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An Analysis of Kirlian Electrophotography

Robert Suba

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by

Robert S. Suba

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Thesis Advisor: Dr. G. W. Schumann

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ABSTRACT

The objective of this research effort was to investigate the process of Kirlian electrophotography with respect to the physical processes which occur during the exposure, and the electrical parameters of the exposing device. This project was not intended to discuss what possible parapsychological phenomina are revealed by Kirlian electrophotography, or it's possible applications. The following is a list of conclusions which were drawn from the experimentation.

1)The Kirlian image is a result of a complex process known as field emission of conducting objects under an applied high voltage AC electrostatic field. Furthermore, it is the belief of the author that this is the only process which contributes to the formation of the photographic image. The process of field emission is mainly a function of the local(microscopic) electric field strength.

2)Field emission will occur only with materials with sufficient free electrons which can be liberated from the object's surface. Metals, and living systems such as human and plant tissue are the only materials known which meet this criterion. Semiconductors were not tried.

3) For the apparatus used, the only electrical parameters which make a signifigant contribution to the subjective quality of images of living systems when compared to experimental error are the applied voltage and the pulse envelope repetition rate. Furthermore, there appears to

exist a linear relationship between the pulse envelope repetition rate and this quality factor. The relationship between voltage and quality is much more complex, and has an optimum value of approximatly 22 Kilovolts peak-to-peak.

INTRODUCTION AND OBJECTIVES

In recent years, much interest has been devoted towards the bject of Kirlian photography(which will be referrred to as Kir-an electrophotography throughout this paper). It has been cited parapsychologists as a means of viewing the dynamics of biolog-al systems,[10] by some doctors as a means of predicting disease,[1] and r its many critics as nothing but an indicator of an objects alt content![3] Obviously, not all of these hypotheses can be correct-erhaps none of them are. What is needed is an analytical investi-ation to scientifically determine what Kirlian electrophotography s and what it can really do. It is the main objective of this re-search effort to answer the former question as thoroughly as possible in the framework of the research course, using the tools of physics, statistics, and photographic science.

A Brief History of Kirlian Electrophotography

The invention of Kirlian electrophotography is attributed to Dr. Semyon Kirlian and his wife Valentia, who began their work in the fifties.[1] His method, which he calls "Photography by High Frequency Currents",was unknown to anyone in the U.S. untill the middle six-ties when Dr. Kirlian published his first paper in the U.S. on the subject.[3] In this essay, he described a way of transforming the nonelectrical properties of an object into electrical ones and recording these properties on photographic film by placing the object in what is essentially a parellel-plate capacitor and applying a high freqency, high voltage AC electrostatic field. Portions of Kirlian's original drawings are shown below.

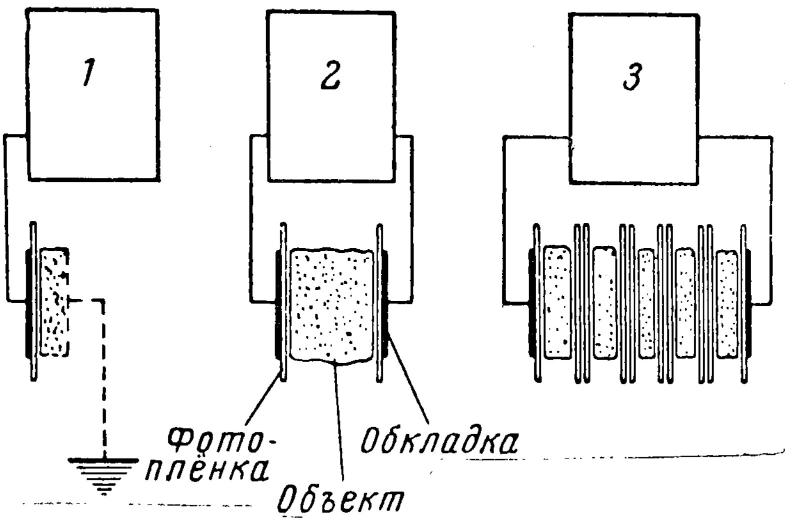


Fig. 1-position of the object in a kirlian device.

1) single electrode (object as ground)

2) dual electrode

3) multiple array

(Source: S.D. Kirlian, <u>Photography and Visual Observations by Means of High Frequency Currents</u>, Journal of Applied and Scientific Photography, June 1961)

Most of Kirlian's subjects were living organisms and tissue. What he was obtaining on the film were images of the topographical configuration of the object. Kirlian stated that these images were the result of the controlled transfer of charges from the subject to the film by the applied electric field.[1] He believes that the dielectric structure (spatial distribution of resistivities) accounted for the varying densities in the images of living systems.[1,10]

An associate of the Kirlians, V. Adamenko, sees the photographs as a demonstration of "cold emission of electrons".[3] His idea lacks the proper theoretical background, but his hypothesis closely correlates with the work of American physicists. Another noted researcher in Russia, V. M. Inyushin, introduced the term "Bioplasma body", which supposedly described a previously unknown fourth state of matter which he said Kirlian electrophotography was able to photograph.[3] His theory has since been abandoned.

In the late sixties, Americans became actively involved in Kirlian research, mainly because of of all the published Russian literature. Leading parapsychologists such as Dr. Thelma Moss state that their experiments have shown Kirlian electrophotography to be a method of monitoring the biodynamics of living systems, particularly humans.[10] These dynamics manifest themselves as changes in the discharge patterns of parts of the body over a period of time.[3] Fingerprints are popular subjects because of their ease of use. Changes in emotional state and pathological changes are said to change the images in a predictable manner.[4] One current use of Kirlian Systems is the location of acupuncture points and meridians. For the most part, the research is in too early a state to draw many definite conclusions.

