SCIENCE

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MSS. intended for publication and books, etc., intended for review should be sent to Professor J. McKeen Cattell, Garrison-on-Hudson, N. Y.

THE STUDY OF THE STARS[1]

THE object of the American Association is the advancement of science. This is a very different matter from the diffusion of human knowledge. The universities and colleges provide liberally for the latter subject, but neglect the former almost entirely. Science is advanced by many individuals who hold offices in the universities, but seldom as a part of their official duties. Few professors are allowed to regard research as a portion of their college work, and still less frequently are appropriations made or funds provided for original investigation. Astronomy is almost the only exception to this rule, and even here in general, the time of the officers is mainly devoted to teaching. Observatories devoted to research like McCormick, Lick and Harvard are supported by funds given specifically for their use, and receive little, or no aid, from the general funds of the universities with which they are associated. It is probable that American universities devote one hundred times as much money to the diffusion of human knowledge, as to its advancement. The great progress made in America in some departments of astronomy is due to the fact that certain wealthy men and women have been willing to give large sums of money for this object. No other country is so fortunate in this respect, although in recent years in Germany large appropriations are being made by the government for similar purposes.

The income of certain funds like the Elizabeth Thompson, Bache and Watson

[1] Address of the President of the American Association for the Advancement of Science, Atlanta, December 29, 1913.

funds is also available, but while these are of the greatest value in aiding particular individuals, the amount is too small to materially advance the entire science. The large funds which might aid individual research are unfortunately employed for other purposes. Scarcely any appropriations have been made to women from these funds. One of the greatest needs of science in America is a fund of moderate size, capable of aiding the men of real genius. The number of such men is not large, and a judicious distribution of a few thousand dollars annually would probably yield greater results than could be obtained in any other way.

A visit to Europe last summer in order to attend the meetings of two national and two international astronomical societies, enabled me to visit several of the larger observatories and to interchange views with the leading astronomers of the world. I have accordingly selected as my subject for this evening "The Study of the Stars," and I shall endeavor to transmit to you the latest views as well as the history of this department of human knowledge. It is my wish to present to my professional friends certain facts of a technical nature, and at the same time to make these clear to those of my hearers who have no previous knowledge of the subject. Astronomy has been called not only the oldest of the sciences but that which has conferred the greatest benefits on man by rendering international commerce possible. While this may be true of the past, the value of the astronomy of the present day lies in its extension of human knowledge and enabling the mind of man to traverse fields which until recently appeared to be hopelessly beyond his ken.

The first catalogue of the stars was made by Hipparchus about B.C. 128, and was inserted by Ptolemy in the "Almagest," for fourteen centuries the authority in astronomy for the world. This catalogue, which contained more than a thousand stars, gave both their positions and brightness. The earliest copy that is known of the "Almagest" is in the Bibliothèque National in Paris. It is a beautiful manuscript in uncial characters of the ninth century. The other later manuscripts unfortunately differ from it and from each other, so that there is some uncertainty regarding two thirds of the stars, owing to errors of copying. A careful study of these discrepancies has been made by Dr. Peters, of Clinton, and Mr. Knobel, of London. Each spent several years on this work, and all the papers are in the hands of Mr. Knobel. He is now preparing the entire work for publication and it is hoped that it will be in the hands of the printer in a few months.

A manuscript of nearly the same age is in the library of the Vatican, and this year a revised edition of it has been published. If we had a correct copy of the original work, it would have a great value at the present time. Half a century ago it would probably have given the best existing values of the proper motions of the stars which it contained, but recent observations enable us to compute their positions in the time of Hipparchus, more accurately than he could observe them, assuming that the motion was rectilinear. This work might, however, throw light on a possible curvature of the motions. The observations by Hipparchus of the light of the stars have a value that will be considered later.

