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ORIGIN OF DETONATION-GENERATED
IONIZATION WAVES

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ABSTRACT

The high electron density which exists in the external ionization wave that propagates away from the free surface of a detonating explosive was investigated by electrostatic probes and an impurity-doping method. Two impurities, potassium nitrate and cesium nitrate, were added to RDX in different molar concentrations. The conduction in the ionization wave was measured by the electrostatic probe technique.

The increased maximum conduction at the front of the ionization wave and the increased thickness of the wave for doped RDX as compared with conduction measurements obtained with pure RDX were discussed in terms of two current models for the origin of the ionization wave - the shock wave model and the detonation generated plasma model.

Introduction

It is well known that the detonation wave in a condensed high explosive is a region of high ionization and has the ability to conduct electric current at low resistance. Investigations have shown that the region in detonation of highest ionization and electrical conduction is the chemical reaction zone. (1,2) Although it was first estimated that the reaction zone contained more than 10^{17} free electrons per cc., (1) later studies have indicated concentrations in excess of 10^{19} free electrons per cc. (3) It is also well known that upon the arrival of the detonation wave at the free surface of the explosive, a highly ionized region propagates away from the free surface of the explosive into the surrounding medium. This ionized wave appears to be common to all explosives. (4) An interesting and significant feature of the ionization wave is that it may be luminous, transparent or opaque depending upon the surrounding gaseous medium and the pressure. (5) The electrical conduction generally remains high regardless of the surrounding medium (including a vacuum). (5,6) Although a large amount of information has been accumulated in recent years as to the nature of the ionization wave, which is sometimes referred to in the literature as a detonated-generated plasma (d.g. plasma), there have existed divergent theories as to its origin.

One theory attributed the high degree of conduction in the wave to thermal ionization of the surrounding gaseous medium, the ionization being induced by a shock wave propagating away from the free surface of the explosive. (7,8) The luminosity was considered to result from decay of the ionization with a direct relationship existing between the

intensity of the visible light and the local electron density. Relative luminosities associated with shocks transmitted through various gaseous media were explained on the basis of the heat capacities of the gases.

Recently, these ionized gas waves were subjected to careful study in this laboratory where it was demonstrated that the high density ionization originates primarily from the reaction zone of the explosive and that only a minor part of the ionization comes from thermal ionization of the surrounding medium by the shock wave.^(1,2,9) In other words, the ionization wave expelled from the free surface of the explosive is, in the main, just a continuation of the chemical reaction zone which decays much more slowly upon encountering the low pressure and density environment at the free surface.

In the Cook theory of the external detonation-generated ionization wave, the observed luminosity was not considered to be the determining or even a directly related criterion of the existence of the external ionization zone.⁽¹⁰⁾ In fact, there appeared to be no direct relationship between the visible light emitted and the high electron density. Luminosity was considered to result largely from interaction of electrons in the ionization wave with molecules of the gaseous medium (probably via negative ion formation). For example, there exists little or no visible luminosity when negative ions are not produced as a result of little or no electron affinity of the molecules of the gaseous medium (e.g., with helium), when there is a critical reduction of gaseous medium (e.g., in a vacuum), or when there is rapid decay of the ionization due to free radical formation (e.g., with propane).

It can be experimentally demonstrated that the external ionization wave has remarkable stability, existing in air sometimes as long as several hundred microseconds before undergoing an accelerated decay to the normal products of detonation.⁽⁹⁾ The ionization wave can also be readily bent and easily extruded through narrow tubes.⁽⁴⁾ This shows that the wave has remarkably high cohesion and little external pressure associated with it. However, the ionized zone can be exploded by rapid expansion from a compressed state, or by collision with a solid surface.⁽⁴⁾ These observations appear to substantiate Cook and McEwan's⁽¹¹⁾ proposed quasi-lattice model for these ionization waves. Similar models have been proposed for the plasma state by Ecker and Weizel,⁽¹²⁾ and by Kirkwood and Cowen.⁽¹³⁾ According to Cook and McEwan's model, these low temperature, high density waves probably involve the promotion of the valence electrons from localized states in atoms or molecules to collective electron states in which they can move freely but are correlated with the ions much like they are in metals.

Since there still exists disagreement as to the interpretation of the experimental results regarding the external ionization wave, especially the origin of the wave itself, it is the purpose of this study to extend the investigation into the origin of the ionization waves or more specifically, into the source of the high electron concentrations in the waves propagated in the surrounding gaseous medium.

Recently, Barton⁽⁶⁾ employed an indium tracer in the explosive to determine the position of the detonation products in relation to the ionization zone as the zone traveled down the length of a constraining

tube beyond the explosive charge. Using a photomultiplier tube centered on a dominant indium line of a spectrograph and reflecting the light from the detonation into the spectrograph, it was shown that radiating indium ions were in the main body of the luminous ionization wave at least for the first 34 mm of its path. Because of the greater diffusivity of electrons, the free electrons from the reaction zone would be located in front of the advancing wave and possibly even in advance of positive ions. It was indicated that the high electron density in the ionization wave originated in the reaction zone of the explosive.

It was considered valuable to extend Barton's work by using different additives in different amounts in the explosive and measuring the effect upon the degree of ionization in the external wave. If the degree of ionization could be altered by adding substances with different ionization potentials, this would indicate that at least part of the ionization wave originated in the reaction zone of the explosive, assuming that the additives did not greatly affect the properties of the detonation, or affected it in a direction opposite to that in the external ionization waves.

Experimental Procedure

As stated above, it was considered desirable to investigate the origin of the high electron density which exists in the external ionization waves emitted from high explosives into gaseous media. The experimental approach adopted was to compare the changes produced in the electron density when the explosive was doped with different impurities.

In shock tubes several experimental methods have been used for measuring the electron density behind shock waves. The relative merits of these methods have been adequately described by Lin, Neal and Fyfe,⁽¹⁴⁾ and will not be elaborated upon here. The requirement for a measuring device of high spatial resolution as well as one that was expendable led to the choice of an electrostatic probe technique. This probe technique is similar to that used by Cook, Keyes and Udy.⁽¹⁰⁾ The electrical resistance or its reciprocal, the conduction, of the ionization wave can be easily obtained by the electrostatic probe method.

Figure 1 is a schematic diagram of the circuit commonly employed in the measurement of electrical conduction. For conduction measurements of the ionization wave, the electrostatic probes are positioned in the constraining tube so as to be in the path of the wave, and perpendicular to it. Following detonation, as the ionization zone comes in contact with the probes, conduction occurs across the probes. The resulting current flow through the viewing resistor, R_1 , produces a voltage drop across the resistor, which in turn is measured by an oscilloscope. The 22.5 volt battery is parallel with a 2000 μfd capacitor form an essentially zero resistance and constant voltage source for the short duration that conduction occurs. The 0.1 μfd paper capacitor helps decrease the rise time of the circuit as a result of its low internal impedance.

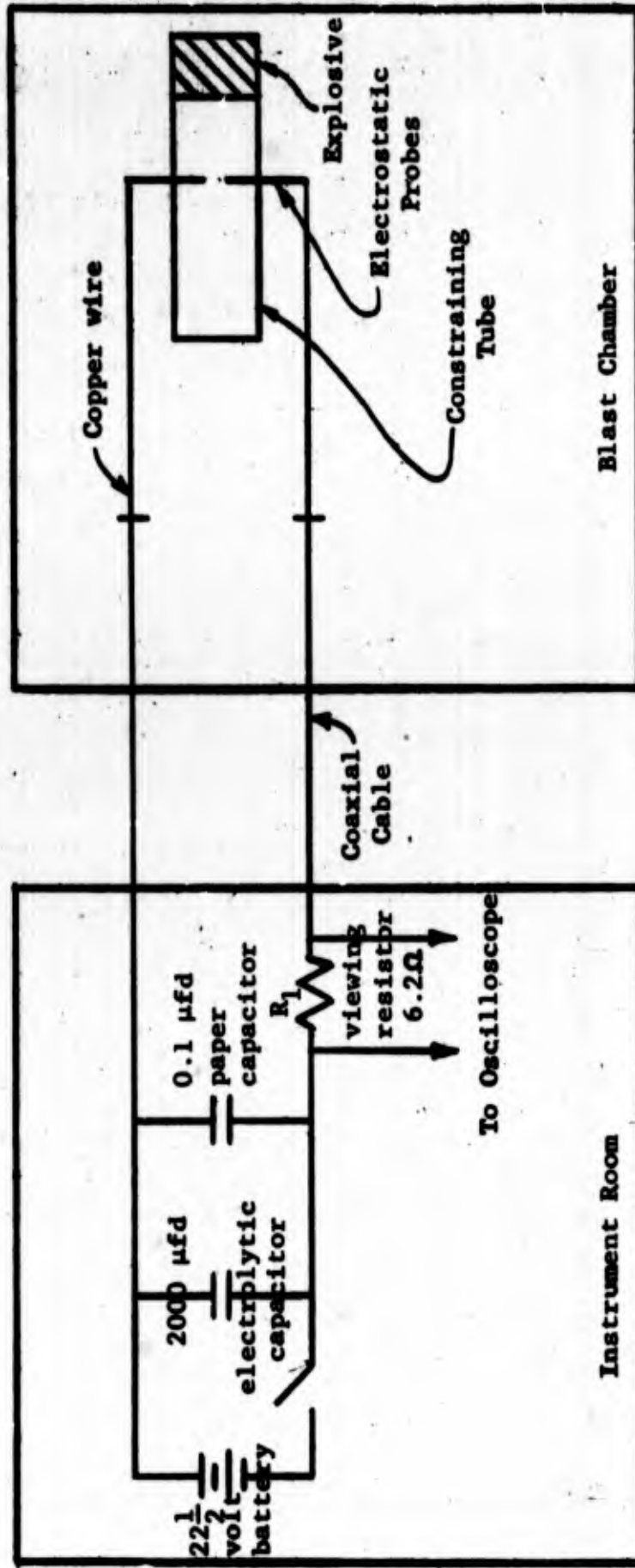


Figure 1: Schematic diagram of circuit commonly used for conduction measurements.

