SPARK PHOTOGRAPHY AS A MEANS OF MEASURING RATE OF EXPLOSION

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ABSTRACT

The explosive was placed in a long cartridge having excess charges in small equally spaced side openings which were set off in succession as the explosive reached them so that each became the center of a spherical sound wave. An instantaneous photograph of shadows of these sound waves was obtained by means of a spark which occurred automatically when the explosion reached a certain opening and closed an electrical circuit. From the radii of the spherical waves and the distance between the openings the rate of explosion was determined. Rates for various charges were found as follows: *lead styphnate* $.11\times.15\times10.0$ cm, 369 meters per second; loosely packed *mercury fulminate* $.15\times.25\times14.0$ cm, 1205 meters per second; well packed *gunpowder* .45 cm in diameter and 12 cm in length, 261 meters per second.

INTRODUCTION

MALLARD and LeChatelier[1] traced the progress of a flame in a horizontal tube by the light effect upon sensitized paper which was made to move vertically. Oettingen and Gemet[2] used a rotating mirror and photographic camera for recording the stages in the development of an explosion. For a like purpose Dixon[3] used a camera with films attached to a revolving drum.

Photographs taken by any of these or similar methods show only those parts of the disturbance which are self luminous and are the cumulative result of a longer exposure than is desirable for instantaneous results. Under proper conditions an electric spark has an intense luminous effect which lasts less than one millionth of a second. It has been used successfully in the photography of falling drops,[4] insects in flight,[5] projectiles in flight[6] and in various experiments with sound waves.[7,8,9] In Bulletin

[1] Mallard and Le Chatelier, Annales des Mines, vol. **4**, 1883.
[2] Oettingen and Gemet, Ann. der Physik und Chemie **33**, 586 (1888)
[3] Dixon, Phil. Trans. Royal Soc. **200**, 316 (1903)
[4] Cranz and Glatzel, Scient. Amer. Suppl. Feb. 1, 1913
[5] Bull. Scient. Amer. Nov. 26, 1910
[6] Cranz and Külp, Zeits. f. Gesamte Scheissund Springstoffwesen; translation in Scient. Amer. Suppl., March 27, 1915.
[7] Hyde, Scient. Amer. Aug. 26, 1916;
Wood, Phil. Mag. **48**, 218 (1889);
M. Toepler, Ann. der Physik **27**, 1043 (1908)
[8] Foley and Souder, Phys. Rev. (1) **35**, 373 (1912)
[9] Foley, Phys. Rev., **14**, 143 (1919); **16**, 449 (1920); **20**, 505 (1922)

No. 23 of the National Research Council, Foley suggested that the method used in sound wave photography be applied to the study of explosives. Using this method Dutcher,[10] has made an extensive study of explosions in certain gases. The present paper presents some results of a study of solid explosives.

General Principle of the Method

An explosive is confined in a heavy metal cartridge which has a series of openings located at definite intervals. At the openings a slightly larger amount of the explosive is placed. The explosion is started at one end of the tube and as it reaches the successive openings each becomes a source of sound. The cartridge is placed in front of and parallel to a photographic plate and an electric spark is produced at a gap located on a line drawn at right angles through the center of the plate and cartridge. If the spark passes at the proper time the photographic plate indicates the location of the various sources of sound and of each of the resulting waves at that particular instant. By measuring the distance which the explosion has progressed in the cartridge and the distance which the sound wave has traveled in air, sufficient data are secured for calculating the rate of the explosion. It should be noted that the waves are not truly spherical since the expiosion is restrained from development in some directions; also that the velocity of the wave is at first not the ordinary velocity of sound in air, as it has been shown[11] that the velocity of sound near a source where the disturbance is violent is much greater than under ordinary conditions. However the distortion due to the first ceases and the velocity becomes normal before the waves have reached points to which measurements are made. Since differences in distances are used, the errors due to these causes disappear.

Arrangement of the Apparatus

For the study of gunpowder a bar of wrought iron 2 cm square was drilled much like a short rifle barrel, but with a series of small openings in the side. The charge was ignited by an ordinary shot gun cap.

