VII.—*Newton's use of the Slit and Lens in forming a pure spectrum.—Common error concerning this.—Effectiveness of Newton's method in showing the dark lines on a screen.*

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I. GENERAL.

The object of the following paper is threefold: first, to call attention to an error which is spreading through scientific books and does injustice to Newton's work in optics; secondly, to point out the extraordinary fact that not only *Newton's method but his actual experiments were fully sufficient, with ordinary luck, to show the dark lines in the solar spectrum*, while, as we know, he did not see them; thirdly, to suggest that a republication of the last edition of Newton's "Opticks" is of sufficient value to students of science of the present day to justify the outlay. The book is not easy of access, yet much may be learned from the account of the original experiments; moreover, when one writer, not having the original at hand, copies from another statements concerning it, error easily arises and is readily propagated. It would be most fitting that Newton's own university should undertake this republication.

The error I wish to point out is the statement that Newton never used the slit in producing the spectrum, and therefore could not have produced homogeneous light, that is, as I take it, sufficiently homogeneous to show the dark lines in the solar spectrum.

The following quotations may be submitted:—

Roscoe ("Spectrum Analysis," 1869, p. 22) says: "The first person who observed these dark lines was Dr. Wollaston. Newton did not observe them, and for the good reason that he allowed the light to fall on the prism from a round hole in the shutter."—"If he had allowed the light to pass through a fine vertical slit, and if this slit of light, if we may use such a term, had then fallen upon the prisms, placed so that the edge of the refracting angle is parallel to the slit, he would have observed that the solar spectrum is not continuous, but broken up by permanent dark lines."

Lockyer ("The Spectroscope," 1873, p. 18) says: "It is very curious, however, that Newton, although he made many experiments on prisms, really omitted one of the most important points."—"Newton made a round hole in a shutter for his experiments, but we now know he ought not to have done that: he ought to have made a slit; but this did not come out until 1802, when Dr. Wollaston, by merely using a slit instead of a round hole, made a tremendous step in advance."

In Parkinson's "Optics," second edition, 1866 (a Cambridge book), the same error is contained, not as a direct statement, but by implication, for, after describing Newton's experiment with a small aperture, it says, p. 149: "Instead of a very small aperture Wollaston and Fraunhofer admitted the sun's light through a very narrow slit, the effect of the slit being to give an assemblage of innumerable linear spectra placed side by side."

Proctor ("Spectroscope," 1877, p. 16) does not seem to be aware that Newton had used a narrow slit, for although he refers to his using an "oblong" and a "triangular" aperture as well as other shapes, yet it appears, from his contrasting these with Wollaston's use of a slit as well as from his diagram, that he considered the triangles (equilateral) and the "oblongs" to be about the same size as the round hole also employed by Newton. It appears, however, more definitely from his work on "The Sun" (p. 101, 1872) that he shared the common error. He says: "Wollaston found that when, instead of a circular, triangular or oblong aperture, a very narrow slit is employed, light of certain degrees of refrangibility is absent from the solar beam;" and on the same page he remarks: "This mode of viewing the spectrum bears the same relation to Newton's plan," etc. He does not appear to have consulted Wollaston's original paper, for he says: "The spectrum seen by Wollaston was not continuous, but crossed by two dark lines parallel to the slit," whereas Wollaston states that he saw *six* lines. Curiously enough, Parkinson also says: "Two of the fixed lines, probably E and F, had been discovered by Wollaston previous to the experiments of Fraunhofer." Yet Sir David Brewster ("Optics," 1853, p. 91) says of them: "These six lines are found to correspond with those marked B, D, b, F, G and H" [by Fraunhofer].

Heath's "Geometrical Optics" (Cambridge, 1887) alludes (p. 195) to Newton's experiments with a small circular hole only, remarking (p. 196) that "the colours will not be thoroughly separated; the spectrum is then said to be impure." How a pure spectrum may be obtained is described immediately afterwards, without any reference to Newton.

I tried to draw attention to this general error by a letter which appeared in 'Nature' in October, 1882, and should hardly have referred to it again had it not been for the recurrence of the same statement in Sir William Thomson's "Popular Lectures" (vol. i, p. 324, 1889), where he says: "Newton never used a narrow beam of light, and so could not have had a homogeneous spectrum." The lecture was on "The Wave Theory of Light," and given in Philadelphia in 1884.

The weight of Sir William Thomson's name is so deservedly great that this statement by him is likely to greatly extend the prevalence of the error. The republication of the original work, now so difficult to procure for consultation, seems the best way of obviating this and other mistakes concerning it. Meanwhile I make the following extracts from the first edition (1704), in which it will be noticed that Newton used the lens also, although not to make the rays parallel.

In Prop. 4, Bk. I, of the "Opticks," 1704, Newton proposes the problem to find a pure spectrum, or, as he words it, "To separate from one another the Heterogeneous Rays of Compound Light."