The Kirlian Apparatus and Its Operation

A block diagram of a typical Kirlian Device is shown below:

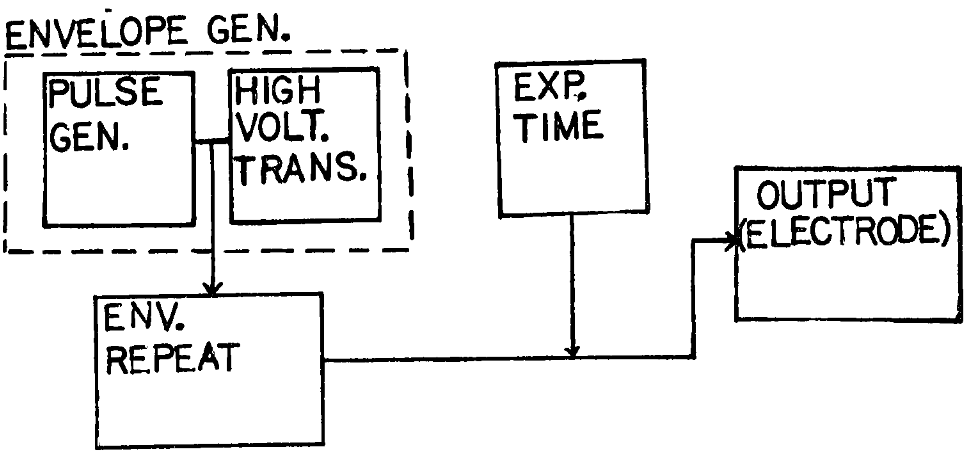


Fig. 2- Kirlian Device Block Flow Diagram

The output of these devices is a train of pulse envelopes. A sketch of the waveform (idealized) with typical values is shown below.

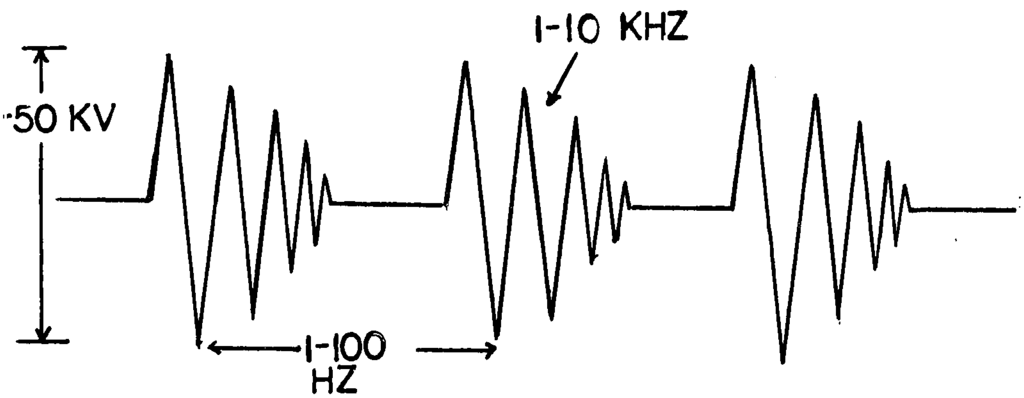


Fig. 3- Kirlian Device Output Waveform (Courtesy, W.A. Tiller)

Exposure time is simply the on time of the device. In practice, the pulses are approximated by damped sine waves(ringing networks) because the cost of devices with these output waveforms are less prohibitive. The apparatus used in this project was of this R-C network type.The object to be exposed is placed in an electrode arrangement like the one in figure four.

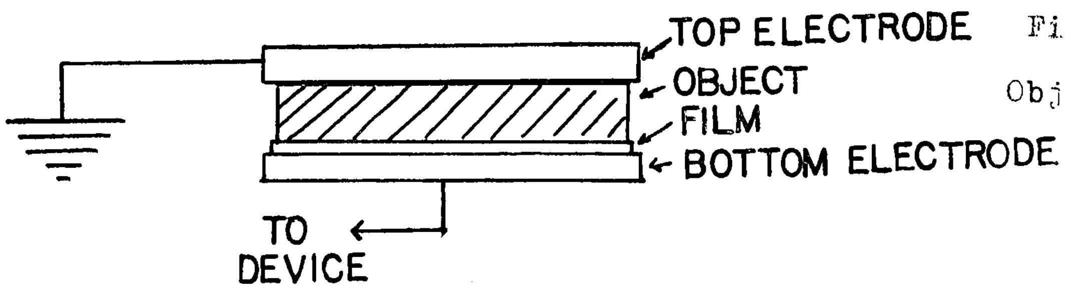


Fig. 4- Object-Electrode Arrangement

With living tissue such as finger pads as the object, the body acts as a ground.

When the device is switched on, one immediately notices the blue glow and ozone gas associated with corona discharge.[I] Therefore, it is obvious that this air discharge must be making a contribution to the formation of the image. Russian literature has told us that the image is also a result of the direct transfer of electrons from the object to the film under the applied field.[I,3] This process is not so intuitively obvious . An AC field must be used, because American research at Stanford University with DC pulses yielded unusable images and presented a shock hazard.[2] AC fields have a relatively low average power.

As research has progressed, many questions have arisen concerning the Kirlian process. They are:

1)How are Kirlian images formed, i.e, what mechanisms or processes are at work during the electrophotographic exposure which creates a photographic image? The question of air discharge or direct electron exposure and their relative contributions comes up here.

2) What types of materials will yield a Kirlian image? And, what properties of these materials account for their responses to the Kirlian system?

3) What characteristics of the exposing waveform have a signifigant effect on the output(images) of a Kirlian device? And, what possible functional relationships exist between these signifigant electrical parameters and the image quality?Finally, are there any signifigant interactions between these parameters?

These questions form the objectives of this research effort. They will be answered in the fullest and most analytical ways possible within the limitations of this course.