It was recognized early that the circuit in Figure 1 did not possess a fast enough response or small enough rise time to be suitable for measuring small changes in the electrical conduction of the ionization wave which would probably result from impurity doping of the charges. This can be seen clearly by referring to Figure 2. Assuming that the maximum electron density occurs at the front of the ionization wave, which experimentally appears to be the case, then the voltage-time profile should appear as in (a). This would also represent the conduction-time profile. However, if the rise time of the circuit is too slow, as depicted in (b), then the peak height of the recorded voltage will be less than that of the actual voltage by the amount shown in the shaded area in (c). As will be shown later, a small error in the voltage can result in a large error in the resistance or conduction.

In order to obtain a smaller rise time, the circuit in Figure 3 was used. The power supply was located in the blast chamber and only the oscilloscope remained in the instrument room. The battery and the 200 μ fd and 0.1 μ fd capacitors were protected from the destructive blast effects by enclosure in a metal box. However, the other two capacitors and the viewing resistor were attached to the electrostatic probes and, consequently, were destroyed each shot. By positioning the capacitors and the resistor close to the probes, the circuit loop consisting of the probes and the viewing resistor was made as small as possible and the extensive use of cables for the circuit loop as in Figure 1 was eliminated. Hence, inductance problems

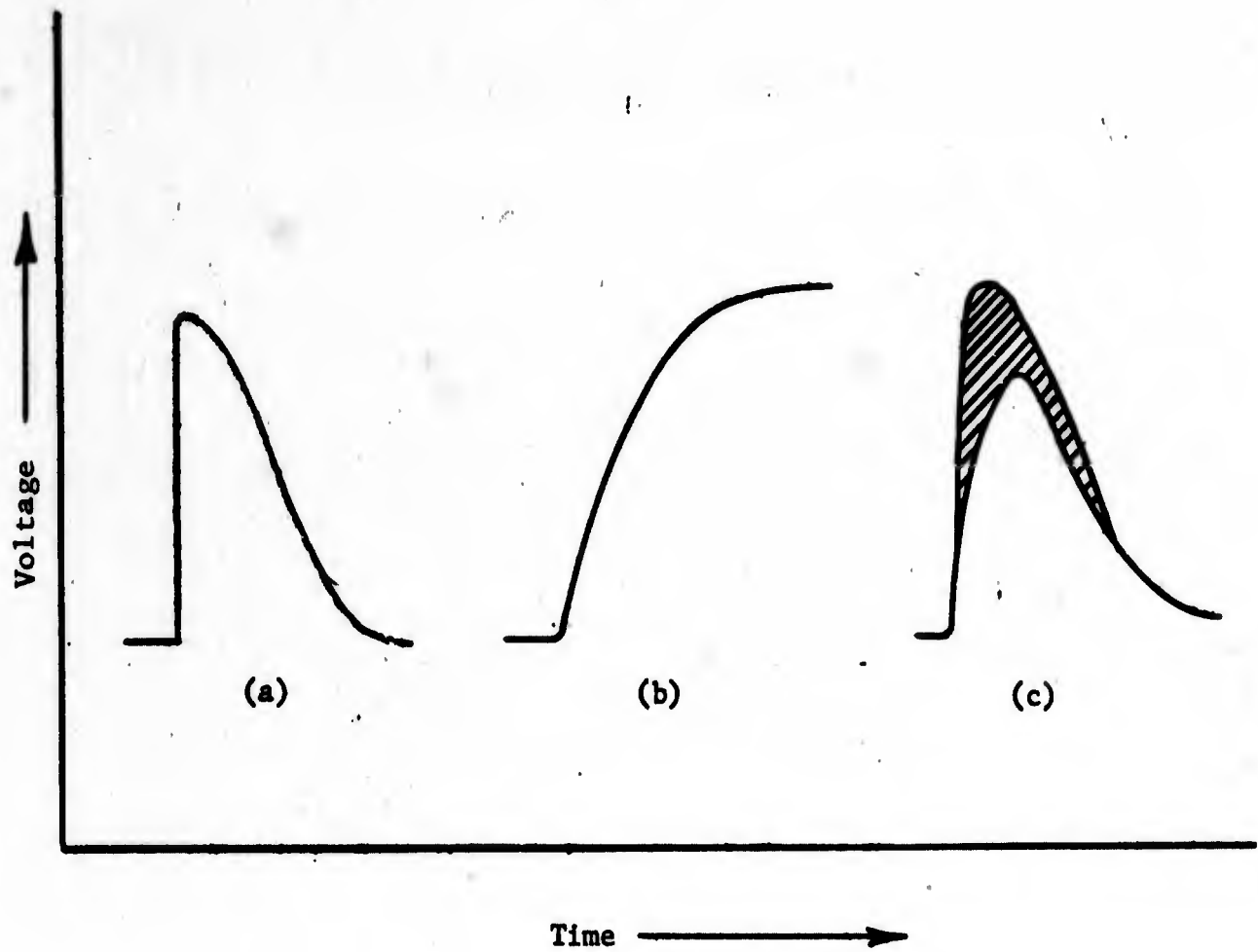


Figure 2: Possible voltage-time profile.

- (a) Probable voltage signal on oscilloscope showing electron density highest at front of wave.
- (b) Rise time of measuring circuit.
- (c) Portion of signal missed (shaded area) due to slow rise time of circuit.

were greatly reduced and the rise time was decreased. Twisted wire was used because of its very low inductance. The 57 ohm termination resistor near the oscilloscope prevented reflection in the cable or ringing in the signal. Actually, the twin lead should be terminated also, but the effect from not terminating was insignificant. The circuit in Figure 3 had a rise time of less than $0.05 \mu\text{sec.}$, which was approximately the rise time of the oscilloscope. This represents an improvement over the old circuit of better than a factor of ten. A Tektronic 551 oscilloscope with a Fairchild polaroid oscilloscope camera was used to record the signals.

The experimental arrangement used for measuring the conduction in the ionization wave is shown in Figure 4. Number 5 Windopak Gold Eye needles were used as the electrostatic probes. These probes were placed diametrically opposite each other in a plastic (tenite) tube, with the tips 4 mm apart. The tube was $1 \frac{1}{8}$ in I.D., $1 \frac{1}{4}$ in O.D. Two pressed, 1 in. x 1 in. cylindrical, RDX charges were inserted completely inside the tube. The distance of the free surface of the explosive from the probes was measured with a 20-power traveling microscope. Number 8 blasting caps were used to detonate the RDX charges. The firing of the caps was accomplished by four one-volt batteries. The plastic tube was always long enough to insure that the entire ionization wave passed over the probes before the front of the wave emerged from the tube. To trigger the oscilloscope a simple capacitor-discharge circuit was used. The triggering needles were positioned approximately one centimeter along the first charge, and were inserted through the tube wall and about 2 mm into the charge itself.

