Carnegie Institution of Washington

CONTRIBUTIONS FROM THE SOLAR OBSERVATORY
MT. WILSON, CALIFORNIA
NO. 10

THE SPECTROSCOPIC LABORATORY OF THE SOLAR OBSERVATORY

BY
GEORGE E. HALE

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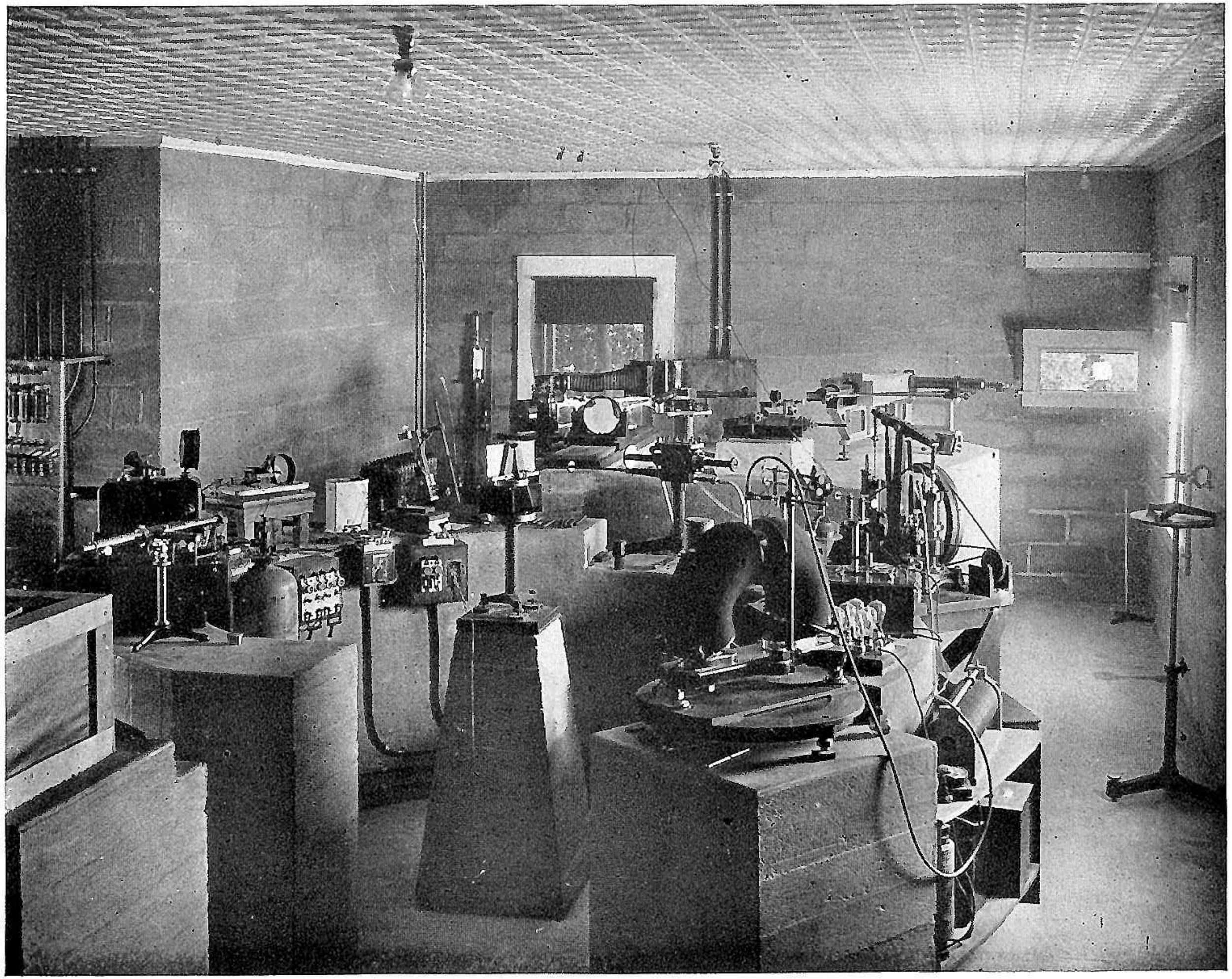
PLATE XIV



