FRAUNHOFER[1]

Discovery and Description of Lines in the Solar Spectrum

(From "Prismatic and Diffraction Spectra," translated by J. S. Ames, 1898, by arrangement with the American Book Company, publishers.)

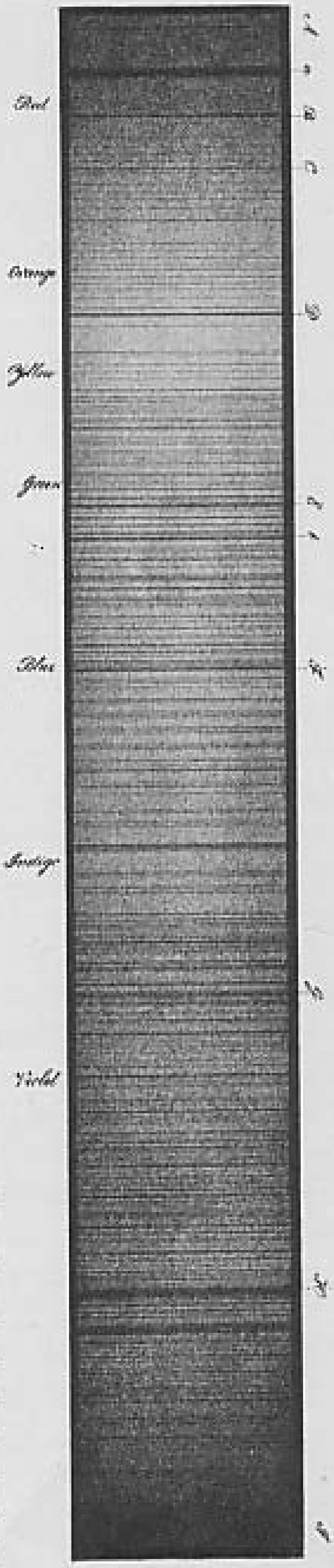
In the window-shutter of a darkened room I made a narrow opening—about 15 seconds broad and 36 minutes high—and through this I allowed sunlight to fall on a prism of flint-glass which stood upon the theodolite described before. The theodolite was 24 feet from the window, and the angle of the prism was about 60°. The prism was so placed in front of the objective of the theodolite-telescope that the angle of incidence of the light was equal to the angle at which the beam emerged. I wished to see if in the color-image from sunlight there was a bright band similar to that observed in the color-image of lamplight. But instead of this I saw with the telescope an almost countless number of strong and weak vertical lines, which are, however, darker than the rest of the color-image; some appeared to be almost perfectly black. If the prism was turned so as to increase the angle of incidence, these lines vanished; they disappear also if the angle of incidence is made smaller. For increased angle of incidence, however, these lines become visible again if the telescope is made shorter; while, for a smaller angle of incidence, the eye-piece must be drawn out considerably in order to make the lines reappear. If the eye-piece was so placed that the lines in the red portion of the color-image could be plainly seen, then, in order to see the lines in the violet portion, it must be pushed in slightly. If the opening through which the light entered was made broader, the fine lines ceased to be clearly seen, and vanished entirely if the opening was made 40 seconds wide. If the opening was made 1 minute wide, even the broad lines could not be seen plainly. The distances apart of the lines, and all their relations to each other, remained unchanged,

[1] Joseph Fraunhofer (1787–1826), German optician, discovered the Fraunhofer lines in the solar spectrum while engaged in perfecting the construction of achromatic lenses. The above excerpts were published in 1817 in *Denkschriften der königlichen Akademie der Wissenschaften zu München;* and in *Edinburgh Journal of Science*, 1827, 1828.

both when the width of the opening in the window-shutter was altered and when the distance of the theodolite from the opening was changed. The prism could be of any kind of refractive material, and its angle might be large or small; yet the lines remained always visible, and only in proportion to the size of the color-image did they become stronger or weaker, and therefore were observed more easily or with more difficulty.

The relations of these lines and streaks among themselves appeared to be the same with every refracting substance; so that, for instance, one particular band is found in every case only in the blue; another is found only in the red; and one can, therefore, at once recognize which line he is observing. These lines can be recognized also in the spectra formed by both the ordinary and the extraordinary rays of Iceland spar. The strongest lines do not in any way mark the limits of the various colors; there is almost always the same color on both sides of a line, and the passage from one color into another cannot be noted.

