XXVII.—*The Propagation of Flame in Electric Fields. Part I. Distortion of the Flame Surface.*

By Ernest Michel Guénault and Richard Vernon Wheeler.

It has long been known that flames, and the hot products of combustion immediately resulting from them, are conductors of electricity. This knowledge has led to the speculation that the propagation of flame may be directly due to the preliminary ionisation of the reacting gases. Attempts have been made to demonstrate by experiment the electrical nature of flame propagation.

Dixon, Campbell, and Slater (*Proc. Roy. Soc.*, 1914, **90**, *A*, 506) studied photographically the effect of a transverse magnetic field of 10,000 gauss on the detonation-wave in mixtures with oxygen of hydrogen, acetylene, cyanogen, carbon monoxide, and carbon disulphide. There was no visible influence on the speed or form of any of the detonation-waves nor, in experiments with acetylene and oxygen, could any alteration in the initiatory phases of explosion flames be detected.

Malinowski (*J. Chim. phys.*, 1924, **21**, 469) recorded the complete arrest of the propagation of flame in rich mixtures of light petroleum vapour (approximating to hexane) and air, and later, with Lawrow (*Z. Physik*, 1930, **59**, 690), the slowing down and occasional complete arrest of flame in mixtures with air of methane, ethylene, and acetylene, as the result of the application of a transverse electric field. Similar results were recorded by Bernackyj and Retaniw (*Ukrain. Phys. Abhand.*, 1928, **2**, 9). In each of these researches the experimental method was as follows : A metal cylinder was arranged vertically and acted as one " plate " of an air condenser. The other was a metal rod the diameter of which was varied so that, when fixed axially in the cylinder, it provided an annular space of chosen width (never more than 5 mm. and often as little as 1·5 mm.). This condenser was used as a gas-burner, the inflammable mixture being allowed to flow upwards through the annular space at such a speed that the flame, when the mixture was ignited at the top, could travel slowly downwards. When an electric potential above a certain voltage was applied to the condenser, the flame was extinguished with mixtures of air with a hydrocarbon such that the oxygen was in defect and carbon could be deposited. No positive result was obtained with hydrogen–air mixtures.

Haber (*Sitz. Preuss. Akad. Wiss. Phys.-Math.*, 1929, **11**, 162) carried out similar experiments, using as a condenser a rectangular tube with two sides of glass and two of metal, arranged vertically, and determining the effect of an electric field on the speed of flame in mixtures of benzene with air and oxygen, of cyanogen with a mixture of oxygen and nitrogen, and of air with a mixture of carbon monoxide and hydrogen. He found that an electric field had a retarding effect only on those flames that gave a well-defined Swan spectrum. Haber's principal deduction from his experiments was that the speed of propagation of an explosion is determined, not by electrically charged dissociation products, but by neutral intermediate products of dissociation (transient uncharged radicals) obtained with an expenditure of less energy. Of such uncharged radicals, C·C and C·H alone appear to have a sufficiently low ionisation potential to allow of dissociation into ions and electrons in the flame, so that an electric field only affects flames in which such radicals are present. Haber noted that the shape of the flame (in a benzene–air mixture) was modified by the electric field, presumably owing to the drag exerted by the moving ions on the flame gases.

It is evident that if an electric field distorts the flame of an explosion, the conditions of propagation, as regards the cooling of the flame by the walls of the explosion-vessel and the free movement of the flame-surface, are materially altered, particularly when the space in which the flame moves is as restricted as in the experiments just described. These altered conditions would affect the speed of propagation of flame apart altogether from any effect of an electric field on the reactions occurring in the flame-gases themselves. For example, Mason and Wheeler (J., 1920, **117**, 1227) have shown that, during upward propagation in a long tube of quartz, 5 cm. in diameter, closed at the upper and open at the lower end, the flame in an 8·3% methane–air mixture would begin to travel at either of two speeds, dependent on whether the shape of the flame-front were symmetrical or (the slower flame) unsymmetrical. The alteration in the shape of the flame-front in Mason and Wheeler's experiments was an effect of resonance. An increase in the speed of upward propagation of flame in a 7% methane–air mixture on the application of an electric field, which may well have been due to an

