188. *Explosions of Methane and Air: Propagation through a Restricted Tube.*

By H. Robinson and R. V. Wheeler.

Mason and Wheeler (J., 1920, **117**, 47) observed that during explosions of methane and air in a steel tube 90 m. long and 30·5 cm. in diameter, open at both ends and restricted at two points by thin steel rings which reduced the diameter to 28·6 cm., combustion of an intensity comparable with that in the detonation wave seemed imminent. Chapman and Wheeler (J., 1926, 2139) studied closely the effect on the propagation of flame, in mixtures of methane and air, of restrictions in a brass tube 240 cm. long and 5 cm. in diameter. The maximum speed observed was 420 m./sec., obtained after the flame in a mixture containing 9·75% of methane had passed through 12 restricting rings each reducing the diameter of the tube to 2·5 cm. and set at intervals of 5 cm.

We have extended this work by experiments in a steel tube 32·3 m. long and 30·5 cm. in diameter, open at both ends, fitted with a series of 11 restricting rings at intervals of 30·5 cm., each reducing the diameter to 10·2 cm. The first ring was 13·4 m. from the end at which ignition was effected.

The tube was built up from flanged sections mounted horizontally on concrete piers. One section contained the eleven restricting rings, which were mounted together on a rigid frame.

An explosive mixture (9·8—10·0% CH_4 in air) was prepared by measuring through a meter into the tube the required quantity of methane, obtained from a natural source, and circulating the whole of the contents of the tube, by means of a fan installed in a by-pass main, during 40 minutes. During this operation, the flanged ends of the tube were closed by steel blanks which, when greased, made gas-tight covers.

Immediately before ignition of the mixture, both blanks were released by electromagnetic devices which allowed them to fall clear of the ends of the tube. Ignition was effected by passing an electric current, sufficient to cause fusion, through a strand of fine copper wire stretched across the tube 0·6 m. from the end.

Photographic records on a revolving drum were obtained, through a series of small windows in the tube, of the movements of the flame as it passed through the restricted portion of the tube; but most attention was directed to measurements of the speed attained in the later unrestricted portion, 15·8 m. long, for it seemed possible, from Chapman and Wheeler's experiments (*loc. cit.*, p. 2144), that a constant high speed might be maintained.

For some of the experiments the windows were 1·25 cm. in diameter and 2·5 cm. apart. They were covered by a ribbon of transparent "cellophane" held in position by long strips of steel with rubber gaskets. The cellophane was tough and only on rare occasions was it ruptured by the force of the explosion.

In the first series of experiments, the camera had a field of view of 2·4 m., and successive lengths of the tube were photographed, each slightly overlapping the next, so that a composite was obtained. The revolving film received light from 96 windows, and the photograph consisted of that number of dark bands alternating with light bands of the same width (see Plate I). In other experiments, in which 15·8 m. of the tube were photographed at once, the windows were 2·5 cm. in diameter and 0·61 m. apart; the camera was at a distance of 32 m. from the tube and the experiments were carried out at night.

Propagation of Flame through the Restricted Zone.—No measurements were made of the speed of the flame between the point of ignition (one end of the tube) and the first restricting ring. From earlier work (see Mason and Wheeler, *loc. cit.*) it is known that the initial speed was slow (about 2 m./sec.) and nearly uniform. Soon after entering the restricted zone, however, the flame attained a high speed and its progress was signalised by a sharp report similar to that accompanying detonation. The mean speeds of the flames between successive restricting rings, as determined in 5 typical experiments, are recorded in Table I. In general, the flame was not of sufficiently high actinic value to be photographed on a revolving film until it had passed the fourth restriction.

The reason why the speed of the flame is increased so rapidly within the restricted zone of the tube can be understood if each pair of restrictions is regarded as forming a chamber, communication between successive chambers being through an orifice the area of which is small (one-ninth) compared with the cross-sectional area of the partition. The propagation of

