Simply Plasma

By IVARS PETERSON

Making sense of thick, seething stews of charged particles

On Earth, it takes a well-aimed burst of intense laser light or a lightning bolt crackling through the air to break down matter into a hot plasma of electrons and positively charged ions.

But in the universe at large, plasmas exist nearly everywhere, from the depths of the sun to gas clouds within and between galaxies. In fact, more than 99 percent of visible matter in the universe exists as plasma of one kind or another.

Plasmas behave like fluids. They can flow; they follow physical boundaries; they carry waves. They also react in diverse ways to electric and magnetic fields.

The details of what happens within a given plasma, however, have remained elusive. Physicists still do not understand fully all the processes that can go on when countless charged particles, driven by attractive and repulsive electrical forces, jostle one another.

Over the years, researchers have tried to describe these complicated interactions in terms of relatively simple mathematical expressions that capture the essence of plasma behavior at different temperatures and densities. In most cases, such equations link plasma characteristics to collisions between ions and highly mobile electrons.

Two physicists have now developed new equations to describe types of plasmas inadequately explained by previous mathematical formulations. "We believe that these equations will in some cases allow physicists to treat a class of plasmas that was previously inaccessible to simple analytic calculations," says Richard D. Petrasso of the Plasma Fusion Center at the Massachusetts Institute of Technology.

For example, using the equations, researchers can calculate simply the amount of energy transferred when highly energetic particles slam into a tiny pellet of nuclear fuel during laser-initiated nuclear fusion, a process that creates plasma.

Nuclear engineering graduate student Chi-Kang Li, who worked with Petrasso in developing the equations, reported the team's findings at an international workshop on atomic physics for ion-driven fusion, held in Santa Fe, N.M., in November.

Until the work of Petrasso and Li, plasma physicists tended to focus on two categories of plasma. So-called weakly coupled plasmas — such as the halo of charged particles in the corona enveloping the sun or the trail of disrupted gas in the wake of a lightning bolt — have very low densities but relatively high temperatures. Strongly coupled plasmas — which exist in the interior of planets such as Jupiter and in the crust of neutron stars — are extremely dense but comparatively cool.

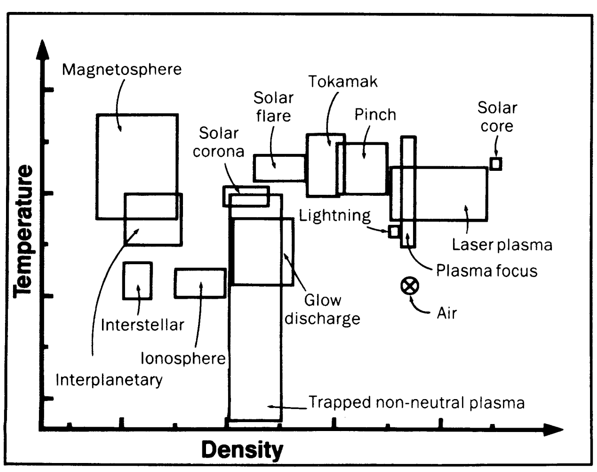
But many plasmas don't fit into either of these categories. "Moderately coupled" plasmas — found, for example, throughout the interiors of sun-like stars, including at their cores where nuclear fusion takes place — fall somewhere between the two extremes. Neither set of equations normally used for strongly and weakly coupled plasmas adequately describes the behavior of the mid-range plasmas.

"There's certainly a large set of plasmas out there for which these equations do not apply in a straightforward fashion," Petrasso says.

To predict plasma behavior in these intermediate cases, physicists sometimes resort to solving large sets of complicated equations, and they can succeed only by using computers to zero in, step by step, on approximate answers. But it's a long and tedious process available only to those who have access to supercomputers and reliable computer programs to do the horrendous calculations.

To find an alternative approach, Petrasso and Li took a close look at the equations often used in describing weakly coupled plasmas. They discovered a way of extending these equations — taking into account additional types of collisions between charged particles — to cover moderately coupled plasmas.

The result was a set of formulas that physicists could use to calculate reasonable answers to questions about plasma behavior without necessarily having to go to supercomputers. "Although this work is in its infancy, we have in some cases already obtained clean, simple expressions that can be easily [worked out]," Petrasso says.



Petrasso

Differences in temperature and density characterize different types of plasmas. As a reference point, the X marks the density and temperature of air.

The sun's core isn't the only place where moderately coupled plasmas play a significant role. They also form when extremely short, intense laser pulses strafe matter.

