ART. XXXII. — *Observations upon the Solar Eclipse of July* 29, 1878, *by the Princeton Eclipse Expedition;* by Professor C. A. YOUNG.

THE Princeton expedition to the Rocky Mountains to observe the recent eclipse, was organized early in the year, and its expenses were mainly provided for by a liberal appropriation made for the purpose by the trustees of the estate of the late John C. Green. I have said, mainly, because we are also greatly indebted to the kindness of the managers of the Pennsylvania, the Chicago and Alton, and Kansas Pacific Railroads, and to the American Express Company, for the free transportation of persons and instruments, to the authorities of the State of Colorado for the loan of camp equipage, and to the Western Union Telegraph Company for various courtesies. We are also under obligations to Mr. Edison, to Rutgers and Dartmouth Colleges, and to the observatory of Harvard College for the gift or loan of apparatus.

Our principal object was to investigate the spectrum of the corona and chromosphere — not only the visible portion, but also, and especially, the invisible portions below the red and above the violet. It was hoped that some new lines might be discovered in these portions by the help of the thermopile, photography or fluorescence, but in this respect, as will be seen, our hopes were not fulfilled. Indeed we were well aware from the outset that the chances were considerably against us, and that it was quite likely, as it turned out, that the corona would sympathize with the present general apathy of the solar surface to an extent which would make the bright lines of the corona spectrum unusually faint and difficult of detection.

Our party, under the charge of Professor Brackett and myself, consisted of ten persons when we left Princeton on July 1st. We were joined in Missouri by another, and after we went into camp at Denver by still another, making up our proper party to twelve persons. Mr. Ranyard of the Royal Astronomical Society was also with us as our guest, and observed from our camp, and on the day of the eclipse we were assisted by several volunteers who came out from the city for the occasion.

Arriving in Denver on July 5th, we went into camp on the 7th in a grove on the bank of Cherry Creek about two and a half miles southeast of the city. Our position was determined by a triangulation made by Messrs. Libbey and McNeill, connecting us with several well determined points in the city.

Assuming for the High School house in Denver, lat. 39° 45′

00·6″, long. $1^h\ 51^m\ 45{\cdot}2^m$ west of Washington, according to the data kindly furnished by the Coast Survey, the position of the pier of our equatorial was, lat. 39° 43′ 27″, long. $1^h\ 51^m\ 40^s{\cdot}4$ west of Washington. The other instruments were all within 150 feet of this. Our equipment was as follows: For time, we had a sidereal box chronometer, with electric break circuit, by Parkinson & Frodsham, No. 4121; also a mean time pocket chronometer by the same makers, No. 5450. The rates of both were small and very regular. Their errors were determined every fair day by altitudes of the sun measured with a Pistor & Martin's prismatic sextant and artificial horizon. It was only rarely that we could get equal altitudes in morning and afternoon, as the afternoons were usually cloudy even when the mornings were fine. For chronographs we had two Morse registers of the European pattern.

For the ordinary ocular observations we had: (1) A four-inch telescope by Clark—the object glass of the meridian circle of the Princeton Observatory—temporarily mounted in a rough tube upon a very rude altitude and azimuth stand. It was fitted with a Herschel solar eyepiece and power of about fifty. Professor Brackett used this in observing the first and last contacts. (2) A four-inch dialytic by the late Mr. Sage of Orange, N. J., equatorially mounted. This instrument was kindly loaned by Mrs. Sage at the request of Professor C. G. Rockwood, who observed with it the first and last contacts, assisted by Mr. J. C. Grant. (3) A telescope of two and three-fourths inches aperture, the object glass, by Clark, belonging to the Princeton transit instrument, mounted upon a rough equatorial stand, and provided with a screen for observing the projected image of the sun. (4) A comet-seeker by Fitz, six inches aperture and about forty-six inches focus, with a curious arrangement of two eyepieces: power 19·5. This was mounted upon a tripod with altitude and azimuth motion. It was used by Mr. Malcolm McNeill during totality in sweeping for intra-mercurial planets, but without success.

After totality the large equatorial of the Princeton Observatory, having nine and a half inches aperture and twelve feet focus, was used by myself with the Merz polarizing eyepiece and power of 250, in observing the cusps and the moment of last contact.

