PHOTOGRAPHY AS A MEANS OF MEASURING THE RATE OF EXPLOSION.

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The work recorded in this paper is an outgrowth of the investigation which has been previously reported under the title, Sound Waves from Explosions.

During the course of the study of explosions of lead styphnate the author spread a thin layer of the same between two strips of glass, approximately 2 x 10 cm. in area, and fired the charge at one end. A photograph taken when the explosion had traveled half the length of the charge revealed a set of sound waves emanating from the crest of the explosion wave. This suggested the possibility of measuring the rate of explosion by a photographic method. Various methods of measuring this rate have been published.[1]

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. If the cartridge is so placed that the photographic plate indicates the location of the sources, and of the various sound waves at some particular instant, the rate of explosion is easily determined. It should be noted that the waves are not truly spherical since the explosion 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[2] 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 were used the errors due to these causes disappeared.

Arrangement of the Apparatus. For the study of gunpowder a bar of wrought iron two 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 shotgun cap. The cartridge shown in figure 1 was used for the lead styphnate and mercury fulminate.

This cartridge was formed from two bars of wrought iron 30 x 4 x 1 cm. One face of each bar was planed and in the upper one was milled

[1] (a) Mettegang, Report of 5th Cong. Appl. Chem. Vol. 2, p. 327. Marshall's "Explosives," Vol. 2, p. 477. (b) Kast, Spreng-und Ziendstoffe, p. 1025. (c) Wagstaff, An Electrical Method of Determining the Velocity of Detonation of Explosives. Proc. Royal Society, March, 1924, Vol. 105, p. 282. (d) Dautriche, Marshall's Explosives, Vol. 2, p. 479. Compt. Rend. 143, 1906, p. 641.

[2] Foley, Phys. Rev. Vol. 16, 1920, p. 449.

a narrow shallow groove. Extending from the groove through to the upper side were the openings which were to be filled with the excess charges. They may be seen in the figure. Directly opposite the groove was drilled a series of holes, close together for the mercury fulminate but 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 the one 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.

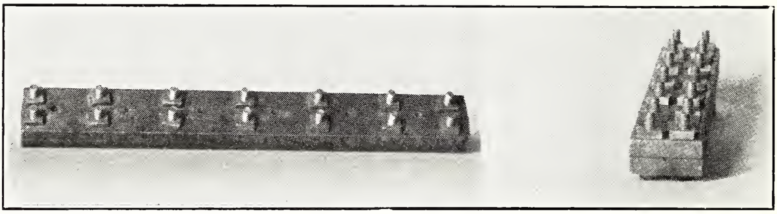


Fig. 1. Cartridge used in exploding lead styphnate and mercury fulminate.

In figure 2 is shown the arrangement of electrical and photographic apparatus. For the sake of simplicity the box enclosing the light gap, firing cartridge and photographic plate is omitted.

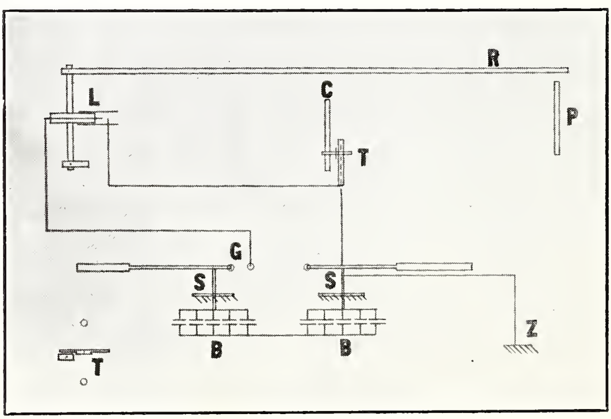


Fig. 2. Horizontal section of apparatus.

C is the cartridge containing the explosive, P is the photographic plate, and L is the gap at which the spark which makes the exposure appears. The electrical circuit includes the induction machine with five Leydon jars on each side, the trigger for closing the circuit at T, a light gap at L and another gap at G. S and S are the collecting brushes on the machine, Z is a ground connection and R is a rod for controlling the length of the gap at L. In the detail at the lower left is shown the trigger 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 proper time interval was obtained. In all cases the time interval was controlled also by varying the length of the gap at G and L.

