How the Great Paris Telescope was Built.

WHEN M. François Deloncle a few years ago proposed, as one of the *clous* for the Paris Exhibition, the construction of a telescope infinitely larger than any the world had yet seen, he did not foresee that if his project were carried out it would, in all probability, inaugurate a new era in our knowledge of the worlds by which we are surrounded, nor, certainly, did he realize all the difficulties in the way of its execution. Thanks, however, to the co-operation of three or four distinguished workers, these difficulties have, one by one, all been overcome, and the telescope now promises to be one of the chief attractions at the Paris Exhibition.

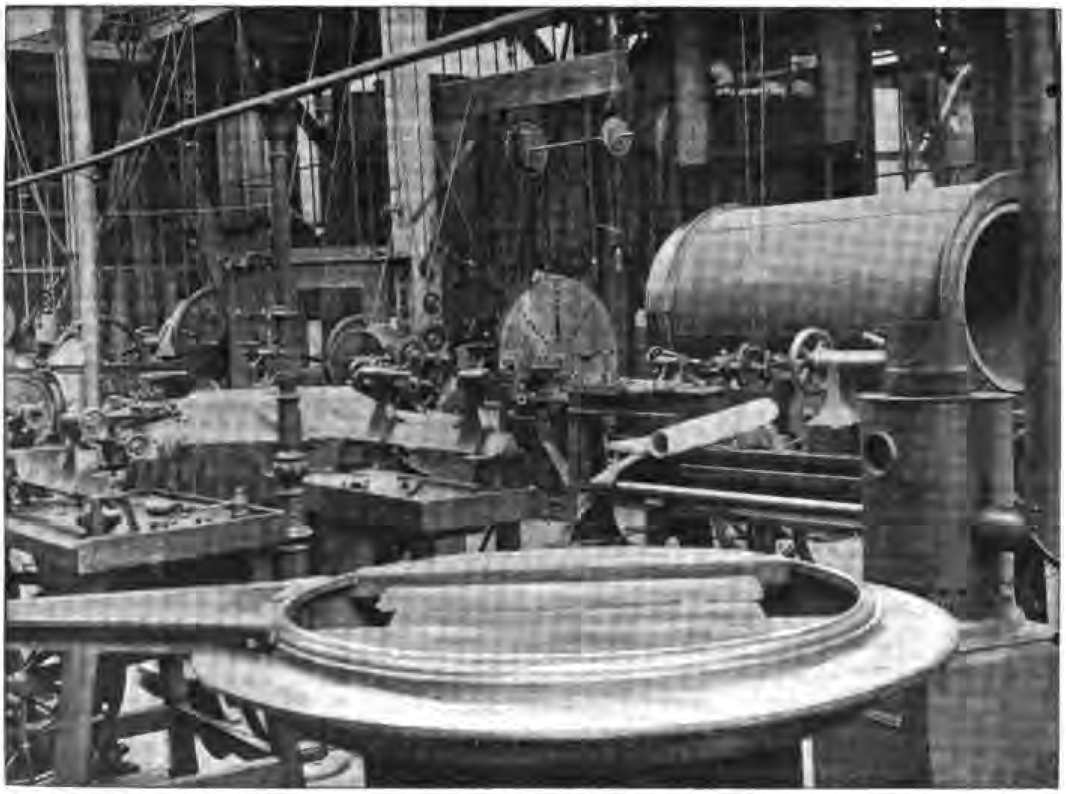
At first sight the layman has some pains in comprehending why, if it be possible to make a telescope 65ft. in length, like the instrument shown at the World's Fair at Chicago, there should be any insurmountable obstacle nowadays to the construction of an instrument double or triple, or even ten times, the size. "Surely," he says, "all that is necessary is to make a longer and wider tube, and have larger lenses!" There are, unfortunately, one or two important factors which militate against the practical realization of the problem thus simply expressed.