THEORY

The work of Prof. William A. Tiller(Physics, Stanford University) forms the basis of this section, and forms the groundwork of most of the experimental work. The important concept in this development is the term " field emission of conductors".[2,7] The model assumes 1) one-band electron distribution using Fermi-Diriac statistics, 2) a smooth planar surface where irregularities of atomic dimensions can be neglected, 3)a classical image force, and 4) a uniform distribution of the electron work function ϕ. The model is carried out for a metal whose properties are far better known than living tissue.

Within the metal, the signifigant quantity is the electron supply function $N(T,\epsilon)$ where, at a given temperature in degrees Kelvin, it measures the relative number of electrons whose kinetic energy normal to the surface is ϵ. At higher temperatures $N(T,\epsilon)$ requires a thermal tail which lifts more electrons into higher energy levels where emission is more readily acheived. In figure five the electron supply function is sketched for a metal.

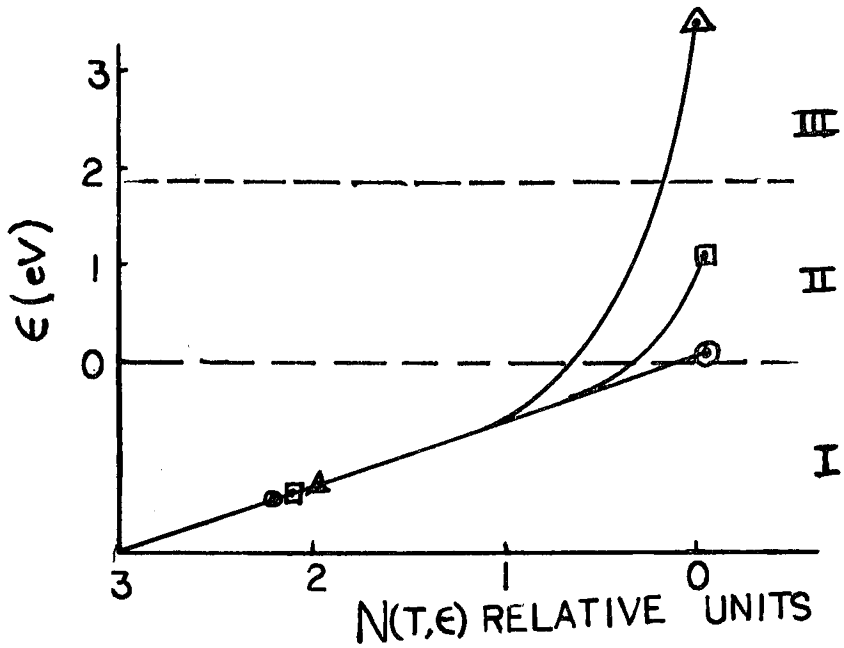


Fig.5- Electron Supply Function for a metal

△ - T=3000 K

□ - T=1000 "

⊙ - T= 0 "

Region1-pure field emission

Region2- mixed emission

Region 3- thermal emission

(Courtesy, W.A. Tiller)

The form of the electron supply function is as follows:[2]

$$N(T,\epsilon) = \ln(1 + \exp^{-e/KT}) \qquad (1)$$

Electrons impinging upon this barrier from inside the metal have a certain probability of penetrating and appearing outside the metal. This probability is given by the transmission coefficient[2] D:

$$D(E,\epsilon,\phi) = \exp^{((-6.83*10^7(\phi-\epsilon)^{3/2}f(y)/E)} \qquad (2)$$

where E is the electric field strength in volts/cm, ϵ is in eV, and f(y) is a dimensionless function which takes care of the image force. Now, multiplying the number of availible electrons at a given energy by the transmission coefficient and integrating over all energies yields the emission current[2] J, given by:

$$J(\text{electrons/cm}^2\text{-sec}) = \int_{-\infty}^{\infty} CN(T,\epsilon)D(E,\epsilon,\phi)d\epsilon \qquad (3)$$

where C incorporates Boltzman's and Planck's constants, and the mass of the electron.

At T=0°, one obtains only field emission and equation (3) can be integrated to yield[2]:

$$J = \frac{1.5*10^{-6}}{\phi} \exp(-6.83*10^{7}\phi^{3/2} f(y))/E \qquad (4)$$

$$=(\text{const})E^{2}\exp^{(\text{const}/E)}$$

Mr. Tiller has made the assumption throughout his model that the electric field is uniform.[2] However, it is the local field E that is the important quantity in equation (4) rather than the macroscopic field so that, for changes in the surface configuration of the object, the local field may vary,and therefore the emission current(and field emission)will also vary.Field emission as used in this context refers to the photons emitted as electrons are accelerated across many mean free paths and collide with air molecules.[7]

From this combined theory, It can be inferred that: 1) insulators will not produce a Kirlian image, because of the absence of free electrons , **and more importantly** 2)the image resulting from the exposure of a conductor is a function mainly of it's topographical configuration, due to point effects of field emission.Therefore, (3) a perfectly smooth conductor should **yield** a **uniform, but weak (low density)** image.Another important inference that can be drawn is (4) that Kirlian images are the result of field emission alone, with no contribution from direct electron transfer.

Experiments will be designed and run to attempt to verify these previous statements, and a statistically-designed experiment will be run to determine the signifigant electrical factors and interactions of the exposing waveform.

EXPERIMENTAL

The first task involved in any experiment involving Kirlian electrophotography is the building (or buying) of a Kirlian device. The device used in this experiment was the Edmund Scientific Co. electrophotography Lab, #72106.An external electrode setup was built as shown below.

