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TITLE: STUDYING EXPLOSIVES WITH AQUARIA: FISHING FOR DATA

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Studying Explosives with Aquaria: Fishing for Data

Selma Goldstein

The detonation of an explosive is a special case of the more general phenomenon of "explosion." An explosion is a rapid expansion of matter into a volume greater than its original volume. While the release of energy required for the expansion could come from any of a number of processes, including combustion or detonation, the explosion differs from combustion in general in that the mode of transfer of energy to the surroundings is mass motion. Heat radiation and conduction are important energy transfer modes for combustion processes. For a detonation, energy is only transferred through motion of the product gases and of the unreacted material. In addition, how combustion proceeds depends on its initial and boundary conditions, while a detonation is essentially independent of any external conditions once it has begun. The detonation occurs at many thousands of times the pressure of combustion, and its chemical reaction is about ten million times faster.

A detonation consists of a (usually thin) reaction zone moving through the explosive at a constant velocity, the detonation velocity. Just behind this front, the product gases are at a very high pressure, the detonation pressure. Parameters such as this velocity, pressure and the time for complete chemical reaction are determined only by the composition and density of the material. Due to the various possible behaviors, explosives may be well suited for different applications. The total amount of energy released, or how much work the explosive can do on its surroundings, may not be the only criterion for its choice, but is certainly an important one.

The reaction zone is important in determining how an explosive will behave, since the final state of the reaction, from which expansion of the products originates, affects the work they will be able to do. In performing calculations to model the behavior of explosives, we need to determine experimentally parameters that will define an equation of state for the expanding detonation product gases. The full equation of state is a thermodynamic function of pressure, volume, and let us say, energy, which describes the detonated explosive. Usually, we must be satisfied to approximate the expansion isentrope for the gases, which is a function only of their pressure and volume, and gives the states of the gas when its energy remains constant. This function is also related to the kinematic behavior of the explosive, the motion of the shock wave that is produced, and the motion of the gases, so that information about these tell us about the thermodynamics. The progress of the shock wave and of the gases relates in turn to the reaction zone structure in the explosive, since that determines the initial state for the gases.

For most high energy explosives, the reaction zone is very thin when compared with any other dimension of interest in the system. All of the chemical energy is released, and then the reaction products begin to expand, passing through thermodynamic states along an isentrope as mentioned above, since there is no further energy given to them. If the reaction zone is not thin, whether because the system happens to be very small, or the particular chemical reactions proceed slowly, then energy will be released over a period of time that is not negligible and which must be now taken into consideration. The expansion isentrope will be perturbed (in fact, it won't really be an isentrope in this case since the energy of the gases will be changing) and the motion of the product gases will differ from what it would have been if the energy were released all at once. When the reaction zone is very short and can be neglected, we call the explosive "ideal." When it is long and energy continues to be released after expansion has begun, we refer to the behavior as "nonideal."

Ideal explosives are not always better for all applications than the nonideal. In a situation like the breaking up of oil shale, a very nonideal blasting agent is desired because the slow release of energy that it provides should allow more uniform rubblization of a larger volume of rock around the charge than would an ideal explosive.

One experimental technique which holds promise for investigating the differences between ideal and nonideal explosives is the aquarium method. The setup of this experiment is shown in Fig. 1. A uniform stick of explosive, or explosive packed into a cylinder of inert material, is suspended in a tank of water and detonated at its upper end. As the detonation proceeds down the stick, several snapshots can be taken of it with a camera. Figure 2 shows the kind of picture that results. This is a double exposure, two pictures superimposed that were taken at two different times. We can see the detonation moving through the explosive, the shock wave expanding outward into the water, and the gases expanding behind it. The gases are referred to as the bubble, and the fact that we can see the interface between the bubble and the shocked water behind the shock front is one of the advantages of the aquarium technique.