As far as the tube is concerned, it is, of course, in these days of Eiffel towers, and Brooklyn, Forth, and Tower bridges, mere child's play for the engineer to make a tube of almost any capacity; but to utilize this tube as a telescope, even supposing lenses of proportionate size were obtainable, is quite another matter. A telescope 2ft. or 3ft. in length can be held in the hand without any very great discomfort, as everyone is aware, and directed towards any distant object we may wish to examine. When, however, the telescope is 10ft., or 20ft., or 100ft. in length, and heavy in proportion, such a system of handling it is manifestly beyond our capacity, and the long tube has to be supported by some mechanical contrivance in such a manner that its direction may be changed at the will of the person using it. The telescope, too, must be under shelter of some kind. These are the two conditions which have produced the well-known hemispherical form of most observatories. The instrument, supported at its centre, is placed under a dome, in one side of which there is an opening from top to bottom. Towards this opening the telescope is pointed, being slung in such a manner that it may be made to cover any portion of the sky opposite the opening. In addition to this, the entire dome, including the platform on which the telescope is fixed, may be made to revolve bodily, so that all parts of the heavens may be successively brought under examination.

When the telescope exceeds a certain length, however, fresh difficulties present themselves. In the first place, a long tube supported at one point only is inclined to shake and vibrate in such a way as to render all exact observation out of the question; and, in the second place, the size of the dome must be increased proportionately to the length of the instrument. The longer the telescope, too, the quicker it has to be moved in order to follow the varying position of any celestial object that may be under observation. For these and other reasons it has hitherto been deemed impossible to make the telescope tubes as long as they might be to correspond with the power of the lenses with which they were supplied. The lenses, for instance, in the Chicago telescope measured 40in. in diameter, instead of 50in., the diameter of those made for the Paris telescope, yet the length of the tube was only 20 mètres instead of 60 mètres, exactly one-third!

To obtain the best results from any optical instrument it is clear that the proper focus must be used, and one of the first conditions decided upon for the Paris instrument was that it should be made as long as was compatible with the size of the lenses, which in their turn were the largest it was possible to construct. The length fixed upon was 60 mètres, and the work was intrusted to the experienced hands of M. Gautier, the constructor of so many famous instruments.

It was soon discovered, however, that the mechanical difficulties would be almost insurmountable. A dome to cover such an instrument would need to have a diameter of at least 210ft., and be high in proportion, while it would be next to impossible to insure the perfect stability of the instrument itself. To move so enormous a dome with facility it would be necessary to float it in some liquid, such as mercury, as has been done in the case of the dome of the Nice observatory. This course, too, has its inconvenient aspects, however. The Nice dome, a mere toy compared to the dome to cover a 60-mètre instrument, provokes vibrations often in turning that may be distinctly felt in the hill on which the observatory is erected, and still more so, naturally, in the delicately-poised telescope itself. When it is considered that even a telescope of 60 mètres is, compared to the incalculable distances it is called upon to explore, like an atom of the thread of a spider's web, it will be understood at once how the slightest vibration may cause it to deviate in such a way as to nullify the exertions of the most skilled astronomer. In addition to this, if the 60-mètre telescope were mounted in the ordinary way, the person using it would have to be constantly moving after the eye-piece at the rate of about a foot every minute. The idea of a revolving dome, therefore, was abandoned as impracticable, and the system of the siderostat, invented by Léon Foucault, nearly half a century ago, adopted in its place. With Foucault's siderostat, the telescope proper is fixed in a horizontal position, and instead of being pointed directly at the sky, is pointed at a mirror in which the sky is reflected. The observer, therefore, looks, not at the moon, for instance, directly, but at the image of the moon reflected in the mirror of the siderostat. The mirror itself, by an elaborate combination of levers and clockwork, moves automatically in all directions, so as to reflect almost every portion of the firmament. Meanwhile, the astronomer is comfortably seated in his arm-chair at the other end of the instrument making his observations.



GENERAL VIEW OF M. GAUTIER'S WORKSHOP—SHOWING VARIOUS PARTS OF THE TELESCOPE IN COURSE OF CONSTRUCTION.
From a Photograph.

