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HIGH VOLTAGE BREAKDOWN INITIATED BY PARTICLE IMPACT*

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This letter describes the techniques employed and reports results of exploratory experiments on the particle initiated high voltage breakdown hypothesis due to Cranberg.[1] The assumption is made that small particles are torn from an electrode by electrical stress and are accelerated across the gap. Upon impact at the opposite electrode, gas and metal vapor are evolved from the surface, creating local conditions conducive to the initiation of a discharge between the electrodes. No attempt is made to explain the mechanism of particle formation nor to justify the existence of such particles on fundamental grounds. However, an analysis by Slivkov[2] applies constraints on particle size. The upper limit is established by requiring that the kinetic energy of the particle be sufficient to vaporize its own mass. The lower limit is established by requiring that the gas cloud be large enough to permit charge multiplication while simultaneously satisfying the conditions at the Paschen minimum.

Maitland[3] has compiled data from a number of experimenters and finds that the results are compatible with the particle initiated breakdown concept. Rozanova[4] has shown conclusively that particle impacts are capable of initiating discharge by placing loosely bound particles on the surface of conditioned electrodes. Application of pulsed voltages resulted in breakdown attributed to the particle impacts. Results of work in our laboratory on the effects of micrometeoroid bombardment of ion engines[5] suggested a similar mechanism. This led to the experiments described below.

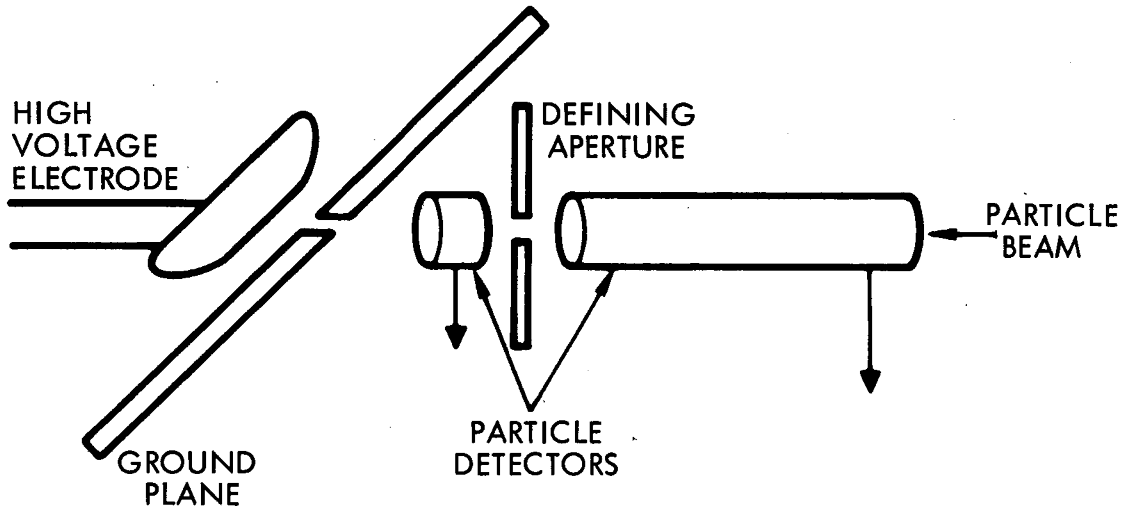
*This work supported by the NASA under Contract No. NASw-936.

In these experiments, particles of known mass and energy are injected through an aperture in one electrode of a plane parallel electrode configuration. The particle parameters are completely independent of electrode spacing and voltages and the experiments are primarily concerned with the investigation of the effects of voltages and electric fields on the developing discharge. The experiments provide no information on the mechanism of particle formation required for the Cranberg hypothesis. However, the parameters of particles required to initiate discharge can be determined and compared to what might be anticipated in an actual case.

The STL electrostatic hypervelocity accelerator[6] was used as a source of particles. In this device, small iron particles are charged by a process described elsewhere[7] and are injected into the accelerating field of a 2-million volt Van de Graaff generator. The particle mass and energy are determined prior to impact by techniques described in Ref. 7.

