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A PRELIMINARY TYPE OF DUST ACCELERATOR FOR HIGH VELOCITY IMPACT STUDY

BY

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ABSTRACT

A preliminary type of dust accelerator was constructed for high velocity impact studies. The fine metallic particles of micron size charged through electrostatic induction were accelerated electrostatically up to about 1 km/s. The impact sites on aluminium targets were observed by a stereoscan electronmicroscope. Ordinary elastic impact events and high velocity impact events with crater formation were recognized. Non metallic particles such as carborandom were also accelerated by this device.

1. Introduction

High velocity impact phenomena between solid objects are interesting in connection with the recent solid state research in the solar system. It is proposed that in the protosolar system the planets were formed after the sticking or fragmentation processes of the high velocity mutual impacts among small solid particle swarms.

In the present solar system we find many small celestial bodies such as asteroids, comets, meteorites and dust particles, however there have been known a few facts concernning their origin, growth and destruction. Especially we have much less information on the orbital elements and the influx rate of dust particles. The dust detection tecnique, which make use of the high velocity impact phenomena, have not been well established.

The rocks and fines returned from the moon in the Apollo projects showed various microcraters on their surfaces.[1)] If the microcraters produced by the impacts of dust particles, the precise observations of these will give some clues about the accretional process or impact history on the moon.

In order to study the high velocity impact phenomena in the laboratory the accelerator for fine solid particles of micron size is needed. The apparatus for the purpose of these laboratory experiments was first designed and constructed by Shelton,[2)] and then many improvements have been made.[3),4)] As the attainable velocity has been increased, the structure of the device becomes so complicated that the whole size of the apparatus becomes larger and more expensive. In order to study the fundamental feature of high velocity impact phenomena and also to develop new type of dust detectors, however, we think an apparatus, which is simple in principle, small in size, easy to handle and less expensive, is valuable.

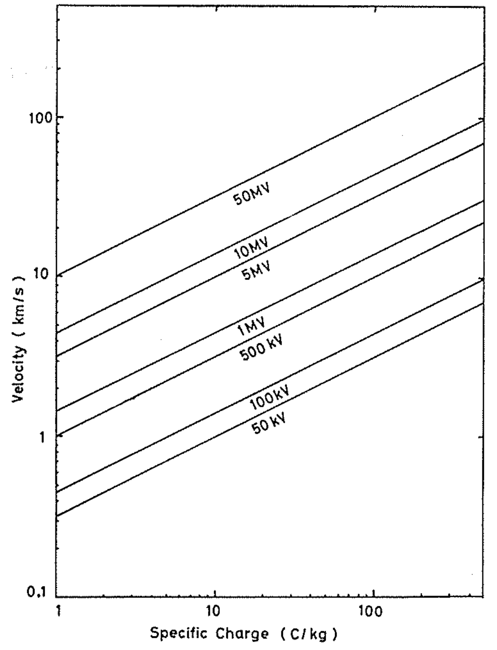

Fig. 1. Particle velocity as a function of charge. Parameters express the accelerating voltage.

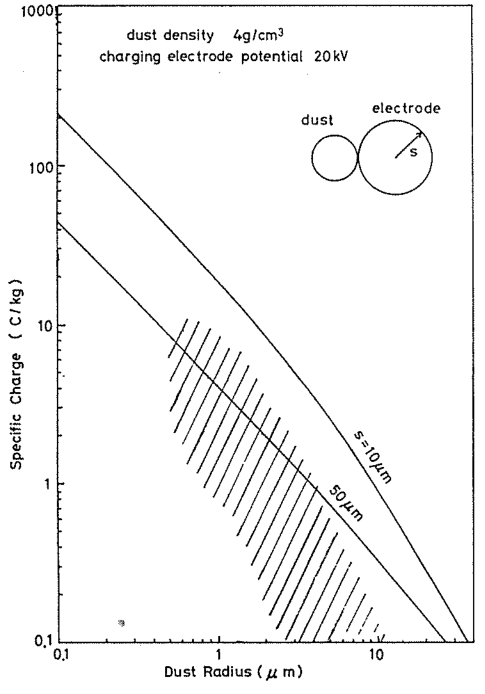

Fig. 2. Specific charge as a function of dust radius. Parameters denote charging electrode radius. Observed region is shaded.