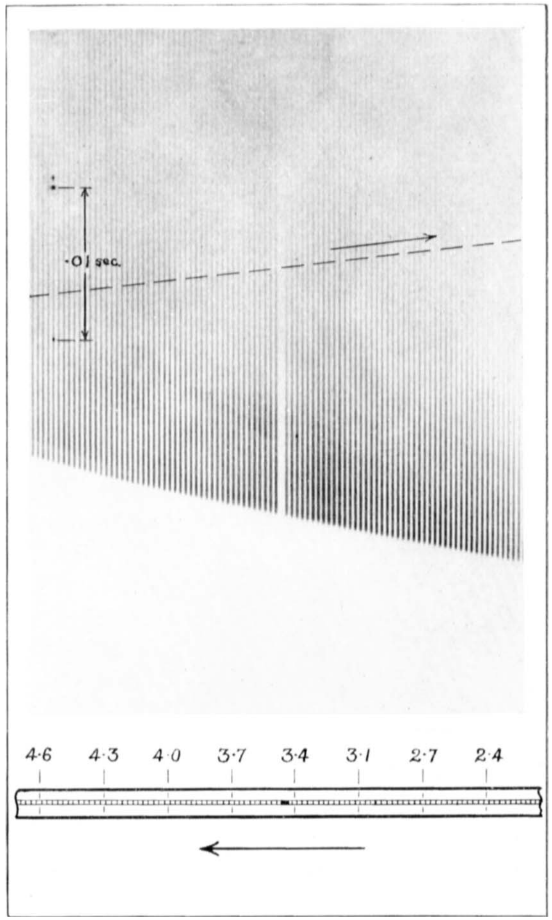

FIG. 1.—*The numbers are those of the restricting rings.*

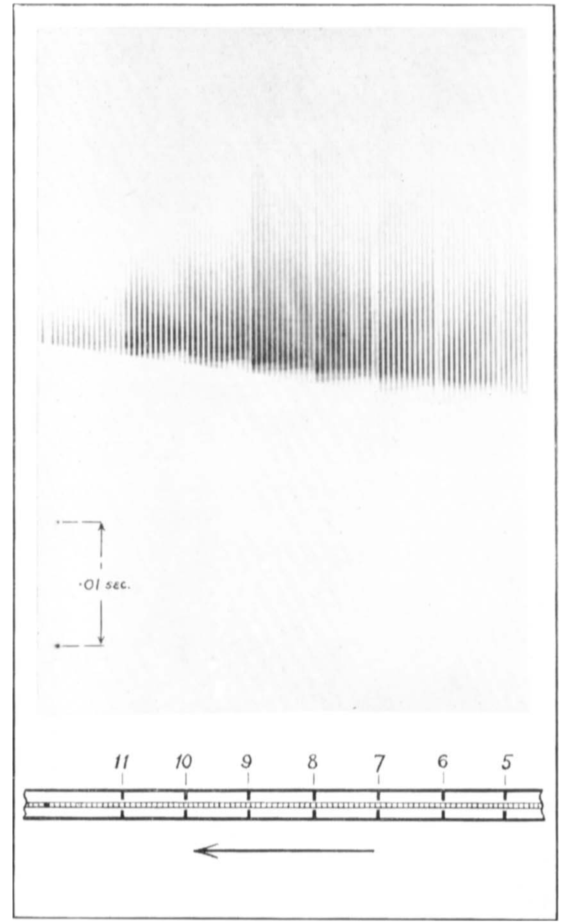

FIG. 2.—*Distances, in m., are those from the last restricting ring.*

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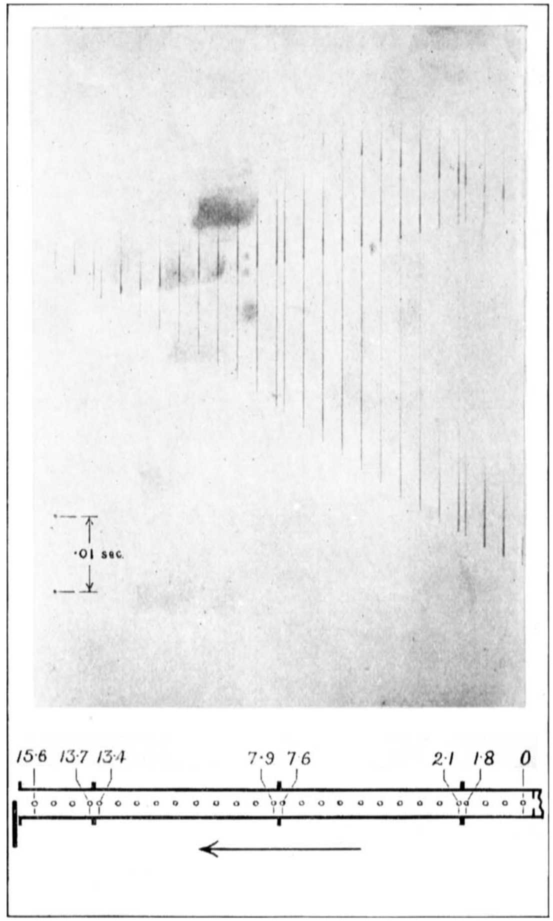

FIG. 3.

