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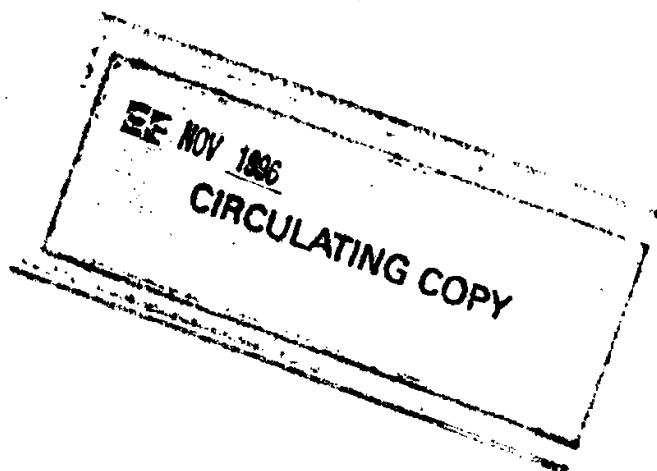
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REPORT NO. 1403

EXPLODING WIRE PARTICLE SIZE BY LIGHT SCATTERING MEASUREMENT

by

F. N. Weber
D. D. Shear



June 1968

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F. N. Weber
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Aberdeen Proving Ground, Md.
June 1968

EXPLODING WIRE PARTICLE SIZE BY LIGHT SCATTERING MEASUREMENT

ABSTRACT

The reddish color seen in photographs of exploding copper wires was assumed to be due in part to the scattering of the blue and green wavelengths of the BH6 mercury lamp used. Accordingly, this scattered light was used to measure particle size by the dissymmetry method. The average value of the predominant particle dimension was found to be time dependent with a value of $(12 \pm 3) \times 10^2 \text{ \AA}$ occurring .6 μsec before the voltage peak.

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I. INTRODUCTION

Insight into the mechanism of vaporization in the exploding wire phenomenon can be gained from a knowledge of sizes of the particulate matter given off in the explosion. Color photographs of exploding Cu wires taken with an unfiltered mercury arc show a predominately reddish color in the region of early expansion, indicating that there may be preferential scattering of the blue and green light of the arc. This suggests that the scattered light could be used to measure the particle size as is done in light scattering measurements of particles in a liquid.

II. THEORY

We denote the relative refractive index of the scattering particles by m , where $m = n/n'$, n is the refractive index of the particles, and n' is the index of the surrounding medium. For Cu and the wavelength of light used in these measurements ($\lambda = 4358 \text{ Å}$)^{1*}

$$|m - 1| \ll 1, \quad (1)$$

and from the measurements of aerosol sizes from exploding wires made by Karioris, et al,²

$$a ka |m - 1| \ll 1, \quad (2)$$

where k is the wave number $2\pi/\lambda$, and a is the length of the order of size of the particle; for a sphere a is the radius. Since the inequalities (1) and (2) hold, the Rayleigh-Gans³ scattering theory is applicable. For unpolarized light scattered at an angle θ (between the incident and scattered wave vector directions), this theory gives

$$I(\theta) = \frac{(1 + \cos^2 \theta) k^4 V^2}{2r^2} \left(\frac{m-1}{2\pi} \right)^2 |R(\theta)|^2 I_0. \quad (3)$$

$I(\theta)$ is the scattered light intensity measured at angle θ , V is the volume of the particle, r is the distance from the scattering particle to the detector, I_0 is the incident light intensity, and $|R(\theta)|^2$ is a

*References are found on page 14.

geometrical factor often referred to as the particle scattering factor. $|R(\theta)|^2$ enters the expression because of interference between the beams of light scattered from different parts of the same particle. If measurements of $I(\theta)$ are made at $\theta = 45^\circ$ and 135° , and their ratios taken,

$$\frac{I(45^\circ)}{I(135^\circ)} = \frac{|R(45^\circ)|^2}{|R(135^\circ)|^2} . \quad (4)$$

This procedure is often referred to as the dissymmetry method⁴.

For a sphere Rayleigh⁵ showed

$$R(\theta) = [9\pi/(2U^3)]^{1/2} J_{3/2}(U) \quad (5)$$

where $J_{3/2}(U)$ is the Bessel function of the 3/2 order and $U = 2ka \sin \theta/2$.

