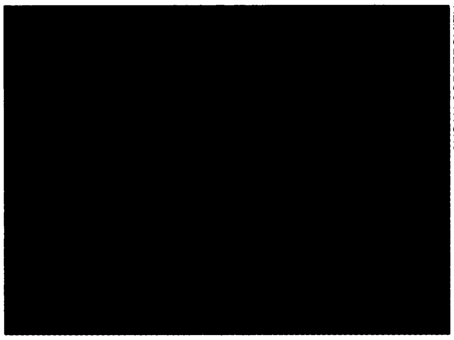
PHYSICS

A Fine-Grained Look at Forces in Sand

KANSAS CITY, MISSOURI—Next time you stand on a sandy beach gazing out over the ocean, you may be intrigued to know that some surprising physics is taking place right under your feet. At an American Physical Society meeting here last month, Susan Coppersmith, of the University of Chicago, described a set of experiments that have begun to piece together just how weight gets divvied up and passed downward in granular materials such as sand and beads. It turns out that the forces are not distributed evenly among the grains, as you might expect. Instead, like a human pyramid in which some of the tumblers are doing more than their fair share of the work, the weight gets transmitted downward from grain to grain in jagged "force chains."



SUSAN COPPERSMITH

Force chains. Beads that change polarization under stress show uneven force distribution.

Coppersmith's group—using devices ranging from high-tech optics to low-tech carbon paper—has provided the first three-dimensional views of these chains. And colleagues such as James Kakalios, a physicist at the University of Minnesota, agree that the experiments are "rather clever." Understanding such measurements, he says, "is very interesting and important, because forces in granular materials do not get transmitted in the same way they would in a fluid." This penchant for pushing in directions other than straight down, says Kakalios, is important in everything from grain silos, the sides of which may suddenly rupture, to the steady, unfluidlike flow of sand in an hourglass.

Coppersmith's group includes researchers at the University of Chicago; the Xerox Corp.; the University of California, San Diego, and Santa Cruz; and the Tata Institute of Fundamental Research in India. The team used a simple image to convey the topic under study: "a foot on the beach in Aruba." Coppersmith described two sets of experiments to examine the way grains under the hypothetical foot might be affected. In the high-tech version, researchers used clamps to apply pressure to a 10-centimeter-tall container filled with half-millimeter beads made of a special material, the light-transmitting quality of which changes under pressure, exhibiting "stress-induced birefringence." As stress increases, this material rotates the polarization of light. Coppersmith's group shone a light through a polarizing filter, then through the beads, and finally through a second filter at right angles to the first. Only light rotated by beads under stress could get through, producing an illuminated map of stress lines.

To learn how the weight is distributed quantitatively, the group went low-tech. They discovered that when the bottom of the stack of beads rested on a piece of carbon paper placed facedown on a clean sheet of paper, the sizes of the resulting smudges were proportional to the weight on a given bead. "The idea that you can get real, quantitative data from carbon paper blows my mind," says Sidney Nagel, a Chicago team member.

The carbon paper not only produced useful results, but those results agreed reasonably well with a quantitative model the group had developed. This model, based on observations of the force chains and computer simulations, assumes that a given bead divides the weight randomly among the three beads on which it rests. This approach leads to sharper spatial concentrations of weight than would be predicted by standard "bell curve" statistics. But the approach keeps the weight more evenly distributed than does "fractal statistics," used to describe some gases and liquids. "It's quite amazing that you can do so well with such a simple model," says Coppersmith. She now aims to apply concepts gleaned from this work to phenomena such as shear motion—which occurs as sand or mud begins to avalanche.

In order to tackle more realistic problems involving piles of grain, says Pierre-Gilles de Gennes of the École Supérieure de Physique et de Chimie Industrielles in Paris, researchers will need to refine the principles they have extracted from this weight-distribution research. For example, he points out, the Chicago model ignores the role of arches of grains that can spontaneously form and direct weight toward the edges of the container. Other groups, especially that of Jean-Philippe Bouchaud at the Atomic Energy Agency's Centre d'Études de Saclay and Michael Cates at the University of Edinburgh in the U.K., are looking into that issue. The curious physics of sandpiles should keep these researchers occupied for years to come.

