THE COMING TOTAL ECLIPSE OF THE SUN.

BY PROFESSOR SIMON NEWCOMB.

WHAT ASTRONOMERS HOPE TO LEARN FROM THIS ECLIPSE.—WHAT THEY HAVE LEARNED FROM PREVIOUS ECLIPSES.

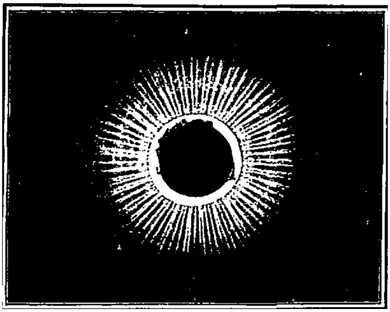
How an image of the sun may be thrown on a screen with a small telescope or a common spy-glass.

A TOTAL eclipse of the sun is one of the most impressive sights that nature offers to the eye of man. Such a sight will be witnessed by dwellers along a certain line in Louisiana, Mississippi, Georgia, and the Carolinas on the 28th of May. To see it to the best advantage, one should be in an elevated position commanding the largest possible view of the surrounding country, especially in the direction from which the shadow of the moon is to come. The first indication of anything unusual is to be seen, not on the earth or in the air, but on the disk of the sun. At the predicted moment, a little notch will be seen to form somewhere on the western edge of the sun's outline. It increases minute by minute, gradually eating away as it were the visible sun. No wonder that imperfectly civilized people, when they saw the great luminary thus diminishing in size, fancied that a dragon was devouring its substance.

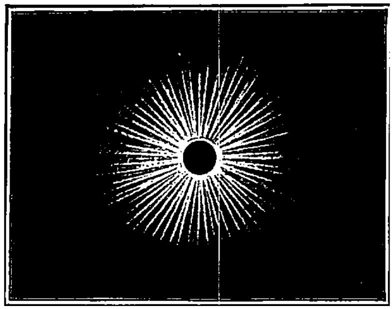
For some time, perhaps an hour, nothing will be noticed but the continued progress of the advancing moon. It will be interesting if, during this time, the observer is in the neighborhood of a tree that will permit the sun's rays to reach the ground through the small openings in its foliage. The little images of the sun which form here and there on the ground will then have the form of the partially eclipsed sun. Soon the latter appears as the new moon, only instead of increasing, the crescent form grows thinner minute by minute. Even then, so well has the eye accommodated itself to the diminishing light, there may be little noticeable darkness until the crescent has grown very thin. If the observer has a telescope with a dark glass for viewing the sun, he will now have an excellent opportunity of seeing the mountains on the moon. The unbroken limb of the sun will keep its usual soft and uniform outline. But the inside of the crescent, the edge of which is formed by the surface of the moon, will be rough and jagged in outline.

A few minutes before the last vestige of the sun is to disappear, the growing darkness will become very noticeable. It is a curious fact that the darkness does not seem to come on uniformly, but like a series of shadows, following each other at intervals of a few seconds. The cause of these seeming shadows has been the subject of some discussion; but there is reason to believe that they are an optical illusion, caused by the unequal rate at which the eye accommodates itself to the diminution of light.

A short time before the fading crescent is to disappear, the observer should look toward the point from which the shadow is to come—commonly not far from the west, say between southwest and northwest. If the air is quite clear, the shadow will first be seen on the distant horizon, advancing at the rate of a mile in every two, three, or four seconds, according to circumstances. The nearer the time is to noon, the slower will



Eclipse of June 24, 1778.



Eclipse of June 18, 1806.

VIEWS OF THE SOLAR CORONA DURING TOTAL ECLIPSES.

be the advance, and the more impressive the sight. On it comes. In a moment the spectator will be enveloped in it. The advancing mountains on the rugged surface of the moon have reached the sun's edge, and nothing is seen of the latter except a row of broken fragments or points of light, shining between the hollows on the lunar surface. They last but a second or two before they vanish.

Now is seen the glory of the spectacle. The sky is clear and the sun in mid-heaven, and yet no sun is visible. Where the latter ought to be, the densely black globe of the moon hangs, as it were, in mid-air. It is surrounded by an effulgence radiating a saintly glory. This is now known as the "corona." Though bright enough to the unaided vision, it is seen to the best advantage with a telescope of very low magnifying power. Even a common opera glass may suffice. With a telescope of high power only a portion of the corona is visible, and thus the finest part of the effect is lost. A common spy-glass, magnifying ten or twelve times, is better, so far as the splendor of the effect is concerned, than the largest telescope. Such an instrument will show, not only the corona itself, but the so-called "prominences"—fantastic cloud-like forms of rosy color rising here and there, seemingly from the dark body of the moon.