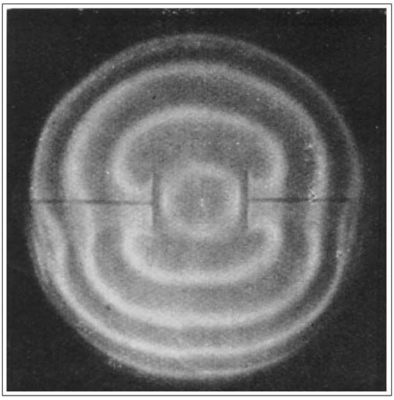

Fig. 1.—*Without electric field.*

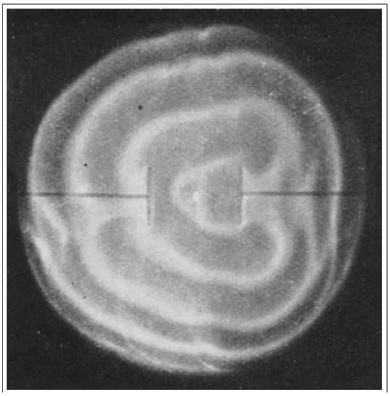

Fig. 2.—*Electric field* 3000 *volts per cm.*

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PLATE II.

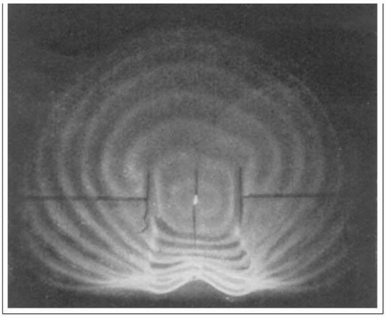


FIG. 1.—*No electric field.*

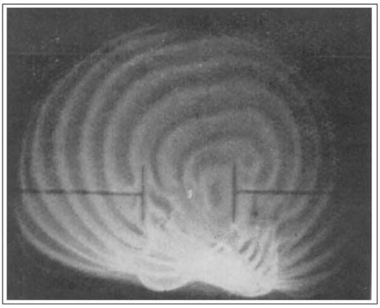


FIG. 2.—*Electric field* 3000 *volts per cm.*

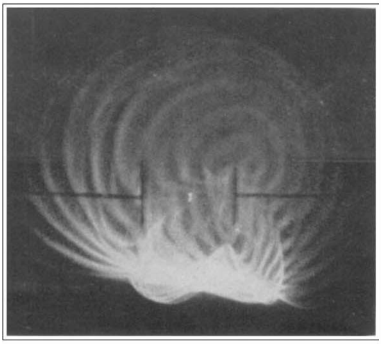
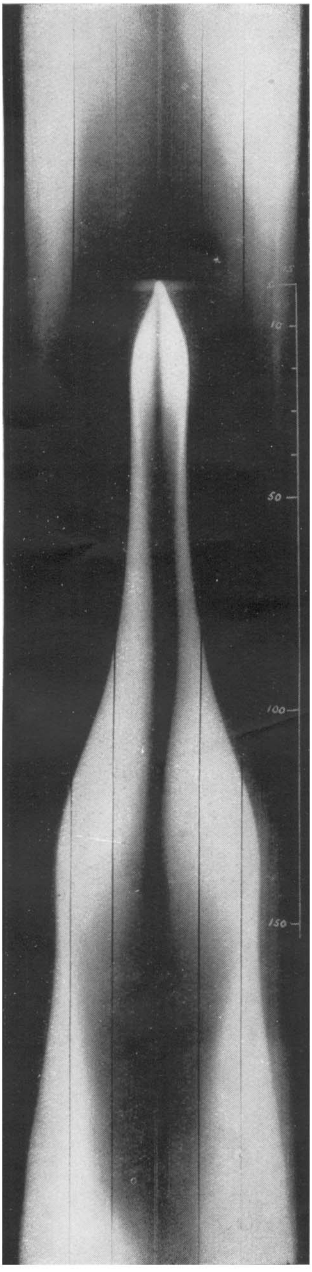


FIG. 3.—*Electric field* 5000 *volts per cm.*

PLATE III.



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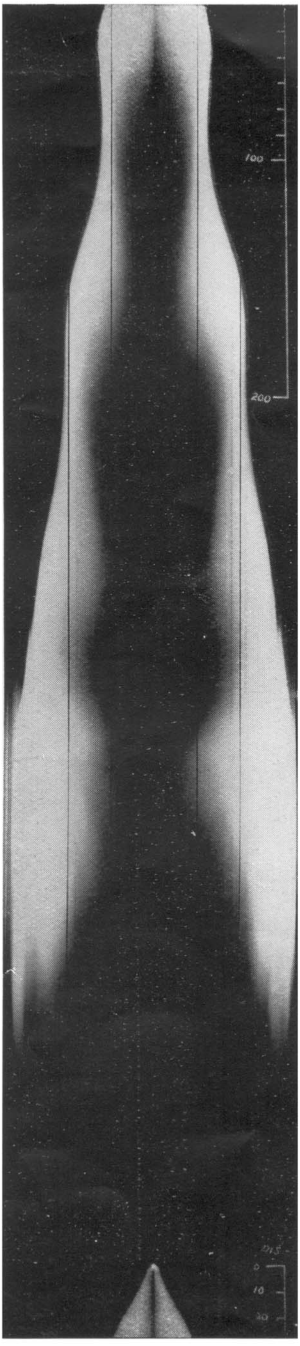

