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IMPROVEMENT IN EQUATORIAL TELESCOPES.

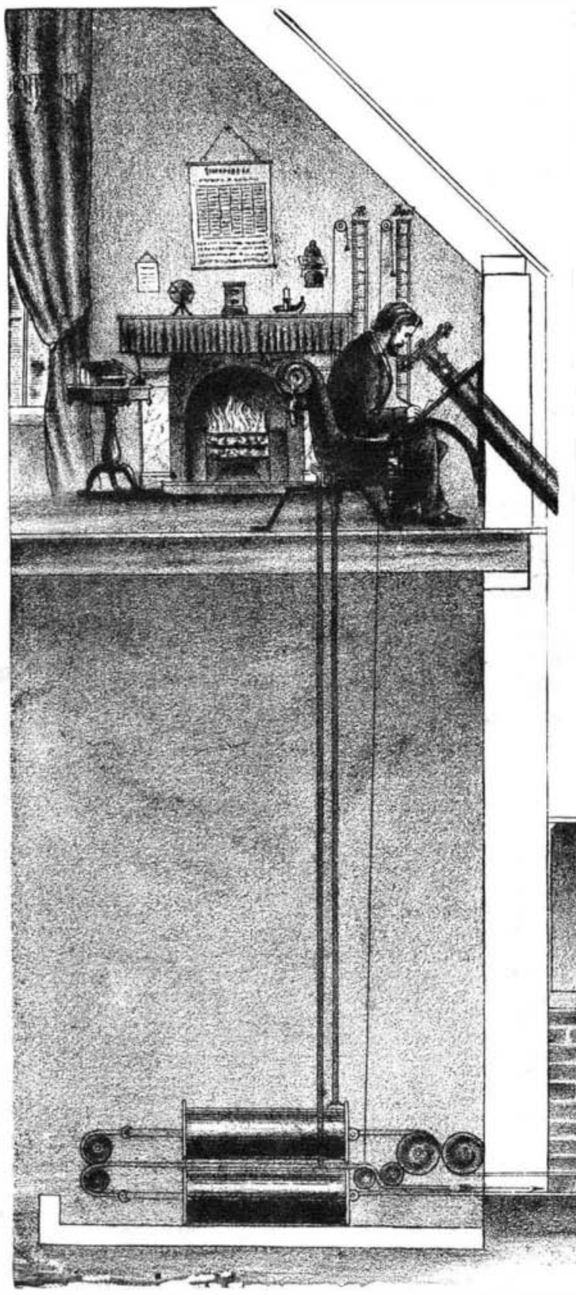
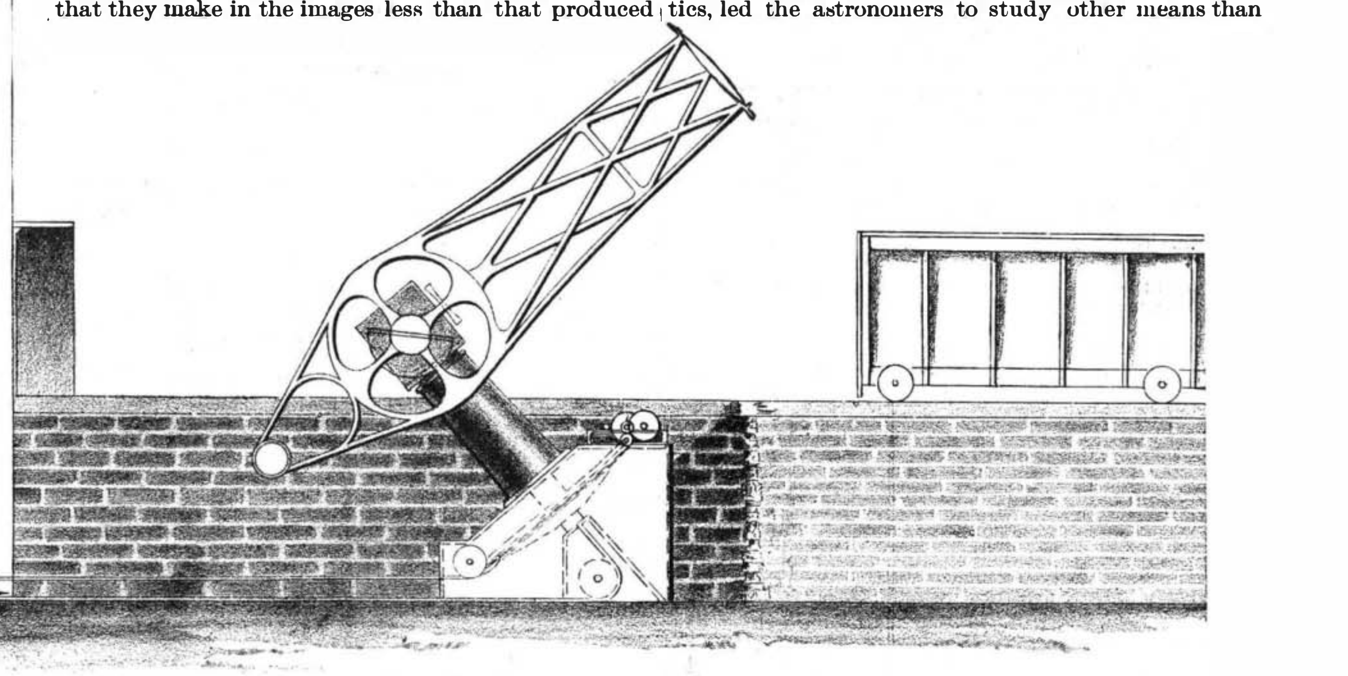
By virtue of the rotary motion of the earth, every direction about us that we imagine fixed has a continuous rotary motion around the line of the poles. The plane of the horizon, the vertical, the north-south and east-west directions, and all that pertains to the earth, revolve around the polar axis of our globe. It necessarily results from this that every direction that is really fixed must seem to move around this same line of the poles, and to describe a cone that has such line for its axis and the position of the observer for its apex.