Everything about the telescope and the siderostat constructed by M. Gautier is on a gigantic scale. The tube of the telescope is made of twenty-four separate sections, for all the world like the sections of a big city water

ON THE TOP OF THE SIDEROSTAT—M. GAUTIER EXPLAINING THE MECHANISM TO THE WRITER OF THE ARTICLE.
From a] *[Photo.*

main, the interior diameter of which is nearly 5ft. The total weight of the tube is over 21 tons. The framework of the siderostat weighs 45 tons, and attains a total height of 34½ft. The steel frame to hold the mirror weighs alone more than 3 tons, and when the mirror is in place, frame and glass together weigh nearly 7 tons, the weight of the glass being over 3½ tons. The portion of the siderostat on which the mirror and its frame are mounted floats in a bath of mercury in such a way that, though it weighs 17½ tons, an effort of only about 11lb. is required to make it revolve. In the eye-piece of the telescope an ingenious device has been elaborated by M. Gautier, by which any inconvenience that might result from the apparent movement of the stars, as reflected in the mirror, is adequately corrected. Such is a brief account of what may be termed the mechanism of the telescope.

The question of the mirror and the lenses is, it is evident, no less important. The former, which measures more than 6½ft. in diameter, is 10½in. thick, and weighs, as has been said, over 3½ tons. It was cast at the celebrated glass-works of Jeumont, in the North of France, under the personal supervision of M. Despret, the distinguished director of the establishment. For the operation a special furnace and oven had to be constructed, the latter capable of containing twenty tons of molten glass. It was only after a long series of experiments extending over several months that a satisfactory result was obtained. The great danger is that, in the process of cooling, which occupies about a month, the temperature being gradually lowered each day, the disc of glass will crack. Out of twenty discs cast, two only

A MOUNT TO HOLD ONE OF THE LENSES.
From a Photograph.


From a] THE BASE OF THE SIDEROSTAT. [*Photo.*

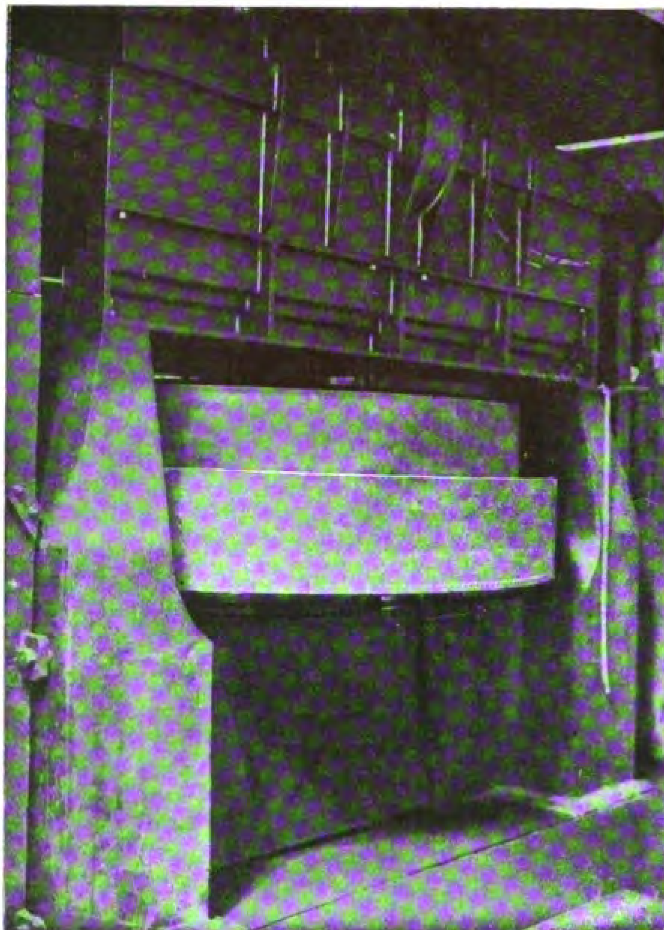
profession than anything else. M. Mantois, whose best previous performances were the 40in. lenses he cast for the Chicago telescope, worthily follows in the footsteps of the *verriers gentilshommes* of the reign of Louis XIV. At that epoch, the largest lenses the *verriers gentilshommes* could furnish the astronomers of the day with had a diameter of barely 6in., yet, even with so imperfect an equipment as this, many important discoveries were made. More than two centuries ago Cassini even went the length of constructing a sort of primitive telescope 70 mètres long, though it is true it had no tube. The lens he fixed at the top of a tower that he found fortunately ready to hand. To catch and follow a star through so tiny a disc of glass perched at the summit of a tower 165ft. in height can have been no easy task, and must have involved a series of gymnastic feats of which not all astronomers would be capable. The paths of the modern stargazers are smoother.

