LETTERS TO THE EDITOR

ELECTRICAL CONDUCTIVITY IN DETONATION GASES.

By KAZUMI TANAKA

In detonation of explosives, it is said that the chemical reactions occur very violently and the gases produced are momentarily ionized by splitting off their electrons. This fact is now so aquainted that it is applied to a measurement of velocity of detonation. Here the author has attempted to study the phenomenon regards to the ionized zone in detonation gases. His measurements have been made with a simple electric circuit which includes an ionization detector inserted in explosive. The explosive charge used is powdery TNT confined in paper cartridge with 0.95 in density and 32 mm in diameter.

In experiments, the ionization detector is prepared by a pair of parallel pins placed on the charge as shown in Fig. 1, and the distance between two pins designated by d in this figure is taken to be 3 or 10 mm. And then the detector makes a series circuit with a battery and two resistors as shown in Fig. 2.

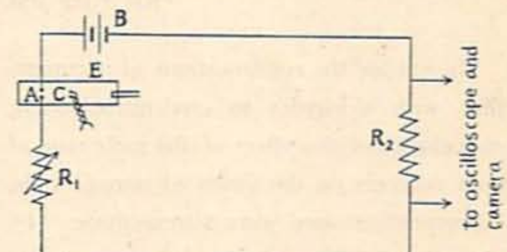

Fig. 2. Circuit for measurements.

There, E is an explosive charge, A is the detector mentioned above, C is another ionization detector which informs an arrival of detonation front to oscilloseope, B is a dry-cell rated to 90 V, R_1 and R_2 ars the resistors. The oscilloscope used is a single sweep type and is equipped so as to be initiated by closing of a starting circuit, in which the detector C is connected. Further in practice, a condenser rated to 10 μF is connected to cell B at both ends so as to hold sudden release of current in the circuit.

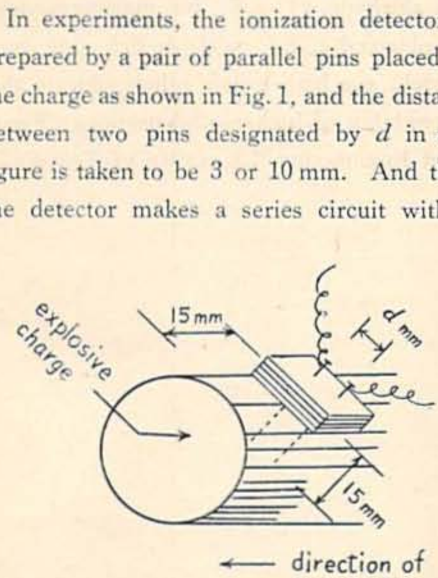

Fig. 1. Ionization detector inserted in explosive charge.

With this method, it is found that the oscillograms obtained change their shapes with values of the resistors R_1 and R_2. Fig. 3 shows this variety by using a simple circuit without R_1 for convenience. This fact can be interpreted as the effect of the "time constant" in C-R circuit which is inevitably formed by a self-formed condenser and the initially connected resistance as the following

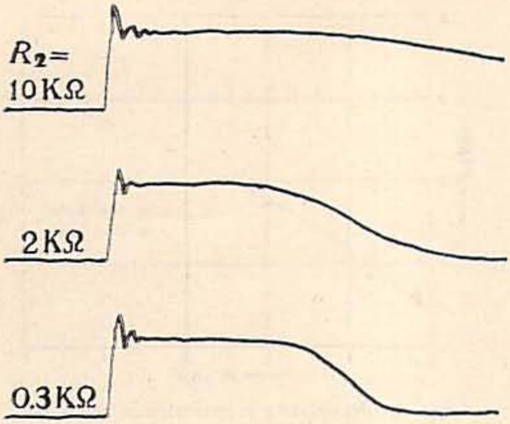

Fig. 3. Shapes of oscillograms and their dependence on resistances.