With reference to these lines the color-image is as shown in the accompanying figure. It is, however, impossible to show on this scale all the lines and their intensities. (The red end of the color-image is in the neighborhood of *A*; the violet end is near *I*.) It is, however, impossible to set a definite limit at either end, although it is easier at the red than at the violet. Direct sunlight, or sunlight reflected by a mirror, seems to have its limits on the one hand, somewhere between *G* and *H*; on the other, at *B*; yet with sunlight of great intensity the color-image becomes half again as long. In



order, however, to see this great spreading-out of the spectrum, the light from the space between *C* and *G* must be prevented from entering the eye, because the impression which the light from the extremities of the color-image makes upon the eye is very weak, and is destroyed by the rest of the light. At *A* there is easily recognized a sharply defined line; yet this is not the limit of the red color, for it proceeds much beyond. At *A* there are heaped together many lines which form a band; *B* is sharply defined and is of noticeable thickness. In the space between *B* and *C* there can be counted 9 very fine, sharply defined lines. The line *C* is of considerable strength, and, like *B*, is very black. In the space between *C* and *D* there can be counted 30 very fine lines; but these (with two exceptions), like those between *B* and *C*, can be plainly seen only with strong magnification or with prisms which have great dispersion; they are, moreover, very sharply defined. *D* consists of two strong lines which are separated by a bright line. Between *D* and *E* there can be counted some 84 lines of varying intensities. *E* itself consists of several lines, of which the one in the middle is somewhat stronger than the rest. Between *E* and *b* are about 24 lines. At *b* there are 3 very strong lines, two of which are separated by only a narrow bright line; they are among the strongest lines in the spectrum. In the space between *b* and *F* there can be counted about 52 lines; *F* is fairly strong. Between *F* and *G* there are about 185 lines of different strengths. At *G* there are massed together many lines, among which several are distinguished by their intensity. In the space between *G* and *H* there are about 190 lines, whose intensities differ greatly. The two bands at *H* are most remarkable; they are almost exactly equal, and each consists of many lines; in the middle of each there is a strong line which is very black. From *H* to *I* the lines are equally numerous. . . .

I have convinced myself by many experiments and by varying the methods that these lines and bands are due to the nature of sunlight, and do not arise from diffraction, illusion, etc. If light from a lamp is allowed to pass through the same narrow opening in the window-shutter, none of these lines are observed, only the bright line *R*, which, however, comes exactly in the same place as the line *D*, so that the indices of refraction of the rays *D* and *R* are the same. The reason why the lines fade away, or even entirely vanish, when the opening at the window is made too wide is not difficult to give. The stronger lines have a width of from five to ten seconds; so, if the opening of the window is not so narrow that the light which passes through can be regarded as belonging to one ray, or if the angular width of the opening is much more than that of the line, the image of one and the same line is repeated several times side by side, and consequently becomes indistinct, or vanishes entirely if the opening is made too wide.

Spectra of Venus and Sirius

I applied this form of apparatus at night-time to observe Venus directly, *without making the light pass through a small opening;* and I discovered in the spectrum of this light the same lines as those which appear in sunlight. Since, however, the light from Venus is feeble in comparison with sunlight reflected from a mirror, the intensity of the violet and the extreme red rays are very weak; and on this account even the stronger lines in both these colors are recognized only with difficulty, but in the other colors they are very easily distinguished. I have seen the lines D, E, b, F perfectly defined, and have even recognized that b consists of two lines, one weak and one strong; but the fact that the stronger one itself consists of two I could not verify owing to lack of light. For the same reason the other finer lines could not be distinguished satisfactorily. I have convinced myself by an approximate measurement of the arcs DE and EF that the light from Venus is in this respect of the same nature as sunlight.

