SCIENCE

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MSS. intended for publication and books, etc., intended for review should be sent to the responsible editor, Professor J. McKeen Cattell, Garrison-on-Hudson, N. Y.

THE INTERFERENCES OBSERVED ON VIEWING ONE COARSE GRATING THROUGH ANOTHER, AND ON THE PROJECTION OF ONE PIECE OF WIRE GAUZE BY A PARALLEL PIECE.

IT has often been a matter of surprise to me that the shadow bands observed, for instance, on looking through one distant picket fence at another, are so seldom referred to in the literature of physics; and moreover, that phenomena so ubiquitous and of such remarkable properties are sparingly, if ever, made use of by the practical physicist. I therefore thought it worth while to look into the subject experimentally, for my own satisfaction, and the results may be of interest to the reader. I hope to show that there is probably no more straightforward example of the diffraction method in geometric optics, or more instructive method of introducing it.

CERTAIN ALLIED SIMPLE PHENOMENA.

1. If a piece of wire gauze is placed on another with the wires nearly parallel, the well-known water lines invariably come out, oftentimes, if one piece of gauze is regularly or geometrically crumpled or dimpled, showing beautiful patterns. The explanation of this is at hand; the upper meshes being nearer the eye subtend a larger angle, and when both are projected on the same plane, two scales result, one a little larger than the other. Hence, similar to the case of the vernier or the analogous case of

musical beats, there is a crowding of the lines in some parts of the field, alternating with a paucity in intermediate parts, if both gratings be uniform, plane and alike. If the drift of the wires in the two gratings be in slightly different directions, the interlacing is dense in the former case and light in the latter, with a diagonal trend. If the gratings be imperfect or not plane, the zones of light and shade must obviously be curved. Even with parallel and equal systems in the same plane, water line effects may be produced, since there is less darkness in the loci where lines cross than where they are distinct.

WHAT ARE THE GENERAL PHENOMENA?

2. This is all simple enough; if, however, the two gratings are placed at a distance apart along an axis, and the first illuminated by strong diffuse light, the second will project a real image of the former grating at definite points on the axis, almost as if it were a zone plate. When these images are looked at by the eye in the proper position, they appear as magnifications of the first grating, oftentimes enormously large the size increasing with the distance of the focal plane from the projecting grating. If the eye be moved along the axis the images vanish rapidly to infinity on the nearer side and more gradually to zero on the farther side. Distant foci are apt to show heavy blue lines on a red ground, and *vice versa.* The indefiniteness of focus when viewed by the normal eye is due to its power of accommodation, and the size is an illusion; for the eye is adjusted for an infinite distance and locates the image of unknown position there. The eye unaided is therefore not well adapted for observations of this character. If, however, one throws the eye out of range with a reading glass of, say, 10 cm. focal distance held close to it, the variability of focal distance is practically wiped out, and the positions of the images may now be charted satisfactorily.

Some years ago, while looking through an ordinary door screen at the Venetian blinds on the opposite side of the street, I noticed that the zones of light and shade were remarkably distinct when viewed by the naked eye (which in my case is near-sighted), but that they all but vanished or were so faint as not to be an annoyance when viewed through spectacles. This observation is general: If the normal eye is put out of proper function by looking through strong convex or strong concave glasses, in either case the shadow zones at the proper distance from the screen become painfully pronounced. They disappear as the eye is properly equipped, naturally or otherwise, for long range vision. It seems probable that this principle (to which I shall return in § 5) could be used practically in fitting the eye with the proper glasses.

For the present purposes therefore either a convex or a concave lens will be needed by the normal eye to fix the proper focal planes of the grating; but as the plane for the convex lens is in front of the eye, this is the more serviceable. Direct projection is only possible in a darkened room and at the strongest focus, supposing that diffuse daylight illuminates the first grating. With sunlight all the real foci may be projected, but the use of sunlight (at the outset) slightly alters the conditions. Foci may also be found by the telescope directed along the axis; though furnishing admirable qualitative results, this is the least accurate of the methods and useful only for finding virtual foci in the cases discussed below, § 5.

