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ELECTROSTATIC ACCELERATION SYSTEM FOR HYPERVELOCITY MICROPARTICLES WITH SELECTED KINEMATIC PROPERTIES

by Anthony R. Lewis and Robert A. Walter

Electronics Research Center
Cambridge, Mass. 02139

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16. Abstract

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SUMMARY

Charged carbonyl iron microparticles (0.02 to 1.0 μm diameter) were accelerated electrostatically to velocities up to 25 km/s using a 150-kV accelerator. Measurements of the particle velocity as a function of size are given. Charge densities higher than previously predicted were observed; these are ascribed to surface irregularities of the charging needle which produced unusually high electric fields. Systems for selecting and measuring the velocity and mass of the particles as well as for automatic data handling were developed.

INTRODUCTION

Carbonyl iron spherules (0.02 to 1.0 μm diameter) have been accelerated electrostatically to velocities up to 25 km/s using a 150-kV machine which had been converted to a microparticle accelerator. Based upon previous work performed by ourselves (ref. 1) and others (refs. 2,3) using van de Graaff accelerators, an upper limit of approximately 16 km/s was expected. The observed upper limit of the velocity range of the microparticles, 25 km/s, was found to be considerably greater than predicted. These results indicate that the entire range of natural meteroid velocities (10 to 70 km/s) can be simulated using accelerators with potentials no greater than 2 MV. If potentials greater than 2 MV are used, more massive particles can be accelerated to these velocities.

APPARATUS

Accelerator

A 150-kV accelerator, originally designed for ion acceleration, was converted to a microparticle accelerator. The charging head, obtained commercially from TRW, uses a needle (radius of curvature ~ 10 µm) at a high potential (~ +14 kV) to charge the microparticles. These are then electrostatically accelerated into a drift tube (Figure 1) where selection and measurement of the particle mass and velocity are performed.

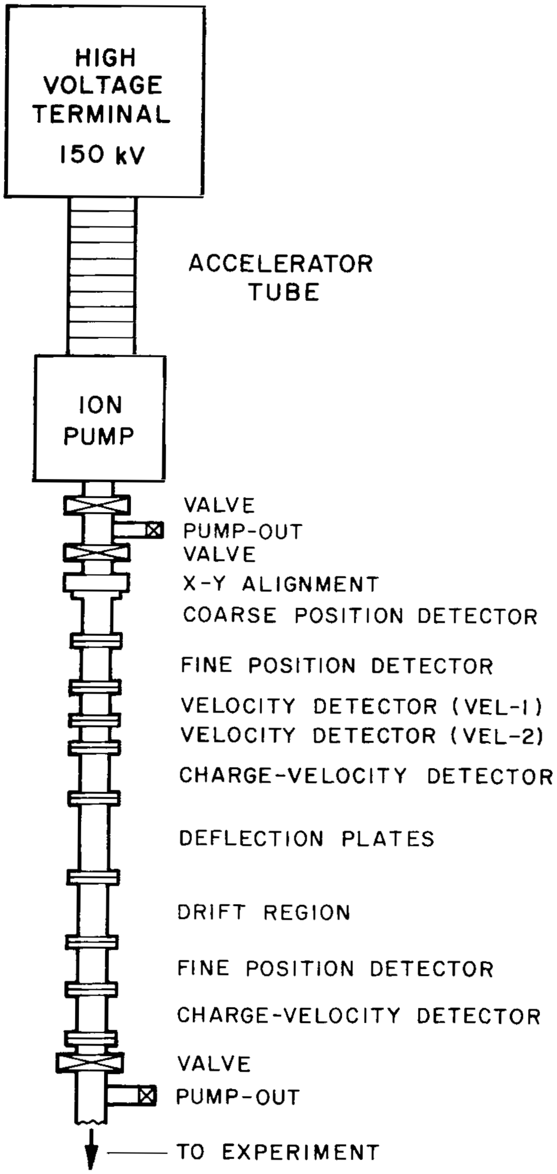

Figure 1.- 150-kV microparticle accelerator and particle detectors

Mass-Velocity Selection System

We have developed a mass-velocity selection system utilizing capacitive charged-particle detectors and standard electronic pulse equipment (Figure 2), which enables the kinematic parameters of the particle to be preselected and which effectively filters out much of the electronic noise in the detectors.