The first accurate measures of the positions of the stars were made in the middle of the eighteenth century. The catalogue of Bradley in 1755 is even at the present time one of the best means of determining the early positions of the stars. A large number of similar, but later, observations by Hornsby are still unpublished. During the next hundred years the meridian circle, which is at present the standard instrument for determining the places of the stars, was gradually evolved. In this instrument, a telescope is mounted so that it will point only to stars in the meridian, that is, to stars exactly north or south of the observer. The declinations of stars, corresponding to the latitude of points on the surface of the earth, are then measured by a finely graduated circle. Owing to the motion of the earth all stars cross the meridian twice during every twenty-four hours. The right ascension, corresponding to longitude, will be given by the time of transit. At first, this time was found by the "eye and ear" method in which the observer counted the ticks of an accurate timepiece and compared them mentally with the instant at which the star appeared to cross a wire in the field of view of the telescope. About the middle of the nineteenth century a great advance was made by recording the time electrically on a chronograph. This method was known for many years as the "American" method, owing to its introduction and general adoption in this country. This continued to be the standard method almost to the present time, and an enormous number of observations have been accumulated in this way, the total cost amounting to millions of dollars. Perhaps the most valuable work of this kind is that of the Astronomische Gesellschaft, which, by international cooperation, secured accurate observations of the positions of one hundred and sixty-six thousand stars. All stars of the ninth magnitude, and brighter, north of declination $-23°$ are included. Of the twenty zones, seven were observed in Germany, four in the United States, three in Russia, one each in Algeria, Austria, England, Holland, Norway and Sweden. Of the American zones, one was observed at Albany, one at Washington, and two at Cambridge. Each of the latter occupied the time of an observer and several assistants for twenty years. It was expected that these stars would be re-observed after an interval of about fifty years, to determine the proper motions, or annual changes in position. As the time is approaching when this great work should be undertaken, careful consideration should be given to it. Fortunately, the twentieth century has already developed two new methods which might replace the older plans. The first of these is the transit micrometer, in which a motion is given to the wire in the field of the telescope so that it shall follow closely the motion of the image of a star as it transits through the field. A wide difference of opinion exists among leading astronomers as to the best method of securing this motion. In the earlier instruments constructed by Repsold, the motion was given by a screw turned by the two hands alternately. This method certainly gives excellent results and is still used largely in geodetic work. Any one who has tried it will find that with the rapid motion of an equatorial star under a high power it is difficult to satisfy himself that the wire always bisects the star. If clockwork is used, the rate must vary with the declination and it is strange that this is not done by electrical control, instead of the somewhat crude mechanical devices now employed. The wire records its position automatically on a chronograph at short intervals. The plan of permitting this record only when the observer is satisfied that coincidence takes place, as is done at Heidelberg, seems a good one. Evidently a certain relative motion will give better results than a greater or less motion. It would appear to follow logically that this apparent motion should be given to all stars and the record permitted only for the few seconds of apparent coincidence. We can expect no better results than those obtained with a filar micrometer. The best plan may therefore prove to be to give a motion to the wire nearly equal to that of the star, whatever the declination of the latter, by a suitable variation of the clockwork. The best rate could readily be determined by observing stars at different distances from the Pole. Successive settings should then be made as with a filar micrometer, closing the circuit on the chronograph only when the bisection was satisfactory. A similar setting should also be made for the declinations. The two coordinates could thus be determined with an accuracy substantially the same as that of a filar micrometer. Experience has shown that one star a minute can be observed in both coordinates with the transit micrometer. There can be little doubt that positions could thus be obtained with much greater accuracy than by the methods now in use. The special advantage would be the elimination of systematic errors.

A second method of determining positions, recently developed at the Allegheny Observatory, is by plates taken with a photographic doublet. Ordinary plates must be replaced by those of plate glass. By taking suitable precautions positions may be determined of even the faintest stars, with an accuracy at least equal to that of a meridian circle. To obtain the best results, the field should be about five degrees square on an 8×10 plate. The focal length of the telescope would accordingly be about two meters. The large field would permit the constants of each plate to be derived from stars as bright as the eighth magnitude. The economy of this method would be very great, as compared with a meridian circle. The usefulness of the latter instrument appears to be confined to observations of the brighter stars. Accordingly, its aperture may be reduced. The ideal plan would apparently be to divide the sky into regions five degrees square and select in each, five or more stars of about the eighth magnitude and of approximately the same class of spectrum as Class K, so that all should have about the same color. The positions of these should be determined with the greatest possible accuracy with meridian circles, as described above. Some brighter stars should be included to render available the vast number of observations of these objects made in the past. Positions of the stars in the Gesellschaft Catalogues and all fainter stars should be determined by photography.

Various attempts are now being made to determine the absolute positions of the stars by means of photography. It appears probable that a pier placed under ground will remain free from irregular motions, and that if this can be accomplished, the absolute positions of the stars near the equator can be found by photography. To determine the equinox, Venus and Mercury should be photographed as well as the sun. By the very satisfactory cooperation of the Princeton, Yale and Harvard observatories the position of the moon is now determined by photography. The results of a preliminary discussion indicate an accuracy at least equal to that of the best meridian determinations, those of the Greenwich Observatory.