In Fig. 3 we see the variety of data obtainable from one of these pictures. The difference in time bet een the two exposures divided into the distance the detonation has traveled gives us the detonation velocity. The slope of the shock front is related to the shock velocity in the water, as the slope of the bubble interface is related to the particle velocity of the products in the water. These quantities also give us information about the pressures produced in the water from the detonation. This pressure is proportional to the product of the shock and particle velocities. Finally, the shock and particle velocities at the jump-off point can be used to calculate the detonation pressure in the explosive.

Because of the variety of data about an explosive that can be obtained from an aquarium experiment, this method seems to lend itself particularly well to distinguishing ideal from nonideal behavior. If not all of the available energy in the explosive is released instantaneously, the shape of the shock front and bubble interface should be different than if it had been. There would be evidence of impulse transferred to the product gases and to the shocked water at later times behind the detonation front than in the ideal case. Figure 4 shows a general conception of what this might be expected to look like. The data would provide information indirectly, then, about the expansion isentropes of the product gases and, therefore, tell us about the equation-of-state.

We have been performing aquarium tests on a series of explosives which are mixtures, in varying proportions, of two materials. HMX is an ideal explosive and has a very short reaction zone length when compared with the size of any stick of explosive we may want to measure, and TATB has a long reaction zone and is considered nonideal.

We have thus far tested four materials: PBX-9502 which is 95% TATB and 5% binder; X-0321, 70% TATB, 25% HMX, and 5% binder; X-0319, 50% TATB, 45% HMX, and 5% binder; and PBX-9501, 95% HMX and 5% binder. In Fig. 5, we have a graph showing curves fit to the squares of the shock velocites, as functions of time behind the detonation front, for these four compositions. This is one way of getting an idea of the energy being transferred to the water. While these results cannot be considered conclusive, there seems to be a variation in shape between the ideal and the nonideal, namely in the progression of the slopes of the curves at short times and at long times. The three compositions containing HMX are very close in energy initially, and are substantially different from the TATB. They also drop to lower energies than the TATB at late times, so that the TATB, the nonideal explosive, does seem to exhibit a more constant energy release over a longer time than the other material.

Since the curves are close to each other, what we intend to do, in addition to testing other mixtures, is to repeat these tests and obtain photographs that can be measured with even greater accuracy. We would also like to make longer sticks of explosive, so that even later times can be examined to see if the trends we think we see persist. If these effects on the aquarium test data are real and can be resolved, we would have a powerful tool for learning more about explosive behavior.

