the actions of one element on another rather than abandon the assumption that chemical affinity acts in definite units.

Portobello, April 28. WM. DURHAM.

[Without discussing the general question, I may point out that unfortunately we are at present unable to base any argument on the thermal behaviour of elements, as the fundamental values are entirely unknown: we do not know, for example, what amount of heat would be given out on combination of H and Cl; the value deduced for H_2,Cl_2 by Thomsen being the algebraic sum of several values, some of which are negative, some positive.—H. E. ARMSTRONG.]

The Spherical Integrator.

I FIND that my name has been alluded to in a letter by Prof. Hele Shaw, in your last number (vol. xxxv. p. 581).

I shall be glad if you will kindly permit me to state that the idea of reducing the moment of inertia of the sphere in a spherical integrator, by making it hollow, occurred to me while abroad in Algeria. An account of the modified form is given in the *Phil. Mag.*, August 1886, p. 147. I now find, from a letter from Prof. Shaw, of this month, that exactly the same method of dealing with the difficulty had occurred to him. At the end of Prof. Shaw's letter in your last issue the following words are used: "Now in the 'sine' form, of which this integrator is an example, this pin should move in the arc of a circle, and it would be interesting to know if approximately correct results have been obtained with what is in some respects a more convenient device." From this it would appear that the principle of the instrument is not correct. This morning I received a post-card from Prof. Shaw in which he writes that he had misunderstood the diagrammatic outline in the *Phil. Mag.* His words are: "You are quite right as you use it; I was thinking of a contrivance in which the sphere and frame move together." With respect to M. Ventosa's letter on the subject, in your paper of a month ago, (p. 513) in which he speaks very favourably of the method of using a hollow sphere, although M. Ventosa used a spherical integrator in a certain form of anemometer at an early date, yet I think that all who have seen and read Prof. Shaw's work will admit that he has expanded the use of the spherical integrator and its mathematical importance in a way which is both masterly and original. FREDK. SMITH.

28 Norham Gardens, Oxford, April 25.

THE HENRY DRAPER MEMORIAL.[1]

DR. HENRY DRAPER, in 1872, was the first to photograph the lines of a stellar spectrum. His investigation, pursued for many years with great skill and ingenuity, was most unfortunately interrupted in 1882 by his death. The recent advances in dry-plate photography have vastly increased our powers of dealing with this subject. Early in 1886, accordingly, Mrs. Draper made a liberal provision for carrying on this investigation at the Harvard College Observatory, as a memorial to her husband. The results attained are described below, and show that an opportunity is open for a very important and extensive investigation in this branch of astronomical physics. Mrs. Draper has accordingly decided greatly to extend the original plan of work, and to have it conducted on a scale suited to its importance. The attempt will be made to include all portions of the subject, so that the final results shall form a complete discussion of the constitution and conditions of the stars, as revealed by their spectra, so far as present scientific methods permit. It is hoped that a greater advance will thus be made than if the subject was divided among several institutions, or than if a broader range of astronomical study was attempted. It is expected that a station to be established in the southern hemisphere will permit the work to be extended so that a similar method of study may be applied to stars in all parts of the sky. The investigations already undertaken, and described below more in detail, include a catalogue of the spectra of all stars north of $-24°$ of the sixth magnitude and brighter, a more extensive catalogue of spectra of stars brighter than the eighth magnitude, and a detailed study of the spectra of the bright stars. This last will include a classification of the spectra, a determination of the wave-lengths of the lines, a comparison with terrestrial spectra, and an application of the results to the measurement of the approach and recession of the stars. A special photographic investigation will also be undertaken of the spectra of the banded stars, and of the ends of the spectra of the bright stars. The instruments employed are an 8-inch Voigtländer photographic lens re-ground by Alvan Clark and Sons, and Dr. Draper's 11-inch photographic lens, for which Mrs. Draper has provided a new mounting and observatory. The 15-inch refractor belonging to the Harvard College Observatory has also been employed in various experiments with a slit spectroscope, and is again being used as described below. Mrs. Draper has decided to send to Cambridge a 28-inch reflector and its mounting, and a 15-inch mirror, which is one of the most perfect reflectors constructed by Dr. Draper, and with which his photograph of the moon was taken. The first two instruments mentioned above have been kept at work during the first part of every clear night for several months. It is now intended that at least three telescopes shall be used during the whole night, until the work is interrupted by daylight.