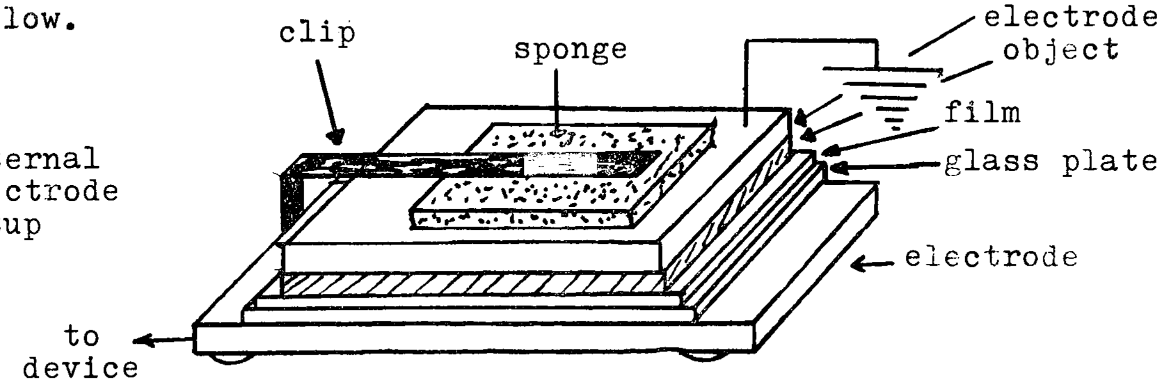


Fig. 6- external electrode setup

the clip and sponge arrangement was designed to keep the object and film in close contact, which proved to be difficult with the device's built-in electrode. The electrodes were steel plates.

Preliminary measurements involved the measurement of the apparatus' output waveform with an oscilloscope(Knight- Kit modelKG-635), and the calibration of the dial settings with the 'scope and a digital multimeter (Heath mod. IM 1212). This data is tabulated in the "Results" section of this report. Appropriate series resistors were used in order to measure the high voltage with divider networks. The film used throughout the experimentation was Kodak Commercial film, type 6127. Development was with HC-110, dil. B, five minutes at 68 degrees. Agitation was RIT tray rock. After making some practice exposures for familiarization, the following exposures were made:

1)A 1/4" lexan* sheet-lexan is known, among it's many other properties, to be an excellent insulator.[8]

2)The same lexan sheet was etched with a series of grooves and re-exposed at the same instrumentsettings.

3)A 1/8" steel plate whichwas highly polished so it's surface would be as free from surface irregularities as possible-

4)This same steel plate was etched with a grid pattern and re-exposed.

5) Some metals of varying surface configurations-

6)One of the objects used in (5), this time with higly conductive liquids between the object and the film. This will eliminate the effect of field emission, and enhance any direct electron transfer.[9]

7)Images of human finger pads like the type used so frequently in current research.[3]

These objects were all chosen to answer the questions of the objectives section as well as possible in the time permitting. The exposure data for all the images is tabulated in the results.

For the last part of the experimentation, the determination of statistically signifigant electrical parameters and interactions, an ANOVA experiment is appropriate.[11] The factors to be considered are the output voltage, the pulse envelope repetition rate(hereafter to be referred

* lexan is a registered trademark of the General Electric Co.

as pulse repetition rate), and exposure time. A larger(more factors) ANOVA could have been run if one of the more complex Kirlian devices was used, but these were the only parameters which could be varied. There were three levels for each factor.The experiment was fixed, fully crossed, with no replicates.The choice of a response variable is a task which requires special thought.Since most of the work in Kirlian electrophotography is with living systems, they should be used in this experiment. Since it is extremely difficult to obtain repeatable images with finger pads(and the generation of 3^3=27 such images would prove to be an uncomfortable task),another popular subject, freshly cut leaves were used. Their images proved to be extremely repeatable.Our actual response variable was a subjective quality determination along the criteria used by previous Kirlian researchers by a sample of observers of these leaf images produced by the device.[3] The 27 images resulting from all treatment combinations were contact printed on Agfa-Gevaert Brovira paper, grade 2,developed in D-72 for 3minutes at 68 degrees, and arranged in random order in a booklet. A set of instructions appeared at the beginning of the booklet and asked the observer to rate the overall quality of each of the following Kirlian photographs by placing them into one of the following categories: 1) excellent, 2)good, 3)fair, 1) not acceptable, or 0)poor. The given criteria on which the observers based their judgements was: 1)overall clarity and contrast, 2)ability to distinguish small details, and 3)amount of the detail in the image. The sample taken was 21 persons. The number which went into the ANOVA table for each treatment combination was the mean category,[12] which equals:

$$\text{Mean Category} = \sum^{k} \frac{1}{N} A_{ij} B \qquad (5)$$

where N= no. of observers

k= no. of categories

j= category no.

$B=j$

i= stimulus no.

A_{ij}= value in cell ij

After the ANOVA table was completed, the standard F-tests were run in order to determine signifigant factors and interactions. Of these, the sums of squares were partitioned to determine any functional relationships between these factors and the response variable, and possible optimum values.

RESULTS

A. Apparatus Data-Edmund Scientific Co. Electrophotography Lab #72106

1) Output Waveform

Voltage setting	V(Kvolts P-P)	Pulse Rep. Rate marked	Pulse Rep. Rate actual
1	2.5	100 Hz	137 Hz
2	10	1 "	2 "
3	20	.5 "	.7 "
4	30	.25"	.4 "

Exposure Data-"Picture number" corresponds to the number marked on each negative.

Picture number	subject	exposure		
1	¼" lexan sheet-smooth	V=30 KV,	PRR=10 Hz,	T=2 sec.
2	¼" lexan sheet-w/ grooves	"	"	"
3	1/8" steel plate-smooth	"	"	T=5 sec.
4	1/8" steel plate-w/grid	"	"	"
5	steel metal punch -printing	"	"	"
6	aluminum print tongs -printing	"	"	T=8 sec.
7	metal screen	"	"	T=5 sec.
8	wrench-printing	"	"	T=10 sec.
9	wrench-printing w/ salt solution@125°F	"	"	"
10	finger pad	V=10KV	PRR=20Hz	T=2 sec.

ANOVA Data

Factor	Levels
Voltage-1	10 KV P-P
" -2	20 "
" -3	30 "
PRR -1	1 Hz
" -2	50 "
" -3	100 "
Time -1	1 sec
" -2	3 "
" -3	6 "

Sample treatment combination

321

Voltage PRR Time
30 KV 50 Hz 1 sec.