After showing at some length (p. 47) why he uses a lens to "diminish the mixture of the Rays," he describes experiment 11, first with a round hole, and *afterwards with a slit*, as follows:

"In the Sun's Light, let into my darkened Chamber through a small round hole in my Window-shut, at about 10 or 12 feet from the Window, I placed a Lens, by which the image of the hole might be distinctly cast upon a sheet of white Paper, placed at the distance of six, eight, ten or twelve Feet from the Lens. For according to the difference of the Lenses I used various distances, which I think not worth the while to describe. Then immediately after the Lens I placed a Prism, by which the trajected Light might be refracted either upwards or sideways, and thereby the round image which the Lens alone did cast upon the Paper might be drawn out into a long one with Parallel Sides, as in the Third Experiment." The "oblong" image thus formed he received upon another paper placed by trial "at the just distance where the Rectilinear Sides of the Image became most distinct." In this case, he says, "the circular images of the hole extended into one another the least they could." "By using a greater or less hole in the Window-shut" he made "the Circular Images to become greater or less at pleasure," and thereby the "mixture of the Rays in the Image to be as much or as little" as he desired. "By this means," (p. 49) "I made the breadth of the image to be forty times and sometimes sixty or seventy times less than its length."

"Yet," he goes on to say (p. 49), "instead of the circular hole F *'tis better* to substitute an *oblong hole shaped like a long Parallelogram*, with its length parallel to the Prism. For if this hole be an *Inch or two long*, and but a tenth or *twentieth part of an Inch broad or narrower*, the Light of the Image will be as Simple as before or Simpler, and the Image will become much broader, and therefore more fit to have Experiments tried in its Light than before."

Instead of this "Parallelogram-hole," he says, "may be substituted a Triangular one of equal sides, whose Base, for instance, is about the tenth part of an Inch, and its height an Inch or more." The edge of the prism is, of course, placed parallel to the perpendicular of the triangle. "The Image will now be formed of Equicrural Triangles."—"These triangles are a little intermingled at their Bases but not at their Vertices," and therefore "the light where the Bases of the Triangles are is a little compounded, but on the darker side is altogether uncompounded."

He is careful in mentioning precautions to be attended to in the experiments—the exclusion of foreign light from the chamber, a good lens, a prism of large angle, "suppose of 70 degrees, and to be well wrought, being made of Glass free from Bubbles and Veins," etc.

In the above description I have italicized the breadth of the hole, the "twentieth parth of an Inch" "or narrower," because "$\frac{1}{20}$th of an inch broad" is the statement which Wollaston makes about the width of the "*crevice*" which he used when he discovered the dark lines. It is curious that Proctor should have referred to Newton's experiments with the "oblong" aperture and not have noticed that it was narrow enough to be called a "slit." Neither Newton nor Wollaston use the term slit themselves, but this term, or rather "a narrow slit," is applied in a description of Newton's experiments given in an account of Newton's optics (64 pages) published in "The Optics," issued in the "Library of Useful Knowledge" (1830). Lloyd, "Light and Vision" (1831) and "Wave Theory of Light," refers correctly to the experiments also, although he does not employ the word "slit." Where the error first crept in I have not the means of determining.

Wollaston's account of his own discovery is in a paper in the 'Philosophical Trans-

actions' for 1802, p. 378, where he says : "If a beam of daylight be admitted into a dark room by *a crevice one-twentieth of an inch broad*, and received by the eye at a distance of ten or twelve feet through a prism of flint glass *free from veins*" (italicized by Wollaston), "held near the eyes, the beam is seen to be separated into the four following colours only, red, yellowish-green, blue and violet." In a diagram accompanying the paper he notes the lines, four of which he considers as boundaries of the colours. They are six in all. Of two of them he attempts no explanation. He changed the materials of the prism, but found no alteration in the lines while he used solar light. But using candle light and the electric light he found the appearances, which, says he, "I cannot undertake to explain," different.

That Newton did not see the dark lines is very remarkable when we consider the great number and variety of his experiments. Among the causes assigned for this it is said, or implied, that Newton always received the spectrum on a screen, whereas Wollaston saw the lines by simply looking through the prism. But Newton mentions that he *looked through* the prism also (Prop. II, Bk. I, p. 22), but it was at the round hole about a quarter of an inch in diameter. If he had been using the slit on this occasion he might have anticipated Wollaston. The other chief cause assigned is that he never used a slit or lens, and did not understand the advantages of them. But, on the contrary, we see that Newton was perfectly aware of the advantages of a narrow slit. In his eleventh experiment he uses a circular hole one-tenth of an inch in diameter. After this he mentions a slit one-tenth of an inch broad, then one one-twentieth of an inch, then "narrower," and, he remarks, "the light will be as simple as before or simpler, and the image will become much broader, and therefore more fit to have experiments tried in its light than before." But he goes farther still in comparing the effects of different breadths of the slit; for in taking the long, narrow, isosceles triangular opening he makes its base the same as the diameter of the circular hole above referred to, namely, one-tenth of an inch, and its perpendicular height being an inch or more, the width of this slit tapers off from one-tenth of an inch to nothing.