Thus the following simple arrangement is suggested for measurement. Along the axis LL' there is placed the ground glass screen C, and the wire gauze* grating A just in front of it. At a distance, x, from A the

*Ordinary door screen wire gauze, say 6 inches high and 12 inches wide, in a wooden frame, answers all purposes.

second grating, B, is adjusted with the wires parallel to A; and at a distance, y, from the latter is the focal plane S, visible to the eye behind the lens (or in the distant correspondingly focused telescope, looking along $L'L$ in Fig. 2, as will be explained below).

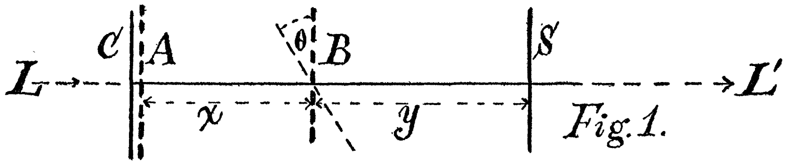


Fig. 1.

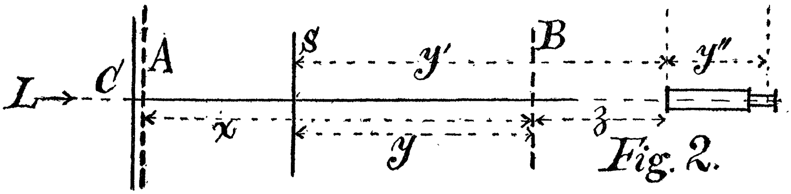


Fig. 2.

It will be convenient to call the grating space at A, a; the space at B, b; and the space of the image at S, s, all being parallel. Then the experimental results of Table 1,

TABLE 1.—EXAMPLE OF FOCAL PLANES FOR GRATINGS WITH EQUAL MESHES. $a=b=.214$ CM. AND WIRES .030 CM. IN DIAMETER, LENS FOCUS 15 CM. $a=b$.

$x=$	100	200	300	400	cm.
$y=$	125 215 —	105 225 —	155 315 615	201 410 —	cm.
Ratio, $y/x=$	1 2 —	$\frac{1}{2}$ 1 —	$\frac{1}{2}$ 1 2	$\frac{1}{2}$ 1 —	

TABLE 2.—EXAMPLE OF FOCAL PLANES FOR GRATINGS WITH UNEQUAL MESHES. MESH OF A, .214 CM., OF B, .033 CM., SO THAT $a/b=6.5$.

$x=$	300	400	cm.
$y=$	35 75 135	65 145	cm.
$y/x=$	1 2 4	1 2 —	

in which relations of x and y for the case of $a=b$ have been inserted as an example of many similar data, will be intelligible at once.

Naturally these results are crude, but as their import is unmistakable, it is not necessary to push the experiment further. The first definite result derived from them is this, that the focal planes are distributed along the axis at distances $\frac{1}{2}$, 1, 2, etc., multiples and submultiples of the distance of the gratings apart, when the two gratings are identical, or $a=b$. The size of the images is usually directly as the distance y from grating B, and if for $a=b$, $x=y$, then $a=b=s$, or image and object are equally large. Remote focal planes are apt to be diffuse and colored nearly uniformly red and blue in alternate bands. Hence the number of foci accessible in this way is not large.

If the meshes are unequal, the focal planes are still apt to be distributed at distances varying as 1, 2, 4, etc., along the axis. Corresponding distances, y, are smaller relative to x if the projecting grating is finer. The law of distribution is not easily worked out in this way, however, because it is difficult to obtain gratings of different meshes but of the same diameter of wire. Neither is it safe to infer the size of image from these experiments. The problem must be attacked in another way.

3. Since the distances x and y are large (2-10 meters), it will be possible to obtain gratings of different fineness (effective horizontal distance of wires apart) by merely *rotating* either grating on an axis parallel to the wires. Since the focal planes have now been shown to be real, it is expedient to project the whole phenomenon with sunlight, and if parallel rays are not wanted a ground glass screen or better, a screen of scratched mica which is more translucent, may be interposed at C in Fig. 1, in front of the first grating, A. Thus if L be the direction of sunlight and θ the angle of rotation of either grating, the figure meets the present case. If A be left normal and B rotated, results are obtained for the case where the projecting meshes are smaller horizontally than those projected. If B be left normal and A rotated, the projected meshes are the smaller. For any angle θ of either A or B, the grating B and screen S may be moved along the axis to locate the other focal planes for the same mesh ratio. With the proper angle θ images may be focused for any distance y relative to x.

