Hope on the Road to Controlled Fusion

The effort toward controlled thermonuclear fusion has now lasted 30 years, and the record of the early years was a bleak one with few achievements slowly and dearly purchased. Recent years have seen some light at the end of the tunnel, or the center of the plasma, and the latest meeting largely devoted to the subject, last week's gathering of the Plasma Physics Division of the American Physical Society at St. Petersburg, Fla., shows that heartening progress is now being made on a number of approaches.

The basic problem is to contain a plasma of nuclei and the electrons that have been stripped from them in a small enough space for enough time so that a useful number of fusions take place. At the same time the nuclei must be supplied with enough energy (temperature) to overcome the electrical repulsion between them so that they can fuse.

A plasma is an electrically conducting fluid, and as such is susceptible to magnetic forces. The earliest attempts to contain plasma centered on the use of magnetic fields, and the modern descendants of that idea are quite various. One of its most widespread applications is the device called tokamak, which was invented in the Soviet Union, but is now under experiment all over the world.

A tokamak is a toroidal chamber in which a plasma is confined by a combination of magnetic fields and heated first by an electric current run through it and then by various auxiliary means. A tokamak called Alcator, at the Massachusetts Institute of Technology has recorded a significant advance in confinement and density, according to the report of Ronald Parker, one of the leaders of the experimental team.

The statistical probability of a good fusion rate depends on the confinement time and the plasma density. The product of these, called the Lawson criterion, is often used to compare experimental achievement. Alcator's Lawson criterion reached 10^{13} (the unit is the somewhat odd-sounding one of seconds per cubic centimeter), five times the greatest number achieved anywhere else. The report drew a number of admiring comments.

However, there is another factor, the temperature. In the Alcator experiment it reached 10 million degrees K., which is about one tenth of the threshold temperature required for useful amounts of fusion. Temperatures of the threshold kind have been achieved in other experiments, notably a level of 130 million degrees in the Lawrence Livermore Laboratory's 2XII-B magnetic mirror device. Getting the right temperature and the right Lawson number in the same experiment is the sticking point. F.H. Coensgen reported that 2XII-B's Lawson number at that temperature is about 7×10^{10} seconds per cubic centimeter.

The difficulties of combining the right factors in magnetic machines led some physicists to go back to the basic idea of the hydrogen bomb: a device in which miniexplosions of small fuel pellets provide recurrent puffs of energy. The first scheme for producing miniexplosions proposed using laser light. Hitting a little sphere with laser light from all sides would cause an ablation of the outer layer. This surface explosion causes (by Newton's third law) an implosive reaction in the rest of the pellet, compressing and heating the fuel to the fusion point.

