

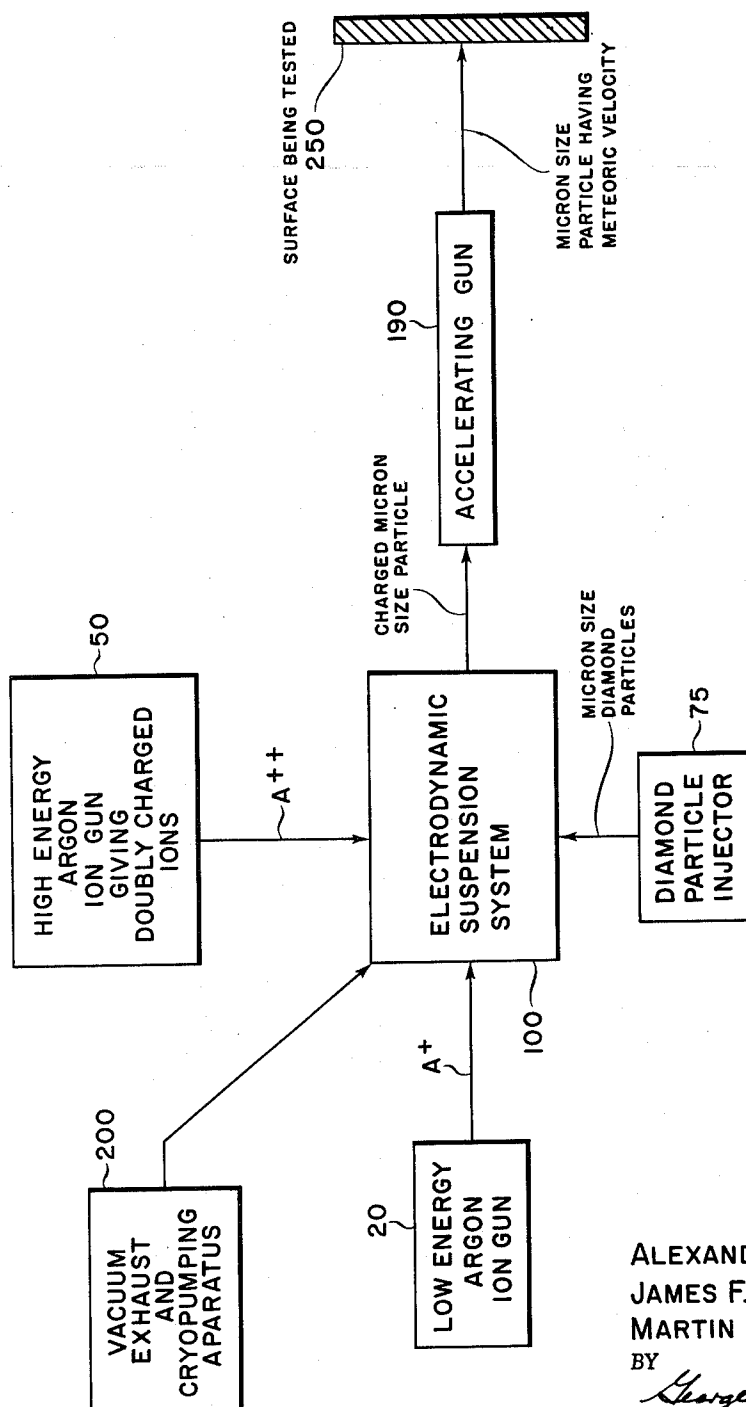
May 22, 1962

A. J. DESSLER ETAL
APPARATUS FOR ACCELERATING MICRON-SIZE
PARTICLES TO METEORIC VELOCITIES

3,036,213