SPECTROSCOPIC LABORATORY OF THE SOLAR OBSERVATORY

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An important requirement in the programme of research of the Solar Observatory is met by the provision of a spectroscopic laboratory, adequately equipped for the investigation of such physical and chemical phenomena as may be encountered in connection with our solar and stellar observations. It will only occasionally happen that data required to explain the results obtained with the solar spectrograph and the spectroheliograph are already available in spectroscopic literature. The Zeeman effect, for instance, has been recorded in the case of comparatively few lines, so that without additional observations it could not be determined whether certain lines which vary together in the Sun, also behave alike in a magnetic field. Displacements due to pressure must frequently be known in connection with measurements of lines in the solar spectrum, but the required values are only occasionally found in published papers. The same may be said of the effects of change of temperature, of potential, of self-induction, of current strength, of the influence of the gaseous atmosphere in which the luminous source is placed, etc. It is evident that what is essential, in case the results constantly encountered in both solar and stellar work are to be interpreted without delay, is a collection of light-sources so designed and arranged that the effect of any of the above mentioned variables can be observed with spectroscopes of any desired resolving power.[1] It is not so much a question of the saving of time, which the provision of these means undoubtedly offers, as it is of the greatly increased efficiency of the working programme thus rendered possible. The immediate imitation in the laboratory, under experimental conditions subject to easy control, of solar and

[1] As an illustration of this it may be remarked that in our study of sun-spot spectra the following light-sources have been employed: ordinary arc, in air, hydrogen, and CO_2; rotating arc, at low and high pressures; synchronous arc; spark in air; spark in water; oxyhydrogen flame; electric furnace.

stellar phenomena, not only tends to clear up obscure points, but prepares the way for the development along logical lines of the train of reasoning started by the astronomical work. It is a question, then, of equipping the laboratory in such a way that its various resources may be effectively utilized at any time, and without the delays ordinarily experienced when apparatus must be specially prepared for a certain investigation. In the desired plan the apparatus must be always ready, needing only the operation of a switch or the adjustment of a mirror to bring it into action.

In the spectroscopic laboratory of the Yerkes Observatory I first tried the principle which has been more fully developed in our spectroscopic laboratory on Mount Wilson. The various light-sources, including an ordinary arc in air, a spark in air, a spark in liquids, and a spark in compressed gases, were arranged on the circumference of a wooden table, having at its center a plane mirror capable of rotation about a vertical axis. By means of this mirror, set at the proper angle, light from any one of the sources was reflected to a concave mirror which, in its turn, formed an enlarged image of the light-source on the slit of a concave grating spectrograph.

At the Solar Observatory the apparatus is arranged as shown in Plate XIV. Instead of a circular wooden table, an annular concrete pier is employed, giving space on the inner wall for the various switches used to control the current supplied to the different sources, and also permitting the observer to inspect any light-source from the direction of the plane mirror at the center of the pier. Instead of a single plane mirror, two are provided, capable of rotation independently of one another, about the same vertical axis. By means of divided circles, the azimuth of either mirror can be read. When the Littrow spectrograph[1] is in use, only the lower plane mirror is employed. By setting this at the proper angle the light from any one of the sources can be sent to the concave mirror (seen near the the middle of Plate I), which forms an image of the source on the slit of the Littrow spectrograph. If the one-prism quartz spectrograph, the interferometer, or the echelon spectroscope is to be used in place of the Littrow spectrograph, for the study of the light-

[1] The rectangular box which carries the slit and plate-holder of this instrument is shown on the pier at the left of Plate I.

source, the concave mirror is tipped back at a small angle, so as to return the light to the upper plane mirror, from which it is reflected to the slit of one of these instruments. In Plate XIV the quartz spectrograph may be seen just above the concave mirror. To the right of this is a Hilger one-prism spectroscope, which provides a monochromatic beam for observation with the interferometer (shown in position near the spectroscope), or with the echelon spectroscope, which stands on the right of the pier that carries these instruments. This pier is separated from the annular pier by a space through which the observer may pass.

The various analyzing instruments, with which the light-sources are studied, may be briefly described as follows:

1. A direct-vision spectroscope by Jobin, for the preliminary visual examination of spectra.

2. A Fuess quartz spectrograph, with collimator of 3.8 cm aperture and 81.3 cm focal length, and camera of the same aperture and focal length. This instrument has a double Cornu prism of quartz, and a Zeiss prism of ultra-violet glass, to be used if somewhat higher dispersion is desired. The spectrograph is provided with means for photographing a series of narrow spectra on a single plate, and is used for preliminary and for qualitative studies, especially in the ultra-violet.

