significance of this plot, considering the arbitrary way in which the points have been classed as air, is doubtful, and it would perhaps have been just as well to assign all of these doubtful collisions to neon, and plot them on the other curve.

In addition to the tracks photographed in neon, one run of about 600 pictures was taken with a mixture of about 30 percent deuterium and 70 percent air. In this series one collision with deuterium was observed, which is reproduced in Fig. 1(b). Unfortunately the complete track of the deuteron (right-hand tine of fork) after collision was not observed. It is interesting to note that this fork may be immediately recognized as a collision with a deuterium atom for the following reasons: The angle of deflection of the alpha-particle, ϕ, is about 25°, therefore it cannot have struck hydrogen since the maximum value of ϕ in hydrogen collisions is 14.5°; the value of ϕ is less than 30°, the maximum for deuterium collisions, so it is consistent with this explanation; the track of the struck particle is finer, showing less ionization, and has the appearance of a proton or deuteron track, and, finally, the value of m/M is calculated to be 0.57, in agreement with 0.5 for a deuteron collision.

In Fig. 1(g) is shown an unusual type of fork, the recoil atom of neon experiencing a marked deflection, producing a second small recoil. Fig. 1(c) shows a photograph of an unusual type of alpha-particle track. Because of a series of small deflections producing negligible recoil spurs, the atom has experienced a net deflection of about 180°, producing a curiously shaped track.

In conclusion, it is a pleasure to thank Professor A. F. Kovarik for constant advice and encouragement throughout the course of the work, Dr. Ernest Pollard for many helpful discussions, and Professor L. W. McKeehan for numerous suggestions regarding the composition.

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Anomalous Diffraction Gratings

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Gratings similar to those described and studied by the author in 1907 and 1912 have been more fully investigated. They show narrow bright and dark bands in the continuous spectrum of a white source. Classical theory has never accounted for these anomalies, though tentative efforts were made at the time by Lord Rayleigh. The present work was done with a chromium plated echelette grating of 7200 lines to the inch ruled on copper, and one of 15,000 lines ruled by Dr. Babcock on an aluminum film on glass. The behavior of the bands as the incidence angle is altered has been very completely recorded by photography and the energy missing in the grating spectra has been found in excess in the spectrum of the central image. The dark bands appear to be due to the circumstance that diffracted wavelets from the lines are inhibited by the collective effects from neighboring lines, i.e., there is a sort of destructive interference along the plane of the grating. This obtains, however, only when the grating space is equal to an integral multiple of λ (for normal incidence) which means that the dark bands correspond to λ values which are passing off the grating on both sides at grazing emergence. The spectra formed by the Al grating are completely plane polarized, because of the circumstance that the width of the scratches is considerably less than the wave-length of the light. The dynamical action of the gratings is discussed, and the anomalous behavior is shown to be due to the presence of exceedingly narrow diffracting elements, which may be present even in the case of rather coarse rulings.

As is well known the distribution of intensity in the spectra formed by gratings varies in the different orders, some being bright in the red, others in the violet, and these variations are easily accounted for by elementary theory.

It is possible, however, to rule gratings showing bright and dark bands in very restricted spectral regions, and these anomalies have never been accounted for.

At the bottom of Fig. 1, Spectrogram 9, we have a photograph of the spectrum of a Mazda lamp filament taken with such a grating extending from the extreme red (at the right) to the violet. The black bands are very sharply