2. Principle of acceleration

Artificial fine particles charged through the contact with a high voltage electrode are accelerated in the high voltage electric field. When the particle with mass m and charge q is accelerated with electric potential E, the attainable particle velocity is given by

$$v=\sqrt{2qE/m}\ .$$

In order to obtain a high velocity particle, (1) high specific charge q/m and (2) high accelerating voltage E are needed. In Fig. 1 the relation between velocity v and specific charge q/m is shown. The charge of the fine particle will be suppressed by the field emission from its surface. The field emission of ions starts at stronger electric field than that of electrons, so the particles are positively charged for high q value. Next we calculate the expected value of the charge induced through the contact with a high voltage electrode. The example is shown in Fig. 2 where q/m is plotted as a function of particle radius. In the calculation both the electrode and the particle are assumed to be spherical. From Fig. 2 a spherical particle of radius 1 μm and density 4 g/cm^3 charged on a spherical electrode of radius 10 μm and charging voltage 20 kV is expected to have a specific charge q/m=18 C/kg and to be accelerated up to 1.8 km/s by the accelerating voltage E=100 kV. If E=10 MV and dust radius is 0.1 μm, the attainable particle velocity will be about 65 km/s, which is nearly equal to the maximum velocity of interplanetary dust particles relative to the earth.

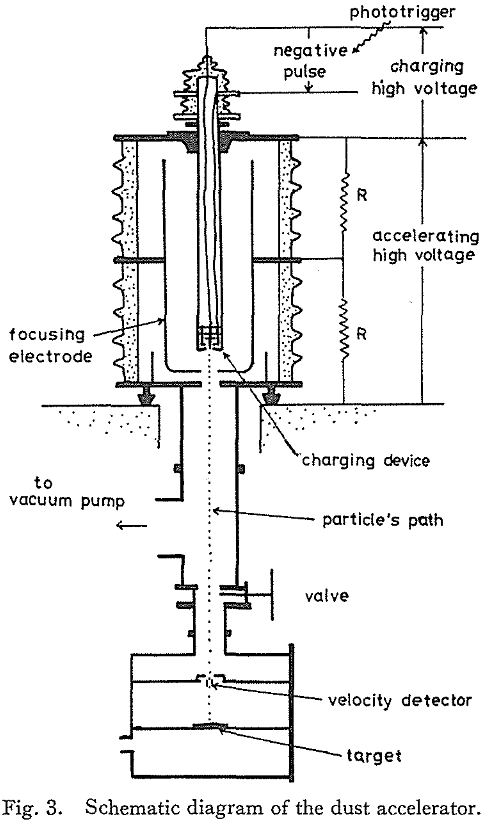

Fig. 3. Schematic diagram of the dust accelerator.

3. Design of the dust accelerator

3.1 Charging and accelerating devices

Whole device is shown in Fig. 3. The apparatus is evacuated to 10^{-5} Torr. The charged fine particles are accelerated downward through the accelerating gaps. The charging device is placed at the top of the accelerator. As is shown in Fig. 4, this device is similar to that of Shelton,[2] however the geometry is modified and particles are ejected downwards. The electrode has a needle shape because of the easiness of manufacture and the protection from destruction. Fine particles are previously put in the reservoir. In the usual time the electrode and the reservoir are kept at the common voltage of 15–25 kV (relative to the accelerating terminal voltage). In acceleration a rectangular pulse of 40 msec long whose polarity is negative to the charging electrode potential is loaded. Then particles go up and down many times between the electrode disk and the reservoir and some of them are gathered and strongly charged at the tip of the needle shape of electrode, at which the electric field is extremêly strong, and then repelled out through the openning to the accelerating high voltage gaps.