Excellent progress is also being made in determining the parallax of the stars by photography. The recent increase in accuracy is at least ten fold, or that of another place of decimals. A hundredth of a second of arc can now be determined with greater accuracy than a tenth of a second, twenty or thirty years ago.

The just criticism has been made of American astronomers that while they have contributed more than their share of the work in astrophysics the older science of astronomy of position has been greatly neglected. This is partly due to the fact that much of this work has been left to the United States Naval Observatory, which in the past has failed to justify the liberal appropriations made for its support. While Congress has given it for many years a much larger income than that of any other observatory in the world, the law has been such that it is impossible to attain the best results. The superintendent must be a naval officer, instead of an astronomer, and even then must go to sea after a short term. Accordingly, the Naval Observatory during a period of 37 years had 20 superintendents with an average term of less than two years. The Greenwich Observatory during a period of 235 years from 1675 to 1910 has had 8 astronomers royal with an average term of 29 years. The work of the latter institution with but half the income has greatly exceeded that of the Naval Observatory. It should be stated, however, that within the last few weeks, the Naval Observatory has established an admirable wireless time service by which any one can obtain, at trifling expense, accurate time within a tenth of a second. The Navy has no need of a great observatory, from which it derives but little credit. Three successive boards of visitors have pointed out the present unfortunate conditions, but the necessary action has not been taken by Congress. The obvious remedy is to remove the observatory to another department, or place it under the direction of the Smithsonian Institution, and appoint an astronomer at its head. What grander field of work could be undertaken by this observatory than that desired by astronomers and neglected elsewhere. For instance, computers of double star orbits are continually complaining that while a surplus of measures of the easy objects are available, many difficult objects are neglected, although measures of them are greatly needed. The same is true of the asteroids, of variable stars, and in fact in almost every department of astronomy. By making the observations desired by experts, every hour would be saved, and work of the greatest value accumulated.

Astrophysics assumed prominence as a science about forty years ago, although it was foreshadowed by certain far-seeing astronomers like the Herschels, G. P. Bond, Huggins, Draper and others. One department, the study of the light of the stars, was developed much earlier, originating in the Almagest and its revision a thousand years later by Sûfi. These catalogues show that the relative brightness of the stars has not changed sensibly during the last two thousand years. Also, that the human eye has the same sensitiveness to different colors, now as then. Stellar brightness was made a precise science by that great astronomer, William Herschel. His six catalogues, two of which remained unknown for eighty years, give precise measures of the light of the three thousand stars contained in them with an accuracy comparable with recent work.

In 1877, stellar photometry was taken up on a large scale at Harvard. Since then, more than two million photometric settings have been made. A station in Arequipa, Peru, permitted the southern stars to be observed on the same system as the northern stars. We have now, accordingly, measures of about eighty thousand stars, including all of the seventh magnitude and brighter, many of the ninth magnitude, and some as faint as the thirteenth magnitude. The excellent work of the Potsdam Observatory gives measures of the light of fourteen thousand stars including all northern stars of the magnitude 7.5, and brighter. The Potsdam and Harvard systems agree admirably if a correction is applied for the color or spectrum of the stars. They should never be combined, or compared, unless this correction is applied.