A particle passing through the first velocity detector induces a pulse on the capacitive unit. This pulse is amplified and routed to the "start" input of the time-to-pulse-height converter (TPHC). The particle then passes through the second velocity detector and induces a pulse which is amplified and sent to the "stop" input of the TPHC. The TPHC output is a pulse whose amplitude is proportional to the time of flight of the particle between the two velocity detectors. The TPHC output goes to a single-channel analyzer which is set to select the velocity range. If the TPHC output falls within the preselected range the single-channel analyzer turns on a time-delay generator. This time-delay generator grounds the high-voltage (10 kV) deflection plates at the proper time to allow only those particles with the desired velocities to pass through. In addition, the time-delay generator is used to trigger the oscilloscope sweep when the particle is expected to be in the charge-velocity detector.

For particle-mass selection, both charge and velocity must be selected. The mass is then given by

$$m = \frac{2qV}{v^2} \tag{1}$$

where q is the charge on the particle, v its velocity, and V the accelerating potential.

The amplitude of the output pulse from the capacitive detectors in the system is proportional to the charge on the particle inducing the pulse. This pulse is amplified and sent to a single-channel analyzer which is used to select a charge "window." The output of this single-channel analyzer, with suitable delay, serves as one input to a coincidence circuit. The other input to the coincidence circuit is taken from the single-channel analyzer following the TPHC in the velocity-selection section of the apparatus. Use of the coincidence unit assures that the signals from the velocity and charge selection channels originate from the same particle. The output of the coincidence circuit is used to ground the high voltage deflection plates to allow particles of

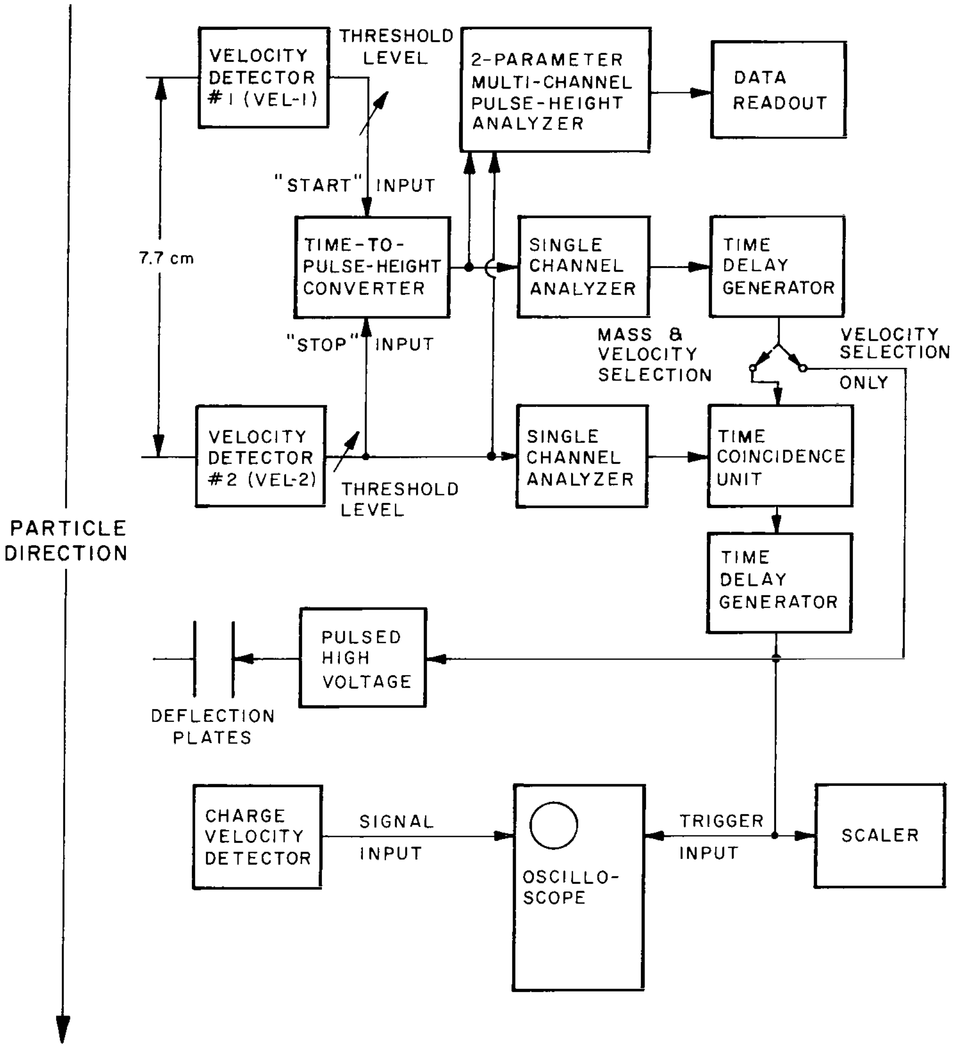

Figure 2.- Mass-velocity selection system

the proper mass and velocity to pass through.