All these troubles are increased when the diameter, and consequently the length, of the instrument is increased.

The inconveniences that depend upon the necessity of the observer's continually moving would be avoided by rendering the ocular fixed. Mr. Loewy, of the Paris observatory, appears to be the first who studied out the arrangement to give an equatorial with fixed ocular, and the instrument which he devised was described to the Paris Academy in a communication presented in 1871.

Mr. H. Grubb, of Dublin, has proposed another arrangement, which we figure herewith. The interrupted polar axis, which performs the office of ocular tube, enters the chamber of observation, and rests externally upon a masonry support. The objective tube is capable of making variable angles (90° in the figure) with the polar axis, so that, in a given position, the revolution of the latter shall describe a cone through the optical axis, and the latter thus remain constantly directed toward the star to be studied. The mirror carried by the cube which is placed at the elbows of the two tubes remains always perpendicular to the bisectrix of the angle formed by the tubes, so that the image always occupies a constant position with respect to the fixed ocular.

It is useless to dwell upon the advantages to be derived from such arrangements. The observer can control all the motions of the apparatus without scarcely moving, and the movable covering can be reduced to a shed which protects only the movable parts, and which can be removed before observations are begun. From an optical point of view, it may be feared that the use of mirrors will be accompanied with loss of light, and distortions due to a want of perfection in their surface, either through vicious construction or as a consequence of variations in temperature and position. It is even certain that such inconveniences must exist in the new system that we have described. An endeavor should evidently be made to reduce their effects as much as possible, and to render the alteration that they make in the images less than that produced by the necessary shortening of the telescope in the old system. The Loewy equatorial, which is but 10½ inches in diameter, appears to possess an optical power equal to that of the ordinary equatorial of the same diameter. It would be interesting to see what results would be obtained with a telescope of greater diameter and having a focal length really proportioned to its aperture.—*Ciel et Terre.*

IMPROVEMENT IN EQUATORIAL TELESCOPES.

This appearance of continual variability in the direction of the luminous rays of every star obliges us to employ special arrangements when we wish to keep a star in the field of an instrument.

The first solution of the problem is furnished by the ordinary equatorial—a telescope mounted perpendicularly to the radius of a circle parallel with the equator. When this instrument is moved around the radius in question, its optical axis describes a plane perpendicular to a line of the equator, and successively meets the parallels that each star describes. When, on the contrary, the telescope is fixed with respect to the radius, and the latter is moved in the equatorial plane, the optical axis of the instrument describes a surface of revolution which meets the celestial vault according to a parallel, and it is only necessary to regulate the rotary velocity of the radius in order to keep in sight a star that would describe the parallel in question. There are, then, really two axes in this instrument, the first of which is perpendicular to the equator, and the second movable in the equatorial plane.