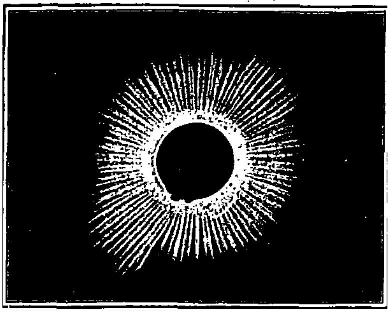
The darkness during the height of an eclipse is not so great as it is sometimes supposed to be. The sun still illuminates the atmosphere outside the region of the shadow, casting into the whole dark interior a "disastrous twilight," as Milton calls it, strong enough to enable the astronomer to read the time by his chronometer without difficulty. It may be likened to the actual twilight about half an hour after sunset.

Under any circumstances the observer will have but a short time to enjoy the scene. In a minute or two, perhaps three, four, or five minutes, according to circumstances, sunlight will be seen coming from the same direction as that from which the shadow advanced. A few seconds more, and it flashes upon the observer. The glory disappears in a moment, and, except for the partially eclipsed sun, nature assumes her usual aspect.

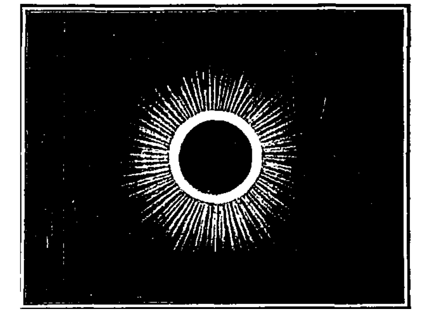
Much has been written about the effect of such an eclipse upon animals. Quite likely these descriptions have been exaggerated. But it has not always been thus in the case of men. Arago tells of a girl in the south of France who was tending cattle in the fields during the eclipse of 1842, which was total over the region in which she lived. Filled with alarm at the black object which had usurped the place of the sun, she ran forward crying. When light returned and the sun reappeared, she dried her tears with the exclamation, "Oh, beautiful sun!"

Of late years a powerful aid has been lent to astronomy by photography. With the sensitive chemicals now used in the photographic art it is possible to photograph celestial objects which are invisible to the eye. Millions of stars are now being charted in the sky, and thousands of faint nebulæ discovered, which the human eye would never have seen, even when aided by the most powerful telescope. Now it is hoped that our astronomers will apply some method of photographing the sky around the sun during the coming eclipse. If there is any object or any group of objects there of which the attraction would produce any effect, we hope that it may be discovered.

The eclipse will in some of these particulars be fortunate and in others unfortunate. It is rare indeed that such a phenomenon occurs in a climate where there is so little cloud as in the region of Georgia and North



Eclipse of July 8, 1842.



Eclipse of July 28, 1851.

VIEWS OF THE SOLAR CORONA DURING TOTAL ECLIPSES.

Carolina, over which the shadow of the moon will pass. On the other hand, the duration of totality is very short, little more than a minute near New Orleans, and less than a minute and a half in North Carolina. This compares very unfavorably with the six-minute duration of the eclipses of 1868 and 1883. But we may rest assured that our astronomers will make the best use of the brief moments at their disposal; and if anything is to be learned, they will undoubtedly find it out.

Eclipses of the sun are of such general interest to the public, as well as to the astronomer, that the reader will perhaps not be wearied if I say something more about them. A sort of dramatic interest is given to them by the fact, so familiar to all of us, that the sun and moon are almost exactly of the same apparent size. Each of these bodies is at certain times a little nearer to us than at others. When the moon is nearest to us, it seems a little larger than the sun, and when farthest away, a little smaller. It makes all the difference in the world in the character of an eclipse which of these two is the case. In the first case, the moon will entirely hide the sun; in the second it cannot.