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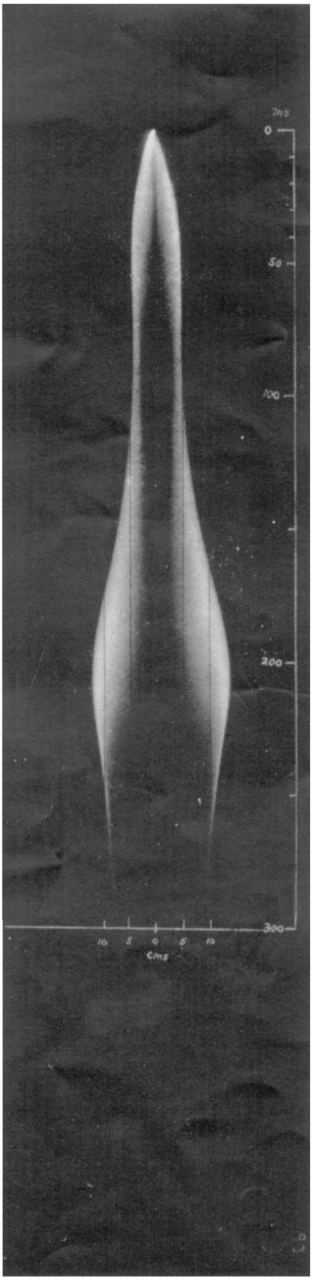
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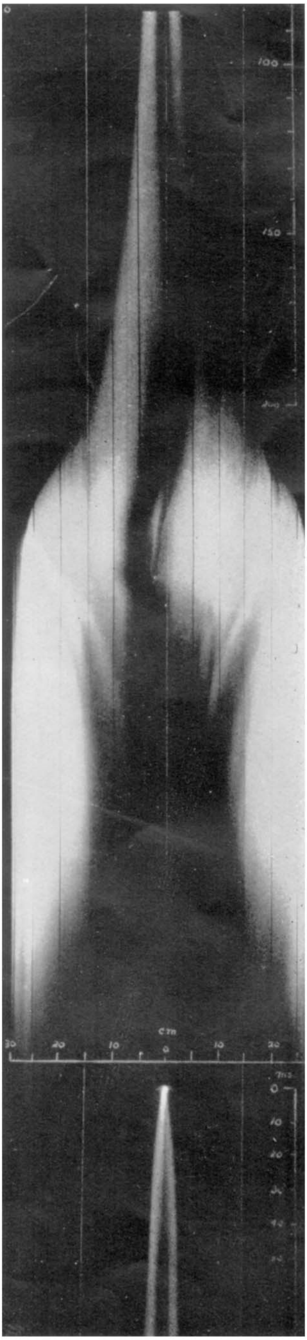
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alteration in the shape of the flame front, has been noted by Thornton (*Phil. Mag.*, 1930, **56**, 260). In his experiments, a closed tube of glass, 1 m. long and 3 cm. in diameter, was used, a metal rod, disposed axially, acting as one plate of the electrical condenser and a metal sheath outside the tube serving as the other plate.

The present paper demonstrates the extent to which the shape of a flame-surface can be altered by an electric field and is preliminary to a study of the effect such an alteration has on the speed of propagation of flame under different conditions.

It is shown that when a flame spreads from the centre of a sphere, its normal symmetry (see Fig. 1, Plates I and II) is destroyed if it is exposed to an electric field (Fig. 2, Plate I, and Figs. 2 and 3, Plate II). Whilst the flame is between the plates of the charged condenser (see " Experimental "), before it has actually touched the plates, it is wholly within the electric field and is most susceptible to influence by it. As soon as the flame surface, which is a conductor of electricity, touches the plates, the system tends to discharge itself and the electric field is almost entirely destroyed so long as any part of the flame-surface touches the plates, the capacity of the condenser being small. The photographs in consequence show that the flame suffers no further distortion after it has touched the plates, but spreads throughout the sphere in a manner occasioned by its shape at that moment.