For Polydisperse random coils Debye showed

$$R(\theta) = \{(2/x^2)[e^{-x} - (1-x)]\}^{1/2} \quad (6)$$

where $x = (2/3) k^2 r^2 \sin^2(\theta/2)$, where r is the root mean square end-to-end length between ends of the coils.

The ratio $|R(45^\circ)|^2/|R(135^\circ)|^2$ can be calculated for various values of U and x . Results of these calculations are given in a table by Doty and Steiner⁷ where D/λ' values are given as a function of $I(45^\circ)/I(135^\circ)$. λ' is the wavelength of the light in the medium containing the scatters.

Values of interest to this experiment are plotted in Figure 1. In the case of a sphere $D = \text{diameter}$; in the case of random coils, $D = r$ of Eq. (6). λ' is assumed $= \lambda$ in both cases. One may therefore measure $I(45^\circ)/I(135^\circ)$ and from Figure 2 find the corresponding D/λ ratio for a sphere and a coil.

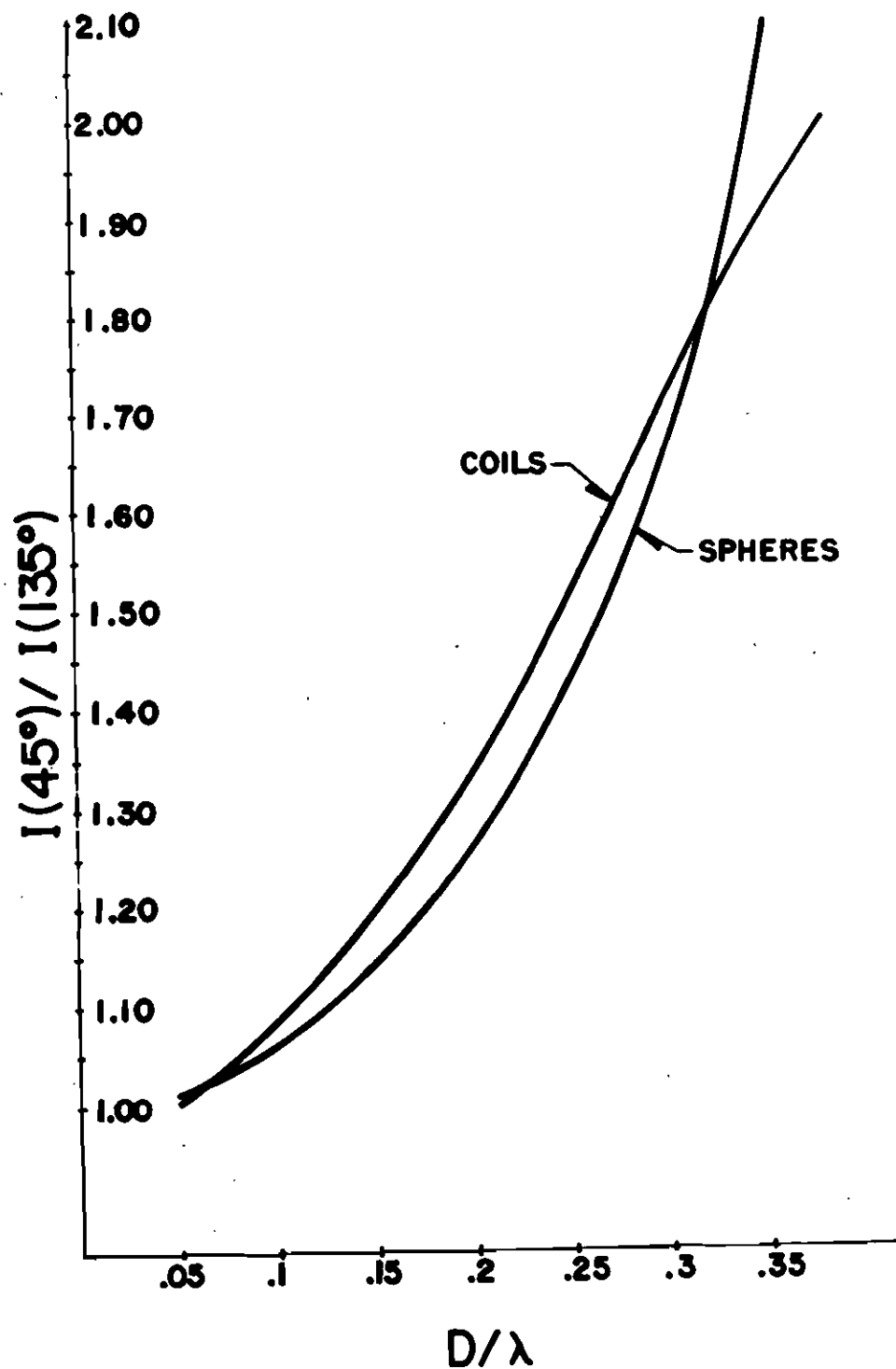


Figure 1. Ratio of Light Intensities vs. Ratio of Particle Size to Wavelength

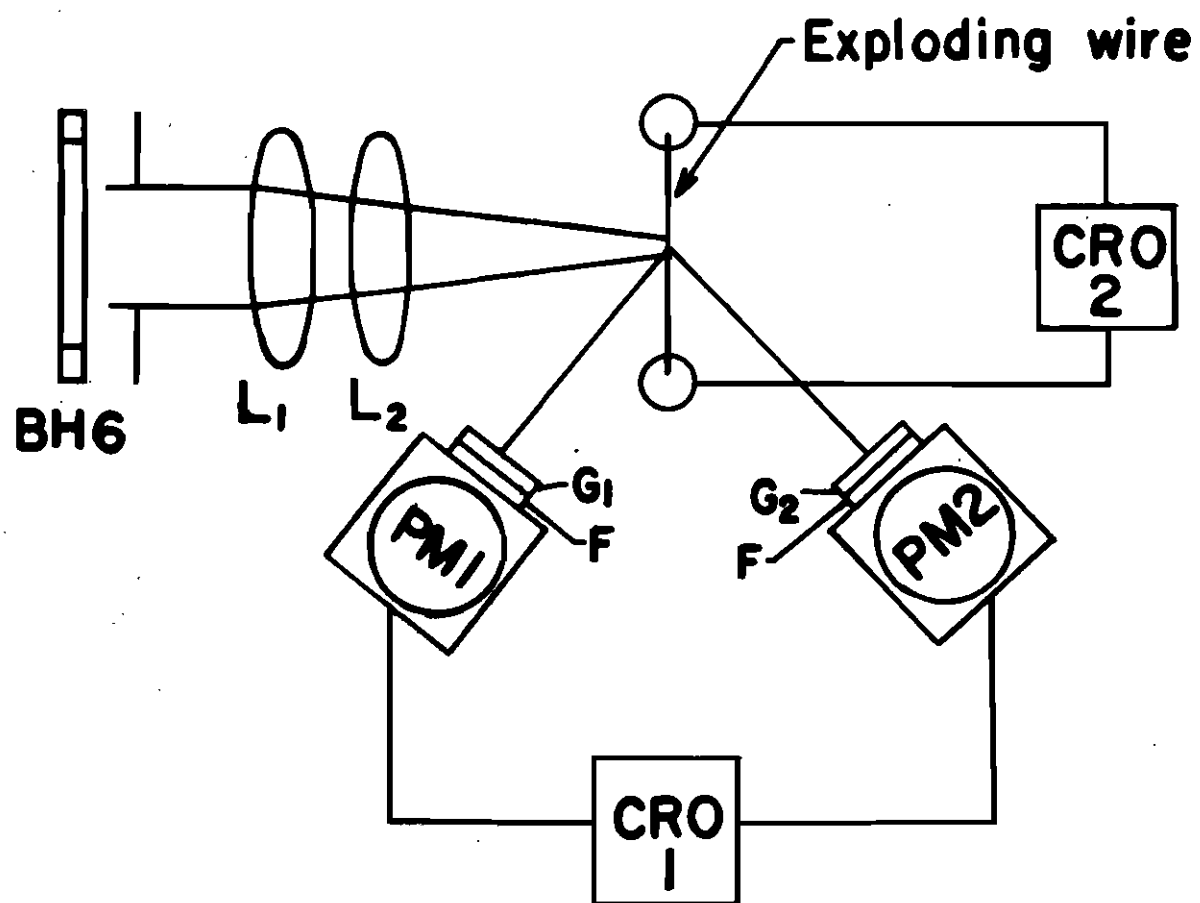


Figure 2. Experimental Arrangement

III. EXPERIMENTAL DETAILS

The experimental set-up is shown in Figure 2. The current and voltage history of the wire were recorded on CRO2. (The capacitor and triggering systems are not shown). 