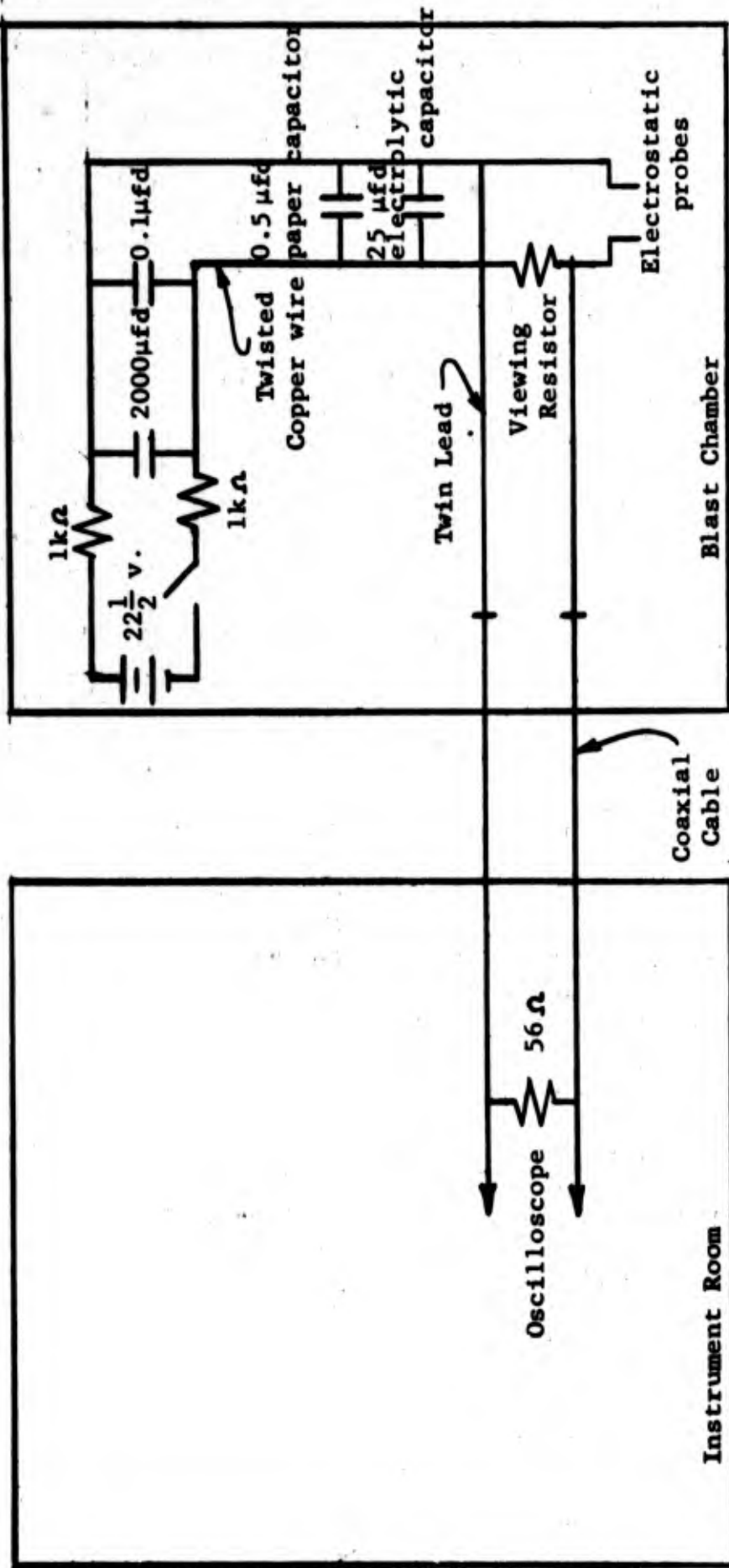


Figure 3: Schematic diagram of improved circuit for conduction measurements.

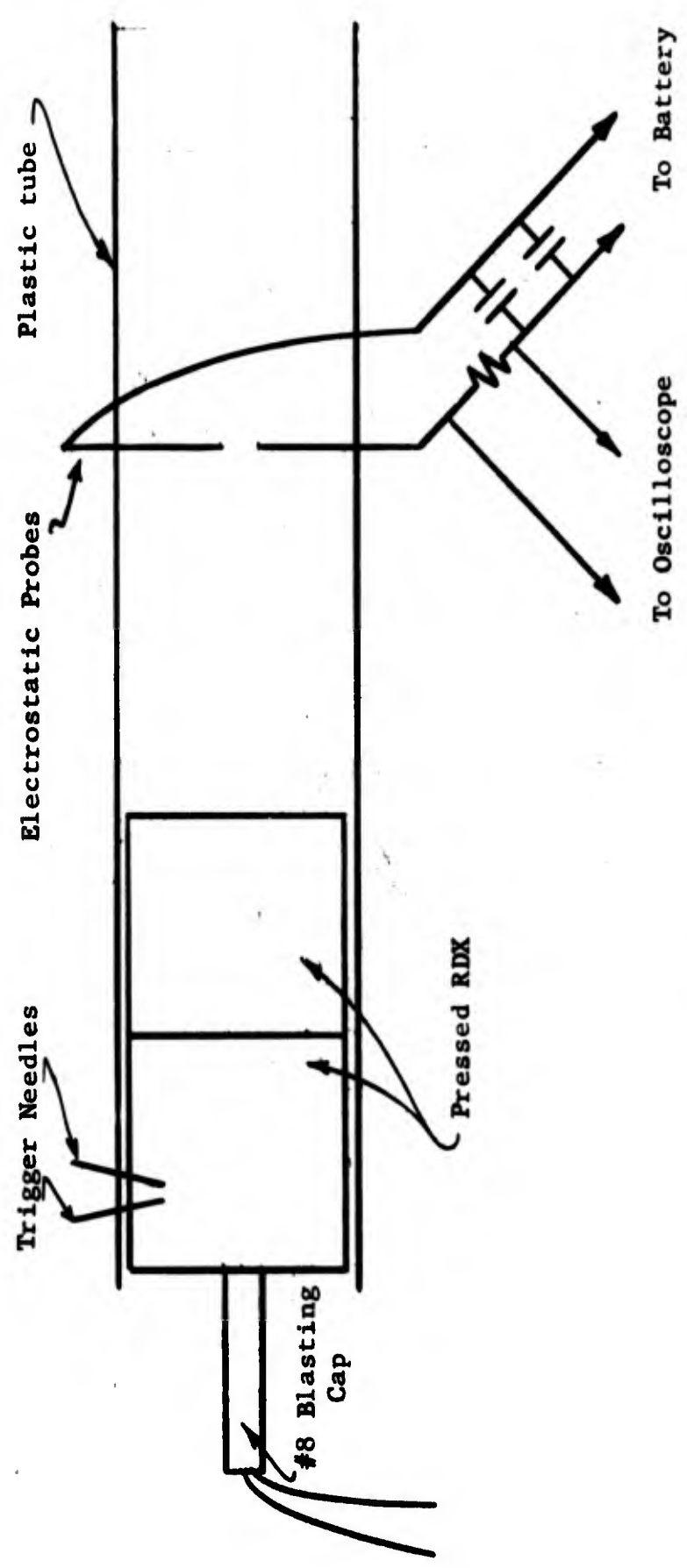


Figure 4: Arrangement of electrostatic probes and charges for conduction measurements.

The explosive used for the present studies was RDX. In order to obtain pressed charges of good cohesion, 1 per cent wax was added to the powdered explosive. The impurities used for doping of the charges were KNO_3 and CsNO_3 . These two compounds were chosen because of the low first ionization potential of the metal cation, the ionization potentials of potassium and cesium in the atomic state being 4.318 volts and 3.87 volts, respectively. For comparison purposes the concentrations of the impurities were based on equimolar quantities. Experiments were run using 1 gram and 0.5 gram KNO_3 per charge (5% and 2.5% KNO_3 , respectively). This corresponds to 0.01 moles and 0.005 moles KNO_3 per charge, respectively. To obtain the same molar quantities for CsNO_3 required 2 grams and 1 gram of CsNO_3 per charge (10% and 5% CsNO_3 , respectively). Before being thoroughly mixed with the RDX the impurity was first crushed in a mortar, then sieved through a 150 mesh screen. A pressure of approximately 1000 lbs/in² was applied to 20 gram amounts of the RDX - wax - impurity mixture.

As a precautionary measure prior to mixing and pressing of the explosive, differential thermal analyses (DTAs) were run on the explosive-impurity mixtures. In all cases, it was found that the mixtures were safe to handle.

To determine the effect, if any, that the impurity had on the detonation properties of the explosive, detonation velocity measurements were made for each mixture. These measurements were accomplished by placing four or five charges end to end, detonating at one end, and recording the propagation of the detonation wave through the charges by means of a streak camera.

Results and Discussion

The electrostatic probe technique was used in the present study to measure changes in the electron density of the external ionization wave which resulted from the addition of impurities to the explosive. Two features made the probe technique valuable, its high spatial resolution and its expendability. The requirement for high spatial resolution was critical since only measurements within the first several millimeters of the free surface of the explosive were anticipated. Differences in electron density from impurity-doping were considered to be most significant within this distance.

The electrical resistance of the ionization wave was computed conveniently from the electrostatic probe measurements by the use of the equation:

$$R_i = R_v R_t (E_b/V - 1)/(R_v + R_t),$$

where R_v is the viewing resistance, R_t is the termination resistance, E_b is the battery voltage (measured across the capacitors at the probe location), and V is the voltage reading on the oscilloscope. The viewing resistance and the battery voltage were measured prior to each detonation. The conduction was obtained as the reciprocal of the resistance. It is noted from the above equation that when the voltage, V , read on the oscilloscope approaches the battery voltage, E_b , the term $(E_b/V - 1)$ approaches zero, and the resistance of the wave, R_i , approaches zero. For a large value of V , which was generally the case in the present experiments, a small error in measuring V could result in a large error in the computed value of R_i . It was therefore necessary to use a measuring circuit with an exceptionally fast response.

The conduction in the ionization wave was used as an indication of the electron density, a change in conduction resulting from a change in the number of free electrons in the wave. To obtain the conductivity, σ , a proportionality constant or probe factor, K, must be obtained. The probe factor depends on the plasma geometry and the type of probes used. This constant, which can be obtained by calibration procedures, relates the resistance of the ionization wave to the conductivity by the equation:

$$\sigma = K/R_i = K(R_v + R_b)/(E_b/V - 1)(R_v R_t).$$

In the present experiments it was decided that a knowledge of the absolute value of the conductivity of the ionization wave was not essential, hence the probe factor was not determined. Rather, relative values of the conduction were considered sufficient for comparing the effects of impurity-doping of the explosive.