TABLE 3.—DATA FOR A FINER PROJECTING MESH (B ROTATED). $x=200$ cm. $a=1$.

y	θ	Appr. $\cos\theta$	s Image.	Remarks.	Symbol in chart.
100	0°	1	.5	bk. and wh.	Fig. 3—α
	49°	$\frac{2}{3}$	.5	"	" 7—β
	71°	$\frac{1}{3}$	.5	"	" 5—γ
200	0°	1	1.0	red and bl.	" 3—δ
	41°	$\frac{3}{4}$	.5	bk. and wh.	" 8—ε
	61°	$\frac{1}{2}$	1.0	red and bl.	" 4—η
	78°	$\frac{1}{4}$	.5	strong.	" 6—ζ
300	52°	$\frac{3}{5}$	1.5	"	" 8—strained
	75°	$\frac{3}{10}$	.75	br. and wh.	" 8— "
400	47°	$\frac{2}{3}$	2.0	"	" 7—μ
	74°	$\frac{1}{3}$	1.0	"	" 5—ν
600	42°	$\frac{3}{4}$	3.0	strong.	" 8—ξ
	70°	$\frac{3}{8}$	1.5	"	" 8—strained
700	—	—	3.5	"	———
			1.75	"	

At long ranges (500 cm. and more) the white shows faint interference fringes usually with a pink center. At 7 meters, when the ground glass screen is interposed in front of the first grating, A, the effect is a remarkably clear diffraction pattern fully two feet square or more, consisting of narrow, strong, black lines on a dull white ground. When the grating space of B is reduced to $\frac{1}{2}$ by rotating it, very fine lines fainter but very clear show on the same ground. For other mesh-ratios the field is blank, and sharp adjustment of θ is necessary. Diffuse, non-parallel light, therefore, is equally active, and being free from the intense but circumscribed glare of full sunlight, gives more striking results. Moreover, the same figures as above show through the dull mica screen for all the distances noted in the table.

Special attention may be called to the fact that the figure is still distinct even at a distance of 30 meters between the image S and the projecting grating B.

The results of the following table were obtained by keeping grating B normal and rotating A.

TABLE 4.—DATA FOR A COARSER PROJECTING MESH (A ROTATED). $x=200$. $b=1$.

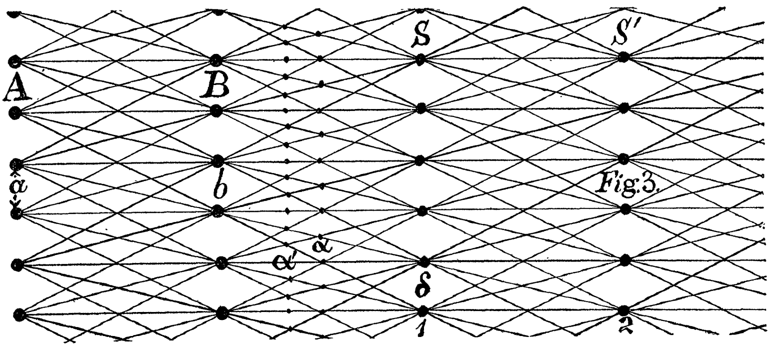
y	θ	Appr. $\cos\theta$	s mage.	Remarks.	Symbol in chart.
200	48	$\frac{2}{3}$	1.50	Strong.	Fig. 7—μ
	60	$\frac{1}{2}$	.50	"	" 4—η
400	42	$\frac{3}{4}$	1.50	"	" 8—prol. bk.
	71	$\frac{1}{3}$	.30	"	" 5—ν'

As the obliquity of A is increased the focal plane frequently does not sharply vanish, the image merely becoming smaller. Because of this indefiniteness of smaller images further measurement was not attempted. It will be seen that the angles θ for the same y do not correspond to the preceding table, as was directly proved by exchanging the gratings. This is the important datum of the new series of observations, and makes it needless to adduce a greater number.

