561156
28p

21p

NASA TECHNICAL NOTE

NASA TN D-2091

NASA TN D-2091

N63 20609

CODE-1

IONIZATION ASSOCIATED WITH HYPERVELOCITY IMPACT

by J. F. Friichtenicht and J. C. Slattery

Prepared under Contract No. NASw-561 *by*
SPACE TECHNOLOGY LABORATORIES, INC.
Redondo Beach, California
for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D.C. • AUGUST 1963

22

TECHNICAL NOTE D-2091

IONIZATION ASSOCIATED WITH HYPERVELOCITY IMPACT

By J. F. Friichtenicht and J. C. Slattery

Prepared under Contract No. NASw-561 by
SPACE TECHNOLOGY LABORATORIES, INC.
Redondo Beach, California

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

IONIZATION ASSOCIATED WITH HYPERVELOCITY IMPACT

ABSTRACT

Interest in the development of micrometeoroid detection systems has led to a program of research at Space Technology Laboratories, Inc., where efforts have been concentrated on phenomena associated with hypervelocity impact which have properties applicable to such systems. It has been found that electrically charged particles are emitted from the site of a hypervelocity impact. Presumably, the large energy release associated with the impact is sufficient to produce ionization and the ions or electrons can be extracted by means of electrical collector systems. The quantity of charge emitted from semi-infinite targets as a function of target material, projectile material, and particle velocity and mass was measured. The experiments were conducted with micron-sized iron and carbon black (graphite) particles from the STL electrostatic hypervelocity accelerator. Data were collected for velocities up to 16 km/sec. All of the data fits the empirical relationship $Q_c = K E_p \frac{v}{A}$, where Q_c is the charge collected, K a constant, E_p the particle energy, A the atomic weight of the particle material, and v the particle velocity. The quantity K contains target material parameters and has not been evaluated, as yet. Qualitative observations of ionization produced from thin foil impacts have also been made.

IONIZATION ASSOCIATED WITH HYPERVELOCITY IMPACT

I. INTRODUCTION

An increasingly large effort has been devoted towards the direct measurement of small bodies in space in recent years. The properties of meteoroids and cosmic dust particles are interesting from both the engineering and scientific points of view, and it appears that experiments pertaining to these particles will be continued for some time to come. The experimental techniques for determining the quantity and properties of particles in interplanetary space by means of instruments aboard satellites and rocket probes and the results of some of the measurements are discussed briefly in a recent paper.[1] Although all of the data are in reasonably good agreement, it is evident that additional, more refined experiments, are required. One of the difficulties encountered in this type of experiment is the development of sensitive, reliable particle sensors.

Generally speaking, the encounter between an earth satellite and a meteoroid in space takes the form of a hypervelocity impact with the meteoroid serving as the projectile and the sensor as the target. The impact velocity may range from nearly zero up to 85 km/sec depending upon the relative orbits of the satellite and the meteoroid. The size range of the particles is also extremely large, although the frequency of occurrence increases with decreasing size. The smallest of them may be only a micron or so in size. Thus, the problem of assessing the characteristics of interplanetary dust can be described as the remote analysis of a hypervelocity impact of a projectile of unknown mass, velocity, composition, and direction, and whose velocity may be such that

---

[1] W. M. Alexander, C. W. McCracken, L. Secretan, and O. E. Berg, "Review of Direct Measurements on Interplanetary Dust from Satellites and Probes", oral paper presented to the COSPAR Meeting, May, 1962.

the impact mechanism is not adequately understood. Considering these complexities, the good agreement of the existing data is all the more remarkable.

Most of the experiments have utilized a crystal transducer type sensor. The assumption is made that the magnitude of the electrical signal resulting from meteoritic impact is proportional to the momentum of the meteoroid. If an average velocity is assumed, the mass distribution of particles can be obtained from this instrument. It is clear from the nature of these assumptions that the development of more sophisticated sensor elements would be desirable. Consequently, Space Technology Laboratories, Inc., has been involved in a research program on those properties of hypervelocity impact which might serve as a basis for meteoroid detection systems. The program has been sponsored by the NASA, under Contract Nos. NASw-269 and NASw-561. One of the properties under study has been the emission of charged particles associated with hypervelocity impact.

We have concluded that some of the atoms near the impact site of a high speed particle are ionized by the large energy release associated with the impact. The emitted charge (either positive or negative) can be collected by means of electrically biased collectors and the resulting signal may be used in various types of meteoroid detectors. The quantity of charge emitted depends upon particle velocity and mass, and upon characteristics of the materials in question. An experimental study of this effect was undertaken and results of these experiments are described below.

II. GENERAL EXPERIMENTAL TECHNIQUES

The STL electrostatic hypervelocity projector was used as a source of high speed particles for all of the work described in the following paragraphs. The operation and properties of this accelerator have been described in the literature[2] and need not be discussed here.

The electrostatic method of accelerating particles is generally restricted to particles with dimensions the order of microns or smaller. Carbonyl iron and carbon black (graphite) particles were used in these experiments. The iron particles were quite spherical while the carbon particles were somewhat more irregular in shape. The average size of the iron particles was about 1.5 microns diameter while the average carbon black particle had a corresponding dimension of about 0.6 micron. Particle velocities ranged from 1.5 to 16 km/sec depending upon particle material and size. The upper part of the velocity spectrum was obtained with the carbon particles while the iron particles were restricted to velocities of 10 km/sec and less. The velocity and mass of each particle were measured prior to impact by techniques described elsewhere[3]. The size of the particles was then computed from the known mass and density. For the iron particles, the radius can be computed exactly. For the slightly irregular carbon particles we defined an effective radius, r, as the cube root of the quantity $\frac{3m}{4\pi\rho}$, where m is the mass and ρ the density.