To see to the best advantage what will happen, the observer on the earth must choose such a place that the center of the moon will pass exactly over the center of the sun. What he then sees is called a central eclipse. If the moon is a little larger in apparent size, it hides the sun, and the eclipse is total. But if it is smaller, the extreme edge of the sun will be seen all around the dark edge of the moon, forming a ring of sunlight. The eclipse is then annular. Such an eclipse does not offer the same advantage in the study of the sun that a total one does, and is therefore of less scientific interest. But it must be very instructive to any one who has the opportunity to see it. On the average the apparent size of the moon is smaller than that of the sun, so that annular eclipses occur a little oftener than total ones. In 1865 an annular eclipse was visible in the Southern States, and another will pass through the Gulf of Mexico and across Florida on June 28, 1908. During the latter the sun will be almost covered.

It is remarkable that, though the ancients were familiar with the fact of eclipses, and the more enlightened of them perfectly understood their causes, some even the laws of their recurrence, there are very few actual accounts of these phenomena in the writings of the ancient historians. The old Chinese annals now and then record the fact that an eclipse of the sun occurred at a certain time in some province or near some city of the Empire. But no particulars are given. Quite recently the Assyriologists have deciphered from ancient tablets a statement that an eclipse of the sun was seen at Nineveh, B.C. 763, June 15th. Our astronomical tables show that there actually was a total eclipse of the sun on this day, during which the shadow passed 100 miles or so north of Nineveh.

Perhaps the most celebrated of the ancient eclipses, and the one that has given rise to most discussion, is that known as the eclipse of Thales. Its principal historical basis is a statement of Herodotus, that in a battle between the Lydians and the Medes the day was suddenly turned into night. The armies thereupon ceased battle and were more eager to come to terms of peace with each other. It is added that Thales, the Milesian, had predicted to the Ionians this change of day, even the very year in which it should occur.

An eclipse of which we have a very explicit statement in the writings of the ancients is now generally known as the eclipse of Agothocles. Agothocles was tyrant of Syracuse, and was long engaged in war with the Carthaginians. In B.C. 310, the latter were blockading his fleet, of which he was in personal command, in the harbor of his own town. He availed himself of a momentary relaxation in the blockade to sail away for the Carthaginian territory. The second day of his voyage, which lasted six days and nights in all, he saw a total eclipse of the sun. This observation would have been of great use to the astronomers of our time in correcting their tables, were they sure of the locality of Agothocles at the time he made it. But it has been an open question whether he sailed directly toward the south or went toward the north, making the circuit of the whole Island of Sicily. The result would be quite different in the two cases. The probability now seems to be that he passed to the north, and this accords with the conclusions from our most recent investigations on the motion of the moon.

In modern times, since it became possible to predict the path of an eclipse along the earth's surface, and the time at which it would begin and end at any given place, the principal interest which astronomers at first took in the phenomenon grew out of the test which it afforded of the tables of the moon's motion. In 1715, the shadow of the moon passed over the western and southeastern parts of England, including London in its range. Halley, who had just been made astronomer royal, planned a more extended and careful series of observations on this eclipse than had ever before been made. Men in various towns near the edge of the shadow noted carefully whether the sun was totally eclipsed or not, and where it was, how long the total phase lasted. In this way it became possible to lay down on a map, from observations, the limits of the moon's shadow without an error of more than two or three miles. The times of beginning and end of the total phase were also carefully noted in London and its immediate neighborhood.

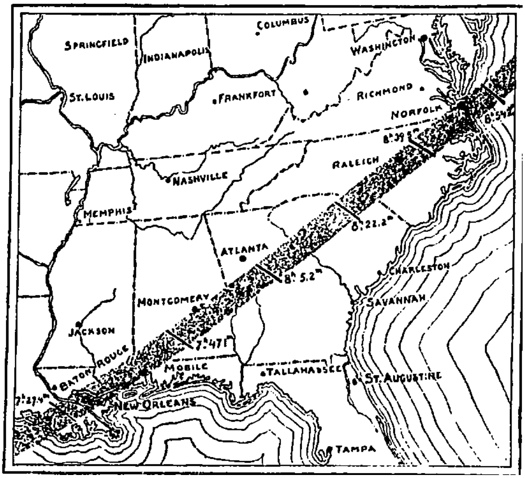
The French astronomers had a different method of observation, which could be equally well applied whether an eclipse was total or not. They did what any of us can do with the aid of a spy-glass: they pointed a telescope at the sun, and then, instead of looking into the telescope, held a screen at some little distance behind it, on which an image of the sun was thrown. By looking at this image the progress of the eclipse could be noted more easily than by looking at the sun itself, because no dark glass was necessary and the observer could sit down and watch the affair at his leisure. The diameter of the sun on the screen was marked off into twelve digits, and the time by the clock at which the sun was eclipsed one, two, or three digits, and so on could be recorded.