In the whole range of industry there is probably no more elaborate process than that of lens-making. The substances of which the glass is formed have to be boiled and melted and cooled over and over again, until the mass is absolutely free from every flaw. Only then can the actual casting of the lens be attempted with any hope of success. After the lapse of about three weeks or a month, to allow for the gradual cooling to take place, the mould is at last broken open, as often as not only to disclose the lens cracked in a score of places, the result of many months' anxious labour wasted! That this is not always the case, however, is sufficiently proved by the fact that M. Mantois has successfully cast all the lenses required for the telescope. They weigh considerably over half a ton apiece, and have cost more than £3,000 each.

The problems of the tube, the mirror, and the lenses being thus solved, it might be thought that all was henceforth plain sailing. An unexpected difficulty now arose, however, that for a long time appeared insuperable, and seemed likely to render the realization

turned out perfect. Exactly how many thousand pounds each of them is worth it is difficult to say, since they are the only two of their species in the world. The glass to be used in the siderostat was conveyed from Jeumont to M. Gautier's Paris workshop with the most extraordinary precautions. A special train was chartered to run during the night, at a time when the line was clear and the journey might be made without a single stoppage *en route.* The engine-driver was instructed to maintain as far as possible a uniform rate of speed all the time. On arrival in the capital, the glass was transferred from the train to the cart, and then to M. Gautier, surrounded by more guards than if a prisoner of State had been in question.

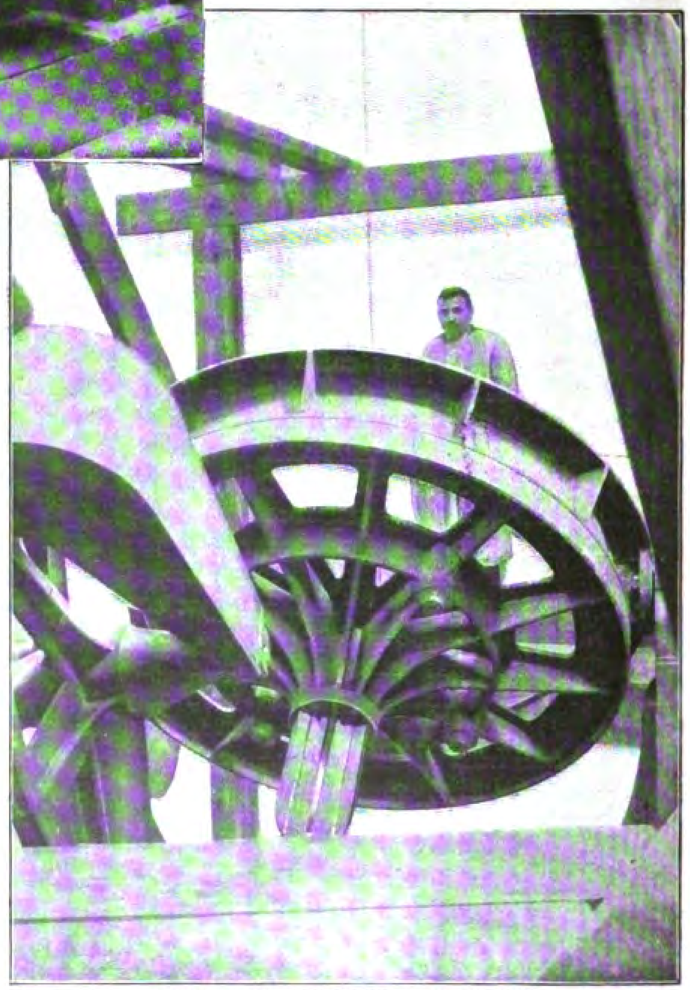
The lenses, 50in. in diameter, were cast by M. Mantois, who occupies the proud position of being the only maker of large lenses, not merely in France but in the whole world. The manufacture of lenses has always been looked upon in France more in the light of a



THE MIRROR IN PROCESS OF POLISHING.
From a Photograph.