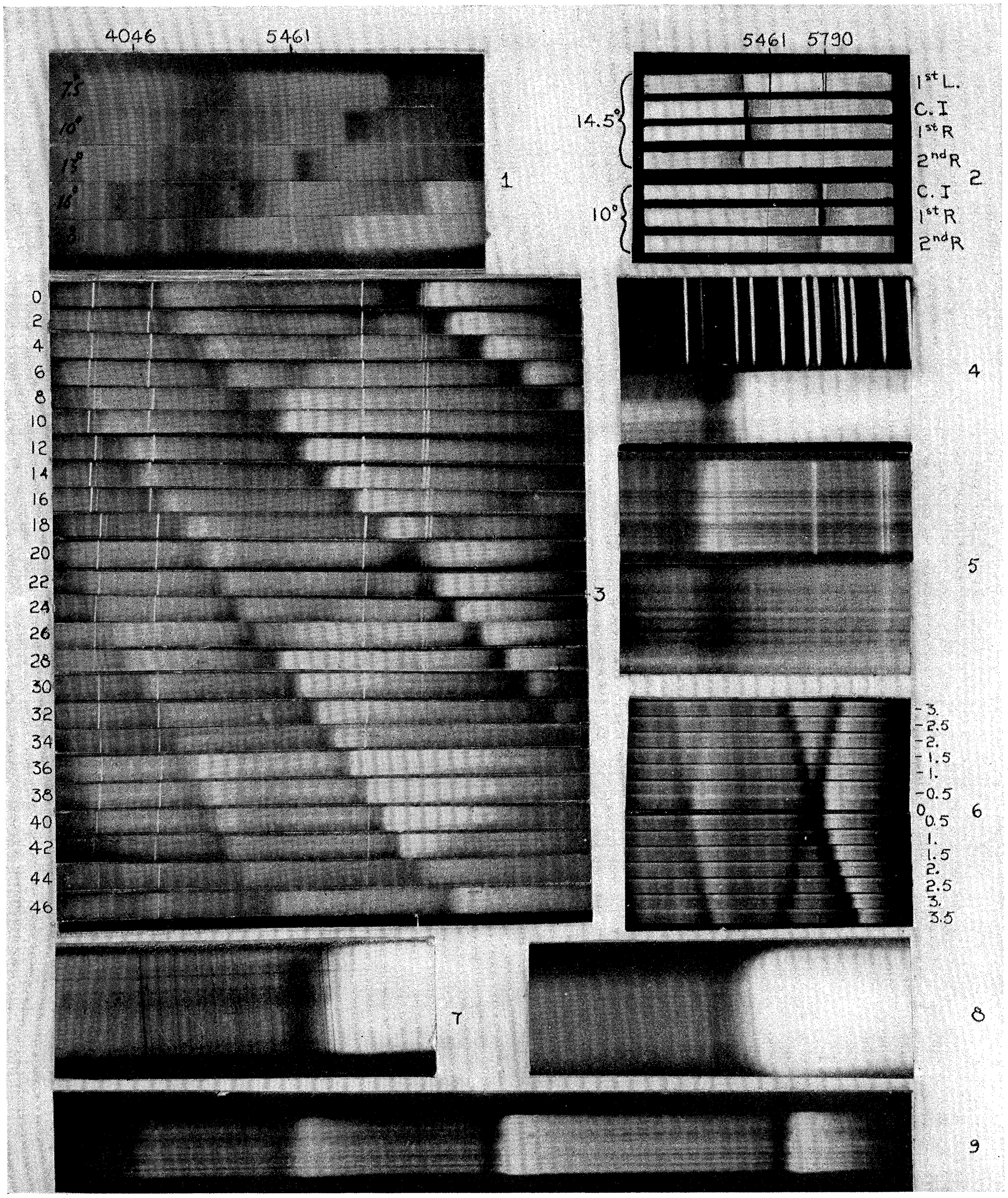

Fig. 1.

bounded on the short wave-length side, and the intensity increment in passing from the minimum to the maximum is from fifteen to twenty-fold. Until such maxima and minima can be accounted for by theory we must confess that our knowledge of the action of a grating is far from complete.

Gratings of this type were studied and described by the author in 1902[1] and again in 1912, and the late Lord Rayleigh became much interested in them and discussed them in several of his papers.[2] He pointed out that anomalies might be expected at regions in the spectrum corresponding to wave-lengths passing off the grating at grazing emergence in the spectra of higher orders, and this I verified in a number of cases, as reported in the second of the two earlier papers referred to above.

One of these gratings showed a narrow bright line in the red and a dark line in the green. These lines approached each other as the angle of incidence was decreased, meeting and canceling each other at 0° incidence. A further slight rotation of the grating developed a dark band at this point which split in two, one band moving up, the other down the spectrum as the incidence angle was increased. The motion of the bands in opposite directions is to be associated with the circumstance that, as the grating is turned, the wave-length passing off at grazing emergence increases on one side of the grating and decreases on the other. Though these effects were first noticed in a ruling on speculum metal the best results were obtained by ruling on a thin film of gold or silver deposited on a polished speculum flat. One of these showed a very bright first-order spectrum on one side and a faint one on the other, and it was in the latter that the bright and dark bands appeared. A very light rubbing with a "powder-puff" brightened the faint spectrum and caused the complete disappearance of the anomalies.

This led me to express the opinion that the faint spectrum came from the wavelets diffracted by the steep sides of an unsymmetrical groove and that the anomalies resulted from energy diffracted by very narrow and fragile ridges running along the edges of the groove, pressed up above the general level. This I have again verified by ruling on a copper flat. The effects shown by the old gratings were so complicated, however, that it was difficult to make any hypothesis as to the manner in which they operated. In one case, for example, a bright narrow line moved down the continuous spectrum towards a wider dark band which it finally entered without any loss of intensity! Lord Rayleigh[2] showed that, in the case of sound waves passing, at normal incidence, through very narrow parallel slits, the passage of energy through any slit might be prevented by the cooperative action of the other slits, *under the condition that the distance between the slits was an integral multiple of the wave-length*, which of course corresponds to the condition of the wave-length passing off of a grating at grazing emergence. He expressed the opinion that some such action operated in the case of the optical gratings. He developed this idea somewhat more fully in his subsequent paper *On the dynamical theory of the diffraction grating*, without however, arriving at any completely satisfactory explanation of the anomalies.