Stellar photography, originating in the work of George Bond in 1857, has revolutionized many departments of astronomy. The great work of a chart of the entire sky, undertaken by the Paris Observatory in cooperation with several others, is a sad example of the danger of undertaking a work on too large a scale. Although several observatories have been continually at work upon it for a quarter of a century, it has been predicted that at least fifty years must elapse before it is completed, and no positions of any southern stars have yet been published. In striking contrast to this is the early completion of the Cape Photographic Durchmusterung which gives the positions and magnitudes of nearly half a million stars south of $-19°$. It illustrates the results of the happy combination of skilful planning with routine organization, conducted on a very large scale. The extension of this work to the North Pole is now being planned, but with the additional condition that the color index as well as the photographic magnitude will be determined. The former will be found by photographing the stars by means of their yellow or red, as well as with their blue, light, the difference in the magnitudes giving the color index. Much might be said of the numerous applications of photography to the determination of stellar magnitude. The sixty-inch reflector of the Mount Wilson Observatory, using exposures of several hours, has succeeded in photographing stars as faint as the twentieth magnitude. An international committee, with members from England, France, Germany, Russia, Holland and the United States, has adopted a scale of magnitudes based on two investigations made at Harvard. One of these was made with the meridian photometer, and the other is an elaborate investigation by Miss H. S. Leavitt of the photographic magnitude of seventy-six stars near the North Pole. A standard scale is thus provided from the first to the twentieth magnitude. We may say from the minus twenty-sixth to the twentieth magnitudes since accordant results for the light of the sun have been obtained by Professors W. H. Pickering and E. S. King. For many purposes, photography may well replace visual photometric measures, since for stars brighter than the fifteenth magnitude photographs may be taken with yellow light. One of the principal uses of measures of the light of the stars is the study of the variables, or those in which the brightness is not constant. A bibliography of these by Miss Cannon is recorded on about forty thousand cards. The number of known variables is now about forty-five hundred, of which three quarters have been discovered by photography, at the Harvard Observatory. There are several kinds of variable stars. Variables of long period undergo changes which repeat themselves somewhat irregularly in a period of several months, and at maximum are often several thousand times as bright as at minimum. The most useful work that an amateur can do with a small telescope is the observation of these objects. An important work undertaken by the British Astronomical Association has been the observation of variable stars. During the last thirteen years they have accumulated twenty thousand such observations, all reduced to the same scale, which is that of the Harvard Photometry. Similar work in this country has accumulated ten and sixteen thousand observations in the last two years, respectively. Variables of short period complete their changes in a few days, or hours. Professor Bailey has found five hundred such objects in the globular clusters. In one of these clusters, Messier 3, out of a thousand stars one seventh are variable, all have a period of about half a day, and their periods are known within a fraction of a second. Their light changes so rapidly that in one case it doubles in seven minutes. It is a strange thought that out of a thousand stars, looking exactly alike, there should be a hundred little chronometers keeping perfect time, and whose rate is known with such accuracy. About a hundred and fifty variables belong to the Algol class, in which the light is uniform for a large part of the time, undergoing a sudden diminution at regular intervals. This is due to the eclipse of two bodies, one darker than the other, revolving around their common center of gravity. An elaborate theoretical study of this problem has been made at the Princeton Observatory and, largely from the photometric and photographic magnitudes made at Harvard and elsewhere, the dimensions of a large number of these systems have been determined.

Photography still can scarcely compete with other methods where the greatest accuracy is desired, as for instance, the measures with the polarizing photometer by the late Oliver C. Wendell. The masterly use of the selenium photometer by Professor Stebbins gives results for bright stars of still greater accuracy, while the experiments in Germany with the photo-electric cell by Rosenberg and Guthnick give results which promise to revolutionize our present methods. The principal source of error appears to be the varying transparency of the air. The trial of the instrument in a location where the air is exceedingly clear and steady for long periods is greatly to be desired.

During the last twenty-five years photographs have been obtained by the Harvard Observatory in order to furnish a history of the stellar universe. Two similar 8-inch photographic doublets have been used, one mounted at Cambridge for the northern, and the other at Arequipa for the southern stars. With each of these instruments about forty thousand photographs have been taken. The total weight of these plates is about forty tons. As each plate covers a region ten degrees square, every part of the sky has been photographed, on the average, a hundred times. This work is now supplemented by two small Cooke anastigmat lenses, each having a field thirty degrees square. The number of plates taken with these two instruments are nine thousand and fourteen thousand, respectively. The exposures with the larger instruments are, in general, ten minutes, showing stars of the thirteenth magnitude. The exposures with the smaller instruments are one hour, showing stars of the eleventh magnitude. A continuous history of the sky is thus furnished from which the magnitude and position of any stellar object of sufficient brightness can be determined for a large number of nights during the last quarter of a century. A striking illustration of the value of this collection occurred when the planet Eros was discovered in 1898. It appeared that this object was nearer the earth in 1894 than would occur again for thirty-five years. An examination of the photographs showed its presence on 23 plates, and from their positions the parallax of the sun and mass of the earth were determined with an accuracy equal to that of any of the methods previously used, and on which an enormous amount of time and money had been spent.

For many years the Kiel and Harvard observatories have served as distributing centers of astronomical discoveries and observations in Europe and America, respectively. The last new star which is known to have appeared, Nova Geminorum, No. 2, was discovered by Enebo at Dombass, Norway, on Tuesday, March 13, 1912. The cable message was received at Cambridge Wednesday morning, and the star was observed at several American observatories the next evening, or the night following its discovery. An examination of the Harvard photographs showed that two plates had been taken on the preceding Sunday, March 11, on which no trace of the Nova was visible, and two on Monday, March 12, showing it of nearly its full brightness. Photographs taken Wednesday compared with those obtained a few days later showed the wonderful change in its spectrum, from the solar type with dark lines, to the typical spectrum of a Nova with bright lines.

