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Apr 1st, 8:00 AM

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Glenn C. Carle
NASA Ames Research Center, MS 239-12, Moffett Field, CA 94035

Guy Fogleman
NASA Ames Research Center, MS 239-12, Moffett Field, CA 94035

Judith L. Huntington

Scholarly Commons Citation

Carle, Glenn C.; Fogleman, Guy; and Huntington, Judith L., "Space Station Gas-Grain Simulation Facility: Microgravity Particle Research" (1988). *The Space Congress® Proceedings*. 4.
https://commons.erau.edu/space-congress-proceedings/proceedings-1988-25th/session-5/4

Space Station Gas-Grain Simulation Facility: Microgravity Particle Research

Glenn C. Carle*, Guy Fogleman**, and Judith L. Huntington***

NASA Ames Research Center, MS 239-12
Moffett Field, CA 94035

(*Solar System Exploration Branch,**RCA Government Services,***SETI Institute)

1. Introduction

A wide variety of experiments significant to Exobiology, Planetary Science, Astrophysics, Atmospheric Science, and basic Chemistry and Physics involves the physical interactions of small particles (micrometer to centimeter in size). In many astro-geophysical systems (atmospheric clouds, interstellar clouds, planetary rings, Titan's organic aerosols, Martian dust storms, lightning, etc.), processes involving small particles determine the overall behavior of the system. Condensation of particles from a gas, aggregation of small particles into larger ones, low velocity collisions, and charge accumulation are a few of the processes that influence particles in these systems. Examples of particles undergoing these processes include interstellar grains, protoplanetary particles, atmospheric aerosols, combustion products, and abiotic organic polymers.

Although processes of the type described above span a wide range of disciplines, the study of these processes places common fundamental constraints on particle handling. Two common constraints are the need for long time periods during which the particles must be suspended and low relative velocities between particles. Experiments involving small particles generally require material be suspended for periods substantially longer than are practical in Earth's 1 g gravitational field. However, one can investigate these processes with a general-purpose particle research facility (in particular, with the proposed Gas-Grain Simulation Facility) on the Space Station[1-3]. Because of the very low gravitational acceleration (microgravity) in the Earth orbital environment, many experiments deemed impractical or impossible to perform on Earth will become feasible. Such experiments are those in which gravity either interferes directly with the phenomenon under study (e.g., gravitational convection masks diffusional processes) or in which gravity precludes the establishment of the proper experimental conditions (e.g., in 1 g, gravity accelerates test objects to unacceptable velocities).

Many relevant details about the small particle processes of exobiological and astro-geophysical interest are not well understood[2,4]. For instance, astrophysicists would like to understand the formation of grains by condensation in the early solar nebula and the subsequent aggregation of these grains into planetesimals. Planetesimal formation probably involved collisions of particles at very low relative velocities (less than one meter per second). Yet, the conditions necessary for particles to adhere together after a collision and the dependance of collisional dynamics on various factors such as particle composition, relative sizes, spin, and ambient gas pressure are poorly determined and difficult to study on Earth owing to high sedimentation rates and the overwhelming magnitude of the gravitational force in comparison to weaker forces that may be involved in these processes. Nucleation, condensation, and growth of particles, in particular carbonaceous particles, also occur in the envelopes of carbon stars, yielding the observable circumstellar dust and molecules; similar processes are also thought to occur in interstellar clouds and the atmospheres of outer planets. Although remote spectrophotometric observation has led to some theoretical discussion on the physical and chemical characteristics of the materials and the nature of the processes that produced them, such knowledge might not be fully gained until experiments modeling dust formation can suspend grains for times substantially longer than is possible on Earth. Particle aggregation is also important in processes which inject large amounts of comminuted (reduced to minute particles) material into a planetary atmosphere (e.g., dust storms, explosive volcanic eruptions, large impact events, nuclear winter scenarios). To better understand these processes many important parameters such as aggregation rates, size distribution of aggregates, and the dependence of aggregation efficiency on material properties need investigation free from the constraints of the 1 g Earth environment.

The above and other processes are central to many fundamental scientific questions which cannot be addressed adequately in 1 g, but which may be better addressed in the proposed Gas-Grain Simulation Facility (GGSF) within the microgravity environment of the Space Station or the Space Shuttle. This paper discusses the advantages of a microgravity environment for performing experiments involving small particles and their interactions with other particles or gases, reviews physics issues that must be considered in planning a GGSF experiment, describes the GGSF and considers specific scientific requirements the facility must meet, and finally, to illustrate these points, several suggested GGSF experiments are described.