This solution, which was known to the ancients, has been generally admitted up to the present. It presents certain inconveniences, however, as regards the stability of the apparatus and the conditions that it imposes upon the observer. In fact, the continual motion of the instrument necessitates corresponding movements of the observer, who has to place himself at variable heights upon a ladder whose position itself must be modified at every instant. Then there is the continual maneuvering of a cupola, whose openings must be kept in the direction of the object studied.

PROGRESS IN ASTRONOMICAL TELESCOPES.

By W. R. Warner, Member of the Civil Engineers' Club of Cleveland. Read January 13, 1885.

The history of the astronomical telescope dates back but two and three-quarter centuries, previous to which time no practical advance had been made in the science of astronomy for more than a thousand years. The credit for the invention has been claimed by the friends of three parties, Lipperhey and Jansen, of Holland, and Galileo, of Italy. No one claims that Galileo first discovered the principle of the refraction of light; but that he first applied it to an instrument for observing the stars there is no doubt.

In 1608, while in Venice, he learned that Jansen had, by a combination of pieces of curved glass, succeeded in making distant objects appear much nearer. He at once gave the subject his attention, and in a few months he had completed an instrument that magnified three times.

He then made other and larger ones, the largest of which magnified but thirty times, and was, of course, very imperfect; but with it he discovered the mountains in the moon, the satellites of Jupiter, the phases of Venus, and what seemed to him handles on the planet Saturn.

The Galilean telescope was very nearly the same as the modern opera-glass, being composed of one double convex lens and one double concave lens, placed as shown in Fig. 1, the light passing through both lenses before reaching a focus. The large lens is called the object glass, or objective, and the small one the eye-piece.

A difficulty was soon encountered, which, for a century and a half, prevented large and powerful refracting telescopes from being made. It was found that a ray of light, when refracted by the lens, was separated into all the colors of the rainbow. These were called prismatic colors, and they surrounded every object observed through Galileo's telescope. This is shown by the passage of a beam of light through a triangular prism, Fig. 2, or more plainly in its application to the telescope in Fig. 3, where the line at *a–b* is the axis of the lens, and *c–d* a parallel ray of white light, which, on passing through the lens, is refracted and separated into the prismatic colors, the red ray meeting the axis at *r*, and the violet ray, being most refracted, meeting the axis at *v*. This, as will be evident, gives a confused image of the star. This difficulty is called chromatic aberration, and it prevents an exact image of the star or object observed being made anywhere on the optical axis of the lens. From the fact that the chromatic aberration is the same in glasses of long and short focus, while the image of the star or object observed is proportionately larger in the former, the astronomers of the 17th century made their telescopes very long—in some cases the focus being over two hundred feet.

As the magnifying power of a telescope is found by dividing the focal length of the object glass by that of the eye-piece, it will be evident that in these long telescopes a low-power eye-piece would give a high magnifying power and reduce the chromatic aberration to a minimum.

The "color line," so marked in optics as well as politics, led the astronomers to study other means than lenses for getting a luminous image of distant bodies. It was discovered, we know not by whom, that parallel rays of light striking a parabolic mirror were reflected to a point at the focus, as in Fig. 4. Newton was the first to apply this principle practically to the astronomical telescope. He made the parabolic mirror of long focus, and intercepted the rays by a 45° mirror just before they came to a focus, thus bringing the image of the object outside the tube, where it is examined by the eye-piece, as in Fig. 5. This is called the Newtonian reflector.

Herschel tilted the parabolic mirror, as in Fig. 6, thus bringing the focus to the edge of the tube, where the eye-piece is applied.

The most convenient method, and that adopted for the great Melbourne reflector, is the Cassegranian system, where the cone of rays is intercepted before reaching a focus and reflected back through a hole in the center of the mirror, where it is examined by the eye-piece, as in Fig. 7. By this system the observer is near the ground when taking observations, while in the others some means must be provided for raising him in the air to the height of the top of the tube, which is a great inconvenience in large instruments.

Of the three systems of reflectors mentioned, the Newtonian is optically the best, while the Cassegranian is the most convenient to use.