The spectra have been produced by placing in front of the telescope a large prism, thus returning to the method originally employed by Fraunhofer in the first study of stellar spectra. Four 15° prisms have been constructed, the three largest having clear apertures of nearly 11 inches, and the fourth being somewhat smaller. The entire weight of these prisms exceeds a hundred pounds, and they fill a brass cubical box a foot on each side. The spectrum of a star formed by this apparatus is extremely narrow when the telescope is driven by clockwork in the usual way. A motion is accordingly given to the telescope slightly differing from that of the earth by means of a secondary clock controlling it electrically. The spectrum is thus spread into a band, having a width proportional to the time of exposure and to the rate of the controlling clock.

This band is generally not uniformly dense. It exhibits lines perpendicular to the refracting edge of the prism, such as are produced in the field of an ordinary spectroscope by particles of dust upon the slit. In the present case, these lines may be due to variations in the transparency of the air during the time of exposure, or to instrumental causes, such as irregular running of the driving clock, or slight changes in the motion of the telescope, resulting from the manner in which its polar axis is supported. These instrumental defects may be too small to be detected in ordinary micrometric or photographic observations, and still sufficient to affect the photographs just described.

A method of enlargement has been tried which gives very satisfactory results, and removes the lines above mentioned as defects in the negatives. A cylindrical lens is placed close to the enlarging lens, with its axis parallel to the length of the spectrum. In the apparatus actually employed, the length of the spectrum, and with it the dispersion, is increased five times, while the breadth is made in all cases about 4 inches. The advantage of this arrangement is, that it greatly reduces the difficulty arising from the feeble light of the star. Until very lately, the spectra in the original negatives were made very narrow, since otherwise the intensity of the starlight would have been insufficient to produce the proper decomposition of the silver particles. The enlargement being made by daylight, the vast amount of energy then available is controlled by the original negative, the action

[1] "First Annual Report of the Photographic Study of Stellar Spectra." Conducted at the Harvard College Observatory." Edward C. Pickering, Director. With Plate. (Cambridge: John Wilson and Son, University Press, 1887.)

of which may be compared to that of a telegraphic relay. The copies therefore represent many hundred times the original energy received from the stars. If care is not taken, the dust and irregularities of the film will give trouble, each foreign particle appearing as a fine spectral line.

Other methods of enlargement have been considered, and some of them tried, with the object of removing the irregularities of the original spectra without introducing new defects. For instance, the sensitive plate may be moved during the enlargement in the direction of the spectral lines; a slit parallel to the lines may be used as the source of light, and the original negative separated by a small interval from the plate used for the copy; or two cylindrical lenses may be used, with their axes perpendicular to each other. In some of these ways the lines due to dust might either be avoided or so much reduced in length as not to resemble the true lines of the spectrum.

The 15-inch refractor is now being used with a modification of the apparatus employed by Dr. Draper in his first experiments,—a slit spectroscope from which the slit has been removed. A concave lens has been substituted for the collimator and slit, and, besides other advantages, a great saving in length is secured by this change. It is proposed to apply this method to the 28-inch reflector thus utilising its great power of gathering light. . . . .

The results to be derived from the large number of photographs already obtained can only be stated after a long series of measurements and a careful reduction and discussion of them. An inspection of the plates, however, shows some points of interest. A photograph of α Cygni, taken November 26, 1886, shows that the H line is double, its two components having a difference in wave-length of about one ten-millionth of a millimetre. A photograph of *o* Ceti shows that the lines G and *h* are bright, as are also four of the ultra-violet lines characteristic of spectra of the first type. The H and K lines in this spectrum are dark, showing that they probably do not belong to that series of lines. The star near χ^1 Orionis, discovered by Gore in December 1885, gives a similar spectrum, which affords additional evidence that it is a variable of the same class as *o* Ceti. Spectra of Sirius show a large number of faint lines besides the well-known broad lines.

The dispersion employed in any normal map of the spectrum may be expressed by its scale, that is, by the ratio of the wave-length as represented to the actual wave-length. It will be more convenient to divide these ratios by one million, to avoid the large numbers otherwise involved. If one-millionth of a millimetre is taken as the unit of wave-length, the length of this unit on the map in millimetres will give the same measure of the dispersion as that just described. When the map is not normal, the dispersion of course varies in different parts. It increases rapidly towards the violet end when the spectrum is formed by a prism. Accordingly, in this case the dispersion given will be that of the point whose wave-length is 400. This point lies near the middle of the photographic spectrum when a prism is used, and is not far from the H line. The dispersion may accordingly be found with sufficient accuracy by measuring the interval between the H and K lines, and dividing the result in millimetres by 3·4, since the difference in their wave-lengths equals this quantity. The following examples serve to illustrate the dispersion expressed in this way: Angström, Cornu, 10; Draper, photograph of normal solar spectrum, 3·1 and 5·2; Rowland, 23, 33, and 46; Draper, stellar spectra, 0·16; Huggins, 0·1. Fig. 1, 0·06; Fig. 2, 0·10; Fig. 3, 0·63; Fig. 4, 1·3; Figs. 5 and 6, 6·5.