For the experiments where the resulting signal was electrical in nature, the signal was displayed on one trace of a Tektronix Model 551 dual-beam oscilloscope while the signal from the particle velocity detector was displayed on the other trace. The signals were photographed with a Polaroid camera for later analysis. Time-of-flight techniques were used to correlate the observed event with the particle producing the event in order to eliminate spurious measurements.

---

[2] J. F. Friichtenicht, "Two-Million-Volt Electrostatic Accelerator for Hypervelocity Research", Rev. of Sci. Inst., Vol. 33, 209 (1962).

[3] H. Shelton, C. D. Hendricks, Jr. and R. F. Wuerker, "Electrostatic Acceleration of Microparticles to Hypervelocities", J. Appl. Phys., Vol. 31, 1243 (1960).

III. IMPACT IONIZATION FROM THICK TARGETS

A. Experimental Procedures

The geometrical configuration of the detector and collector system used in examining charge emission from thick targets is illustrated in Figure 1. Particles from the accelerator pass along the axis of a velocity-charge detector, pass through a grid structure, and impact upon the surface of the target sample at normal incidence. For all of the measurements discussed here, the target was biased 300 volts negative with respect to the grounded grid. With this bias, negative charge produced at the target surface is repelled from the collector while positive charge is retained. The quantity of charge retained by the target is determined from the relationship $q_c = C V$, where C is the electrical capacitance of the collector and V is the amplitude of the induced voltage signal. The RC time constant of the collector system was made long compared to the signal duration so that the signal is proportional to charge as opposed to current flow. We had previously determined that the quantity of collected charge was nearly independent of the polarity and magnitude of the bias voltage for biases exceeding a few tens of volts. For this work, the choice of bias voltage and polarity was made arbitrarily and it is assumed that corresponding results would be obtained with different choices.

Figure 2 is a tracing of a typical photographic record of an event. In this case, a copper target sample was used. The particle detector signal is displayed on the lower trace while the collector charge signal appears on the upper trace. Since the impacting particle is charged, a voltage signal is induced on the collector independently of that produced by subsequent charge emission. This effect accounts for the structure on the upper trace. The particle charge produces the first step in the signal

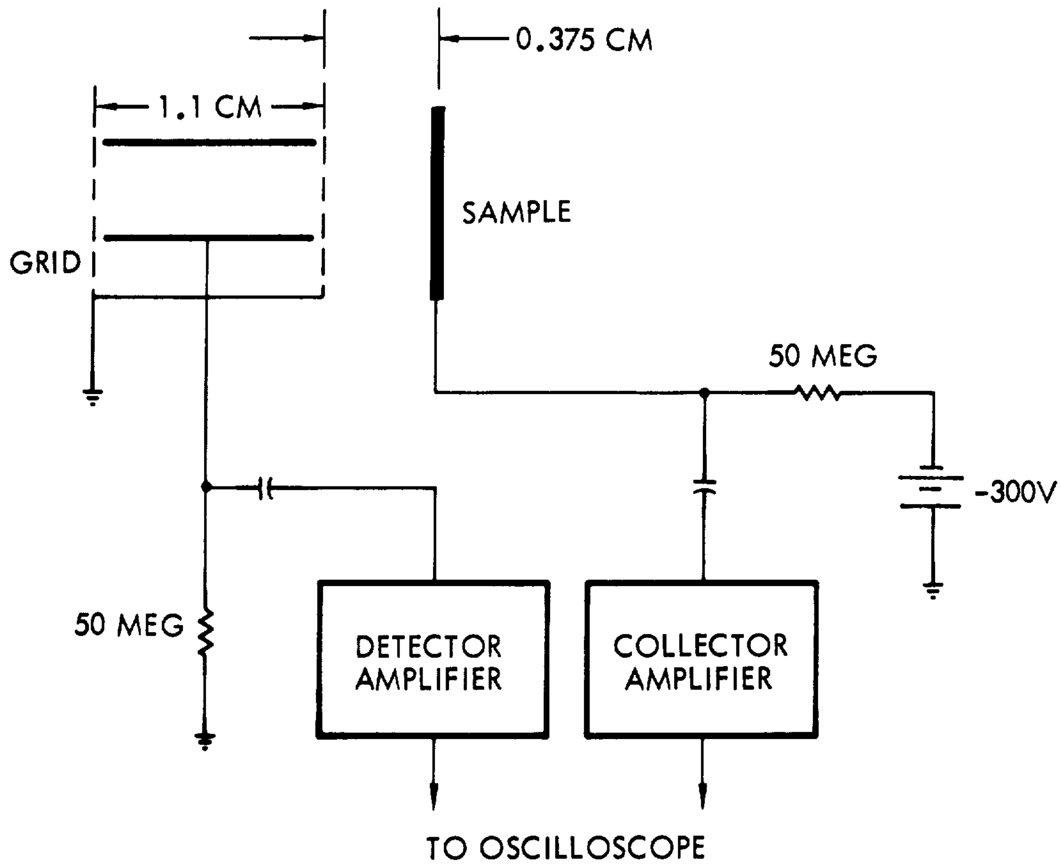


Figure 1. Experimental arrangement for the measurement of impact ionization from thick target impacts.

