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FINAL DETERMINATION
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THEORETICAL COMMENTS TO DR. KISTIAKOWSKY'S MEMORANDUM

H. A. Bethe
June 16, 1944

I. Interaction Between Detonation Waves

According to our present theoretical belief, regular reflection of a detonation wave from a rigid wall is possible only for angles of incidence up to 45°. At 45° the velocity of the Mach wave is not sufficient to keep pace with the intersection between incident detonation wave and reflecting wall. It is estimated that a Mach wave can only exist for angles of incident greater than 57°. It is not known what happens between 45 and 57°; it is possible that two successive reflected shock waves will be formed or some still more complicated type of reflection may occur.

II. Partitions

Very little is known theoretically about delaying partitions. It seems likely that low sound velocity is desirable and therefore heavy materials of high compressibility. High density may also be desirable in its own right.

III. Lenses

It is desired to produce a plane detonation wave using a single detonation point. Suppose we use high velocity explosive of detonation velocity C_1 and low velocity explosive of C_2 as indicated in Figure 1. Let us also assume that the detonation velocity is strictly constant in a given explosive and that we do not get any transition effects in going from high to low velocity explosive. Whether this assumption is true is being investigated here at present from the theoretical point of view.

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It then is a simple problem in geometric optics to find the shape of the boudary between high and low velocity explosive. We wish the detonation to arrive simultaneously at all points along the line AB. It is clear that for this purpose the detonation wave must have travelled perpendicular to AB in the low explosive. An example of a possibel path of the detonation is given by the line OCD in Figure 1. We require that the time taken should be the same for all such paths, i.e.

$$\frac{OC}{C_1} + \frac{CD}{C_2} = \text{constant} \qquad (1)$$

It is easily found that this condition requires that the boundary ACB, be a hyperbola and that the detonation point O be at the far focus of the hyperbola.

Let a be the distance from the detonation point to the apex E of the hyperbola. Then the axes of the hyperbola are

$$\alpha = \frac{a\,C_2}{C_1+C_2} \qquad (2)$$

in the direction OE and

$$\beta = a\sqrt{\frac{C_1-C_2}{C_1+C_2}} \qquad (2a)$$

in the direction perpendicular to it. In terms of these axes the equation of the hyperbola is

$$\frac{\left(X - \frac{a\,C_1}{C_1+C_2}\right)^2}{\alpha^2} - \frac{Y^2}{\beta^2} = 1 \qquad (3)$$

where the detonation point is the origin and the X axis is in the direction OE.

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The distance of the detonation point O from the plane AB is arbitrary; the only condition is that A and B lie on the hyperbola. Likewise arbitrary is the shape of the outer boundary of the high velocity explosive which is sketched with dashes in Figure 1. The explosive can be used in a thin slab, i.e. its thickness perpendicular to the paper can be thin compared with AB. It would also be possible to use thick explosive and to rotate Figure 1 about the axis OE.

In order to get focusing on a reasonably large plane AB with reasonable short distance of the detonation point O from the plane it is necessary that the ratio of the two detonation velocities C_1 and C_2 be as large as it can conveniently be made.

Assume that there is explosive extending below the line AB as indicated in Figure 1. Then the detonation front at later times should be parallel to AB everywhere below the line AB, and should be circular at the ends as indicated by the line FGHI. It would be interesting to observe this shape for various thicknesses of the explosive below AB. It should not make any difference whether this explosive is high velocity or low velocity but experiments with high velocity would be somewhat more interesting.

The deviations from geometric optics are likely to be in the sense that the detonation velocity in the low velocity explosive is somewhat greater than normal when the explosive is hit by a detonation wave from a high velocity explosive especially if it is hit head on. To compensate for this effect it would probably be necessary to increase slightly the height of the low velocity explosive near the point E as indicated by the dotted

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line in Figure 1. It is expected that no great change from the hyperbola is required.

If no satisfactory results can be obtained with the arrangement in Figure 1, the arrangement in Figure 2 may be contemplated. In this arrangement there is low velocity explosive around the detonation point, the low velocity explosive forms an ellipse with the detonation point at the far focus and the waves are supposed to be plane in the high velocity explosive below. This arrangement is definitely inferior to the arrangement in Figure 1 because it uses more low velocity and less high velocity explosive. The reason why it might be easier to construct is that there is no transition from high to low velocity at which deviations from the usual detonation velocity might occur. No such deviations are expected for the transition from low to high velocity because the detonation wave must always have at least the velocity given by the Chapman-Jouget condition.