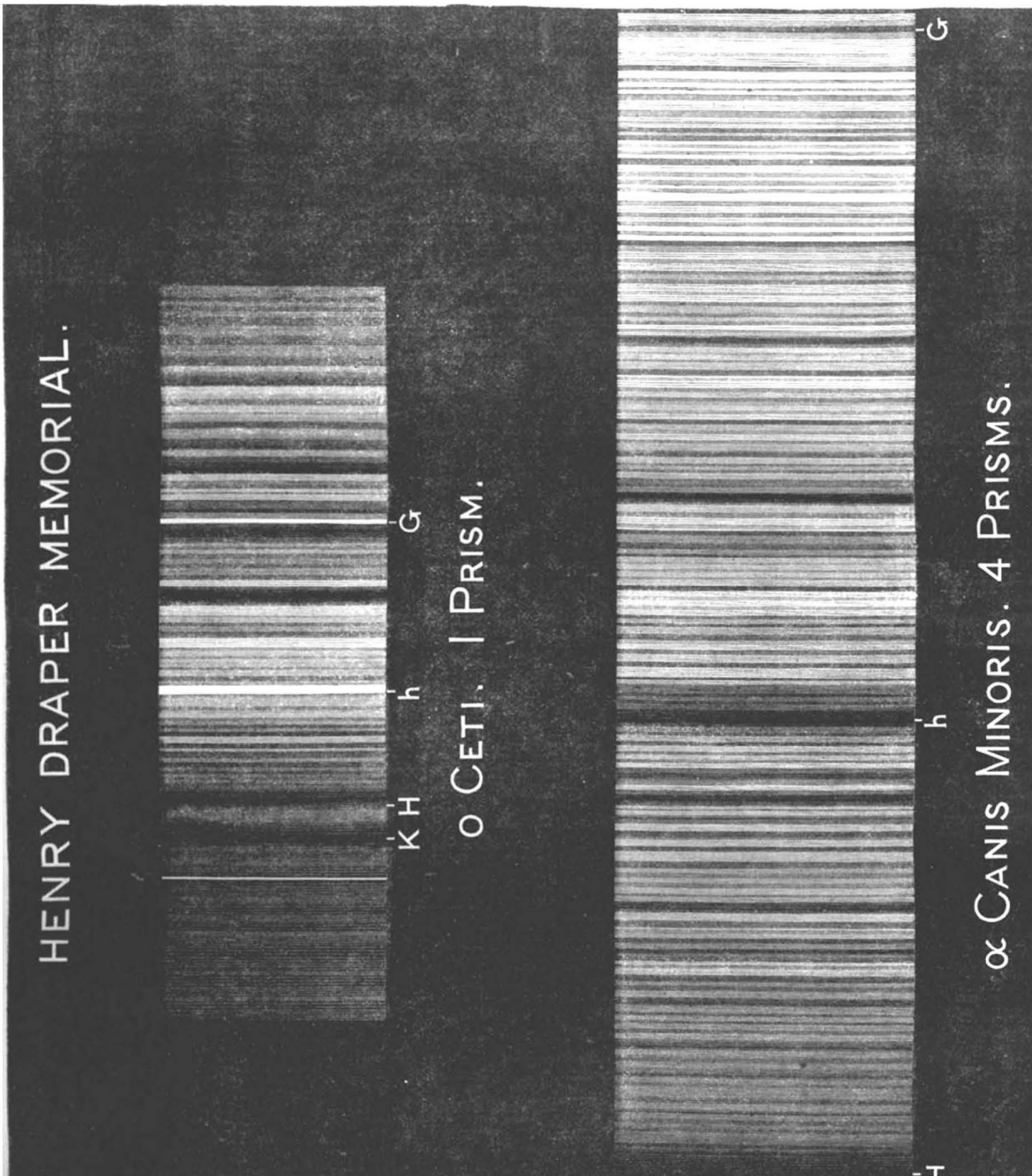
The most rapid plates are needed in this work, other considerations being generally of less importance. Accordingly the Allen and Rowell Extra Quick plates have been used until recently. It was found, however, that they were surpassed by the Seed Plates No. 21, which were accordingly substituted for them early in December. Recognising the importance of supplying this demand for the most sensitive plates possible, the Seed Company have recently succeeded in making still more sensitive plates, which we are now using. The limit does not seem to be reached even yet. Plates could easily be handled if the sensitiveness were increased tenfold. A vast increase in the results may be anticipated with each improvement of the plates in this respect. Apparatus for testing plates, which is believed to be much more accurate than that ordinarily employed, is in course of preparation. It is expected that a very precise determination will be made of the rapidity of the plates employed. Makers of very rapid plates are invited to send specimens for trial.