My interest in the subject, which has smoldered for more than a quarter of a century was rekindled by seeing a grating exhibited by Dr. John Strong at the Berkeley meeting of the Physical Society in 1934. The bands shown by this grating appeared to be of a simpler type and much easier to study. They were of the same wave-length in each spectrum, and were very black. As I have always pointed out, the first thing to do in any case where certain wave-lengths are absent as a result of an unknown process (i.e., a case of unexplained color) is to find out where the absent wave-lengths have gone. They did not appear to be present in excess in the central image, and Dr. Strong and I looked for an increased heating of a small sliver of the grating, illuminated by light from a monochromator, when the wave-length corresponded to that of the black band. The result was negative, but the experiment seemed worth trying as I have found that the total light reflected by a freshly ruled grating on speculum, (i.e., central image plus all of the spectra) may be much less than the light reflected from a corresponding area of unruled surface. This means absorption by the grating, and Lord Rayleigh stated in his paper that "the grooves were clearly acting as resonators" in the case where the anomalies were shown, though I have never been able to find out just what he had in mind or on what theoretical point he based this view. At one time I ran across a paper in which

[1] Wood, Phil. Mag. Sept. (1902); Feb. (1912).
[2] Rayleigh, Phil. Mag. July (1907).

the analogy of the reflection of sound waves by a series of parallel equidistant slats (Venetian blind) was cited as an illustration of resonance of this type, but I am unable to find the paper and have forgotten by whom it was written. I shall be grateful for the reference.

In the present paper very complete investigations with two gratings of this type will be discussed, one of 15,000 lines to the inch ruled on a surface of aluminum by Dr. Babcock of Mt. Wilson Observatory, the width of the diamond scratches being of the order of one-eighth of the grating space, or one-third of the wave-length of red light; the spectra formed by this grating are all completely plane polarized with the electric vector perpendicular to the groove, and are of low intensity, while the central image or directly reflected light is nearly as strong as from the unruled surface.

The other grating I ruled on a polished flat of copper, with a diamond edge ground to an angle of about 110 degrees, 7200 lines to the inch, the grooves symmetrical with respect to the normal, and meeting along their edges. The central image was extremely weak and there was a very strong concentration of energy in the spectra lying in the direction of reflection from the groove edges. The two gratings are therefore about as different in type as it is possible to make them. They have, however, this feature in common: At normal incidence the energy diffracted at nearly 90° is of considerable intensity. In the case of the aluminum grating this is due to the narrowness of the scratches, which also accounts for the polarization, for, as was shown by Lord Rayleigh, a very narrow scratch diffracts powerfully in the direction from which the incident light is coming, and the diffracted light is polarized perpendicular to the scratch, as in the case of light transmitted by a narrow slit. As we shall see, at oblique incidence with this grating the spectrum leaving at grazing emergence, which is the one which governs the appearance of the anomalous bands, is very bright on the side nearest the light source, i.e., in the direction from which the light is coming. In the case of the copper echelette, however, the strong spectrum at grazing emergence which controls the bands leaves the grating on the side farthest away from the source in the case of oblique incidence. The anomalous bands in this case appear to be due to fragile and very narrow ridges lying along the edges of the deep grooves, for the lightest rubbing with the rouged finger tip, abolishes completely the bright and dark bands and brightens up the entire spectrum. This makes it appear as if the ridges diffracted powerfully in the direction away from the source, instead of towards it. The importance of relative high intensity at grazing emergence appears to depend on the circumstance that the emission of a diffracted wavelet from a grating element can be abolished (or in certain cases augmented) by the cooperative effects exerted by neighboring elements.

One of the puzzling questions raised in my earlier paper was that regarding the manner in which such a great change in intensity could occur over a region only a few Angstrom units in width, which would appear to require the cooperation of a large number of lines. I do not now attach much significance to my observation that they could be seen when only a very narrow portion of the grating was illuminated, and I hope to be able to make some anomalous rulings of only 50, 100, 200, etc., lines, all made under the same condition, with the same point, to test this matter more fully. The circumstance is connected, I think, with the very high dispersion of a grating in the vicinity of grazing emergence, (becoming infinite at true grazing).