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FIGURE 1

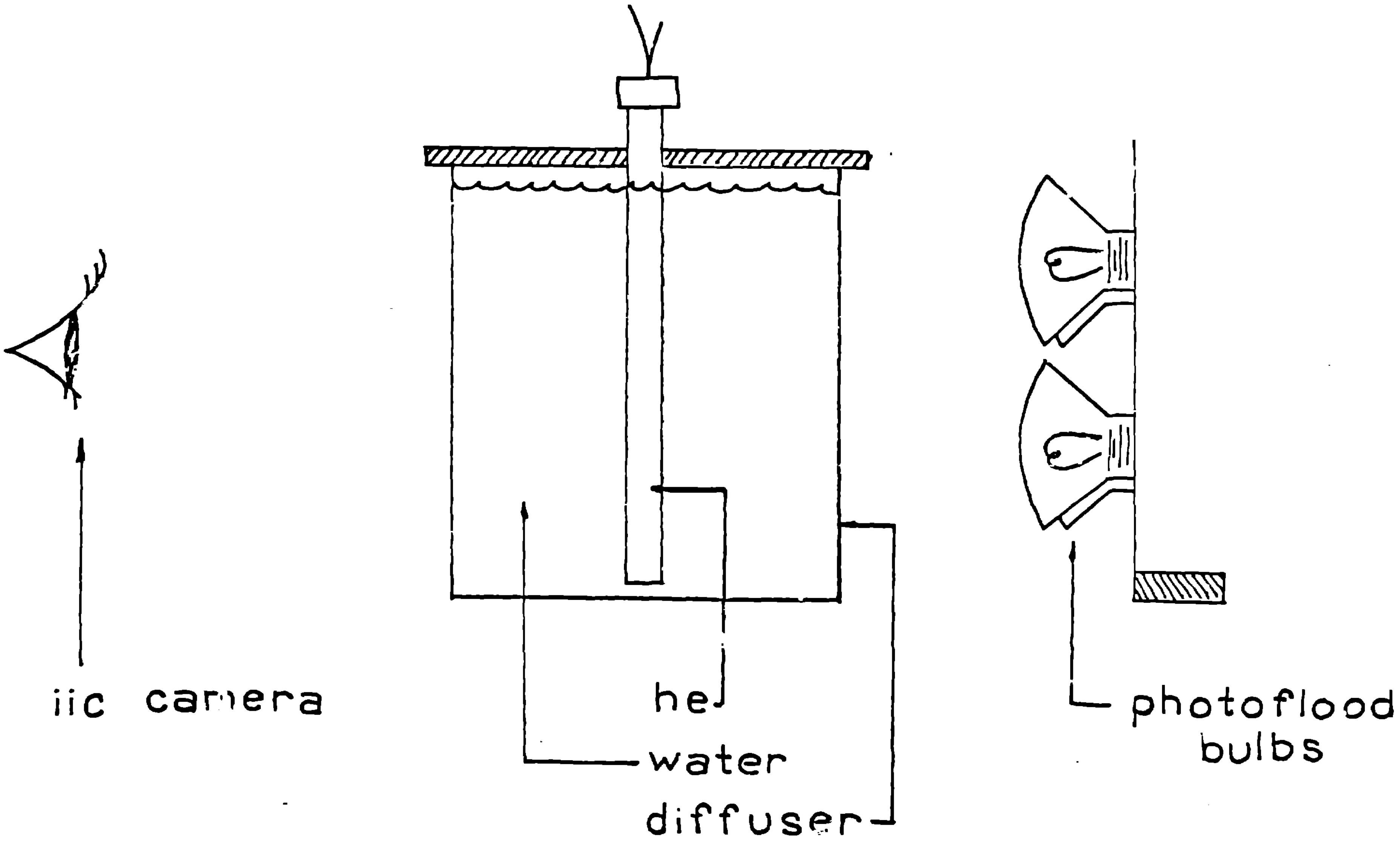


FIGURE 2