For observing the visual spectrum of the corona four instruments were provided. (1.) The large equatorial with clockwork just mentioned. This was fitted with a single-prism spectroscope, and fluorescent eyepiece, having a film of solution of Æsculin about 1mm. thick. With this the dark lines of the ordinary solar spectrum could be easily seen as far as O, and with precautions I could see even farther. The eyepiece could be set axially as well as obliquely. I used this instru-

ment myself during totality. (2.) The finder of the equatorial is a fine telescope of three inches aperture. To this was fitted a spectroscope with a diffraction grating on silvered glass by Rutherfurd, 17,280 lines to the inch. With this I observed the first contact, and the behavior of the spectrum up to totality. During totality it was not used. I was assisted during the eclipse by my son, Mr. C. I. Young, who pointed the telescope and made my records.

(3.) A single-prism integrating spectroscope mounted equatorially, with an opera glass in front of the slit as a condenser. The collimator and telescope had each an aperture of two and a half inches, and a focal length of twenty-six and a half. The prism, kindly loaned for the occasion by Professor Emerson of Dartmouth College, had a refracting angle of forty-five degrees, and faces two and a quarter by two and a half inches. It was mounted, not at the angle of minimum deviation, but in such a way that by moving a lever it could be slightly rotated so as to throw the spectrum across the field of view. The whole was mounted equatorially, but without clockwork, and was committed to Mr. C. D. Bennett. (4.) An integrating spectroscope of high dispersion by Grubb. This had telescope and collimator of one inch aperture and twelve inches focus, with a train of dense sixty-degree prisms, varying in number at pleasure from ten to four—six were used during totality—it was fitted with an opera-glass condenser like the preceding. The dispersive power was too great, and nothing at all was seen with it by Mr. H. S. Smith who had it in charge.

(5.) For the observation of the spectrum-images of the corona, a slitless spectroscope of peculiar arrangement was employed, constructed specially for the purpose by Clark & Sons. Two small telescopes, precisely similar, each of two inch aperture and fourteen inch focus, with a magnifying power of ten and a half were placed parallel to each other upon a board, and in front of their object glasses were secured two thirty-degree prisms each four and a half inches long by two and a quarter wide. One face of the anterior prism was set so as to be perpendicular to the incident light, and one face of the other prism was perpendicular to the optical axes of the telescopes. The whole affair was mounted equatorially upon a post by Professor Rockwood (who had charge of the instrument) in a very ingenious manner, so that the plane of dispersion could be altered at pleasure. The three inch telescope before mentioned was attached to the same stand and arranged for polarization observations during the totality, but Professor Rockwood did not get time to use it. During the totality, Professor Brackett also examined the coronal images as seen by looking with the naked eye through a direct-vision prism of considerable dispersion.

Our photographic attack upon the corona spectrum employed four instruments. (1.) A spectroscopic camera with diffraction grating of 8640 lines to the inch, the ruled surface two and one-fourth by one and three-fourth inches. The collimator had an achromatic lens of three inches aperture and about forty inches focus; the slit was about three-fourths of an inch long, and so arranged that one-half of it could be uncovered at a time, for the purpose of securing the dark lines of the solar spectrum as reference marks by a short exposure of one-half the slit after totality, the other half having been exposed during the totality. The image was formed upon the plate by a quartz lens two inches diameter and twenty inches focus. The light was concentrated upon the slit by an opera-glass condenser with quartz lenses. The whole was equatorially mounted upon a post. With sunlight this instrument gave strong and beautifully defined impressions of the spectrum from F to O with exposures of between one-fourth and one-half a second; but the plate exposed through the whole of the totality showed no trace of action, to the great disappointment of Mr. W. Libbey, Jr., who had charge of the instrument and undoubtedly got from it all it would do.

(2.) A prismatic camera, consisting of a slit, a prism and a single quartz lens of ten inches focus. This instrument also had an opera-glass condenser, but of glass lenses, and was mounted equatorially upon a post. The rays from the slit were not rendered parallel before passing the prism, the lens being between the prism and sensitive plate. The slit of this instrument was arranged so that exposures of different lengths could be given to different adjacent portions of the plate. It gave impressions even more quickly than the preceding in full sunlight, but like it, failed to give any result during totality, notwithstanding the skillful management of Mr. W. W. McDonald, to whom it was intrusted.