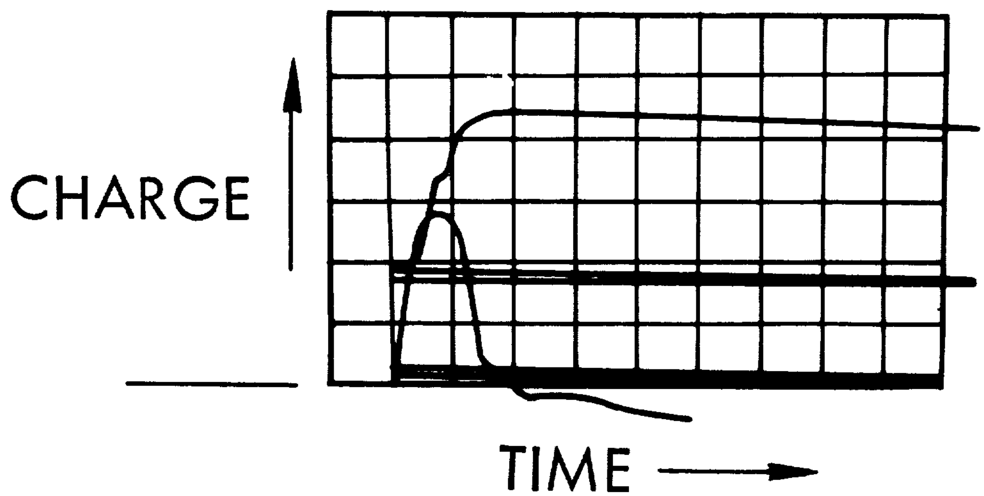


Figure 2. Tracing of an oscillograph obtained from the thick target measurements

while the charge emission effect accounts for the remainder. The total charge emitted is obtained by subtracting the particle charge from the total signal. In cases where the signal from the particle charge was small compared to the total, the particle charge was determined from the particle detector.

B. Velocity Dependence of Impact Charge Emission

Since few theoretical guidelines were available to assist us in interpretation of the experiments, the data were compared on a more or less empirical basis*.

For the purposes of discussion, assume that the amount of charge liberated upon impact is proportional to the kinetic energy of the particle. Further, assume that the energy term is modified by a velocity dependent function which takes into account threshold effects and variations of cratering mechanisms with velocity, i.e., $Q_c \propto E_p\, f(v)$. This is equivalent to

$$\frac{Q_c}{m} = K_1\, v^2\, f(v) \qquad (1)$$

where m is the particle mass and K_1 is a constant of proportionality.

To evaluate f(v), the quantity, Q_c/r^3, (which is equivalent to Q_c/m for a given particle material) was plotted as a function of particle velocity for all of the particle-target combinations used. Figures 3 and 4 show these plots for iron particles impinging on targets of tantalum and indium respectively, while Figure 5 shows data for carbon particles on a tungsten target. Generally speaking, these data exhibit little scatter and the

*The format of the succeeding sections is primarily chronological in nature. The data are presented in this way to illustrate the evolution of the final result.

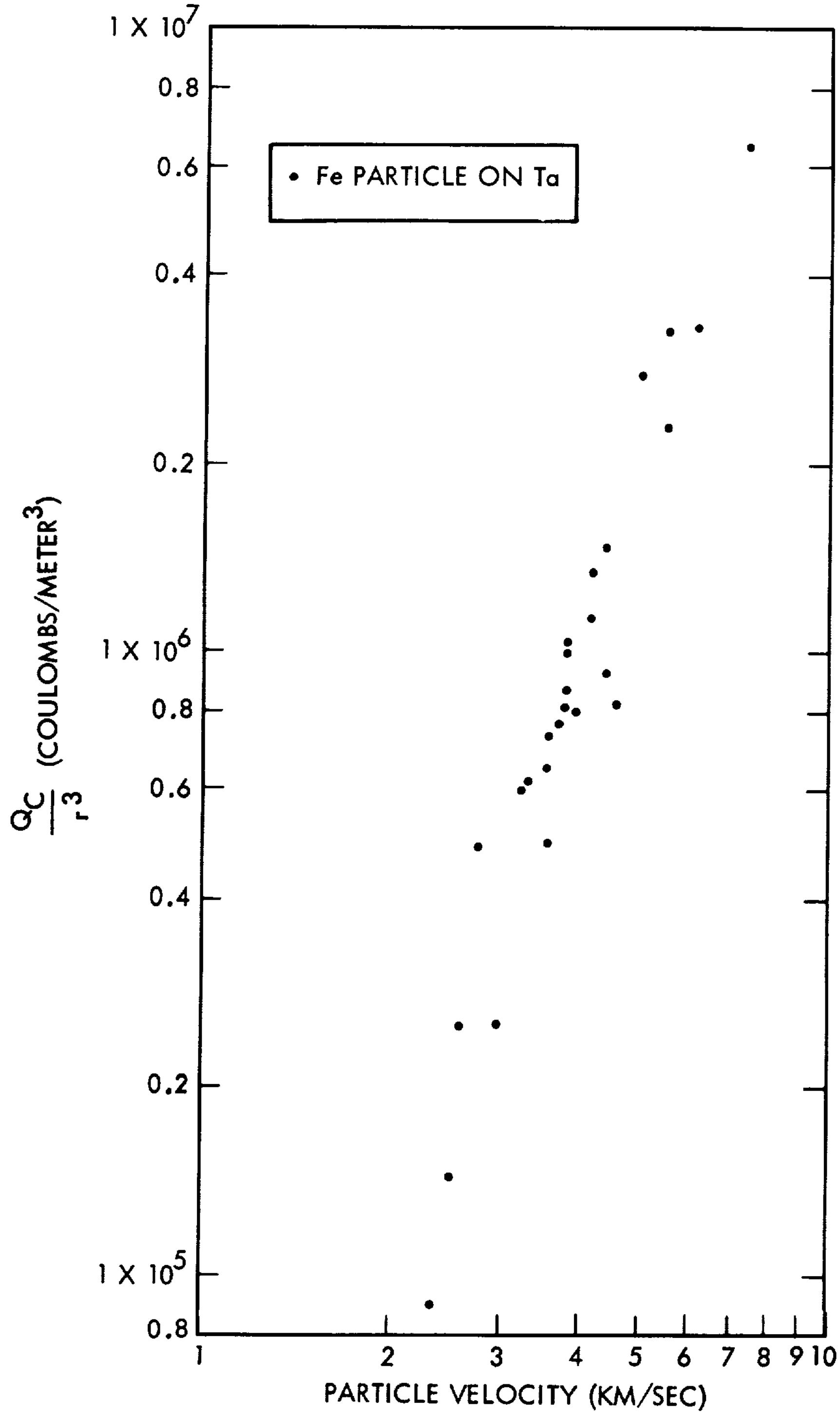


Figure 3. Charge collected normalized to r^3 plotted as a function of particle velocity for iron particle impacts on a thick tantalum target.