There appears to be little or no alteration in the rate of growth of the flame in a direction transverse to the field. In a direction longitudinal to the field, the electrons move towards the left-hand (positive) plate. In this direction, therefore, the field would cause electrons produced in the flame to move ahead of it with an increased speed, and in the opposite direction it would retard them. The photographs show, however, that the electric field did not stimulate the growth of the flame towards the left-hand plate, so that electrons shot ahead of the flame do not appear to have assisted its propagation. The positive ions are moved by the field towards the right-hand plate and it is in this direction that the speed of the flame is apparently increased. There is, however, a bodily movement of the whole of the spherical flame-surface towards the right-hand plate and sometimes (*e.g.*, in Figs. 2 and 3, Plate II) wholly to the right of the spark that caused ignition. The movement of the flame-surface towards the left-hand plate is therefore not only retarded but actually reversed by the field. This suggests that the movement of the flame-surface may be mechanical, due to the movement of the heavy positive ions dragging the flame-surface with them, and not necessarily the result of a stimulus to chemical activity imparted by the electric field.

EXPERIMENTAL.

Mixtures of carbon monoxide and air or oxygen were ignited electrically at the centre of a spherical explosion-vessel and the movement of the flame-surface as it spread, with and without an electric field, away from the point of ignition was studied photographically. The explosion-vessel (Fig. 1) was of glass, 9 cm. in diameter. An electric field could be applied between two parallel plates of a condenser, 2 cm. apart, consisting of discs of platinum, 1·5 cm. in diameter, set on rods of platinum sealed into the glass diametrically opposite each other. Ignition of the mixtures was at a spark-gap between thin platinum wires sealed into the glass in a plane at right angles to the rods bearing the condenser plates.

FIG. 1.

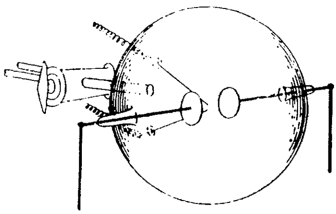
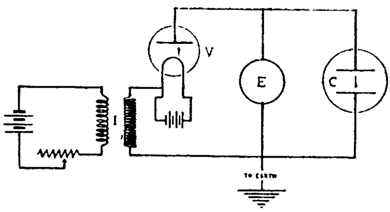


FIG. 2.



The plates of the condenser (C, Fig. 2) were charged to the required difference of potential by means of an induction-coil, I, the output from the secondary circuit being rectified by a diode thermionic valve, V. The voltage was controlled by a variable resistance in series with the primary circuit of the coil and measured by an electrostatic voltmeter, E. The direction of the electric field, and of the electron flow when gas between the condenser plates is ionised, is shown in Fig. 2 by arrows.

The gas mixtures, before entering the explosion-vessel, were dried by passage through calcium chloride and concentrated sulphuric acid to maintain electrical insulation of the condenser. To ensure easy ignition of mixtures of carbon monoxide and air thus dried, a small quantity (about 1%) of hydrogen was added. Ignition was by the secondary discharge from an induction coil on breaking the primary circuit, the trembler being locked.

The development of the flames was studied by the method of "snapshot" photography devised by Ellis and Robinson (J., 1925, **127**, 764; see also Ellis, Safety in Mines Research Board Paper No. 32, 1927), the interval between ignition and the first, and between each successive, snapshot being 19·26 milliseconds. For the photographs here reproduced (Plates I and II) the right-hand plate of the condenser was negatively charged, so that the movement of positive ions was towards that plate and that of electrons and negatively-charged particles towards the left-hand, positive plate. Attention should be directed towards the earlier, inner, snapshots in each photograph. The later gravitational distortion at the base of the flames on Plate II, where the snapshots merge and overlap, does not concern the present research. It is fully explained by Ellis in *Fuel*, 1928, **7**, 202.

The photographs on Plate I are of the movements of flame in a mixture of 92·2% of carbon monoxide and 1·0% of hydrogen in oxygen, Fig. 1 without and Fig. 2 with an electric field of mean strength 3000 volts per cm. For the photographs on Plate II, a mixture of 12·5% of carbon monoxide and 1·5% of hydrogen in air, in which flame moves more slowly, was used. For Fig. 1 there was no electric field, whilst for Figs. 2 and 3 the mean strength of the field was 3000 and 5000 volts per cm. respectively.

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