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3 Sheets-Sheet 1



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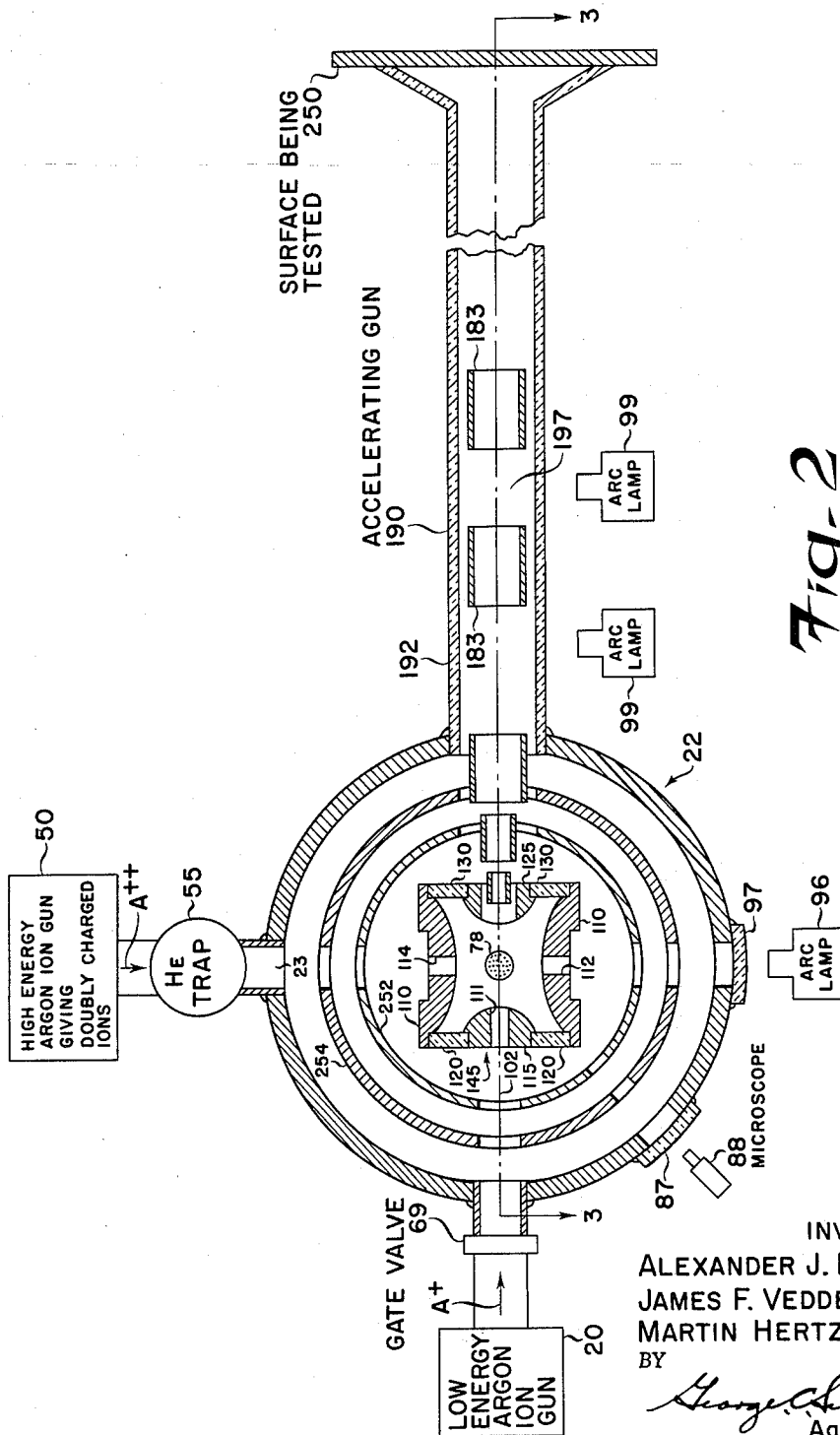


