[Journal of the Arkansas Academy of Science](http://scholarworks.uark.edu/jaas)

Volume 53 | Article 29

1999

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Electron shock waves are luminous pulses that propagate through a long discharge tube subjected to a large (20,000-40,000 volts) potential pulse. A dramatic, natural example of shock (or breakdown) waves can be seen in lightening. Though this example has been observed for centuries, little scientific study of the phenomenon had been recorded until the late 19th century. Early experimental work supplied information that led to an approximation of wave speed and a probable mode of propagation. Through subsequent investivations, an approximate mathematical model was developed. This model has been refined to the point that it can now be applied to correctly model breakdown wave characteristics such as wave speed, electron temperature, electron number density, and electric field strength distributions inside the wave.

J. J. Thompson (1893) reported the first observation of waves propagating down the length of a discharge tube. Using a rotating beam arrangement, Thompson was able to determine a propagation velocity of about one-half the speed of light for waves propagating down a 15 meter long discharge tube. Thompson also noticed an absence of Doppler effect in the emitted light.

Using an apparatus similar to that of Thompson, Beams (1930) was able to confirm the approximate wave speed determined by Thompson. Beams went on to repeat the experiment and, by varying discharge tube parameters, found that the wave velocity increased with increasing pressure (to about three Torr), diameter of the tube, discharge potential and displacement down the tube. Beams also found that the breakdown waves travel from the discharge electrode to ground regardless of potential polarity. Along with this discovery, a nomenclature for the wave direction developed. Proforce waves refer to waves that have a velocity in the same direction as the electric field force. Antiforce waves refer to the opposite case. As well as his experimental findings, Beams proposed a qualitative explanation of the wave propagation. He explained that in the neighborhood of the discharge electrode, a strong electric field causes intense ionization. Due to higher mobility electrons, a space charge is formed in the ionized gas. This space charge reduces the net electric field in that region and is pushed down the discharge tube regardless of applied potential polarity. The ionized gas left behind is conductive and carries the potential of the discharge electrode. Therefore, the intense ionization, and consequently the luminosity, propagates down the discharge tube. This mode of propagation is still accepted by current researchers.

Like Thompson and other observers, Shelton and Fowler (1968) detected no Doppler effect in the spectral lines of the emitted light, showing that the atoms that are emitting the light are not accelerating. Since there is no heavy particle acceleration, Shelton and Fowler stated that the phenomenon was due to electron fluid action, and a better name for the propagating waves would be 'Electron Fluid Dynamical Waves'.

In an attempt to develop a theoretical model for the breakdown waves, Paxton and Fowler (1962) developed a three-component, one-dimensional, steady state fluid model to describe the phenomena. Considering no heavy particle (ions and neutral atoms) acceleration, a zero current condition and a heavy shock at the front of the wave, a successful set of equations has been found. The three fluid equations coupled with Poisson's equation and written for proforce waves with modifications by Fowler et al. (1984) are

$$\frac{dE}{dx} = \frac{e}{\varepsilon_o} n\left(\frac{v}{V} - 1\right),$$

$$\frac{d(nv)}{dx} = \beta n$$

$$\frac{d}{dx}\left[mnv(v - V) + nkT_e\right] = -enE - Kmn(v - V),$$

and

$$\frac{d}{dx}\left[mnv(v-V)^2 + nkT_e(5v - 2V) + 2e\phi_i nv - \frac{5nk^2T_e}{mK}\frac{dT_e}{dx}\right] = -3\frac{m}{M}nkKT_e - \frac{m}{M}Kmn(v - V)^2$$

where the variables are electron mass m, neutral particle mass M, wave velocity V, ionization potential ϕ, electric field E, electron temperature T_e, electron concentration n, electron velocity v, position inside the wave profile x, ionization frequency β, and elastic collision frequency K.

To reduce the set of electron fluid dynamical equations to nondimensional form, Shelton (1968) introduced a set of dimensionless variables. This set with modifications by Fowler et al. (1984) is:

$$\nu = \frac{2e\phi_i}{\varepsilon_0 E_0^2} n, \quad \psi = \frac{v}{V}, \quad \theta = \frac{kT_e}{2e\phi}, \quad \eta = \frac{E}{E_0}, \quad \xi = \frac{eE_0}{mV^2} x, \quad \mu = \frac{\beta}{\kappa}, \quad \alpha = \frac{2e\phi_i}{mV^2}, \quad \kappa = \frac{mVK}{eE_o}$$

In the above set of dimensionless variable equations, the variables υ, ψ, θ, η, κ, and ξ represent electron density, electron velocity, electron temperature, electric field strength, ionization rate, elastic collision frequency, and position inside the wave, respectively. The equation set for proforce waves is written as

$$\frac{d}{d\xi}(\nu\psi) = \kappa\mu\nu$$

$$\frac{d}{d\xi}\left[\nu\psi(\psi - 1) + \alpha\nu\theta\right] = -\nu\eta - \kappa\nu(\psi - 1)$$

$$\frac{d}{d\xi}\left[\nu\psi(\psi^2 - 1) + 5\nu\psi\alpha\theta + \nu\psi\alpha\right] = -2\nu\psi\eta - 2\kappa(\psi - 1)$$

$$\frac{d\eta}{d\xi} = \frac{\nu}{\alpha}(\psi - 1)$$

with variables defined as above.

Hemmati et al. (1998) and more recently Hemmati and George (1999) have succeeded in integrating this set of nondimensional fluid equations through the dynamical transition region for a wide range of wave speeds with results that conform to the boundary conditions and are consistent with observed experimental results for those wave speeds measured by Blais and Fowler (1973) and Uman (1993).

Recent work in the field of ionization waves by A. N. Lagarkov and I. M. Rutkevich (1993) of the former Soviet Union, has been found to correlate well with the work discussed to this point. Lagarkov and Rutkevich have performed experimental and theoretical investigations of ionizing waves in a variety of tube geometries with shielded and unshielded tubes. Though in their publications the same basic concepts have been used, some of the theoretical derivations and variables differ from those of this work. It is hoped that investigation of their recent experimental work will help to further the success of the fluid model being developed by the Arkansas Tech University group.

ACKNOWLEDGMENTS.—The authors would like to express their gratitude to the Scientific Information Liaison Office for their financial support of this research project.

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