Acronym: BCAT-3-4-CP

Title: Binary Colloidal Alloy Test - 3 and 4: Critical Point

Principal Investigator(s):
David A. Weitz, Ph.D., Harvard University, Cambridge, MA
Peter J. Lu, Ph.D., Harvard University, Cambridge, MA

Contact(s):
Primary - David A. Weitz, weitz@deas.harvard.edu, 617-496-2842
Secondary - Peter J. Lu, plu@fas.harvard.edu, 617-496-8915
Project Scientist - William Meyer, william.v.meyer@grc.nasa.gov, (216) 433-5011

Mailing Address:
Dr. David A. Weitz
Harvard University
Harvard Engineering & Applied Science
Pierce 231
29 Oxford St
Cambridge, MA 02138

Payload Developer(s):
Glenn Research Center, Cleveland, OH
ZIN Technologies, Cleveland, OH

Sponsoring Agency: National Aeronautics and Space Administration (NASA)

Increment(s) Assigned: 8, 9, 10, 12, 13, 15, 16, 17

Brief Research Summary (PAO): Binary Colloidal Alloy Test - 3 and 4: Critical Point (BCAT-3-4-CP) will determine phase separation rates and add needed points to the phase diagram of a model critical fluid system. Crewmembers photograph samples of polymer and colloidal particles (tiny nanoscale spheres suspended in liquid) that model liquid/gas phase changes. Results will help scientists develop fundamental physics concepts previously cloaked by the effects of gravity.

Research Summary:

- Binary Colloidal Alloy Test - 3 and 4: Critical Point (BCAT-3-4-CP) is one of four investigations in the BCAT suite of experiments. BCAT-3: Binary Alloy (BCAT-3-BA) and BCAT-3: Surface Crystallization (BCAT-3-SC) were performed on previous ISS expeditions. BCAT-4: Polydisperse (BCAT-4-Poly) will begin during ISS Expedition 17.

- BCAT-3-4-CP will investigate fundamental problems in colloid science and provide data which will evolve the field of colloidal engineering (creating materials with novel properties using colloidal particles as precursors). BCAT-3-4-CP takes advantage of the microgravity environment on the ISS to prevent the model colloidal particles from encountering sedimentation, convection, and gravitational jamming.

- The focus of the BCAT-3-4-CP is to watch what happens during phase separation near the critical point. Liquids are denser than gases, so watching the two separate on Earth, the liquid just pools at the bottom. However, in space interesting patterns form when liquids and gasses separate.

- Phase separation slows down near the critical point, until right at that point, where there is no phase separation, the time to separate is considered infinite. But exactly what happens at an individual particle level really close to that point has not been well explored.

Detailed Research Description: The Binary Colloidal Alloy Test (BCAT) hardware supports four experiments. The first hardware, BCAT-3, consisted of three separate investigations, Binary Alloy (BCAT-3-BA), Critical Point (BCAT-3-CP) and Surface Crystallization (BCAT-3-SC), which were delivered to the International Space Station (ISS) during expedition 8. The next hardware, BCAT-4, consists of two separate investigations, Critical Point (a continuation of the investigation on BCAT-3) and Polydispersion (BCAT-4-Poly).

In an ordinary pot of boiling water, bubbles of water vapor coalesce on the bottom of the pot, growing until they detach and float to the surface where they escape into the atmosphere. At the boiling temperature water exists simultaneously in two distinct phases, liquid and gas, and as the bubbles burst, those two phases are spatially separated. But what should the mixture look like in the absence of gravity, when the vapor no longer floats to the top? Moreover, the behavior changes with increasing pressure: seal the pot, as in a pressure cooker, and the boiling temperature rises. Continuing the pressure increase, the mixture will reach its critical point, a unique pressure and temperature value where the properties of the liquid and gas merge. Just above this point is the supercritical regime where there are no longer distinct phases, but rather a homogeneous supercritical fluid. Seven of the BCAT-4 samples will examine critical point and add important data points to the phase diagram explored by the critical point samples in BCAT-3, where the phases analogous to liquid and gas can be seen as two different colors.

Supercritical fluids are technologically important because they uniquely combine the properties of liquids and gases, flowing easily (like gases), yet still having tremendous power to transport dissolved materials and thermal energy (like liquids). Supercritical water so efficiently transports heat that it is being explored in Iceland as a potentially superior geothermal power source; it is also used to remove toxic waste from contaminated soil. Additionally, NASA's Jet Propulsion Laboratory is working on using supercritical fluids as unique propellants for future rocket engines. A better understanding of critical behavior as a result of microgravity experiments like BCAT might thus contribute to fundamental understanding that may contribute to the future development of such diverse things as new drugs, cleaner power, and interplanetary transportation.