Fig. 2

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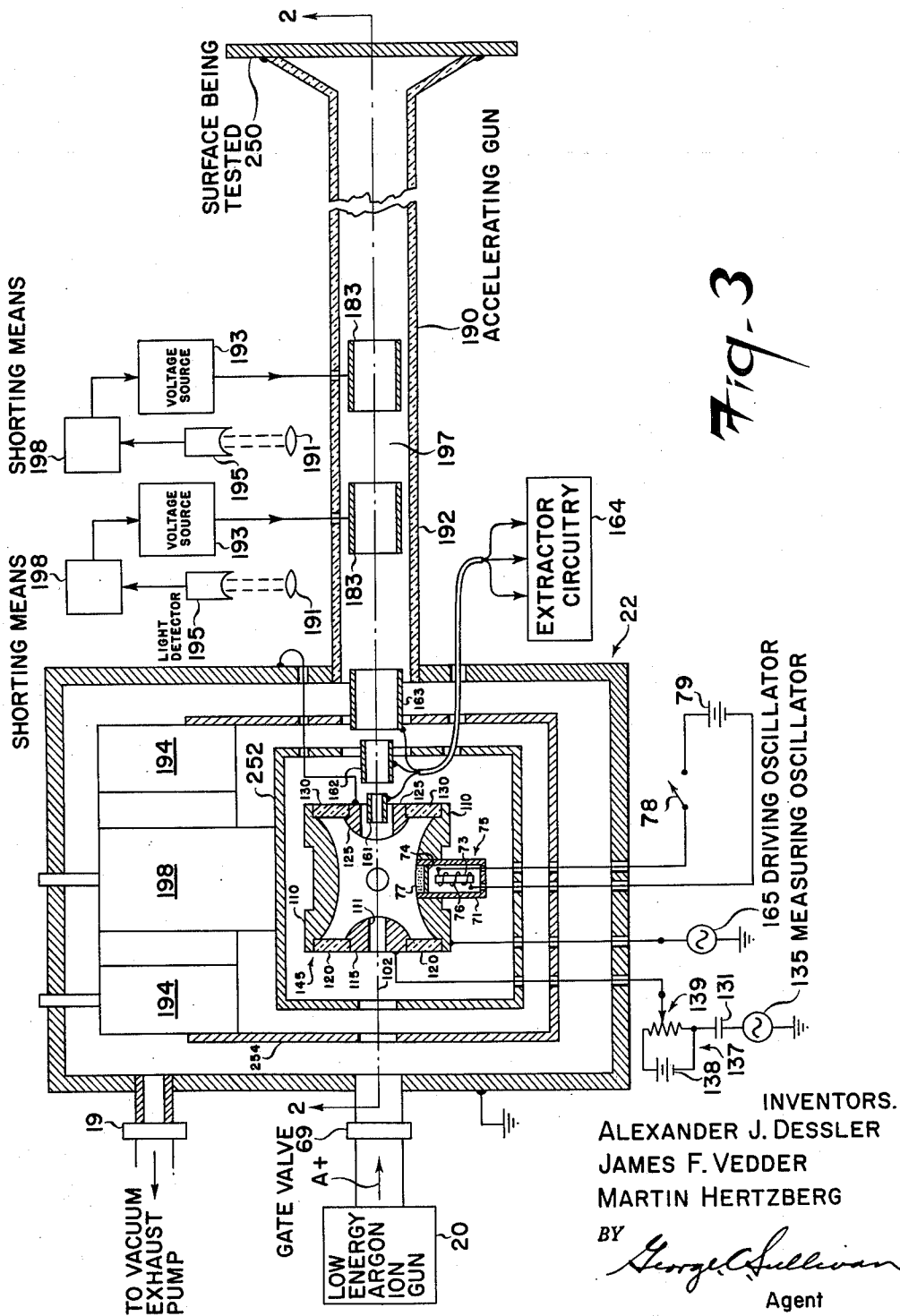
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APPARATUS FOR ACCELERATING MICRON-SIZE PARTICLES TO METEORIC VELOCITIES

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4 Claims. (Cl. 250—41.9)

This invention relates generally to particle charging and acceleration apparatus, and more particularly to apparatus for accelerating micron-size particles to meteoric velocities.

With the advent of space exploration, it has become of considerable importance to be able to determine the properties of various types of materials in a space environment. One of the characteristics of a space environment is the presence of micron-size particles traveling at meteoric velocities. These particles impact on the exterior of any vehicle traveling through space and have been found to cause erosion of the vehicle surfaces.

Since a knowledge of the effect of these meteoric particles is of considerable importance in the design of space vehicles, it would be most advantageous to be able to simulate these meteoric particles in the laboratory and examine the effects caused by their impacting with various types of materials. However, techniques have not heretofore been available for accelerating micron-size particles to meteoric velocities.

Accordingly, it is the broad object of this invention to provide methods and apparatus for accelerating micron-size particles to meteoric velocities.

A more specific object of this invention is to provide a method and apparatus for accelerating a micron-size particle to meteoric velocities by means of an electrodynamic suspension chamber where the particle is charged to a high charge-to-mass ratio, and an accelerating gun for accelerating the charged particle to meteoric velocity.

Another object of this invention is to provide an improved apparatus for charging a micron-size particle to a high charge-to-mass ratio.

In a typical embodiment of the invention, micron-size diamond particles are injected into an electrodynamic suspension chamber which is maintained at a very high vacuum by means of cryopumping apparatus operating in conjunction therewith. A single micron-size particle is retained in dynamic equilibrium in the suspension chamber and charged to a high charge-to-mass ratio by a high energy argon ion beam containing doubly charged ions. The charged micron-size diamond particle is then extracted from the suspension chamber, accelerated to meteoric velocity by means of an electric field accelerating gun, and then caused to impact upon the surface being tested. The specific nature of the invention, as well as other objects, uses and advantages thereof, will clearly appear from the following description and from the accompanying drawing in which:

FIGURE 1 is a block diagram of a system for accelerating micron-size particles to meteoric velocities, in accordance with the invention.