3. A Littrow spectrograph of 12.5 cm aperture and 3.72 m focal length. The combined camera and collimating lens is by Brashear, and is corrected for work in the visible spectrum. The plane grating, by Michelson,[1] has a ruled surface 8.3×4.4 cm, with 7,000 lines to the cm. It may be used in any order, by setting it at the proper azimuth. The slit is mounted immediately above the photographic plate. The plate-holder can be raised or lowered, so as to permit several spectra to be photographed on a single plate.[2]

4. A Michelson interferometer (not shown in the plate), for the analysis of spectral lines, the determination of absolute wave-lengths and the measurement of lengths. This instrument receives mono-

[1] We are indebted to Professor Michelson for the use of this excellent grating, which is one of the first products of his new ruling engine.

[2] This temporary instrument will be replaced by a permanent one of 5.5 m focal length.

chromatic light from a one-prism spectroscope by Hilger, provided with a prism of special form, from which the beam emerges at an angle of 90° with the axis of the collimator. Different parts of the spectrum can be brought to the slit of the interferometer collimator by rotating the prism. The same spectroscope can be used in connection with a Pérot-Fabry interferometer or with an echelon spectroscope.

5. A Pérot-Fabry interferometer by Jobin, exactly similar to the instrument used by Messrs. Pérot and Fabry for the determination of absolute wave-lengths and the analysis of spectral lines.

6. A 33-plate echelon spectroscope by Hilger, with plates 15 mm thick. This instrument is used in studies of the Zeeman effect, and other work requiring the highest obtainable resolving power. The slit can be opened or closed from the eye-end, or moved entirely out of the way when a spectral line is being picked out for observation. In the latter case the echelon is moved to one side and the image of the spectrum, formed by the auxiliary spectroscope in the focal plane of the collimator of the echelon spectroscope, is seen with the observing telescope. Provision is made for using the echelon at 90° from its ordinary position, as Nutting has done, for the purpose of separating the overlapping spectra. For spectra having but few lines it is sometimes advantageous to remove the prism from the auxiliary spectroscope and insert it beyond the echelon. When this is done the observing telescope stands at 90° with the axis of the echelon, as shown in Plate XIV.

The following apparatus stands on the annular pier: The first instrument on the right is a DuBois magnet of Hartmann & Braun's larger model, for studies of the Zeeman effect. It is mounted on a base in such a way that it can be rotated through an angle of 90°, so that light from the source can be observed parallel or at right angles to the lines of force. A bismuth spiral is provided for measuring the strength of the field. In the illustration a mercury tube is hung between the poles of the magnet, and connected by heavy pressure tubing with the Geryk duplex vacuum pump shown on the wooden table at the right. The magnet requires a potential of 64 volts, which is supplied from a storage battery in an adjoining building. The vacuum pump, which is supplied with a McLeod gauge by

Müller-Uri, is driven by a small electric motor. A transformer of 600 watts capacity, giving from 6,000 to 10,000 volts, is used to illuminate the mercury tube. This is supplied with an alternating current from the generator in the power house. In connection with the transformer there are provided a condenser of variable capacity, and a coil of variable inductance.

Just beyond the magnet may be seen the apparatus for the study of the spark spectrum in air, at atmospheric pressure. The metals to be investigated are held by a pair of clamps in the lower set of terminals. The upper terminals are in series with the lower ones and serve as an auxiliary spark-gap. An electric fan, blowing a strong current of air upon the two sparks, prevents arcing and undue heating of the poles.