3.2 Electric circuits

The block diagram of electric circuits are shown in Fig. 5. The positive high voltage

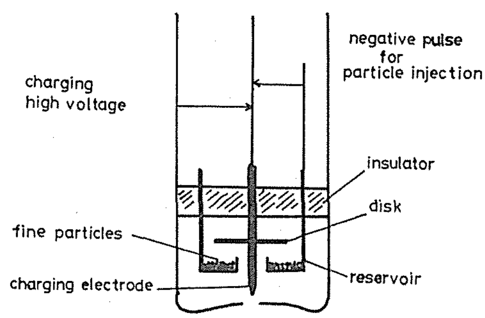

Fig. 4. Charging device.

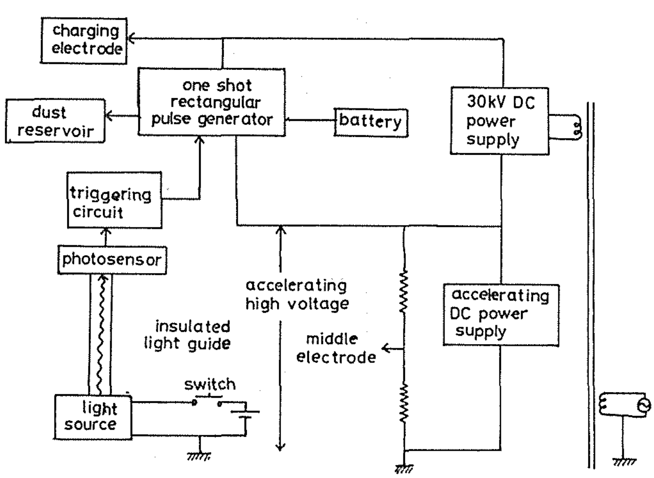

Fig. 5. Block diagram of electric circuits of the dust accelerator.

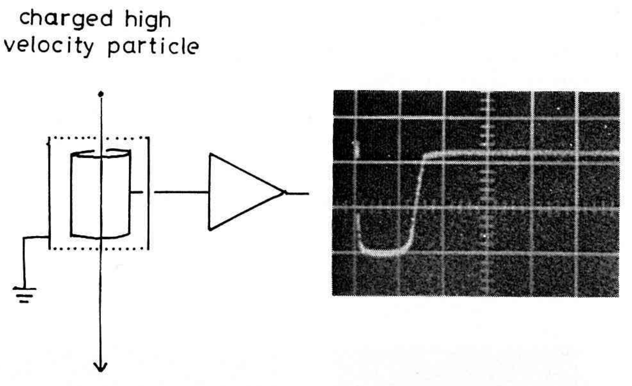

Fig. 6. Velocity detector and its typical output pulse shape.

is supplied to the first and second accelerating electrodes. As the charging device is set on the high tension side of the accelerating tube, its power is supplied from the grownded AC power supply through the transformer whose first and second coils are highly insulated. The above mentioned high voltage charging pulse is drived with the trigger pulse from the photodetector whose light source is grounded and switched on manually.

3.3 Velocity detector

The mass and velocity of the accelerated particles are determined in the following way. The accelerated particles with positive charge induce negative charge on the cylindrical detector as they pass through it. (Fig. 6) After the induced pulse is amplified by a charge sensitive preamlifier, the pulse shape is observed on a memory synchroscope. A typical pulse shape is shown in Fig. 6. The particle's charge q is determined from the pulse height divided by the feedback capacitance in the charge sensitive preamplifier and the velocity v is directly determined from the pulse width. By knowing the accelerating potential E the mass of the fine particle is evaluated. Then the particle radius was calcurated assuming the particles are spherical.

4. Acceleration test

Acceleration test were made by using bronze particles. Their form was almost spherical having a radius of 0.5–20 micron. Every particle size was uniquely determined by the procedure mentioned in the preceeding section. It was difficult to prepare the particles of equal size, so the velocity and size of the accelerated particles were different one by one. The number of particles at every one shot fluctuated, however, until now the spherical bronze particles of size 0.5–1 micron have been accelerated to about 1 km/s at the accelerating voltage 100 kV and maximum charging voltage 25 kV. (As the latter also acts as accelerating voltage, total effective accelerating voltage for charged fine particles is 125 kV.) The specific charge region obtained so far are shown by the hatched zone in Fig. 2. This is in rather good agreement with the value expected in section 1.