ANOVA Data- Raw Data (Table 1)

Photo No.	Category 0	1	2	3	4	Mean Category
221	0	5	13	3	0	2.00
231	0	0	3	14	4	3.70
123	0	4	13	4	0	2.10
131	9	12	0	0	0	0.60
222	0	0	0	6	15	3.90
322	0	0	0	14	7	3.50
112	18	3	0	0	0	0.15
221	0	0	3	15	3	3.15
311	2	12	7	0	0	1.30
332	0	0	0	13	8	3.55
212	9	8	4	0	0	0.80
111	20	1	0	0	0	0.05
312	0	6	15	0	0	1.80
122	12	9	0	0	0	0.45
113	7	14	0	0	0	0.70
321	12	9	0	0	0	0.45
233	0	8	9	4	0	2.40
333	0	2	11	8	0	2.40
232	0	0	0	6	15	3.90
132	0	11	9	1	0	2.10
133	0	17	4	0	0	1.25
213	0	4	10	7	0	2.25
323	0	0	13	8	0	2.50
313	0	0	0	14	7	3.50
211	5	16	0	0	0	0.80
223	0	0	3	12	6	3.30
331	0	0	6	11	4	3.05

ANOVA Tables

Table 2

Pulse Rep. Rate	Time	Voltage 1	Voltage 2	Voltage 3		
I	A	0.05	0.80	1.30	2.15	11.00
I	B	0.15	0.80	1.80	2.75	
I	C	0.70	2.25	3.15	6.10	
II	A	2.00	3.15	0.45	5.60	21.35
II	B	0.45	3.90	3.50	7.85	
II	C	2.10	3.30	2.50	7.90	
III	A	0.60	3.70	3.05	7.35	22.95
III	B	2.10	3.90	3.55	4.55	
III	C	1.25	2.40	2.40	6.05	
		9.4	24.20	21.7		

Table 3

Source	S.S.	d.f.	M.S.	F_{calc}	F_{table} (α=.05)	
Voltage A_i	13.95	2	6.98	12.25	4.45	***
Pulse Rep. Rate B_j	10.35	2	5.18	9.09	"	***
Time C_k	1.86	2	0.93	1.63	"	N.S.
$(A*B)_{ij}$	3.98	4	1.00	1.75	3.84	N.S.
$(B*C)_{ik}$	5.00	4	1.25	2.19	"	N.S.
$(A*C)_{jk}$	1.78	4	0.45	0.79	"	N.S.
E_{ijk}	4.53	8	0.57	—		
TOTAL		26				

table 4-

Tests for Functional Relationships

1)

Voltage Level	Total $T_{i..}$	Coefficients		Products	
1-10 KV	9.4	-1	+1	9.4	-9.4
2-20 KV	24.2	0	-2	0	-48.4
3-30 KV	21.7	+1	+1	21.7	21.7
	divisor	18	54	31.1	-36.1

Linear Sum of squares $= \frac{(31.1)^2}{18} = 53.73$

Quadratic S. S. $= \frac{(-36.1)^2}{54} = 24.13$

2)

PRR Level	Total $T_{.j.}$	Coeff		Products	
1-1 Hz	11	-1	+1	-11	11
2-50 Hz	21.35	0	-2	0	-42.7
3-100 Hz	22.95	+1	+1	2295	22.95
	divisor	18	54	11.95	-8.75

Linear S. S. $= \frac{(11.95)^2}{18} = 7.93$

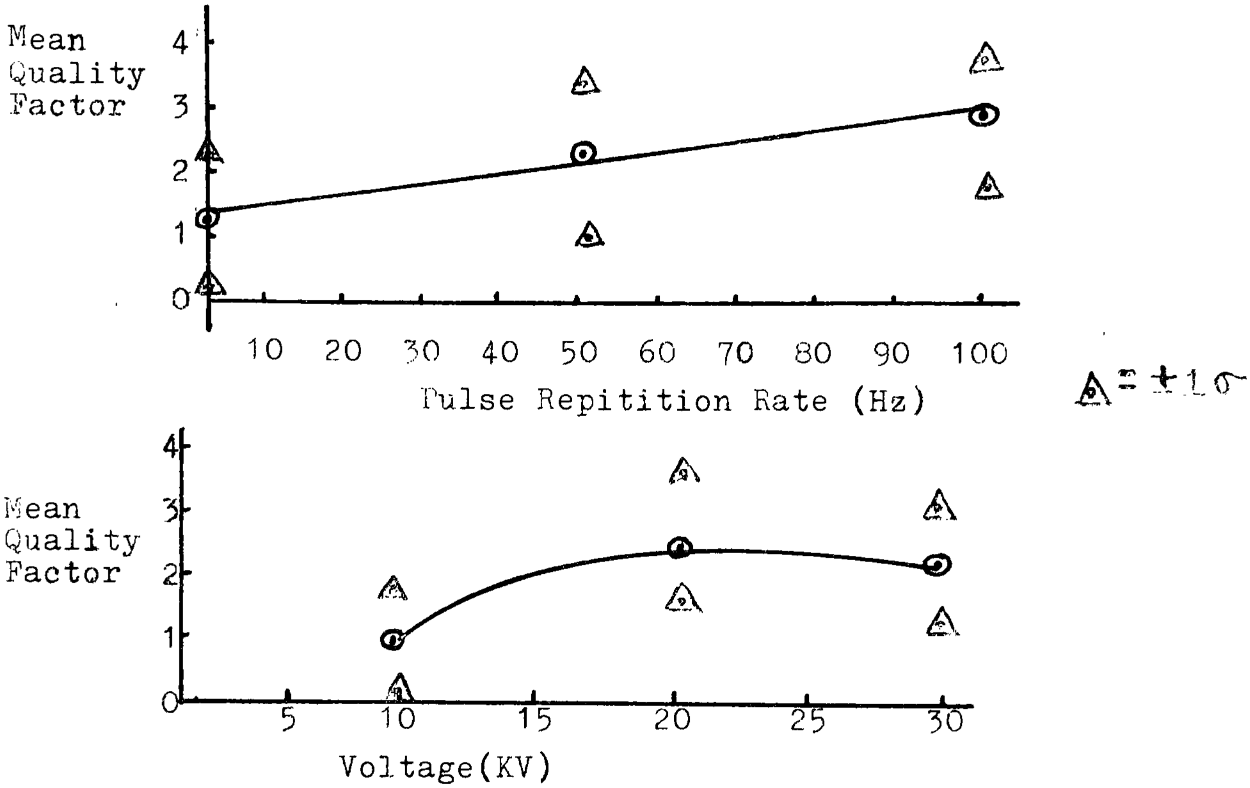
Quad. S. S. $= \frac{(-8.75)^2}{54} = 1.4$