2. Physics of Particles in Microgravity

Microgravity reduces many undesirable environmental effects such as gravitational convection and sedimentation and thus allows weak interparticle forces such as van der Waals and dipole-dipole forces to dominate systems of particulate matter. In considering particle experiments on the Space Station, it is important to understand the microgravity environment provided and the physics of particles in the context of that environment. This section briefly discusses these issues. Also, such issues will be developed in greater detail in a paper currently in preparation.

The term "zero gravity" is commonly used to describe the environment of an object (such as the Space Station) in Earth orbit. This term, though, is not really an apt description of the Earth orbital environment nor the Space Station environment. The gravitational acceleration of the Space Station's center of gravity (C.G.) is non-zero; consequently, objects located at the C.G. still experience a gravitational acceleration, but are allowed to fall freely (i.e., they are in free-fall). In free-fall, the centripetal force required to keep an object in circular orbit is equal to the gravitational force acting on the object, giving the object the appearance of "weightlessness" to observers inside the Space Station. However, only small objects located exactly at the C.G. will fall in the same orbit as the C.G. and appear not to experience a gravitational force. Objects placed in any other region of the Space Station will appear to experience small gravitational forces due to tidal effects. One contribution to this residual gravitational acceleration arises when a particle is placed at rest relative to the Space Station's center of gravity and at a distance radially above or below the center of gravity. Initially, the particle has the same Earth orbital velocity as the center of gravity. If the particle is above the C.G., it has an initial orbital speed too large to maintain a circular orbit, consequently moves into a larger elliptical orbit, and thus appears to experience a force away from the center of gravity. Similarly, a particle below the C.G. will move to a smaller elliptical orbit, appearing to experience a force away from the center of gravity.

In the laboratory region of the Space Station, tidal effects are expected to cause a residual gravitational acceleration on the order of 1 μg in magnitude (note, in this paper the symbol "g" will be used as a unit of acceleration, i.e., $g = 9.8$ m/s^2). In reality, though, this value of the acceleration is overly optimistic once the effects of crew motion, life support systems, and other lab facilities are taken into consideration[5]. More realistic acceleration values are on the order of 10 μg during Space Station quiet time and at other times may vary as much as two orders in magnitude. In general, the net residual acceleration will consist of three components--a steady state component (caused by tidal effects, atmospheric drag, etc.), a periodic component occurring once per day or less frequently (resulting from crew exercising, shuttle docking and shuttle's mass, etc), and a higher frequency vibrational component (produced by the running of fans, pumps, etc.)[5]. Also, shock-like accelerations will occur as a result of general crew activities such as shutting drawers and moving about the cabin. The effects of periodic and vibrational accelerations on particle motion will be dependent in part on the frequency of these components. Without going into complexities presented by time-varying accelerations, one can gain, nonetheless, a sense of the magnitude of the effect residual accelerations have on particles by considering their motion caused by steady-state gravitational accelerations alone.

In a vacuum of 10^{-8} torr, all particles larger than 1 nm in radius experiencing a constant 10 μg acceleration are effectively ballistic and take 45 seconds to fall 10 cm. In a 1 mtorr vacuum, however, the effects of the gas on a particle must be taken into consideration (to be discussed below). Although particles larger than 1 cm in radius would still move ballistically at this pressure, a 1 μm particle would take nine minutes to fall 10 cm. Aside from comparison purposes, particle behavior in a high vacuum is not relevant to microgravity particle experiments as many such experiments will be performed in an atmospheric or low pressure gas instead of a high vacuum. Thus, most of the following discussion is limited to motion of a particle in a homogeneous gas (no temperature, light, nor concentration gradients) under the influence of a steady gravitational acceleration.

In the absence of any interparticle or external (non-gravitational) forces, particle motion in a gas can be described entirely by Brownian motion and sedimentation. Brownian motion is a particle's net motion over time produced by random collisions of gas molecules with the particle. For Brownian motion, the root mean square distance d_B a particle travels in time t is given by

$$d_B = (2kTBt)^{1/2} \tag{1}$$

where k is Boltzmann's constant, T is the temperature (Kelvin), and B is the mobility (see equation 3 below).