If we accept Lord Rayleigh's hypothesis, we may perhaps refer what we may term the high resolving power of the anomaly (i.e., great intensity change over a very narrow spectral region) to the circumstance that the annihilation of the diffracted wavelet at its source requires the combined cooperation of effects from a large number of neighboring lines.

This high resolving power is well shown in Spectrograms 7 and 8, Fig. 1, the former a small portion of the green region of the solar spectrum in which the little *b* triplet of magnesium lies at the right-hand edge of the dark band. The extremely sharp edge of the band on the short wave-length side is still better shown by Spectrogram 8, made with a Mazda lamp in the same region, as the edge is not masked by the Fraunhofer lines. As I have said before, until we can explain this photograph we cannot pretend that

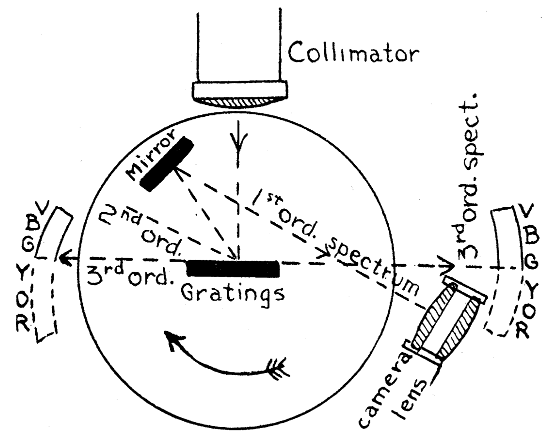

FIG. 2.

we have a completely satisfactory theory of the diffraction grating.

We will now take up the study of the behavior of a typical grating of this type, the one ruled on aluminum. Spectrogram 3, Fig. 1, gives a complete picture of the behavior of the grating at all angles of incidence from 0° to 46°. It is a composite of 23 spectrograms, mounted in coincidence. The source of light was a small Mazda lamp backed by a mercury arc, so that the strong mercury lines appear on the continuous spectrum and serve as reference marks. The lamp was focused on the slit of a collimator and the grating mounted on a graduated circle furnished with a vernier as shown in Fig. 2. The grating was at first set at normal incidence by holding a card perforated with a small hole in front of the collimator lens and turning the grating until the narrow beam was reflected back through the hole. The spectrum used was the first order to the *left* as shown in the figure, as it was desired to study the effects from zero to the largest possible angles of incidence, turning the grating clockwise as indicated. When working with the grating at angles which projected the spectrum in the direction of the collimator a mirror was used on which narrow horizontal strips of silver had been removed, the light passing through the clear spaces to the grating (tilted up very slightly) while the rays forming the spectrum were reflected from the silver strips. At large angles of incidence the mirror was dispensed with, though this reversed the spectra of course. The upper spectrum of Spectrogram 3, Fig. 1, was taken at normal incidence, and we find a dark band between the 5461 and 5790 mercury lines, and another nearly in coincidence with 4046. The grating space is 0.001667, and since the third-order green is passing off at grazing emergence on both sides we calculate the wave-lengths of these two bands as 0.001667 divided by 3 and 4, respectively, namely, 0.0005557 and 0.0004167. There should also be a band at 0.000833 corresponding to $0.00166=2\lambda$, and this was found by photographing the spectrum on an infrared plate.

Now at normal incidence it is clear that, since $\lambda=0.000555$ is passing off at grazing in the third order, the red, orange, and yellow of the third order spectra are "below the horizon" (so to speak) of the grating, or more exactly this portion of the third-order spectra is absent, as indicated in Fig. 2. Turning the grating clockwise lifts the spectrum at the left above the horizon and depresses the one at the right. The grazing emergence λ is thus increased in the left-hand spectrum, causing the corresponding dark band to move towards the red, while in the right-hand spectrum it is diminished, causing the corresponding dark band to drift towards violet, in other words the single band at $\lambda=0.000555$ at normal incidence is in reality two superposed bands, which divide as soon as the grating is rotated even through as small an angle 0.5°, one component moving *down*, and the other *up* the spectrum. So sensitive is the appearance of the band that a visual observation served better than the perforated card for setting the grating at normal incidence. We thus obtain a very clear picture of the relation between the two sets of dark bands, and the grazing λ's on each side. It is clear from the photograph that the bands which move towards the red are blacker and more distinctly defined than the other set, which have nearly disappeared at 40° incidence, and are invisible at all larger angles.

The successve spectra of Spectrogram 3, Fig. 1, were taken with 2° increments of the incidence angle. At 10° the violet band has moved up the spectrum and has met the green band which has moved down, and it is by this continuous meeting and crossing of the bands that the chess-board pattern is formed.

