of the methods and task of ethnology, by "Achelis"; a map of the Congo, with accompanying description, by Herr Richard Kiepert; and a note on the additions and changes made in the Chinese administrative organisation of the Thienshan region. The *Verhandlungen* (Band xii. No. 2) of the same Society contains a criticism by Herr Erman, who has for some years had charge of the historical and geographical departments of the Royal Library at Berlin, of the methods in which the work of compiling a bibliography of the geographical works relating to Germany—a "Bibliotheca geographica Germaniæ"—is being carried out.

At the meeting of the Geographical Society of Paris on March 20, a letter was read from the French Consul at Asuncion in Paraguay, giving details of the expedition sent by the Argentine Government to explore the Pilcomayo, and to ascend to the Bolivian frontier if possible. It has been found that, owing to impassable rapids, the river cannot be utilised as a route between Paraguay and Bolivia. The only practicable route is that by land, the possibility of which was recognised in 1883 by M. Thouar's expedition. M. de Cailland described the Pescadore archipelago in the Formosan channel. The islands have excellent roadsteads, and form the key to Formosa. M. Simonin read a note on the Indian population of the United States; and M. Jules Garnier described his project of an aërial railway for Paris.

A NEW ARRANGEMENT OF THE APPARATUS OF THE ROTATING MIRROR FOR MEASURING THE VELOCITY OF LIGHT[1]

Having now been engaged for a number of years in measuring the velocity of light by means of the rotating mirror, I have succeeded in rearranging the apparatus in such a manner as, by means simply of two mirrors, one fixed, the other movable, placed at a distance of a few metres from each other, to obtain, even with a very moderate velocity of rotation, a deviation of the image of a fixed object as large as may be desired in theory and limited in practice only by the intensity of the light and the perfection of the optical apparatus.

To describe in a few words the plan of L. Foucault's celebrated experiment:—The rays issuing from a narrow aperture fall, at a distance of 1 m., on a rotating mirror 14 mm. in diameter, and, on being reflected there, traverse an object-glass placed as near the mirror as possible. This object-glass throws an image of the aperture on a spherical concave mirror having a radius of 4 m. placed at a distance of 4 m. from the rotating mirror. A second mirror, in all respects perfectly corresponding with the first, receives the reflected pencil, which produces a fixed image of the rotating mirror, and transmits a movable image of the aperture to a third mirror, and so on. Foucault's apparatus comprised five similar mirrors. The last, in which a fixed image was formed, reflected on the fourth the light, which retraced its previous course and so came back to the rotating mirror, which again in turn transmitted it deviated in respect of its rotation by an angle twice as large as that at which it had turned when performing the double passage of the mirrors, *i.e.* twice 20 m. The velocity of rotation being 400 revolutions per second, Foucault obtained a deviation of 7 mm.

One of the objections taken to Foucault's experiment and the values he deduced from it respecting the velocity of light, is the smallness of that deviation. It is known how he ingeniously cleared the difficulty by substituting for the measurement of the deviation that of the distance of the aperture from the rotating mirror producing a determined deviation. He did not, however, disguise the fact that the advantage of this substitution is perhaps more specious than real, and he brought forward the plan of an apparatus composed of a series of objectives and of a concave mirror, by means of which the passage of the light might be extended to several hundreds of metres. He had even selected, at the Observatory, the place where his new experiments might be carried out.

I have to confess that, in endeavouring to take advantage of Foucault's scheme, whether by means of object-glass or of mirrors, I struck on such difficulties as caused me to desist from the prosecution of my researches by either of the methods indicated.

In the United States in 1879 Mr. Michelson put in operation the experiment of the rotating mirror at great distances, but under an arrangement which brings the experiment much nearer to the celebrated one of MM. Fizeau and Bréguet than that of Foucault. The aperture from which the light issues was placed at a distance of about 30 English feet (9·15 m.) from the rotating mirror, the diameter of which amounted to 1¼ inches (3·2 cm.). A simple non-achromatic lens, 7 inches (17·8 cm.) in diameter, and having a focus of 150 feet (45·75 m.) was placed in such a manner as to throw an image of the aperture, seen by reflection in the rotating mirror, on the surface of a plain mirror, 7 inches in diameter, placed normally to the line passing through the centres of the two mirrors and the lens, at a distance of 1986·23 feet (605·80 m.) from the rotating mirror. The pencil then returns on itself, and gives an image of the aperture coinciding with it, point for point, when the mirror is fixed, deviated as soon as it rotates. The lineal displacement of the image during a rotation of 258 revolutions per second amounted to 114·15 mm. The advantage, however, of such a large displacement seems to be counterbalanced by the inferior quality of the image. A lens 7 inches in diameter, and with a focus of 150 feet will, even under the best conditions, necessarily give an image bounded by very large fringes of diffraction, which atmospheric agitations transform into a luminous blot so ill-defined that, as Mr. Michelson himself confesses, it is impossible to study the effect of the parallax due to the defect of coincidence of the plane of the image with that of the lines of the micrometer; in other words, there is no defined focus.

