Number of stars</th>
<th>Super-giants</th>
<th>Bright giants</th>
<th>Normal giants</th>
<th>Faint giants</th>
<th>Dwarfs</th>
</tr>
</thead>
<tbody>
<tr>
<td>M0 to M9</td>
<td>247</td>
<td>-4.5(9)</td>
<td>.............</td>
<td>-0.2(91)</td>
<td>.............</td>
<td>+6.7(2)</td>
</tr>
<tr>
<td>K3 to K9</td>
<td>378</td>
<td>-4.5(7)</td>
<td>.............</td>
<td>-0.1(91)</td>
<td>.............</td>
<td>+6.1(1)</td>
</tr>
<tr>
<td>K0 to K2</td>
<td>1058</td>
<td>.............</td>
<td>-2.5(14)</td>
<td>+0.3(78)</td>
<td>+2.7(7)</td>
<td>+6.1(1)</td>
</tr>
<tr>
<td>G0 to G9</td>
<td>601</td>
<td>-3.0(19)</td>
<td>+0.4(49)</td>
<td>+2.8(23)</td>
<td>+4.2(3)</td>
<td>+6.1(1)</td>
</tr>
<tr>
<td>F0 to F9</td>
<td>622</td>
<td>-3.0(9)</td>
<td>+1.2(45)</td>
<td>+3.2(46)</td>
<td>+6.1(1)</td>
<td></td>
</tr>
<tr>
<td>A2 to A5</td>
<td>478</td>
<td>-3.2(15)</td>
<td>.............</td>
<td>+1.2(5)</td>
<td>+6.1(1)</td>
<td></td>
</tr>
</tbody>
</table>

The small percentage of dwarf stars is, of course, due to the fact that their apparent magnitudes in most cases are fainter than the limit of 6.0. In all the spectral types a frequency-minimum separates the supergiants from the normal giants, which, in the case of the A, F, G and M stars, amounts to a complete absence of stars of intermediate absolute magnitude. The dwarfs become steadily brighter in the progression from K to A and coalesce with the normal giants in the spectral interval A2–A5.

**LABORATORY INVESTIGATIONS**

**RARE-EARTH SPECTRA**

The rare-earths are being studied by King for the more complete identification of their spectral lines, the segregation of the lines of the neutral and ionized atoms, and a determination of the response of the lines to the successive stages of excitation furnished at different temperatures by the electric furnace, the arc and the spark. All fourteen elements of the rare-earth group, with the exception of illinium of which no specimen is obtainable, have now received a preliminary survey to determine the character of their spectra in the different light sources. For nine of the elements, the regular temperature classification of spectral lines has been carried out, at least for the most important region. This supplies data which determine the presence and physical state of these elements in celestial bodies and
permit the analysis of spectral structures by means of the grouping of related lines. As a part of the program, ytterbium and lutecium have been studied by King during the year, about sixty spectrograms having been made for the range \( \lambda 2950 \) to \( \lambda 6900 \). These elements are extremely scarce, and the existing tables contain many errors of identification. The tests applied in the present work, supplemented by data from Dr. Meggers, have resulted in much improved lists. Many new lines, especially for ytterbium, have been measured, and the temperature classes have been determined for about 500 lines in the two spectra. Hyperfine structure is present in fully half of the lutecium lines, the variety in the patterns evidently relating to the energy levels from which various groups of lines arise. Hyperfine structure, which according to theory results from the reaction of the nucleus on a deeply penetrating electron, has now been shown by King to occur in the spectra of all rare-earths of odd atomic number thus far examined, with the possible exception of thulium.

The examination of the rich spectra of neodymium and samarium and the measurement of new lines have continued. The improved photographic emulsions for the infra-red now obtainable are expected to give an important addition to this material. The more prominent lines of the very rare element thulium have been identified on the spectrograms of ytterbium and lutecium as a result of the close chemical affinity of the three elements. Since a large proportion of the thulium lines between \( \lambda 2950 \) and \( \lambda 6900 \) are given by low excitation, the furnace spectrum is especially rich in data for their classification.