(3) and (4) were slitless spectroscopes mounted together upon an equatorial stand kindly loaned to us by Professor Pickering, of the Harvard College Observatory. Professor Brackett, with great skill and ingenuity, attached to this an excellent clockwork compiled for the occasion mainly from the movement of the chronograph of the Princeton observatory. In one of the instruments the dispersion was effected by a speculum-metal grating of 17280 lines to the inch, with a ruled surface two and one-fourth by one and three-fourth inches. In the other a sixty-degree prism of white flint was used. The image-forming lens in each case was an achromatic of about two and one-half inches aperture and twenty-four inches focus. About eight minutes before totality, the diffraction instrument, with a five-second exposure gave a fine spectrum, but neither

of them succeeded during totality. Professor Brackett, assisted by his wife, took this double instrument as his special charge, though he besides had the entire management and oversight of all the photographic work; and not only so, but nearly everything that was ingenious in contrivance and skillful in execution was his also.

For photographing the corona, we had a six-inch telescope by Clark, with an object glass specially corrected for the actinic rays, loaned us by Professor Pickering. This was mounted upon an equatorial stand with clockwork, lent to us by Rutgers College. Mr. G. H. Calley was put in charge of this instrument and obtained with it three fine pictures of the corona with exposures of ten, fifteen and twenty-five seconds respectively. A plate which was to have had forty seconds exposure was unfortunately lost.

Only one instrument remains to be mentioned, that with which we attempted to explore the infra-red portion of the spectrum. It was a spectroscope, with thermoscopic apparatus substituted for the retina. A tube about five feet long carried at the upper end a slit two inches long taken from a Duboscq electric lantern. At the lower end of the tube was mounted a large spectrum-metal diffraction grating 5760 lines to the inch, in such a manner that it could be slightly turned by moving a long lever. In front of the grating was fixed a two-inch quartz lens, at the end of a bifurcated tube, suitably diaphragmed, and carrying at the other end a delicate line thermopile and a tasimeter. The whole apparatus was attached to a board equatorially mounted. In a large box close at hand was placed a delicate differential reflecting galvanometer, constructed by Professor Brackett specially for the purpose—as, indeed, was also the thermopile—both galvanometer and thermopile distinctly superior to anything we could otherwise obtain.

We had relied mainly upon the tasimeter, which Mr. Edison himself constructed, and gave to us, with a wholehearted generosity which deserves and has our sincerest thanks. We received the instrument, however, only the day before leaving home, and when we came to experiment in the field we found it quite impossible to do anything with it without completely remodelling the whole apparatus, which there was no time to do. Whenever the direction of the instrument was changed to keep the collimeter pointed to the sun, the whole adjustment of the tasimeter was destroyed. It needs to stand unmoved upon a firm foundation, while the rays under investigation are brought to it by reflection. Under the circumstances we were, therefore, obliged to rely wholly upon the thermopile.

Mr. A. D. Anderson managed the lever which moved the

grating and observed the galvanometer, while Mr. Taylor, of Denver, who joined us for the day, directed the collimator. Doubtful indications were obtained of a heat line having a wave length of about 8540 of Ångström's scale.

Of the instruments described the large equatorial was mounted under a sort of railroad car, which could be run off on a track so as to uncover the telescope when wanted. The photographic telescope and Professor Brackett's instrument were in a separate house, which also contained the photographic dark room, the telegraphic apparatus and chronometers. The other instruments were so arranged that they could be easily dismounted and brought under shelter when necessary.

The weather was very unsatisfactory for most of the time between our arrival upon the ground and the eclipse, especially for the ten days immediately preceding. The mornings were very generally clear, but by eleven o'clock the sky would be more or less completely overcast with heavy cumuli rolling down from the mountains, and in the afternoon there would be thunderstorms, sometimes of great violence. But the day of the eclipse was almost perfect; there were no clouds except one or two little fleecy things which kept out of our way, and a heavy bank over Long's peak, just where it was wanted to bring out the effects of the advancing shadow.

Observations of Contacts, etc.