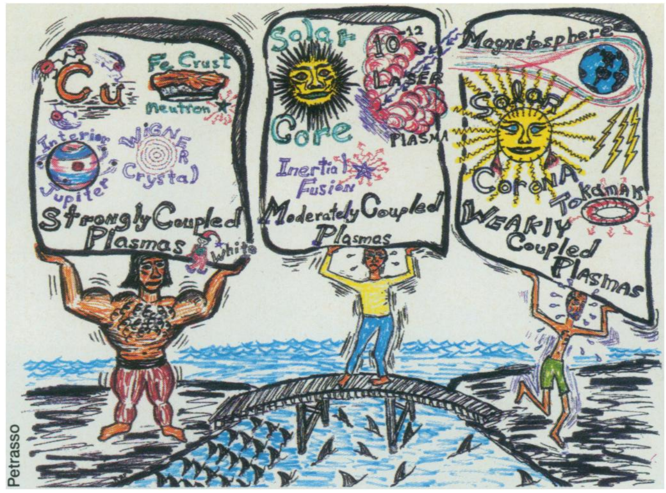
In inertial confinement fusion, for example, lasers irradiate a tiny nuclear fuel pellet — about 1 millimeter in diameter — from all directions. Composed of compressed deuterium and tritium, the pellet implodes, creating a plasma that has many of the same characteristics as the plasma at the sun's center. Inside the plasma, nuclei fuse and release energy, which researchers hope to harness to generate electricity.

Using their new equations, Petrasso and Li have calculated how speedy, charged particles — alpha particles, tritium nuclei, or electrons — deposit energy into a dense, moderately coupled plasma formed at the center of a nuclear fuel pellet as it goes from its initial cold state to full ignition. They described their techniques in two papers in the May 17, 1993, PHYSICAL REVIEW LETTERS.

When Li presented these results at the Santa Fe meeting, they prompted a great deal of heated discussion. "In some ways, this work engendered more controversy than any other topic," says Thomas A. Mehlhorn of the Sandia National Laboratories in Albuquerque, N.M., who chaired the meeting.

Some critics complained that the most significant parts of the work were of little practical value in plasma calculations for fusion research. The extra terms included in the new equations turn out to be unimportant in most real situations, they argued.

"I don't think we know all the answers at this point," Petrasso replies. "But if nothing else, I do feel confident that [our approach] provides a different insight into the problem, and I think it's much simpler mathematically. Alternative approaches tend to be more complicated."



Richard Petrasso's cartoon depicts three categories of plasmas, characterized by different ion densities (as seen in the concentration of shark fins).

Other critics insisted that supercomputer-based calculations intrinsically take into account the effects highlighted in the Li-Petrasso equations. However, not every physicist wants to turn automatically to a computer for the solution to any problem that comes up in understanding plasmas or other aspects of the physical world.

"There are complicated problems, and there are problems that need computers," Petrasso readily concedes. "But how do you know you have the physics [properly encapsulated in the computer program]?" he asks.

Moreover, for researchers unfamiliar with the details of exactly how certain computations are carried out, results that come out of a complex computer model can often prove less than insightful.

"Maybe our contribution will be that [our formulation] helps us to see things from a different point of view," Petrasso says. "That might be useful. We have a simple formula, and it's easy to understand physically. The final result has a certain clarity about it that's very difficult to obtain through other approaches." □

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The Hearing Loss Handbook — David M. Vernick, Constance Grzelka, and the editors of Consumer Reports. For people facing hearing loss or auditory disorders, this reference provides a basic introduction to sound and how the ear works, then outlines testing procedures for hearing problems and common causes. Additional chapters describe how to detect hearing problems in children and find the right medical help and schools, how to find the right hearing aid, and preventive measures for hearing loss. Consumer Reports, 1993, 278 p., b&w illus., hardcover, $22.95.

The Independent Home: Living Well with Power from the Sun, Wind, and Water — Michael Potts. A compilation of interviews with people from every corner of the United States who have left the utility grid and created self-sustaining homes that use renewable and clean resources. Functional advice for virtually anyone looking to achieve these goals is intertwined with first-hand accounts, including descriptions of every aspect of building an independent home — from planning, to finding an appropriate location, to potential problems. Ancillary items such as solar hot water heaters and cars are featured as well. Chelsea Green Pub, 1993, 300 p., b&w photos and illus., paperback, $17.95.

Scribes, Warriors and Kings: The City of Copán — William L. Fash. The ruins of Copán are some of the most complete excavated in the New World; however, deciphering scripts found there was a tedious process that hindered the project for years. Fash, director of the Copán Acropolis Archaeology Project, relays the major discoveries that broke the code and describes what we now know about the ancient Maya at every sociological level. The environment, political structure, and art of the Maya are also described. Originally published in hardcover in 1991. Thames Hudson, 1993, 192 p., color photos and b&w photos and illus., paperback, $19.95.

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The Young Scientists: America's Future and the Winning of the Westinghouse — Joseph Berger. Students competing in the Westinghouse Science Talent Search vie for more than $200,000 in scholarships, making this the premier science competition in the United States. And the prestige of being a top 40 finalist virtually guarantees admittance to a top college or university. Berger investigates how teenagers reach this pinnacle and how many are able to produce original research projects at the graduate level or higher. He focuses on their home life and cultural heritage and specifically examines the teaching methods of the science-oriented schools that many of these students attend. He focuses on Stuyvesant and the Bronx High School of Science in New York City, where the Westinghouse has created rivalries comparable to those centered on football in most other high schools. Addison-Wesley, 1994, 243 p., hardcover, $21.95.