SPECTRUM OF COLUMBIUM

The determination of the ionization and the temperature classification of the lines of columbium was concluded by King during the year with the description of approximately 650 of the stronger lines between \( \lambda 3100 \) and \( \lambda 7000 \). In spite of the high vaporization point of columbium, 200 of these were obtained in the furnace spectrum. Hyperfine structure was found in about 40 per cent of these lines, with much variety in the patterns. The term analysis of this spectrum requires, in addition to the temperature classification, better and more complete wavelengths, since those of the only comprehensive list available were found from the term values obtained by Meggers and Scribner in a partial analysis of the spectrum to be inaccurate, often to the extent of 0.15 \( \AA \). Another essential is a study of the hyperfine structure with high resolution. In the cooperative work on this spectrum Dr. Meggers at the Bureau of Standards has measured arc and spark spectrograms supplied by King, of which about forty additional ones have been made during the year. Thus far, over 5000 lines have been measured by Meggers, usually in both arc and spark spectra, with the extremes of the range, which now extends from \( \lambda 2100 \) to \( \lambda 9000 \), still to be measured. The accuracy throughout seems to be better than 0.01 \( \AA \), which, besides supplying accurate term values, should make it possible to identify additional columbium lines in the solar spectrum. About 25 per cent of the lines measured show hyperfine structure. The examination of this structure with high dispersion is now being made by Meggers and King with the large spectrographs on Mount Wilson and in the laboratory.
SPECTRUM OF TUNGSTEN

Examination in the electric furnace of the highly refractory elements zirconium, hafnium and columbium resulted in each case in the isolation from a multitude of lines of those which appear at the moderate excitation of the furnace and therefore arise from the lower energy levels of the neutral atom. Such lines are fundamental for the structural analysis of these spectra. Little progress has been made as yet in the analysis of the spectrum of tungsten, the metal which has the highest known melting-point; but recent experiments by King show that the electric furnace, through the formation of a carbide in the graphite tube, produces tungsten vapor at a temperature much below the melting-point of the pure metal. A considerable number of lines of tungsten were thus obtained. These should be the fundamental lines of the element, and may be expected, by analogy with the other refractory metals, to be the low-level lines required in the analysis.

INVESTIGATIONS WITH THE LARGE CONDENSER

During the autumn, Anderson continued his experiments on the accurate control of opening and closing the electro-optic shutter for the purpose of studying the early stages in a wire explosion. Several methods were tried without satisfactory results. The arrival of Dr. T. Takamine in November 1930 made it necessary to discontinue this work, since the condenser equipment was needed for his investigation on the hydrogen spectrum.

After Dr. Takamine's departure in April a quantitative study of the energy distribution in the continuous spectrum given by the high-current vacuum tube was started. The tube is of fused silica and has a capillary 3 mm. in diameter. The total duration of the discharge in the tube is about 1/20,000 second. The changes in the spectrum throughout this interval have been recorded with the rotating-mirror camera, the dispersion used being either one or three prisms. The energy-distribution itself will be determined with a vacuum thermocouple at the focus of the Bausch and Lomb quartz monochromator. Only a few preliminary trials have been made with the apparatus, but it appears to be quite adequate for the purpose, since readable deflections have been obtained as far as λ2000.

Dr. Takamine and his co-workers at the Imperial University at Tokyo have found that by using hydrogen as an impurity in neon it is possible to photograph the Balmer series as far as the twenty-fifth member. An interesting extension of this work would be the production of the Balmer lines in absorption by passing white light of sufficiently high intensity through a neon-hydrogen tube when the tube is excited by its proper discharge current. This could be accomplished in our laboratory by using as a source of white light the high-current vacuum tube studied by Anderson, and passing all or part of its current through the hydrogen-neon tube.