In a gas, a particle's gravitational acceleration is exponentially damped by the viscosity of the gas. This damping is characterized by a time constant $\tau = \frac{2}{9} A a_p^2 \rho \eta^{-1}$ where a_p and ρ are particle radius and density respectively, and A is defined below in equation 4. Except in cases of large particles in a low pressure or low viscosity gas, τ is very small. For instance, $\tau = 2\times10^{-7}$ sec for a 0.1 μm radius water drop in 300 K air at 1 atm. After a time $t_o \gg \tau$ (roughly, $t_o = 10\tau$), the particle's velocity is effectively constant. Sedimentation is the particle motion (along the direction of the gravitational acceleration) resulting from this terminal velocity. For sedimentation, the distance d_S a particle travels in time $t \gg t_o$ is given by

$$d_S = \frac{4}{3} \pi a_p^3 \rho B \alpha_g t \tag{2}$$

where ρ is the particle density, a_p is the particle radius, α_g is the magnitude of gravitational acceleration, and again, B is the mobility.

For a particle of radius a_p moving through a gas of viscosity η, the expression for mobility is given by

$$B = \frac{A}{6\pi a_p \eta} \tag{3}$$

where

$$A = 1 + 1.257\ K_n + .400\ K_n\ e^{-1.10/K_n} \tag{4}$$

and K_n, the Knudsen number, is the ratio of the mean free path l_g of the gas to particle radius a_p ($K_n = l_g/a_p$). When the Knudsen number is very small ($K_n \ll 1$), A (eqn. 4) is nearly 1 and has no effect on the mobility for given changes in particle size. In this sense, A can be considered a correction to the mobility for large Knudsen number regimes. This correction for particles in air at atmospheric pressure is only significant when particles are less than a tenth of a micron in radius, but at much lower pressures (< 1 mbar), it is significant for particles up to a tenth of a millimeter in radius.

One dimensionless number which characterizes particle motion in a gas is the Reynolds number, $R_e = \rho_g v a_p/\eta$, where ρ_g and η are gas density and viscosity, and v and a_p are particle terminal velocity and radius. The above equations for diffusion and sedimentation only apply to regimes in which $R_e < 1$. For regimes relevant to the types of experiments that might be performed on the Gas-Grain Simulation Facility in the microgravity environment of the Space Station, Reynolds number will be less than one except in extreme cases in which an experiment uses relatively large particles, a high pressure gas, or a gas at low temperature. This paper restricts discussion of particle motion to the $R_e < 1$ regime.

For various given lengths of time, gravitational accelerations, and particle size, Tables 1 and 2 compare the distance a particle moves from Brownian motion and sedimentation in air at 1 atm and 1 mbar respectively. Although the values in these tables are specific to a particle in 300 K air, the tables can be used to estimate distance for different temperatures. Roughly, d_B is proportional to $T^{1/4}$ and d_S is proportional to $T^{-1/2}$ since viscosity (for an ideal gas) is proportional to $T^{1/2}$.

A critical particle radius a_c can be defined such that sedimentation dominates the motion of a particle with radius $a_p > a_c$ and Brownian motion dominates the motion of a particle with radius $a_p < a_c$. When $a_p \sim a_c$, Brownian motion and sedimentation play nearly equal roles in determining particle motion, resulting in Brownian motion biased along the direction of sedimentation. One can see from Table 1, in 1 g, a_c is just a bit larger than 0.01 µm, but in 10^{-5} g, a_c is between 1 and 10 µm or is 100 to 1000 times larger than in 1 g.

Perhaps a more useful way of looking at this critical radius is to find a_c (from equations 1 and 2) as a function of chamber radius d. In this case, a_c represents the size of a particle which, when placed at the center of the chamber, would take the same time to reach the wall by Brownian motion as it would by sedimentation. $a_c(d)$ is given by

$$a_c = \left(\frac{3kT}{2\pi\rho g d}\right)^{1/3} \tag{5}$$

where again, ρ is the particle density. In illustration, particles under the same conditions specified in Table 1 are considered in a chamber 10 cm in radius. In 1 g, $a_c = 0.01$ µm, but in 10 µg, $a_c = 0.47$ µm. This demonstrates one of the major advantages of microgravity, namely, particles which would settle out in 1 g can remain suspended by the effects of Brownian motion in microgravity.