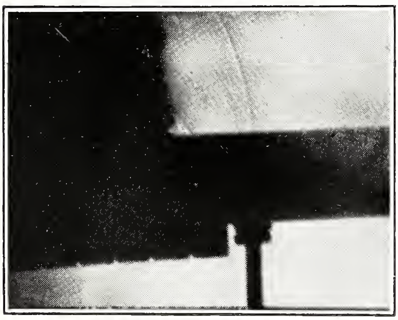


Fig. 3. A thin layer of explosive upon a flat block. Explosion half completed.

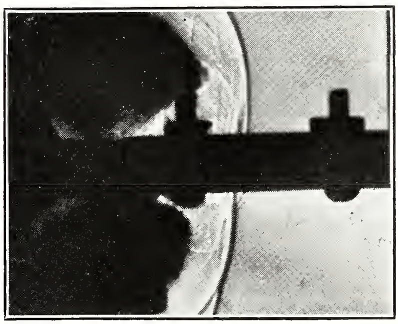
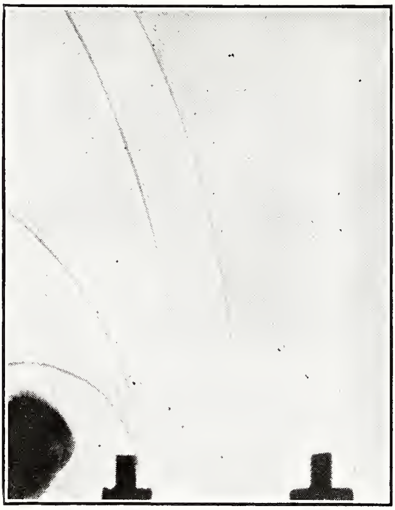


Fig. 4. Explosive confined in a cartridge. Sound waves and gases coming from small openings.

Operation of the Apparatus. The operator starts the induction machine some time before he is ready to take the picture, in order that it may be generating uniformly. While the machine is shorted by rods on itself, he adjusts the cartridge and the photographic plate. After removing the short he lights the fuse and the explosion takes its own picture.

Adjustments. If the plate shows no sound waves but a clear image of the cartridge it is evident that the light spark has occurred too soon. The trigger must then be shifted farther from the fuse end of the cartridge, or the gaps in the circuit lengthened. In case the picture is taken too late opposite adjustments must be made.

Discussion of the Photographs. Figure 3 shows the result of spreading a thin layer of lead styphnate between two long glass plates, placing this flat on a block of wood and firing the charge at one end. The photograph was taken at right angles to the strips and shows a series of sound waves. Figure 4 shows the first of the series obtained when using the cartridge. Close to the source the distortion of the sound waves is to be expected and it is evident in the photograph. In this position the photograph was necessarily taken too soon. Accordingly the plate was placed with its length vertical and the cartridge was moved until its image lay at the lower edge. Figure 5 is one of several made when using lead styphnate and figure 6 is typical of those secured when using mercury fulminate.



Figs. 5 and 6. Explosive confined in a cartridge. Sound waves coming from small openings.

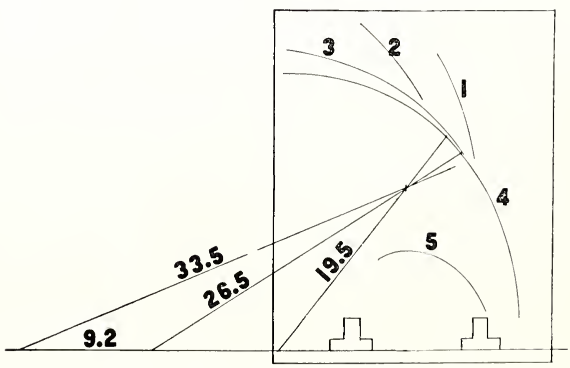


Fig. 7. A photograph showing shadows of spherical waves and their approximate radii.

Method of Taking Measurements from the Plate. In figure 7 is shown 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 wave was then measured.

The measurements in figure 7 were taken in this way from one of the plates. Evidently the progression is uniform since the increase in the distance from source to wave is so. The wave from the source immediately below the center of the plate is not included 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 figure 8A.