The photographic work has been done by Mr. W. P. Gerrish, who has also rendered important assistance in other parts of the investigation. He has shown great skill in various experiments which have been tried, and in the use of various novel and delicate instruments. Many of the experimental difficulties could not have been overcome but for the untiring skill and perseverance of Mr. George B. Clark, of the firm of Alvan Clark and Sons, by whom all the large instruments have been constructed.

The progress of the various investigations which are to form a part of this work is given below:—

(1) *Catalogue of Spectra of Bright Stars.*—This is a continuation of the work undertaken with the aid of an appropriation from the Bache Fund, and described in the Memoirs of the American Academy, vol. xi. p. 210. The 8-inch telescope is used, each photograph covering a region 10° square. The exposures for equatorial stars last for five minutes, and the rate of the clock is such that the spectra have a width of about 0·1 cm. The length of the spectra is about 1·2 cm. for the brighter, and 0·6 cm. for the fainter stars. The dispersion on the scale proposed above is 0·1. The spectra of all stars of the sixth magnitude and brighter will generally be found upon these plates, except in the case of red stars. Many fainter blue stars also appear. Three or four exposures are made upon a single plate. The entire sky north of −24° would be covered twice, according to this plan, with 180 plates and 690 exposures. It is found preferable in some cases to make only two exposures; and when the plate appears to be a poor one, the work is repeated. The number of plates is therefore increased. Last summer the plates appeared to be giving poor results. Dust on the prisms seemed to be the explanation of this difficulty. Many regions were re-observed on this account. The first cycle, covering the entire sky from zero to twenty-four hours of right ascension, has been completed. The work will be finished during the coming year by a second cycle of observations, which has already been begun. The first cycle contains 257 plates, all of which have been measured, and a large part of the reduction completed. 8313 spectra have been measured on them, nearly all of which have been identified, and the places of a greater portion of the stars brought forward to the year 1900, and entered in catalogue form. In the second cycle, 64 plates have been taken, and about as many more will be required. 51 plates have been measured and identified, including 2974 spectra. A study of the photographic brightness and distribution of the light in the spectra will also be made.

The results will be published in the form of a catalogue resembling the Photometric Catalogue given in vol. xiv. of the Annals of Harvard College Observatory. It will contain the approximate place of each star for 1900, its designation, the character of the spectrum as derived from each of the plates in which it was photographed,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the references to these plates, and the photographic brightness of the star.

(2) *Catalogue of Spectra of Faint Stars.*—This work resembles the preceding, but is much more extensive. The same instrument is used, but each region has an exposure of an hour, the rate of the clock being such that the width of the spectrum will be as before 0·1 cm. Many stars of the ninth magnitude will thus be included, and nearly all brighter than the eighth. In one case, over three hundred spectra are shown on a single plate. This work has been carried on only in the intervals when the telescope was not needed for other purposes. 99 plates have however been obtained, and on these 4442 spectra have been measured. It is proposed to complete the equatorial zones first, gradually extending the work northward. In all, 15,729 spectra of bright and faint stars have been measured.

(3) *Detailed Study of the Spectra of the Brighter Stars.*—This work has been carried on with the 11-inch photographic telescope used by Dr. Draper in his later researches. A wooden observatory was constructed about 20 feet square. This was surmounted by a dome having a clear diameter of 18 feet on the inside. The dome had a wooden frame, sheathed and covered with canvas. It rested on eight cast-iron wheels, and was easily moved by hand, the power being directly applied. Work was begun upon it in June, and the first observations were made with the telescope in October. Two prisms were formed by splitting a thick plate of glass diagonally. These gave such good results that two others were made in the same way, and the entire battery of four prisms is ordinarily used. The safety and convenience of handling the prisms is greatly increased by placing them in square brass boxes, each of which slides into place like a drawer. Any combination of the prisms may thus be employed. As is usual in such an investigation, a great variety of difficulties have been encountered, and the most important of them have now been overcome.