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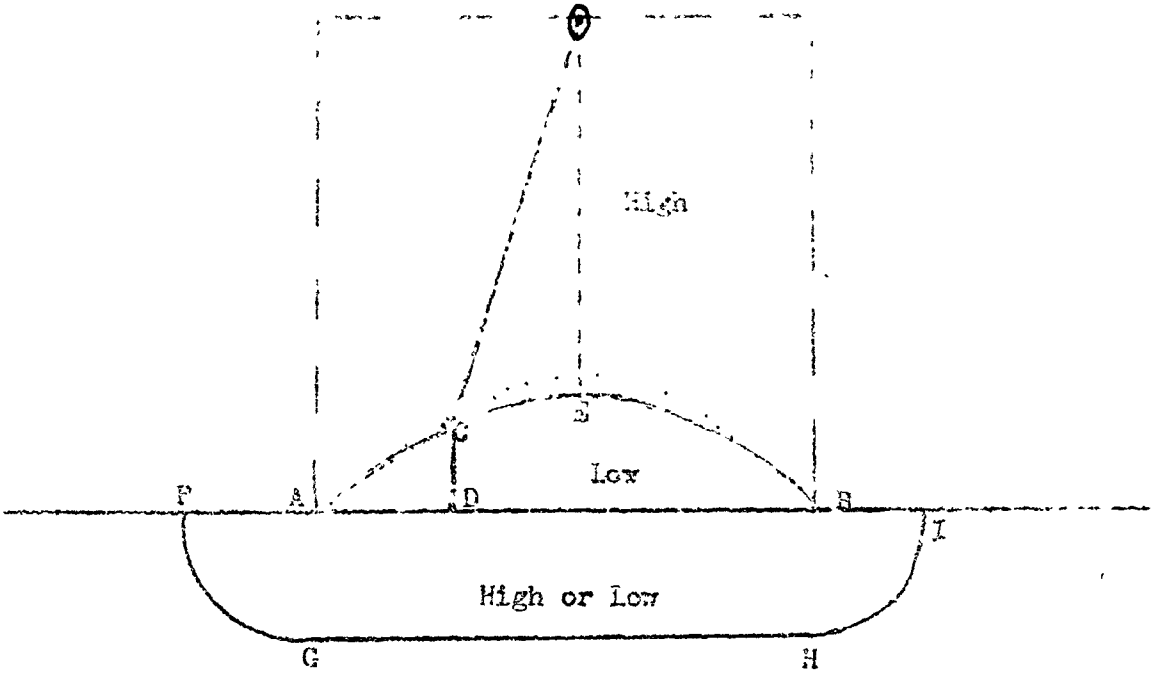

Figure 1

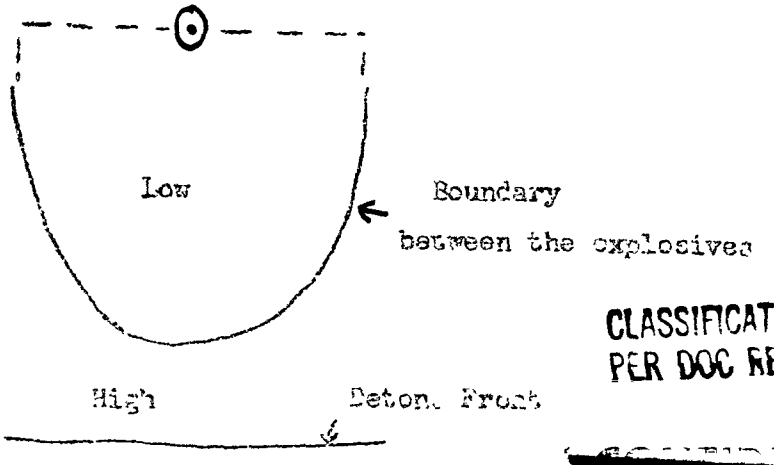

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Figure 2