II. Experimental.

While getting this paper ready for the printer I took some opportunities for repeating the experiments in which Newton used the slit and lens, as closely as possible in Newton's own manner, not expecting much from them as regards the dark lines, as I had never seen any hint given that the lines might be seen in this way, yet thinking that, with a previous knowledge of their existence, they would be visible on careful inspection, and that in the experiments as performed by Newton they might have been overlooked, because of his entrusting the division of the colours (in seeking for which Wollaston discovered these lines) chiefly to an assistant, in whose eyes he had more confidence than in his own.

Newton's method.—Newton's method, as may be seen by a comparison of different places in the "Opticks" and also by the instance he quotes in Experiment 11, was to place the lens at or about double its focal length from the aperture, by which means an image of the same size as the aperture might be received on a white paper screen about the same distance beyond the lens, then to put the prism immediately behind the lens, receive the

spectrum in the position of minimum deviation on a white paper screen and examine it. This method I followed closely, letting the light pass through the prism as near the refracting edge as possible. The sunlight was thrown on the slit by a heliostat worked by the hand (the "porte-lumière" of Duboscq). The slit was one of variable width belonging to the Duboscq collection of apparatus.

Experiments with slit and object-glasses of telescopes, etc.—I was naturally surprised to find that it was absolutely impossible to overlook the lines even when the slit was opened to the widest extent that Newton mentions. The number seen at any one time varied according to the prism or lens used or the brightness of the day, or the width of the slit, but they were always plainly visible on the spectrum. One bright day, when the width of the slit was about $\frac{1}{4}$ mm., I counted thirty-eight distinct lines, without reckoning others which were vague in outline. They were distinct enough to be visible to half a dozen persons or more at the same time. Afterwards, opening the *slit to one-tenth of an inch* (the widest used by Newton), I saw plainly ten dark lines on the white paper screen. I ought to say that I was careful always to find the exact distance at which they were best defined, but I did not take any special pains to exclude foreign light, finding that the darkness sufficient for lecture purposes was quite enough for all I wanted. I made experiments with three different prisms, viz., one by Duboscq for projection experiments, another belonging to a Duboscq spectroscope, the third was very inferior in its action to either of these. I also used three different lenses—one belonging to a Dollond telescope, of three feet six inches focal length; the second belonged also to a telescope of somewhat greater focal length; the third was simply the Duboscq lens used for projection experiments.

On seeing the results, I came to the conclusion at once that it was exceedingly improbable that they had not been published before, although I had found no mention of them in any English work that I had been able to consult (nor have I yet); nor had I found any allusion to them in Jamin's "Traite de Physique" (1881), nor in Daguin's (1862), although on re-examining this I found something like the experiments, *two* slits, however, being used. But on examining Pouillet (vol. ii, p. 208, 1853), there I found this method recommended and connected with Newton's name. In an earlier French work (Lamé, 1840) the same method is recommended, but nothing is said about Newton.

Circular hole.—In Experiment 11 Newton used a *circular hole of one-tenth of an inch* diameter. Nothing is said of experimenting with this in the above manner in any of the books I have referred to, but on examining the spectrum due to it and formed in this way I saw *four* lines very distinctly.

The above experiments, conducted after Newton's method and showing that it gave a spectrum pure enough to show as many as thirty-eight lines, were nevertheless not conducted under a condition by which Newton was restricted. I think it has been sometimes forgotten by writers on this subject that Newton had no achromatic lens, and that he could not, if he would, have made all the rays fall parallel on the prism by means of a collimating lens. In Experiment 11 he used several different lenses, as may be seen from the extract given above. The dispersion produced by any of them was probably great enough to prevent the appearance of dark lines. It seems probable that the same error which led him to despair of the construction of an achromatic lens did, as another

consequence, deprive him of the discovery of the dark lines. It was not, however, an inevitable consequence, as may be seen by making the experiment with a crown glass lens alone, as he did.

Experiment with a crown glass lens.—For this purpose I separated the parts of one of the object glasses that I had used previously, and tried further what could be done with the crown glass convex lens thus obtained. Its focal length was eighteen inches and aperture two and three-quarter inches. The results are as follows :

With the slit of one-half mm. width I counted on one occasion ten dark lines, and on others eight.

Widening the slit to *one-twentieth of an inch* (a width mentioned by Newton), I saw four lines, viz , E, b, F and G, of Fraunhofer. I noted at the time *that it was quite impossible to overlook them.*

Opening the slit still farther *to the widest extent recorded by Newton, viz., one-tenth of an inch, two lines* (F and G) *were still visible, and impossible to be overlooked.* There were also traces of others. This experiment was repeated more than once, with the same result.

Round hole —I tried also a round hole. When the diameter was one-twentieth of an inch I still could see one line (G), but with a width of one-tenth inch could see none.

The following is a summary of the conclusions arrived at :

1. That if Newton had had an achromatic lens, his method was so effective that it would have been impossible for the dark lines in the spectrum to have escaped his notice whether he used a slit or even a round hole one-tenth of an inch in diameter, without taking into account the slit one-twentieth of an inch " and narrower "

2. That even with a crown glass lens the lines must have been seen had he been ordinarily fortunate in the particular lens used.

3. That the rise of the error concerning the slit seems to have been contemporaneous with the introduction of spectrum analysis, judging from the dates given above.