10 mil copper wire 2.5 cm in length was vaporized by discharging a 31.7 μ f capacitor charged to 3,000 v through the wire in the usual manner⁸. Lenses L_1 and L_2 focused the light from the BH6 mercury arc onto the exploding wire. Light scattered from the vapor was detected by photomultipliers PM1 and PM2. Filters F in front of the photomultipliers selected the wavelength of light ($\lambda = 4358 \text{ \AA}$) admitted to the photomultiplier cathodes. G_1 and G_2 were neutral density filters which compensated for the difference in gain between PM1 and PM2. The output from the photomultipliers went to CRO1, which was triggered by CRO2. CRO2 was triggered by the current pulse through the wire. $I(\theta)$ was not obtained immediately from CRO1, because the light falling on the photomultipliers consisted of a combination of the scattered light plus the light emanating from the wire due to ohmic heating. We refer to this light as self-luminosity. This self-luminosity must be deducted from the total intensity of light impinging on each photomultiplier. This necessitated exploding wires in pairs, one with the BH6 back lighting and one without the back lighting. $I(\theta)$ is obtained by subtracting the non-back lighted oscilloscope readings at each point of interest from the back light readings at the same point. Figure 3 is a complete set of superposed oscilloscope traces. The top pair of curves are the forward photomultiplier outputs for the wires, with and without back-

