California Institute of Technology

Pasadena , California

A STUDY OF ELECTRICALLY EXPLODED WIRES

Thesis for Degree

Doctor of Philosophy

Sinclair Smith

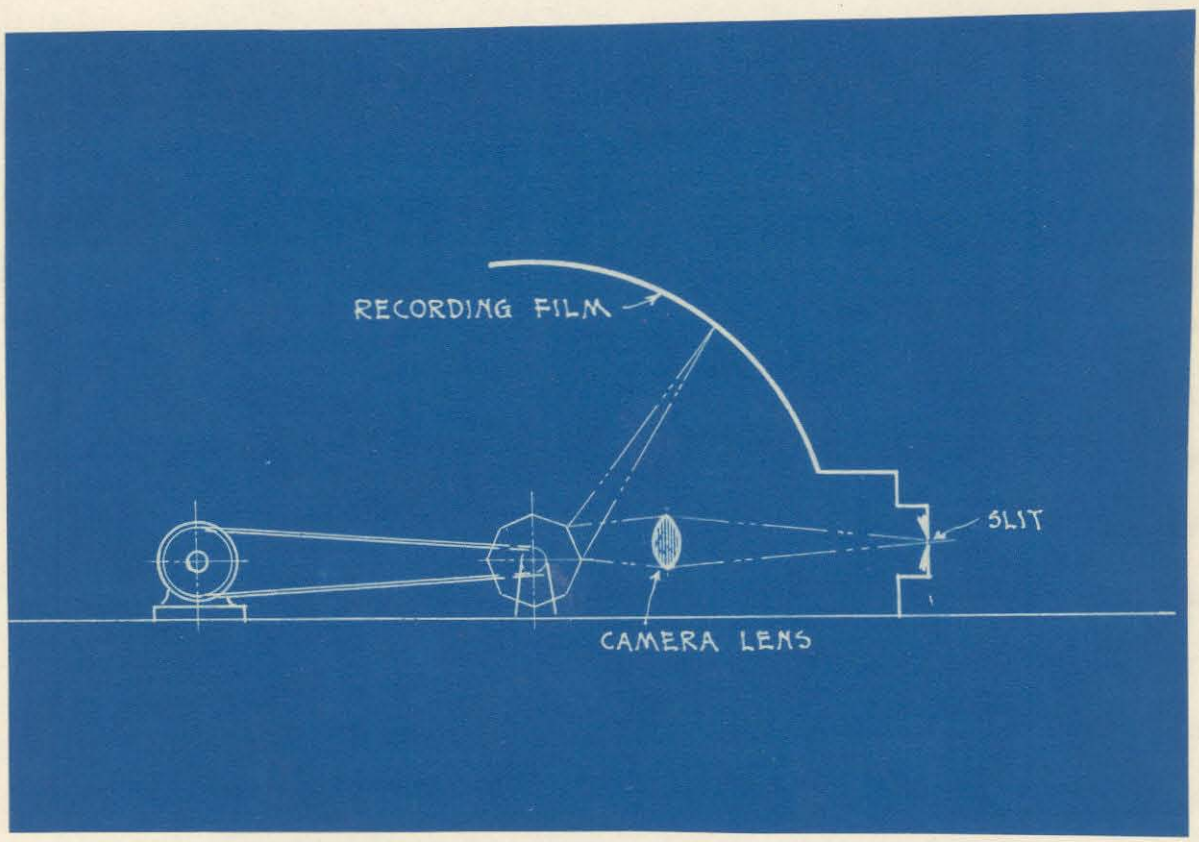
1924

NOTE ON DIRECT ROTATING-MIRROR PHOTOGRAPHS

In the following paper, a number of references are made to direct rotating-mirror photographs. These photographs were taken with a rotating mirror camera built by Dr. Anderson. This camera was described by Dr. Anderson[1] at the Pasadena meeting of the Amer. Phys. Soc. of May 5, 1923. As the full description of this instrument is not yet in the literature, the following description is given.

The general arrangement is as shown on the diagram. An image of the source to be studied is projected on the slit of the instrument. The light coming thru the slit passes thru the camera lens, and after having been reflected from one of the faces of the octagonal mirror, comes to a focus on the film as shown. In use, the instrument isolates a narrow strip or section across that part of the source image which falls on the slit, and registers on the film the changes that take place in this region of the source.

1. Phys. Rev. Vol. 22. p. 206, 1923.



Rotating Mirror Camera.

A STUDY OF ELECTRICALLY EXPLODED WIRES

Dr. Anderson has shown that electrically exploded wires furnish spectroscopists with a source of metallic vapor at an exceedingly high temperature, and further that this vapor retains a high intrinsic brilliancy for a relatively long time after the excitation has ceased. As the spectrum shows a great variety of lines, the question naturally arises, Do all the lines appear simultaneously, or do different lines appear at different times? In order to answer this question, a new type of spectrograph was built which made possible the study of the variations of the spectrum with time.

METHODS AND APPARATUS

1. The essentially new feature of this spectrograph is a rotating mirror so mounted that the beam, after having passed thru the slit and ~~then~~ suffered dispersion, is reflected from one of the faces of the rotating mirror to the focal plane of the instrument. Two of these instruments were built, one using a prism, and the other a concave grating. The arrangement of the optical parts of the prism instrument is shown diagrammatically in Fig. 1. Fig. 2 shows the position of the photographic film relative to the rotating mirror. This kind of an instrument should be faster than the one to be described, but though a number of good camera lenses were tried, no lens combination was available having the desired characteristics. What is needed, is a combination which will accurately focus the desired range of spectrum on a plane perpendicular to the axis of projection. A range of only about 100 A was the best that could be done with the lenses available, so this form of the instrument was abandoned and the concave grating type was adopted.

2. The arrangement of the slit, grating, and rotating mirror, is shown in Fig. 3, while the position of the film relative to the rotating mirror is as before.