FIGURES 2 and 3 are respectively top and front cross-sectional and schematic views of an embodiment of apparatus for accelerating micron-size particles to meteoric velocities, in accordance with the invention. The cross-section of FIGURE 2 is taken along 2—2 of FIGURE 3 and the cross-section of FIGURE 3 is taken along 3—3 of FIGURE 2.

In general, a direct and convenient way of obtaining a high velocity particle is to place a charge on the particle and then accelerate the particle by means of electric fields. Broadly, such an accelerating technique is well known in the art and has the advantage that common

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and simple electronic circuitry can be employed to sort, deflect, focus, and measure velocity, mass or charge of the particle. Theoretically, using such an accelerating technique, a charged particle can be accelerated to as high a velocity as is desired, up to almost the speed of light, if a sufficient number of electric field acceleration operations are provided. Practical considerations, however, such as loss of charge on the particle while it is being accelerated, and the difficulty of practically providing any great number of electric field accelerating operations, have made it necessary for the particle to have a high charge-to-mass ratio if it is to be accelerated to the very high velocities in the meteoric range (11 to 72 kilometers per second). The difficulty arising with micron-size particles is that, heretofore, it has not been possible to charge such large particles to a sufficient charge-to-mass ratio to permit them to be accelerated to these meteoric velocities. This difficulty is overcome by our invention as will hereinafter become evident.

FIGURE 1 illustrates a block diagram of a basic system for accelerating micron-size particles to meteoric velocities in accordance with the invention. In FIGURE 1, a diamond particle injector 75 injects micron-size diamond particles into an electrodynamic suspension system 100 which operates in cooperation with a low energy argon ion gun 20, a high energy argon ion gun 50 producing doubly-charged ions, and vacuum exhaust and cryopumping apparatus 200 to charge one of the micron-size diamond particles to a high charge-to-mass ratio. The charged micron-size diamond particle is then fed to an accelerating gun 190 which accelerates the particle in steps up to meteoric velocity, whereupon the particle is then caused to impact upon the surface being tested 250.

An electrodynamic suspension system, as indicated at 100 in FIGURE 1, is a system which permits one or more charged particles to be held in dynamic equilibrium by alternating electric fields in the presence of an ion beam, or any other suitable beam (for example, electrons or X-rays). Such an electrodynamic suspension system is described in the article "Electrodynamic Containment of Charged Particles" by R. F. Wuerker, H. Shelton and R. V. Langmuir, published in the Journal of Applied Physics, vol. 30, No. 3, March 1959, pp. 342 to 349.

The advantage of an electrodynamic suspension system for charging particles is that because it permits a particle to be stably maintained within a charging ion beam, the particle can be charged to a much higher value than could be achieved by a single passage through the charging beam. The effect, therefore, is to achieve an infinite increase in transit time so as to remove the requirement of dense space charge beams. However, even the advantageous particle charging electrodynamic suspension system, such as described in the aforementioned article, has heretofore failed to provide a sufficiently high charge-to-mass ratio on a micron-size particle to permit it to be accelerated by electric fields to meteoric velocities. In accordance with the present invention, an electrodynamic suspension system 100 similar to that described in the aforementioned article is also used, but in a manner which overcomes the failure of the basic electrodynamic suspension system, as will hereinafter be shown.

Now referring to FIGURES 2 and 3, which are respectively top and front cross-sectional and diagrammatic views of an embodiment in accordance with FIGURE 1, it can be seen that the electrodynamic suspension system there shown is basically similar to that described in the aforementioned article and illustrated in FIGURE 2 thereof. The heart of the electrodynamic suspension system is an electrodynamic suspension chamber 145 formed by an annular metal ring 110 and metal end caps 115 and 125, which are constructed and arranged

to provide the required potential distribution for electrodynamic suspension operation within the chamber 145 as taught in this article. A better idea of the structure of the electrodynamic suspension chamber 145 may be obtained by realizing that the cross-section shown in FIGURES 2 and 3, if rotated about the central axis 192, will give the resultant chamber 145.

The annular ring 110 and the end caps 115 and 125 are insulated from each other by means of annular insulating rings 120 and 130 interposed therebetween as shown in FIGURES 2 and 3. The suspension chamber 145 is suitably mounted within a vacuum chamber 22 so as to provide a vacuum environment.

As shown in FIGURE 3, electrical connections are made to the annular ring 110 and the end caps 115 and 125 in order to provide the driving and measuring signals for the suspension chamber 145 as described in the aforementioned article. The driving signal is provided by a driving oscillator 165 connected between the annular ring 110 and circuit ground. The measuring signal is provided by a measuring oscillator 135 connected through an adjustable D.-C. source 137 represented by a battery 138 and a potentiometer 139, and a coupling capacitor 131 to the end cap 115. The end cap 125 is connected to circuit ground.