The experiment was tried by Dr. Takamine in the Physical Laboratory in Pasadena under a rather wide variety of conditions, but only the first five members of the Balmer series could be obtained in absorption, and these appeared to be abnormally wide when compared with their appearance in emission. The explanation of this fact is not known, and it would be of interest to pursue the investigation much farther than was possible during Dr. Takamine's visit. This he plans to do on his return to Tokyo.
OXYGEN BAND SPECTRA

The investigation by Babcock of the spectrum of molecular oxygen in the earth's atmosphere, originally undertaken for the purpose of establishing reliable standards of wave-length, has become important in several respects. The possibility of varying the intensities of the lines by differences of air-path, the perfect symmetry of the lines, and the test of their relative wave-lengths afforded by the theory of band structure have permitted determinations of wave-length with extraordinarily high precision. About 400 lines have now been measured, the wave-lengths of those of strong and medium intensity, as well as some of the fainter lines, being accurate to 1 part in 5,000,000.

The discovery of the isotopes O\textsuperscript{17} and O\textsuperscript{18} following the accurate determination of the wave-lengths led to other important developments. Thus it stimulated the use of band spectra for the discovery of isotopes of other elements, such, for example, as C\textsuperscript{13} by King and Birge, N\textsuperscript{15} by Naudé, and Be\textsuperscript{8} by Watson and Parker. Of even more importance, however, is the applicability of the method to the precise determination of the relative masses of isotopic atoms, as was pointed out by Giauque. This is of special interest because of its connection with "packing effect," that is, the difference between the mass of an atomic nucleus and the sum of the masses of its constituent alpha particles and protons. The generally accepted relation between mass and energy is that developed by Einstein, $\Delta E = mc^2 \Delta m$, which underlies the theory of the origin of cosmic radiation and is a basic idea in astrophysics and chemistry. Every independent test of its validity is thus to be sought for and critically examined, and one step in this direction consists in the precise determination of the masses and the "mass-defects" of atoms from the band spectra of the molecules which they form.

Technical reasons make the case of oxygen exceptional among band spectra for the study of the relative masses of isotopes. In a cooperative investigation, Babcock and Birge are using for this purpose the best data now available. With the mass of O\textsuperscript{16} taken as 16 exactly, they have found that the mass of O\textsuperscript{18} is 18.0065 with a probable error of 1 part in 100,000. With the exception of silver, no other atomic weight is so accurately determined as this. The mass of O\textsuperscript{17} is now being derived in the same way, and although its probable error will be much greater than that of O\textsuperscript{18}, it is fully expected that eventually the mass of O\textsuperscript{17} can also be used to check Einstein's equation. As Birge has pointed out, the mass of C\textsuperscript{12}, spectroscopically determined, provides the first experimental test of this kind, which, though rough, is of great value.

It should be noted that since the discovery of the isotopes of oxygen two systems of atomic weights have necessarily been used; one is the chemical system, in which the natural mixture of oxygen isotopes is taken equal to 16 by definition, while in the other, which may be called the physical system, the most abundant form of oxygen, O\textsuperscript{16}, is by definition made equal to 16. The exact relationship of these two systems should be known in order that atomic weights may be accurately transferred from one system to the other, and that eventually one system may be adopted for all purposes. This relationship evidently depends on the relative masses of O\textsuperscript{16}, O\textsuperscript{17}, and O\textsuperscript{18} and on the proportions which constitute the mixture that we
call oxygen. The masses have been discussed; the relative abundance is still somewhat uncertain. From relative intensities of the isotopic bands Babcock derived the first values for the abundance of O\textsuperscript{16}, O\textsuperscript{17}, O\textsuperscript{18}, as noted in the Report for 1928–1929. The result was an approximation, indeed for O\textsuperscript{17} scarcely more than a rough estimate, since the bands due to the molecule O\textsuperscript{16}–O\textsuperscript{17} are so weak that a comparison of intensity with the bands of O\textsuperscript{16}–O\textsuperscript{18} is exceedingly troublesome. Naudé, however, found substantially the same abundance of O\textsuperscript{18}, although he used entirely different data derived from spectrograms of the NO bands. More recently Mecke and Childs from an extended study find for the ratio O\textsuperscript{16}: O\textsuperscript{18} a value of 630, as compared to Babcock’s rough result of 1250. Theoretical discussion of these results is in progress, and, in addition, an entirely independent observation by means of a mass-spectrograph is being carried out by Smythe at the California Institute of Technology. It is probable that a definite conclusion will be reached during the year.