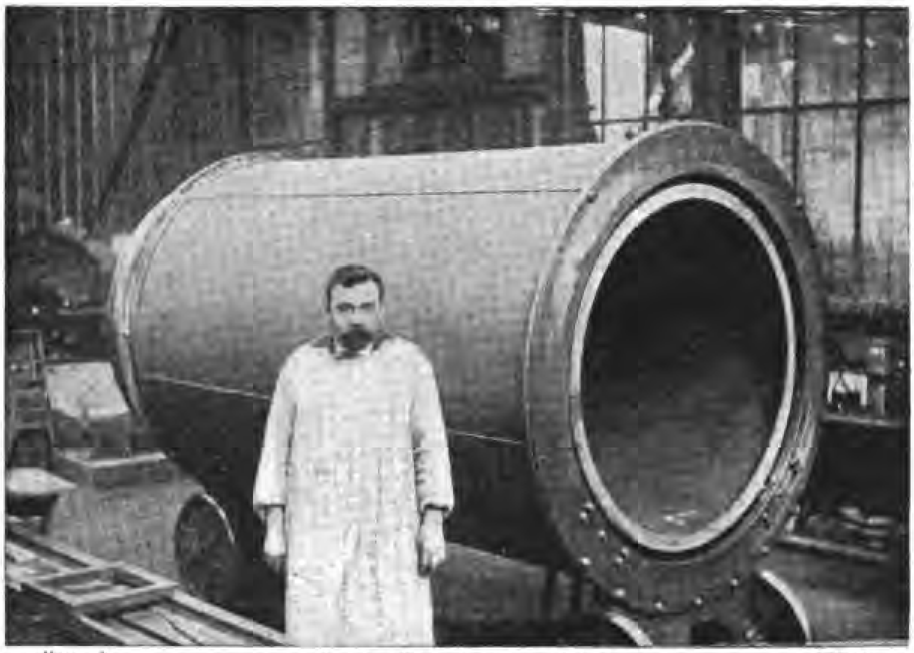
of the telescope impossible after all. Mirrors and lenses for optical purposes have not only to be cast, they have to be polished as well. A workman sufficiently skilled to polish large optical lenses is worth almost his weight in gold. There are probably not more than a score or two of really perfect operators in the two hemispheres. The slightest inequality in the surface of the glass—if, for example, it is the twenty-thousandth part of an inch thicker at one part than at another—robs it of all value, being sufficient to distort the image reflected in it out of all recognition, and especially would this be the case with such a powerful instrument as a 60-mètre telescope.

Ever since the first glass for optical purposes was made it has been accepted as an axiom that the polishing could only be efficiently performed by the human hand. When it was noised abroad, however, that there was a glass of 6½ft. in diameter to smooth down and polish perfectly flat and level, the doughtiest champions among the polishers paled and stood aghast. The existence of the telescope seemed again in jeopardy, when M. Gautier came forward with a proposition he had been revolving in his mind for years past. "Why not polish and grind down the surface of the glass by machinery?" he asked. The polishers scouted the idea as utterly ridiculous. According to them, the human hand, and the human hand alone, was sensitive enough for such work; but a glass with a surface two mètres in diameter was beyond even the most sensitive hand to attempt. M. Gautier persisted, therefore, and has triumphantly vindicated the superiority of machine over hand labour, though