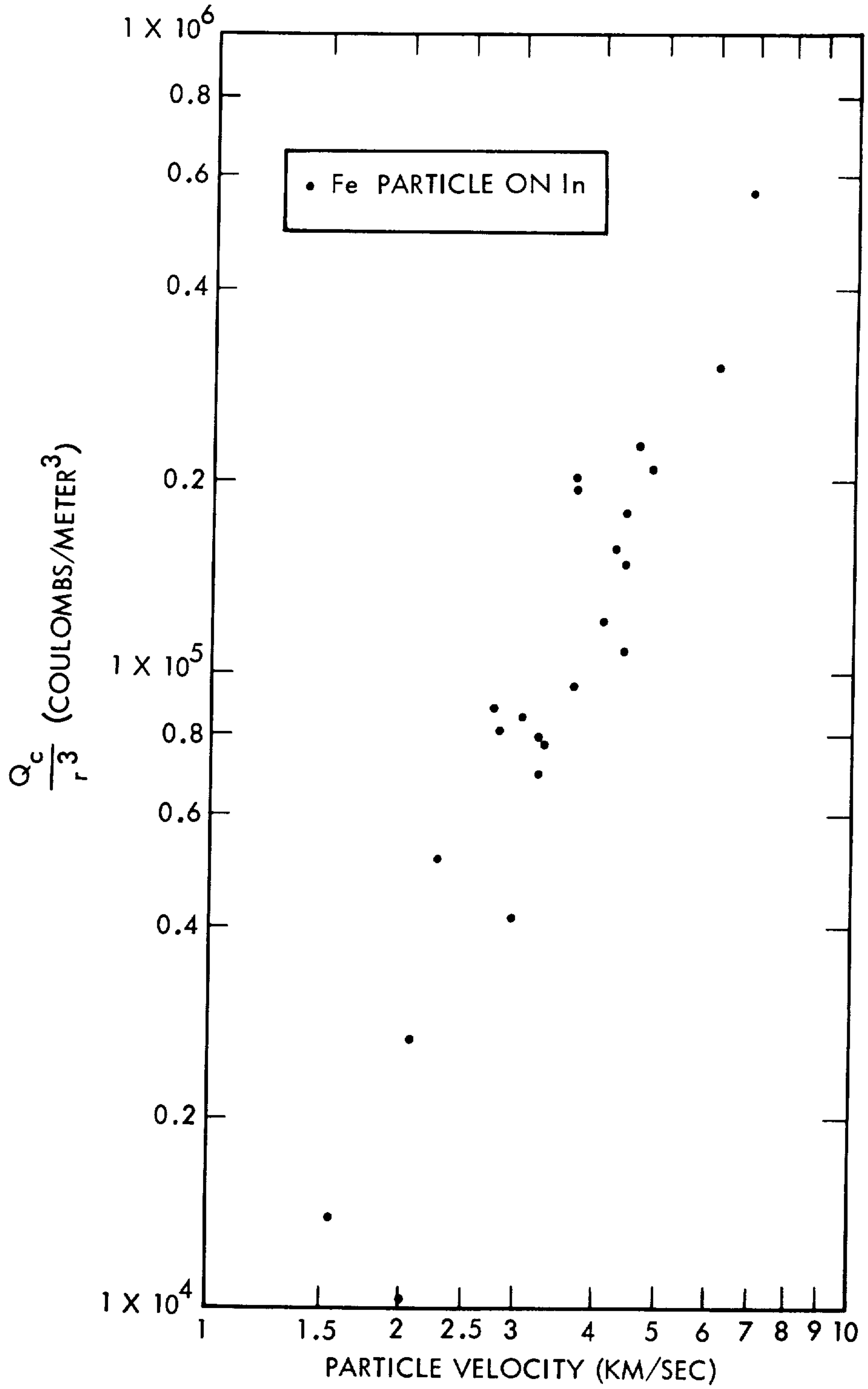


Figure 4. Charge collected normalized to r^3 plotted as a function of particle velocity for iron particle impacts on a thick indium target.