It will be noticed that at large angles of incidence the dark band is narrower and more sharply defined on the short wave-length edge. Spectrograms 7 and 8, for example, were taken with an incidence angle of 60°, and are of course much more highly enlarged than the spectra of Spectrogram 3.

Another feature, of considerable importance for the discussion of the theory is that the bands become less conspicuous in the short wave-length region of the spectrum. For example in Spectrogram 9 the intensity ratio of the minimum to the maximum is about 1 : 15 in the red (at the right) and about 1 : 3 in the violet. There was only the barest suggestion of a band in the ultraviolet beyond the one shown at the left of Spectrogram 9. As we shall see presently, this feature may be explained when we come to the treatment of the dynamical action of the grating. Spectrogram 6 is similar to Spectrogram 3 except that the spectra were taken with half-degree angle increments on both sides of the normal or zero angle of incidence, the minus sign indicating counterclockwise rotation in Fig. 2.

The intensity in the region between the bands, which are receding from each other, is much greater in the case of counterclockwise rotation. This is to be expected since the upper left-hand branch of the X corresponds to the lower right-hand branch, which has the maximum on the long wave-length side.

Location of the Missing Energy

It is a matter of great importance to discover where the energy goes which is absent in the spectra.

As the dark and bright bands appear at the same wave-lengths in all of the spectra, one would expect the spectrum of the central image to show bright and dark bands at corresponding points unless the energy was lost by absorption. The central image was accordingly examined through a direct vision prism, and a faint dark band was seen at exactly the same wave-length as the bright maximum in the spectrum. As the spectra formed by this particular grating were completely plane polarized a properly oriented nicol prism was combined with the direct-vision prism, with the result that the dark band now became very distinct. There was, however, no trace of a *maximum* in the spectrum of the central image, to correspond to the dark minimum of the grating spectrum. It seemed probable, however, that this resulted from the circumstance that the intensity of the spectrum on the short wave-length side of the dark band was less than three times the intensity of the band (see Spectrogram 8) while the intensity of the central image was many times greater than that of the sum of all of the spectra. This would make it impossible to detect visually the very slight change of intensity at the point corresponding to the left-hand edge of the dark band. But this slight change might be augmented by multiple reflections as in the method of "reststrahlen." The grating was accordingly mounted in front of, and very close to, a silver on glass mirror and the light reflected to and fro between the mirror and grating. The spectrum of the multiply reflected light was then observed with the nicol and direct-vision prism and was seen to exhibit a fairly pronounced maximum bordering the minimum on the short wave-length side, as shown by Spectrogram 5, in which the upper spectrum is that formed by the grating in the vicinity of Hg 5461, and the lower that of the multiply reflected light, taken with the nicol and direct-vision prism. The poor resolution of the image obtained through the nicol and prism, and the smaller dispersion of the prism (requiring greater enlargement of the spectrogram) rendered the contrast less pronounced than when observed visually.

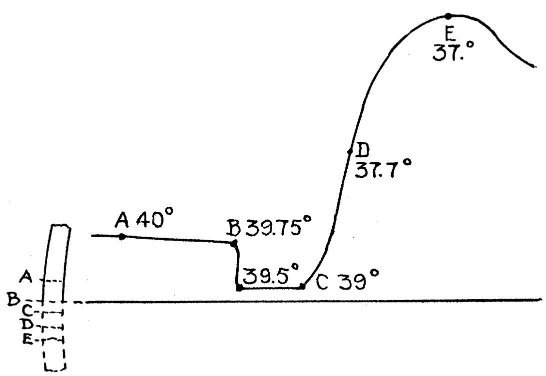

Fig. 3.

It thus appears that the energy, missing locally in the spectra, is found in the central image, which is faint in the regions corresponding to the bright bands of the spectra.