It was not until after the beginning of the nineteenth century that men began to avail themselves of total eclipses to make observations of the sun's surroundings, with a view of throwing light upon the question of the physical constitution of our great luminary. The corona and the prominences had been observed since the seventeenth century, and drawings and descriptions of the appearances made; but it does not seem to have occurred to any one that questions respecting the nature or cause of these objects could be answered. Even now the reader may inquire how it is that we can learn anything about the sun by hiding him from our sight, and, if we can, why a chimney would not answer the purpose as well as the moon. The answer is not far to seek. In the daytime the whole air around the sun is so brightly illuminated that it is impossible to see anything in the immediate neighborhood of that body. We may cut off the sunlight from our eyes by a chimney, but we cannot cut off the illumination of the air except by an object far above the air. The size and distance of the moon are such that it cuts off a great deal of light for hundreds of miles around us, and enables us to see the region close around the sun through an almost dark sky.

Even when curiosity as to the corona and prominences began to be aroused, it was long before any answers to questions about them were apparent. Any one could look into a telescope, describe what he saw, and, if a good draughtsman, make a picture of the scene. But what could he learn from such a picture? So much in the dark were even the most advanced astronomers on the subject up to the middle of the nineteenth century, that it was not established whether the corona belonged to the sun or to the moon. If, as might be the case, the latter was surrounded by a very rare atmosphere, even one so rare that we could not see it on ordinary occasions, its bright illumination by the rays of the sun might show as a corona around the moon. In 1851 a total eclipse was visible in Northern Europe, which enabled the question of the whereabouts of the red prominences to be settled. It was found that, as the moon traveled along over the sun, she traveled over the prominences also, advancing on those in front, uncovering those behind. This showed that these objects certainly belonged to the sun and not to the moon. The same would probably be true of the corona, but in this case it was difficult to reach so positive a conclusion.

About 1863–64 the spectroscope began to be applied to researches on the heavenly bodies. Mr. (now Sir William) Huggins, of London, was a pioneer in observing the spectra of the stars and nebulæ. For several years it did not seem that much was to be learned in this way about the sun. The year 1868 at length arrived. On August 18th there was to be a remarkable total eclipse of the sun, visible in India. The shadow was 140 miles broad; the duration of the total phase was more than six minutes. The French sent Mr. Janssen, one of their leading spectroscopists, to observe the eclipse in India and see what he could find out. Wonderful was his report. The red prominences which had perplexed scientists for two centuries were found to be immense masses of glowing hydrogen, rising here and there from various parts of the sun, of a size compared with which our earth was a mere speck. This was not all. After the sunlight reappeared, Janssen began to watch these objects in his spectroscope. He followed them as more and more of the sun came out, and continued to see them after the eclipse was over. They could be observed at any time when the air was sufficiently clear and the sun high in the sky.

By a singular coincidence this same discovery was made independently in London without any eclipse. Mr. J. Norman Lockyer was then rising into prominence as an enthusiastic worker with the spectroscope. It occurred independently to him and to Mr. Huggins that the heat in the neighborhood of the sun was so intense that any matter that existed there would probably take the form of a gas shining by its own light. The spectrum of such a gas is composed of bright lines, which are but little enfeebled to whatever extent the spectrum as a whole may be spread out by the prism through which it passes. But the sun's light reflected from the air is more and more enfeebled the more it is spread out. Consequently, if a spectroscope of sufficient power were directed at the sun just outside its border, the brilliancy of the light reflected from the air might be so diminished that the bright lines from the gases surrounding the sun would be seen. It was anticipated that thus the prominences would be made visible. Both of the investigators we have mentioned endeavored to get a sight of the prominences in this way; but it was not until October 20th, two months after the Indian eclipse, that Mr. Lockyer succeeded in having an instrument of sufficient power completed. Then, at the first opportunity, he found that he could see the prominences without an eclipse!



MAP SHOWING THE PATH OF THE COMING ECLIPSE (MAY 28, 1900), WITH THE EXACT TIME IN THE MORNING AT WHICH THE ECLIPSE WILL OCCUR AT VARIOUS POINTS DESIGNATED.