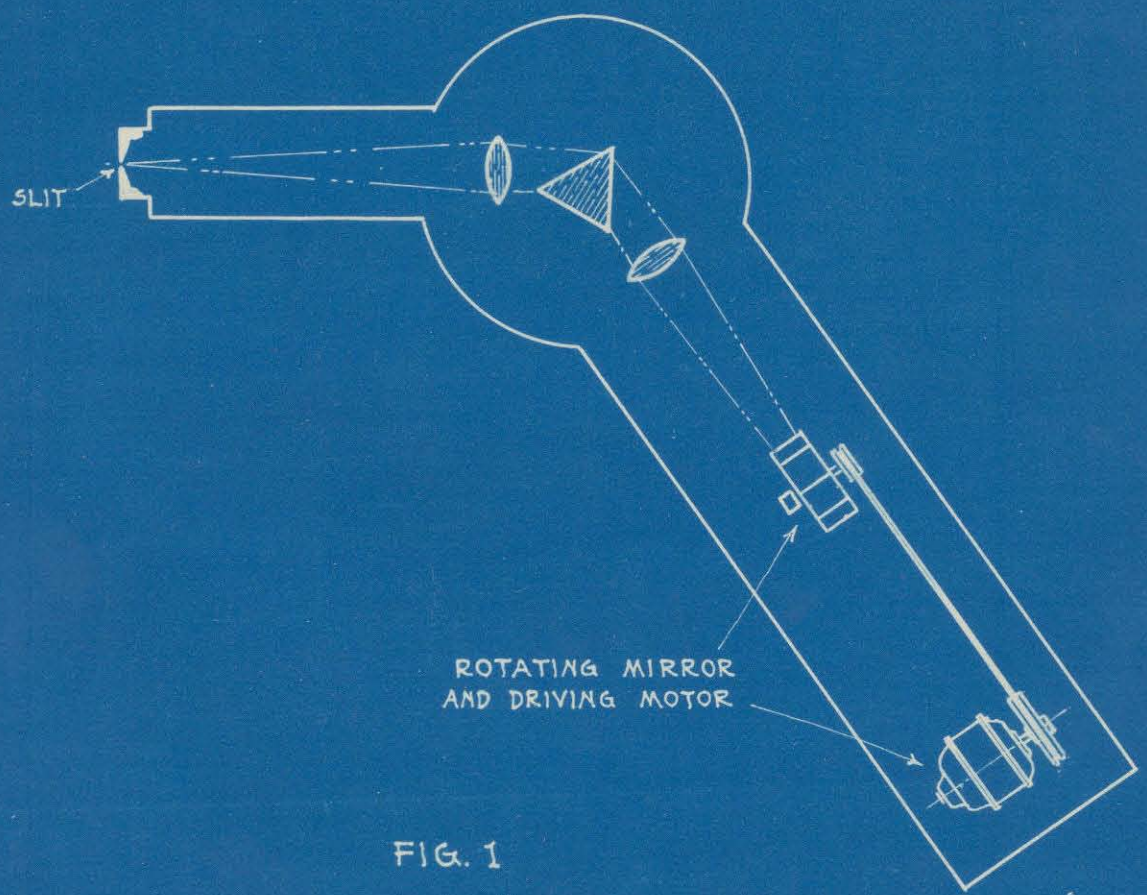


FIG. 1

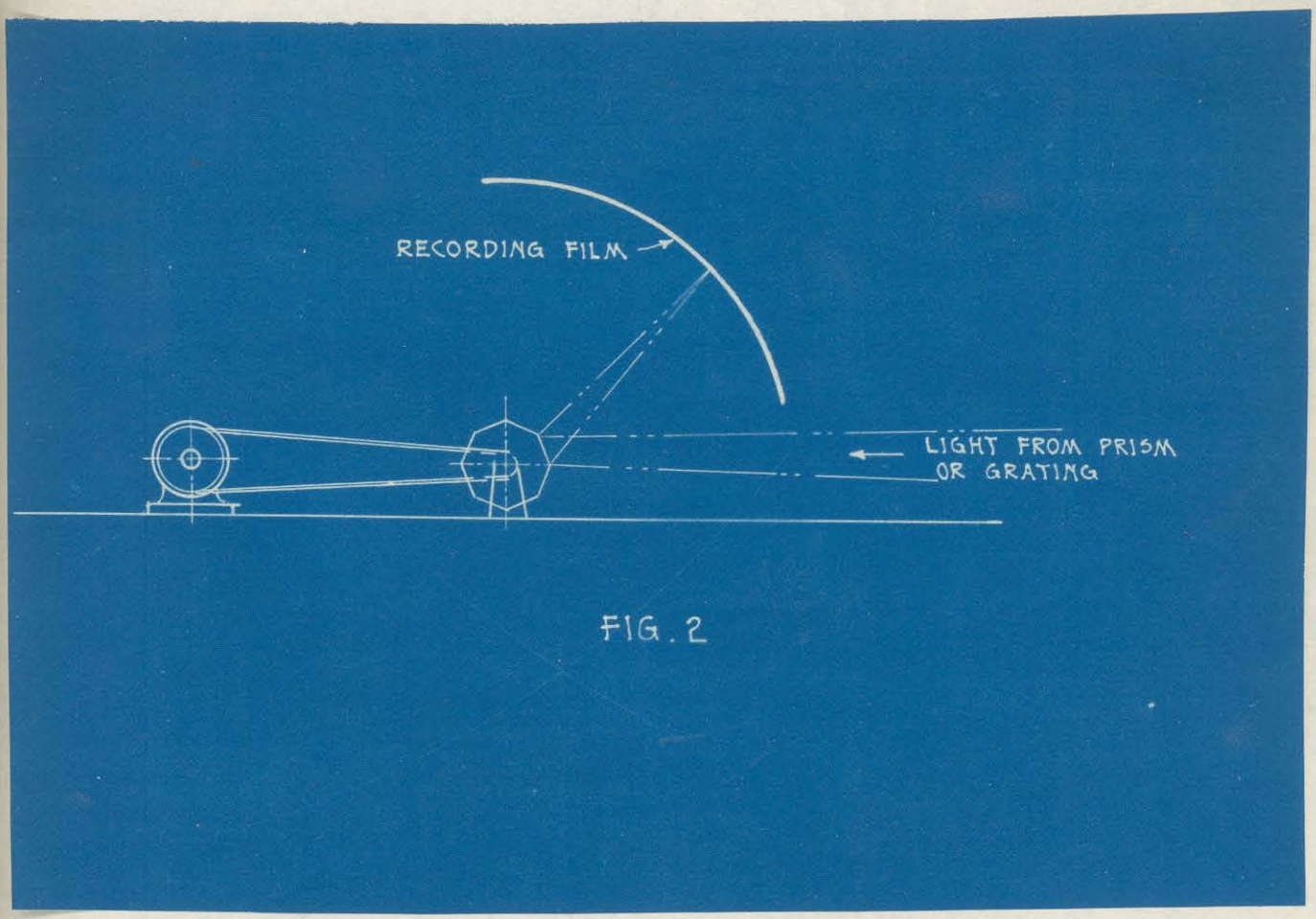


FIG. 2

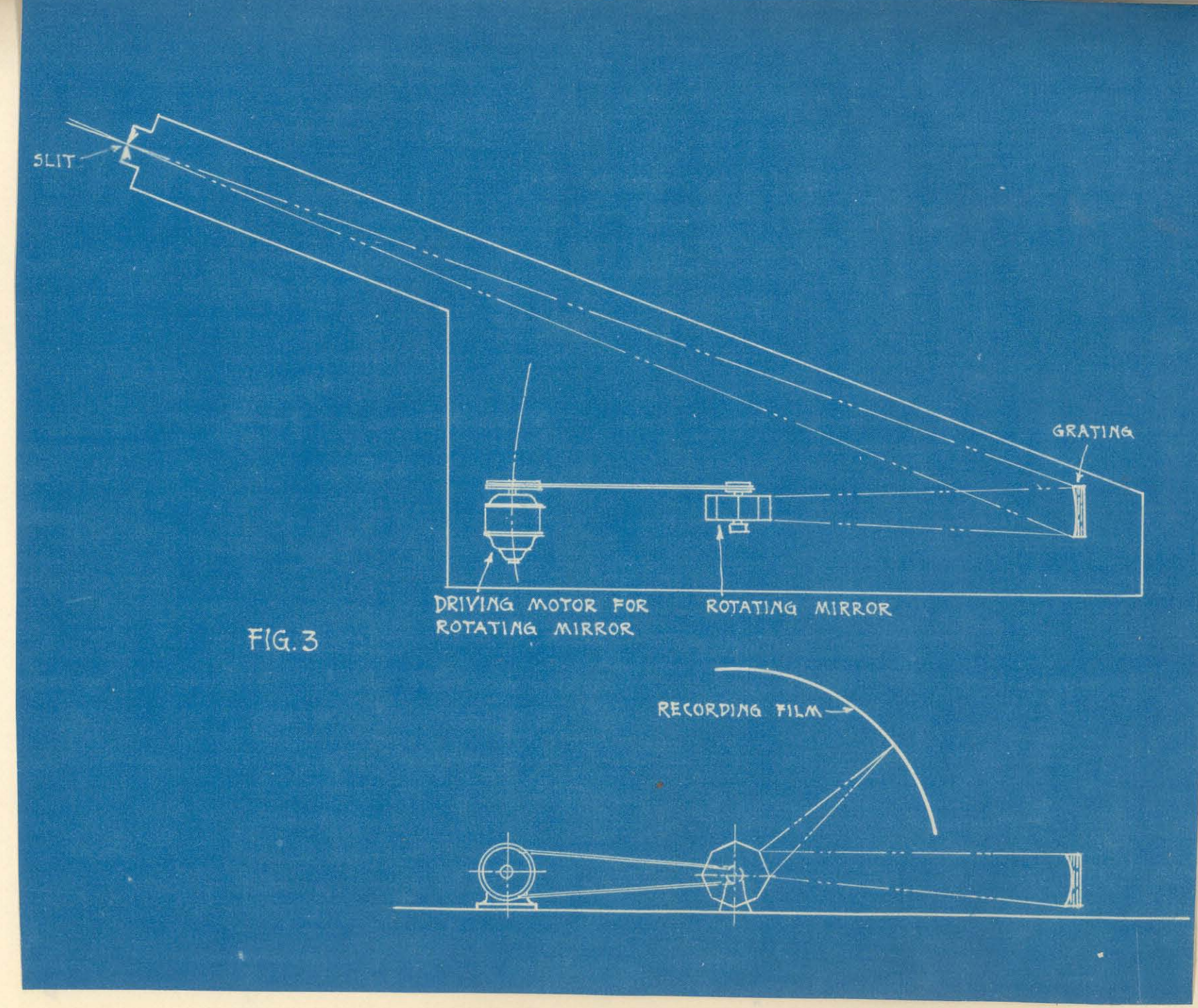

SLIT
GRATING
DRIVING MOTOR FOR
ROTATING MIRROR
ROTATING MIRROR
RECORDING FILM

FIG. 3

(See Fig. 2). A four-inch, one-meter radius, concave grating having 15,000 lines per inch was used. The slit was placed two meters from the grating, which fixed the distance from the grating to the focal plane at 66 cm., and gave a scale in the first order of 25 A per mm. The film was held in a circular holder having a 25 cm. radius. The actual focal curve is not a circle, but a circle was found to approximate it sufficiently well. The octagonal mirror was used to insure a record of every exposure. As the film subtends an angle of slightly more than 90° as seen from the rotating mirror, the light from the grating will always fall somewhere on the film, regardless of the position of the mirror.