At the time the experimental work was being conducted at this laboratory with respect to impurity-doping, an Aeronautical Systems Division technical report, ⁽¹⁵⁾ authored by M. W. Burnham, was published. The report contained results of the effects which impurity-seeding of shaped charges had upon the conductivity of the expelled jet. A magnetohydrodynamic generator was used to obtain the conductivity values. Sodium chloride and cesium fluoride were used as the impurities. Since the MHD generator measured average electrical generation over a conductor length of approximately one inch, it lacked the high spatial resolution which the electrostatic probe technique possessed. As a result of the spatial resolution problem and the fact that shaped

charges were used in the Aeronautical System report, the experimental work reported in this section was continued.

Burnham⁽¹⁵⁾ reported that the impurities used in their work produced little effect on the initial portion of the oscilloscope pulse, but that the magnitude of the back side of the pulse was significantly increased. Also in their measurements of conductivity it was reported that the cesium fluoride produced a smaller effect than the sodium chloride. The suggested explanation for the latter experimental observation was that the optimum mixture (2.5% in the case of NaCl and 0.25% in the case of CsF) of seeding material and explosive had not been used.

The maximum conduction versus distance curves obtained for RDX and the RDX - impurity mixtures by the electrostatic probe technique are presented in Figures 5 through 9. Maximum conduction always occurred at the front of the ionization wave. Conduction measurements of the wave were limited to the first 25 millimeters from the free surface of the explosive since the distance close to the explosive face should be the most critical space for correlating impurity effects on conduction.

Note that in Figure 5 the RDX - 5% KNO_3 mixture produced greater conduction than pure RDX, at least for the first 25 mm. Also from Figure 6 it will be seen that the RDX - 5% KNO_3 mixture produced an ionization wave with a higher electron density or conduction than the RDX - 2.5% KNO_3 explosive mixture. Conclusions as to differences in the conduction for the potassium and cesium explosive mixtures with the same molar

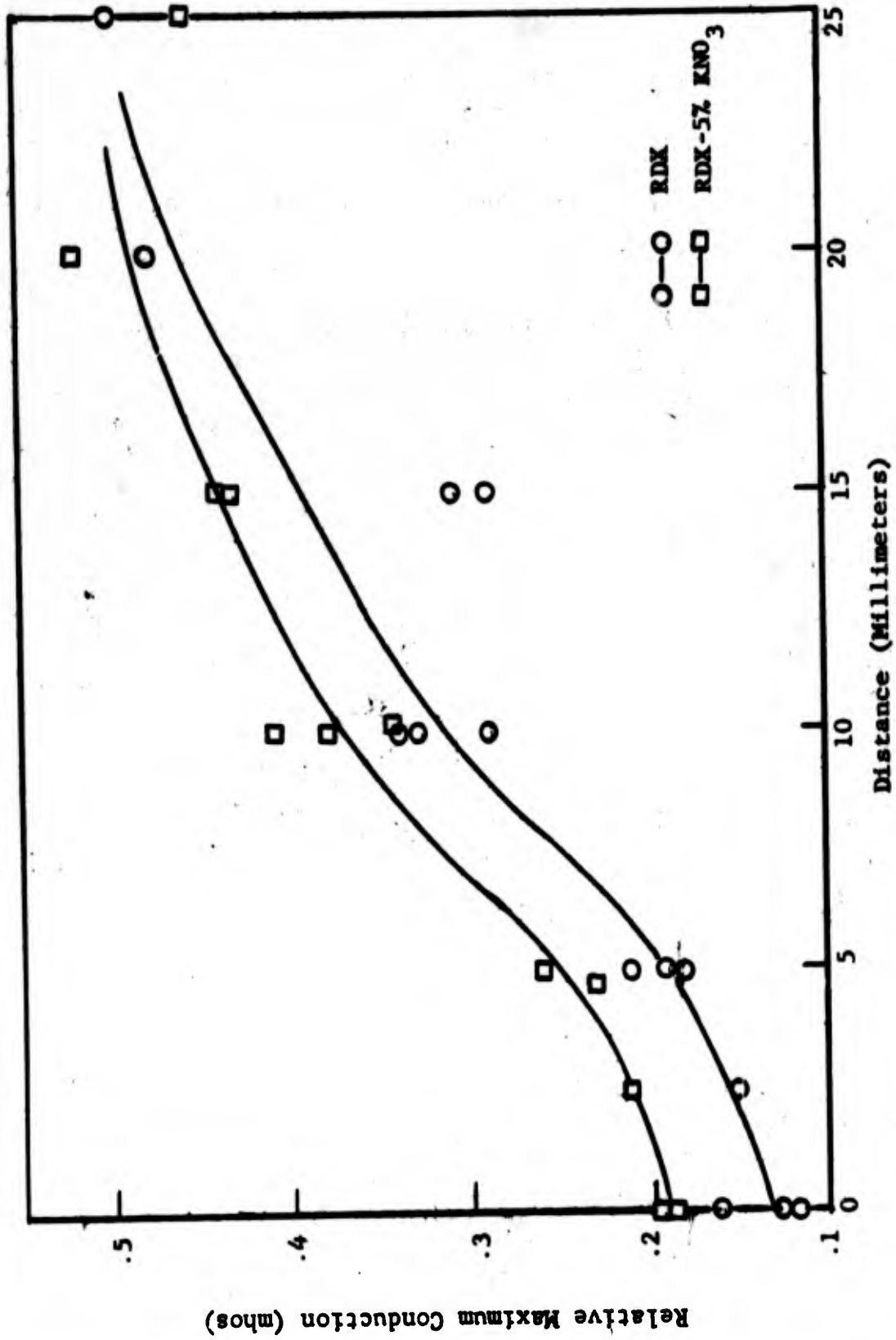


Figure. 5: Relative maximum conduction of the ionization wave for RDX and RDX - 5% KNO₃ mixture as a function of distance from the free surface of the charge.

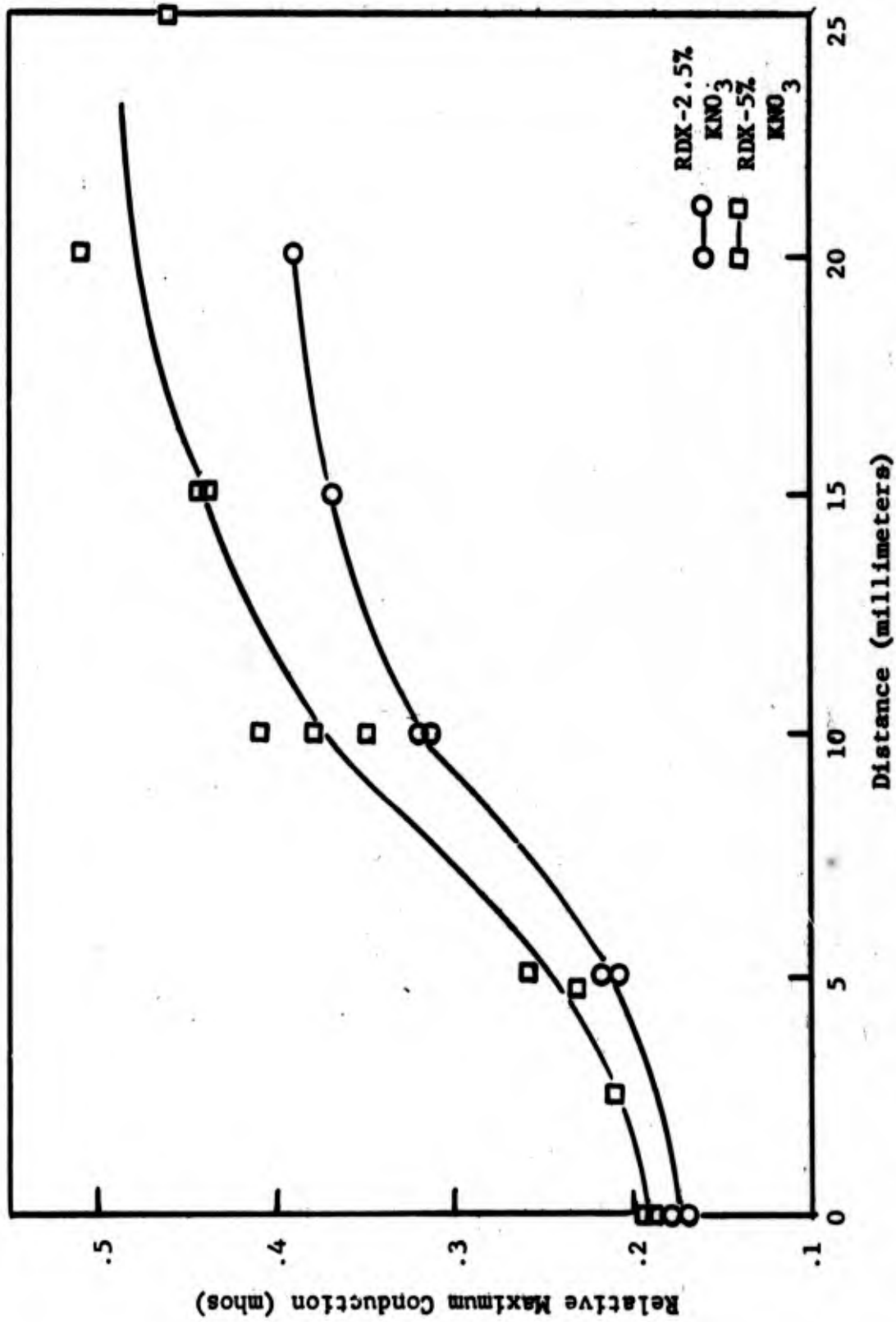


Figure 6: Relative maximum conduction of the ionization wave for RDX - 2.5% KNO₃ mixture and RDX - 5% KNO₃ mixture as a function of distance from the free surface of the charge.

