Brookhaven
Instruments Corporation

Article

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Brookhaven augments NASA Hard Spheres Experiments

Microgravity experiments performed aboard the US Space Shuttle Columbia are helping physicists and chemical engineers at Princeton University understand how the properties of engineering materials are determined by their atomic structure. It's hoped the work, using equipment supplied by Brookhaven Instruments Corporation in New York State, will provide the key to solving fundamental problems in condensed matter physics, and could lead to revolutionary new "designer" materials for the manufacturing industry.

All materials are made of the same basic building blocks: atoms. This means that atomic physics determines many of the properties of matter. The way the atoms in a material are arranged fixes its density, strength, hardness, flexibility, electrical conductivity, and even colour. Understanding the explicit connections between atomic physics and material properties is of enormous importance for many areas of industry, for example: semiconductors, electro-optics, ceramics and composites.

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But atomic interactions are highly complex, and their connections with material properties aren't yet fully understood. One of the principal reasons for this is that atoms are simply too small to be observed. Recently, however, a team of researchers led by Professors Paul Chaikin and William Russel, of Princeton University, has adopted a novel alternative. They've been using tiny plastic beads – small, but nowhere near as small as atoms – to mimic the behaviour of atomic systems.

Atoms can behave in similar ways to larger particles, found in what are known as colloids. A colloid is a suspension of particles in a liquid; paint, milk and ink are commonplace examples. In many cases, atoms act like impenetrable spheres, only interacting with one another when they are very close to each other. So a colloid made up of tiny, coated hard plastic spheres suspended in just the right kind of fluid can closely parallel the physical characteristics of an atomic system.

One immediate similarity is atomic geometry – the way atoms pack themselves together. The geometry of the spheres in a colloid determines its thermodynamic properties. Similarly, the geometry of atoms is the basis for melting and solidifying in many real materials. The major difference between atoms and colloids, however, is that while the plastic spheres are still tiny – each measuring less than a micron across – they are large enough to observe, measure and manipulate experimentally.

It's not quite that simple though. The size of the plastic spheres brings with it a new problem. Because the spheres are much larger than real atoms, they are also much heavier and so are affected to a far greater extent by gravity. The force of gravity causes the particles to sink to the bottom of the colloid's less-dense fluid component. It also creates convection currents that are absent at the atomic level, making the behaviour of the colloid differ from that of atomic systems.

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The solution is to perform the experiments in low-Earth orbit. Here, the pull of the Earth's gravitational field is just one millionth of its strength at the surface of the planet, eliminating problematic sedimentation and convection. In this microgravity environment the spheres are evenly distributed and offer an excellent representation of the physics of atoms.

This is just what Professors Chaikin and Russel and their team did. They flew their apparatus, called PHaSE (Physics of Hard Spheres Experiment), into space in April 1997. It was one of a number of projects participating in NASA's Microgravity Science Laboratory-1 mission, aboard the Columbia. The long-duration microgravity environment provided by the shuttle made it an ideal platform for the study.

PHaSE uses a colloid of plexiglass beads, each measuring about 0.6 microns in diameter (less than the width of a human hair). The beads are coated in stearic acid, to prevent them sticking together, and suspended in a mixture of the organic solvents decalin and tetralin.

PHaSE focuses on the development of crystals in the colloid. As the concentration of the beads increases, the colloid changes from a fluid state, in which the beads are randomly distributed, to a solid state where they adopt an ordered structure. When the average distance between the beads has decreased sufficiently, they begin to space themselves periodically and a crystalline structure starts to form. The nucleation and growth of crystals in the colloid mirror that of real systems, such as the formation of ice in water as the temperature is lowered. Investigating this parallel was the main objective of the project.

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The team compared its microgravity results with similar measurements performed on Earth. This allowed them to discard the effects of gravity and so pinpoint "pure" features of the hard sphere colloid that may also occur in real systems of atoms. Their findings let them determine the precise structure of the crystals and their elasticity, the dynamics of crystal growth and the viscosity of the fluid state. The team also examined the nature and appearance of what is known as the glass transition. This is when the concentration of the spheres becomes so high that they can only move very slowly. In this state, the colloid behaves like glass, taking geological timescales – typically millions of years – to form crystals. The research suggests that the glass transition may in fact be a product of gravity, rather than a genuine thermodynamic effect.

They also found that colloids allowed to crystallise in a microgravity environment form a different kind of crystal to those on Earth. Under the effect of gravity, the crystal structure has a random hexagonal close-packed orientation, whereas on Earth, a face-centred cubic orientation is dominant. Colloids crystallising in microgravity also form dendritic arms. Although these snowflake-like structures are a common feature of atomic materials, they aren't seen in colloid experiments on Earth because the planet's gravity disrupts their formation. In addition, the team found that colloids generally crystallise much faster in microgravity than they do on Earth.
The spheres in the colloid were observed using a multi-purpose laser light scattering system developed specially by NASA’s Glenn Research Center (GRC) for use in a microgravity environment. PHaSE consists of a number of colloid samples, each with a different concentration of spheres. A beam of laser light passes through each sample in turn. Some of the light is

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scattered and this is picked up by a fibre optic cable, which feeds the light to a very sensitive photodetector. The detector measures how much light has been scattered and passes this information to a computer and a correlator, which use it to trace the movements of the spheres in the colloid. The formation of any crystals is easily detected because this causes the scattered laser light to emerge from the colloid at specific angles. Video imaging of the scattered light determines the precise form of the crystals.

At the heart of the PHaSE investigations were two Brookhaven BI-9000AT Digital Correlators which interpreted the data from the light scattering apparatus, sampling the signal at intervals as short as 25 billionths of a second. Brookhaven has been a pioneer in designing, developing and manufacturing correlators and laser light scattering equipment for more than 20 years. The company has a renowned worldwide reputation for its superior products and expert technical support. It also offers a range of software packages to support its hardware products.

"We have been working closely with Brookhaven Instruments Corporation for well over a decade now," says Dr William Meyer, of the Advanced Technology Development group, a division of GRC that contributed to PHaSE. "They offer excellent service and are first rate when it comes to backing their products."

PHaSE was a difficult undertaking. It had to overcome a number of obstacles, both technical and budget related. The project's desired capabilities had to be reconciled with a host of engineering restrictions that are absent when working in a laboratory on Earth. So much so that experimental and packaging requirements were typically in direct conflict, and ensuring PHaSE performed as

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required necessitated state-of-the-art components and some novel design innovations in its optics and detectors.

Nevertheless, the project was completed in record time. A "fast-track" cycle shortened PHaSE's development time by 1-2 years from the normal 4-5 year cycle for a project of this scope; the hardware was delivered in an unprecedented 32 months. This was achieved despite the project's development coinciding with a NASA resizing and rebudgeting effort, severely limiting both the schedule and the cost of the project.

Following the success of PHaSE, Professors Chaikin and Russel and their team now hope to perform further, more sophisticated hard sphere experiments in microgravity aboard the International Space Station early in the new millennium.

For more on the Brookhaven BI-9000At Digital Correlator, see: http://www.bic.com/9000.htm
Further details of the PHaSE experiments can be found at: http://zeta.lerc.nasa.gov

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