3. When the instrument is in adjustment, the spectrum must of course be focussed, and further, the rulings of the gratings must be parallel to the slit and at the same time the projected slit images, i.e., the spectrum lines, must be parallel to the direction in which they move when the mirror is rotated. The focussing can be done visually with a high power lens, but the second combination of conditions described above, can not be met so easily. The procedure adopted was as follows. The grating was first rotated to a position such that the central image fell on the film. A film was then placed in the holder and exposed to a series of slit images with the mirror in different positions, and finally a reference line was put on the film by making a short exposure with the mirror slowly rotating. An arc was used for illumination. After the film was developed, by comparing the slope of the slit images with the reference line, the parallel position was determined. This operation so oriented the slit that its projected image on the photographic film moved accurately along its own length when the mirror was rotated. The grating was then rotated back to its original position, and the normal adjusted. By watching the spectrum lines with a high power lens and slowly

rotating the grating about its normal, the rulings were made parallel to the slit.

4. It is convenient to introduce a new term at this point. As we are going to be interested in determining time differences as well as differences in wave-length, let us call the smallest time difference that we can clearly determine, the "time resolving power" of our instrument. Now since time differences are determined by measuring along the time axis of our film the distance, say in cms., from some arbitrary zero line to one of the points in question, and then to the second point in question, and multiplying the difference between these two distances by the proper factor (in this case the time required for the image to move one cm. along the film), it might appear that the accuracy with which we measure linear distances is the only limit to our ability to determine small time intervals. But if we limit the time resolving power in this way, we shall be crediting the instrument with powers it does not possess. A consideration of optical resolving power makes this clear. It is quite true that regardless of the optical resolving power of a spectrograph, the difference in wave-length of two spectrum lines which are widely separated, can be determined to the same degree of accuracy with which we can measure on the photographic plate, the linear distance between them. (Assuming the plate constant to be known) But if these two lines are quite close together, then our determination no longer depends on our ability to make close settings, but depends upon the resolving power of the instrument. For this reason we shall mean by time resolving power, not the smallest measurable time interval between say the appearance of two different spectrum lines, but rather the smallest measurable time interval between changes that take place in the behavior of some particular spectrum line. For example, suppose that a spectrum line disappears for a very short time and then appears again. If this time is less than the time resolving power of our instrument, we

will not be able to detect the change, but if greater, we will be well aware of the temporary disappearance of the time. It appears then, that the time resolving power of our instrument will be equal to the time required for the image on the photographic film to move its own width. Thus the time resolving power depends both on the speed of the rotating mirror and on the width of the spectrum in the focal plane.

In order to limit the width of the spectrum, a horizontal slit was used as well as the slit proper. As the concave grating is not used in parallel light, the system is astigmatic. The conjugate focus of a line in the focal plane, perpendicular to the spectrum lines, is farther from the grating than the conjugate focus of the spectrum lines themselves. The spectrograph slit is of course at the conjugate focus of the spectrum lines, but the horizontal slit must be placed at the conjugate focus of the line in the focal plane perpendicular to the spectrum lines. The width of this second slit must be of course, governed, by the intensity of the light source. In the present work, the width used was such that the spectrum was a half mm. wide in the focal plane.

In most of the work to be described, the speed of the mirror was about 150 rev. per sec. At this speed the spectrum travels along the film with a velocity of about 450 meters per sec., so that, assuming that uncertainties along the time axis of the film, due to the finite width of the spectrum and a possible lack of critical focus, do not exceed a half mm., the time resolving power turns out to be of the order of one one-millionth of a second. In other words, if changes take place in the spectrum of the source, the order in which events take place can be determined, provided that the difference in time is not less than about one one-millionth of a second.

5. The spectra studied were produced in the manner described by Dr. Anderson. Two different condensers were used, one of them having already been described

by Dr. Anderson.[2] It was made up of 200 single strength window glass plates, 20 x 24 inches, having tin foil coatings 17 x 21 inches. The capacity was about one microfarad, and in use, this condenser was changed to 20,000 volts. The second condenser was also built under Dr. Anderson's direction, The plates ~~having been~~ were furnished by the Mississippi Glass Co. These plates were 36 x 36 inches and 7/16 of an inch thick. A closely woven wire gauze 32 x 32 inches was imbedded in the center of the plates during the manufacture, and a single wire brought out on one side to serve as a lead. These plates were then stacked in holders with the leads of alternate plates on opposite sides, and the leads were then joined to common terminals. The resulting condenser could be charged to a much higher voltage than the ordinary form, and in the present work a voltage of 55,000 was used. During the assembling, the condenser plates were tested in pairs at 85,000 volts, but it was not thought safe to use the whole condenser at this voltage on account of surge difficulties. 150 plates were used, which gave a capacity of 0.6 microfarad.

As the intensity of the light varies with the oscillations present in the explosions, for practical purposes, these oscillations furnished a very convenient time scale. After having once determined the period of each of the electrical circuits, time differences on the spectrograms were determined by comparison with the separation of the oscillations. The frequency of the 20,000 volt circuit, as measured by Dr. Anderson, was 87,000 and that of the 55,000 volt circuit, owing to much less inductance, turned out to be 185,000. Dr. Anderson[2] found that the maximum current in the 20,000 volt circuit was some 10,700 amperes. On the same basis, the maximum current in 55,000 volt circuit turns out to be 65,000 amperes.

6. Some of the explosions studied were produced in air, while others were confined

in a slotted block of wood. These blocks were made of pieces of oak 2x2x2 1/2 inches, and a 1/8 inch slot, 3/4 of an inch deep, was cut the long way in each block. Holes were drilled in the side and electrodes inserted in such a manner that the top of the electrodes was just above the bottom of the slot. The electrodes were 2 inches apart.