TABLE 1

Distances (in cm) for several time scales for the following conditions: a 2 gm/cc particle in 300 K air at 1 atmosphere

	t = 1 hour			t = 1 day			t = 1 week		
Particle Radius (µm)	Sedimentation in 1g	Sedimentation in 10^{-5}g	Brownian Motion	Sedimentation in 1g	Sedimentation in 10^{-5}g	Brownian Motion	Sedimentation in 1g	Sedimentation in 10^{-5}g	Brownian Motion
.001	$9x10^{-3}$	$9x10^{-8}$	9	$2x10^{-1}$	$2x10^{-6}$	5x10	2	$2x10^{-5}$	$1x10^{2}$
.01	$9x10^{-2}$	$9x10^{-7}$	1	2	$2x10^{-5}$	5	2x10	$2x10^{-4}$	1x10
.1	2	$2x10^{-5}$	$1x10^{-1}$	4x10	$4x10^{-4}$	$6x10^{-1}$	$3x10^{2}$	$3x10^{-3}$	2
1	9x10	$9x10^{-4}$	$3x10^{-2}$	$2x10^{3}$	$2x10^{-2}$	$2x10^{-1}$	$2x10^{4}$	$2x10^{-1}$	$4x10^{-1}$
10	$9x10^{3}$	$9x10^{-2}$	$9x10^{-3}$	$2x10^{5}$	2	$5x10^{-2}$	$2x10^{6}$	2x10	$1x10^{-1}$
100	*	9	$3x10^{-3}$	*	$2x10^{2}$	$1x10^{-2}$	*	$2x10^{3}$	$4x10^{-2}$
1000	*	$9x10^{2}$	$9x10^{-4}$	*	$2x10^{4}$	$5x10^{-3}$	*	$2x10^{5}$	$1x10^{-2}$

* particles of this size and larger would travel a smaller distance during the given time interval than calculated by equation (2)

TABLE 2

Distances (in cm) for several time scales for the following conditions: a 2 gm/cc particle in 300 K air at 1 mbar

	t = 1 hour		t = 1 day		t = 1 week	
Particle Radius (µm)	Sedimentation in 10^{-5}g	Brownian Motion	Sedimentation in 10^{-5}g	Brownian Motion	Sedimentation in 10^{-5}g	Brownian Motion
.001	$9x10^{-5}$	$3x10^{2}$	$2x10^{-3}$	$1x10^{3}$	$2x10^{-2}$	$4x10^{3}$
.01	$9x10^{-4}$	3x10	$2x10^{-2}$	$1x10^{2}$	$2x10^{-1}$	$4x10^{2}$
.1	$9x10^{-3}$	3	$2x10^{-1}$	1x10	2	4x10
1	$9x10^{-2}$	$3x10^{-1}$	2	1	2x10	4
10	$9x10^{-1}$	$3x10^{-2}$	2x10	$2x10^{-1}$	$2x10^{2}$	$4x10^{-1}$
100	2x10	$4x10^{-3}$	$4x10^{2}$	$2x10^{-2}$	$3x10^{3}$	$5x10^{-2}$
1000	$9x10^{2}$	$1x10^{-3}$	$2x10^{4}$	$5x10^{-3}$	$2x10^{5}$	$1x10^{-2}$

When particles with initial velocity v_o are injected into a gas, one must consider the effects of the gas' drag force on the particle. Generally, small particles come down to thermal velocities over a very short distance and time. In 300 K air at 1 atm, a 1 µm radius water drop with $v_o = 100$ cm/s will slow to thermal velocities in 85 µsec after traveling 13 µm. At lower pressures, however, such drops can have stopping distances and times much larger. Particle stopping distance is nearly independent of pressure when the pressure is sufficiently large such that $K_n \ll 1$, but is inversely proportional to pressure when the pressure is low enough such that $K_n \gg 1$. Then, if one wants to use the gas' drag force to dampen the effects of sudden disturbances (such as Space Station crew motion) on particles, a small stopping distance and therefore high gas pressure would be preferable. On the other hand, if one wants to perform low velocity (< 10 cm/s) collisions with particles ~ 100 µm in radius, low (< 1 mm Hg) gas pressures should be considered to avoid significant damping of particle velocities. Often, though, particles are injected into a gas along with a stream of air (e.g., by using an aerosol generator). Because such particles are carried along with the moving stream of air, particle stopping time (usually called "stilling time" in this case) and stopping distance relative to the surrounding gas can be greatly increased.