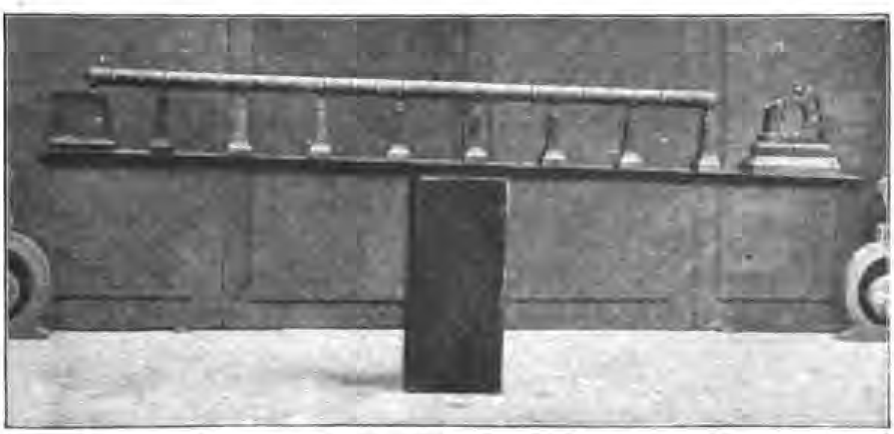
STEEL FRAME FOR HOLDING THE MIRROR.
From a Photograph.

at cost of what efforts it would be too long to set down here at length. It is enough to say that he had to construct special workshops and invent special machines, modifying the latter as the experiment pro-


From a] THE EYE-PIECE OF THE TELESCOPE. [Photo.

ceeded. One of the greatest obstacles to be overcome was to counteract the heating of the glass by friction during the polishing process, which has taken the greater part of a year. It was at times not possible to continue the polishing for more than ten minutes in the course of the twenty-four hours, all the rest of the time being spent in cleaning and regulating the machines. A variation of a single degree in the temperature of the workshop, or an excessive amount of dust in the atmosphere, was sufficient to destroy the effect of a week's labour. The workman charged with the task of supplying the fine emery powder to the machine had to hold his breath each time he approached. M. Gautier proved to demonstration that, if a hand were laid for an instant on the surface of the glass, the heat evolved was enough to raise a sort of bump at the spot, not distinguishable, of course, by the naked eye, but quite sufficient to destroy the uniformity of the surface and render it useless for the purpose for which it was intended. A bump raised in this way by the contact of a hand for a few seconds may take hours before it finally subsides and disappears. If such a bump passes under the polisher, a hollow at that particular spot is the result, which, in turn, has to be got rid of by polishing down all the rest of the surface! It was even found necessary to regulate the temperature of the various parts of the machine itself by making careful and continual tests with a delicately graduated thermometer, placing a movable gas-burner, with the flame lowered to the merest speck, near any part that was colder than the rest.

It was said at the commencement of this article that the 60-mètre telescope will probably inaugurate a new era in astronomical science. Should this prediction prove correct, it will be due principally to M. Gautier's discovery, which is equivalent to a perfect revolution in the optician's art. Henceforth the lens-founder is independent of the human polisher, and if he can succeed in making larger lenses, M. Gautier's machines are there to complete them. M. Gautier himself


From a] MODEL OF THE FINISHED TELESCOPE AND SIDEROSTAT. [Photo.

From a] THE TELESCOPE COMPLETED. *[Photograph.*

does not hesitate to designate everything that has up to now been constructed in the shape of optical instruments as "infantine" compared to what the near future will probably produce. Lenses of 60in. and more in diameter are already spoken of!

At the Exhibition the telescope is housed in a long gallery pointing due north and south, the siderostat being, of course, placed to the north. The southern end of the gallery, where the eye-piece of the telescope is, terminates in a large amphitheatre, in which the public will be seated. When the atmosphere is clear and propitious for astronomical observations, the images reflected by the instrument will be projected directly on to an enormous screen, about 30ft. in height, at the extremity of the amphitheatre, and a lecturer will be there to explain to the audience the various scenes in the moon and stars that pass before their eyes on the screen, enormously magnified, of course.

Cloudy weather does not necessarily imply an empty theatre, however. The telescope plays the *rôle* of a gigantic photographic camera as well as that of an ordinary telescope, and, at odd moments, will take photographs of all that is going on in the firmament. The moon and stars have, it is true, been photographed a good deal of late years, but the largest pictures yet taken have only had a diameter of between 6in. and 7in. Those that M. Deloncle's telescope will take are over 2ft. in diameter, and by the time the picture is thrown on to the screen this is magnified by 10ft. or 12ft. The spectator will see the surface of the moon at an apparent distance of only thirty-five miles, and almost have the illusion of making an excursion among its mountains and valleys!