Form of Energy Curve and Its Relation to Grazing Emergence Angle

The very curious form of the curve of spectral intensity at the band should prove an important clue in developing a theory of the dynamical action of the grating. It is shown roughly by Fig. 3. The angle values given on the curve show the incidence angle necessary to bring the green mercury line to the corresponding part of the anomalous band, in other words they indicate the rate at which the band moves across a point of fixed λ value in the spectrum as the incidence angle is altered. The position of the fifth-order spectrum for this setting is shown at the left, the horizontal line which represents zero intensity being considered as the plane of the grating in this connection; the dotted portion of the spectrum (below the horizon) has no real existence of course. The letters indicate corresponding λ values on the curve and the grazing spectrum. It seemed very important to discover the exact point on this curve corresponding to the wave-length of grazing emergence from the grating. This was done in the following way: A very powerful end-on neon tube was placed in front of the collimator slit, and the grating set at an incidence angle of about 40°. The spectrum near grazing emergence was viewed by bringing the eye as close as possible to the edge of the grating, a good method when very faint lines are to be observed. By turning the grating the lines of the spectrum could be made to disappear in succession as they passed below what I have called "the horizon" of the grating. The camera was placed in position for photographing the spectra of the neon tube and the Mazda filament in coincidence in the spectrum of the first order, and the grating rotated until all of the red (as viewed directly in the grating) had passed below the horizon and disappeared. When the next to the last line (yellow) had just vanished (and this position could be determined with an accuracy of a small fraction of a degree) the photograph shown in Spectrogram 4 was made, showing that the grazing λ coincided with that of the sharp edge of the dark band on the short λ side. The bright bands in the spectra thus correspond to wave-lengths below the horizon in the spectra of higher order, the dark bands to wave-lengths very near and apparently a little below the horizon, while the portion of spectrum on the short wave-length side of the dark band corresponds to wave-lengths above the horizon, i.e., actually represented by a spectrum near grazing emergence.

In the case of the 7200 copper grating which was plated with chromium the anomalous bands were of a different type. With increasing angle of incidence they moved always towards the region of shorter wave-length, and were controlled by the grazing emergence spectrum on the side of the grating which was moving *away from* the light source. They thus corresponded to the bands of Fig. 1, Spectrogram 3, which slope down towards the left and disappear at large incidence angles. They were usually very black at the edge and shaded off gradually, sometimes towards the red and sometimes towards the violet, and were often bordered on the dark side by a rather narrow bright band. They were much more conspicuous when examined with a properly oriented nicol, as they were formed only when the electric vector was perpendicular to the groove. Another set of much fainter bands could be observed with opposite polarization, but their behavior has not yet been investigated.

It was found that if the central image was observed with a direct-vision prism and a nicol, bands of similar type and of equal intensity ratios were seen. These were usually similar in appearance and position to the bands in the first order spectrum on one side, and complementary to those of the other first order spectrum, i.e., the black edge occupied the same position but the band shaded off in the opposite direction. These effects are, however, so complicated that it seems doubtful whether they can be explained until a satisfactory theory of the simpler type of bands obtained with a grating formed of very fine scratches has been developed. In this case the spectra are formed by diffracted disturbances from the wide edges of the grooves and not from exceedingly narrow lines, and the anomalous bands, as I have said, appear to result from inhibiting or enhancing effects due to energy diffracted from narrow and fragile ridges bordering the grooves, which can be removed by very light rubbing.

Photographs of the spectra at incidence angles increasing from 7.5° to 23° are reproduced in coincidence in Fig. 1, Spectrogram 1. Two sets of bands appear, one shaded off towards the right (red), the other towards the left, and both move down the spectrum as the incidence angle increases. The mercury lines 5461 and 4046 appear also on the continuous spectrum. The bright line on the edge of the dark band is fairly conspicuous.

Fig. 3 is a drawing representing the spectrum of the central image in coincidence with three spectra by the grating at the same incidence angles (10° and 14°). The positions of the yellow and green mercury lines are indicated.

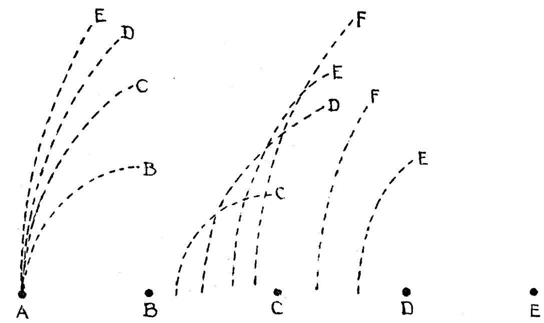

FIG. 4.

THEORY OF THE ANOMALIES

We will start with the simplest case possible and discuss in the most elementary manner the relation between the wave-length which leaves the grating at grazing emergence, and the distribution of intensity in the other spectra.

If, with normal incidence, the third-order spectrum can form for violet blue and green radiations (the yellow Hg lines being "on the horizon") it is obvious that for these wave-lengths there is less energy available for the formation of first and second-order spectra, than in the case of red and yellow radiations, which are not, in part, spent in the formation of a spectrum of third order. We should thus expect these spectra to be slightly brighter on the red side of the yellow lines than on the violet. This is roughly what we have, as shown in the upper spectrum of Fig. 1, Spectrogram 3. Rotation of the grating, however, raises one of the third-order spectra above the horizon, and depresses the other, and if we apply the previous reasoning to this case we find that the expected phenomenon in the other spectra would be high intensity in the red, a sudden decrease in the orange and another sudden and larger decrease in the green extending down to the violet, and not a doubling of a dark band, with a bright region between the two components, which is what we observe. We will now introduce another possible effect which we may perhaps term secondary diffraction.