The driving oscillator 165 thus applies a driving signal between the end cap 115 and the annular ring 110, thereby performing the same function as the driving voltage V_{a-c} in FIGURE 2 of the aforementioned article. The series voltage V_{a-c} referred to in the aforementioned article is conveniently made zero, but it is to be understood that a suitable value may be provided if desired. Similarly, the measuring oscillator 135 corresponds to the measuring voltage $V\beta$ in FIGURE 2 of the aforementioned article, while the adjustable D.-C. voltage source 137 corresponds to the uniform voltage V_g .

Particles are introduced into the electrodynamic suspension chamber 145 by means of a particle injector 75 suitably mounted within the vacuum chamber 22. (See FIGURE 3.) The particle injector 75 comprises a casing 71, a striker rod 73 adapted for longitudinal movement, a coil 76 wrapped around the rod 73, and a constrained disk 74 upon which rests the particles 77 which are to be injected into the suspension chamber 22. A battery 79 and a switch 78 are connected in series with the coil 76. The rod 73, the coil 76 and the disk 74 are constructed and arranged within the casing 71 so that when the switch 78 is closed, the current flowing through the coil 76 causes the rod 73 to move longitudinally so as to strike the disk 74, ejecting a cloud of particles 77 into the electrodynamic suspension chamber 145. It may be noted that the particle injector 75 differs somewhat from the one described in the aforementioned article, but for all practical purposes it operates in the same general way as the one there shown.

The particles injected into the electrodynamic suspension chamber 145 are charged by means of a low voltage argon ion gun 20, which is adapted to send a beam of argon ions through a port 111 in the end cap 115. As described in the aforementioned article, the electrodynamic suspension chamber 145 then operates in cooperation with the driving voltage from the driving oscillator 165 to cause the particles to be suspended within the chamber 145 in dynamic equilibrium. The particles contained within the suspension chamber 145 may then be observed by means of a microscope 88 and an illuminating arc lamp 96 which are suitably provided outside the vacuum chamber 22 adjacent transparent members 87 and 97, respectively. The insulating ring 120 is made transparent to permit the inside of the suspension chamber 22 to be visible.

As so far described, the embodiment of FIGURES 2 and 3 is essentially the same as that described in the aforementioned article and diagrammatically illustrated in FIGURE 2 thereof. That is, the electrodynamic sus-

pension chamber 145, the means for injecting particles 75, the driving oscillator 165, the D.-C. voltage source 137 and the measuring oscillator 135 are constructed and arranged to provide electrodynamic suspension operation and measurement of the charge-to-mass ratio of a contained particle, in a manner similar to that described in the aforementioned article. As was previously brought out, the use of this basic electrodynamic suspension system alone, using conventional vacuum exhaust techniques, has not been able to charge a micron-size particle to a sufficiently high charge-to-mass ratio to permit the particle to be accelerated to meteoric velocity. On the contrary, however, we have found that by employing properly chosen techniques and apparatus in cooperation with an electrodynamic suspension system, such a system is quite able to provide a sufficiently high charge-to-mass ratio on a micron-size particle as will now be described in connection with the specific embodiment of the invention illustrated in FIGURES 2 and 3.

First, instead of using only a conventional vacuum exhaust system as in the aforementioned article, a cryopumping system is additionally provided so that a very high vacuum can be obtained within the vacuum chamber 22, and thus in the suspension chamber 145. We have found that the provision of a very high vacuum within the suspension chamber 145 is an important feature which was overlooked when the electrodynamic suspension system was previously used for charging micron-size particles. Cryopumping techniques are well known in the art and essentially involve the use of extreme cooling to obtain a high vacuum.

A typical cryopumping system is illustrated in FIGURE 3. The system basically comprises a central reservoir 198 and a jacket reservoir 194 both initially filled with liquid nitrogen. Cylindrical heat-shield tubes 252 and 254 are provided in contact with the central reservoir 198 and the jacket reservoir 194, respectively, the heat-shield tube 252 surrounding the electrodynamic suspension chamber 145 and the heat-shield tube 254 surrounding the heat-shield tube 252. Suitable ports are provided in these shields 252 and 254 where necessary as indicated in FIGURES 2 and 3. Also, suitable holes are provided for electrical lead wires from the suspension chamber 145 to the external circuitry. Those familiar with cryopumping techniques will understand that the cooling of the heat-shield tubes by their respective reservoirs, acting in cooperation with conventional vacuum exhaust pumps, will reduce the pressure within the vacuum chamber 22 to a very low order, thereby achieving an extremely high vacuum.

