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# Very Fast Dynamical Wave Phenomenon*

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An unusual luminous wave of $10^8$ cm/sec speed moves out from the driver of a plasma shock tube immediately following breakdown, and propagates more than a meter into a field-free region.

## DESCRIPTION OF THE PHENOMENON

An improved design of the linear electron-driven shock tube has been constructed, and will be described elsewhere. It generates a column of driver gas 1 m long at an electron temperature sufficient to produce mach 40 electron driven shocks at capacitor potentials of only 10 kV, in a tube 50 mm in diameter. Expansion is made into a collinear chamber which is also a meter in length. It has been tested in hydrogen and argon, and found to produce shock waves of the normal electron-driven variety described by the theory of Fowler and Fried.[1] The purpose of this paper is to describe a new wave phenomenon observed in this tube, which seems to possess some unusual properties.

The new wave appeared at first sight to coincide with gas breakdown and to move instantaneously along the expansion chamber, owing to the slowness of the wave speed cameras in use. On careful comparison with a fiducial pattern, however, it was later found to have a speed of about $2.0\times10^8$ cm/sec in argon at 100 $\mu$Hg. We, and others, have previously noticed somewhat similar phenomena which we have tended to dismiss as scattered light fronts. The same fate would probably have overtaken this observation if it had not been for a weak pre-ionization discharge which was present intentionally in the expansion chamber, with the recombination afterglow from this discharge producing a slight background exposure on the photograph. The fast wave *reduced* the luminosity of this afterglow in a narrow zone just in advance of its leading edge.

The following additional observations were then made with a faster mirror. The wave velocity was not radically different in hydrogen or argon. It is independent of gas pressure at pressures below 500 $\mu$ Hg but decreases with pressure at higher values as shown in Fig. 1. It was not affected by the presence or absence of the pre-ionization. It was not influenced by an axial magnetic field of as much as 1000 G. It was perhaps affected in brilliance, but not perceptibly in speed, by a short zone of transverse magnetic field of about the same magnitude. It was much less brilliant in hydrogen than argon. It was unaffected by moving toward a grounded electrode at the far end of the shock tube, or, with this electrode unconnected, into a space free of electric fields (except for a very weak quadrupole field of less than 30 V per meter).

An increase in wave speed with increasing field in the driver chamber was found to exist and is shown by the data in Fig. 2. The data seem to indicate that the speed-controlling factor is the electron temperature in the driver chamber.

The front takes the form of a strong pulse of luminos-

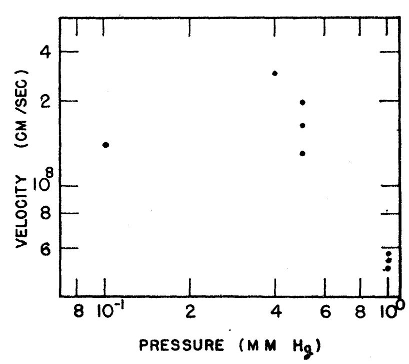


FIG. 1. Wave velocity vs gas pressure.

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[1] R. G. Fowler and B. D. Fried, Phys. Fluids 4, 767 (1961).

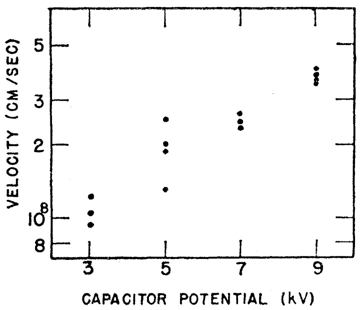


FIG. 2. Wave velocity vs capacitor potential.

ity, at low pressures and strong driver fields, but becomes quite diffuse with weak fields, and changes in form to a step of luminosity at high pressures.

## DISCUSSIONS AND CONCLUSIONS

In a companion paper by Paxton and Fowler, it is shown that electron hydrodynamic waves are possible, as well as the electron driven plasma hydrodynamic waves previously described by Fowler and Fried. Paxton identifies these waves with the breakdown waves observed in strong fields, and finds that they are insensitive to the mechanism which serves to transport energy to the wave front. We believe that the wave we are observing here is of electron hydrodynamic character. Two possibilities suggest themselves for the mode of energy transport to the front. Either the walls of the expansion chamber act as a light pipe for the intense radiation from the driver, or else the energy of the driver is delivered to the front by heat conduction processes. It does not appear possible to decide which is correct on a basis of the evidence, although the dependence observed on electric field in the driver implies a concomitant dependence upon electron temperature in that region which suggests the latter hypothesis rather strongly. The first mechanism is suggested by the research of Loeb[2] on streamers. Absorbed at the front by the neutral gas, photons could be converted into ionization and fast electrons by reactions such as the binary reaction

$$M^*+M^* \rightarrow M^+ + e + \text{K.E.},$$

or the dissociation reaction

$$h\nu + M \rightarrow M^+ + e + \text{K.E.}$$

These electrons would then further augment the ionization by impact upon the metastable and blockaded resonance states. The reactions suggested are only two of several possible electron-energizing photon-induced reactions, and may not be the correct ones. If the photon theory is correct, one would estimate that the electron temperature in the wave is closely related to the residual energy of the reaction. Energies of order 10 eV are easily possible, consistent with flow velocities of $2\times10^8$ cm/sec. It is difficult, but not impossible to make this model consistent with a dependence of velocity on driver chamber field.

Explanation in terms of heat conduction is based on arguments of sufficiency only. If it be assumed that the wave ionizes the gas substantially to a fraction $\alpha$, then the waves observed would require a power flux density to the front of about $2\alpha$ megawatts/cm$^2$. In a neutral gas the electron heat conduction coefficient would be $10^{-4}\alpha$ (MW/cm$^2$)/unit gradient. In a fully ionized gas it would be $2\times10^{-3}\alpha$. Thus a temperature gradient of about $10^3$ to $10^4$ °K/cm is all that is needed to deliver the power required. Beginning with an electron gas at $10^6$ °K in the driver, the required gradient need hardly be noticeable in a flight of 100 cm. The flow would therefore proceed at driver electron temperature, as is roughly observed.

Suppression of the luminosity in advance of the wave is one of the strongest reasons for explaining the wave on the Paxton-Fowler model since the electric double layer which must exist at the leading edge of the electron hydrodynamic wave would stop the recombination processes which are responsible for the afterglow light from the pre-ionization.

Further work is contemplated.

[2] L. B. Loeb, in *Handbuch der Physik,* edited by S. Flügge (Springer-Verlag, Berlin, 1956), Vol. XXII, p. 445.