The velocity may be determined either from the time between the beginning of the oscilloscope trace and the leading edge of the pulse (which is a measure of the time of flight between the second velocity detector and the charge-velocity detector) or by the width of the pulse (which is the transit time of the particle in the charge-velocity detector). Measurements have been made in both ways and, in all cases, agree within the limits of the accuracy of the measurements. A typical output pulse from a large slow moving (6.47 km/s) particle is shown in Figure 3; one for a small fast particle (21.2 km/s) is shown in Figure 4. The systematic errors in velocity measurement are less than 3 percent; errors in charge measurement are due mainly to calibration uncertainties and amount to 10 percent. The resultant uncertainty in the calculated particle mass and radius is 20 and 6 percent, respectively.

Automatic Data Handling System

The fact that the velocity and charge (i.e., mass) are a function of pulse amplitude allows the use of a data handling system utilizing a multiparameter pulse height analyzer (MPPHA). This system records all charge and velocity data in a form convenient for display, readout, and calculation. The velocity pulse serves as an input for the X-axis of the MPPHA and the charge pulse is sent into the y-input. Time coincidence is demanded of these two inputs to insure that the velocity and charge pulses originated from the same particle. Figure 5 shows the oscilloscope output of the MPPHA where the x-axis is 1/v, the y-axis q, and the z-axis the number of events. This system allows velocity measurements with an accuracy of 1.25 percent for a 5 km/s particle to 5 percent for a 25 km/s particle.

PERFORMANCE

Velocity

A plot of the velocity as a function of particle radius for carbonyl iron spherules is shown in Figure 6. The expected curve based upon the charging-head manufacturer's specification is shown for comparison. The velocities are higher than predicted; this is ascribed to the charging mechanism discussed below.

Surface Charging

The measured charge density as a function of particle radius is presented in Figure 7. It exceeds the value of 0.88 x 10^{-2} C/m^2