**PHOTOCHEMICAL CELLS**

The properties of several photochemical cells have been studied by Smith in the hope that they might prove useful for astronomical purposes. In general, these cells consist of two electrodes placed in an electrolyte, the surface of one of the electrodes having been treated in such a way that it is rendered sensitive to light. For example, if one of the electrodes is of copper covered with a thin layer of copper oxide, the electromotive force of the cell changes when radiation falls on the treated electrode. A silver electrode covered with a thin layer of silver halide exhibits the same behavior. Cells of this type constructed in the laboratory, as well as some commercial cells, have been tested, but the results are not promising. The cells are all subject to erratic fluctuations, and their sensitivity is not sufficiently high to warrant an attempt to increase their stability.

**USE OF CYLINDRICAL LENS TO REDUCE EFFECT OF PLATE GRAIN**

During the year, Anderson has devoted much time to an appraisal of the value of a cylindrical lens in the measurement of absorption spectra. As mentioned in last year’s Report, the value of this device in the case of bright-line spectra is great, and it was hoped that it might prove equally valuable for absorption spectra. This does not appear to be the case, however. True absorption lines are much improved in character and intensity, but owing to the irregular distribution of silver grains, innumerable spurious lines are produced, and in a spectrogram of moderately high density, these are comparable in intensity with the weaker real lines. With the rapid photographic plates now in use, it is consequently doubtful if the cylindrical-lens method would improve very much the ease or accuracy of measurements.

**ASTIGMATIC FOCUS OF A CONCAVE GRATING**

Experiments with a concave-grating spectrograph have been undertaken by Pettit with a view to correcting astigmatism by placing a convex cylindrical lens behind the slit. A plano-convex glass spectacle lens of 33 cm. focal length has been used. In the case of the one-meter concave grating mounted in the Eagle form, this lens, placed 11.1 cm. behind the slit,
brings dust lines into sharp focus over a range of 100 angstroms and into fair focus over 300 angstroms at about $\lambda$4700. As the lens is moved toward the slit a centimeter at a time, the region of good focus moves to the violet about 370 angstroms. This lens has been applied successfully to the 8-inch concave-grating spectrograph with a radius of 6.4 meters.

**PHOTOGRAPHIC EMULSIONS**

Many new emulsions have been received during the year from Dr. Mees of the Research Laboratories of the Eastman Kodak Company, whose cooperation has been of the utmost value to the Observatory. Among these emulsions have been two of particular value for panchromatic photography. One is faster than any previously available in the green and yellow region, while the other is extremely sensitive in the yellow and red. The grain of these plates is comparatively fine and the contrast high. They have been especially useful in photographing the green and red regions of the spectra of stars with the coude and the plane-grating spectrographs and in solar photography. Important improvements have also been made in plates sensitive to infra-red light. The Imperial Eclipse plates have been found to have many advantages in the blue region of the spectrum. Their speed is excellent; the contrast is at least as high as on other plates only half as fast, and the grain is scarcely more noticeable. These plates have been used extensively for observations of radial velocity and absolute magnitude.

Accurate tests of the characteristics of emulsions are becoming increasingly important. A small experimental plate-testing spectrograph having a plane grating has been designed by Dunham with a logarithmic raster to give quantitative comparisons between emulsions. A wave-length scale is impressed directly on the plate. From the point of view of spectroscopic work the most useful description of an emulsion seems to be the exposure-time required to produce a density of 0.6, together with a statement of the contrast at this density. These values may be easily determined for plates exposed in the testing spectrograph.

**RULING MACHINE**

During the year the ruling machine has been provided with a new diamond carriage of aluminum alloy weighing less than half as much as the carriage formerly in use. This has resulted in much better performance, particularly as regards vibration. An improved link connects the diamond carriage to the driving crosshead. The carboloy end-thrust plane bearing failed after some three years of service and has been repolished and replaced in the machine. The operation of the engine since these changes were completed is definitely improved. A 4-inch plane grating made very recently shows only two minor defects, neither of which interferes with its performance. Recently a new stock of excellent rough diamonds was secured, and a supply of finished ruling edges is now being prepared, a much simpler and more expeditious process than in earlier stages of our experience in such work.