As the rays of light are not separated into the prismatic colors by reflection, this system of telescopes was the most popular, and did the best work down to the middle of the 18th century, when Dolland, an English optician, discovered that prisms of hard flint-glass dispersed the rays of light twice as much as those made of crown-glass (see Figs. 8 and 9), while the angle of refraction remained the same in each. This principle furnished the key to the modern refracting telescope, for by combining prisms of crown and flint glass, as in Fig. 10, having the angle of the flint half that of the crown, their dispersive powers are the same, and the ray of white light *a–b* will pass through both prisms and come out a white ray, *c-d*, the flint prism having counteracted the chromatic effect of the crown; while, being but half the angle of the crown, it eliminated but half its refractive power.

This principle is applied to the telescope by making a double convex lens, *a b*, Fig. 11, of crown-glass, and just back of it place a plain convex lens of flint-glass, having half the curvature of the combined surfaces of the crown lens. The flint counteracts the chromatic effect of the crown lens, and the rays come to a focus at the same place. No exact rule can be given for the several curves for an object glass, for the refractive powers of glass made at different meltings varies greatly.

To determine the refractive powers of different pieces of glass, small prisms are made, and the indices of refraction found by trial. From these data the, proper proper curves are computed.

We stated that the chromatic effect of the crown and flint glass was eliminated by combining them.

This is not exactly true, for if we make prisms of flint and crown glass having equal dispersive powers, we shall find that they do not disperse the rays uniformly, for in the crown the red band is broadest, while in the flint the blue is broadest. The result is that when combined they cannot wholly counteract each other, and in large instruments more or less color is always seen about a bright star.

This color is called the secondary spectrum, and being in the nature of the glass itself, no skill in working the glass can wholly correct it.

During the past fifty years great improvements have been made, both in refractors and reflectors. The largest reflector ever made is that constructed about 1840 by Lord Rosse, at Parsonstown, Ireland. This monster instrument, called "The Leviathan," is fifty-four feet long and has a mirror of six feet diameter. It is not mounted equatorially, but has a movement of 10° each side the meridian.

The large reflectors following it are those at Melbourne and Paris, each of four feet diameter. Many smaller reflectors are mounted in England, while in our country there are but few, for refractors seem to be much preferred. The mirrors, or specula, of the early reflectors were made of a composition of 32 parts tin to 15 parts of copper. In 1859, Foucault, a French physicist, invented the silvered-glass speculum, which greatly increased the value of the reflecting telescope. A disk of common glass is accurately ground on one side to the proper parabolic curve, on which a coating of silver about $\frac{1}{200000}$ of an inch in thickness is chemically deposited. This silver film can be polished or renewed at any time without affecting the figure of the speculum. The glass speculum also keeps its shape, and figures much better than one of speculum metal.

The four-foot reflector of the Paris Observatory has a silvered glass speculum, it being the largest ever made.

In 1840, Merz & Mahler, the renowned opticians of Munich, made a refracting telescope of 15 inches aperture for the Royal Observatory at Pulkowa, Russia.

This was the wonder of its time, and, indeed, not until 1862 was a larger one made, and then by our own countrymen, Messrs. Alvan Clark & Sons, who made one of 18½ inches aperture for the Dearborn Observatory of Chicago. This has been followed by a refractor of 25 inches aperture, made by Cook & Sons, of York, England; our Washington telescope, of 26 inches aperture, made by the Clarks; also one of 26¼ aperture, for the McCormick Observatory, University of Virginia, and one of 23 inches aperture, for Halsted Observatory, Princeton, N. J., both by the Clarks; and one of 27 inches aperture, by Grubb, of Dublin, for the Imperial Observatory at Vienna; and last and largest, the 30-inch refractor, made by the Clarks, for the Royal Observatory at Pulkowa, Russia. This, however, will remain the largest but a short time, for one of the disks of glass is already cast for the 36-inch refractor for the Lick Observatory, now being built in California. The location of this observatory is said to be the finest in the world. It is just inside the coast range of mountains on Mt. Hamilton, 4,400 feet above the sea and about 50 miles southwest of San Francisco. When finished, the Lick Observatory will be the most complete of any in the world. Besides the 36-inch refractor, there will be several smaller ones; also meridian circles, transit instruments, and the great variety of instruments pertaining to astronomy. The question naturally arises, Is there any limit to the size and power of telescopes? And we can now answer yes, and say that probably the limit will be reached in the completion of the 36-inch Lick refractor, and has been reached in the Rosse reflector.