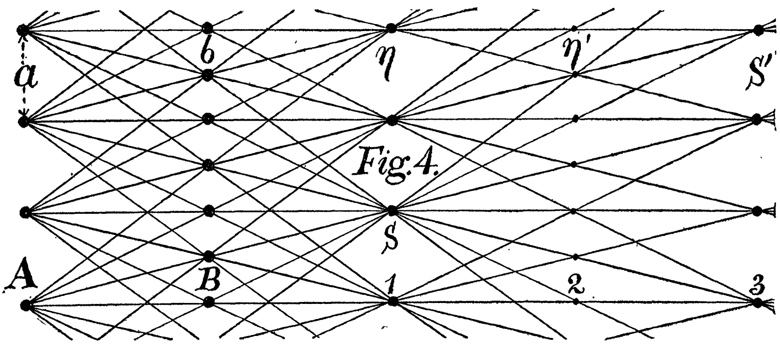
SCHEME FOR THE PROJECTION OF ONE GRATING BY ANOTHER.

4. In order to interpret these results it will be expedient to introduce a simple

hypothesis, of a kind which in the sequel may be modified to meet the true case. I shall proceed, therefore, to trace what may be temporarily called the effective planes of shadow in diffuse light. In other words, planes are to be passed between the two gratings through their consecutive wires and the loci of intersection determined. If the wires are vertical the result may be mapped out by drawing the traces of the two planes in question on a horizontal plane, and the object would be gained by solving a few straightforward problems in the modern geometry of pencils of rays. It will greatly facilitate inspection, however, if some of the chief cases which have been considered are drawn out in plan. This has been done in Figs. 3–8, which will be found additionally useful in the physical questions of the next section. *A* and *B* show the positions of the gratings and *S*, *S'*, etc., are the successive positions of the focal plane or screen. Grating spaces and image spaces are denoted by *a*, *b*, and *s*, respectively. Reference planes designated by Greek letters will be presently referred to. Wherever lines mass in a single point, there one may look for a deficiency of light coming to an observer behind both gratings. Corresponding groups of intersections thus determine a focal plane.



To begin with Fig. 3, in which $a = b$ or the two paralleled wire gratings are identical, the diagram is seen at once to reproduce the results of Table 1. At relatively remote distances the diverging planes tend to pass out of the field, and the images must therefore weaken for this reason alone. Table 3 describes the images α and δ, the latter colored; the focal plane α' with $s = \frac{1}{3}$ is also sharp. Following *S*, the planes *S'*, *S''*, etc., did not appear distinctly enough to be recorded.



The figure shows, moreover, that between A and B there should be virtual focal planes, and these must also be discoverable to the left of A. That such actually occur will be shown below, § 5, by the telescope method. The absence of S', S'', etc., will not appear surprising, since the distance AB is two meters and shadows become dif- and S' the second, the focal plane ν' will appear.

In Fig. 6, with the space ratio $\frac{1}{4}$, the image ζ is strong; the image ζ' was also found; but with these cases of high inclination θ, the images are confused and focal planes are apt to be continuous. Thus an image may be found at S', but not sharply

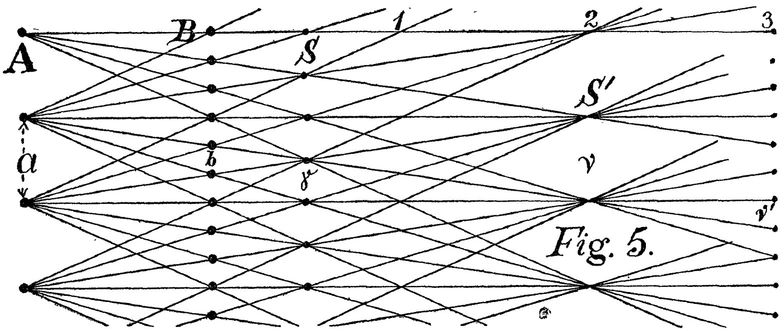


Fig. 5.

fuse. It is rather surprising that images properly produced can be obtained at over 30 meters from the projecting grating.

In Fig. 4 the meshes of B are half as large as A. Table 3 shows at η that the plane S comes out strongly and colored. S' was not found nor were the other images in position. In general a contracted diagram is liable to exceptions to be explained below.