HYPOTHESIS OF SECONDARY DIFFRACTION

Lord Rayleigh's analogy of the case of sound-waves passing through a system of very narrow parallel slits, in which case he showed theoretically that a decreased transmission might be expected when the distance between the slits was an integral number of λ is about the only foundation that I have been able to find on which to build an hypothesis. I have no physical picture of the process by which "the passage of the waves through a single slit is destroyed or lessened by the cooperative effect from the neighboring slits," but have been wondering whether it may not be termed "secondary diffraction," by which I mean that the emission of a diffracted wavelet from a single grating element is inhibited by the combined effects of diffracted wavelets from the other elements of the grating as they sweep across the surface at grazing emergence, in which direction they would all be in the same phase when arriving at the element in question. I have attempted to give in Fig. 4 a diagram of what I have in mind. It is of course only a very elementary and incomplete representation, and it is evident that only a very elaborate mathematical treatment of the whole subject will give a full explanation of all of the phenomena. For normal incidence, and with the grating space equal to 3λ, at the moment at which a secondary wavelet is about to start from grating element A secondary wavelets excited by previous waves in the incident train, arrive in phase at element A, wavelet B coming from element B, wavelet C from element C, etc. The envelope of these wavelets gives the diffracted wave front, which is extremely narrow and produces the ray leaving at grazing emergence. For slightly shorter waves the condition is as shown between elements B

and C, the wavelets from C, D and E arriving with a phase retardation. The envelope forms the wave front of the third-order spectrum leaving the grating "above the horizon," using the previous nomenclature. For waves longer than λ the condition is as shown between elements C and D—the secondary wavelets have an advance of phase, and since there is no envelope, no third-order spectrum is formed. If it can be shown that, in the last case the cooperative effects of adjacent rulings enhance, rather than suppress, the intensity of the diffracted disturbance from a single ruling a distinct advance will have been made in the development of the theory.

The conditions under which the effects of secondary diffraction might be expected to manifest themselves appear to be fulfilled in the case of all gratings of the following type. The spectra in which the anomalies occur must be weak and the spectra leaving at grazing emergence relatively strong. This condition is fulfilled if the grating is composed of exceedingly fine scratches or ridges, narrow in comparison to the grating space. In the case of the aluminum grating under consideration this was found to be the case, the width of the scratch appearing to be about one-eighth of the grating constant. Such fine ridges produce weak spectra, but diffract the light through a very wide angle, enabling the diffracted disturbance from one ridge to reach the neighboring ridge. The diffracted disturbances are polarized with the electric vector perpendicular to the ridge, in much the same way as the light transmitted by an exceedingly narrow slit. Though similar and equally marked bright and dark bands have been found with certain echelette gratings where the entire surface has been cut up by the rulings and only a very feeble central image appears, it has been found that the anomalies are caused by very narrow and fragile ridges of material along the edges of the groove, which are removed by the lightest possible rubbing with a rouged finger tip, causing the complete disappearance of the bands and a brightening of the entire spectrum.

It has been found that the anomalous bands are associated with the spectrum passing off at grazing emergence on the side of the grating which is nearest to the light source, in the case of large angles of incidence.

Assuming now that the dark bands in the spectrum result from the circumstance that the diffracted wavelets (which form the spectrum when united at the focus of a lens) are inhibited at the start by wavelets coming from the neighboring lines, we must account for the following experimentally observed phenomena.

1. That the dark minima are most pronounced in the long wave-length region of the spectrum and become less and less conspicuous as we descend towards violet. This can possibly be explained as a result of the circumstance that diffraction through a large angle, which is necessary if the secondary disturbance from one ridge is to reach the next adjacent ridge, will be more pronounced in the case of the longer waves.

2. That the set of bands which move towards the red with increasing angle of incidence become more pronounced (i.e., show a greater change of intensity in passing from maximum to minimum) as the incidence angle increases. This effect may perhaps be due to the fact that as the incidence angle increases, the grazing emergence spectrum passes off in a direction more and more nearly directed towards the source and Lord Rayleigh showed that in this direction the diffracted wave from a very narrow scratch had its maximum value. One might therefore expect a maximum effect, in this case, of the cooperative annihilating action of disturbances from neighboring grooves on the wavelet emitted by a single groove.