Table 5-

Revised ANOVA Table

Source	S. S.	d. f.	M.S.	F_{calc}	F_{table} (α=.05)	
Voltage: Linear	53.73	1	53.73	94.26	5.32	***
Quadratic	24.13	1	24.13	42.33	"	***
Pulse Rate: Linear	7.97	1	7.97	13.90	"	***
Quadratic	1.40	1	1.40	2.50	"	N.S.
Error	4.53	8	.57	---		
Total		12				

Plots from Revised ANOVA Data



DISCUSSION

The exposure with the lexan sheet yielded no image at all, with or without surface irregularities. Other materials,such as balsa wood and cloth also did notyield an image at any electrical setting. This correlates with Prof. Tiller's theory that an insulator is incapable of field emission, due to it's lack of free electrons[2].

With the smooth steel plate as the subject, the results were also as expected.A uniform, minimal density resulted(max. density= 0.4). This is a consequence of the liberation of free electrons under the applied field, but also an air gap so small that little field emission could occur.When a grid pattern was etched into the plate,however, some interesting effects were observed. A clear image of the grid resulted so, at first look it appeared that a higher-than-background density occurs wherever a line has been etched.However a closer look reveals more intriguing phenomena than greater field emission with greater air gap.Refer to the smoothed Microdensitometer trace below.

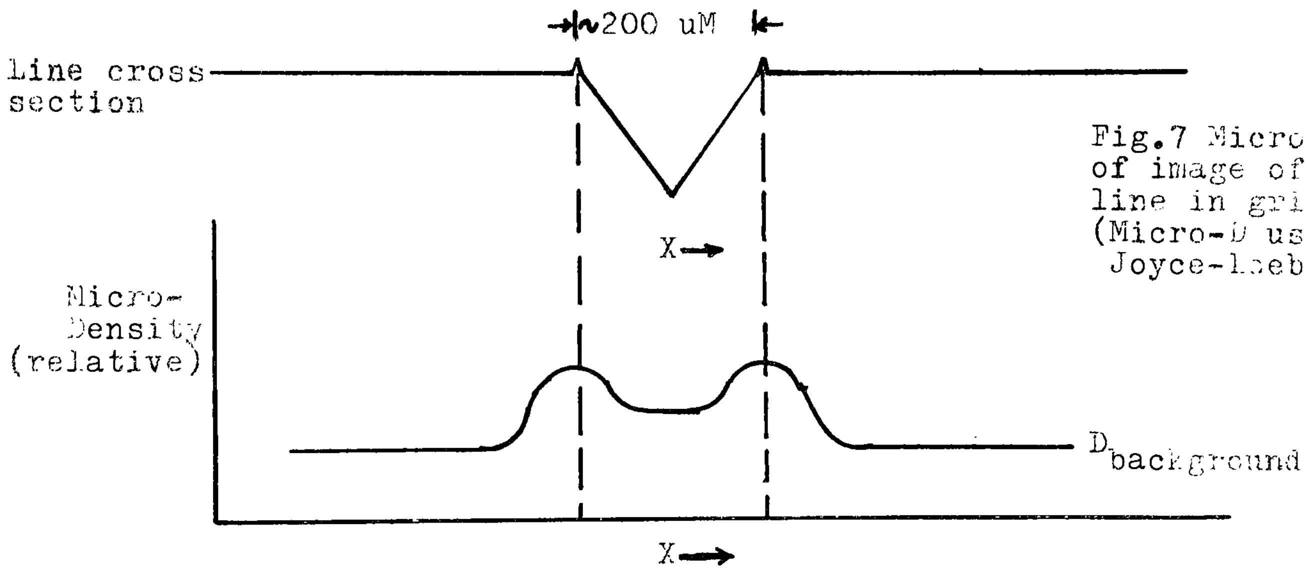
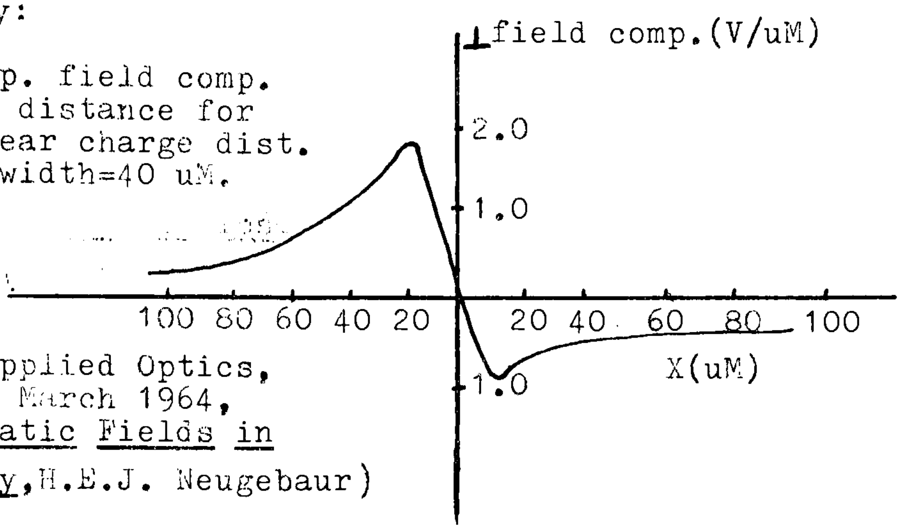