The first contact was noted by Professor Brackett with the four-inch telescope at $2^h\ 19^m\ 43^s{\cdot}3$, local time. By myself, with the spectroscope attached to the three-inch finder of the equatorial, the moon was first certainly made out encroaching upon the chromosphere at $2^h\ 19^m\ 33^s$, and contact with the limb was noted at $2^h\ 19^m\ 46^s{\cdot}0$, both local time.

Professor Rockwood with the four-inch dialytic, power 100, noted the first contact as having occurred—a *past* event—at $2^h\ 20^m\ 07^s{\cdot}8$, local time. He remarks, "I was conscious that this was too late by certainly several seconds." The instrument was not provided with a convenient means of marking the place of contact, which occurred at a point not exactly where it was expected. No observations were made of second and third contact. The last contact was noted by Professor Brackett at $4^h\ 35^m\ 10^s{\cdot}7$; by Professor Rockwood at $4^h\ 34^m\ 53^s{\cdot}8$; by myself, with the nine and a half-inch telescope, full aperture, polarizing eye-piece and power of 250, at $4^h\ 35^m\ 14^s{\cdot}5$—a very satisfactory observation.

It will be remembered that the error of the standard chronometer was determined by sextant observations upon the sun, and the local time is therefore uncertain to the extent of at least 1·5 seconds from this cause.

During the progress of the eclipse, before totality, Professor Rockwood looked carefully for any such phenomena as brushes of light at the cusps, and after totality both Professor Brackett and myself joined him in the examination with our instruments, but nothing abnormal was seen by either of us. With the large equatorial the definition was most of the time very fine indeed.

Fringes.—Mr. McNeill, who was in charge of the comet-seeker, observed them hurriedly as totality came on. He says: "On the approach of totality I observed a series of shadows parallel to each other, somewhere about five inches wide and three feet apart. They extended from southwest to northeast, and moved in a direction perpendicular to this toward the southeast, at a rate of some eight or ten miles an hour."

Mr. Smith also saw them and gives the following account of them: "During the last thirty seconds of totality, when looking to see if my instrument was properly pointed, I saw a series of black shadowy bands moving in a direction contrary to the moon's motion. They were about three inches in breadth and about two feet apart, and their length was at right angles to their line of motion. After totality I measured approximately the direction of their length and found it to be about north thirty east. In the limited field of view that I had these lines appeared to be straight, but not even, looking as if made up of crescents having their points overlapping. I did not look at them for more than a few seconds." Mr. Smith also informs me verbally that the velocity of movement rather exceeded a very fast walk—say from five to six miles per hour—also that he estimated the dimensions by measuring, the next morning, upon the ground, the distance between objects over which the fringes passed simultaneously. The fact that the movement as he saw it was just opposite to Mr. McNeill's impression, is of course noticeable. Perhaps the explanation may be connected with the fact that one observed at the beginning, and the other at the end of totality. Mr. Pickering, however, who though not of our party observed in our enclosure, described the movement as *vibratory* rather than progressive.

Spectroscopic Observations.

Analyzing spectroscope.—I observed the first contact with the diffraction spectroscope attached to the finder, and after that, during the progress of the eclipse, I gave a most careful scrutiny to all the principal dark lines of the spectrum to ascertain whether there was any absorptive action to be detected at the moon's limb. I tried spectra of various orders, so as to give both extremely low and extremely high disper-

sion, but in all cases and with all the lines found only one emphatic negative result.

About ten minutes before totality the number of chromosphere bright lines, visible in this instrument began to increase. 1474, the *b.s* and others in that part of the spectrum began to be conspicuous, and I turned my attention to the single prism instrument with the fluorescent eyepiece. At this time I found I could see the dark lines quite to 0, and rather better than before the eclipse began. I adjusted the slit tangent to the expected point of contact, and brought to the center of the field the portion of the spectrum between D and E, the field extending from about C on one side to above F on the other. At the moment when totality began, the field was filled with bright lines, which came into brightness, not instantaneously, but brightening perhaps half a second, remained steady nearly a second and then faded out and disappeared, not all together but successively, most of them being lost within two seconds of their first appearance, while some lasted three or even four seconds. After this there remained bright in the field C, D_3, 1474 and F. No lines could be seen between D_3 and 1474. I immediately began to work the tangent screw to bring down the ultra violet into the field, and while I was doing so, my son accidentally let the image of the corona get off from the slit, and as it moved off I noticed the persistency of 1474 still visible in the edge of the field to a distance of at least ten minutes from the limb. F disappeared at a distance not much more than five minutes. There was a little difficulty in repointing the instrument, as the *slit* could not be easily seen, though the image of the corona was fairly bright. While my son was bringing things to place I looked at the eclipse for perhaps ten seconds and saw the *polar* streamers of the corona, but did not notice the equatorial ones and was surprised at not seeing them. I also noticed a quivering of the air along the telescope tube. The corona seemed to me much less brilliant, but not less extensive than in 1869 and 1870. Applying my eye again to the eyepiece I worked up as rapidly as possible into the ultra violet, and tried every device I could think of to find lines there, but without success, though there was a faint continuous spectrum. In a few seconds the totality ended, its termination being heralded by the reversal of the two H (calcium) lines as the image of the prominences and chromosphere fell upon the slit. I had never been able to see this before since my first observations of the same thing in 1872, at Sherman. I saw no other lines reverse at close of totality.