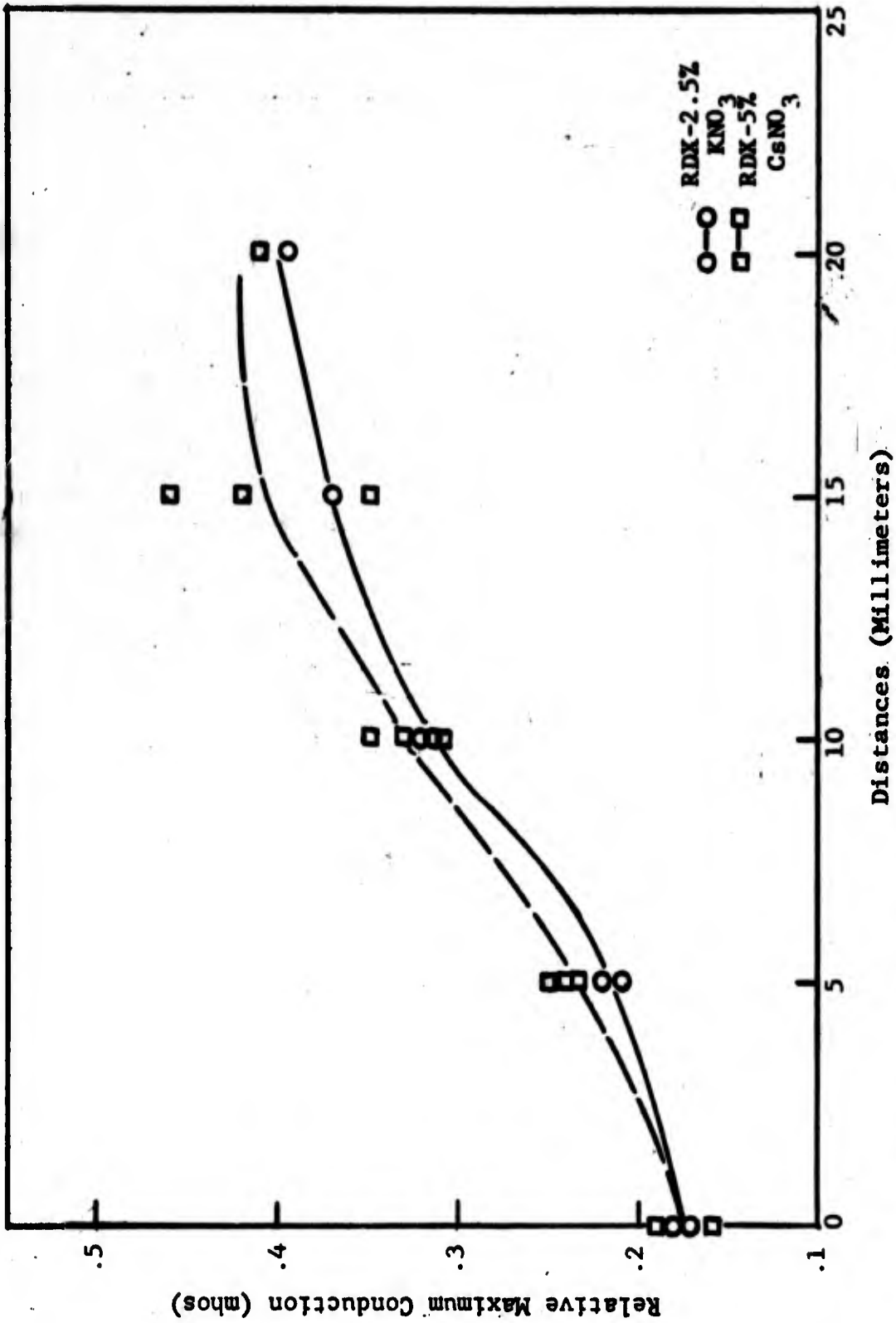


Figure 7: Relative maximum conduction of the ionization wave for RDX - 2.5% KNO₃ mixture and RDX - 5% CsNO₃ mixture as a function of distance from the free surface of the charge.

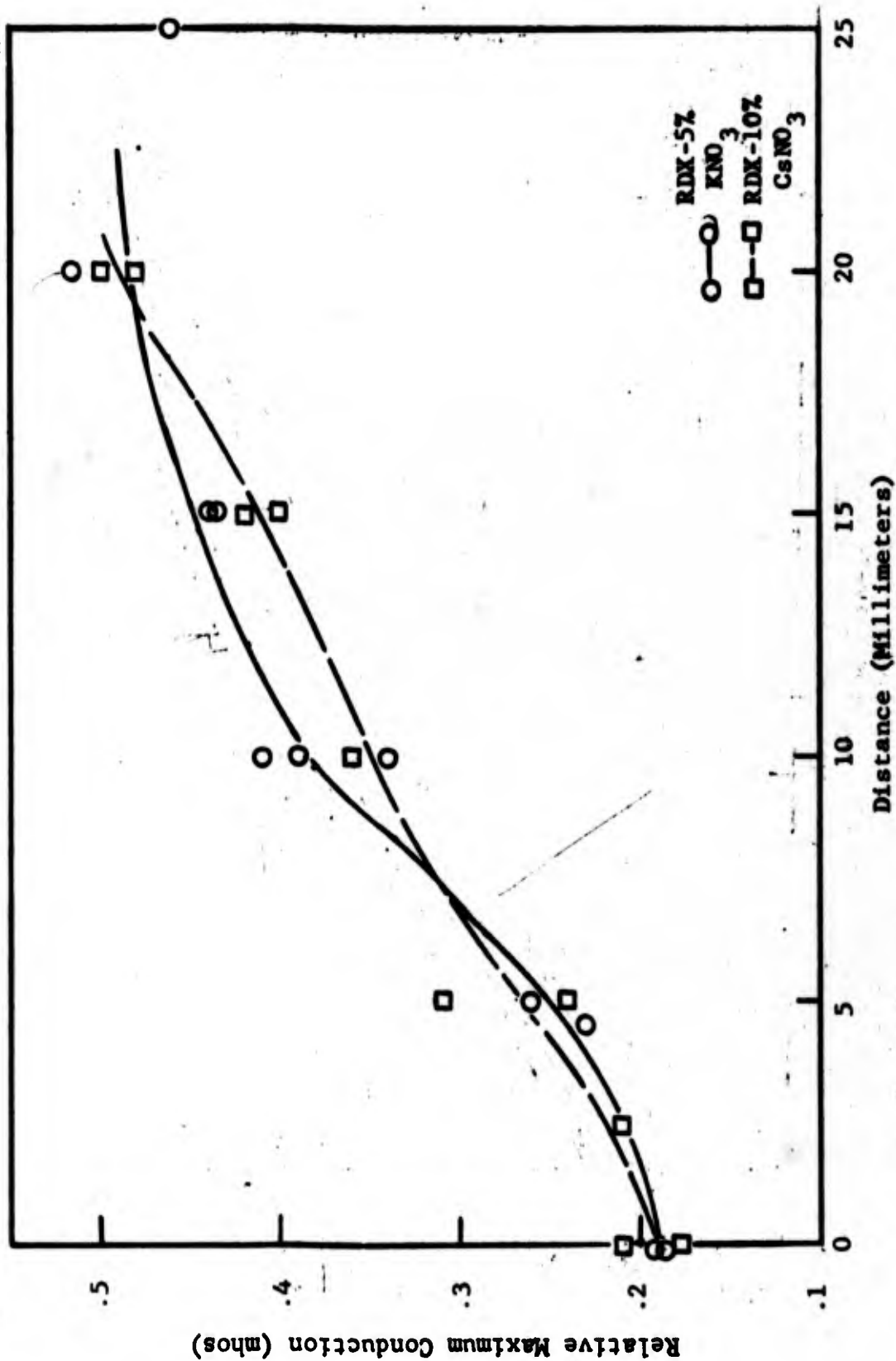


Figure 8: Relative maximum conduction of the ionization wave for RDX - 5% KNO₃ mixture and RDX - 10% CsNO₃ mixture as a function of distance from the free surface of the charge.