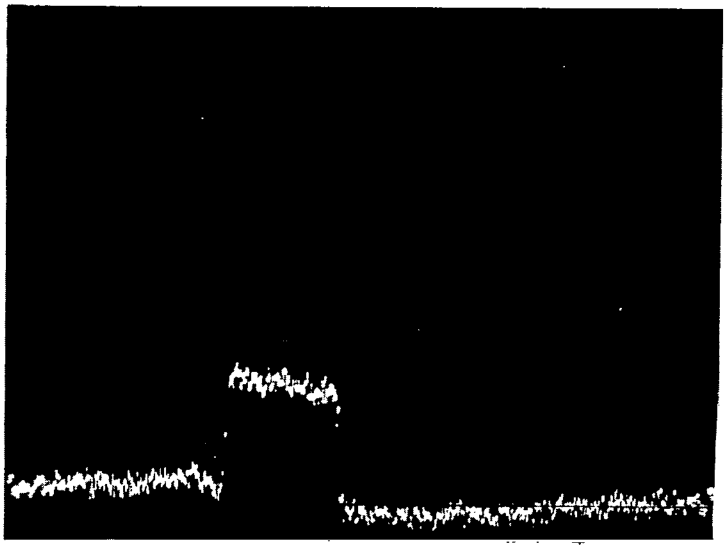

Figure 3.- Charge-velocity output signal for 6.47 km/s particle

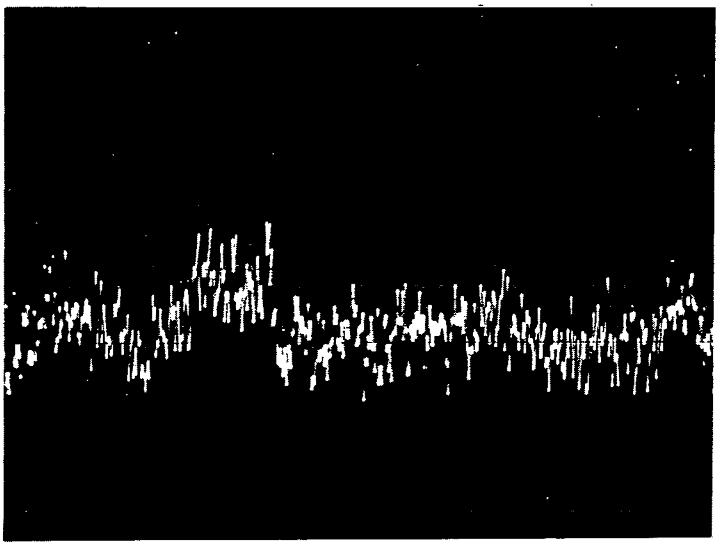

Figure 4.- Charge-velocity output signal for 21.2 km/s particle

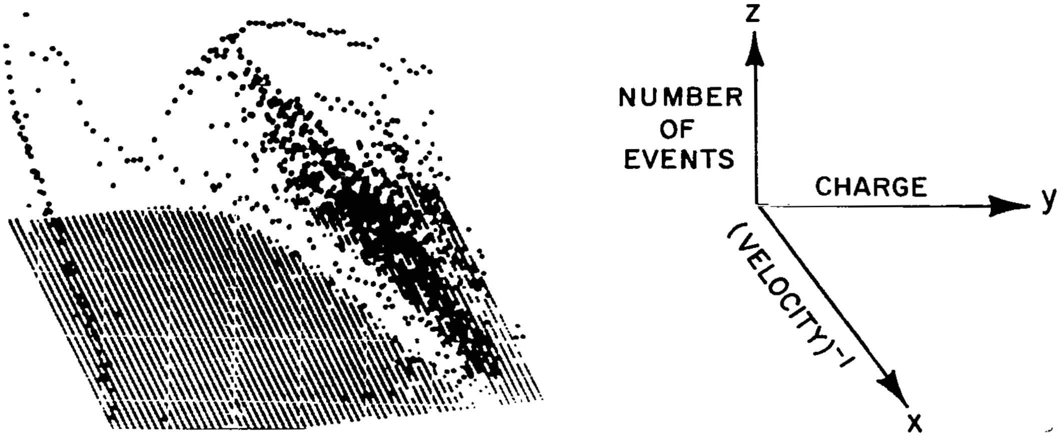

Figure 5.- Output of multiparameter pulse-height analyzer showing charge-velocity spectrum

specified for the particle radii 0.01 to 10 μm. Examination of the charging needle showed localized surface irregularities which enhance the electric field considerably above the value specified. A large particle ($\gtrsim$1 μm) effectively integrates these local fields and is subjected to the average field which would maintain in the absence of irregularities. However, particles whose dimensions are of the order of those of the irregularities will receive a higher charge density than the average.

Noise

The high-velocity particles reported here may not have been observed by previous investigators owing to a combination of two factors both involving the charge of these particles.

First, the high velocity particles are small (< 0.1 μ) and have a higher charge density than the slower, larger particles as shown in Figure 7, where the charge density is plotted as a function of particle size. Since it had not been originally assumed that large and small particles would have different charge densitities, no reported systematic search for particles with the charges and sizes reported in this paper has been made.

Second, although the small high velocity particles have a large charge density, they also have a very small surface area which results in their having a small total charge. The high velocity particles, therefore, induce smaller signals in the capacitive units used for in-flight detection of these particles. The small signals may easily be swamped by the electronic noise from