In the preceding cases the original grating space is reproduced, as, for instance, at S' in Fig. 6, when, if $x = 1$, $x + y = a/b$. The figures are symmetrical with respect

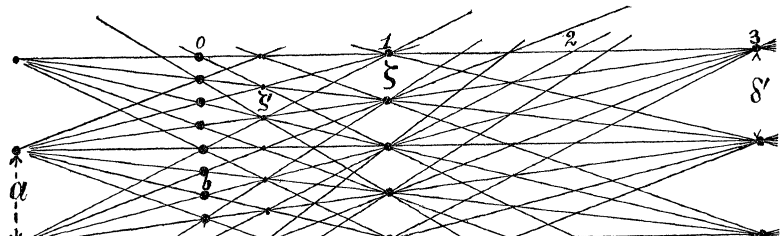


Fig. 6.

striking. Virtual foci are here also suggested. Table 4 indicates that if B be the first grating and S the second (larger) the focal plane η' is sharply traced.

In Fig. 5 the grating spaces are as $\frac{1}{3}$. Table 3 shows that the planes S and S' are both pronounced (marked γ and ν). According to Table 4, if B is the first grating to the strongest focal plane (ζ in Fig. 6, for instance). The original grating space is reduced in the image or at most equal to it. There is no magnification.

In the following cases the ratio a/b is not a whole number, and the image may therefore be magnified to an extent which is the least common multiple of a and b. Moreover, $s/a = y/x$, so that the strong image is usually remote. The projected grating is here taken as the larger, $a>b$. If $a<b$ the corresponding image space will be $s' = b(1 + (x/\overline{x+y})(\overline{2a-b}/b))$.

In Fig. 7 the ratio a/b is 3/2. Table 3 shows the focal planes β and μ to be pronounced. The magnification at μ is 2, with strong brown lines on a white ground which contains faint traces of a pinkish diffraction band in the middle.

the light areas which are alternately white and colored reddish.

The final case to be exhibited in detail is Fig. 8, where $a/b = 4/3$. The focal planes ε and ξ are marked phenomena, the latter at the long distance of 6 meters from B, strong and coarse as usual. With the mica screen clean cut dark bands .2 cm. broad and .7 cm. apart, cover an area of a square foot. If B is the projecting and A the projected grating ($a/b = 3/4$, light retrogressing), Table 4 shows the focal plane at 4 meters well marked, and found from Fig. 8 by prolonging the lines backwards, in the direction BA.

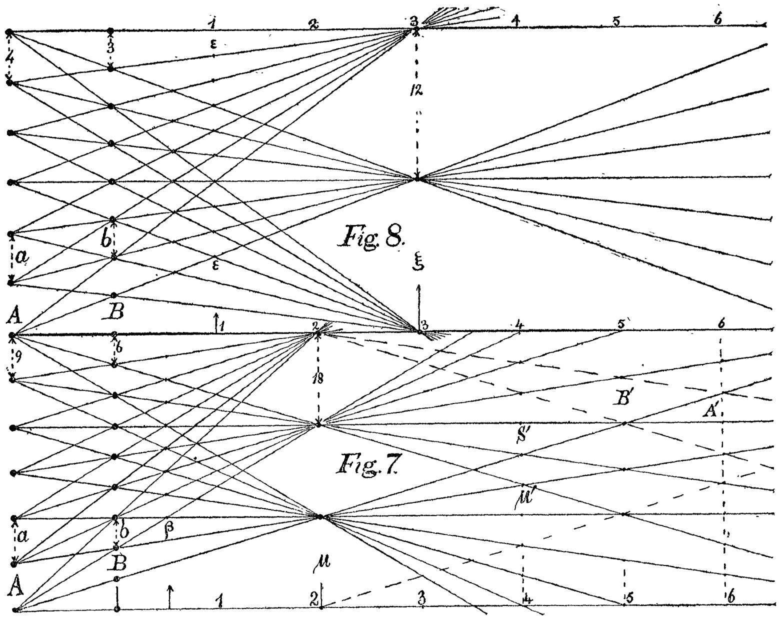


Fig. 8.

Fig. 7.