To the left of the air spark stands the apparatus for the study of the spark spectrum in water and other liquids. This consists of a strong iron case, into which the horizontal terminals are led through long corrugated cylinders of vulcanite. Glass windows, in the front and rear of the case, permit the spark to be seen from either side. The metals to be investigated are turned or ground into the form of small rods, and are mounted in brass caps, which can be screwed as terminals to the rods passing through the vulcanite cylinders. These rods are threaded, permitting the distance between the terminals to be varied at will. As the poles are rapidly consumed during the passage of the spark, it is necessary to adjust the distance between them while the exposure is in progress. For this purpose a gear is attached to the rod carrying one of the terminals (the left one in the illustration), and this can be turned by means of a pinion at the inner extremity of a long ebonite handle, mounted on a conical ebonite support attached to the iron case. By this means the distance between the poles can safely be controlled, even when a transformer giving 64,000 volts is employed. When water is used it is kept circulating through the tank during the exposure, entering by means of a rubber tube near the bottom of the tank, and passing out through a rubber tube at the top. An auxiliary air-spark, blown out by the electric fan, is always used in series with the water-spark. The voltage, self-induction, capacity, etc., of the discharge circuit can be varied as desired. A tight-fitting iron cover is provided for the tank, in case high liquid pressures are to be used.

To the left of the central plane mirrors may be seen the ordinary arc, for experiments at atmospheric pressure with carbon or metallic poles. This arc is provided with an automatic regulator, so constructed as to keep the poles well separated during the exposure. By means of a suitable rheostat, the current through the arc can be varied as desired. Important differences in metallic spectra are obtained by the use of currents of 2 amperes and 30 amperes respectively, the difference of potential between the poles remaining the same in each case. Direct current of any desired voltage, up to 110, is applied to this arc from a storage battery, and alternating current, of one, two, or three phase, from the generator in the power house.

The next light-source on the pier is a synchronous rotating arc designed by Professor Crew, and constructed for us under his kind supervision. It consists of a small alternating motor, with a device for bringing it into synchronism with the single phase alternating current from our generator. By means of a position circle the rotating metallic electrode can be set at any desired angle, so as to permit the arc to be observed at any phase from 0° to 90°. The fixed electrode is adjustable by means of a hand-screw. The interesting variations in arc spectra obtained by varying the phase have been described by Professor Crew in the *Astrophysical Journal*.[1]

Next to the synchronous arc stands the pressure arc, for the study of the low potential discharge (up to 110 volts, direct or alternating current) in various gases at low and high pressures. This apparatus was constructed by Gaertner. The rotating arc is viewed through a window in the front of the case. One of the electrodes can be adjusted, if necessary, during the exposure. Pressures up to 60 atmospheres are supplied from cylinders of liquid CO_2, obtained in Los Angeles. For higher pressures a special pump, kindly designed by Mr. Petavel of the University of Manchester, and constructed under his supervision by Charles W. Cook, the University instrument maker, will soon be installed. For low pressures the Geryk pump is used.

[1] 22, 199–203, 1905.

All investigation on the details of the solar image are made with the Snow telescope. Sunlight is nevertheless frequently required in the laboratory for comparison spectra, etc., and is supplied by the Fuess heliostat shown on the shelf outside the window, on the right of the plate.

The switch-board, with connections to the power house and storage battery, is shown on the left of the plate. Ammeters and voltmeters for direct and alternating current are provided. A large 5 K. W. transformer, specially built by the Peerless Electric Company, giving 1,000, 2,000, 4,000, 8,000, 16,000, 32,000 or 64,000 volts, will soon be installed.

A Ducretet coil, giving a 35-cm spark, with rotating mercury interrupter, has recently arrived. This will be used for various purposes, and with an X-ray tube for certain investigations on ionization. A sensitive radiometer, built by Gaertner, and fitted by Professor Nichols with a suspension system which he was kind enough to make for us, is also available.

Our recent study of sun-spot spectra has made it necessary to supplement the above equipment with a Moissan electric furnace, of 50 K. W. capacity. This is being installed, with a large Littrow spectrograph, in our Pasadena laboratory, since the power plant on Mount Wilson cannot supply sufficient current. The 5 K. W. high-potential transformer will also be used for the present in Pasadena.

It is not the purpose of this article to describe in detail the other rooms of the laboratory, which include a plate-measuring room, with a stereocomparator and other measuring machines for the study of photographs of spectra and spectroheliograph plates; an enlarging room, with cameras for use with skylight or electric arc; two photographic dark rooms; a clock room, containing a Riefler mean time clock, with nickel-steel pendulum, which controls electrically a mean time clock in the Snow telescope house; a small chemical laboratory, etc. The laboratory is heated by steam and lighted by electricity.

SOLAR OBSERVATORY,
Mount Wilson, California
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