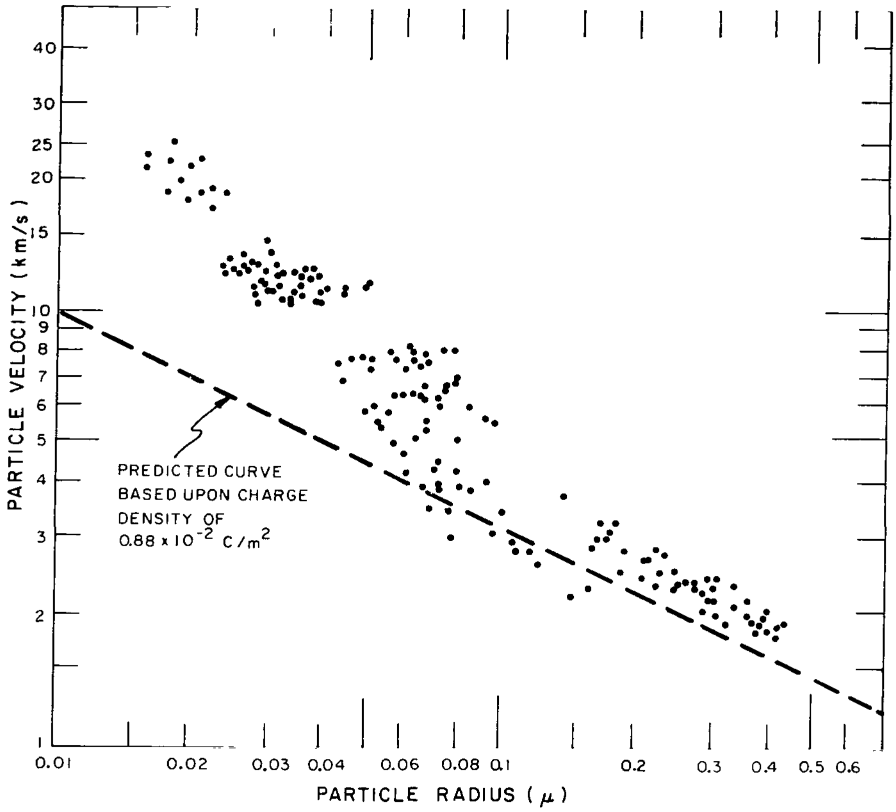

Figure 6.- Microparticle velocity as a function of size (150 kV accelerating potential)

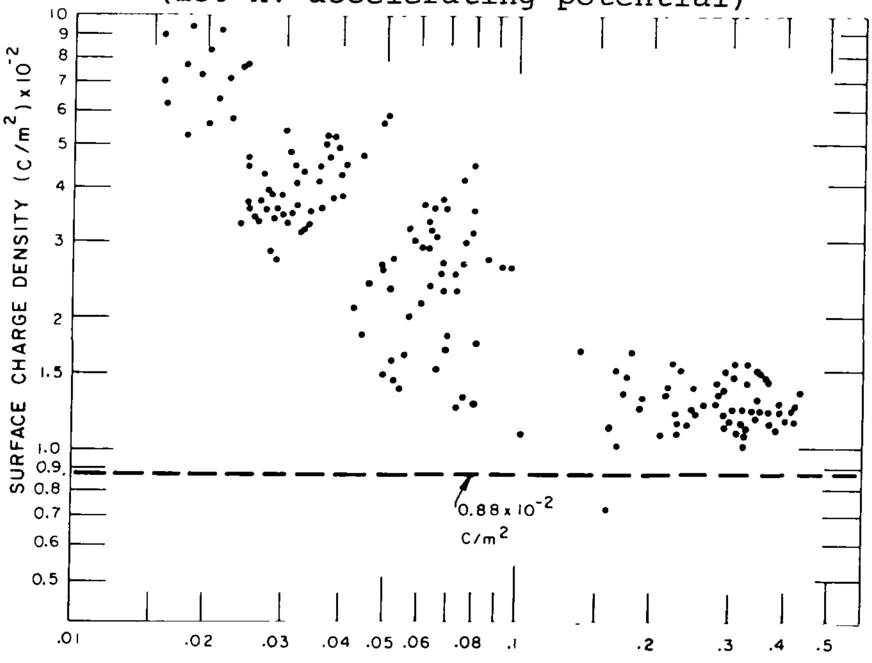

Figure 7.- Microparticle charge density as a function of size

the capacitive units, the amplifiers, and other sources.

The amplitude of the noise from the capacitive detectors, without the selection system being used, is equivalent to a charge of approximately 10^{-15} C. However, using the velocity-selection system we have been able to observe signals equivalent to a few times 10^{-16} C. It should be noted that the signal in these detectors cannot be characterized by its amplitude alone. We must, rather, take into account the total information of the signal – in this case, the frequencies and time-correlations of the signal vis-a-vis the noise. The noise from the detectors consists primarily of two components, 60 Hz pickup from the environment and a high frequency component due primarily to amplifier noise. Between the output of the velocity detectors and the TPHC inputs we have inserted amplifiers to operate as threshold setting devices which will only pass the signal if it has a certain amplitude. This amplitude is set so that it is just above most of the noise. A small signal riding on this noise will then be above the threshold if it does not occur at a time when the 60 Hz component is at its low point (in such a case this particle would be deflected as if it were not in the proper velocity range since the sum of signal and noise would be below the threshold). The signal passes through the threshold device to the "start" input of the TPHC. If a similar event occurs at the second velocity detector, a signal is sent to the "stop" input of the TPHC. If the particle is not in the preselected velocity range, the deflecting plates are not pulsed off and this particle never appears in the charge-velocity detector to add its noise (i.e., undesired signal) to the total there. If the particle lies in the proper range of velocities, it induces a signal in the charge-velocity detector. As mentioned above, the oscilloscope sweep is triggered only when a particle of the proper velocity is known to be passing through the detector. A signal such as shown in Figures 3 or 4 is obtained. Much of the 60 Hz noise component is capacitively filtered out by the amplifiers used in this system.

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