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FUTURE UTILIZATION OF SPACE

Silverton Conference on Material Science and Phase Transformations in Zero-Gravity

SILVERTON CONFERENCE ON
MATERIAL SCIENCE & PHASE TRANSFORMATIONS

SUMMARY OF PROCEEDINGS
OF CONFERENCE HELD IN SILVERTON, COLORADO
APRIL 3-6, 1975

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PROGRAM

SILVERTON CONFERENCE ON MATERIAL SCIENCE & PHASE TRANSFORMATIONS

April 4-6, 1975

April 4 - Friday

9:00 - 12:00 noon

Introductory Remarks	- Dr. Melvin Eisner
Perspectives for Science & Technology in Shuttle	- Dr. Joe Allen
Current Status of Crystal Growtn in Space	- Dr. A. F. Witt
Gravity Effects on Phase Equilibria in Crystals Growths in Skylab	- Mr. David Larson

Lunch Break

3:00 - 6:00 p.m. Informal Discussions

Dinner

8:00 p.m. Film Session

April 5 - Saturday

9:00 - 12:00 noon

Model Studies of Liquid-Solid Interface in Crystal Growth	- Mr. Frans Spaepen
Gravity Effects in Critical Phenomena in Binary Liquid Systems	- Dr. C. M. Knobler
Gravity Induced Concentration Gradients in Binary Liquid Mixtures	- Dr. R. L. Scott

Lunch Break

3:00 - 6:00 p.m.

Gravity Effects in Light Scattering Techniques Applied to Critical Phenomena	- Dr. Dae Mann Kim
Renormalization Group Theory of Critical Exponents	- Dr. Joseph McCauley
Floating Zones in Space	- Dr. John R. Carruthers

April 6 - Sunday

8:30 - 11:00 a.m. - Plenary Session

INTRODUCTION

The Space Shuttle will usher in a new era of space exploration and make possible for the first time the exploitation of many areas of science and of applications. Many of these areas are well recognized and the planning of appropriate payloads is progressing accordingly, for example the Large Space Telescope in the area of astronomy. However, in other areas of interest, particularly those areas not yet associated with past space flights to any degree, there is very little awareness of, or plans for utilization of, the unique flight opportunities which the Shuttle space transportation will offer. Since the ultimate economic success of the Shuttle depends to some degree on its total usage, it is in the direct interest of the Shuttle program to identify hitherto unrecognized areas of possible science and applications payloads and to interest potential users in exploring the possibilities of developing these payloads. Further it is necessary to understand as early as possible the demands which will be placed on the orbiter, the Spacelab, and their respective subsystems by these potential payloads. This will help assure that the design of these key elements of the Space Transportation System be as responsive as possible to the needs of the ultimate users. For these reasons, the conference summarized here was held.

MATERIAL SCIENCE AND PHASE TRANSITIONS IN ZERO GRAVITY

The importance of the zero gravity environment of space for research development and production of new and improved materials is generally appreciated; however, the potential importance of the zero gravity environment for studies in areas which ultimately bear on the material problem in varying degrees, such as gravitational effects on phase changes or critical behavior in a variety of systems, appears less widely appreciated. This study session is designed to both stimulate and inform scientists working in areas such as those cited above about the nature of current space material programs and planned facilities and to initiate critical interdisciplinary dialogues between these scientists and those currently engaged in materials research in zero gravity. Participants were selected with interests ranging from the rather abstract ones to the more applied ones. Attempts were made to provide as broad a spectrum of interests within the proscribed group size limitation as compatible with cross field communication.

A. Study Session Format

The study sessions were held in the isolated, small town of Silverton located in the San Juan mountains of Southwest Colorado. The facilities of the Grand Imperial Hotel were reserved exclusively to provide for lodgings, meals and meeting rooms for the conference. The constant close association of the participants enforced by these arrangements provided a fertile environment for reflective, interactive, critical interchanges among the participants. The stark beauty of the surrounding San Juan mountains provided a site for both recreation and relaxation for the participants at times between sessions.