The cartridge used for the lead styphnate and mercury fulminate was formed of two bars of wrought iron $30 \times 4 \times 1$ cm. One face of each bar was planed and in the upper one was milled a narrow shallow groove. Extending from the groove through to the upper side were the openings which were filled with the excess charges. Directly opposite the groove was drilled a series of holes, close together for the mercury fulminate but

[10] Dutcher, Phys. Rev. **15**, 228 (1920)
[11] Foley, Phys. Rev. **16**, 449 (1920)

more widely separated for the lead styphnate. The two bars were held together by fourteen quarter inch bolts. The cartridge was loaded by separating the bars, filling the milled groove in one bar with the charge, covering the entire face of the bar with paper, and bolting the other bar to it. For firing the charge a fuse was inserted at one end.

In Fig. 1 is shown the arrangement of the electrical and photographic apparatus. For the sake of simplicity the box enclosing the light gap, firing cartridge and photographic plate is omitted.

The cartridge containing the explosive is at *C*, the photographic plate at *P*, and the gap at which the spark which makes the exposure appears, at *L*. The electrical circuit includes the induction machine with five

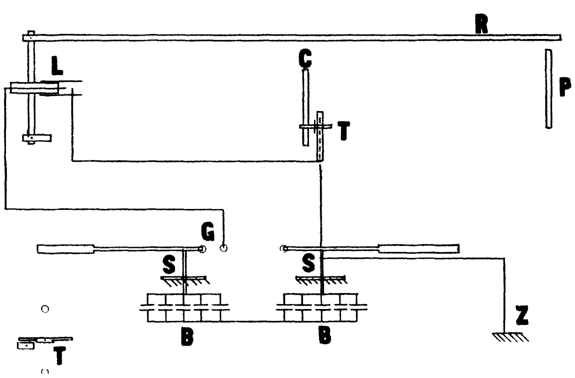

Fig. 1

Leyden jars on each side, the trigger for closing the circuit at *T*, a spark gap at *L* and another gap at *G*. *S* and *S* indicate the collecting brushes on the machine, *Z* a ground connection and *R* a rod for controlling the length of the gap at *L*. In the detail at the lower left is shown the trigger *T* which was used for closing the circuit when studying gun powder and lead styphnate. It is a strip of aluminum 10 cm long, 1 cm wide and 0.2 cm thick, riveted to a heavier block through which the axle passes. The trigger was placed so that one end came directly over one of the holes in the cartridge. The explosion caused it to rotate so that its ends came very near the terminals which were located directly above and below the axis of the trigger. Thus the discharge took place through the trigger and the circuit which included the spark gap at *L*. By changing the location of the trigger different time intervals between explosion and exposure were obtained. An attempt was made to use the same trigger with mercury fulminate, but the explosion of even a very small quantity was too violent. Various devices were tried and finally the trigger was discarded. The two heavy terminals were simply held in a horizontal position about 10 cm above and below the cartridge, respectively. Thus when the explosion drove hot gases through the openings the air was ionized and the spark passed. By shifting the terminals along the cartridge the

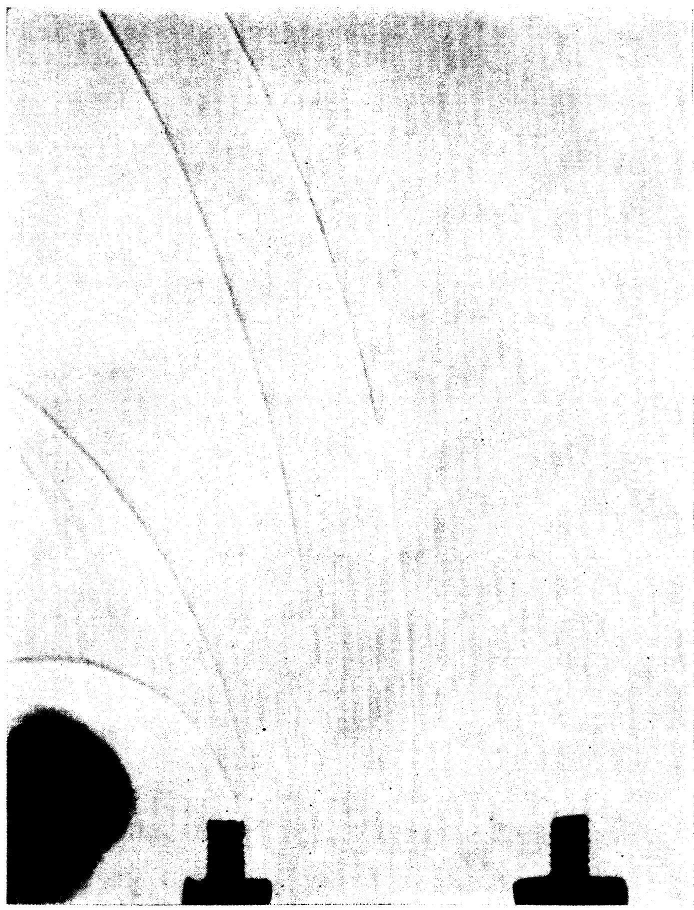

Fig. 2. Photograph showing sound waves due to explosion.

proper time interval was obtained. In all cases the time interval was controlled also by varying the length of the gaps at *G* and *L*. Photograph 9 shown in Fig. 2 is one of several made when using lead styphnate.