A diagram of the experimental configuration is shown in Fig. 1. Particles from the accelerator pass through a detector used for the measurement of particle mass and velocity. Most of them pass through a 0.75 mm diameter defining aperture which is aligned with a 1 mm aperture in the ground electrode. Finally, the particles impact upon the high voltage electrode. Another particle detector is interposed between the two apertures and serves to identify which of the particles passing through the main detector eventually strike the target. In practice, slight misalignment results in less than 100 per cent transmission through both apertures. For each set of conditions, the transmission was determined and the observed frequency of discharge was weighted accordingly.

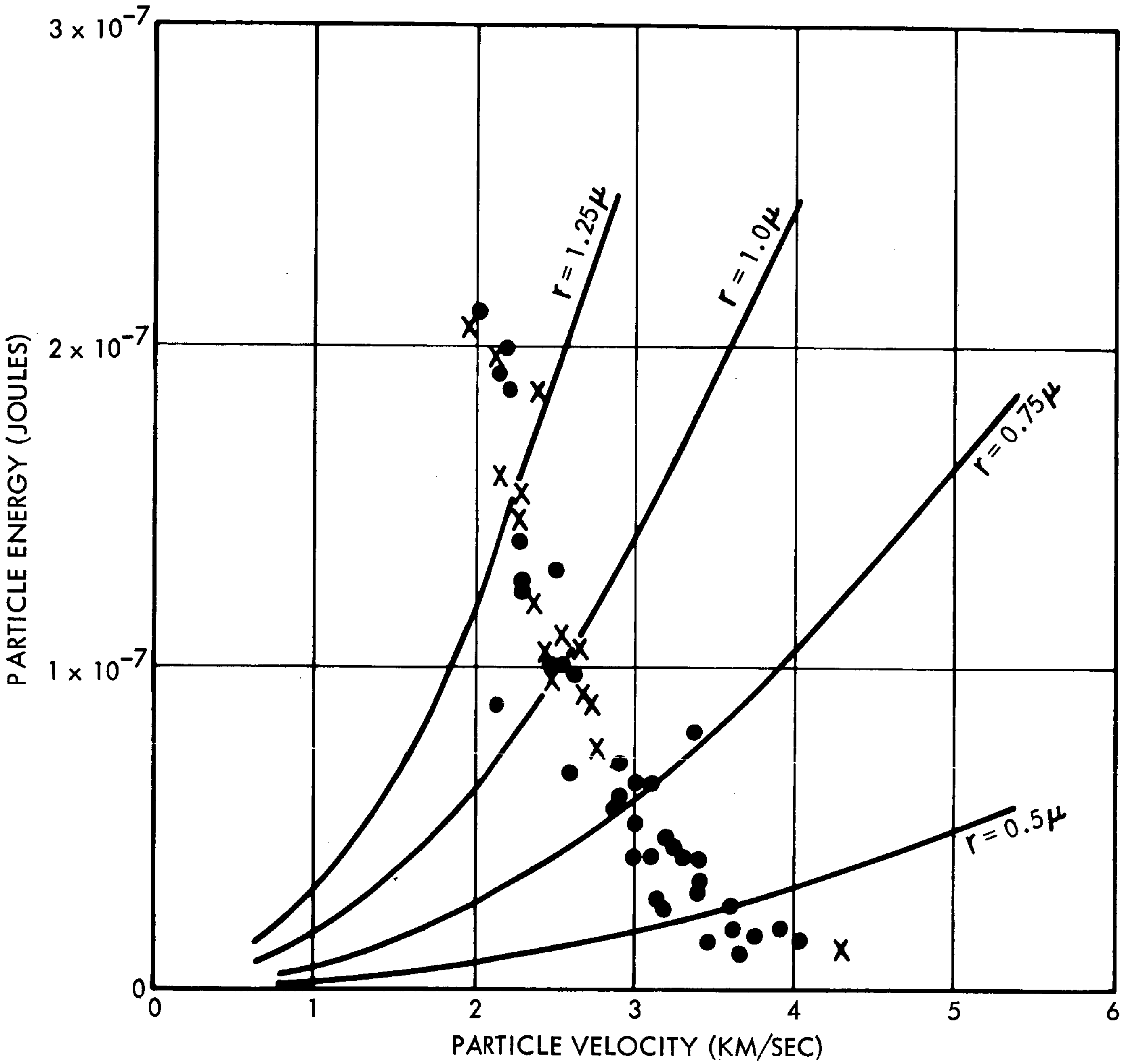
Both of the electrodes were made of polished stainless steel. The ground plane was in the form of truncated cylinder about 3.8 cm in diameter. The high voltage electrode was machined to a Rogowski[8]