way. In these experiments the author has stretched a long thin wire, which was 5 m long and 1 m high, from explosive to oscilloscope to avoid needless hurts in the equipment. Then how small its capacity may be, the condenser is made between the stretched wire and the earth, and when the circuit is closed by occurence of the detonation the condenser is charged, and after the circuit is opened with the end of the phenomenon it discharges through the resistance. Thus when too large value of the resistance is taken in the circuit, the oscillogram hardly downs in the tail part even where the cut off of the phenomenon occur, as shown in Fig. 3. Therefore it is known that the value of the resistance has important role to obtain accurate oscillogram especially in tail decrement. On account of these fact the author has decided the value of R_2 to be 2 kΩ for subsequent experiments. However, a smaller R_2 results in a smaller "time constant" and more probable deflection of oscillograms, but it gives a smaller deflection which makes the analysis more difficulty. Then in effect, we must select some appropriate value of R_2 in the measurements. At the same time the resistance R_1 is connected near the explosive across the stretched wire in order to exclude the effect of its value on the "time constant", because the value of R_1 is varied in subsequent measurements.

Fig. 4 shows a typical oscillograms thus obtained, where the longitudinal deflection is to be proportional to the intensity of electric current in the circuit and also to the conductivity in the detonation gases. From this we can realize that there is a zone of high conductivity and it is kept for a relatively long time compared to the reaction zone which shall be continue less than one microsecond in these conditions. The duration of the flat part as designated by τ_2 in this figure scatters from 2 to 4 micro-seconds in the experiments; this scattering probably means that the phenomenon will be maintained until the breakdown of cartridge or falling off of the detector occur. Validity of the above illustration may be shown from the following result, that even when the detector is inserted at the end surface of the explosive in parallel to charge axis the flat part have almost same value of duration as the above,

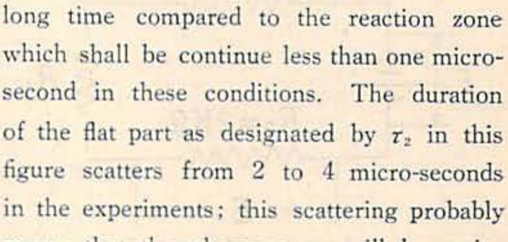

Fig. 4. Typical oscillogram obtained.

When explosives are fired for different values of resistances R_1, taking R_2=2kΩ in Fig. 2, the hights of oscillograms are also varied, reserving a similar shape. These results are tabulated in Table 1.

Now the circuit of experiments can be simply replaced by that shown in Fig. 5.

Table. 1. Measurements of shapes of the oscillograms.

R_1 (kΩ)	d (mm)	h (mm)	τ_1 (μsec)	τ_2 (μsec)
0.15	10	17.8	1.3	2.8
	3	18.0	1.1	3.4
0.75	10	12.5	1.5	2.3
	3	13.5	1.5	2.8
2.0	3	8.5	1.6	1.9
5.0	10	4.8	1.1	5.1
	3	4.8	1.3	3.6

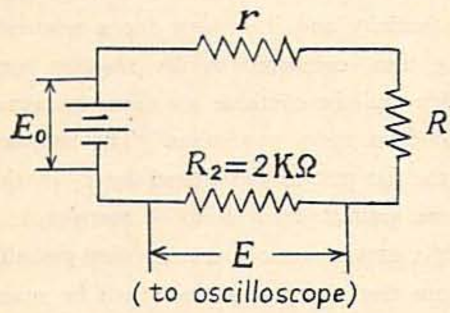

Fig. 5. The circuit simplified for calculation.

With this figure and Ohm's law we can introduce an equation, that is

$$E_0/E=r/2+R_1/2+1, \qquad (1)$$

where E_0 is battery voltage, E is the voltage derived on oscillogram, r is the resistance of detonation gases appeared on the detector pins. Left hand of Eq. (1) can be replaced by h_0/h, where h is that defined in Fig. 4 and h_0 is the deflection especialy measured in a circuit without resistances. Here, since h_0 has deen measured to be 24.2 mm, the author has evaluated r to be that shown in Fig. 6 with relations to R_1 although they must be independent each other in an ideal case. This dependence may come from the fact that a smaller resistance in the circuit leads to a larger voltage on the detector and gives rise promoted electrical dissociation of gases more easily showing smaller resistance r on appearance. As seen in Fig. 6 the curve seems to have an asymptote, therefore by