DISCUSSION OF SPECTROGRAMS

1. The spectrum of a number of elements was examined in the region from λ 3000 to λ 5000, and very great differences were found in the behavior of different spectrum lines. The spectra of Sn, Al, Cn, Cd, and Mg are discussed in detail in the tables. In general, the arc lines were found to be completely reversed, while the spark lines frequently appeared in the emission. The spark lines generally strengthened with the peaks of the oscillations, and some of the spark lines appeared only on the peaks. Ordinarily the spark lines disappeared from the spectrum when the circuit stopped oscillating. However, as may be seen from the reproduction, the spectrum lines showed almost all possible variations in their behavior.

2. The lines were also found to behave differently with the two condensers. For example, when the explosions were produced with the 20,000 volt condenser, the two spark lines of Pb, λ 4245 and λ ~~4167~~ 4387 appeared as sharp lines and showed no tendency to reverse. With the 55,000 volt condenser, these two lines became quite broad and diffuse and showed definite reversal. As a rule, the spectra obtained with the second condenser were almost entirely absorption spectra.

3. The spectra also behaved differently when the explosions were confined in a slot, from the way in which they behaved when they were produced in the open air. The difference was very marked when the 20,000 volt condenser was used, but not so noticeable in the case of the 55,000 volt condenser. With the lower voltage condenser, confining the explosions increases the strength of the continuous spectrum and also the tendency for lines to reverse. This tendency is also present, but not so marked, when the higher voltage condenser is used, for in this case the continuous spectrum is already quite strong in the unconfined explosions and confirming them adds but little to its strength.

4. The presence of this continuous spectrum is interesting in itself. In the case of most of the elements studied, it is quite strong thru out the third half oscillation, and in some cases it persists as late as the fifth. As may be seen from the reproduction, direct rotating mirror photographs of the explosions show that by the time the third half oscillation occurs, the vapor is expanding relatively slowly, and hence one may infer that the pressure is not much above ~~the~~ atmospheric. This is significant, in that it shows we have a mass of vapor, certainly not much above atmosphere pressure, in which the excitation is sufficiently high to produce radiation almost entirely continuous. Just how much of this excitation is electrical, and how much is due to temperature, is of course not known. The fact that the continuous shows such a marked increase with the electrical oscillations, does not necessarily preclude a pure temperature excitation, since the effect of the current during the peaks of the oscillations may be only to increase the temperature of the vapor. The fact that the enhanced lines appear most prominently when the continuous is strongest, suggests an interesting hypothesis regarding the mechanism by which continuous radiation is produced. That is, ~~that~~ the quanta contributing to continuous radiation are produced when ionized atoms recombine. When recombination occurs, we should expect the sum total of the change in potential energy of the system, plus the kinetic energy of the electron relative to the atom, to be radiated in a single quantum. Now no two of these quanta need have anything like the same value. In the first place, the kinetic energy of the electron may have almost any value, and further, in recombining the electron may stop in any one of a great many orbits so that the potential energy contributed to the ~~line~~ quantum described above can have a wide range of values. However, true or false this picture may be, it is at least in qualitative agreement with the foregoing, and furthermore, it explains the existence of the continuous background found in spark spectra.

5. Another interesting feature of this work is the behavior of impurity lines. In general, for the first six or eight millionths of a second the spectrum is that of the element under observation, and practically no impurity lines appear. Those that do appear, air lines in the case of unconfined explosions, and the calcium lines when the explosions are confined, apparently arise from neighboring materials rather than from the material under observation. The source of the air lines is obvious, while the calcium lines are probably due to calcium in the wooden blocks. This effect is quite noticeable in the reproduction of the cadmium spectrogram.

In one of the aluminum spectrograms the following impurity lines were identified in the region λ 3510 to λ 4500 :

Lines due to Lead

3572.95	3842.2
3639.72	3854.11
3683.62	4058.00
3740.20	4245.42
3835.15	4387.11

No trace of 4019.20 or 4168.19

Lines due to Calcium

3933.81	4226.90
3968.62	4307.90

Lines due to Iron

3553.87	3648.00	3765.69	3840.61	4143.59
57.02 (2?)	3720.09	67.35	60.03	44.08
65.54	27.79	86.81	72.70	81.94
70.29	35.02	95.12	78.19	99.25
81.38	37.30	3816.00	4045.99	4202.20
85.88 (2?)	45.70	20.61	63.77	4260.68
3618.91	49.62	26.07	71.92	71.95
21.61	58.39	28.00	4118.70	4325.97
31.60	63.99	34.40	32.25	83.71
				4404.95

EXPLANATION OF TABLES

For convenience the lines were classified as follows:

Class I Pure absorption lines which remain sharp throughout their existence.

Class II — Pure absorption lines which are somewhat diffuse.

Class III — Pure absorption lines which widen very greatly during certain phases of the explosions.

Class IV — Strongly reversed lines showing emission edges and showing only a slight tendency to vary with the oscillations.

Class V — Diffuse lines showing faint reversal and pronounced variation with the oscillation.

Class VI — Diffuse lines showing no trace of reversal, but quite pronounced variation with the oscillation.

Class VII — Sharp lines showing no trace of reversal, but definite variation with the oscillations.

Class VIII — Diffuse lines showing no trace of reversal and appearing only on the peaks of the oscillations.

Class IX — Sharp lines showing no trace of reversal and appearing only on the peaks of the oscillations.

This classification is purely arbitrary, and in many cases not sufficient, but a detailed discussion of the behavior of each line is out of the question. Intensities are given merely as w, m, or s, meaning weak, medium, or strong. A more elaborate system seems unnecessary. In a few cases, the series classification is given after the wave-length. In the remarks column, is listed the time of first appearance in terms of the half oscillations. For example, late in 3rd means that the line appeared for the first time on the spectrogram, during the later part of the third half oscillation. Any extraordinary behavior of the line is also noted in the remarks column.