Method of Taking Measurements from the Plate

Fig. 3 illustrates the method of taking from the plate the measurements necessary to calculate the final results.

Traces of waves on a photographic print were made on a sheet of drawing paper. The trace of the upper edge of the cartridge was extended to the left as shown and the various openings from which the sound started located upon it. The distance from source to each wave was then measured. The measurements in Fig. 3 were taken in this way

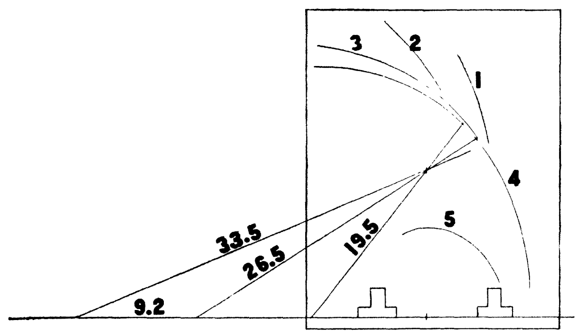

Fig. 3. Diagram of various sound waves.

from one of the plates. Evidently the progression is uniform since the increase in the distance from source to wave is so. The fifth wave from the source immediately below the center of the plate is not measured since it is still distorted.

Method of Computation

The pictures of sound waves secured by this method are, in reality, the projections of spherical sound waves upon the photographic plate. Their geometrical relation to the various parts of the set-up is illustrated in Fig. 4.

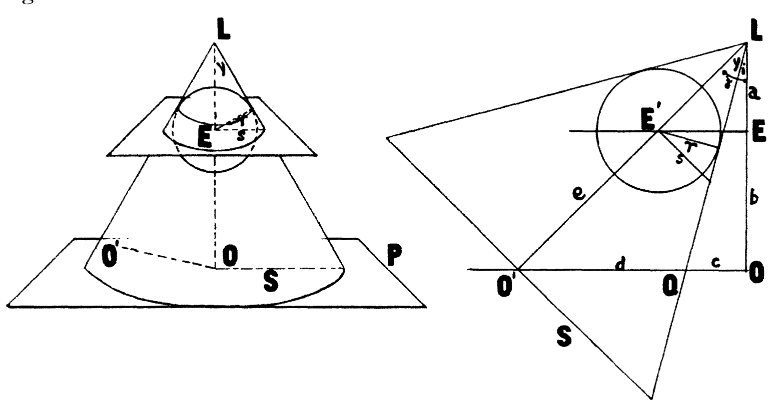

Fig. 4. Diagram showing geometrical relations.

The apparatus is so designed that the point source of light is at L, the photographic plate is in the plane P, so placed that the normal from

L passes through its center, and the cartridge is in some plane parallel to P, between L and P. One of the openings in the cartridge lies at E in the plane p and also in the normal drawn from L to the planes. This opening is the source of the spherical waves, represented in the figure by the sphere whose center is at E. The shadow of the sphere, falling upon the plane P produces the waves in the photograph. The radius of this sphere, then, measures the distance the sound wave has traveled up to the instant the picture is taken, and is therefore the distance which must be found.

To compute the radius r, lines are drawn through L tangent to the sphere, forming a right circular cone.

S may be measured on the photographic plate; LE and LO are constant, s may be found by proportion and r is equal to s cos y.

In the cross section diagram at the right of Fig. 4 is represented the condition when the explosion takes place at an opening E' which is not in the normal drawn from the spark gap to the center of the photographic plate. O' is a fixed point and thus the angle j ($O'LO$) is constant. Point Q and consequently the angle i (QLO) varies with different explosives. The angle y is equal to the difference between j and i. By proportion and trigonometric substitution

$$r = a \sec j \operatorname{sn} y \ .$$

Since the first two members are constant the value of r depends directly upon the value of y.