Round table discussions were held for the first two days of the meeting in the course of which each participant presented a survey of areas of his field of interest in which the zero gravity resource of space might prove to have useful applications. Films of "life in zero gravity" and of experiments carried out in Skylab, were shown in the evening session.

The final session was used to summarize, evaluate and consolidate the previous days' discussion. Emphasis was placed on identifying experiments and applications where the zero-g environment would be of particular significance.

Later as this summary of conference proceedings was being prepared, the possible experiment requirements themselves were compared to the shuttle payload accommodations and Spacelab payload accommodations documents in order to surface any potentially serious mismatch between user requirements and transportation system capabilities.

B. Suggested Experiments

In the course of the discussions many experiments were considered. Although most of the suggested experiments had not been studied in critical detail and were put forth as examples of possible areas of experimental investigation, they are nonetheless of interest since they provide some guidance on estimating the demands which may be placed on the shuttle by a set of experiments whose implementation appears to have some scientific interest.

(1) Fine Scale Phase Separation in Zero Gravity

(F. Spaepan)

It would be of interest to study how a homogeneous binary liquid, which is supercooled into a miscibility gap, phase separates into two liquid phases in zero gravity.

There is evidence, from the phase separation of a metallic glass ($Pd_{.74}$ $Au_{.08}$ $Si_{.18}$) above its glass transition temperature, that liquid-liquid phase separation can result in a microstructure consisting of two interconnected networks, typical of the structures obtained by spinodal decomposition. Because the surface tension between liquid phases is likely to be smaller than between solid phases, one would expect the scale of phase separation in a liquid-liquid system to be even finer than for solid-solid systems. Whether this also holds for liquids at high temperatures, where the viscosity is lower and the diffusion is higher, is not a priori clear, but it seems worth the experiment.

An important application of this very fine scale phase separation could be the production of superconducting materials. As a simple example, consider the system Cu-Pb. This system has a liquid miscibility gap. When the homogeneous melt phase separates into a Cu-rich and Pb-rich melt, the structure is preserved in zero gravity. On further cooling, both phases will crystallize and the result will be a composite consisting of a superconducting material (Pb) and a ductile matrix (Cu). This is similar to the composite wire that C. C. Tsuei at I.B.M. has developed, which consists of

Nb_3Sn in Cu. The very fine scale of the liquid-liquid phase separation could result in a very fine dispersion of the superconductor in the matrix, which is considered a desirable feature to increase the critical field.

There are of course many other systems that can be considered, but as a first check on the liquid-liquid phase separation in a metallic system at high temperatures, Pb-Cu might be a good choice.

(2) <u>Glass Formation in Zero Gravity</u>

(F. Spaepan)

In the absence of gravity a liquid does not have to be kept in a container. Since the container walls are a possible source of heterogeneous nucleation of the crystalline phase, the elimination of the container will facilitate undercooling of the liquid, and hence glass formation.

It would be advisable to test this on systems that are marginal glass formers, i.e., systems that require very high cooling rates or systems with compositions similar to those of known glass formers, but which so far have failed to form a glass. A good example here are the metallic glasses.

Most metallic glasses require fairly high quench rates, and for this reason they are limited in dimension (ribbons, foils). It might be possible to produce bulk samples by using a known good glass forming composition (i.e., a multicomponent system of the A_4B type, where A are noble metals and beta transition metals and B are metalloids, c.f. Ni_{49} Fe_{29} P_{14} B_6 Al_2 or Pd_{77} Cm_6 Si_{17}), and letting it cool reasonably fast without a container in zero gravity.

The chance of heterogeneous nucleation can greatly be reduced, at least in part of the system, by dispersing the liquid in small droplets. This technique might be the one to try on metallic glass compositions that so far have been unsuccessful in producing a glass. The advantage of zero gravity here is that the droplets do not have to be dispersed in some medium, which might be a source of heterogeneous nucleation. A possible technique for making this dispersion is by atomization.

(3) <u>Effects of Gravitational Perturbations on Determination of Critical Exponents</u>

(R. L. Scott & C. M. Knobler)

Experimental investigations of phenomena in the critical region are severely hampered by gravitational effects.