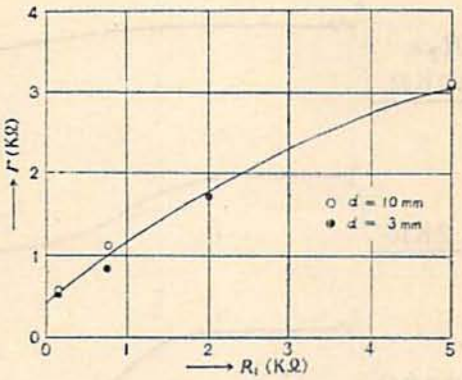

Fig. 6. Resistance r evaluated in relation to R_1.

the reason considered above the author has prefered to take the resistance r as 4 kΩ extraporated at infinite R_1. Now it is regrettable that in his experiments the measurements with more than 5 kΩ R_1 has not been made because too large value of R_1 results in too small deflection of the oscillograms.

Next, to correlate the conductivity in gases with the resistance r obtained above, the following procedure has been taken. First, if it can be assumed that the detector is made by two parallel wires without tips inserted in continuous conductive materials having specific conductivity σ (ohm^{-1}cm^{-1}), the relation between the conductivity and reduced resistance gives the next form,

$$r\sigma=\ln(d/a)/l, \qquad (2)$$

where l is the effective length of wires in the conductor, a is their radius and d is the distance between them. According to the present conditions, l=1.5 cm, d=1.0 or 0.3 cm and a=0.02 cm, then Eq. (2) is calculated to be

$$r\sigma=0.83\,\text{cm}^{-1} \ (\text{at } d=1.0\,\text{cm})$$
$$=0.58\,\text{cm}^{-1} \ (\text{at } d=0.3\,\text{cm}). \qquad (3)$$

Here, it is notable that the effect of wire distance on reduced resistance is only logarithmic by the theory, thus the difference between 1.0 and 0.3 cm in preceding experiments is not so large as previously shown in Table 1. Secondly, the relation like Eq. (3) can be also derived from the experiment where the same ionization detector is inserted into an electrolytic solution of known conductivity to measure its resistance. The author has tested this method and obtained a relation which shows a fairly good agreement with the theoretical Eq. (3), that is

$$r\sigma=1.0\,\mathrm{cm}^{-1}\ (\text{at } d=1.0\,\mathrm{cm}). \quad (4)$$

When $r\sigma$ is 1.0 after Eq. (4) for simplicity and the observed value of the resistance in detonation gases r is 4 kΩ, the specific conductivity σ of the gases becomes to 2.5×10^{-4} ohm^{-1} cm^{-1} or 2.5×10^{-13} cgs. emu. This value of conductivity approximately corresponds to that of 0.002N NaCl water solution. Furthermore, it is known that the electrical conductivity in slightely ionized gases can be calculated as follows due to Kantrowitz *et al* (J. Appl. Phys., **26**, 109 (1955)),

$$\sigma=\frac{\alpha e^2}{(2\pi m_e kT)^{1/2}}\cdot\frac{1}{Q}. \quad (5)$$

Where α is the degree of ionization of the gases, e and m_e are the electric charge and the mass of electrons respectively, k is Boltzmann's constant and Q is the collision cross section of the gas species to the electrons. On derivation of Eq. (5) an assumption that the velocities of electrons are distributed in Maxwellian form at equilibrium temperature T is used, then T in above formula shall be the electronic temperature. Now, taking Q to be about 10^{-16} cm^2, and substituting other constants and values in Eq. (5), one can lead next formula,

$$\alpha=8.6\times10^{-11}\sqrt{T}. \quad (6)$$

Of course Eq. (6) may have accuracy only in decimal orders. And further if T is assumed to be 3,000—4,000°K as reliable one in detonation of TNT, we can estimate the degree of ionization in detonation gases to be about 5×10^{-9}. This value may be received as a reasonable one.

Thus, the author has derived the following conclusions on the ionized zone appeared in detonation of TNT.

(1) The ionized zone in detonation gases is maintained for a relatively long time about 2–4 μ sec, and the electrical conductivity in the zone is kept almost constant during the period.

(2) By this experiments, the specific conductivity of the detonation gases is calculated to be 2.5×10^{-4} ohm^{-1} cm^{-1} and the degree of ionization 5×10^{-9} with some reasonable assumptions.

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