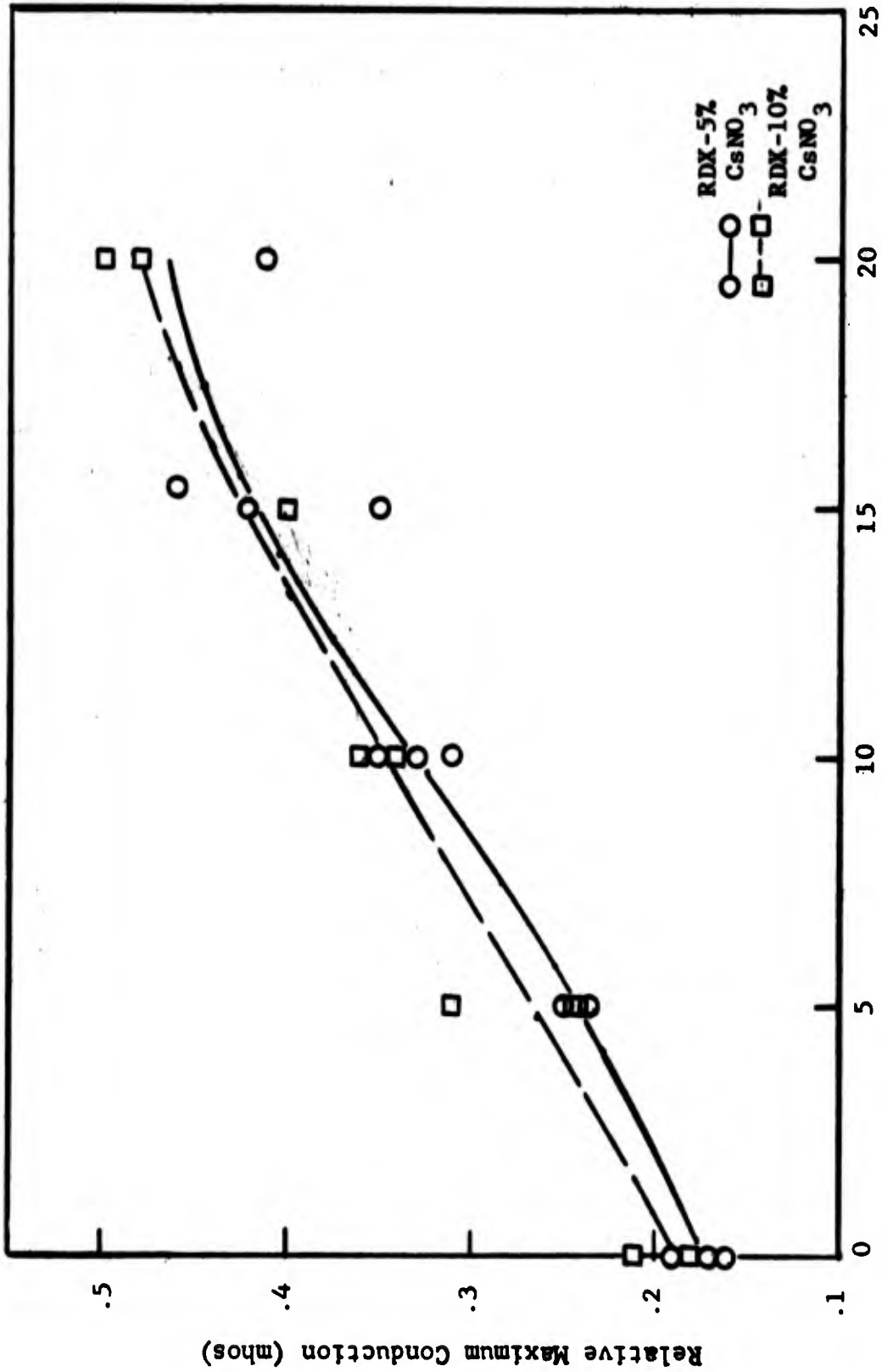


Figure 9: Relative maximum conduction of the ionization wave for RDX - 5% CsNO₃ mixture and RDX - 10% CsNO₃ mixture as a function of distance from the free surface of the charge.

concentration of impurity were not possible as can be seen in Figures 7 and 8. The curves fell so close together and the experimental scatter was large enough so as to raise a question as to the actual difference in conduction. The same problem of comparison existed for the conduction curves obtained for the RDX - 5% CsNO₃ mixture and the RDX - 10% CsNO₃ mixture, as can be seen from the curves presented in Figure 9. In all cases, the conduction curve for pure RDX fell below the curves for the RDX - impurity mixtures, at least over the first 10 millimeters from the charge.

Besides the effect of the impurities upon the maximum conduction of the ionization wave, the effect upon the thickness of the wave was also determined. The breadth of the oscilloscope traces at an arbitrary value of one-half maximum height was used as an indication of the wave thickness. The resulting breadth versus distance curves are shown in Figures 10 through 13.

Note that in all cases thicker ionization waves were expelled from the impurity-doped charges than from the pure RDX charges. Also, while the differences between the curves for equimolar amounts of different impurities (see Figures 12 and 13) and the curves for different molar concentrations of the same impurity (see Figures 10 and 11) were slight, there appeared to be a real difference outside the limits of experimental error. For example, the curve for the RDX - 2.5% KNO₃ mixture fell slightly below that for the RDX - 5% KNO₃ mixture, and the curve for the RDX - 5% KNO₃ mixture fell slightly below that for the RDX - 10% CsNO₃ mixture.

It was expected, on the basis that the ionization wave was a detonation-generated plasma, that impurity-doping would produce an increase

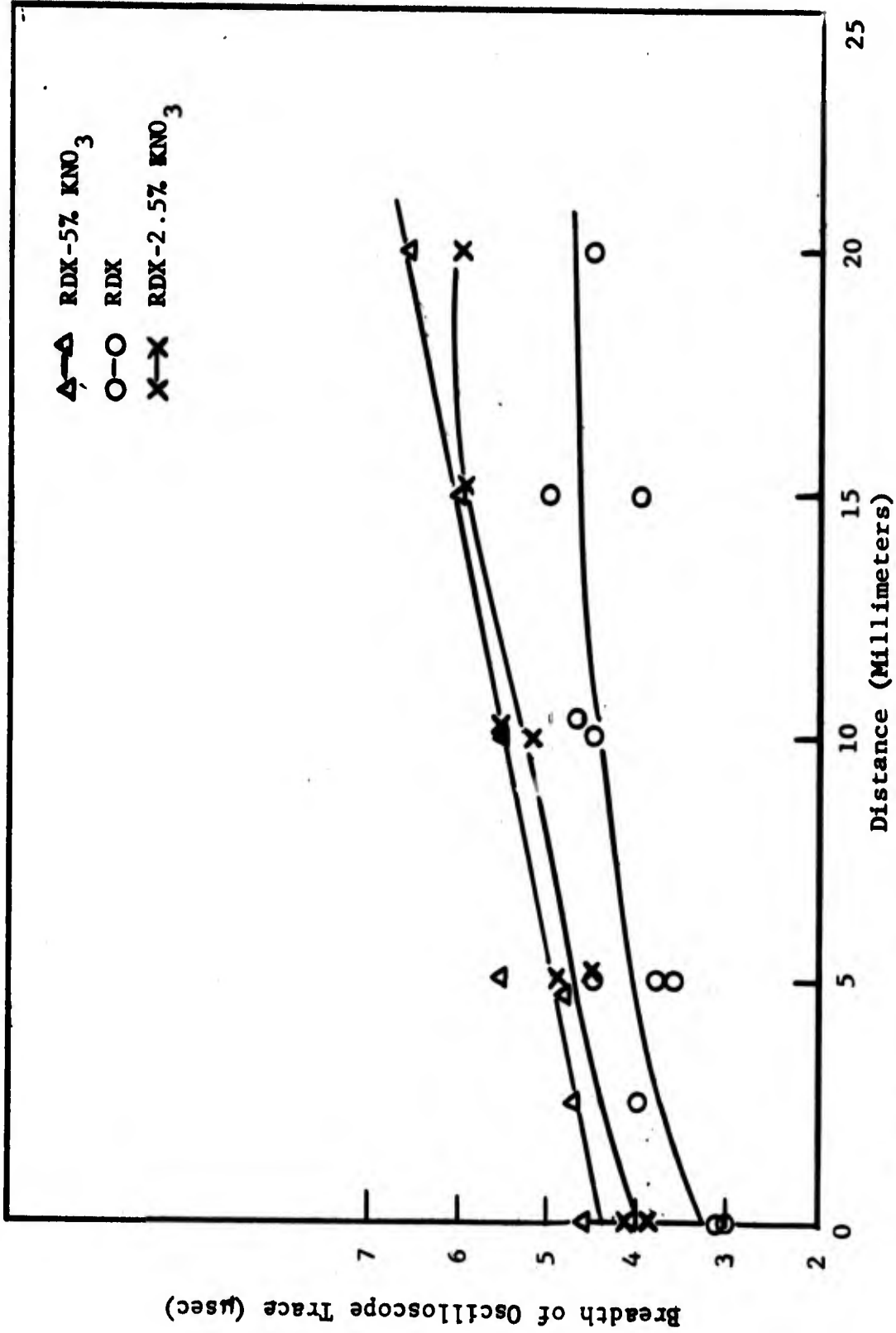


Figure 10: Breadth of oscilloscope trace for the ionization wave from RDX, RDX - 5% KNO₃ mixture and RDX - 2.5% KNO₃ mixture as a function of distance from the free surface of the charge.