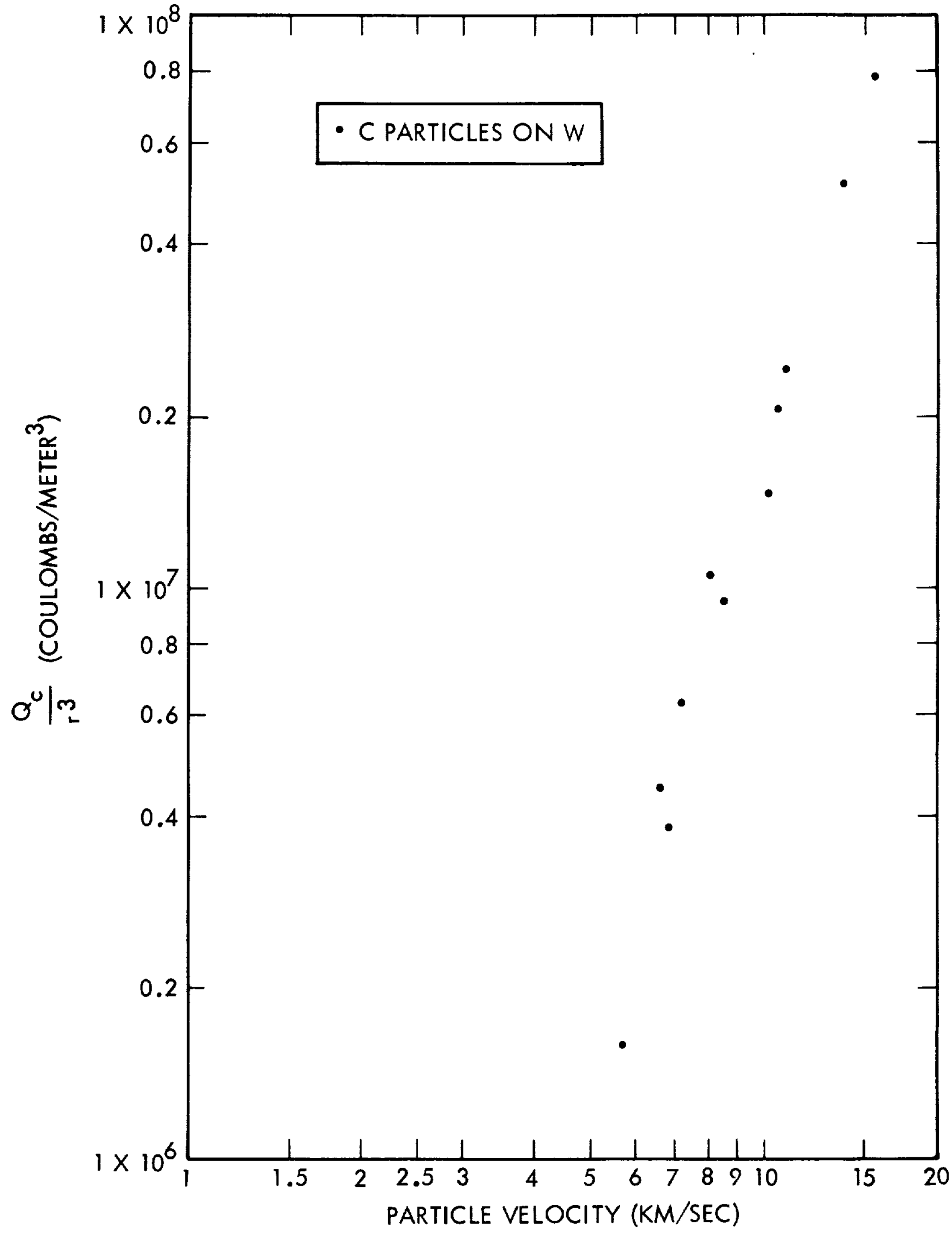


Figure 5. Charge collected normalized to r^3 plotted as a function of particle velocity for carbon particle impacts on a thick tungsten target.

data points tend to lie along straight lines on the logarithmic presentation. The slope of the lines, drawn by eye through the data points, is about three for all of the material and particle combinations used. This implies that $f(v) \approx v$. Consequently, we can write

$$Q_c = K_1 \, m \, v^3 \tag{2}$$

It should be emphasized that this is an empirical relationship and is valid only for the conditions described above. It can readily be seen, for example, that the expression is invalid for massive particles at very low velocities since charge emission does not occur under those circumstances. Yet, Equation (2) predicts a charge emission proportional to m.

C. Target Material Dependence

For a given particle mass and impact velocity, the quantity of charge emitted is dependent upon the target material. This is illustrated in Figure 6 where smoothed curves are plotted for each of the target materials. These data were obtained with iron particles. It can be seen that the materials examined fall into two distinct categories. More charge is emitted from the Ta, W, and Pt targets than from targets of Cu, Be-Cu, In, and Pb. With the possible exception of lead, all of the targets exhibit identical results.

It is almost certain that the quantity of charge emitted is a function of more than one characteristic of the target material. Because of the complexity of the problem, no attempt has been made to explain the material dependence. However, certain characteristics of the materials exhibit a similar grouping. For example, Ta, W, and Pt all have higher melting and vaporization temperatures than the others. Also these same materials are