The above discussion considered an aerosol particle in a homogeneous gas. An aerosol particle is now considered in the presence of a vapor-concentration, light, or thermal gradient. The random motion of such a particle through the gas is biased toward one direction and is called, respectively, diffusiophoresis, photophoresis, and thermophoresis. The motion of such a particle can also be affected by interparticle forces and external forces such as light pressure forces, acoustic forces, electrostatic and magnetic forces. All of these external forces have been utilized in the development of various particle levitation techniques (see reference 6 for detail) and implemented on Earth to overcome sedimentation in particle experiments. Although sedimentation rates are greatly reduced in the Space Station, they are not eliminated; as discussed above, tidal effects will create residual gravitational accelerations of 10^{-4} to 10^{-6} g inside Space Station laboratory areas. Thus, in a facility such as the proposed GGSF, long duration experiments will require levitation to counteract the resulting sedimentation. The levitation force required, however, is four to five orders of magnitude weaker than that required to keep particles suspended in 1 g. This is a major advantage for experiments that study phenomena involving weak interaction forces. If the levitation forces required to perform an experiment under 1 g conditions impair or obscure the effect under investigation and if a reduction of these levitation forces by five orders of magnitude would result in them having a negligible impact on the process under investigation, then the experiment would benefit from the Space Station environment. Levitation techniques have been shown to work well in 1 g and some also have been tested and shown to work in microgravity[1]. Yet, levitation techniques may not be as promising in cloud/multiparticle experiments because they all have been found to artificially coerce coagulation and render unrealistic the simulation of multiparticle interactions. This effect is discussed in more detail in reference 6.

It is possible cloud coagulation experiments could be performed in microgravity without levitation as long as chamber walls are sufficiently inert. The chamber itself should be as big as possible and, preferably, the experiment should begin with a large particle density to minimize the effects of losses to chamber walls. For experiments in a general-purpose particle facility such as the GGSF, not only should wall deposition be considered in light of its effect on the actual coagulation experiments performed, but also in terms of its effect on the cleanliness of the chamber walls and the ability of the chamber to be cleaned and readied for use by other experiments. In order to understand these effects in more detail, GGSF coagulation experiments should be modeled theoretically and tested experimentally in ground based simulations. Current coagulation models have been verified in the small particle regime characteristic of Earth's 1 g environment, but not in the large particle regime attainable in a microgravity environment. Nonetheless, these current coagulation models are very important to GGSF experiment planning. Moreover, the early GGSF experiments may increase or modify our understanding of coagulation processes and, as a consequence, help to better model and plan later GGSF experiments. Perhaps, too, GGSF experiments will benefit from a current program which has been initiated by the Exobiology Flight Program at NASA Ames Research Center to investigate theoretical and experimental aspects of coagulation.

3. The Gas-Grain Simulation Facility

The proposed Gas-Grain Simulation Facility (GGSF) is a facility that will provide the necessary microgravity environment for small particle experimentation (see Figure 1 for an artist's conception of the facility) and is currently being developed for the Space Station by the Exobiology Flight Program at NASA Ames Research Center. The purpose of the GGSF is to perform, in microgravity, basic research on small particle processes. Examples of experiments that have been suggested for the GGSF will be discussed in Section 4. The GGSF is a "lab in space" which will extend ground based experimental programs to new domains as well as allow completely new types of experiments to be performed.

The GGSF will occupy a Space Station double rack and consist of a number of subsystems supporting an experiment chamber. The chamber will have a working internal volume of four to ten liters and may be connected to subsystems that provide environmental (e.g., temperature, pressure, gas mixture and humidity) controls, mechanisms for injecting and removing particles and clouds of particles, levitation systems (e.g., electrostatic, acoustic, laser trapping, and aerodynamic) to keep particles in fixed positions away from the chamber walls, shock mounts and other vibration-isolating systems, energy sources (e.g., UV light), and a number of experiment monitoring and measuring devices (e.g., video cameras, optical particle counters, spectrometers, an accelerometer). See reference 7 for a recent determination of the functional requirements of the GGSF.