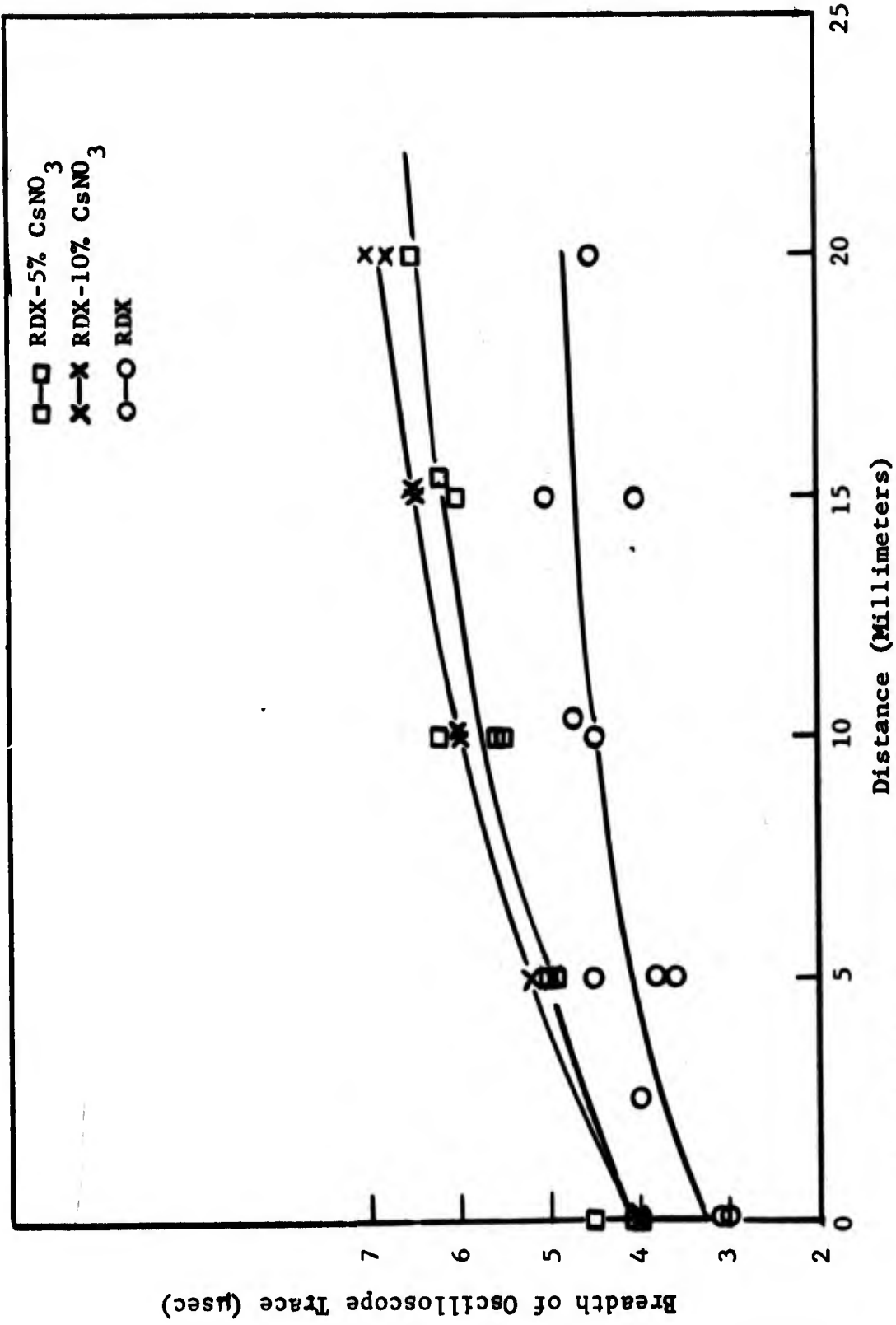


Figure 11: Breadth of oscilloscope trace for the ionization wave from RDX, RDX - 57% CsNO₃ mixture and RDX - 10% CsNO₃ mixture as a function of distance from the free surface of the charge.

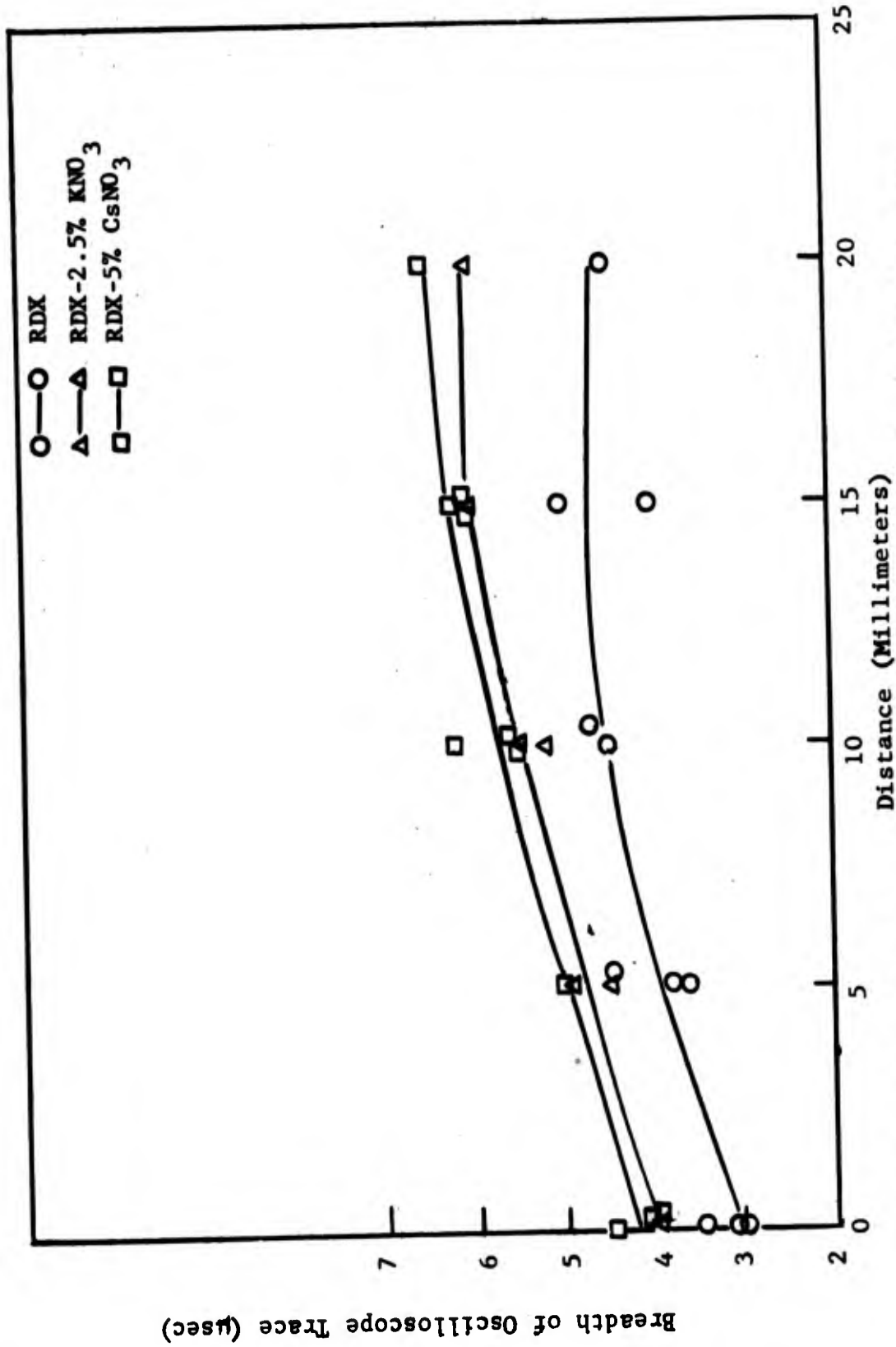


Figure 12: Breadth of oscilloscope trace for the ionization wave from RDX, RDX - 2.5% KNO₃ mixture, and RDX - 5% CsNO₃ mixture as a function of distance from the free surface of the charge.