There is no department of astronomy which is now receiving greater attention than the study of the spectra of the stars. Dr. Henry Draper was the first to photograph the lines in a stellar spectrum, although Sir Williams Huggins had already obtained a mark from the spectrum of Sirius, and later was the first to publish his results in successfully photographing stellar spectra. The untimely death of Dr. Draper, in the midst of his work, led to the establishment at Harvard of the Henry Draper Memorial. For nearly thirty years Mrs. Draper has maintained an active interest in this work. By placing a large prism over the objective of a telescope, the light of all the brighter stars in the field are spread out into spectra, so that instead of photographing the spectrum of one star at a time, as with a slit spectroscope, as many as a thousand have sometimes been taken on a single plate. Such photographs, covering the entire sky, have been taken with the two 8-inch doublets already mentioned. A study of the spectra thus obtained enabled Mrs. Fleming to discover many hundred objects whose spectra are peculiar. Among them may be mentioned 10 of the 19 new stars known to have appeared during the years in which she was engaged in this work, while five of the others were also found at Harvard by other observers. She discovered more than two hundred variable stars, 91 out of the 108 stars of the very peculiar fifth type, and showed that these objects occurred only very near the central line of the Milky Way. During the last two or three years a great demand has arisen for the class of spectrum of large numbers of stars. The Harvard photographs show the class of spectrum of nearly two hundred thousand stars. Miss Cannon has, accordingly, undertaken to prepare a catalogue of these objects, with the result that she has already classified about one hundred and fifteen thousand spectra, covering more than one half of the sky. The work is progressing at the rate of five thousand stars monthly, and the results will fill seven of the large quarto *Annals* of the Harvard Observatory. The organization of this work has required the most careful application of the principles of "scientific management."

One of the most important results derived from the Harvard photographs was the discovery that in certain spectra the lines were alternately double and single. This, and the discovery by Vogel at Potsdam that the lines of the variable star Algol continually changed their position revealed the existence of spectroscopic binaries. No department of astronomy is receiving more attention, at the present time, than these objects, and in general the motion of the stars in the line of sight. The Lick, Yerkes, Greenwich, Potsdam, Bonn and Ottawa observatories are only a portion of those directing a large part of their energy to this subject.

One of the most important generalizations of recent times is the discovery by Professor Campbell that the velocity of a star depends upon its class of spectrum. The proper motion of a star was similarly found by the late Lewis Boss to be dependent on the same quantity.

In conclusion, the United States has attained an enviable position in the newer departments of astronomy. Can this be maintained? In Europe, especially in Germany, observatories and instruments of the highest grade are now being constructed, the government furnishing appliances with the most liberal hand. Perhaps the most promising sign for the future is the friendly cooperation of American astronomers, which has never been more marked than at the present time.

The possibilities of work are now greater than ever before. A small fraction of the effort expended in teaching science if devoted to its extension and progress would fulfil the objects of the American Association for the Advancement of Science.

EDWARD C. PICKERING

PROGRESS OF THE CHEMISTRY OF AGRICULTURE[1]

IT is the object of this address to present briefly the important recent advances made in agricultural chemistry. In so doing, it is not my intention to go back one hundred years or fifty years or even to the period included in the memory of the veterans of this association; but only to consider such a period as is within the memory and the experience of a youngster like myself.

Agricultural chemistry is so closely interwoven with the other sciences which have been applied to agriculture, that it is practically impossible to disentangle them. Hence, to a certain extent, the progress of the chemistry of agriculture is closely related to the progress of other agricultural sciences, and to agricultural science, in general. The contributions of the chemist to agricultural science have been so many, so varied and so important, that for a long time the sciences applied to agriculture have been termed agricultural chemistry. This period is passing, and the term agricultural chemistry is being more restricted in its significance, but the field is still broad, and the harvest bountiful to the worker who seeks to garner the grain of knowledge.

There has been a tendency in some colleges to discontinue the teaching of agricultural chemistry, and to divide the subject-matter between the agronomist and the animal husbandman. It is a serious question whether such tendency is in accord with the known laws of specialization in science. There is no doubt but that, as time goes on, the agricultural chemist must specialize more and more in one of these fields of work, but there is a difference between the specialization of the scientist in his own field, and the attempt of other branches of agricultural science to take over the work of the chemist, or the chemist to take over other branches of agricultural science. As I see it, both the agronomist and the animal husbandman have their special problems. They must have their special training in their own fields, and while this training must include some chemistry, it is not sufficient in quantity to

[1] Presidential address before the Association of Official Agricultural Chemists of North America (November 18, 1913).