The observations were greatly facilitated by the count of seconds which was kept up with perfect steadiness and accuracy

by Mr. W. H. Pierce, of Denver, who kindly volunteered to assist us in this way. Starting his stop watch at a signal given by Professor Rockwood, he beat once in two seconds with a small hammer upon an anvil so as to be distinctly heard through the whole ground, and called out every tenth second. Thus every observer knew precisely how much time remained at his disposal. With the single prism integrating spectroscope, Mr. Bennet saw at the beginning of totality, for three or four seconds F and 1474, and these only—he could not see C—why, I cannot imagine, but with nearly the same instrument Mr. Abbay had a similar experience in Spain in 1870. During totality the continuous spectrum was too faint to show the spider lines. Four seconds before the end of totality 1474 "shot out" again, followed by the bluish green line, which was seen to change into the dark line F. F was much brighter and broader than 1474. No dark lines could be seen, nor indeed lines of any kind except the two named, and that only for a few seconds at beginning and end of totality.

With the six-prism Grubb spectroscope, Mr. Smith could see absolutely nothing.

Slitless spectroscopes.—Professor Brackett reports his observation as follows: "About thirty-five seconds of the totality had passed when I had put my plates in their places and waited for quiescence and exposed them. My eye of course was in its most sensitive condition as I had just left the dark room. The first thing I did, therefore, was to take a large direct vision prism having neither slit nor telescope, and look for rings. I saw none but did see clearly the following that were very clear and distinct. A line in the red, one in the yellow, one in the green and a fourth in the violet [? blue]. All these lines were clear and sharp as long as I continued to look, perhaps ten or fifteen seconds. They were not to be seen at any considerable distance from the moon, and only along its eastern limb, extending over an arc of about 120°." Of course the lines seen were C, D_3, 1474, and F. Professor Rockwood used the binocular instrument described previously. I give his interesting report in his own words and in full. "As totality approached I went to the binocular and by help of a dark glass watched the spectrum of the sun's crescent seen there, having placed the instrument so that the plane of dispersion of the prisms was perpendicular to the line of the cusps. I had previously focussed the telescopes carefully upon the distant mountains, and during totality this focus was not changed. Some considerable time (probably eight or ten minutes) before totality I was able to see the prominent dark Fraunhofer lines. The number of these increased until just before totality, when the crescent was very narrow. I had a bright continuous spectrum some ten minutes

wide, showing, as it seemed to me, the full solar spectrum with all its dark lines as when a slit is used. These lines were so sharp and distinct that I counted and noted five distinct dark lines between the two H's. At this time, and before, I noted also a bright band in the neighborhood of *h*, which may have been due to Hδ or may have been owing to the absorption of the dark glass I was using, a London smoke. When the light was sufficiently reduced, some fifteen seconds or so before totality, I discarded the dark glass, and moved my eye so as to see only the violet end of the spectrum and then followed it down toward the red, as fast as the fading brightness of the light would permit, until I was able to see the whole spectrum about covering the field of my instrument.