At that time communication with India was by mail, so that for the news of Mr. Janssen's discovery astronomers had to wait until a ship arrived. By a singular coincidence his report and Mr. Lockyer's communication announcing his own discovery reached the French Academy of Sciences at the same meeting. This eminent body, with pardonable enthusiasm, caused a medal to be struck in commemoration of the new method of research, in which the profiles of Lockyer and Janssen appeared together as co-discoverers. Since that time the prominences are regularly mapped out from day to day by spectroscopic observers in various parts of the world.

Up to the present time the question of the corona is an unsettled one. There appears to be some yet unsolved mystery enveloping its origin. Everything about it shows that it cannot be an atmosphere of the sun, as was once supposed. Were such the case, it would, unless composed of some substance vastly lighter than hydrogen, be drawn down to the sun's surface by the powerful attraction of that body. It could not rise hundreds of thousands of miles from the sun, as the corona does; and even if it did, its light would be smooth and uniform, whereas the coronal light has a sort of hairy or fibrous structure. This may be seen on most of the good photographs of the corona.

Professor F. H. Bigelow has noticed a remarkable resemblance between these seeming fibers and the curves which iron filings scattered over paper assume when we place a magnet under the paper. He has thus formed a theory of the corona based on some action of the sun akin to magnetism. The coincidence between the results of this theory and the general figure of the corona, especially the direction of the fibers, is, to say the least, very curious. Some sort of polarization in the direction of the sun's axis seems to be clearly indicated. But we have here no explanation as to how the matter forming the corona is kept from falling into the sun by the powerful attraction of gravity, which is there twenty-seven times what it is on the earth. Quite likely this is brought about by some form of electrical or other repulsion, similar to that which is seen to act in the tail of a comet.

Another mystery is the nature of the long streamers, sometimes extending far beyond the outer parts of the corona. Some analogy has been suspected between these and the streamers of the aurora. The view has thus arisen that the corona may be an aurora around the sun. More observations and studies must be made, both upon the aurora and the phenomena of terrestrial magnetism, before we can reach any decided conclusion on this question.

The composite nature of the spectrum of the corona shows that the substance which forms it is not all in the same state. Most of the light which it emits gives an unbroken spectrum, seemingly without dark lines. This shows that it emanates partly from hot particles, and not wholly from diffusing gases. It is likely that this matter shines partly by its own light and partly by the reflected light of the sun. But there are also bright lines in the spectrum, one of which has particularly attracted the attention of investigators ever since its discovery in 1869. It seems to be emitted by some gas not known to exist upon the surface of the earth, and to which the name *coronium* has been given. It is interesting to remark in this connection that the solar spectrum shows at least one other substance in the sun which was formerly not known to exist on the earth, and which was therefore called *helium*. But, only a few years ago, this substance was found in clevite, a somewhat rare mineral of Norway. Possibly we may yet discover coronium somewhere on the earth.

We may consider it as certain that the corona, considered as a mass of matter, is a very flimsy affair. When we recall that its extent is to be measured by hundreds of thousands, nay, millions of miles, and that it surrounds a globe of more than a hundred times the diameter of the earth, and therefore having more than ten thousand times the earth's surface, we might think of it as a very massive structure. But we should be deceived. A few quarts of water condensed in the air will make a very respectable-looking fog or cloud. Such a cloud in the immediate neighborhood of the sun would shine with a hundred thousand times the light which any terrestial cloud ever shone with in the brightest rays of the sun. Quite likely, if we should surround the earth with a corona like that of the sun, we should never be able to see it, or to detect its existence in the air or above the air, by any research we could make. But an observer on the moon would see it plainly. It would be the same with the tail of a comet, which is so tenuous that we can see a small star through a million miles of its thickness. Fifty miles' thickness would not suffice to make it visible in the brightest rays of the sun.

Perhaps the most interesting object which the spectroscopists have examined during total eclipses is known as the "reversing layer." This was first discovered by Professor Young, during the eclipse of 1870, which he observed in Spain. He was noticing the changes in the appearance of the spectrum given by the sun's light when the moon was nearly cutting it off. At the very last moment, when no part of the sun was visible except its extreme edge, the dark lines of the spectrum were changed to bright ones. As the last ray disappeared, all the bright lines of the spectrum flashed out. This showed that the substances which compose the sun exist at its immediate surface as a layer of glowing gases, all substances being vaporized by the fervent heat which there prevails. This heat is more intense than anything we can produce by terrestrial means.