5. Preliminary observation of impact sites

As the preliminary observation of impact sites, fine spherical bronze particles were impacted to aluminium plate targets at normal incidence. A few examples of these impact sites are shown in Fig. 7. Figures 7 (a) and 7 (b) were photographed by a stereoscan electron microscope and figure 7 (c) by a reflecting type optical microscope. It is difficult to identify on the target plate at what velocity each impact happened, although each particle's mass and velocity were electronically detected in acceleration. In Fig. 7 (a) three basins are seen which seem to be probably made large incident particles with low velocity. Their features seem to show the elastic impact because no incident particles are left at the bottom of the basin. The events in Fig. 7 (b) and 7 (c) seem to be made by smaller particles with the velocity of higher than 1 km/s. They show the high velocity impact aspect, because the incident particles are welded at the bottom of the craters.

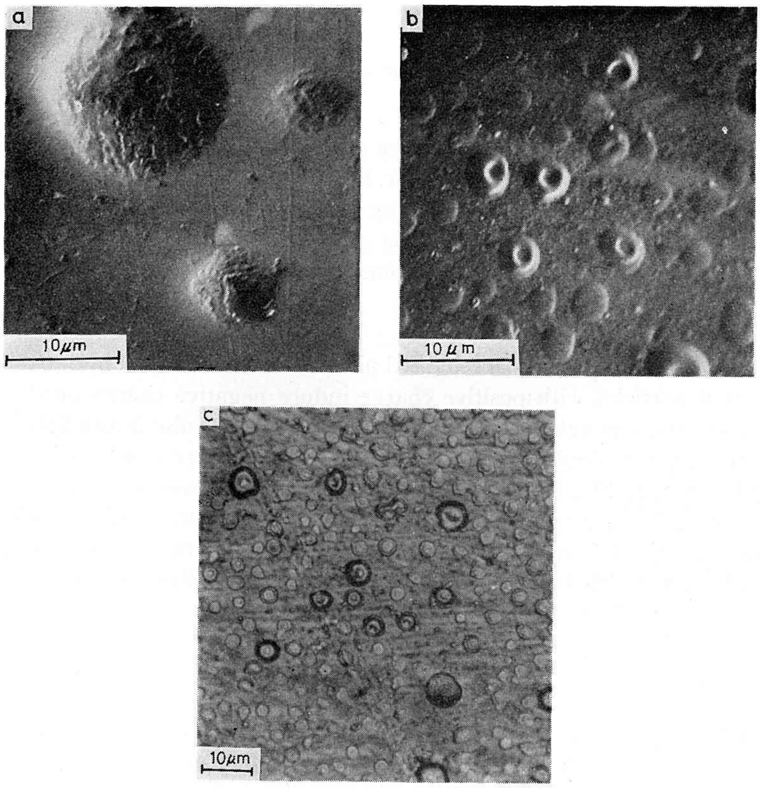

Fig. 7. Impact sites on aluminum targets produced by accelerated bronze particles. They were photographed by (a) (b) stereoscan electron microscope and (c) reflecting type of optical microscope.

6. Final remarks

Although the particle energy obtained by this preliminary type of dust accelerator is rather low, preliminary tests on various useful experiments have been made. As was mentioned in section 5, the crater formation and related high velocity impact phenomena, for example heating and welding of projectile and target materials by shock wave, seem already to be caused at the velocity of higher than 1 km/s. Studies of the impact phenomena in the transient velocity region from elastic impact to high velocity impact offer the knowledge on the sticking probability for the dust-dust collision in space. Also the test of new type of dust detectors based on high velocity impact phenomena has been performed in this velocity region. This device was first designed for the acceleration of metallic particles. However, it was found that nonmetallic particles such as carborandom are also charged and accelerated by this deivce. It is to be noted that most of the actual fine particles in space are supposed to be nonmetallic ones such as graphite flakes and silicate grains. In the experiment about 20 micron irregular shaped carborandom particles were accelerated up to a few hundred m/s. The use of smaller particles will make it possible to study the high velocity impact phenomena of nonmetallic particles.

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