With this same apparatus I made observations also on the light of some fixed stars of the first magnitude. Since, however, the light of these stars is much weaker than that of Venus, it is natural that the brightness of the spectrum should be much less. In spite of this I have seen with certainty in the spectrum of Sirius three broad bands which appear to have no connection with those of sunlight; one of these bands is in the green, two are in the blue. In the spectra of other fixed stars of the first magnitude one can recognize bands; yet these stars, with respect to these bands, seem to differ among themselves. Since the objective of the telescope has an aperture of only 13 lines [1 centimetre equals 4.43296 lines], it is clear that these observations can be repeated with much greater accuracy. I intend to repeat them with suitable alterations, and with a larger objective, in order to induce, perhaps, some skilled investigator to continue the experiments. Such a continuation is all the more to be desired, because the experiments would serve at the same time for the accurate comparison of the refraction of the light of the fixed stars with that of sunlight.

Spectra of the Moon and Starlight

As is well known, the prismatic *color-spectrum* of the light coming from a *flame* (*lamplight*) does not show the dark fixed lines which are present in the spectrum of sunlight; instead of them there is in the orange a bright line which is prominent above the rest of the spectrum, is double, and is at the same place where in sunlight the double line *D* is found. The spectrum obtained from the light of a flame which is blown with a *blast-tube* contains several prominent bright lines. Of still greater interest for optical experiments is the fact that, by skilful blowing of the flame, the light of the *front half* of the flame can be dispersed no further by the prism, and, consequently, is simple homogeneous light. This light has, so far as I have investigated it, the same refrangibility as the *D* ray of sunlight. Simple homogeneous light which proceeds in all directions is, for known reasons, very difficult to produce, and can never be obtained with prisms directly; therefore, this flame is of great use in many experiments . . .

The light of the *moon* gave me a spectrum which showed in the brightest colors the same fixed lines as did sunlight, and in exactly the same places.

To observe the *spectra of the light of the fixed stars*, and at the same time to *determine the refrangibility of this light*, I prepared a short time ago a suitable apparatus specially adapted to this end, the telescope belonging to it having an objective of 4 inches' aperture . . .

Up to the present we have found no *fixed star* whose light, so far as its *refrangibility* is concerned, is sensibly different from that of the *planets*. When the fixed lines of the spectra are seen plainly, one can be certain with this instrument to 10 seconds; and when the fixed lines cannot be seen, one can still be certain for the *orange light* to ½ minute. Since the total refraction through the prism is 26°, a difference amounting to $\frac{1}{9360}$ of the whole refraction could still be noticed with this instrument, a difference which even with the horizontal refraction in the atmosphere did not amount to ¼ second. Up to this time, as is well known, some astronomers have doubted whether the refraction tables for different stars should not be somewhat different; therefore, this doubt seems to be removed by the experiment noted. The continuation of this investigation will lead us, I hope, to more complete knowledge.

In order to see the *fixed lines* of the different stars (with this large instrument) the air must be most favorable—a condition which happens rarely to a sufficient extent. The spectra of the light from *Mars* and *Venus* contain the same fixed lines as does sunlight, and in exactly the same places, at least so far as the lines *D*, *E*, *b*, and *F* are concerned, whose relative positions can be exactly determined. In the spectrum of the light from *Sirius* I could not distinguish fixed lines in the orange and yellow; in the green, however, there is seen a very strong streak; and in the blue there are two other unusually strong streaks, which seem to be unlike any of the lines of planetary light. We have determined their positions with the micrometer. *Castor* gives a spectrum which is like that of Sirius; the streak in the green, in spite of the weak light, was intense enough for me to be able to measure it; and I found it in exactly the same place as it was with Sirius. I could also distinguish the streaks in the blue; but the light was too feeble to allow of measurement. In the spectrum of *Pollux*, I recognized many fixed lines which resembled those of Venus; but all were weak. I saw the *D* line quite plainly, in exactly the same position as with planetary light. *Capella* gives a spectrum in which, at the places *D* and *b*, the same fixed lines are seen as in sunlight. The spectrum of *Betelgeux* (α Orionis) contains countless fixed lines which, with a good atmosphere, are sharply defined; and, although at first sight it seems to have no resemblance to the spectrum of Venus, yet similar lines are found in the spectrum of this fixed star in exactly the places where with sunlight *D* and *b* come. Some lines can be distinguished in the spectrum of *Procyon;* but they are seen with difficulty, and so indistinctly that their positions cannot be determined with certainty. I think I saw a line at the position *D* in the orange.