Gradients in density and concentration become increasingly large as the critical point is approached and these gradients are proportional to the gravitational field. The existence of gradients makes it virtually impossible to determine the properties of systems very close to the critical point and it is this limiting behavior that is described by theory.

Modern phenomenological treatments of critical phenomena are cast in the form of limiting laws that are characterized by critical exponents. For example, the coexistence curve is given by the relation $(\rho-\rho_c)/\rho_c \propto [T-T_c)/T_c]^{\beta}$ where β, the critical exponent is approximately 1/3. Questions to be answered are:

(1) What are the values of the exponents?

(2) Are the exponents the same for all substances?

(3) Are the exponents the same for one-component (gas-liquid) and two-component (liquid-liquid) systems?

(4) Are the small apparent disagreements between the experimental exponents for fluids and those theoretically deduced from the Ising model real?

Although the determination of all the exponents in a "low g" environment would be desirable, priority should be given to the study of those properties most affected by gravity and most poorly characterized by terrestrial measurements. We consider that the exponent α is the most uncertain and should be investigated in space. This exponent can be derived from measurements of the heat capacity (C_V) or compressibility of a one-component gas-liquid system or the heat capacity (C_p) or thermal expansion coefficient of a binary mixture. In order to determine α it is necessary to perform measurements over at least 3 decades in $(T-T_c)/T_c$ and very close to T_c (at least within 1 mK). The difficulties in making such measurements at 1 g are well documented.

In a terrestrial environment, each of the methods for determining α offers certain advantages and disadvantages. Whether these characteristics are enhanced or diminished in space is not immediately obvious and would require careful consideration. Our present feelings are that the most promising experiments would be measurements of the volume of a binary mixture as a function of T at constant P and light scattering measurements on one- and two-component systems. All studies in the critical region have the common requirement of precise temperature control and uniformity of T in the sample. Techniques will have to be developed to insure these conditions in a space experiment.

a series of qualitative experiments should be performed in a low-g environment to determine the shapes and stability of confined multiphase fluid systems. Do such systems assume the shapes predicted to be thermo-dynamically stable (e.g., concentric spheres)? What is the role of wetting, interfacial tension and surface impurity? As the critical point is approached is the integrity of homogeneous bulk phases progressively lost?

(4) Light Scattering From Long Wave Fluctuations in Liquids in Zero Gravity

(D. Kim)

The spectrum of laser light scattered from a fluid contains a quasi-elastic component known as Rayleigh line, whose width is the decay rate of the spontaneous density - density fluctuations[1]. Recently, two theories of critical point dynamics have been proposed, viz. the mode-mode coupling theory of Kawasaki[2] and the decoupled mode theory of Ferrell[3]. These two theories lead to the identical result for the decay rate in the region where $q\xi \lesssim 3$ (q, ξ being respectively the wave vector of the momentum transfer and long range correlation length) and the theoretical values of the decay rate have been shown to agree with the experimental results extremely well in this region. However, very near the critical point where $q\ \xi > 3$, these two theories predict slightly different results. Furthermore, the existing data points in this region are rather inconclusive for testing these theories.[4] It is therefore important to have more experimental data point very near the critical point.

The measurement and the interpretation of the decay rate of the spontaneous density fluctuations at the critical isochore is difficult due to the gravitationally induced, anomalous density gradients in a fluid near the critical point.[5] Because of this large gradient of the density profile in the sample, it is rather hard to pin point precisely the value of the decay rate at the critical isochore and also to relate the measured value to the true theoretical results. These kinds of difficulties can be avoided by performing the light scattering experiment in an environment where there does not exist any gravitational effects, provided temperature control to within 0.5 millidegree K can be achieved and modest scale optics laboratory can be established.

1. R. Mountain, Rev. Mod. Phys. 38, 205 (1968).
2. K. Kawasaki, Phys. Rev. A1, 1750 (1970).
3. R. Ferrell, Phys. Rev. Lett. 24, 1169 (1970).
4. H. L. Swinney and D. L. Henry, Phys. Rev. a8, 2586 (1973).
5. Dae M. Kim, D. L. Henry and R. Kobayashi, Phys. Rev. A10, 1808 (1974).