–James Glanz

SCIENCE PUBLISHING

Fermilab Group Tries Plain English

Leonardo da Vinci composed his notebooks in mirror-image script, in part to make them incomprehensible to prying competitors. A casual reader of today's physics journals, packed with jargon and unwieldy diction, might conclude that modern savants have discovered how to achieve the same goal in standard, left-to-right prose. Now, however, a major research group in one of the field's most intimidating enclaves—particle physics—has decided it cares enough about its readers to post, on the World Wide Web, a "plain English" version of every technical paper it publishes. The seemingly revolutionary experiment aims to bring particle physics to a wider audience and ease the job of scientists trying to stay abreast of specialties outside their own.

The philosophy is simple, says John Womersley, a physicist in a collaboration known as D0, at the Fermi National Accelerator Laboratory (Fermilab), just west of Chicago. "We really feel that if we can't explain what we're doing, then we shouldn't be doing it," says Womersley, who wrote the first of three D0 group reports now available on Fermilab's Web site.*

Early reviews of the Web products' accessibility have been decidedly mixed, but at least one other group has plans to begin a similar program, and some observers predict that more will be forced to follow suit. "D0's 'plain English' is a first, very important step" toward better public communication, says Petra Folkerts, a press and information officer at the Deutsches Elektronen-Synchrotron in Hamburg, Germany.

Members of the D0 group, the name of which is derived from the huge D0 particle detector hunched over Fermilab's Tevatron accelerator, concede that generating publicity was at least part of the motivation for starting the project. "We know there is going to be a lot of pressure on science in the future to justify its existence," says Harry Weerts, a D0 spokesperson at Michigan State University. "We shouldn't forget where the funding is coming from, right?" Taxpayers, who foot the bills, are on D0's readership wish list. But the physicists say they don't want to create just another type of press release; instead, they hope to educate the public about the way scientific research is usually done—not in big jumps, but in many small steps. That way, says Womersley, "we don't have to worry so much about writing a punchy story that will get us above Michael Jackson's baby" in the daily newspapers. The reports, he says,

* http://d0sgi0.fnal.gov/public/pubs/d0_physics_summaries.html

will be written by the principal author of the technical report itself and reviewed mainly within the collaboration. Then, each will be put on the Web when the technical report gets submitted to a journal.

Like any literary debut, the group's first efforts have been deconstructed by the critics. "I certainly welcome" their intentions, says Michael Riordan, a particle physicist at the Stanford Linear Accelerator Center and the author of several books, including *The Hunting of the Quark*. "But I caution that [translating physics to English is] not so easy to do." The writers' style in the first reports, he says, "assumed the reader already knew what they were talking about."

Getting the message beyond the scientific community to the wider public could be difficult. "The main issue," says Teri Ann Doerksen, who uses science articles as an aid for teaching composition at Hartwick College in Oneonta, New York, "is one I see in composition papers all the time"—expecting too much of the readers. "If you can't gauge your audience, you have no way to figure out what level of detail you need to go into when you define your terms," says Doerksen. Weerts admits that the expositions are "not totally plain English yet," but predicts that as D0 blazes the trail, other groups will follow.

Within Fermilab, at least, the idea already seems to be winning new adherents. Members of a competitor group, called CDF, have announced that they will write lay versions of not only technical publications but major conference presentations as well. "I wouldn't be surprised if other groups do this also," says Alfred Goshaw, a CDF spokesperson-elect at Duke University. "It's such an obviously good idea."

–James Glanz

PHYSICS

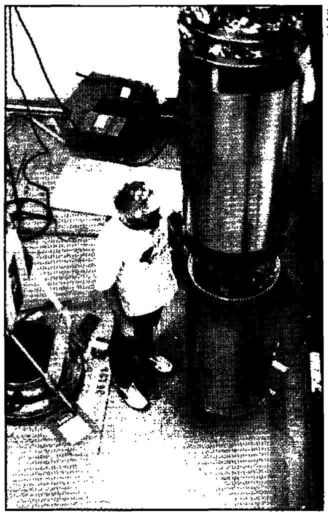
In Search of the Cleansing Axion

Few particles offer so much as the axion: Its proponents claim it will iron out a wrinkle in the Standard Model—physicists' description of nature's fundamental particles and forces—while solving the mystery of the universe's missing mass. First, however, this elusive beast must be discovered. Physicists are keenly awaiting the results of two experiments—one just analyzing its first data and the other just starting up—which may finally answer the question of whether these ghostly particles really exist. "If the axion is discovered, it would be an extraordinary triumph for theoretical physics," says Frank Wilczek of Princeton's Institute for Advanced Study.