3. That the bands which move towards the violet become less pronounced with increasing incidence angle and disappear entirely at angles greater than 45°. This is shown on Fig. 1, Spectrogram 3 in which the dark lines which slope down towards the left are nearly invisible on the lower part of the figure. This results from the *decrease* in the intensity of wavelets diffracted in the direction away from the source which becomes more marked at large incidence angles, the grazing emergence spectrum eventually vanishing.

The above arguments apply only in the case of the grating composed of very fine scratches on a surface of aluminum. In the case of the echelette the governing spectrum is on the side away from the light source.

It seems probable that the optical constants of the metal will have to be taken into account (as was done by Voigt in his extension of Rayleigh's theory) especially since Strong's observation that the position of the bright bands varies with the nature of the metal composing the surface of the grating. This will affect the velocity of that portion of the diffracted wavelet which is traveling along the surface of the metal, as has been suggested by Langer.

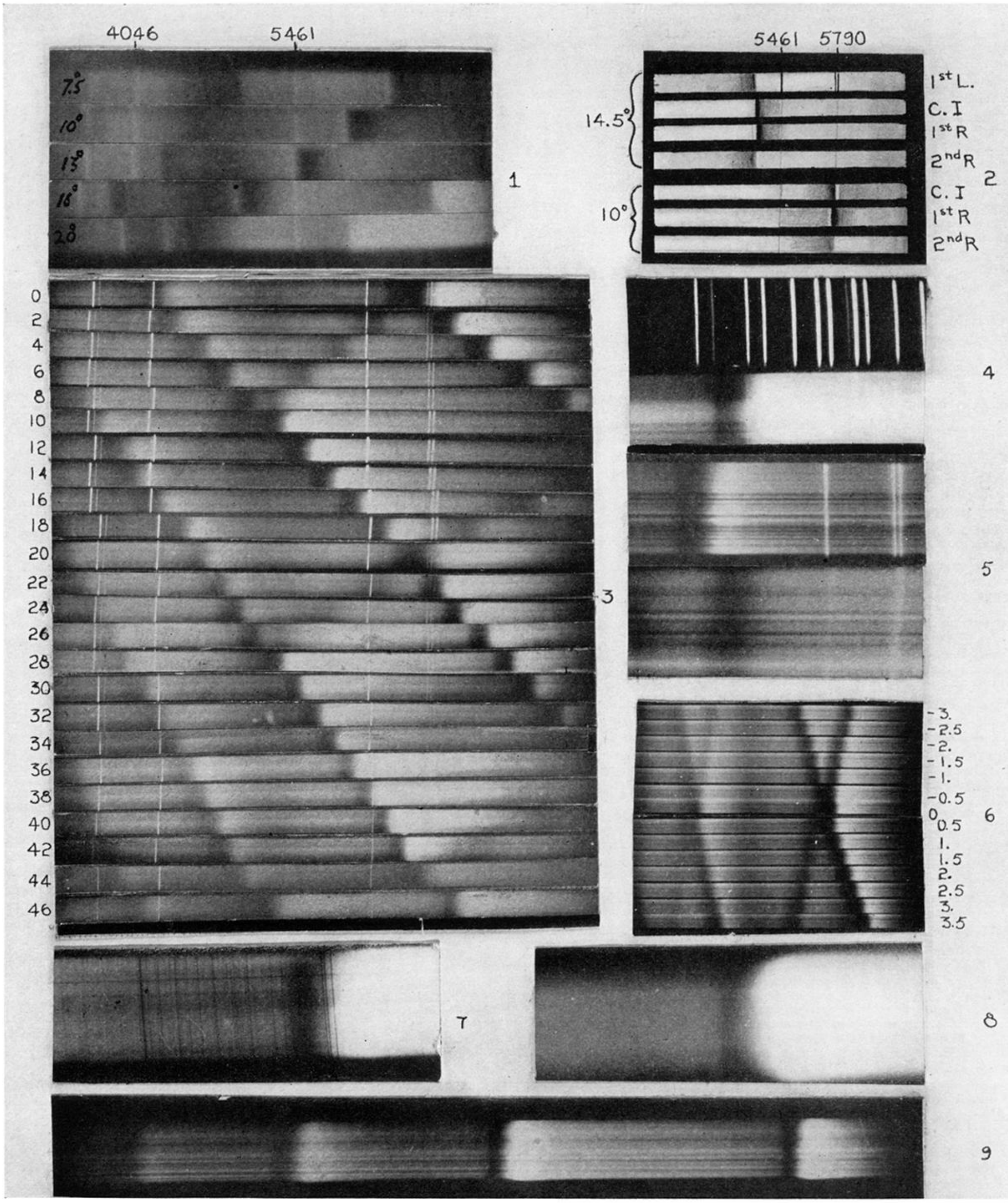

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Fig. 1.