If the ratio a/b is 2/3, A' and B' may represent the positions of the grating, the light retrogressing, so that S' is the corresponding focal plane. It is marked μ' in Table 4, where moreover μ is again reproduced as the second focal plane of this series. The coarse images for this and succeeding cases of long distance (6-10, even 30 meters), are a striking feature. The phenomenon becomes fainter but otherwise more remarkable and much larger if the ground glass or, better, the mica screen is placed before the first grating. The diffraction character then becomes manifest in

The other cases of Tables 3 and 4 are found by subjecting Figs. 7 and 8 to a homogeneous strain, with the principal strains in the horizontal and vertical directions. Similarly, 7 would follow from 8 or from the above figures. Focal planes corresponding to S are usually well shown.

As a rule, therefore, the diagrams are a convenient means of predicting the relations of size and distance of the images.

They do not account for the accompanying color which is a not infrequent occurrence; and they predict more focal planes than are easily found. The latter discrepancy might be ascribed to the imperfect gratings (wire gauze), or to lack of intensity taken as proportional to the number of lines which cross at a point in the diagrams. It would merely have been confusing to record other than the strong cases. The diagrams fail altogether to suggest how a thin wire is to cast a shadow of the order of 10–30 meters in length, even in diffuse light. It is in this respect that the explanation will have to be supplemented. In the meantime, however, it seems worth while to test the position of the virtual foci between AB and beyond B.

5. For this purpose it is convenient to place the gratings far apart and observe with a telescope as shown in Fig. 2. If f be the focal distance of the objective, and y'' the reduced distance of the conjugate focus, corresponding to the virtual focal plane S at a focal distance y', we may write $1/y' + 1/y'' = 1/f$. With y' computed in this way, $y = y' - z$, where z is the distance between the objective of the telescope and the grating B; and y, as usual, the distance between this and the image. The distance x may be measured or found by the same method.

This experiment gives excellent results for the number and relative size of the successive images between A and B. It is a crude method of finding the distances y, sufficing, however, to pick out their position in a series. If A be the clapboarding of a distant house and, B an ordinary window screen through which A, distant about 300 feet, is observed, the conditions for many virtual foci will be realized. Table 5 gives an example of results of this kind.

The table shows that the limits of y are pretty well given, the visible foci should all lie near B as found. All the focal planes observed are predicted by a diagram of intersecting pencils of rays of the kind above exhibited, as indicated by the third and fourth columns of the table. Nevertheless,

TABLE 5.—VIRTUAL FOCI BETWEEN THE GRATINGS. $x = 10{,}000$ CM. $z = 274$ CM. GRATING SPACES, $a = 10.7$, $b = 22$ CM.

Focus. No.	y'', reduced.	y, predicted.	y, observed.		Size.
Screen	37.0	0	0	(0)	——
2	35.8	63	56	(1)	small.
3	35.5	125	137	(2)	larger.
—	—	188*	—	—	——
4	34.8	250	272	(4)	largest.
—	—	313	—	—	——
—	—	375*	—	—	——
—	—	437	—	—	——
5	34.1	500	532	(8)	smaller.
—	—	563*	—	—	——
—	—	625	—	—	——
—	—	688	—	—	——
6	33.7	750*	756	(10)	much smaller.
Clap boards	32.8	—	10,000	—	——

many images are predicted which do not occur; and whereas the predicted images should be all of nearly a size, practically of the same grating space as B, the images found are all much smaller. They increase to a maximum and then diminish again in the direction BA, with the largest not more than $\frac{1}{2}$ of b. Possibly the presence of two or more focal planes in the telescope at once would account for the discrepancy of size and number, but the planes marked * which should be strong do not appear specially so in the experiment. In general, therefore, the diagrams give a good outline of the phenomena, but fail in the particulars. One may note that the foci found are in a distance ratio of 0, 1, 2, 4, 8, 10, which is liable to be more than a coincidence.

Another class of virtual foci consists of images not lying between the gratings, but on one side of both when looked at from the other side. This implies the same method of telescopic observation: obviously the cases of Figs. 3–8 can all be found as virtual images by a telescope in front of A, looking from A to B. In such a case A may be moved quite up to the object glass or drawn on it. Knowing the position of the images, it is possible that such an arrangement might be used in measuring distances, A being for this purpose taken suitably greater than B.