Of the two systems of telescopes, refractors and reflectors, each has its strong advocates, and each, doubtless, has advantages in certain kinds of work.

The lens of the refractor and the mirror of the reflector serve as light-gatherers, not as magnifiers. They give us a luminous image, and by the aid of the eye-piece, which serves as a microscope, we magnify that image. The perfection of the image, and the amount of light with which to examine it, give us the limit of magnifying power we can use in the eye-piece.

In a reflector, the light-gathering power is represented by the proportion of light reflected to the whole light that falls on its surface.

In a refractor, the light-gathering power is represented by the amount of light left after absorption by the glass and reflection from its several surfaces, in proportion to the whole light that falls on its surface.

This comparison will show that the light-gathering power of a unit of surface of a reflector is independent of its size, while in a refractor it diminishes as the size increases, on account of the extra absorption of light by the increased thickness of the glass. A limit, therefore, to the size of refractors will soon be reached, beyond which nothing would be gained by increasing the size. That limit is found to be between 34 and 36 inches.

The limit to the practical size of reflectors is met by the difficulty in keeping the mirror in proper figure and the unwieldy nature of the instrument. When we consider that the moderate size reflectors have surpassed the best work of the largest ones, we may feel sure that the practical limit has already been passed.

In comparing refractors with reflectors, we can say that the 26-inch refractor at Washington has shown the most difficult objects that have ever been seen.

The modern astronomical telescope, whether refracting or reflecting, is mounted equatorially, with the polar axes parallel to the axis of the earth, so that, wherever the instrument is pointed, a movement about this axis will follow the apparent diurnal motion of the star. The declination axis being at right angles to the polar axis enables the instrument to be pointed to any star in the heavens. Each axis carries a finely-graduated circle, from which is read the position of the star being observed.

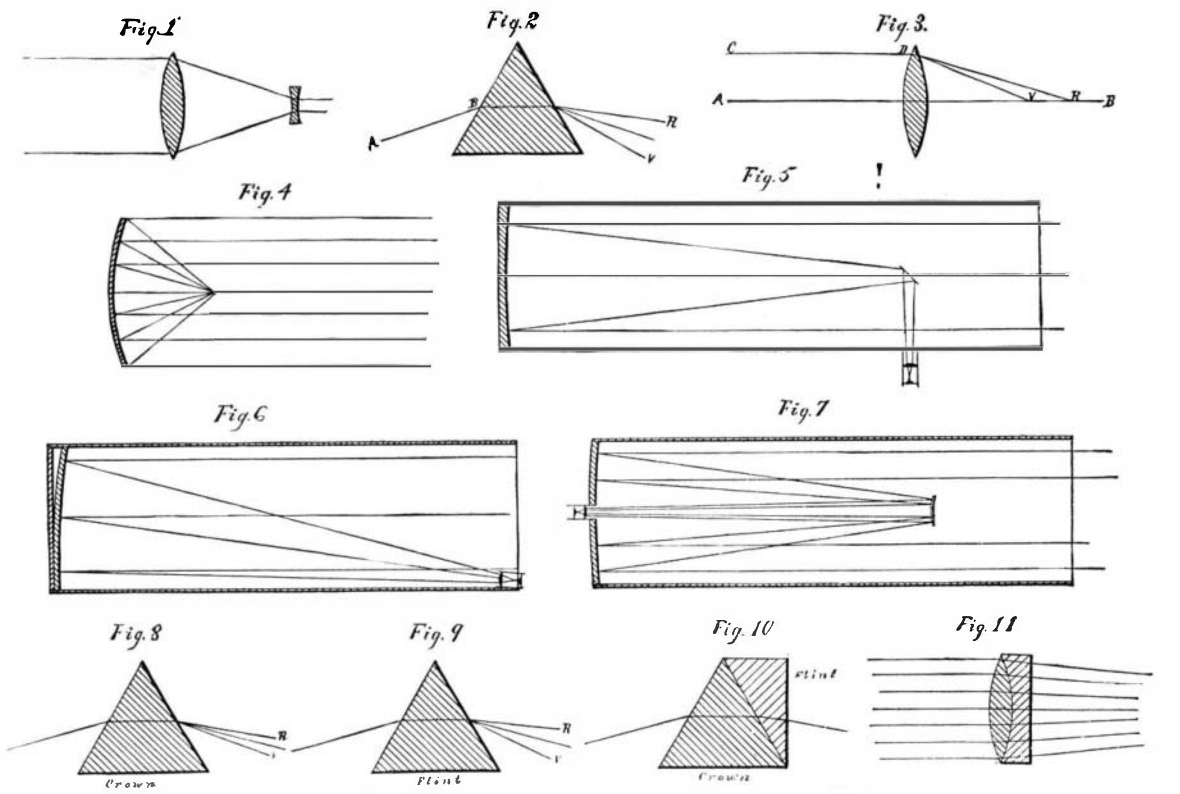
The tubes of telescopes were formerly made of wood.