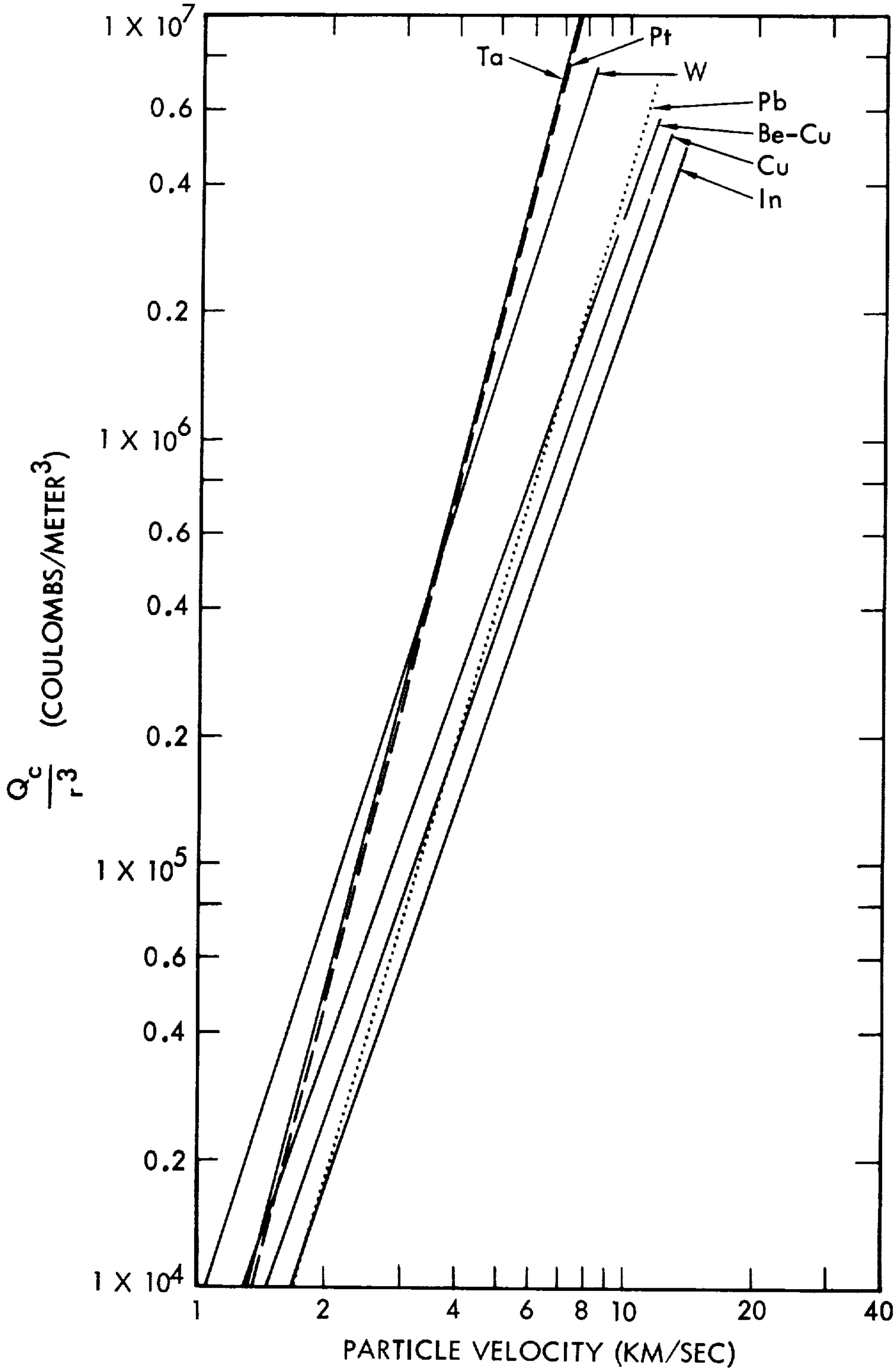


Figure 6. Q/r^3 vs. v for iron particle impacts on several target materials.

classified as good thermionic emitters while the others are not. Perhaps the most significant property of all (based on the discussion of the next section) is that of resistance to hypervelocity penetration. The craters produced in Pb, In, Cu, and Be-Cu, are generally larger than those in Ta, Pt, and W.

D. Particle Material Dependence

As mentioned earlier, both iron and carbon particles were used in these experiments. The relationship given by Equation (2) appears to fit the experimental results for both kinds of particles separately, but does not yield consistent results for both kinds of particles impacting on identical targets. When normalized to particle mass, the amount of charge produced by carbon particles was greater than that produced by iron particles at a given impact velocity. In order to explain this difference, one must invoke a mechanism for the charge production process. Initially, the assumption was made that the charge produced at the impact site was strongly dependent upon the energy per unit mass imparted to the target material. The quantity of charge collected would depend upon the extraction mechanism. For example, the charge could be dependent upon either the surface area or the volume of the emitting material. Application of several combinations of hypervelocity penetration formulae and assumed extraction mechanisms failed to provide the desired agreement. All of these hypotheses assume that the bulk of charge results from ionization of atoms of the target material. Failure to achieve correlation in this manner led to the development of the model discussed below.

Let us assume that most of the charge results from ionization of atoms of the impacting particle. The number of atoms ionized depends upon the number available, the energy required for ionization, and the energy available for ionization. The kinetic energy of the particle is dissipated in several ways and the relative amount available for ionization is impossible to predict on the basis of existing knowledge on hypervelocity impact. Therefore, let us again adopt the empirical approach. Rather than normalizing the charge to the particle mass, let us normalize it to the number of atoms in the particle. This quantity, Q_c/N is plotted as a function of velocity for iron and carbon particle impacts on a tungsten target in Figure 7 and for a lead target in Figure 8. Since N is proportional to m, the same v^3 dependence is obtained. However, the agreement between the results of using iron and carbon particles is much better in this case. Normalization to the number of atoms is equivalent to the following expression:

$$Q_c = K_2 \frac{N_o}{A} m v^3 \tag{3}$$

where N_o is Avogadros number, A the molecular weight of the particle atoms, and K_2 a constant of proportionality. Equation (3) can be rewritten in the form

$$Q_c = K E_p \frac{v}{A} . \tag{4}$$

From this we see that Q_c depends upon the kinetic energy of the particle and upon a quantity which can be interpreted as a factor which determines the fractional part of the energy which is available for ionization. The role of the target in this interpretation is simply that of resisting penetration by the particle. The higher the resistance, the larger is the fraction of energy which goes into ionization.