The questions that relate to the sun are not the only ones that total eclipses enable the astronomer to attack. Such of our readers as have specially interested themselves in celestial science are doubtless aware that the motion of the planet Mercury shows a minute deviation which might be produced by the attraction of a planet, or group of planets, between it and the sun. This deviation was first discovered by Le Verrier, celebrated as having computed the position of Neptune before it had ever been recognized in the telescope. His announcement set people to looking for the supposed planet. About 1860, a Dr. Lescarbault, a country physician of France who possessed a small telescope, thought he had seen this planet passing over the disk of the sun. But it was soon proved that he must have been mistaken. Another more experienced astronomer, who was looking at the sun on the same day, failed to see anything except an ordinary spot, which probably misled the physician-astronomer. Now, for forty years the sun has been carefully scrutinized and photographed from day to day at several stations without anything of the sort being seen.

Still, it is possible that little planets so minute as to escape detection in passing over the sun's disk may revolve in the region in question. If so, their light would be completely obscured by that of the sky, so that they might not ordinarily be visible. But there is still a chance that, during a total eclipse of the sun, when the light is cut off from the sky, they could be seen. Observers have, from time to time, looked for them during total eclipses. In one instance something of the sort was supposed to be found. During the eclipse of 1878, Professor Watson, of Ann Arbor, and Professor Lewis Swift, both able and experienced observers, thought that they had detected some such bodies. But critical examination left no doubt that what Watson saw was a pair of fixed stars which had always been in that place. How it was with the observations of Professor Swift has never been certainly ascertained, because he was not able to lay down the position with such certainty that positive conclusions could be drawn.

The Pickerings, of the Harvard observatory, have devised a special combination of four photographic telescopes, to take the region on each side of the sun during the total phase, and see whether any new objects are found on the negatives.

There is a curious law of recurrence of eclipses, which has been known from ancient times. It is based on the fact that the sun and moon return to nearly the same positions relative to the node and perigee of the moon's orbit after a period of 6,585 days, 8 hours, or 18 years and 12 days. Hence, eclipses of every sort repeat themselves at this interval. For example, the coming eclipse may be regarded as a repetition of those which occurred in the years 1846, 1864, and 1882. But when such an eclipse recurs, it is not visible in the same part of the earth, because of the excess of eight hours in the period. During this eight hours the earth performs one-third of a rotation on its axis, which brings a different part under the sun. Each eclipse is visible in a region about one-third of the way round the world, or 120° of longitude, west of where it occurred before. Only after three periods will the recurrence be near the same region. But in the meantime the moon's line of motion will have changed so that the path of its shadow will pass farther north or south.

A study of the eclipses of the series to which the present one belongs will illustrate the law in question. The first one that we need mention is that of 1846, April 25. The middle point of the shadow-path, that is, the point where the total phase occurred at noon, was then in the West Indies, among the Bahama Islands. This was the first eclipse of the series that was really total, and here it was total only near the middle of the path. The path passed from the Pacific Ocean over northern Mexico, touched the northern end of Cuba, and crossed the Atlantic Ocean to the African coast of the Mediterranean. The central point was in 25° north latitude.

The next recurrence was on May 6, 1864. The shadow swept over the Pacific Ocean, and the middle point of its path was in 32° north latitude. After the lapse of another period, the eclipse returned in 1882, May 17. The shadow swept across the great desert of Sahara, passed through Egypt and the continent of Asia, leaving the earth in the Pacific Ocean south of Japan. The middle point was now in 39° north latitude.

Next we have our present eclipse of May 28th. After passing from New Orleans over the Gulf States along the line shown on our map, the shadow will enter the Atlantic Ocean at Norfolk, cross over to the Spanish Peninsula, and pass along the Mediterranean into Northern Africa. The central point will be in the Atlantic Ocean, in 55° north latitude.

During the three periods of recurrence the changes in the respective positions of the sun and moon have been such as to throw the shade some seven degrees farther north at each recurrence, or about twenty degrees in all That is, it will now pass twenty degrees farther north than it passed in 1846.