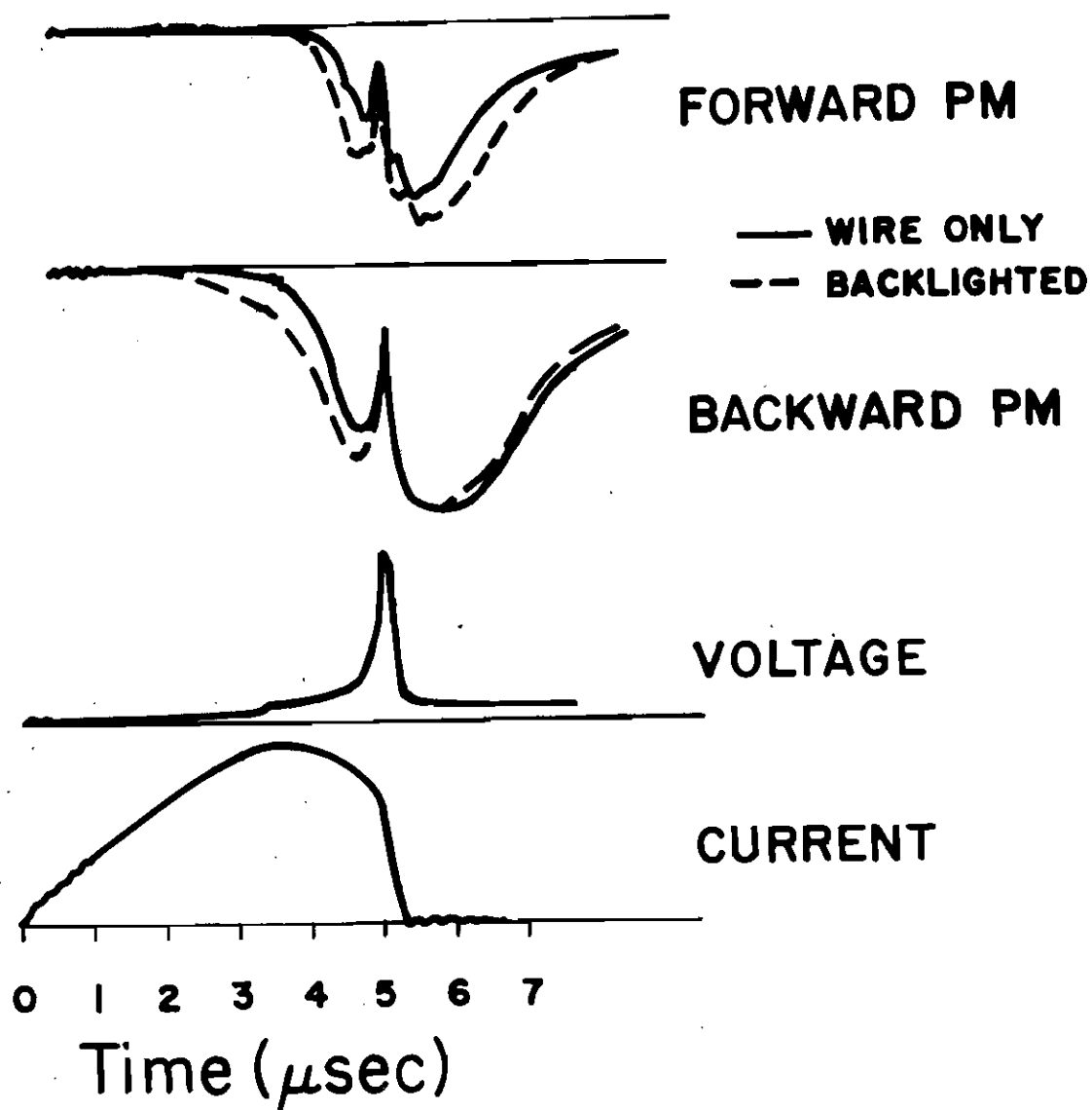


Figure 3. Photomultiplier Output Correlated with Voltage and Current

lighting. The second pair from the top are for the backward photomultiplier. Beneath the photomultiplier traces are the usual voltage and current traces. Beneath the voltage-time curve at the top of Figure 4 is a sketch of a streak picture of the exploding wire. The dotted region appears red in color photographs made of the event. Each trace on the left of Figure 4 has the same time scale, i.e., at any abscissa value the time elapsed since the initial current rise is the same for each curve and sketch.