The problem resulting from empirical data analysis is that one has difficulty in attaching physical significance to the

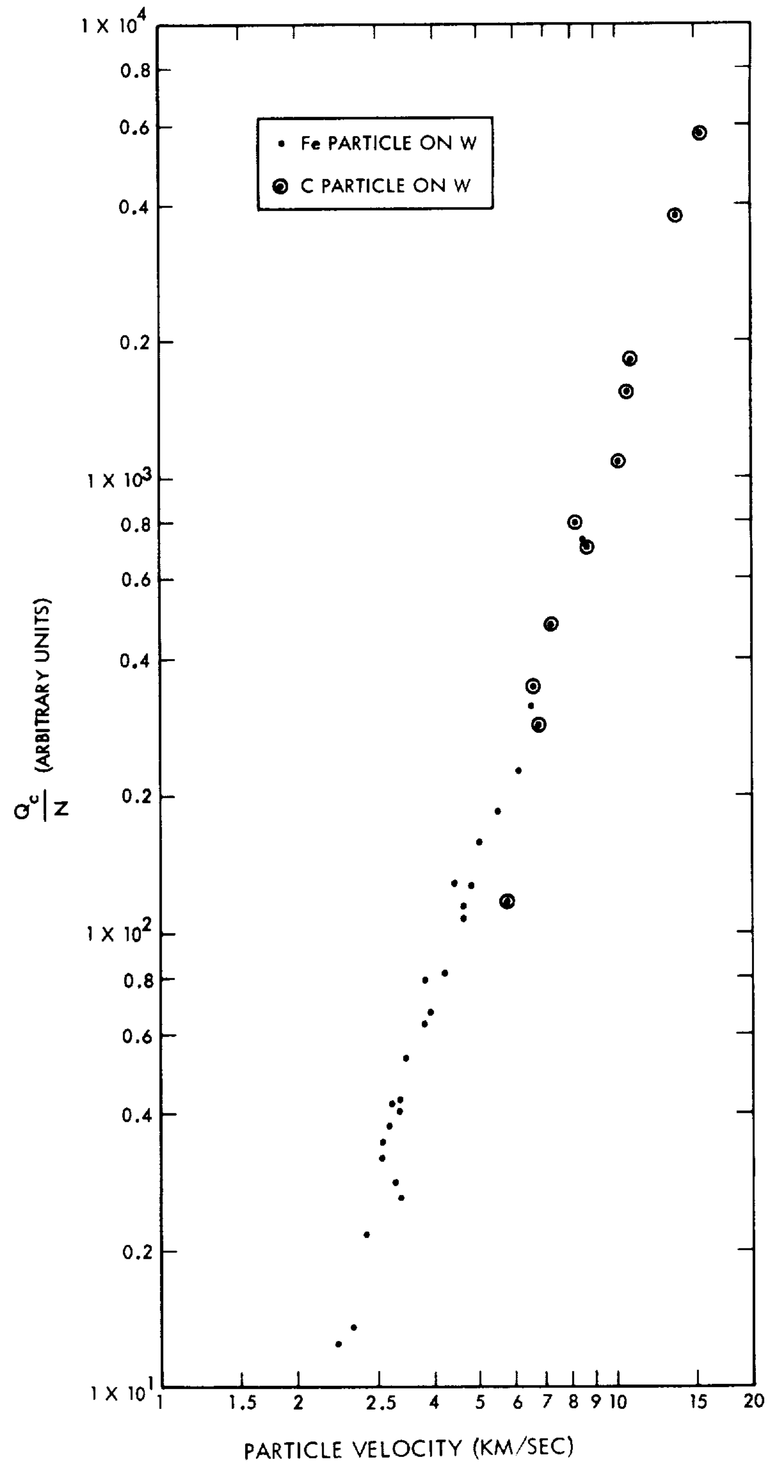


Figure 7. Charge collected normalized to the number of atoms in the particle as a function of velocity for carbon and iron particle impacts on a tungsten target.