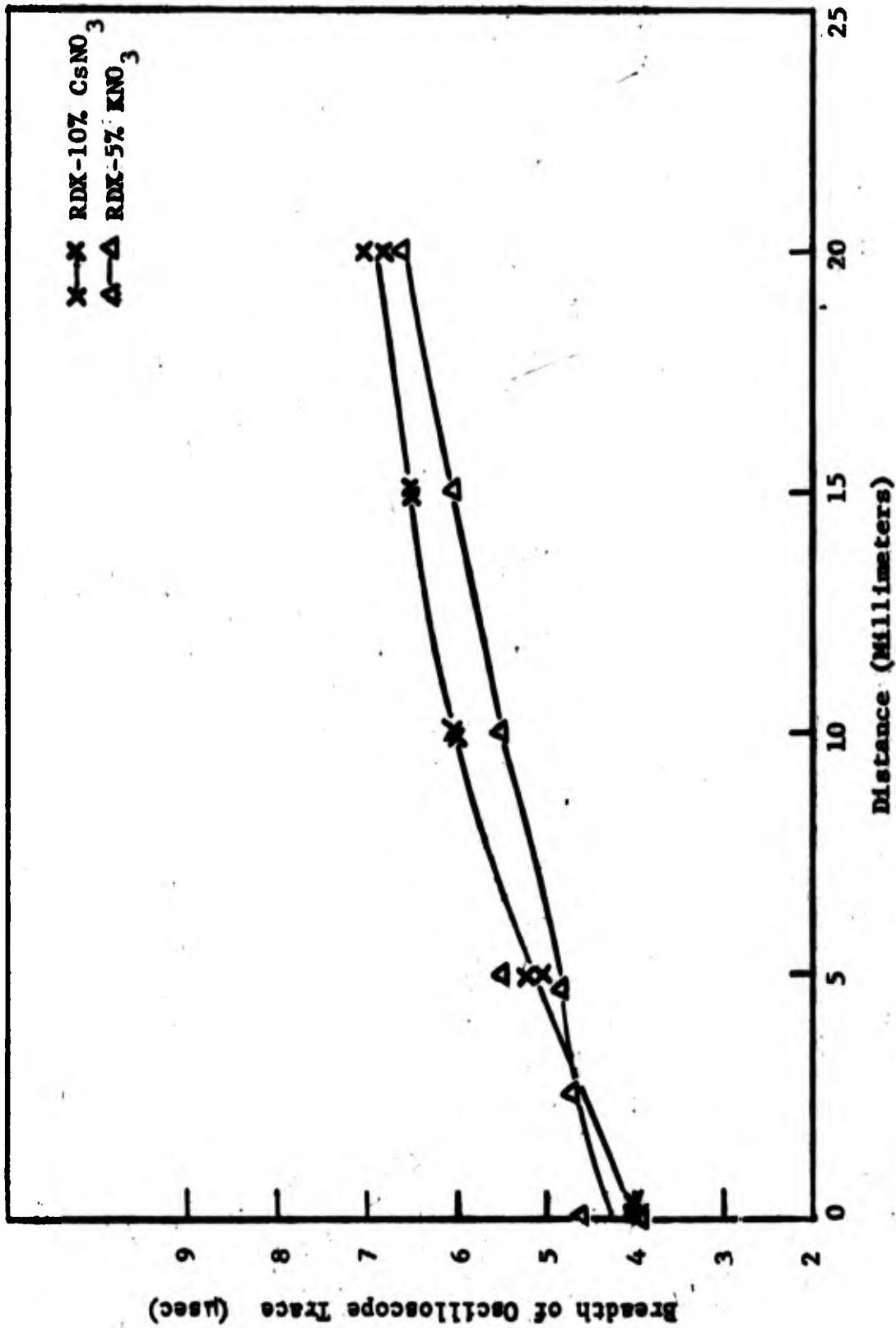


Figure 13: Breadth of oscilloscope trace for the ionization wave from RDX - 10% CsNO₃ mixture and RDX - 5% KNO₃ mixture as a function of distance from the free surface of the charge.

in conduction in the ionized wave propagating beyond the free surface of the explosive. An "easy" source of electrons was made available to the detonation wave and the external ionization wave by doping.

However, it was thought that the cesium nitrate, because of the rather low ionization potential of cesium, would have a more significant effect on the maximum electron density of the ionization wave than was observed, especially when compared with the effects produced by equimolar concentrations of potassium nitrate. The explanation might be that the high temperature and pressure in the reaction zone of the explosive, leading to an extremely high degree of ionization, masked any significant differences between two impurities whose cation ionization potentials are reasonably close. Alternatively, it is possible that these impurities required too much time to react, with insufficient time having elapsed in the intervals in question for any significant degree of ionization to have occurred to affect the initial portion of the pulse. The reaction time was obviously short enough, though, to affect the thickness of the wave, the explosive doped with cesium nitrate producing a slightly thicker wave.

There are at least two reasonable explanations for the increase in thickness of the ionization wave associated with the addition of impurities to the explosive. The impurities could require enough time to react in the explosive to result in an increase in the reaction zone length. This would probably lead to an increase in the thickness of the ionization wave. The increased thickness of the ionization wave from doped explosives as compared with the undoped explosives as measured adjacent to the free surface of the explosive (zero distance

in Figures 10 and 11) supports the above argument. An alternative explanation is that unreacted explosive and impurity were expelled from the free surface of the charge along with the ionization wave, the material reacting as it propagated away from the charge. If the impurity requires more time to react than the explosive material, a reasonable possibility, then there would exist a reserve supply of electrons for the external ionization wave which contained reacting impurity. This reserve supply of electrons would then lead to a thicker wave. Furthermore, this might explain the greater increase in wave thickness with distance that occurred for the doped explosive as compared with the undoped one (see Figures 13 through 15). For impurity doped charges the thickness of the wave increased with distance of propagation to a greater extent than the normal spreading out of the wave. The increase in maximum conduction with distance lends support to the latter explanation.

Detonation velocity measurements of the pure RDX and RDX-impurity mixtures are tabulated in Table I. Note that except for the velocity of the RDX - 2.5% KNO_3 mixture, the detonation velocities showed a regular decrease as listed. It is of interest to compare the experimentally observed detonation velocities with computed detonation velocities. The computed detonation velocities were obtained by treating the impurities as simply diluents. Using the covolume equation of state⁽¹⁶⁾ one obtains:

$$D/D^* = (NT_2/N^* T_2^*)^{1/2} = N^{1/2}$$

TABLE I. DETONATION VELOCITIES OF
RDX AND RDX - IMPURITY MIXTURES

Impurity	Molar Conc.	Weight per cent	Velocity (m/sec.)
None			8000
KNO ₃	.005	2.5	8300
KNO ₃	.01	5.0	7940
C _s NO ₃	.005	5.0	7800
C _s NO ₃	.01	10.0	7550

where D is the detonation velocity, N is the number of molecules produced in detonation per kilogram of explosive, T_2 is the Chapman-Jouguet temperature, and α is the extent of reaction. The asterisks indicate ideal detonation conditions. Using the detonation velocity of the undoped RDX in Table 1 as D_1^* and assuming that N can be represented as the ratio of the percentage of explosive in the doped RDX to the percentage in pure RDX, the computed value of the detonation velocity for doping with 5% impurity was 7800 m/sec., and that for the 10% impurity was 7580 m/sec. It was found that the computed values were in very good agreement with the experimental values for cesium nitrate - doped RDX. It is not clear why the detonation velocities of the potassium nitrate - doped RDX mixtures were greater than those of the cesium nitrate - doped RDX mixtures, and

also greater than the computed values. It would be expected that of the two compounds, the potassium nitrate would behave more as a diluent than the cesium nitrate. However, the above analysis was not intended to show that the impurities did or did not act as diluents.

It would be expected in a shock wave model that the conduction would decrease as the detonation velocity decreased. This, however, was not the case as seen in Table 1 and Figures 9 and 12. Thus, whereas the impurity (especially for the case of cesium nitrate) appeared to act almost as a diluent in the explosive by lowering the detonation velocity, it still produced an increase in the conduction in the ionization zone. Furthermore, even though the detonation velocity was lowered as the percentage of impurity was increased, the conduction in the ionization wave did not decrease, but remained as high as or even higher than the conduction for the charges with a lesser amount of impurity. In this regard compare the curves for RDX - 5% KNO_3 and RDX - 2.5% KNO_3 in Figure 5. It would be interesting to dope the charges with still higher concentrations of impurities in order to lower the detonation velocity further, and then measure the resulting conduction in the wave.

As stated in the Introduction, there are two current theories as to the origin of the ionization wave - the shock wave theory and the ionization wave or plasma theory. The experimental results are obviously not conclusive by themselves insofar as the two theories are concerned. However, it appears that conclusions may be made as to the relative merits of the two theories in the light of the results reported in this section. It is clear that the results can not be explained in

terms of a shock theory alone. If the ionization zone were simply shock induced, there would be no logical reason for the increase in conduction resulting from impurity-doping, especially where the detonation velocity, and thus presumably the velocity of the shock propagating from the free surface of the charge, have decreased through doping. However, the increase in conduction which resulted through impurity-doping can be explained in terms of the ionization wave theory. Since in this theory, the external ionization zone is simply a continuation of the internal ionization zone or reaction zone, doping of the explosive with material of a low ionization potential would be expected to yield an additional source of electrons to the reaction zone and hence to the external ionization wave.

Although the plasma model can explain the experimental results, this does not mean that that model is the best or only possible one. It may be possible, for example, to explain the results by a combination of the shock theory and the plasma theory. That is, there could be a shock wave propagating from the free surface of the charge and mingled in with the shock ionization zone there could exist material (both ions and electrons and unreacted material) ejected from products or reactants of the explosive. The result would be an increase in conduction and thickness of the wave for the impurity-doped explosive. The ejected material could follow or even penetrate the shock front. Such a model explains the experimental facts as easily as the plasma model. Further research would be needed to more definitely establish the best model.

Conclusions

Electrostatic probe measurements of the external ionization wave produced by RDX, RDX - potassium nitrate mixtures and RDX - cesium nitrate mixtures showed that there was an increase in the maximum conduction and in the thickness of the wave as a result of doping (at least for a distance from the free surface of the explosive of 10 mm for the conduction and 25 mm for the thickness). These results indicate that the impurities were contributing electrons to the ionization wave.

The detonation velocity of impurity-doped RDX was less than the detonation velocity of pure RDX. Increasing the concentration of impurity in the explosive resulted in a decrease in the detonation velocity; however, the conduction in the external wave was not decreased by a lowering of the detonation velocity.

The above results can not be explained in terms of a pure shock theory in which the external ionization wave is a result of thermal ionization of the gas atmosphere by a shock propagating away from the charge. However, the results can be explained by the detonation - generated plasma model in which the ionization wave originates in the chemical reaction zone of the explosive.

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