The axion was proposed nearly 20 years ago to overcome a problem in quantum chromodynamics (QCD), a central plank of the Standard Model that describes how quarks—the building blocks of protons and neutrons—are held together by gluons. QCD requires that the interactions between quarks and gluons be symmetrical under time reversal—they must work identically if time runs backward—and that they have handedness symmetry, too: Left- and right-handed quarks and gluons must be treated equally. In 1978, Wilczek and, independently, Steven Weinberg of the University of Texas, Austin, realized that a new particle would be required to guarantee the symmetry of quark-gluon forces. Wilczek had seen a detergent called Axion and thought it sounded like a good name for a particle. "When it appeared that one needed a particle to clean up a problem with the axial baryon number current of QCD, it was impossible to resist," he says.

Since then, numerous attempts to detect axions have all ended in failure. Wilczek says part of the problem is that physicists searching for axions in particle collisions or nuclear transitions were looking in the wrong place. Now, they are looking to cosmology and astrophysics: Current theories of the formation of the universe predict that the primordial fireball spawned axions in huge numbers, and we should, theorists argue, be awash in a soup of axions each weighing just a few microelectron volts. There could be as many as a million million axions per cubic centimeter around us, so although they are very light, they could make up a large proportion of the invisible 90% of the mass of the universe.

Axion proponents are pinning their hopes on two experiments to detect this axion soup. Both are based on an idea first proposed in 1983 by Pierre Sikivie of the University of Florida. "The principle is that an axion may convert to a photon in a large, externally applied magnetic field," says Sikivie. "The conversion probability is very small but gets enhanced if the conversion occurs inside a cavity tuned to resonate at the [photon] frequency set by the axion mass."


LLNL

In the can. The bottom cylinder is the cavity that catches axions in Livermore's detector.

One of the experiments involves one Russian and six U.S. institutions and is based at Lawrence Livermore National Laboratory (LLNL) in California. "Basically, the experiment is a radio receiver," says physicist Karl van Bibber, co-leader of the LLNL-based effort. The receiver is a copper cavity, cooled to 1.3 kelvins and bathed in the strong magnetic field from a 6-ton superconducting magnet. The researchers tune the cavity so that its resonant frequency matches the frequency of the photon an axion should transform into, and if one does, it would be detected electronically.

The experiment has now been running for a year, and the team expects to finish analyzing the first data this month, says van Bibber. They have some candidate axion signals, but if these do not pan out, the researchers hope to at least set some limits on the number of axions around us, or on the chance that they convert into photons. Van Bibber says they plan to increase the experiment's sensitivity 10-fold next year, putting all favored axion models within reach.

Meanwhile, across the Pacific, Seishi Matsuki and his team at the Institute for Chemical Research at the University of Kyoto in Japan are in the process of starting up a rival axion experiment that is even more technologically challenging. "We visited his lab in early December ... and it is really a fantastic project," says van Bibber.

Matsuki's experiment also relies on converting axions to photons in a resonant cavity, but he plans to detect the photons with Rydberg atoms, in which electrons are pushed to the outermost orbitals, almost out of reach of the nucleus's pull. If any axions convert into photons, these are absorbed by Rydberg atoms in a beam passing through the cavity. The beam then passes through an electric field that will ionize only those atoms that have absorbed a photon. "Thus, ions are detected as a signal of axions," says Matsuki. First, the group is searching for axions with masses of about 10 microelectron volts. "It will take about 3 months to complete the measurements with the present experimental sensitivity," says Matsuki.

Van Bibber says even agnostics who are not "sold on axions until they are found" are eagerly awaiting the results of the two experiments: "It is encouraging to us that even those people are strong supporters of our experiment."

–Andrew Watson

Andrew Watson is a science writer in Norwich, U.K.