HIGH
VOLTAGE
ELECTRODE
DEFINING
APERTURE
PARTICLE
BEAM
GROUND
PLANE
PARTICLE
DETECTORS

surface having a flat center portion of about 1 cm diameter and an overall diameter of 2.5 cm. The gap between electrodes was adjustable over a relatively wide range as was the voltage applied to the electrode. However, no voltages exceeding positive or negative 30 kilovolts were used.

The electric field lines at the impact point are somewhat distorted by the presence of the aperture in the ground plane. To reduce this, the electrodes were inclined by 45^{o} to the particle beam. The effects of distortion have not been evaluated completely, but it is assumed that the discharge occurs between the impact point and a smooth portion of the ground plane. Discharges were sensed by observing the voltage developed across a 0.1 ohm resistor interposed between the ground plane and true electrical ground.

Results obtained under typical conditions are shown in Fig. 2. The x's denote the parameters of particles which initiated discharge while the points represent particles that did not. For the case illustrated, a 15 kv positive voltage was applied to the electrode and the gap was 0.5 mm. The probability of discharge is evidently much greater for particles with energies and radii in excess of about 0.8×10^{-7} joules and 0.9 microns, respectively. The relatively sharp threshold between discharge and no discharge is exhibited for all voltages and fields used. This defines a lower limit in particle energy (or size) below which discharge is not initiated. No upper limits were observed. Thus Slivkov's prediction of particle size limits is only partially verified by these experiments. However, the requirement imposed by Slivkov that the particle possesses enough kinetic energy to vaporize its own mass is an oversimplification of the case. Partial vaporization of a large particle would release more gas than complete vaporization of a small one. The fraction of particle material vaporized is a strong function of velocity, but Slivkov does not consider this aspect. A revision of Slivkov's criteria to include


3 x 10^-7
2 x 10^-7
1 x 10^-7
0
PARTICLE ENERGY (JOULES)
0
1
2
3
4
5
6
PARTICLE VELOCITY (KM/SEC)
r = 1.25μ
r = 1.0μ
r = 0.75μ
r = 0.5μ

velocity effects may be in order.

The thresholds in particle energy and size required to initiate breakdown shift with voltage and electric field. Smaller, less energetic particles are capable of initiating discharges for higher voltages and fields. Insufficient data are available to define the voltage and field dependence but it appears that the electric field is a more critical factor. This again is in general agreement with Slivkov. He implies that charge multiplication with the expanding gas cloud is dependent upon the potential difference across the cloud. For a cloud with dimensions smaller than the gap spacing, the total voltage across the cloud is determined by the voltage gradient.

The parameters of particles charged and accelerated under conditions suggested by Cranberg and Slivkov can be computed and compared to the parameters of particles used here. Assuming spherical iron particles, a charging mechanism similar to that described in Ref. 7, and conditions identical to those used in obtaining the results given in Fig. 2, a 30 micron radius particle would be required to attain the threshold energy shown in Fig. 2. This is obviously too large to be compatible with the Cranberg-Slivkov formulation. However, the particle impact hypothesis is not directly applicable at the voltages and fields used here. It is interesting to note that the estimate in particle size is compatible with the experimental observations of Rozanova.

A definite dependence on the polarity of the applied voltage was observed. Significantly less energetic particles are required to initiate discharge when the particle impacts on the cathode. For example, virtually all of the particles shown in Fig. 2 would have initiated discharge if the polarity had been reversed.

In summary, the experiments described above provide quantitative information on the particle initiated voltage breakdown hypothesis. The existence of a low energy limit for particles capable of initiating discharge has been verified and measured.

A definite polarity dependence was noted and the effects of applied voltage and electric field were observed qualitatively. Although the validity of the Cranberg hypothesis cannot be verified directly by these experiments, extension of the measurements to higher voltages and fields would enable one to define the parameters of particles required to initiate breakdown under conditions where the particle impact hypothesis is presumed to be valid. Evaluation of particle formation mechanisms in light of these results could be instrumental in testing the validity of the Cranberg breakdown hypothesis.

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