TIN

Wave-length		Int.	Class	50,000 volt condenser (Explosions confined in block) Remarks
4525		s	I	Appears at beginning

IMPURITIES

3934	Ca	m	I	Appears in 2nd
3969	Ca	m	I	" " "
4227	Ca	m	I	" " "
4737	C	w	Band	Four heads show faintly in 4th, 5th and 6th

MAGNESIUM

Wave-length	Int.	Class	50,000 volt condenser (Explosions in air) Remarks
3829	s	III	Appears at beginning
3832	s	III	" " "
3838	s	III	" " "
4481	s	VI	Appears at beginning; very wide at first (possibly 50 Å)

Wave-length	55,000 volt condenser (Explosions confined in block)			20,000 volt condenser (Explosions in air)		
	Int.	Class	Remarks	Int.	Class	Remarks
3081 1p-2s	m	II	Begins late in 1st			
3133 1p-2s	m	II	" " " "			
3253 1p-2s	m	II	" " " "			
3261 1S-1p_2	m	I	Appears at beginning very sharp thruout			
3404 1p-2d	s	III	Appears at beginning	s	IV	Appears at beginning
3466 1p-2d	s	III	" " "	s	IV	" " "
3536			Not present	m	IX	Appears at 1st and 2nd only
3611 1p-2d	s	III	Appears at beginning	s	IV	Appears at beginning
4416	s	V	Appears late in 1st	m	VII	Very strong in 1st
4678 1p-1s	s	II	" " " "			
4800 1p-1s	s	II	" " " "			
5086 1p-1s	s	II	" " " "			
IMPURITIES						
3159 Ca	w	I	Begins late in 2nd			
3179 Ca	w	I	" " " "			
3934 Ca	m	I	Begins late in 1st		VII	Begins late in 1st
3969 Ca	m	I	" " " "		VII	" " " "
4227 Ca	m	I	" " " "		VII	" " " "

ALUMINUM

Wave-length	55,000 volt condenser (Explosions in air) Int.	Class	Remarks	20,000 volt condenser (Explosions in air) Int.	Class	Remarks
3587	s	V	Very wide in first gradually narrowing to a class IX line in the 5th or 6th.	s	VI	In some cases this line appears in the 1st as a broad diffuse line and continues until about the 4th when it disappears. In other cases it appears very faintly in the 1st and then disappears until the 3rd when it appears quite strong and persists until the 8th or 10th
3602	m	IX	Appears on peaks of 2nd, 3rd and 4th			
3613	m	IX	" " " " " " " "			
3944	s	I	Appears at beginning	s	IV	These lines appear thruout and show a
3962	s	I	" " "	s	IV	marked widening about the time 3587 disappeared.
4480	w	VIII	Appears on peaks of 2nd to 5th			
4513	m	IX	" " " " " " "			
4530	m	IX	" " " " " " "			
4664	s	VI	Appears 1st in 3rd	s	VI	Behaves like 3587
IMPURITIES						
3995 N	m	IX	Appears on peaks of 1st, 2nd, 3rd, and 4th	w	IX	Appears in 1st only.
4447 N	m	IX	" " " " " " " " "			
4631 N	m	IX	" " " " " " " " "			

Explosions confined in block

The nitrogen lines do not appear and Ca lines come up in the usual manner.

The two strong lines 3944 and 3961 develop very wide wings in the beginning, the central portion however, remains quite sharp.

The spark lines 4480, 4513, and 4529 disappear almost entirely showing only as mere traces on a few spectrograms.

4663 appears later than before beginning with the 5th. It is rather diffuse shows more pronounced variation with the oscillations.

The 4842.40 Al. band shows faintly in the 1st.

LEAD

Wave-length	55,000 volt condenser (Explosions confined in block)			20,000 volt condenser (Explosions in air)		
	Int.	Class	Remarks	Int.	Class	Remarks
3574	s	III	Begins in 2nd, widens during 3rd	s	V	
3640	s	III	" " " " " "	s	V	These lines become class IV lines after
3672	s	II	Begins in third	s	V	the 3rd.
3684	s	III	Begins in 2nd " " "	s	V	
3740	s	III	Begins in 2nd " " "	s	V	
3786			No trace	m	VII	Appears late in first.
3854			" "	m	IX	Appears at very beginning of 1st again in 3rd to 8th.
3833			" "	w	IX	Appears on peaks of 3rd to 8th.
3842			" "	w	IX	" " " " " " "
4020	m	I	Begins in 2nd		VII	Begins at end of 1st. Trace of reversal on some exposures.
4058	s	II	Appears thruout	s	V	Changes to class IV after the 3rd.
4168	w	I	Begins in 2nd		VII	Behaves like 4019.76
4245	s	V	Almost entirely reversed in 1st	s	VII	Diffuse in 1st
4387	s	V	" " " " "	s	VII	" " "
4437	m	I	Begins in 3rd			
4455	m	I	" " "			
5006	m	I	Begins late in 1st			

LEAD

Wave-length	55,000 volt condenser (Explosions confined in block) Int.	Class	Remarks	20,000 volt condenser (Explosions in air) Int.	Class	Remarks
IMPURITIES						
3248 Ca	w	I	Begins in 3rd.			
3274 Ca	w	I	" " "			
3934 Ca	m	I	Begins late in 1st	m	VII	Begins late in 1st
3944 Al	w	I	Begins in 3rd	w	VII	Begins in 3rd
3962 Al	w	I	" " "	w	VII	" " "
3969 Ca	m	I	Begins late in 1st	m	VII	Begins late in 1st
4227 Ca	m	I	Begins in 2nd	w	VII	Begins in 3rd
4283 Ca	w	I	Begins in 3rd			
4289 Ca	w	I	" " "			
4299 Ca	w	I	" " "			
4303 Ca	w	I	" " "			
4308 Ca	w	I	" " "			
4319 Ca	w	I	" " "			