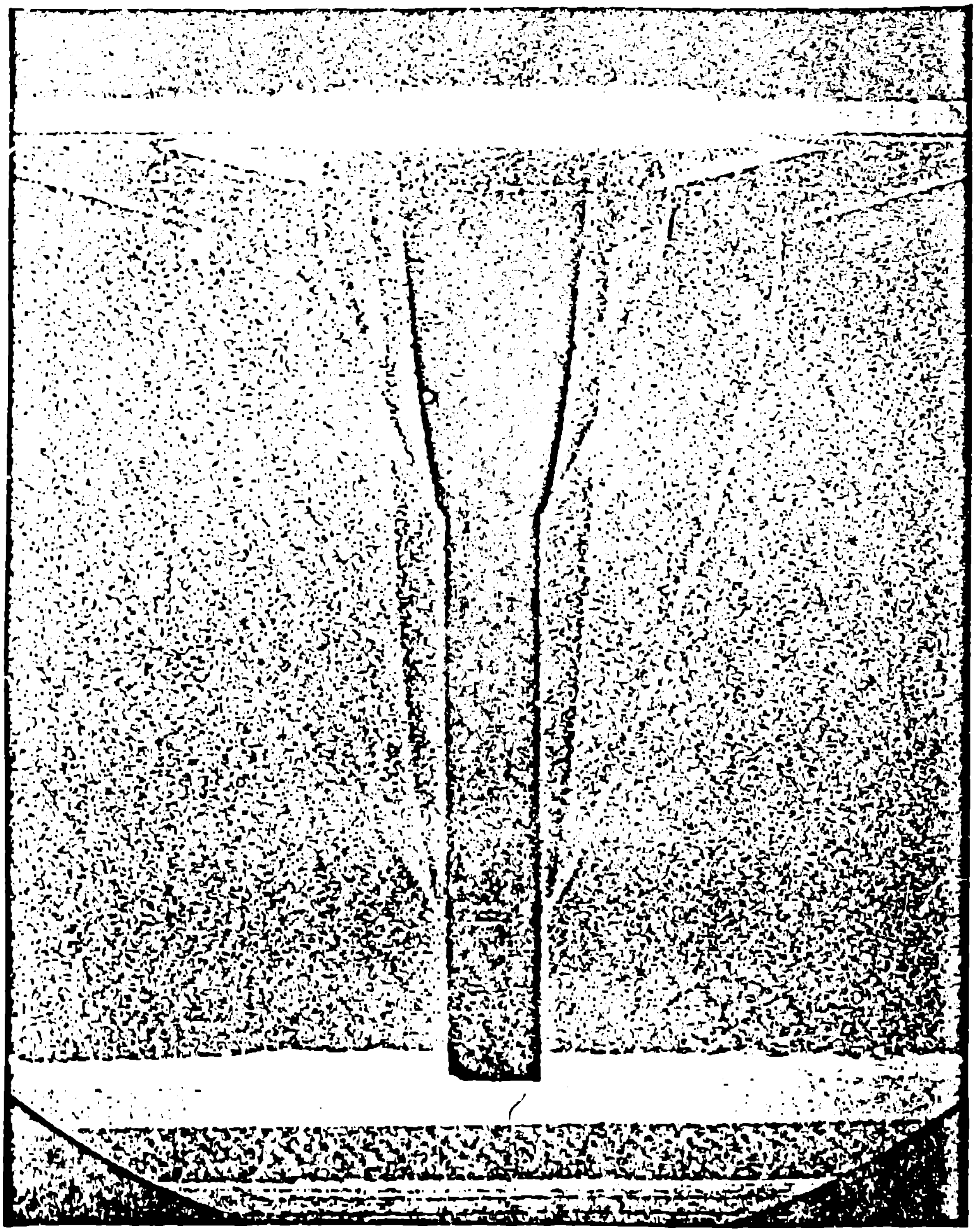
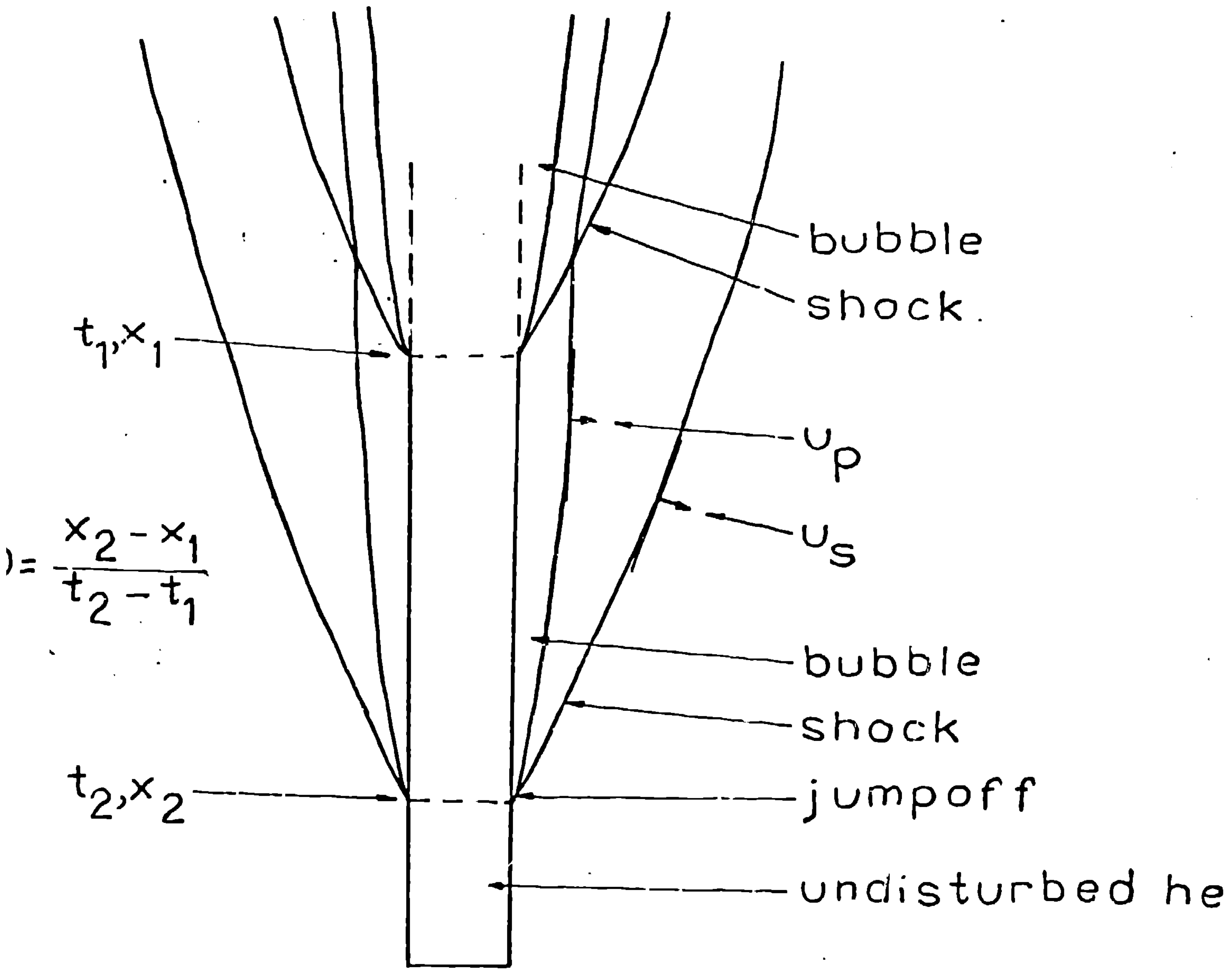