During the year seven 4-inch and five 6-inch plane gratings have been ruled, all of sufficiently high quality to be used in actual observing. One of
the 6-inch gratings gives 90 per cent of its theoretical resolving power on absorption lines in the second-order spectrum.

The design has been completed by Babcock, Nichols and Jacomini for a new medium-sized ruling machine containing certain modifications of the large machine which experience has shown to be desirable, and construction is already well advanced. The screw of the new machine is nearly ready for grinding, practically all the castings are finished, and the spacing-wheel is graduated and ready for cutting. By the end of 1931 the new machine should be well toward completion. Much of the work is being done in the main instrument shop under the supervision of Jacomini, but he will carry out the final operations and assemble the machine himself.

**VELOCITY OF LIGHT**

The preparation of the equipment for Dr. Michelson's redetermination of the velocity of light was completed last year, and work on the adjustments and definitive measurements has proceeded actively during the present season. Fortunately the apparatus was in readiness for final use shortly before Dr. Michelson's illness, and he was able to take part in some of the actual measurements. Since his death early in May, the work has been continued by Pease of the Observatory staff and Mr. Pearson of the University of Chicago, who have been closely associated with the investigation from the beginning.

It soon became evident from tests of the images formed after multiple reflection through the mile of pipe-line that a lower air-pressure would be required than was at first thought necessary. An additional air-pump with a capacity of 350 cubic feet per minute was installed, the rubber tubes at the junctions of the sections of pipe were renewed, and all seams were treated repeatedly with a special type of rubber paint. Under these conditions the pressure was reduced to 0.5 mm., and the measurements were made at pressures between 0.5 mm. and 2.3 mm. Some trouble was experienced with the tarnishing of the mirrors, but Dalton of the optical shop succeeded in coating them with a thin lacquer in such a manner as not to impair their optical properties. A system of remote controls was provided to manipulate the mirrors and lights at the distant end of the long tube.

The first measurements were made on February 19, 1931, and were continued intermittently until July. Five series of observations have been completed, all with the use of the 32-sided rotating mirror figured by Mr. Pearson. Two of these were over an optical path of approximately 10 miles and the other three over a path of 8 miles. Toward the end of the second series the images were found to be drifting, probably because of slight displacements of the mirror mountings and local refractions in the tube. Accordingly, in the last three sets of observations the readings were taken in such a way as to eliminate the effect of drift, and low weight was assigned to the previous measures.

The length of the base-line was measured with high accuracy by Commander Garner of the United States Coast and Geodetic Survey, who derived a value of 1,594.259.4 ± 0.47 mm. (5230.7695 feet). The transfer of the reference points into the tube and the measurement of the remaining distances were carried out by Pease and Pearson. The resulting 8-mile
optical path was 12,811,131.2 mm., and the 10-mile path 15,999,680.0 mm.

The speed of the rotating mirror was derived from comparison with a free gravity pendulum which was rated with a Bond chronometer and with a constant-frequency crystal oscillator set loaned by the General Radio Corporation. The time-rates of these instruments were determined by comparison with radio signals received from Arlington.

During the earlier observations, measures could be made during most of the night, but with the approach of summer and the increase in the daily range of temperature the surfaces of the plane mirrors frequently became distorted and there was serious scattering of light. As a result the return image became very faint and of poor quality. At such times the observations were confined to the few hours each night when balanced conditions of temperature provided satisfactory images.

Thus far five sets of measurements have been made, each consisting of about 60 groups of 20 or more readings each. Four sets are in remarkably close agreement, but the fifth deviates systematically, probably because of a drift of the image which occurred during some of the earlier measures.

CONSTRUCTION DIVISION

ENGINEERING AND DESIGN

The design of new instruments and apparatus has been under the immediate charge of E. C. Nichols throughout the year, H. S. Kinney assisting in the details and making the finished drawings for the instrument shop. Pease has given much attention to the new support system for the 100-inch mirror and the ruling machine now under construction.