Another important feature of the system in accordance with the present invention, which is significant in overcoming the failure of the previous electrodynamic suspension system for charging a micron-size particle to a high charge-to-mass ratio, is the use of micron-size diamond particles 77 in place of the other types of particles previously used. It has been found that in order to obtain a high charge-to-mass ratio on a micron-size particle, it is important that the particle have a low density and a high tensile strength. We have discovered that micron-size diamond particles best fit this description.

Still another feature of the system of this invention, which is important for effectively charging a micron-size particle to a high charge-to-mass ratio, is the use of an additional argon ion gun, indicated by 50 in FIGURES 1-3. This additional ion gun 50 is chosen to be capable of providing a high energy beam having significant numbers of doubly charged ions. A helium trap 55 is interposed between the high energy argon ion gun 50 and the vacuum chamber 22 to reduce the flow of gas from the ion gun 50 to the chamber 22. Argon is used in the ion gun 50 because the helium impurity in argon is small, a factor of importance in cryopumping since helium will not freeze out. Also, the use of argon is advantageous in that a good percentage of the ions produced in the

discharge are doubly-charged, thereby permitting these doubly charged ions to be separated by a reasonable size electromagnet for use in providing the desired ion beam of doubly-charged ions. In operation, the ion beam from the high voltage argon ion gun 50 passes through the helium trap 55, through an opening 23 in the vacuum chamber 22, through suitably located openings in the heat-shield tubes 252 and 254 and through a port 114 in the annular ring 110 into the electrodynamic suspension chamber 145.

Spaced tubular electrodes 161, 162 and 163 are provided in suitable openings in the end cap 125, the heat-shield tubes 252 and 254 and the vacuum chamber 22. The electrodes 161, 162 and 163 have wires connected thereto, as shown in FIGURE 3, which pass through suitable openings to connect these electrodes with extractor circuitry 164. The extractor circuitry 164 is constructed and arranged to cooperate with the electrodes 161, 162 and 163 in a conventional manner for the purpose of extracting, focusing and measuring the charge and mass of a particle as it is extracted from the electrodynamic suspension chamber 145 and fed to the accelerating gun 190.

The accelerating gun 190 comprises a series of substantially identical accelerating stages, each comprising a tubular electrode 183, a stored energy voltage source 193 adapted to apply a high voltage to the electrode 183, a lens 191, a light detector 195 adapted to receive light incident on the lens 191, a shorting means 198 adapted to short out the stored energy voltage source 193 in response to the receipt of light by the light detector 195, and an illuminating arc lamp 99 (FIGURE 2) adapted to send a beam through the transparent tubular wall 192 of the accelerating gun 190 at right angles to the lens 191 and the light detector 195. The surface being tested 250 is located at the end of the accelerating gun 190 in a position such that the accelerated particle will impact therewith. Although only two accelerating stages are shown in FIGURES 2 and 3, it will be appreciated that any desired number may be provided.

In order to provide a thorough understanding of the construction and operation of a system in accordance with the invention, the following relatively specific operating procedure of the embodiment of FIGURES 2 and 3 is now presented. It is to be understood that this specific procedure is presented only for illustrative purposes, and in no way should be considered as limiting the scope of this invention.

Operation of the embodiment of FIGURES 2 and 3 is initiated by first exhausting the vacuum chamber 22 by conventional vacuum exhaust pumps as indicated in FIGURE 3. The central reservoir 194 and the jacket reservoir 198 are then filled with liquid nitrogen, thereby further reducing the pressure within the chamber 22 as a result of cryopumping action to the order of 10^{-5} millimeters of mercury. With 1,000 volts R.M.S., at one kilocycle per second placed on the annular ring 110 by means of the driving oscillator 165, and the low energy ion gun turned on at 1,000 electron-volts energy, the diamond particle injector 75 is now activated by closing the switch 78, causing a cloud of micron-size diamond particles to be injected into the electrodynamic suspension chamber 145. The ion gun 20 is then immediately turned off in order not to charge any of the diamond particles in the chamber 145 above the stability limit for the given conditions.