GAS-GRAIN SIMULATION FACILITY

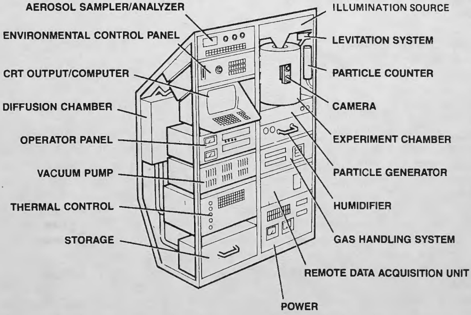

FIGURE 1

Because of limited crew time on the Space Station, the facility will be designed to operate in a nearly autonomous mode. One possible scenario is as follows: a chamber designed for a sequence of experiments is "plugged in" to the GGSF and subsystems are attached in the configuration necessary for the first experiment. A command is then given to begin the execution of preprogrammed instructions required to perform the experiment. After the first experiment is completed, the system may be reconfigured for the second experiment. The experiments would be performed in a logical order, perhaps from "clean" to "dirty." When the sequence of experiments associated with the first chamber is completed, the chamber is removed and stored for return to earth, and a second chamber is then attached for the next sequence of experiments. Or, alternatively, a chamber cleaning subsystem could be activated before a second sequence of experiments is performed in the same chamber. New experiment chambers will be brought to the Space Station periodically and so give the GGSF a very long, useful lifetime.

The GGSF will be designed to have an adaptable configuration allowing the subsystems to be connected to the experiment chamber in a variety of ways. Also, the GGSF will be implemented in an evolutionary fashion. The earliest experiments performed on the GGSF will be those that are the simplest (i.e., require the smallest number of subsystems); more complicated experiments will be performed later in the facility's development. The above criteria can be achieved by requiring the facility to be modular in design. Modularity will also allow subsystems that become outdated to be replaced by modules using more modern technology.

Many of the technical details of the GGSF are yet to be determined. A two year GGSF reference design study is scheduled to begin in the middle of 1988. On completion of the reference design study, the Announcement of Opportunity for experiments for the GGSF will be released (currently planned for 1990) and the final GGSF design will be based on the experiments selected to fly. The development of the facility will be coupled with a vigorous ground based research program aimed at developing GGSF experiments and testing various facility subsystem concepts. The Exobiology Flight Program's goal is to have the GGSF available for launch and ready for use at the time of the Permanent Manned Presence of the Space Station.

4. Example GGSF Experiments

Twenty strawman experiments were suggested for the GGSF at the "Space Station Microgravity Gas-Grain Simulation Facility Experiments Workshop" held August 31 through September 1 in Sunnyvale, California[3]. To provide instructive examples of the types of experiments that could be performed on the GGSF, six experiments from the 1987 workshop are described below:

(a.) Titan Atmospheric Aerosol Simulation[8]. The objective of this experiment is to simulate the formation of organic haze particles in Titan's atmosphere, study the growth of these particles, measure their optical properties, and determine their chemical composition. This experiment will yield data important to the resolution of well posed scientific questions about the nature of Titan's organic haze and will provide information valuable to the preparation of future planetary probe experiments such as the proposed Cassini mission to Titan. In the experiment, a premixed gas mixture of methane, nitrogen, and hydrogen is introduced into the chamber and allowed to equilibrate. The baseline scattering is measured, and then the gas mixture is irradiated with ultraviolet light to form particles. Levitation may be needed at this point to fix the position of the particles. The particles' optical properties, shapes, and size distribution are measured by laser scattering techniques over the 1 to 4 week period during which the particles grow by coagulation. Samples of the particles are then returned to Earth for chemical analysis. Microgravity is necessary because this experiment must be performed without the particles interacting with the chamber walls and because suspension times of the particles in 1 g would not be sufficiently long to achieve this.

(b.) Investigations of Organic Compound Synthesis on Surfaces of Growing Particles[9] The objective of this experiment is to simulate and study the prebiotic synthesis of amino acids and other complex organic compounds by UV photolysis during particle growth in the primitive atmosphere of the Earth. This experiment is relevant to the hypothesis that molecules important to life were produced on the surfaces of growing particles of cometary origin and then protected from ultraviolet degradation by the particles' further growth by coagulation. For this experiment, a multicomponent aerosol cloud is generated and exposed to a UV light source. The aerosol size spectrum is monitored with an aerosol spectrometer. Periodically, samples of the aerosol are taken from the chamber and returned to Earth for chemical analysis. Microgravity is necessary in this experiment because particle suspension time in 1 g is not long enough for photolysis to take place on micron-sized particles or for such particles to form by coagulation.