Fig.7 Micro-D scan of image of one line in grid pattern (Micro-D used-Joyce-Loebl)

It would appear that the greatest density occurs at the edges of the line.The explanation for this effect is called the"point effect of field emission"[27]. When the lines were etched into the metal, ridges or"points" were built up along the edges of the line, such as the ones illustrated in the cross-section drawing of figure seven. The perpendicular electric field component(E being a vector quantity) is much greater at these points than in the center of the line, in a way analogous to the distribution of the perpendicular field component for a linear charge in Xerography:[6]

Fig.8-Perp. field comp. vs. distance for linear charge dist. of width=40 uM.



(Source: Applied Optics, Vol.3,#3, March 1964, Electrostatic Fields in Xerography, H.E.J. Neugebaur)

Therefore, as in Xerography where toner is pulled more strongly to the edges of the line,[6] field emission is signifigantly stronger and more exposure results in those areas. Prof. Tiller himself pointed out that "for sharply pointed electrodes, the local field will be much larger than the total macroscopic field"[3].

Some of the other metal objects exposed with surface configurations not unlike the grid also demonstrated this effect to varying degrees. Photo #5 demonstates this effect very clearly.

When various liquids with high conductances were placed between the and the film to eliminate the effect of field emission and enhance any direct electron transfer, no images at all resulted. Photo #9 is a re-exposure of photo#8(Craftsman wrench) with a super saturated salt solution at 125°F degrees. Photo 8 yielded a clear image, but with the liquid no imag results. Other liquids tryed were heated dilute acid solutions, some aromatic hydrocarbons(benzene, tri-chloro ethelene) and even boiling H_2O.

None of these combinations yielded even a trace of an image. It becomes clear that Prof. Tiller's theory of pure field emission is sound.[6] Further work on this topic might include the making of exposures in a vacuum. Although more tedious, this would also effectively negate the effect of field emission.[7]

The finger pad images were made mainly to test their feasibility for use in the next part of the experiment. With this particular apparatus used, the voltage and pulse rep rate had to be turned up to extremely uncomfortable levels in order to obtain detailed images. At lower settings, only the corona with no fingerprint detail appeared. It was then determined that some other living system had to be used as the subject for the ANOVA. Cleanliness appears to be very important in the making of these images. perspiration and photographic chemicals, which contain conductive salts, will alter the conductances in the fingerand therefore the resulting image. Obviously, the conductances of the human skin are sufficiently high so that enough free electrons are availible for field emission. This agrees with with other research done on the conductances of living things.[9] In fact, RG+E publishes material warning children against playing in trees near power lines because, in their words, the high currents from these lines can"actually travel through tree branches". Pressure is another important factor in the making of the finger pad images. Pressing down hard on the film during exposure causeda complete loss of fingerprint detail.

The corona, or "aura" as it has been sometimes called, is a phenomenon which needs some clarification. It is one of the main tools the parapsychologists have used in relating the Kirlian image to the biological condition of the organism.[10] This corona, which appears as a halo effect around the object is due to the skin effect of AC fields.[7] In this context, "skin" refers to the surface of the object, not living tissue. When an AC field is applied to a conducting object, it is well known that the value of the field inside that object is zero. The field, therefore travels along the surface of the object, seeking the path of least resistance. This is represented by the film itself into which the instantaneous current leaps, thereby causing an air discharge, a field emission to the film. The photons emmited by this process give rise to the corona pattern on the film.

The ANOVA experiment on the effect of the electrical parameters of the device proved to be a very interesting one. The sensitivity of the system to small electrical changes was remarkable. For example, the difference in quality beween the images made at 30KV, 50 Hz, 6 seconds, and 30KV, 50 Hz, 3 seconds was three mean categories. The resulting image quality from any given combination was almost unpredictable.

The ANOVA table shows that the factors voltage and pulse repetition rate are statistically signifigant when compared to experimental error. Exposure time and all interactions were insignifigant. Apparently the only factors for this device which which have a signifigant effect on the quality of biological images when compared to the effect associated with random factors are the output voltage and the pulse envelope repetition rate.The results of this experiment could be applied to any ringing network-type Kirlian device with similar fixed factors.

The partitioning of the sums of squares similarly produced interesting results.There appears to exist a linear relationship between the or pulse repetition rate and the quality of the resulting images, while the relationship between quality and voltage is more complex than a simple linear or quadratic one.There appears to be an optimum voltage after which increases in voltage cause a reduction in the subjective quality. A possible optimum value also exists for the pulse repetition rate, but the device's range of control did not extend far enough to determine that value.

Future work in this area might include performing a similar experiment with a more complex device which would provide more varibles for the ANOVA. Among these would be pulse envelope frequency,and pulse duration.

CONCLUSIONS

The overall conclusion from this experimentation and data reduction to be drawn is that the processes involved in Kirlian electrophotography are governed by some well-known and understood physical principles, not unknown forces.It is inevitable that the author did not posess the means or time to discover everything that is to be known on the subject, but here are the answers to the questions which these experiments were designed to answer. They should be taken in the context of the project's limitations.

1)The Kirlian image is the result of a complex process known as field emission of conducting objects under an applied D.C. AC electrostatic field. The amount of field emission is a function of the local electric field strength, which in turn is a function of many variables, including surface configuration of the object +tempurature. Insulators will not give rise to a Kirlian image because of the lack of free electrons in their conduction bands to contribute to field emission. Living tissues, however, do have sufficient free electrons do give rise to the field emission process.Furthermore, field emission appears to be the <u>only</u> process by which these images are formed-no direct transfer of elctrons which contribute to the formation of an image occurs.