Wave-length	55,000 volt condenser (Explosion confined in block)			20,000 volt condenser (Explosion in air)		
	Int.	Class	Remarks	Int.	Class	Remarks
2824	w	II	Appears at beginning			
2883	w	II	" " "			
2961	m	I	" " "			
2998	w	I	" " "			
3011	m	I	" " "			
3036	m	I	" " "			
3064	m	I	" " "			
3094	m	II	Begins late in 1st			
3100	m	II	" " " "			
3109	m	II	" " " "			
3126	m	II	" " " "			
3143	m	II	" " " "			
3194	w	I	Appears at beginning			
3208	w	I	" " "			
3248	s	III	Very wide thruout			
3274	s	III	" " "			
3291	m	I	Appears at beginning-slightly diffuse			
3308	m	I	Appears at beginning-slightly diffuse			
3317	w	II	" " "			
3338	w	I	Appears at beginning-very sharp			
3355	w	I	Begins in 2nd			
3450	w	I	Begins late in 1st			
3476	w	I	" " " "			
3484	w	I	" " " "			
3512	w	I	" " " "			
3599	m	I	Appears at beginning			
3602	m	I	" " "			

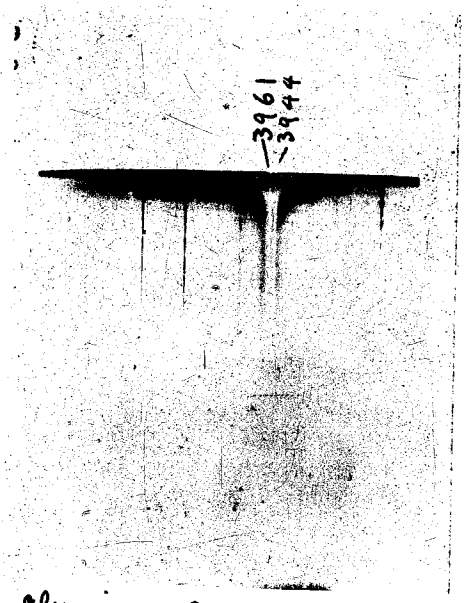
COPPER

Wave-length	55,000 volt condenser (Explosions confined in block)			20,00 volt condenser (Explosions in air)		
	Int.	Class	Remarks	Int.	Class	Remarks
4023			A mere trace appearing in the 5th & 6th only.	s	VI	Appears thruout no variation with oscil's
4063			A mere trace appearing in the 5th & 6th only.	s	VI	" " " " " "
4076				w	VII	" " " " " "
4081				w	VII	" " " " " "
4104				w	VII	" " " " " "
4123				m	VII	" " " " " "
4178				m	VII	" " " " " "
4249				m	VII	" " " " " "
4259				m	VII	" " " " " "
4275	m	IV	Appears at beginning	s	VII	" " " " " "
4378	m	IV	" " "	s	VII	" " " " " "
4416	m	IV	" " "	w	VII	" " " " " "
4510	m	IV	" " "	m	VII	" " " " " "
4540	m	IV	" " "	m	VII	" " " " " "
4587	m	IV	" " "	m	VII	" " " " " "
4651	m	IV	" " "	m	VII	" " " " " "
4675	w	IV	" " "			
4705	w	IV	" " "			

A NEW ABSORPTION PHENOMENON

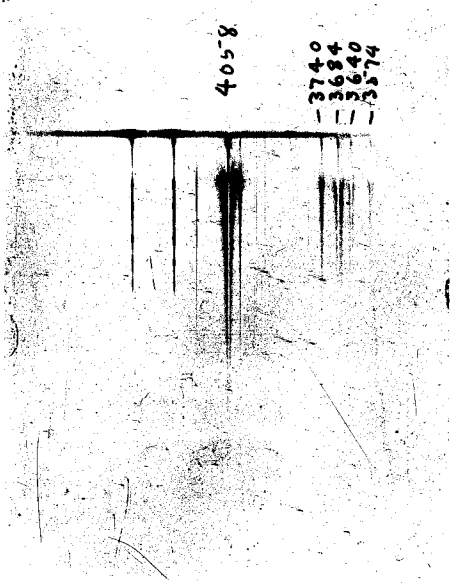
1. In the case of a number of spectrograms of Al., Pb., Cd., Ca., and Mg., explosions, a new absorption phenomenon presented itself. For a very short interval of time, usually for not more than about three millionths of a second, that part of the explosion which was projected on the slit of the spectrograph, became highly absorbing and produced no photographic effect. As may be seen from the reproductions, the light appears to be completely cut off for a very short time. In the regions very close to strong arc lines, this cutting off occurs a little later than in more remote regions, so that the general appearance is that of an infinitely wide absorption line rapidly becoming narrow. This delayed absorption is best illustrated by the aluminum spectrogram № 1, in which the light from the explosion first appears to be completely cut off except in the region within a few angstroms from the two strong arc lines 3944 and 3961. Then as time progresses, the vapor becomes transparent to wave-lengths remote from these two lines, but opaque to wave-lengths within a few angstroms from them. Immediately after the absorption sets in, the appearance is of an infinitely wide absorption line having an emission center some 50 angstroms wide, with the emission core itself showing two sharp absorption lines upon its central region. In the lead spectrogram № 2. the same effect is seen except that in this case the lack of a continuous background makes the effect less prominent. In this case, the arc lines 3574,3640, 3684, 3740 and the very strong arc line 4058, play the prominent part. The effect shows quite a variation, both as regards duration, as can be seen from the series of aluminum spectrograms, and as to time of occurence. In the case of one of the lead explosions, the effect occured about twenty-five millionths of a second after the beginning of the explosion. Ordinarily this

N° 1.