FIGURE 3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shock.
t_1,x_1
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$)= \frac{x_2 - x_1}{t_2 - t_1}$
bubble
shock
t_2,x_2
jumpoff
undisturbed he

FIGURE 4

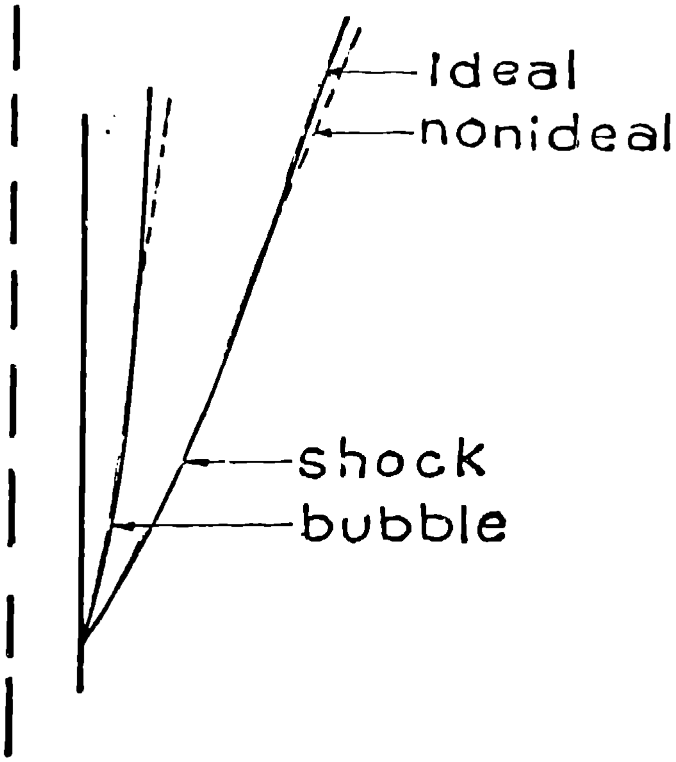
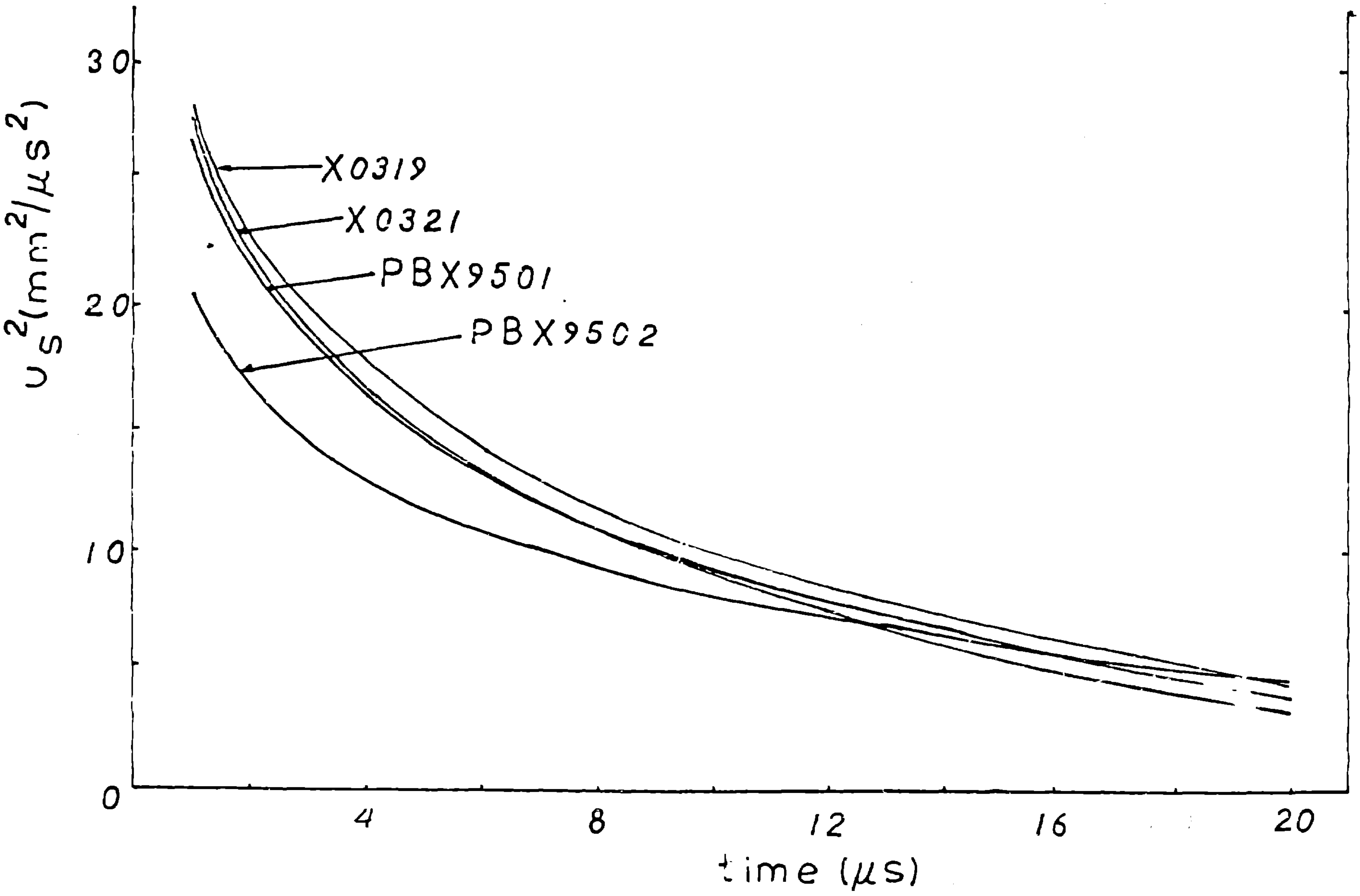


FIGURE 5



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16
20
time (μs)