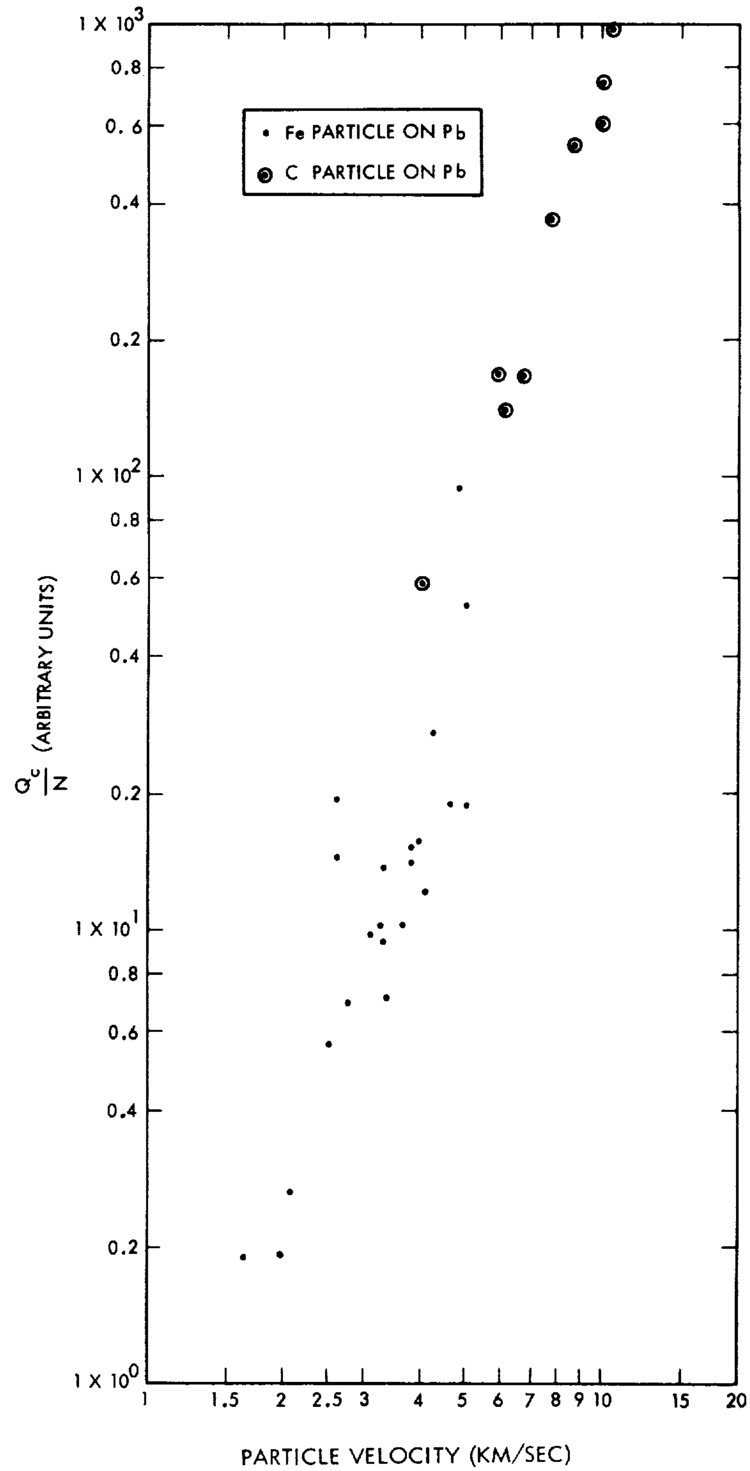


Figure 8. Charge collected normalized to the number of atoms in the particle as a function of velocity for carbon and iron particle impacts on a lead target.

results. The choice of $\frac{v}{A}$ as a multiplying factor is strictly empirical and we cannot justify it from a physical point of view. Despite these drawbacks, one must have a framework within which to work and the approach used in the preceding section provides such a framework. Additional experiments should be helpful in developing physical concepts to describe the charge emission phenomenon.

IV. IMPACT IONIZATION FROM THIN TARGETS

Ionization produced by particle impacts on thin foils has also been the subject of experimental investigation. The observations have been more qualitative in nature than thick target measurements because of the increased complexity. A brief discussion of the more interesting observations is given in the following paragraphs.

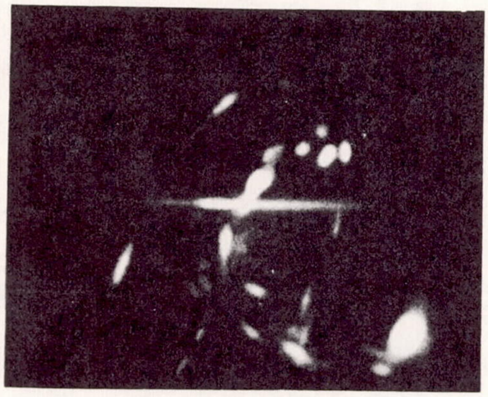
We have found that electrical charge is produced by a high speed particle impact on a thin foil. The charge can be collected by means of various types of electrically biased collectors placed on the "downstream" side of the foil. Generally, we find that the charge collected is greater in magnitude than would be predicted on the basis of thick target measurements. One possible explanation of the the results (suggested by O. E. Berg from NASA) is that "spray" particles from the foil interact with the surface of collectors. Each spray particle would produce charge upon impact in a manner analogous to that described in Section III.

Since the velocity and size distribution of spray particles is dependent upon the nature of the impact, qualitative analysis is difficult. The nature of the impact depends upon particle velocity and the thickness of the foil relative to the size of the particle. We have observed at least three types of impacts, namely: (1) those where the energy loss is small and the particle passes through the foil intact; (2) those where particle break-up occurs; and (3) those where the particle appears to be completely vaporized. A recently developed technique has enabled us to photograph these events. The foil is placed in the high pressure region (pressure the order of a few mm Hg) of a differential pumping system. Debris from a high speed impact interacts with the gas leaving trails which can be photographed with the aid of a sensitive image intensifier tube. Typical photographs are shown in Figure 9. Figure 9-a shows a particle which passes through the foil with only a slight brightening of its trail. The fragmentation of a particle is illustrated in Figure 9-b. In this case, large discrete trails are left by the fragments. Complete vaporization of a particle is shown in Figure 9-c. These are unretouched photographs and the consistent pattern on the photographs is the result of a low-level image intensifier background which is repetitive from photograph to photograph.

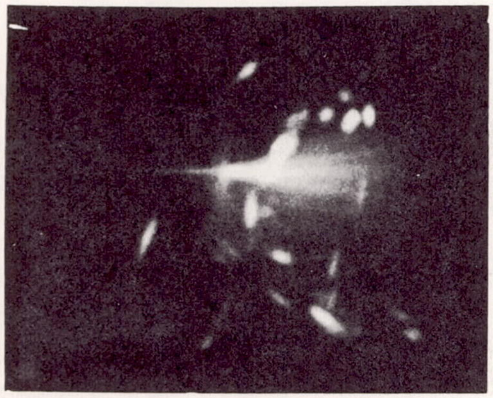
V. SUMMARY

Preliminary experiments on the impact ionization effect have been described along with an empirical analysis of the results. Clearly, more definitive measurements are required to adequately assess the impact ionization effect. A continuing program of research may answer some of the questions raised by the results of experiments described above. The authors wish to express their appreciation to Mr. N. L. Roy for his invaluable assistance in the acquisition of the data described in this report.

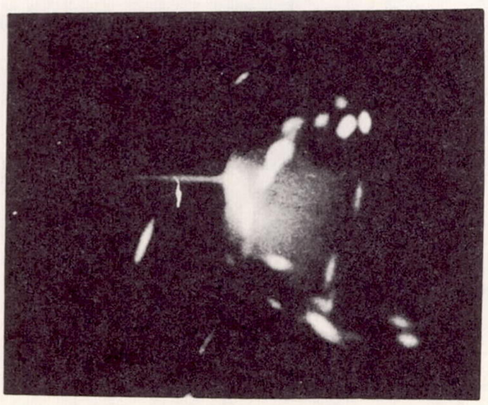
Space Technology Laboratories, Inc.
Redondo Beach, California
March 1963



a



b



c

Figure 9. Photographs of particle impacts on an 800 Å thick gold foil in a low pressure oxygen atmosphere.