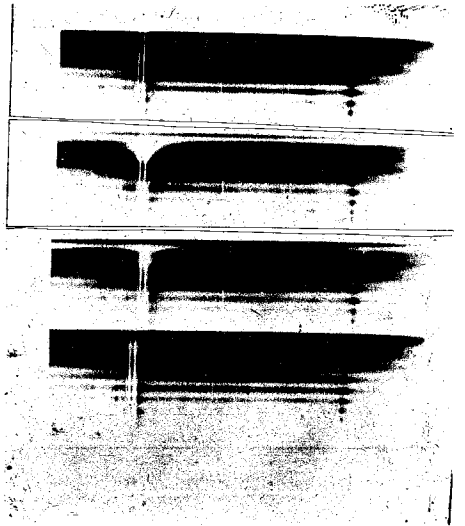
Aluminum. λ 3500 – λ 4500
Explosion in Air

N° 2



Lead λ 3500 – λ 4500
Explosion in Air

N° 3



Series of Aluminum Spectrograms showing Variations in "Absorption" Explosions Confined in Block.

effect occurs at the minima of the oscillations, but not always. In one of the lead spectrograms, one of these "absorption bands" was found on the peak of the third half oscillation. This particular one was of very short duration, somewhat less than two millionths of a second.

2. It is very probable that when this absorption occurs, it only occurs over a very small area of the explosion. Direct rotating mirror photographs of the explosions show that in the case of the elements which exhibit this effect, the explosions have a "mottled" appearance. Small areas appear which apparently give off no light, or at least not enough to effect the photographic film. The area of these "spots" is only a few square mm. It seems very probable that these"spots" are merely regions in which the absorption described in the preceding paragraph is occuring. It would be very strange indeed, if the whole mass of vapor stopped emitting light for a short time, and if this ever occured, the direct rotating mirror photographs should certainly show the effect. No such effect was found, so it seems reasonable to conclude that the absorption occurs only in small areas at any one time.

3. No explanation is offered for this phenomenon. There is a small possibility that it is a kind of photo-electric absorption, but while this might explain the general absorption, it is difficult to see on this basis why the absorption should be "delayed" in the vicinity of strong arc lines. The fact that it appears to occur only in small regions at any one time, might be explained in this manner: One might suppose that for some reason a large percentage of the atoms in some small region got into the same state of excitation. This state might be one from which the atom could be ionized by the absorption of a quantum of visible light. In this case we might expect the vapor in this small region to be opaque to all wave-lengths below that one having just the

ionizing energy; ~~In~~ in other words, all wave-lengths below the ~~large~~ long-length wave limit. In the case of aluminum, this long wave-length limit was looked for. By using a wide slit and red sensitized films, the spectrum was photographed out to λ 7500, but no long wave-length limit was found. This of course has very little bearing on the explanation, for even though the absorption were of a photo-electric nature, one mihgt have a mixture of atoms in various states of excitation doing the absorbing. In this case, as atoms in different states would have different long wave-length limits, we would not expect a very definite red limit to the absorption. However, even if we grant that a photo-electric kind of absorption can play a part in the above, we have not explained the "delayed" action in the neighborhood of strong arc lines. Hence, to the writer at least, this photo-electric type of absorption is very unsatisfactory as an explanation of the above phenomenon.

In conclusion, the author wishes to express his deepest appreciation to Dr. J. A. Anderson, under whose direction this work was done.

1 Astrophysical Journal 51, 37, 1920.

2 " " 59, 76, 1924

FURTHER EXPERIMENTS

During the study of the explosions, it developed that some metals were more difficult to explode than others. The effect presented itself in the following manner. When wires of copper, silver, or gold were exploded, unless the leads to the electrodes which supported the wires were well separated, a spark would pass across the space between the leads and a part of the discharge would thus be shunted around the explosion. However, it was found that by keeping the leads well separated, all the discharge could be made to go thru the explosion.

In order to investigate this phenomenon, a sphere gap was placed in parallel with the wire to be exploded so that a measure could be made of the maximum voltage built up across the vapors of the explosion. The electrodes which supported the wires were arranged so that their separation could be varied, and measurements were made using electrode separation of from one to ten cm. The measurements consisted in determining the minimum separation of the sphere gap which would force all the discharge thru the vapors of the explosion. The 55,000 volt condenser was used.

Curves were plotted for a number of elements; plotting electrode separation, i.e. length of wire exploded, against the legnth of the sphere gap. A few of the curves are shown. They all appeared to be straight lines thru the origin. As a basis for comparison, the sphere gap separation in mm. corresponding to a five cm. length of wire, is listed for all the elements studied.

Cn. 37 mm.	Ni. 31 mm.	Al. 18 mm.	Li. 14 mm
Ag. 29 mm.	W. 22 mm.	Pb. 17 mm.	Fe. 13 mm
Au.	Zn. 22 mm.	Sn. 18 mm.	

As the supply of gold wires gave out before sufficient data was obtained, a definite value for gold cannot be given. However, the evidence on

hand indicates that the value is very close to copper and silver.

The fact that these three "high" elements belong to the same group in the periodic system, suggests that elements in any one group should behave alike in the explosions. However, a glance at the elements just listed shows that the agreement rather haphazard.

Two one and one half inch spheres were used for the gap, and the voltages listed on the curves were computed in the usual way. The fact, that some of the voltages come out much higher than the voltage used on the condenser, is not surprising when one remembers that we are dealing with rapidly changing currents.

In order to determine just when the voltage across the explosion reached a maximum, things were so arranged that light from both the gap and the explosion fell on the slit of the rotating mirror spectrograph. It was found that as far as the spectrograph could determine, the beginning of the spark and the beginning of the explosion were simultaneous. Probably the wire first vaporized and then developed a high resistance, but did not become sufficiently luminous to photograph, until this high resistance stage was reached.

If the sphere gap was set near the critical position for the wire in question, only part of the current of the first half oscillation passed thru the gap. The balance of the current of the first half oscillation and all the subsequent oscillations passed thru the vapors of the explosion. If the gap was made sufficiently short, practically all the discharge could be made to pass across the gap.

The mass of the wire exploded seems to have very little effect on the determinations, as wires of various sizes of the same metal, gave quite similar sphere gap settings. Screening the gap from the light from the explosions, made no noticeable difference.

It is thought that these determinations are proportional to the resistance of the various metallic vapors.