Normally, a number of micron-size diamond particles will be suspended. However, when more than one particle is in the suspension chamber 145, the various motions they produce are difficult to observe with the microscope 88. Therefore, the oscillations of the particles are damped in order to remove all diamond particles except the one having the highest charge-to-mass ratio. This is accomplished by increasing the pressure within the vacuum chamber 22 by closing the valve 19 (FIG-

URE 3) to the vacuum exhaust pumps so that the gas leak from the low energy argon ion gun 20 leaks into the chamber 22 to increase the pressure therein. All particle motion stops near 10^{-3} millimeters of mercury. A positive D.-C. voltage applied to the cap 115 by the adjustable D.-C. voltage source 137 (FIGURE 3) will then remove the particles from the suspension chamber 22, beginning with the one having the lowest charge-to-mass ratio. This is continued until only the particle having the highest charge-to-mass ratio is retained within the electrodynamic suspension chamber 145. The valve 19 to the vacuum exhaust pumps is then closed again and the pressure returned to its high vacuum of the order of 10^{-5} millimeters of mercury. Another reason for retaining only one particle in the suspension chamber 145 is that otherwise, charging will be hampered by the electrical interaction between particles and by electrical interaction between particles and the ion beam.

The charge-to-mass ratio of the remaining particle which is retained in the suspension chamber 145 may then be measured by finding its resonant frequency. This is accomplished with the cooperation of the measuring oscillator 135 and the D.-C. voltage source 137 as described in the aforementioned article. After the charge-to-mass ratio on the micron-size diamond particle suspended in the chamber 22 has been measured, the low energy charging beam of argon ions from the low energy argon ion gun 20 (which may have an energy of 100 electron-volts) is turned on for a few seconds to increase the charge on the particle. The charge-to-mass ratio on the particle is then remeasured and the process repeated over and over again, the charge-to-mass ratio on the particle continuing to build up in stepwise fashion.

If the charge-to-mass ratio on the particle is observed to approach too close to the limit of stability for the given conditions, the voltage magnitude of the driving oscillator 165 is lowered or the frequency increased in order to raise the upper stability limit to permit the particle to be charged further. Also, it will occasionally be necessary during this charging process to increase the energy of the argon ion beam obtained from the low energy argon ion gun 20 so that the ions from the beam are not repelled away from the particle before they can transfer charge to it.

When the maximum energy limit of the low energy gun 20 is reached, the gate valve 69 thereto is turned off (to prevent gas leakage into the chamber 22) and the charging continued with the high energy argon ion gun 50 which produces an ion beam having doubly-charged ions. This high energy argon ion gun 50 may have an energy as high as 100,000 electron-volts. The use of doubly-charged ions makes the ion beam much more effective in charging the particle, and permits a much higher charge-to-mass ratio to be obtained for a given ion beam energy. It should be noted that the energy of the high energy ion gun 50 must be raised in stepwise fashion, since if the energy of the beam is too large, sputtering (ejection of atoms from the surface of the particle due to ion impact) will limit the charge-to-mass ratio obtainable, since charged atoms will be more easily ejected.

Finally, a point will be reached where the particle loses charge as fast as it can be charged, even with the high energy ion gun 50 on continuously. This charge loss is caused by the presence around the particle of gas atoms which lose their electrons to the particle in an ionization process. We have found that this effect can be reduced by providing a further lowering of the pressure in the vacuum chamber 22. To accomplish this further lowering of pressure, the liquid nitrogen in the central reservoir 198 is removed and replaced by liquid helium. The valve 19 to the vacuum exhaust pump is then closed to prevent any possible leakage into the system, the gate valve 69 from the low energy ion gun 20 already being closed. As a result of cryopumping

action, the temperature within the chamber 22 will then fall considerably below that which was obtainable when liquid nitrogen was used in the central reservoir 198, thereby causing the pressure within the chamber 22 to drop to a significantly lower value of less than 10^{-8} millimeters of mercury. This occurs because all gases except helium freeze at the very low temperature now present within the chamber 22. Leakage from the high energy ion gun 50 which might increase the pressure is prevented by means of the liquid helium trap 65.

Now that the pressure within the electrodynamic suspension chamber 100 is at the lowest value possible, a much higher charge-to-mass ratio can be obtained on the micron-size diamond particle by continuing the charging operation, as previously described. Eventually, the maximum charge-to-mass ratio obtainable for the system will be reached. The particle is then ready to be accelerated. The particle is extracted from the suspension chamber 145 by placing a sufficiently positive voltage on the cap 115 of the suspension chamber 145 (by means of the D.-C. source 137), thereby forcing the particle towards the opposite cap 125. The extractor circuitry 164 then applies the proper signals to the electrodes 161, 162 and 163 to focus and accelerate the charged particle into the accelerating gun 90. Also, one of the electrodes, 161, 162 or 163 serves as an induction electrode and operates in cooperation with the extractor circuitry 164 in a conventional manner so that the mass and charge of the particle may be determined as the particle leaves the suspension chamber 145 and enters the accelerating gun 190.