C. Comments on the Utility of the Study Session

(David Larson)

The multi-discipline approach is both challenging and rewarding, but terminology poses some problems. In future meetings perhaps abstracts could be distributed beforehand by each individual and terminology problems could be anticipated.

The meeting reached a strong consensus that critical experiments exist in all disciplines (physics, chemistry, materials science, fluids, etc.) that are of very high technological importance (value?) but which cannot be envisioned as a commercial payload. It would be advantageous to establish a formal mechanism to fund and perform these experiments.

To this end (see paragraph 2) it would seem worthwhile to try to establish a mechanism similar to that which conducts the research in the polar regions, and in particular Antarctica. This mechanism consists of a large research funding agency (NSF), a program office (U. S. Antarctic Research program--USARP), individual scientists, and a support logistics and supply agency (U. S. Naval Support Force, Antarctica). The funding agency might still be NSF, the liaison office must be established and staffed and the support force would now be NASA. They would be paid for their services just as the Navy is in Antarctica.

Some areas of high commercial return seem to be overlooked in that highly reactive (chemically) and high melting point materials are receiving little attention. More work is needed in this area.

Many anomalies exist within existent experiments and much material is in hand. These materials should be utilized to the fullest extent to explain the anomalous results or point to critical experiments within the very limited number of flights before Space Lab.

I feel strongly that much information on fluids and solidification can be obtained inexpensively in existent drop towers.

Publication in reputable scientific journals will present the space processing environment to the best scientists in each discipline. Quality study groups will help, too. An opportunity to conduct fundamental research will attract still more.

Proprietary and Patent Protection must be afforded commercial participants.

Commercial materials of a high return nature are for the most part for highly competitive and dynamic industries and subject to rapid change. As a result, economic projections are very questionable. It might be better to fully analyze materials in hand and define a working environment and then assess what it can be utilized for. This working definition of the environment is critically important to the fundamental and the commercial ventures.

We are conducting research--failures should not be considered absolute. Negative results should be pursued vigorously to understand <u>why</u> the experiment failed.

Contrary to the beliefs of others, I believe that a technical ground support force, or interface will be needed to incorporate these disparate experiments within the limited confines of Space Lab. It is a serious problem.

In addition to highly reactive and high melting point materials, specific mention was made of superconducting array of materials and bubble dispersed arrays that might be unique to the low-g environment. These are worth pursuing.

CONCLUSION

The study sessions served several useful purposes. Those of the participants who had little previous experience with the space program and the operational modes in which it might be available to them were made aware of its potential and were stimulated into considering the utility of its application to a variety of problems in their field of interest. A critical discussion of the relative merits of a variety of experiments was carried out, and although great caution was expressed of doing experiments "just to see what will happen" in zero-g, it was also realized that there exists a plethora of interesting phenomena whose elucidation requires, or is greatly facilitated by, the zero-g environment.

The ideas, interchanges, and interactions which took place in the small but highly interactive group of participants should be widely diffused by the participants to their professional colleagues and continuing studies in this mode could serve a useful function in maintaining a link between potential users and the space program.

The experiments discussed in this study session would require laboratory facilities similar to those found in terrestrial laboratories and no inherent problem is seen in accommodating adequately in the space laboratory any of the proposed or closely related studies.

The participants endorsed the idea of a broad-based program ranging from highly applied to quite abstract studies. In addition, the value of close coordination with related ground based programs was recognized.

The ideas for experiments developed during the 2-1/2 day meeting were, in all cases cited here, intriguing. The purpose of the meeting was not to pass scientific judgment on the importance or relevancy of each individual suggestion, nor to study in detail the technical feasibility of carrying out each experiment aboard the Shuttle/Spacelab system. It was rather to serve as a forum for open exchange of ideas among shuttle designers and potential shuttle users; in this regard it was quite successful.