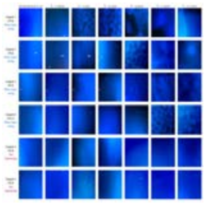
The colloid-polymer mixtures are in a glass cuvette, which the crewmembers can illuminate with a flashlight from the rear, at a high angle. The colloidal spheres scatter the light from the flashlight, and appear blue, so the bright blue areas in the photographs are regions with high colloid density. The darker areas, filled with solvent and polymer, don't scatter much light, which is why these areas are darker. The term "phase separation" is clearly visualized in the photographs: the sample has separated into two phases, a bright blue "liquid" phase with a high colloid density, and a darker "gas" with far lower colloid-density. We measure the characteristic width of the bright-blue region, quantifying the size of the liquid regions, as a function of time.

The BCAT-3-4-CP critical point samples may have a tremendous impact upon fundamental physics. Understanding critical phenomena was an important theoretical advance in physics during the last half century, but ground-based experiments have been limited by gravity, which invariably causes the denser liquid phase to fall to the bottom of any container, precluding direct observation of phase separation, which in the absence of gravity should manifest a boundary between separating phases that looks like a jagged coastline.

Project Type: Payload

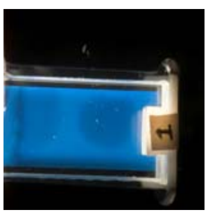
NASA Image: ISS008E20221- BCAT-3 sample holder affixed to a wall inside ISS on Expedition 8.

NASA Image: ISS010E06640 - ISS Commander and Science Officer, Leroy Chiao performing BCAT-3 operations on board ISS during Expedition 10.



Critical point fluctuations observed in BCAT-3 onboard the ISS.

NASA Image: ISS012E07685 - Expedition 12 Commander and Science Officer William McArthur photographs BCAT-3 experiment samples.



NASA Image: ISS012E13082_nr - BCAT-3-CP sample 1 taken during ISS Expedition 12 using a new camera setting and flash placement. The new camera flash position allows the camera to see the light from the evolving critical fluid experiment interface. These tests will now enable the EarthKAM computer to take a series of computer controlled photographs, which will track the evolution of this critical fluid experiment after it has just been mixed in the absence of gravity.

BCAT-4 Slow Growth Sample Module.

Cathy Frey (BCAT Crew Trainer) and Peter Lu (BCAT Investigator) showing astronaut Daniel Tani, time-lapse video of sample evolution from photos taken by Bill McArthur during ISS Expedition. 12.

Operations Location: ISS Inflight

Brief Research Operations:

- BCAT-4 consists of ten different individual sample cells. BCAT-3-4-CP uses seven of the sample cells.

- Crewmembers will homogenize the samples and photograph one sample at a time, to capture the rate of phase separation in the samples using EarthKAM automated photography software over a period of 2 - 3 weeks per sample. Images will be downlinked to allow scientists to provide immediate feedback to the crewmembers on board the ISS.

- After photography the samples are stowed and left undisturbed to allow for continued growth of the colloidal structure for up to 6 months.

Operational Requirements: The BCAT-4 hardware consists of ten samples of colloidal particles. The microscopic colloid particles and a polymer (samples 1 - 7) are all mixed together in a liquid. The BCAT-4 samples are contained within a small case the size of a school textbook. The experiment requires a crew member to set up on the Maintenance Work Area (MWA) or on a handrail/seat track configuration, EarthKAM hardware and software to take digital photographs of samples 1 - 7 at close range using the onboard Kodak 760 camera. The pictures are then downlinked to investigators on the ground for analysis.

Operational Protocols: A crewmember sets up all hardware on the Maintenance Work Area (MWA). The crewmember then homogenizes (mixes) the sample(s) and takes the first photographs, manually. The crewmember activates the EarthKAM software to automate the rest of the photography sessions over a 3-day to 3-week period. Crewmembers perform a daily status check to assure proper alignment and focus of the camera. At the completion of the session, a crewmember tears down and stows all hardware.

Review Cycle Status: Draft

Category: Physical and Biological Sciences in Microgravity

Sub-Category: Physical Sciences

Space Applications: BCAT-3-4-CP addresses basic physics questions, but some of the areas may eventually have applications for space exploration. Supercritical fluids, which are one of the applications of the critical point experiment, are of potential application in propulsion systems for future spacecraft design.