(c.) Studies of Fractal Particles[10]. The objective of this experiment is to measure the coagulation coefficients of a variety of bare silicates, ice-coated silicates, organic-refractory coated silicates, and organic-refractory grains, grow fractal aggregates of these materials, measure their cohesive strength, and measure their light scattering and extinction properties as a function of wavelength. First, refractory silicate nucleation sites are nucleated from vapor and allowed to coagulate, and the particles' optical properties are monitored using light scattering techniques. Once grains have grown to a desirable size, they are broken apart with acoustic shock waves to measure their cohesive strength. Particles are then allowed to recoagulate and further measurements are made. Finally, particles are coated with ice or irradiated to obtain organic-refractory coatings on the silicates, and the measurements are repeated. Here, microgravity is necessary because of the long particle suspension times required and because macroscopic fractal particles are gravitationally unstable in 1 g and collapse under their own weight.

(d.) Planetary Ring Particle Dynamics[11]. The objective of this experiment is to conduct low velocity collisions of simulated planetary ring particles in a variety of configurations and environments in order to study the dynamics of planetary ring structures. In particular, the coefficient of restitution will be measured over the range of velocities. This experiment addresses the process of energy loss in low velocity collisions which is one of the important factors that determines the dynamics of planetary ring structures. In this experiment, "ice balls" (predominantly H_2O) are produced *in situ.* After the particles' properties are measured, two of them will be positioned in the chamber and given a small relative velocity toward each other. The resulting impact is then observed by high-speed stereo photography or video. Microgravity is necessary because the relevant impact velocities are so low that particles would fall out of any reasonably sized chamber in 1 g.

(e.) Aggregation of Fine Geological Particulates in Planetary Atmospheres[12]. The objective of this experiment is to understand the way in which finely comminuted materials aggregate within and ultimately precipitate from planetary atmospheres. In particular, the growth rates, sizes, composition, and other properties of aggregates will be determined as a function of time, initial particle size, particle charge, atmospheric composition, and mode of comminution. This experiment measures the rate and extent of aggregation which is important in determining the sedimentation rate and thus the residence time of fine particles injected into planetary atmospheres. These residence times are relevant to hypotheses concerning nuclear winter scenarios, species extinction caused by climatic change, climatic change itself, the potential hazards of volcanic eruptions and the distribution of volcanic products, the duration of (e.g., Martian) dust storms, and the distribution of loess. Time sequenced high magnification photography and light scattering techniques will provide records of aggregation events. Microgravity is necessary for this experiment because sedimentation in 1 g acts too rapidly to allow the desired growth potential of aggregates.

(f.) Dipolar Grain Coagulation and Orientation[13]. The objective of this experiment is to investigate the process of grain agglomeration in dust clouds of grains with electric dipole moments and to study the polarization of light passing through filamentary agglomerations which are oriented in an external electric field. This experiment investigates these phenomena as a possible mechanism for the formation of elongated grain agglomerates and grain alignment in interstellar clouds, resulting in the polarization of light passing through the clouds. In this experiment, dust is produced *in situ* or brought from earth and injected into the chamber. Grain agglomeration and alignment are followed in time using light scattering techniques and polarization measurements. The process is repeated using different values of an external electric field. Microgravity is necessary in this experiment because the dipole-dipole interaction between grains is weak and would be overwhelmed by gravitational forces at 1 g. Also, suspension time at 1 g would not be long enough for large aggregates to form.

5. Conclusion

A Space Station microgravity particle research facility such as the GGSF will allow a wide variety of previously unfeasible small particle experiments to be performed. The Gas-Grain Simulation Facility will provide scientists in many disciplines with the opportunity to extend to a new domain present ground-based experimental programs that study processes involving small particles and weak interactions.

This paper reviewed many of the issues that must be considered by scientists wishing to propose microgravity particle experiments. More theoretical and experimental work is needed, however, on the details of the physical processes involved in microgravity particle experimentation. This work is in progress and will be presented in forthcoming papers.

Acknowledgement

This work was sponsored by the Exobiology Flight Program at NASA Ames Research Center. The artist's conception of the GGSF is from a sketch by D. Schwartz.

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