Included among other instruments and accessories designed during the year are: the 15-foot stigmatic concave-grating spectograph for the 100-inch telescope; a stellar spectrometer for use with a radiometer; a spectroheliograph and spectrohelioscope for the Solar Laboratory; several camera mountings for stellar spectrographs; a periscope attachment for examining faint stars in the field of the telescopes; the new winding for the large laboratory magnet; a modified shutter for the dome of the 10-inch photographic telescope; and many auxiliary parts for the equipment used in the investigation of the velocity of light. Drawings and charts for the Observatory publications and the Annual Exhibit of the Carnegie Institution have been prepared in this department.

INSTRUMENT SHOP

The work of the instrument shop has remained under the charge of Alden F. Ayers, and Clement Jacomini has given all of his time to the operation of the large ruling machine and the design and construction of the smaller machine now partially completed. L. R. Hitchcock has continued to act as instrument maker at the Solar Laboratory and to assist in the observations. John E. Kimble has devoted much of his time to the work on the velocity of light at the Irvine Ranch, assisting in the mechanical and optical adjustments and in the maintenance of the light-source during the measurements.

The construction and installation of the support system for the 100-inch mirror were completed by the instrument shop during the year, and much
time was given to the velocity-of-light apparatus and to repairs and main-
tenance of equipment. Among the instruments partially or wholly com-
pleted are: the 3-prism ultra-violet spectrograph; the 15-foot concave-
grating spectrograph for the 100-inch telescope; three spectrohelioscopes;
a stellar spectrometer and a small microphotometer, both for use with radio-
meters; the new ruling machine; the cooling coil for the solenoid magnet
and a new coil for the Weiss magnet; a plate-testing photometer; the
mounting of the Ross correcting lens for the 60-inch reflector; and several
attachments for the stellar spectrographs. Early in the year considerable
time was devoted to parts of the 50-foot interferometer mounting, and
more recently the mechanism for the new shutter on the dome of the 10-inch
photographic telescope was completed in the shop.

OPTICAL SHOP

In the optical shop, W. L. Kinney has figured a 12-inch objective prism
with an angle of 121° for the 10-inch photographic telescope; two 10-inch
plane mirrors; a 19-inch concave mirror with a radius of 50 feet; a 4-inch
achromatic lens as a finder for the 60-inch telescope; two plane parallel
plates 4¼ inches in diameter for use in the large ether-drift interferometer;
four small Fresnel prisms; and many other small optical lenses and prisms.

John S. Dalton has devoted much time to the preparation of plane and
concave speculum plates for the ruling machine. He has also figured a
number of lenses from 1 to 6 inches in diameter of glass, fused silica, crystal-
line quartz, calcite and rock salt; numerous small mirrors and prisms for
experimental purposes; and the plane mirrors for three spectrohelioscopes.
The removal of the 100-inch mirror from its cell at the time the new support
system was put in place was under the supervision of Dalton.

On July 1, 1931, W. L. Kinney withdrew from the service of the Institu-
tion in accordance with the plan for retiring allowances. It is with deep
appreciation that the Observatory recognizes the value of his contributions
to its work over a period of nearly 25 years. During this time he aided in
the construction of the 60-inch and 100-inch mirrors, and brought to the
solution of a great variety of practical optical problems a remarkable degree
of skill and resourcefulness.

CONSTRUCTION, MAINTENANCE AND OPERATION

George D. Jones, superintendent of construction for many years, has been
on leave of absence throughout the year, and building and maintenance have
been under the charge of A. N. Beebe.

The large house of temporary construction to cover the projection appara-
tus used for the lunar map planned by Dr. F. E. Wright was completed
during June 1931. It is situated north of the 100-inch telescope building
on Mount Wilson and is 135 feet long, with a width narrowing from about
40 feet at one end to 15 feet at the other. The house has a wooden frame
with double walls and is covered with a special type of building paper.

In order to provide a wider observing field near the zenith for the 10-inch
photographic telescope, a new shutter of the usual split type has been con-
structed and built into the existing dome. This work was carried out by
Beebe with some assistance from the instrument shop.
Further construction work on Mount Wilson has included a concrete retaining wall around the seismological laboratory, an additional underground tank at the Monastery for sewage disposal, and various minor improvements on the roads along the mountain top. The interiors of the laboratory building on Mount Wilson and of the office building in Pasadena have been painted throughout, and general repairs on the equipment have been continued as needed during the year.