2)For the apparatus used, the applied voltage and the pulse envelope repetition rate make a signifigant contribution to the quality of the images obtained when compared with experimental error. The exposure time and all interactions are statistically insignifigant.This is true for images of living systems and these results do not neccessarily correlate to those obtained with metals. Furthermore, there appears to exist a linear lelationship between the pulse repetition rate and this subjective quality. The relation between quality and voltage is more complex, and appears to have an optimum value(approx. 22 KV P-P).

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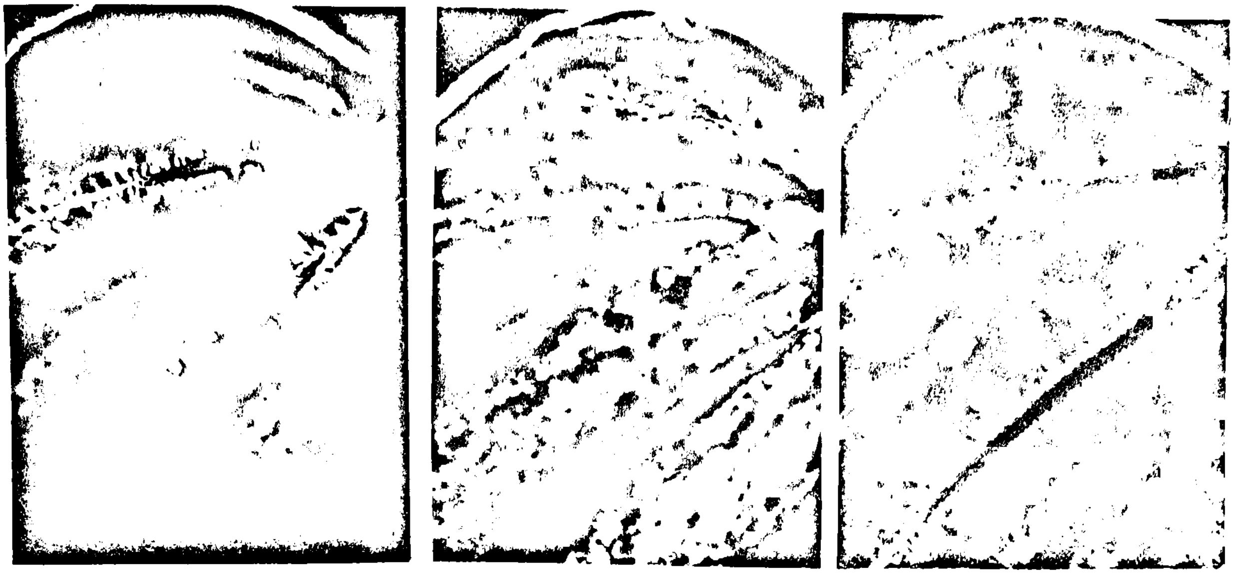
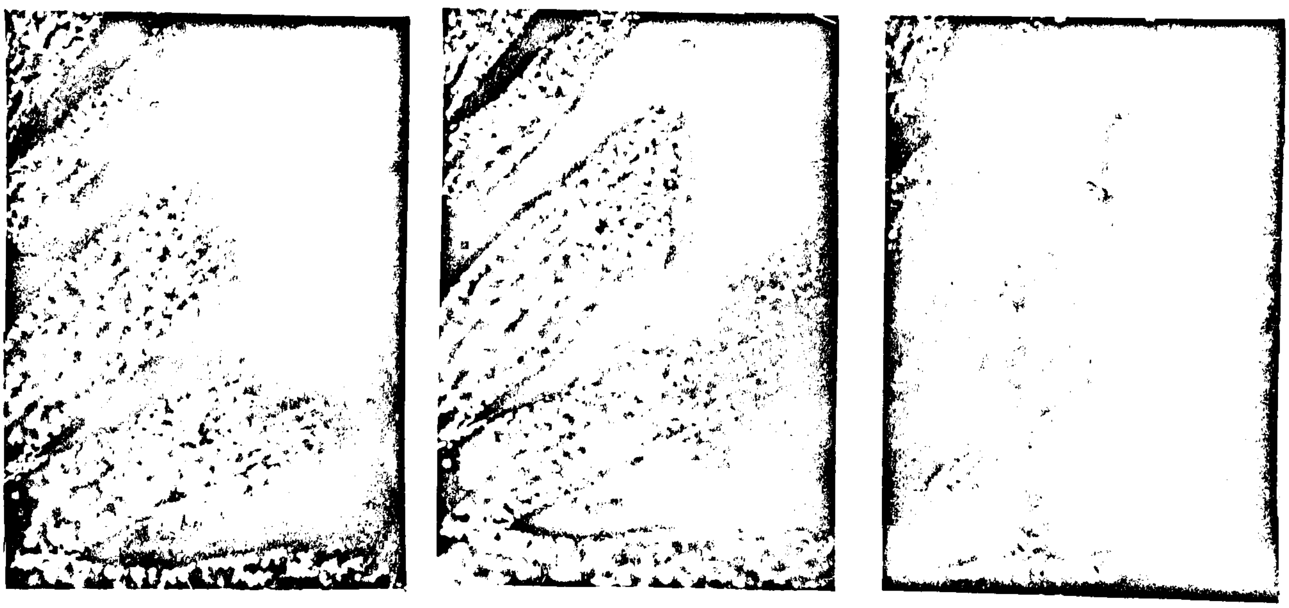


IO KV 20 KV 30 KV

FIG.9 Effect of Increasing Voltage, Other Factors Held Constant



I Hz 50 Hz IOO Hz

Effect of Increasing Pulse Repetition Rate, Other Factors Held Constant