Here I may revert to the observations with and without spectacles instanced above. If the eye is so circumstanced as to focusing power as to be able to see grating A in the distance through grating B distinctly, then the shadow bands will be out of focus and faint. If, however, a near-sighted eye or one made abnormal by convex or in a second case by concave lenses, grating A is quite out of the range of vision. The eye will then find and fix upon one of the focal planes, virtual or real, due to the projection of A by B. If there be not too much stray light, the shadow bands in such a case are painfully obtrusive.

LONG SHADOWS CAST BY THIN WIRES IN NON-PARALLEL LIGHT.

6. It is finally necessary to explain the long lines of shadow assumed tentatively in the above hypothesis. Even in sunlight a filamentary wire will not cast an effective shadow further than 5 or 10 inches; the shadows here encountered may be 100 feet in length.

Clearly the phenomenon is one of diffraction, and it will be expedient to recall the fundamental case of a single slit and a single edge. The pattern is well known, consisting outside of the geometrical shadow of a very bright and then very dark band, followed by colored alternations of light and shade more cramped and much less distinct and intense. Within the shadow the light sinks gradually into darkness.

Suppose the slit to be displaced laterally to the left a small distance; the whole diffraction pattern will then move toward the right over the same distance if $x = y$, and for other distance ratios, proportionally. Now suppose that both slit actions occur simultaneously. The feature of the diagram will be the two maxima of light enclosing between them a shadow band without color, which is a compound of the darkness within the geometrical shadow for the first slit, now limited on the right side also by the maximum of the second slit and its external dark band. *The effect therefore is the same as if the bar between the two slits were projected.* For $x = y$ the distance between the light maxima will be the same as the distance between the slits otherwise in proportion to relative distance. If the slits are finer the phenomenon is darker and sharper; if coarser, brighter and more vague. If the slits move closer together the bands move closer proportionally. Color is rarely apparent.

It follows from the preceding that with 3 slits and an edge, 3 maxima of light and 2 dark bands without color will appear; with 4 slits, 4 maxima and 3 shadows, etc. The whole phenomenon may be regarded as crowded into the geometrical shadow of the first slit. Hence if the slits increase in number the number of bands will soon reach a limit as more and more light falls inside the edge of the shadow in question. With a coarse grating (rods and spaces say .2 cm.) but 5 shadow bands may appear for an indefinite number of spaces. In general the diffraction pattern covers a certain area; if the slits move closer together there will be more and finer bands visible; if they move farther apart, fewer. With an edge just in front of a telescope or on the objective and light nearly screened off, an indefinite number of lines may be seen on looking at a distant white surface through grating A. From the distance of A from the objective (.1 to several meters) and the size of image and object the magnification of the telescope may be inferred.

7. With the case of an edge and multiple

slit sufficiently disposed of, the case of a single wire and multiple slit is not far to seek. There will be a series of light and shade bands for each edge of the wire, and the two series will eventually run through each other. A single slit has within the geometrical shadow the well known brownish band, finely fluted and broad for a thick wire, coarsely fluted and narrow for a thin wire. With 2 slits there will be 2 shadow bands with a maximum of light between for a fine wire, or 3 bands with an intensely dark one in the middle for a stout wire (say 3 mm.). With 3 slits and a fine wire 3 shadow bands appear at long ranges ($y/x = 1/3$), more at short distances. With a coarse wire 4 at long ranges with the two internal bands intense, 5 or more at short ranges, etc. It follows eventually that with a *multiple* slit and wire the diffraction patterns may be looked upon as compounds of the light and shade bands of *each edge.* At $x = 2$, $y = .5$ meters, a blur usually appears for the thin wire, sharp fine lines edging a broad central shadow for the thick wire. This continues up to 2 meters in the latter case; but with the thin wire with y between 1 and 2 meters, there are apt to be colored blue and red bands of a very complicated pattern. Beyond two meters the figure is in all cases again simply white and black, with the former or the latter wider conformably with the structure of grating A, supposed to be at 2 meters from B. Size of rod is without influence here. With the thick wire the central ever-narrowing shadow may be visible beyond 2 meters, and as it apparently thrusts the bands apart the figure is relatively broad. In so far as the edge effect predominates and overlapping is obscured in the middle, the bands appear in focus at all distances.