(4) *Faint Stellar Spectra.*—The 28-inch reflector will be used for the study of the spectra of the faint stars, and also for the fainter portions near the ends of the spectra of the brighter stars. The form of spectroscope mentioned above, in which the collimator and slit are replaced by a concave lens, will be tried. The objects to be examined are, first, the stars known to be variable, with the expectation that some evidence may be afforded of the cause of the variation. The stars whose spectrum is known to be banded, to contain bright lines, or to be peculiar in other respects, will also be examined systematically. Experiments will also be tried with orthochromatic plates and the use of a coloured absorbing medium, in order to photograph the red portions of the spectra of the bright stars. Quartz will also be tried to extend the images towards the ultra-violet.

(5) *Absorption Spectra.*—The ordinary form of comparison spectrum cannot be employed on account of the absence of a slit. The most promising method of determining the wave-lengths of the stellar spectra is to interpose some absorbent medium. Experiments are in progress with hyponitric fumes and other substances. A tank containing one of these materials is interposed, and the spectra photographed through it. The stellar spectra will then be traversed by lines resulting from the absorption of the media thus interposed, and, after their wave-lengths are once determined, they serve as a precise standard to which the stellar lines may be referred. The absorption-lines of the terrestrial atmosphere would form the best standard for this purpose if those which are sufficiently fine can be photographed.

(6) *Wave-Lengths.*—The determination of the wave-lengths of the lines in the stellar spectra will form an important part of the work which has not yet been begun. The approximate wave-lengths can readily be found from a comparison with the solar spectrum, a sufficient number of solar lines being present in most stellar spectra. As a difference of one ten-millionth of a millimetre in wave-length exceeds half a millimetre in Figs. 5 and 6 of the accompanying plate, the readings may be made with considerable accuracy by a simple inspection. For greater precision special precautions are necessary on account of the deviation caused by the approach and recession of the stars. The deviation found by Dr. Huggins in the case of Sirius would correspond to a change in the position of the lines of Figs. 5 and 6 of about half a millimetre. If, then, satisfactory results are obtained in the preceding investigation, the motion of the stars can probably be determined with a high degree of precision. The identification of the lines with those of terrestrial substances will of course form a part of the work, but the details will be considered subsequently.

From the above statement it will be seen that photographic apparatus has been furnished on a scale unequalled elsewhere. But what is more important, Mrs. Draper has not only provided the means for keeping these instruments actively employed, several of them during the whole of every clear night, but also of reducing the results by a considerable force of computers, and of publishing them in a suitable form. A field of work of great extent and promise is open, and there seems to be an opportunity to erect to the name of Dr. Henry Draper a memorial such as heretofore no astronomer has received. One cannot but hope that such an example may be imitated in other departments of astronomy, and that hereafter other names may be commemorated, not by a needless duplication of unsupported observatories, but by the more lasting monuments of useful work accomplished.

EDWARD C. PICKERING,
Director of Harvard College Observatory.
Cambridge, Mass., U.S.A., March 1, 1887.

SCIENCE AND GUNNERY.

I.

IN the last lecture which Prof. Tyndall delivered at the Royal Institution, he expressed a doubt as to whether extensive reading and study had not a tendency to hamper original genius, whether doctrines handed down for generations as articles of faith, which it would be heresy to dispute, had not materially checked the progress of science. Had he wished to illustrate his theory, he could not have had better examples than are to be found in the administration of our naval and military systems. It has been a reproach to us, as by far the greatest maritime nation of the world, that we have no School of Shipbuilding, that, until quite recently, naval officers have had no instruction except such as they could get in the practical execution of their duties, and no method existed of testing their knowledge except such rough-and-ready examinations as their superior officers could administer. Yet under these seeming disadvantages the Navy and the merchant service have kept in the forefront of progress, and have adopted all the newest discoveries of science, or of practical skill, as fast as they have been brought to light.

On the other hand, the officers of Artillery and Engineers have long been considered as belonging to the scientific branches of the service; they have been regularly trained in schools in which theory and history have been taught, and the consequence seems to be that it is most difficult to make the departments with which they are connected move with the times. How else can it be explained that we have adhered to wrought iron as a material for guns, and to muzzle-loaders, long after nations esteemed semi-barbarous have used steel and constructed breech-loaders? or how can we explain the waste of millions in constructing fortifications of patterns long obsolete, and which show no more originality than that exhibited in using