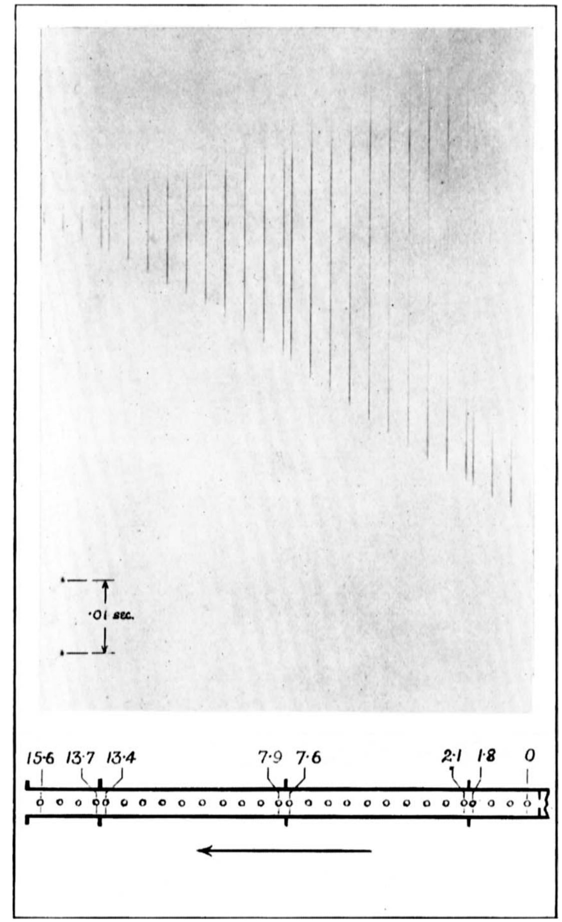

FIG. 4.

Distances, in m., are those from the last restricting ring.

TABLE I.

Explosions of Methane and Air through a Restricted Tube.

Between restrictions Nos.	Mean speed, m./sec. (1).	(2).	(3).	(4).	(5).	Average values.
2— 3	—	—	174	—	—	174
3— 4	—	—	204	—	—	204
4— 5	218	272	266	222	216	239
5— 6	290	289	298	287	281	289
{6— 7	396	383	376	365	366	377}
{6— 7	326	—	325	407	343	350}
7— 8	403	—	373	417	359	388
8— 9	432	355	402	402	410	401
9—10	453	412	395	422	436	423
{10—11	471	431	448	444	447	448}
{10—11	442	441	454	466	469	454}

flame up to the restricted zone proceeds slowly and smoothly so that, at the moment when the flame passes into the first " chamber," the mixture within the series of chambers is quiescent. As soon as the mixture within the first chamber is inflamed, however, the conditions of combustion suddenly change : whereas formerly they approximated to those of the " uniform movement," they now approach those of explosion in a closed cylinder. Release of pressure from the first chamber not only produces turbulence of the mixture in the successive chambers, but launches a tongue of flame through it, so that the area of the flame surface is much increased and combustion therefore becomes rapid and violent.

A study of the photographic records (*e.g.*, Fig. 1) fails to reveal any discontinuity in the combustion within the restricted zone, or any sudden increment in speed of the flame such as occurs when the detonation wave is initiated. On the contrary, the acceleration in the speed of the flame from about 2 to 450 m./sec., although it occurs within 0·01 sec., is smooth and continuous.

Propagation of Flame Beyond the Restricted Zone.—The speed over the last 15·8 m., as shown by photographs of each 2·4 m. length in successive experiments, was not constant but steadily decreased, from 450 m./sec., as the flame left the restricted zone, to 300 m./sec. at a distance of 5 m. After remaining nearly constant over a short distance, it gradually increased again until it attained 600 m./sec. as the flame approached the open end of the tube.

Many of the records, one of which is reproduced in Fig. 2, show reflected compression waves traversing the flame front and the burning gases behind it. A strong compression wave is produced on the sudden combustion of the mixture within the restricted zone, and travels ahead of the flame. At a point 3·6 m. from the open end of the tube, a slight obstruction (due to an imperfectly aligned flange) presented a reflecting surface. The reflected wave recorded in Fig. 2 (accentuated by broken line) has a speed of 700 m./sec.

The variations in speed of the flame beyond the restricted zone are well shown by the record reproduced in Fig. 3, obtained from a single photograph of the final 15·8 m., whilst Fig. 4 shows a record of reflected waves. The latter photograph is of an experiment in which the far end of the tube was partly obstructed. The wave reflected from the obstruction has met the flame front at a point 13·4 m. from the last restricting ring (No. 11), checking the flame and causing increased luminosity of the burning gases behind the flame front as it travels through them. On meeting restricting ring No. 11, the wave is reflected back again.

Discussion of Results.—It is clear from these records that, despite the high speed at which the flame travelled after it had passed through the restricted zone, a constant régime comparable with that of the detonation-wave was not established.

The luminosity observed immediately beyond the restricted zone is probably not that of flame " propagated " in the usual manner, but rather that of a tongue of flame, a metre or more in length, projected through the final restricting ring. Such a projected flame would be expected to have a high initial speed, which would gradually decrease as the pressure within the restricted zone obtained release.

The propagation of flame further beyond the restricted zone (as recorded photographically) would then be from the tip of the projected tongue of flame centrally along the tube, whilst from every part of the surface of this tongue flame would propagate towards the wall. The pressure in this part of the tube, which would be behind the flame front proper, would therefore increase rapidly and cause a bodily movement of the column of unburnt mixture towards the open end of the tube. So long as the pressure behind the flame front continued to increase, the speed of movement of the column of unburnt mixture would increase and the flame would thus travel in a medium which was itself moving at an increasing speed.

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