8. From these results to the actual case of the grating is an easy step. Grating A furnishes the multiple slits, about 5–10 of which are effective for every wire of grating B. Each of these has its own series (about 8 in the above case) of shadow bands, all identical in form. When for any position on the axis the shadow bands of all the wires of B coincide, there will be a focal plane at that point and B will project an image of A. At other points there will be no image, for patterns overlap irregularly, light falling on shade and producing more or less uniform illumination. Figs. 3–8 show the conditions to be such that many band series must overlap, and hence the greater definition of focus.

At close ranges, therefore, both the width of the wire (in relation to the independent shadow bands of each of its edges) and the distance apart of the wires (in relation to the above Figs. 3–8) must be of proper value to produce coincident effects. At long ranges coincidences depend more on the diagrams.

From another point of view we may consider the band series of the right and left hand edges of the wire of the grating independently. The former will be brought to focus at those points of the axis where the successive images of corresponding edges overlap. The latter equally so. The two images so formed, and corresponding respectively to the two edges of all the wires of B, will not blend in a compound image, unless the images coincide. If the separate edge images are apparently displaced relatively to each other, *i. e.*, if there is appreciable non-coincidence of shadow bands, there will be no focal plane even if the images of the separate edges are perfect. Hence there is an adequate account given of the absence of focal planes predicted by the above constructions. Again, just as there may be color effects for a single wire at certain distances, so for the wires conjointly there will be color phenomena between the images of all corresponding edges. Finally, an inkling is given as to why focal planes which from diagrams 3–8 one would expect to be strong, do not so appear; and *vice versa*. Images which would be strong for the right and left edges separately need not be so when the former are superimposed on the latter.

With these remarks I believe to have given a sufficient account of these interesting diffractions. I began the work since in all my reading in physics I had never seen a reference to these ubiquitous phenomena, and I hoped with the present paper to furnish at least one contribution of known whereabouts. In the course of the work I found much greater subtlety than I was prepared for, and some of the cases given are available for more rigorous treatment elsewhere.

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THE CROSSLEY REFLECTOR OF THE LICK OBSERVATORY.

THE leading article in the June number of *The Astrophysical Journal* has the above title and was written by Professor Keeler. It is a very full account of the instrument and of the work accomplished with this telescope since its installation on Mt. Hamilton. I am very glad to comply with the request of the editor to furnish an abstract for SCIENCE.

The frontispiece of the number is an excellent heliogravure plate of the 'Trifid' nebula in Sagittarius, from a negative made with the Crossley reflector. In this connection it ought to be said that no known method of reproduction gives all the detail to be seen on the original negatives of such subjects. There are also halftone illustrations, from photographs, of the details of the telescope and its observatory.

This telescope was made by Dr. A. A. Common, of London, in 1879, and used by him until 1885, when he decided to build one of 5 feet aperture. He then sold the 3-foot instrument to Edward Crossley, Esq., of Halifax, England. For the construction of the instrument and for photographs obtained with it, Dr. Common was awarded the gold medal of the Royal Astronomical Society in 1884.

Mr. Crossley built a very complete observatory and dome for the telescope and used it for a number of years. The climate of Halifax was not adapted to the use of reflectors, however, and in 1895, at the request of Professor Holden, then director of the Lick Observatory, Mr. Crossley presented the telescope and its dome to this institution. The expenses incurred in transporting it from England and in erecting a suitable building on Mt. Hamilton were borne by friends of the Lick Observatory, principally residents of California. It was mounted here the same year. Its dome is situated on a spur of the mountain some 350 yards to the south of the main observatory and about 150 feet lower. The building contains, in addition to the dome and vestibule, a photographic darkroom, a study, a room for apparatus and storage, and a room for the hydraulic machinery which was used in England to revolve the dome. The present site is such that the hydraulic system which is used for the large refractor is not available for the Crossley reflector. The dome is turned by hand by means of an endless rope and a set of gears working in a cast-iron rack bolted to the inside of the sole plate of the dome. The dome is covered with sheet-iron, the framework being of iron girders. It is of the usual form, with a shutter in two parts which are rolled to each side, exposing a slit six feet wide. The slit extends well beyond the zenith. From the inside of the dome is swung a system of platforms around the telescope for the observer to stand upon. The cylindrical walls upon which the dome rests are double, 36¼ feet inside diameter. The dome itself is 38 feet 9