As the particle passes through the accelerating gun 190 it is progressively accelerated to higher and higher velocities. In each stage an arc lamp 99 is located ahead of the electrode 183 and at right angles to the collecting lens 191 and the light detector 195. The lens 191 and the light detector 95 are constructed and arranged so that light incident on the lens 91 is focused on the light detector 195. The voltage source 193 is adapted to apply a voltage of the order of 200,000 volts D.-C. to the electrode 183. When no particle is passing across the path of the arc lamp 99 its beam shines unimpeded through the transparent wall of the accelerating gun 190 and, since the arc lamp beam is at right angles to the lens 191, no light is incident thereon. However, when a particle passes through the beam of the arc lamp 99, it scatters light in all directions causing some light to be incident on the collecting lens 191, which is then focused on the light detector 195. The light detector 195 then triggers the shorting means 198 which shorts out the stored energy voltage source 193, effectively grounding the electrode 183. Thus, as the particle leaves the electrode 183, it will be accelerated by the electric field existing in the gap 197 between the grounded electrode 183 and the electrode 183 of the next stage which is still at a high voltage.

It will be understood, therefore, that the particle is progressively accelerated in each gap 197 of the accelerating gun 190, until it finally impacts with the surface being tested 250 mounted at the end of the gun 190. Using twenty stages similar to the two shown in FIGURES 2 and 3, and stored energy voltage sources 193 each of which applies a voltage of 200,000 volts to its respective electrode 183 (a total energy of the order of 4,000,000 electron-volts), it was found that a micron-size diamond particle, charged to a high charge-to-mass ratio as herein described, can successfully be accelerated to meteoric velocities before impacting with the surface being tested 250.

It will be noted in the figures of the drawing that certain structural details, such as the mounting of various members and vacuum sealing means, have not been shown. This has been done for convenience and clarity so as not to confuse the figures of the drawing with un-

necessary details. It will be understood, however, that such structural details are merely a matter of mechanical design and can readily be provided by those skilled in the art.

It is further to be understood that the embodiment described and illustrated in the figures of the drawing, and the operative procedure thereof, are only exemplary and that various modifications can be made in construction, arrangement and procedure within the scope of the invention. For example, various other types of accelerating guns may be employed for the accelerating gun 190 in FIGURES 2 and 3. The accelerating gun exemplified, however, is a particularly desirable one. Also, the cryopumping apparatus shown in FIGURE 3 may be provided in a number of equivalent ways and with a variety of arrangements which will occur to those skilled in the art. Furthermore, one composite ion gun capable of covering the energy range and producing doubly-charged ions may be used in place of the two argon ion guns shown in FIGURE 2. These examples of possible modifications are not exhaustive and many others will occur to those skilled in the art. The invention, therefore, is to be considered as including all possible constructions, methods and apparatus within the scope of the invention as defined in the appended claims.

We claim as our invention:

1. Particle charging apparatus comprising: a vacuum chamber, an electrodynamic suspension chamber within said vacuum chamber, vacuum exhaust and cryopumping means for producing a very high vacuum within said vacuum chamber, means for injecting a beam of doubly charged ions into said suspension chamber, an energy source cooperating with said suspension chamber to hold a particle therein in dynamic equilibrium in the presence of said beam, at least one micron-size particle of relatively low density and relatively high tensile strength, and means for injecting said particle into said suspension chamber.

2. Particle acceleration apparatus comprising: a vacuum chamber, an electrodynamic suspension chamber within said vacuum chamber, vacuum exhaust and cryopumping means for producing a very high vacuum within said vacuum chamber, means for injecting a beam of doubly-charged ions into said suspension chamber, an energy source cooperating with said suspension chamber to hold a particle therein in dynamic equilibrium in the presence of said beam, at least one micron-size particle of relatively low density and relatively high tensile strength, means for injecting said particle into said chamber, means for extracting said particle from said chamber, and accelerating gun means for charging said particle to meteoric velocity.

3. The invention in accordance with claim 2 wherein said beam of doubly-charged ions is an argon ion beam and wherein said micron-size particle of relatively low density and relatively high tensile strength is a diamond particle.

4. The invention in accordance with claim 3, there being additionally provided: means for observing the motion of said particle within said suspension chamber and means for measuring the charge-to-mass ratio on said particle.

References Cited in the file of this patent

UNITED STATES PATENTS

2,789,221	Tobias	Apr. 16, 1957
2,867,748	Van Atta et al.	Jan. 6, 1959
2,880,337	Langmuir et al.	Mar. 31, 1959
2,944,172	Optiz et al.	July 5, 1960
2,960,614	Mallinckrodt	Nov. 15, 1960

FOREIGN PATENTS

62,383	France	Jan. 12, 1955
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