In all my experiments, therefore, it has been my aim to maintain the perfect accuracy of optical effects, such as had been achieved by Foucault, believing that it is of greater advantage to measure even the small deviations of a perfect image than the exaggerated displacement of a blot of light. I have consequently sought to amplify the deviations of Foucault without increasing the distance to be traversed by the light, and without having recourse to great velocities of rotation on the part of the mirror.

I call to mind, by the way, that Bessel noted, as a means of increasing the deviation, the return of the deviated ray on the rotating mirror. This method, which has never yet been applied, might be utilised by means of a series of little plain mirrors placed in couples on one side and the other of the rotating mirror, in such a way as to transmit the pencil alternatively on one and the other of the two parallel faces of the rotating mirror. With each reflection the deviation increases by a quantity equal to its primitive value.[1] But this process would greatly complicate the measurement of the path traversed by the light. The advantage contemplated by it may, besides, be secured by a method much more elegant and simple.

The apparatus I bring under the notice of the Academy consists purely of two mirrors, one fixed, having a diameter of 0·20 m., the other movable, 0·05 m. in diameter, the two placed at a distance of 5 m. from each other. Both are concave and spherical, and have the same radius of curvature, 5 m. The source of light is a narrow aperture cut in the silver, in the centre of the large mirror. The pencil emanating from it and entirely covering the rotating mirror is reflected by the latter, and returns to form on the surface of the fixed mirror a movable image of the aperture and of the same size. In each of its positions this movable image becomes a source of light; the rays return to the movable mirror, which concentrates them anew into a fixed image: this is the image of Foucault, which coincides with the aperture when the rotation is very slow, which is deviated in respect of the rotation when the latter is a little rapid. Suppose the velocity of the rotating mirror to be such that the lineal deviation is equal to the breadth itself of the aperture, the image will then come to be formed on the fixed mirror, rim to rim with the aperture itself. There it falls on the reflecting surface of the silver, becomes then a source of light exactly similar to the first, producing a second image deviated by the same quantity. The latter in its turn acts like the first, in such a manner that, if one could look on the surface of the fixed mirror, one would there be able to see, issuing from the aperture itself, an indefinite series of identical images placed rim to rim and indistinguishable from each other, except in respect of their regularly increasing brightness. If the velocity of rotation is increased, all these images will be found to separate from each other and form on the fixed mirror a series of equal luminous lines, separated by equal intervals from each other, and

[1] Paper, by M. C. Wolf, in the *Comptes Rendus* for February 9.

[1] These plain mirrors, disposed in couples, might also be used to collect and transmit in one constant direction the light scattered in all directions by the rotating mirror. By this means the advantage would be obtained of observing the doubled deviation of a much more brilliant image.

which will continue increasing their distance from each other, proportionately with the increase of the velocity. If one succeeds in determining micrometrically the distance of one of these lines from the original aperture, he will measure no longer the single deviation of Foucault, but as high a multiple of that deviation as may be desired. The distance of my two mirrors from each other being 5 m., and the velocity of the rotation of the mirror only 200 revolutions per second, the deviation will be five-eighths of that obtained by Foucault—*i.e.* five-eighths of 0·7 mm., or nearly 0·44 mm. The tenth image will consequently be at 4·4 mm. from the aperture.

To assure myself, above everything, of the existence of these multiple images, I employed Foucault's mode of observation, and placed before the luminous aperture, at a little distance from the fixed mirror, a plate of glass with parallel faces, inclined at an angle of 45° to the direction of the axis of the mirror. By this means there is thrown back laterally a portion sufficiently faint, it is true, but still a portion, of each of the deviated pencils which one receives in a microscope. There will then be seen, so soon as the velocity of rotation is great enough to give a continuous image, appearing on the rim of the image of the aperture a second, less distinct image, next a third at the rim of the second, increasing in breadth in proportion as the first is more and more deviated, and ending by separating from one another. With the electric light generated by a small gas-machine of half-horse power, or with the wan sun of these late days, I have managed to see as many as three images and catch a glimpse of the fourth. The actual result very well corresponded with my anticipations. What remains to be done is to improve the method of observation and increase the quantity of light.[1]

Suppose the tenth image is sufficiently intense to be observed, I cut away the silver of the mirror from a little rectangle with rims parallel to those of the aperture. The tenth image will come to be formed in this rectangle, all the following images will be suppressed, and the deviated pencil traversing the glass of the mirror, the posterior face of which is plain and polished, will be received behind on a prism of total reflection, which will transmit it into the micrometric microscope. The distance of the rim of the image from the rim of the rectangle will be measured; then, by an independent operation, the distance of this rim from that of the aperture; the sum of the two will give the line of magnitude of the deviation. It remains to ascertain the order m of this deviation. For this purpose the rotation of the mirror will be accelerated till the image of the order $m - 1$ comes to be substituted for that which was observed. Let n and n' represent the numbers of revolutions of the mirror per second, δ and δ' the lineal values of the simple corresponding deviations, then

$$\delta = kn, \qquad \delta' = kn' \qquad \text{and } m\delta = (m - 1)\delta',$$

thence

$$mn = (m - 1)n'.$$

whence

$$m = \frac{n'}{n' - n}.$$

The number of revolutions is measured electrically by the methods M. Cornu has so carefully discussed in his work on the velocity of light; I need not dwell on it. Finally, the measurement of the passage of the light is easily got at; it is that of the distance from each other of the centres of the surfaces of the two mirrors.