The next period of 6,585 days will bring us to 1918, June 8. The shadow will then pass from near Japan over the northern part of the Pacific Ocean, strike our Pacific coast near the mouth of the Columbia River, and travel over the United States in a southeasterly direction, through Oregon, Idaho, southwest Wyoming, Colorado, Arkansas, and the Gulf States and Florida. Somewhere in Mississippi or Alabama it will cross the path of the present eclipse. At the point of crossing the inhabitants will have the pleasure of seeing two successive total eclipses of the series. Their fortune, however, will not be so remarkable as that of the inhabitants at a point in the Northwest who saw both of the total eclipses of 1869 and 1878.

The series will continue at the regular intervals we have mentioned until 2044, August 23, when the shadow will barely touch the earth in the region of the North Pole. After that it will skip our planet entirely.

There are two series of eclipses remarkable for the long duration of the total phase. To one of these the eclipse of 1868, already mentioned, belongs. This recurred in 1886, and will recur again in 1904. Unfortunately, at the first recurrence, the shadow was cast almost entirely on the Atlantic and Pacific oceans, so that it was not favorable for observation by astronomers. That of 1904, September 9, will be yet more unfortunate for us, because the shadow will pass only over the Pacific Ocean. Possibly, however, it may touch some island where observations may be made. The recurrence of 1922, September 21, will be visible in Northern Australia, where the duration of totality will be about four minutes.

To the other series belongs the eclipse of 1883. This will recur in 1901, on May 18th, when the moon's shadow will sweep from near Madagascar and cross the Indian Ocean, Sumatra, Borneo, and Papua. Unfortunately, this region is very cloudy, and however carefully the preparations for observations may be made, the astronomers will run a great risk of not seeing the eclipse. But hope springs eternal in the human breast; and it is not likely that observers will be deterred from an heroic attempt by any threats of the weather.

At the successive recurrences the duration of totality will be longer and longer through the twentieth century. In 1937, 1955, and 1973 it will exceed seven minutes, so that as far as duration is concerned our successors will have a more remarkable opportunity than their ancestors have enjoyed for many centuries.

The question may arise as to the degree of precision with which the path of an eclipse can be predicted by the astronomer. It is sometimes supposed that he can determine a hundred years in advance, and to the exact second, when such a phenomenon will begin or end. This is a great exaggeration of his powers. One entertaining such an idea may have a very high opinion of the power of modern mathematics, but he has no conception of the difficulties of the problem of the moon's motion. The pull which the sun exerts on the earth and moon by its gravitation second after second, minute after minute, hour after hour, day after day, and year after year must be known, and its effect continually added up by a mathematic method of which man had no conception until the time of Leibnitz and Newton. The changes in the positions of the two bodies caused by the pull of the sun continually changes the action of that pull, because, as one will readily see, the latter depends upon the relative positions, while the positions are continually changed by the pull. This is what makes the problem so complicated.

If we had only the sun to deal with, we might hope to get along. But the planets, especially Venus, come in, and insist on having their little pull also. Before their action was found out, there were some deviations in the motion of the moon which are now attributed to the action of Venus. To compute this action is the most complex problem which the mathematical astronomer has to deal with, and he has not yet succeeded in solving it to his satisfaction. And when he has solved it, he is by no means at the end of his trouble. There are several indications that the rotation of the earth slowly changes from time to time, our planet turning on its axis sometimes a little faster and sometimes a little slower. The change is, indeed, very slow; not more than two or three thousandths of a second in a day. But, if it takes to rotating faster even by this minute amount, it will get ahead of its calculated place by a second in a year and a minute in sixty years; and then the astronomer who fixes his point of observation so that he will be carried to exactly the center of the moon's shadow, according to calculations made sixty years before, may find himself out of the way by several miles.

What makes the matter difficult is that these changes in the earth's rotation cannot, so far as we have yet learnt, be exactly observed, or even predicted; they probably arise from changes in the position of ice around the North Pole, changes in ocean currents, and perhaps in the movement of the winds. The reason that they cannot be directly determined is that we cannot make any clock which will keep time year after year without the error of a second. The rotation of the earth on its axis affords the astronomer the only measure of time he can use in his work, and if it goes wrong, he is, for the time being, left at sea. But his motto to-day is always forward; he has not lost one particle of enthusiasm because his science has been progressing for 2,000 years. He will leave no device untried to learn everything that is to be learned about the motions of the earth and heavenly bodies, confident that if he must fail, his successors will carry on his work to perfection. If to-day he cannot tell his successors of the year 2000 when to expect an eclipse within one minute by the clock, he of the year 2000 may do it for his successor of 2100.