The time which has elapsed between the explosion at one opening and that at the next is represented by $t=(r_2-r_1)/V$ and the rate of explosion is expressed by $D/t=DV/(r_2-r_1)$ where t is time in seconds, r_2 and r_1 are the respective radii of the sound spheres, D is distance between sources, and V is velocity of sound in air.

Results

Data for lead styphnate are given in Table I. In a similar manner results were obtained for gunpowder and mercury fulminate. The average rate for three charges of gunpowder well packed in a cylindrical barrel 0.45 cm in diameter and 12.0 cm in length was 261 meters per second. That for three trials with mercury fulminate loose in a chamber $0.15\times0.25\times14.0$ cm was 1205 meters per second.

The author has been unable to find data on the rate of explosion of lead styphnate. The rates given for gunpowder vary from 200 to 300

[12] Wagstaff, Proc. Royal Soc. **105**, 282 (March 1924)

[13] Marshall's Explosives, Vol. **2**, p. 477

meters per second. Wagstaff[12] found it to be 265 meters. Marshall's "Explosives"[13] gives the rate of detonation for a much larger charge of mercury fulminate as 2200 meters per second.

TABLE I

Data for lead styphnate.

Photograph	c	d	j	y	r	r_2-r_1
No. 9A	7.8 cm	7.5 cm	3°38′	1°47′	4.08 cm	
	5.6	16.5	5°14′	3°54′	8.96	4.88 cm
	5.3	25.0	7° 1′	5°54′	13.57	4.61
No. 9B	8.8	8.0	3°59′	1°54′	4.36	
	5.4	17.0	5°18′	4° 1′	9.22	4.56
	5.0	25.5	7°12′	6° 1′	13.83	4.61
No. 9C	9.0	6.9	3°46′	1°38′	3.74	
	6.4	16.0	5°18′	3°47′	8.68	4.94

Mean value of $r_2-r_1=4.72$ cm. Resulting rate 369 meters per second.
Constants used: $a=131$ cm; $b=110.3$ cm; $D=5$ cm; $V=34820$ cm; temperature 27°C.
Dimensions of charge, $0.11\times0.15\times10.0$ cm; condition, well packed.

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FRANKLIN COLLEGE,
FRANKLIN, INDIANA,
December 22, 1924.

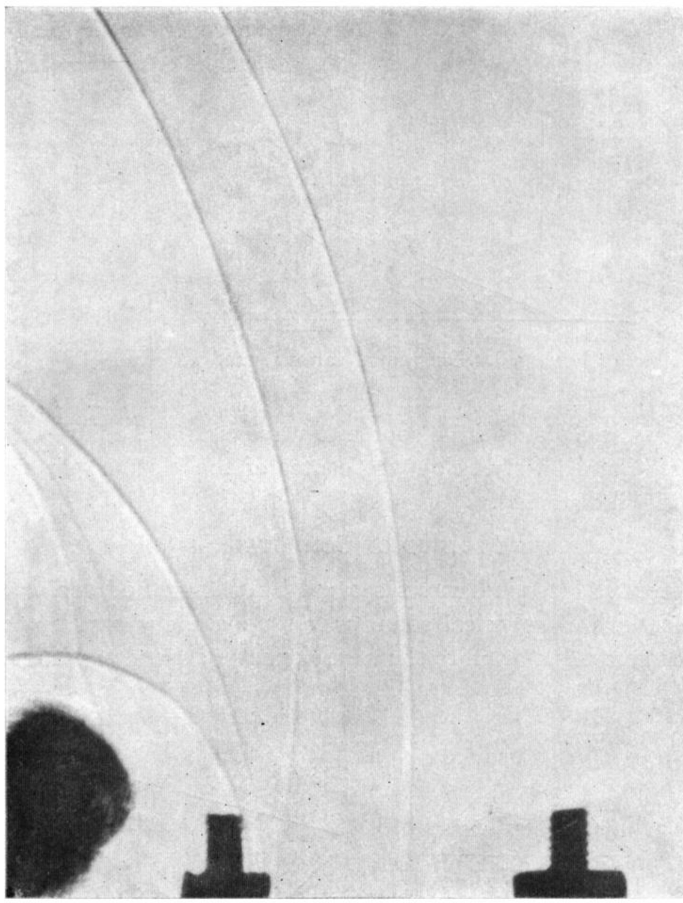

Fig. 2. Photograph showing sound waves due to explosion.