"At the commencement of totality I was thus watching the dark lines, when suddenly the sun's disk was entirely covered and I saw a number of *bright* crescents crossing the still visible continuous spectrum. They projected on both sides beyond the continuous spectrum, being certainly fifteen minutes and perhaps twenty minutes long. They showed upon them several prominences. I noted two small ones near the south limit and three larger near the north limb, the most northern one having a hook form. I failed to get note of *what* lines these crescents belonged to, but immediately afterward I put down from memory these—near B(?), C, D_3, 1474, F, (Hγ). On the appearance of these bright crescents I gave the word to Mr. Pierce to begin counting. I continued to watch them and the continuous spectrum, looking for the latter to break up into rings. The moon gradually covered the crescents, leaving still the tops of the prominences visible as bright points seen in several colors. When these points were almost covered I called "stop" to Mr. Pierce, and found afterward from his watch that two minutes twenty-eight and a quarter seconds had elapsed since I first saw them. But by this time the prominences on the western limb had begun to be uncovered, and in a few seconds the northern ones had joined in a long sierra, and then I had a new set of crescents in view. Of these I noted the following lines: near B, C, D_3, 1474, F, Hγ, H_1, H_2. These all showed clear and bright, and in addition there were four or five fainter ones between F and Hγ which I could not locate exactly. Those named did not differ much in brightness, and I *did not notice* but that the forms of the prominences were the same in all, still I cannot be positive about that.

"The spectrum of the corona during all of totality was continuous and tolerably bright. I saw no dark lines crossing it, but did not look particularly for them and should not expect to see them with my instrument. It did *not* show any *bright*

rings. I looked most carefully for them, expecting to see them. Once about the middle of totality I thought I saw traces of a ring about where 1474 ought to be, but a second look did not confirm the impression. The continuous spectrum seen during totality was somewhat wider than the moon's disk, but I cannot say how much, nor can I tell just when it assumed the greater width. Before totality it was quite narrow and the bright crescents projected on both sides beyond it. But I remember that in looking for the rings I expected them to be seen *upon* this spectrum and not to project beyond it. I did not take my eyes from the instrument during totality, my intention being to see these rings if there were any to see, and my first feeling when totality was over was one of failure because none had been visible."

Thermoscopic observations.—Mr. A. D. Anderson reports his observation with the thermospectroscope as follows: "As soon as the corona appeared the slit-tube (collimator) was pointed to it, the slit opened, the galvanometer balanced, and the lever which turns the grating moved so that the spectrum from the orange through the ultra-red traversed the face of the pile. When the extreme red was reached the lever was moved back to its original position. During totality the instrument was pointed four times to the corona, and four observations were made. The only result obtained was during the third observation when a decided deflection of the galvanometer index was noticed, in the direction indicating heat, from 54 to 57·5 on the scale, the index returning to its original position as the lever was moved past the point. A precisely similar and equal deflection occurred when the lever on the return stroke reached the same point." The position of the lever at the moment of the deflection was carefully marked, and after the eclipse it was found that a point in the spectrum of the *second order* just above G was upon the face of the pile. This would tend to indicate a heat line in the ultra-red with a wave length twice that of the coincident blue light. At the same time it must be admitted that the conclusion is doubtful, for, though it is not easy to explain what cause other than a coronal heat line could have produced the observed deflection, it is equally difficult to explain why the three other sweeps across the spectrum failed to show the same thing.

It is proper that I should here add that the American Academy of Sciences at Boston had placed at our disposal a considerable appropriation for this thermoscopic research; thanks, however, to the industry and ingenuity of Professor Brackett in constructing our apparatus, the generosity of Mr. Edison in giving us a tasimeter, the kindness of our railroad friends in the matter of passage and freights, and the liberal scale of the

original appropriation of the Green Trustees, it was not found necessary to draw upon this fund, though we are none the less grateful for its provision.

I need not occupy much space with a discussion of the photographic work. I think we failed in obtaining the desired results, simply because the lines we hoped to find in the ultra-violet did not exist there on this occasion, though it is of course certain that lenses of more light-gathering power would have increased our chances. That there was no fault with the chemicals and the manipulations is evident from the splendid success of Mr. Calley's pictures of the corona. In twenty-five seconds he obtained a far more extensive and better photograph than the same instrument gave in 1870 at Jerez with an exposure lasting through the whole totality, more than two minutes.

I ought not to close without a word of recognition of the courtesy and helpful kindness of our Denver friends. I do not know what they could have done that they did not, to aid us in our work and make our stay among them pleasant.

Princeton, September 6, 1878.