240,000 miles, this would require a power of 6,000. Should the 26-inch refractor at Washington be provided with an eye-piece giving this power, the emergent pencil of light coming to the eye would be but $\frac{1}{230}$ of an inch in diameter, and the focal length of the eye-piece would be but $\frac{1}{16}$ of an inch.

Such a power would be manifestly absurd. A power of 100 to the inch of aperture is considered a maximum that can be used to advantage with the best glasses and under the most favorable circumstances, and it is seldom that more than 60 to the inch of aperture is used.

Professor Newcomb says: It is doubtful whether the moon has ever been seen with any telescope so well as it could be seen with the naked eye at a distance of 500 miles.

But a few years ago, only the largest universities



PROGRESS IN ASTRONOMICAL TELESCOPES.

The great Rosse 6-foot reflector has a wooden tube over 50 feet long, built up of staves and bound with iron. The Harvard College 15-inch refractor also has a tube of wood; but all large telescopes of recent date have tubes of sheet steel, which can be made very light and rigid.

The methods of reading the circles on large instruments have been so improved that, instead of climbing ladders with lantern in hand, the observer can sit at the eye end of his instruments and, by the aid of small telescopes fastened to the tube, and a series of prisms, can read the star's exact position, both in declination and right ascension.

Many systems of driving clocks have been devised to make the telescope automatically follow the star. The conical pendulum seems to be the most satisfactory regulator, and by its aid the image of the star can be kept in the center of the field even under the highest powers. In the most exact kind of work, like spectroscopic observations, where the variation of $\frac{1}{16}$ of a second would vitiate the result, the driving clock is often connected electrically with the standard clock of the observatory. Methods have been devised by which all the movements of large instruments may be made by the observer or his assistant, by simply pushing a series of buttons, which make electrical connection with power from a hydraulic or gas engine.

We often hear exaggerated statements as to the magnifying powers of large telescopes. When we consider that all imperfections of the instrument, as well as all the disturbances of the atmosphere, are magnified as much as the star, we see that we shall soon arrive at a limit beyond which we cannot pass and retain a clear view of the object.

A newspaper item went the rounds a few years ago, stating that the largest telescopes showed the moon as if it were but 40 miles distant. As its real distance is

could afford an astronomical observatory, and when, in 1843, Merz, of Munich, made a 15-inch refractor, a subscription was taken up by the citizens of Boston to purchase it and present it to Harvard College.

Until 1871 the largest telescope in the National Observatory at Washington was but 9½ in. aperture, but at the present time instruments of great power and excellence are in nearly every college of importance, and in many of the high schools of our country.

The interest, however, which has developed in the wonderful science of astronomy does not stop with the educational institutions, for many private observatories have been equipped, and their number is being multiplied every year.

The Chicago Astronomical Society was formed many years ago, and within the past month the "State Astronomical Society of Indiana" has been organized.

At the present rate of progress, the time is not far distant when every large city will have its astronomical society, as it now has its civil engineers' club, its attorney's club, and its literary circles.

Cleveland is well prepared for such a society; for she has her Case School of Applied Science, her Adelbert College, her many men of learning and culture, with such a leader as our honored member, whose nightly vigils in his observatory on Case Avenue have extended his fame even beyond the limits of our own country, and given scientific results of great value.

With these elements and such opportunities, let us look forward to the Cleveland Astronomical Society.—*Journal Ass. of Engineering Societies.*

THE MIGRATORY LOCUST.

In 1878, as well known, the English annexed the island of Cyprus to their immense colonial empire, and Queen Victoria ascended the throne of the Lusignans. This

Nymph. Adult. Adult: gray variety.

THE MIGRATORY LOCUST.