Merritt C. Dowd, engineer on Mount Wilson for a period of nearly 23 years, retired on January 1, 1931. His services during that time have been of immense value to the Observatory. Much of the electrical switchboard equipment on Mount Wilson and in the Pasadena laboratories was designed and built by him, and the efficiency of the operating plant on the mountain is in large part due to his unfailing skill and ability. Since the retirement of Dowd, Sidney Jones has been appointed engineer and Nelson G. White assistant engineer.

In cooperation with the Forest Service and the Pasadena-Mount Wilson Toll Road Company, the Observatory has continued to assist in maintaining a fire patrolman on Mount Wilson during the summer months. No serious forest fires have occurred near the mountain during the past year.

THE LIBRARY

On June 30, 1931, the bound volumes in the library numbered 11,213; the number of pamphlets was about 8000 and of lantern slides about 2500. Between July 1, 1930, and June 30, 1931, 509 bound volumes were acquired by the library, 203 by purchase, 190 by binding, 116 by gift. The unusually large number of gifts is accounted for by the presentation in May 1931, by Mrs. Michelson, of an exceedingly interesting and valuable collection of volumes from Dr. Michelson's personal scientific library. These have been appropriately marked with a special book-plate. During 1931, 121 periodicals and transactions of learned societies have been received, of which 38 are gifts or exchanges. In addition, the library receives at more or less frequent intervals the publications of about 200 observatories and research institutions.
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ORGANIZATION OF MOUNT WILSON OBSERVATORY, JULY 1, 1930, TO JUNE 30, 1931

GEORGE E. HALE, Honorary Director
WALTER S. ADAMS, Director
FREDERICK H. SEARES, Assistant Director
ALFRED H. JOY, Secretary

Research Division

Stellar Photometry: Frederick H. Seares.
Stellar Interferometers: Francis G. Pease.
Trigonometric Parallaxes and Proper Motions: Adriaan van Maanen.

Research Associates

A. A. Michelson,* University of Chicago; Henry Norris Russell, Princeton University; Sir James Jeans, Dorking, England; Charles E. St. John, Pasadena; Toshio Takamine, Institute of Physical and Chemical Research, Tokyo, Japan.

Investigators Temporarily Associated with the Observatory

Giorgio Abetti, Royal Astrophysical Observatory at Arcetri; John C. Duncan, Wellesley College; Charlotte E. Moore, Princeton University; Frank E. Ross, Yerkes Observatory; C. D. Shane, University of California; B. W. Sitterly, Wesleyan University; Joel Stebbins, Washburn Observatory; Otto Struve, Yerkes Observatory; R. v. d. R. Woolley, Commonwealth Research Fellow; Fred E. Wright, Geophysical Laboratory of the Carnegie Institution of Washington.

Computing Division


Office and Design

E. C. Nichols, instrument design; H. S. Kinney, draftsman; Deforest S. Mulvin, bookkeeper; F. Louise Gianetti and Alice S. Beach, stenographers; Anne McConnell, stenographer and telephone operator.

Instrument Construction

Optical Shop: W. L. Kinney and John S. Dalton, opticians; D. O. Hendrix, assistant optician.
Instrument Shop: Clement Jacomini, instrument maker; Alden F. Ayers, foreman; C. D. Shumway, Elmer Prall, Albert McIntire, M. C. Hurlbut, John Kimpie, C. O. Ladd, Fred Scherff, Oscar Swanson, L. R. Hitchcock, machinists; James Chapman, pattern maker; H. S. Fehr, cabinet maker; Albert Labrow, helper.

Operation and Erection

A. N. Beebe, superintendent of transportation and erection; Merritt C. Dowd and Sidney A. Jones, engineers; G. Nelson White, assistant engineer; Thomas A. Nelson, A. K. Wright, Glenn C. Moore, night assistants; Joseph Hickox, photographer and day assistant; I. S. and Mrs. Wolf, stewards; E. L. Aden, Frank Lavers, Kenneth Pitt, janitors; E. W. Hartong, truck driver.

Several of the individuals whose names are listed above have been associated with the Observatory only a part of the year.

* Died May 9, 1931.