In order to observe a deviation of a rather high order, all that is needed is a sufficiency of light. Now, in this case, I manage to augment considerably the proportions of utilised light. In the first place the rotating mirror may be made to reflect on its two faces, care being only taken that both have exactly the same radius of curvature. In the second place, having suppressed every object-glass, I am able to utilise the pencil reflected by the rotating mirror throughout the whole space in which it gives a good image of the aperture, and this space is considerable, because the astigmatism resulting from the obliquity does not sensibly affect the rectilineal form of this image. It is, next, possible to tack on to the mirror of 0·20 m., of which I have spoken, a series of other identical mirrors placed at the same distance in the plane of rotation of the pencil. The condition of identity of the radius of curvature is, besides, much less rigorous for these mirrors than in the case of the two faces of the rotating mirror. It is, however, always indispensable that the movable image given by this latter is reflected exactly on to the surface of each of the fixed mirrors.

I have also to remark that it is necessary that the lineal distance of the image observed from the aperture is large enough to allow the observation to be made. For in the thickness of the glass of the mirror and on its two surfaces there will inevitably arise a diffusion, as also reflections of the incident light, to embarrass and even frustrate the exact vision of the deviated image when it is too near the aperture. I have just shown that the actual apparatus ought, under good conditions, to show an image of the sixteenth order, perhaps even one as high as the twentieth—that is to say, at 8·8 m. from the aperture. It would be useful, however, to have recourse to an apparatus of more considerable proportions.

If 20 m. is taken for the radius of curvature of the mirrors and for the length of the simple passage of the light, the movable mirror ought to have a diameter of 0·20 m. Let there be impressed on it a velocity of rotation of only fifty revolutions per second, the deviation calculated according to the experiment of Foucault will be:—

$$0{\cdot}7 \text{ mm.} \times \frac{40}{40} \times \frac{20}{1} \times \frac{50}{400} = 1{\cdot}75 \text{ mm.}$$

The displacement of the twentieth image will then be 35 mm., which, measured to the hundredth of a millimetre, will give an approximation of $\frac{1}{3500}$. Now I do not think it impossible to turn a mirror of 0·20 m. as many as fifty revolutions per second without causing deformation of its surfaces. The turbines and the movable pieces of the dynamo-electric machines of the present day frequently attain a similar velocity.

It is my duty to make known to the Academy that the funds necessary for my first and long experiments were generously supplied to me by M. de Romilly, to whom I am happy to make this public testimony of my gratitude.

[1] The quantity of light utilised by this mode of observation on a glass is hardly the tenth of the actual quantity. The ratio of the geometrically decreasing progression representing the intensities of the successive images being 0·656, allowing 0·90 for the reflecting power of the silver, the brightness of the third image seen by reflection from a plate of glass is inferior to that of the eighth image seen directly. The reflecting power of new silver being 0·96, it would be possible by its means to attain to the sixteenth image.

ACCIDENTAL EXPLOSIONS PRODUCED BY NON-EXPLOSIVE LIQUIDS[1]

III.

THE only real danger which may attend the use of the little sponge lamps arises from accidental spilling of spirit used for filling them in the neighbourhood of a flame, or from carrying out the operation of filling in the vicinity of a light. Indeed, such casualties as have been attendant upon the use of petroleum-spirit as an illuminant have been mainly connected with the keeping and handling of the supplies of this very volatile liquid, and are largely attributable to want of caution or to forgetfulness. The salutary regulation prescribed by law, that vessels containing the spirit shall bear a conspicuous label indicating its dangerous character, has undoubtedly operated very beneficially in diminishing the frequency of accidents with it, by constantly admonishing to caution. It is a matter for much surprise and regret that the manufacturers of a class of miners' safety lamps, consisting of modifications of well-known types, with the ordinary oil lamp replaced by the sponge lamp, in which petroleum-spirit is burned, should have allowed trade interests to induce them to mislead those who use these lamps with regard to the nature of the illuminant supplied with them, by devising a name for it which gives a false indication of its nature, being designed to create the belief that it is an article of special manufacture, allied in character to a comparatively very safe oil largely used in miners' lamps, while in reality it is a well-known article of commerce, the safe storage and use of which demand special precautions and vigilance.

The lecturer took occasion to point out here, ten years ago, that a large proportion of the accidents arising out of the employment of petroleum- or paraffin-lamps were not actually due to the occurrence of explosions. Thus the incautious carrying of a lamp, whereby the liquid is brought into contact with the warm portion of the lamp close to the burner, may give rise to a liberation of vapour which, in escaping from the lamp, may be

[1] Address delivered at the Royal Institution of Great Britain, Friday, March 13, 1885, by Sir Frederick Abel, C.B., D.C.L., F.R.S., M.R.I. Continued from p. 496.