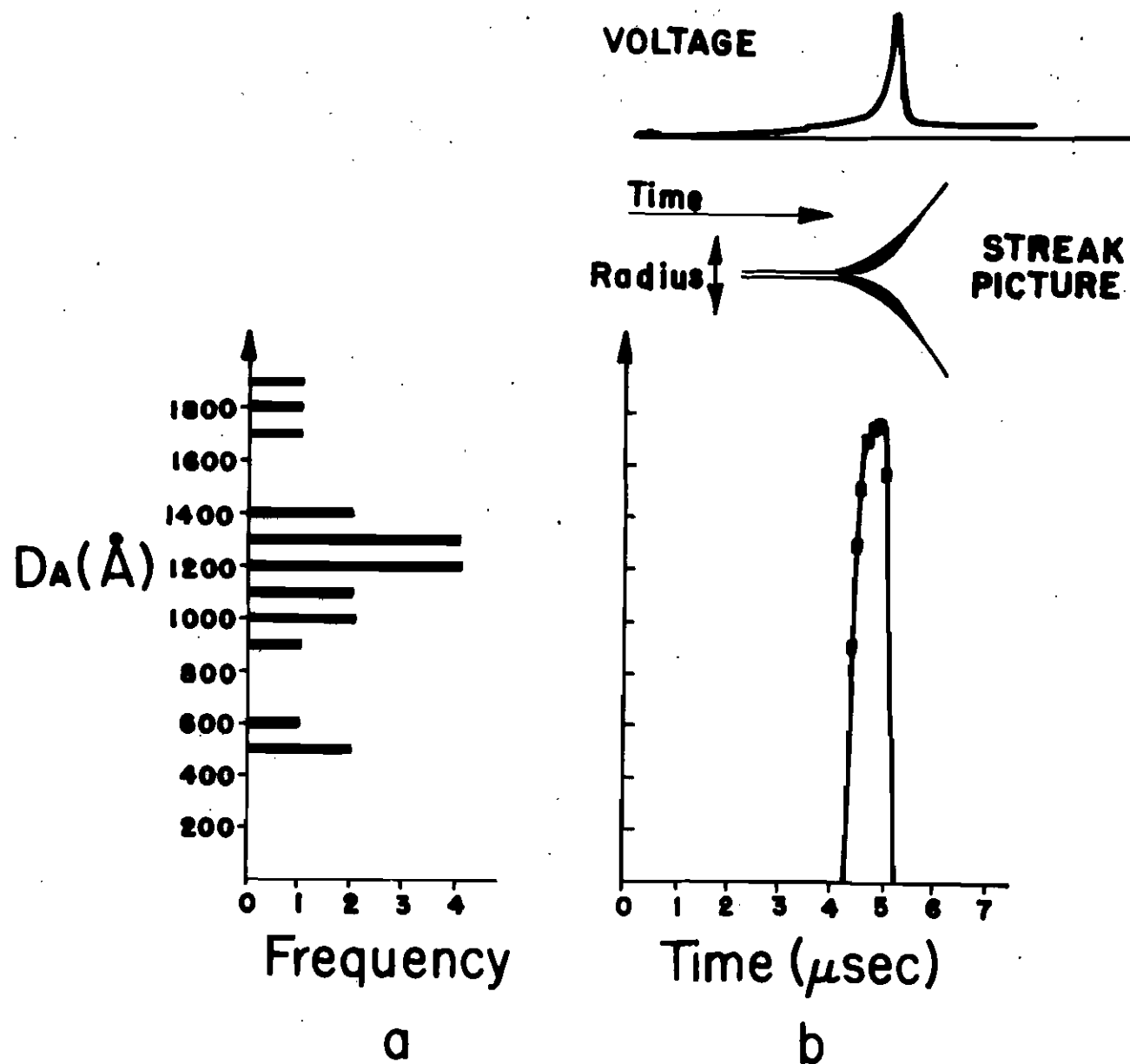


Figure 4. (a) Frequency of Particle Size .6 μsec before Peak Voltage
 (b) Particle Size vs. Time Correlated in Time with Optical Shadowgraph and Voltage

IV. RESULTS

Values of D were obtained for the corrected (for self-luminosity) $I(45^\circ)/I(135^\circ)$ oscilloscope readings. Thus, for a given $I(45^\circ)/I(135^\circ)$, D for a sphere and D for a coil were found. The two were averaged without weighting to give D_A . The sphere and coil configurations are about equally probable, based on the photographs of Karioris².

Twenty-one pairs of shots were analyzed by this method. The measurements were all taken at approximately .6 μ sec before the voltage peak occurred. Measurements much before or after this time were of doubtful value. The results of these measurements are shown in Figure 4a which shares the ordinate of Figure 4b. The mean of these values of D_A was 1200 $\text{\AA}$ with a standard deviation of 350 $\text{\AA}$. Plotted in Figure 4b is a size versus time plot of one of these shots which was especially amenable to such a representation. The particles first have a measurable size ($> 100 \text{\AA}$) where color is first noted in the streak color photograph (the dotted area of the streak picture). The size reaches a maximum in the middle of the dotted area, then sharply drops to an immeasurable value near the time of the voltage peak. It should be pointed out that this method of measurement is independent of the concentration of particles, so that the fact that the particles appear to decrease in size cannot be accounted for by a diminution in their number.

There are two major sources of error in this experiment. Probably the largest is due to the small increase of intensity of light for the backlighted shot over the non-backlighted shot. Sub-

traction thus introduces errors due to small differences. Another source of error results from a shot to shot variation of self-luminosity of the wire, again casting some doubt on the subtraction process. These errors together might account for a maximum error of 40% in one determination of D_A .

V. SUMMARY

A measurement of the mean dimension of the particles from an exploding Cu wire yielded a particle dimension of $(12 \pm 3) \times 10^2 \text{ \AA}$ at 4.5 μsec after the initial current rise. A time resolved particle dimension study showed that these particles were first evident when the red color in the streak photographs was first visible. The particle dimension reached a peak at the same time that the voltage peak occurred, and fell off sharply (within approximately 0.3 μsec) to an immeasurably small value.

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