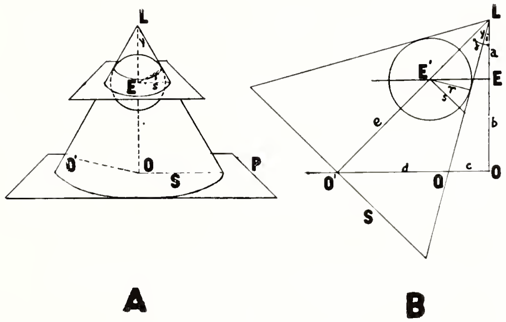


Fig. 8A and B. The projection of spherical sound waves upon a plane surface.

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. Let this plane be designated as 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 at the instant the picture is taken, and is therefore the distance which must be found.

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

Now $$\frac{s}{S} = \frac{LE}{LO},$$

$$s = S.\frac{LE}{LO}$$

and r = s cos y.

Since LE and LO are constants, measuring the distance from the point source of light to the cartridge and to the plate, respectively, and since S can be measured from the photographic plate, the value of r can readily be computed.

But this value of r holds true only for waves emanating from the point in the normal OL. If the waves are generated by an explosion at one of the other openings, the point E, while still in the plane p, is shifted to some point E′, such that its shadow falls at O′. This produces a rotation of the entire cone, its axis moving in the plane determined by L, O, and O′, about L as a center. The shadow of the sphere upon P now becomes an ellipse. It is still possible, however, to find the radius of the sphere from measurements made upon the shadow.

Figure 8B is a plane figure, showing the cross section of the cone, and the planes, p and P, cut by the plane L O O′. Let LE=a, EO=b, OQ=c, QO′=d, and O′L=e. As was shown above, the distances a and b are constant and can be measured from the apparatus. Furthermore, as the shadows of the sound wave, and of the cartridge fall upon the plate at Q and O′ respectively, and as O is the center of the plate, it is evident that the distances c and d may be measured by the method given above for taking measurements from the plate. Then, referring to figure 8B, it may be seen that

$$i = \tan^{-1} \frac{c}{a + b}$$

$$j = \tan^{-1} \frac{c + d}{a + b}$$

$$y = j - i$$

$$e = (a + b) \sec j$$

$$S = e \tan y$$

$$\frac{s}{S} = \frac{a}{a + b}$$

$$s = S . \frac{a}{a + b}$$

$$r = s \cos y.$$

Then by substitution,

$$r = a \sec j \sin y.$$

Since the cartridge always remains in the same place, sec j becomes a fixed quantity for each of the several openings, and need not be recalculated. Thus, after one set of data is solved, the calculation of the radii of the various sound spheres is reduced to finding values for sin y.

After the exact distance which the sound wave has progressed has been found in this way, from the plate, the time and rate are calculated according to the method outlined in the discussion of the general principle. Thus, the time which has elapsed between the explosion at one opening and that at the next is represented by

$$t = \frac{r_2 - r_1}{V}$$

and the rate of explosion is expressed by

$$\text{Rate} = \frac{D}{t} = \frac{D}{\dfrac{r_2 - r_1}{V}} = \frac{D \times V}{r_2 - r_1}$$

where t is time in seconds, r_2 and r_1 are respective radii of sound spheres in cm., D is distance in cm. between sources, and V is velocity of sound in air in cm./sec.

RESULTS.

TABLE 1. Data for lead styphnate.

Photograph	c	d	j	y	r	$r_2 - r_1$
	7.8	7.5	3°38′	1°47′	4.08	
No. 9A	5.6	16.5	5°14′	3°54′	8.96	4.88
	5.3	25.0	7°10′	5°54′	13.57	4.61
	8.8	8.0	3°59′	1°54′	4.36	
No. 9B	5.4	17.0	5°18′	4°1′	9.22	4.56
	5.0	25.5	7°12′	6°1′	13.83	4.61
	9.0	6.9	3°46′	1°38′	3.74	
No. 9C	6.4	13.0	5°13′	3°47′	8.68	4.94

Mean Value of $r_2 - r_1$, 4.72 cm.

Constants u ed:

a = 131 cm; b = 110.3 cm; D = 5 cm; V = 34820 cm; Temperature 27°C; Dimensions of charge 0.11 × 0.15 × 10.0 cm; Condition, well packed. Resulting rate 369 meters per second.

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 x 0.25 x 14 cm. was 1,205 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 meters per second. Wagstaff[1c] found it to be 265 meters. Marshall's "Explosives" gives the rate of detonation for a much larger charge of mercury fulminate as 2,200 meters per second.