Earth Applications: Increased knowledge of some of the areas of this basic physical research may have future benefits in the application of the same physical processes on Earth. Supercritical fluids (fluids possessing properties of a gas and a liquid, simultaneously) have numerous applications in a wide variety of fields. An example is supercritical carbon dioxide used to decaffeinate coffee beans. Supercritical fluids can also be used to wash toxic waste from soil and to extract higher concentrations of compounds from plants for use in new drugs. The development and use of newer supercritical fluids is dependent on further understanding of the critical point of those fluids, which BCAT-3-CP and BCAT-4-CP are providing. Additionally, product shelf-life may be dependent upon binodal decomposition; so, a better understanding of this could have an enormous commercial impact.

Manifest Status: Planned

RPO: Life Support and Habitation - GRC (LSH-GRC)

Previous Missions: The predecessors to BCAT-4; BCAT-3 operated on ISS, and BCAT, operated on *Mir* in 1997 and 1998.

Results: The phase separation rates of the different samples were measured. The data gave some surprising results about the rates. The samples have been remixed for another session to verify the observations using a remote-controlled camera system from the EarthKAM educational payload to get more frequent images. Final results will not be available until the experiment is completed.

These dynamic data will help determine the boundary conditions for future models of critical behavior. Present observations also include a determination of the shape of the interface and which part of the sample wets the cell. The long-term observation of which samples phase separate will allow precise determination of the critical point of this colloidal mixture, and will allow inference of the fundamental physics underlying critical point behavior.

Results Publications:

Lu PJ, Weitz DA, Foale CM, Fincke EM, Chiao L, McArthur WS, Williams JN, Meyer WV, Owens J Hoffmann MI, Sicker RJ, Rogers RB, Frey CA, Krauss AS, Funk GP, Havenhill MA, Anzalone SM, and Yee HL, Science Applications International Corporation, Microgravity Phase Separation Near the Critical Point in Attractive Colloids, Proceedings of the 45th Aerospace Sciences Meeting and Exhibit. 2007; AIAA-2007-1152.

Related Publications:

Lu PJ, Conrad JC, Wyss HM, Schofield AB, Weitz DA. Fluids of Clusters in Attractive Colloids. Physical Review Letters. 2006;96: 028306.

Doherty MP, Koudelka JM, Motil SM, Saavedra SM. Light Scattering for complex Fluids Research on ISS: Investigator Dreams and Anticipated Hardware Development. Proceedings of the 37th Aerospace Sciences Meeting and Exhibit. 1999; AIAA 1999-0964.

Manley S, Cipelletti L, Trappe V, Bailey AE, Christianson RJ, Gasser U, Prasad V, Segre PN, Doherty MP, Sankaran S, Jankovsky AL, Shiley B, Bowen J, Eggers J, Kurta C, Lorik T, Weitz DA. Limits to Gelation in Colloidal Aggregation. Physical Review Letters. 2004; 93(10):108302.

Lant CT, Smart AE, Cannell DS, Meyer WV, Doherty MP. Physics of hard spheres experiment--a general purpose light scattering instrument. Applied Optics. 1997: **36**, No. 30, 7501-7507.

Doherty MP, Lant CT, Ling JS. The Physics of Hard Spheres Experiment on MSL-1: Required Measurements and Instrument Performance. Proceedings of the 36th Aerospace Sciences Meeting and Exhibit. 1998; AIAA 1998-0462.

Ansari RR, Hovenac EA, Sankaran S, Koudelka JM, Weitz DA, Cipelletti L, Segre PN. Physics of Colloids in Space Experiment. Space Technology and Applications International Forum. 1999.

Cheng ZD, Chaikin PM, Zhu JX, Russel WB, and Meyer WV, "Crystallization Kinetics of Hard Spheres in Microgravity in the Coexistence Regime: Interactions between Growing Crystallites", Phys. Rev. Lett. 88, 015501 (2002).

Cheng ZD , Zhu JX, Russel WB, Meyer WV, Chaikin PM, "Colloidal hard-sphere crystallization kinetics in microgravity and normal gravity", Appl. Optics **40**, 4146-4151 (2001).

Web Sites:
BCAT-3
http://exploration.grc.nasa.gov/life/bcat3_iss.html

Experimental Soft Condensed Matter Group
http://www.deas.harvard.edu/projects/weitzlab/index.html

Photographing Physics: Critical Research in Space
http://www.nasa.gov/mission_pages/station/science/BCAT_feature_093005.html

Related Payload(s): BCAT Investigations, EXPPCS

Last Update: 6/12/07