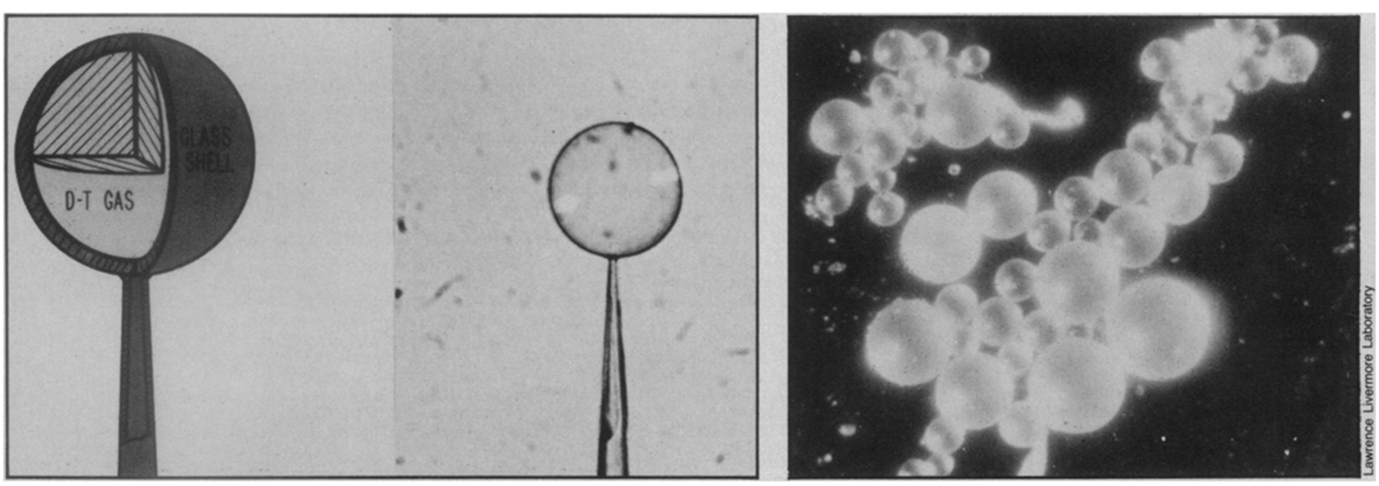
The physics of this implosion are such that John H. Nuckolls of the Lawrence Livermore Laboratory can say it depends on the principle that "the best things in life are free." This caused a lot of muttering that you have to pay a lot to get to the point where the free ride begins, and indeed Nuckolls's Livermore colleague, H.G. Ahlstrom, remarked: "Laser fusion is a very expensive experiment at Livermore."

Nonetheless, progress is being achieved at Livermore and elsewhere. Compressions achieved lead to claims of Lawson numbers of 10^{12}. More significant perhaps, some time ago KMS Fusion of Ann Arbor, Mich., claimed experiments that yielded neutrons that came from fusions at the center of the implosion. Now Livermore people think they see such neutrons too.

Although the Livermore experiment irradiates the target with only two beams, Ahlstrom says the implosions "are indeed thermonuclear." The 10 million or so neutrons they record are "not a very significant number," according to Nuckolls, but they hope for better in the next few years when the experiment will be able to deliver several terawatts of power to the target.

But the nitty is beginning to get a little gritty. Progress seems to depend on how the laser light couples to the pellet. There are problems with reflections and with electrons that get energized and do unwanted things. Livermore is experimenting with layered pellets to try to get around these problems. One example is a glass shell containing deuterium and tritium. The glass is used as a pusher for the implosion. The shape of the pellets seems crucial too. Nuckolls says they have to be accurate to within 10 to 100 angstroms. This requirement caused some intakes of breath around the room. Some expressed doubt that such finely machined pellets can be manufactured economically in the numbers that eventually would be needed.

A way around some of the difficulties



One example of laser fusion target, glass shelled D-T pellet, with models of various sized pellets under consideration.

of laser implosion, it seems, may be by the use of beams of electrons or protons to compress the pellets. Work of this sort was described by M.J. Clauser of Sandia Laboratories. It promises to avoid some of the reflection and other energy-coupling difficulties of laser implosion and uses larger targets (several millimeters across), which make irradiation easier. The targets have metal shells filled with deuterium and tritium. At first the metal was gold; then the experimenters found that adding some carbon helped, so they wound up with the exotic combination of diamond on gold. They have been working with electrons of one million electron-volts (MeV) and 10-MeV protons. Clauser figures that break even—getting as much energy out of fusion as you put in to make it go—could come with 300 megamperes of 1-MeV electrons or 10 megamperes of 10-MeV protons.

Certain magnetic-confinement devices also implode the plasma (thus heating and condensing it) by sudden increases in magnetic field strength. These are called pinches. The most famous pinch in the United States is the Scyllac project of Los Alamos Scientific Laboratory. It will be a torus 15 feet in diameter, and is being assembled out of short sections. Tests of the sections indicate they are working well.

Another, unusual kind of pinch, is the belt pinch at the Max Planck Institute for Plasma Physics at Garching, West Germany. This is a pinching tokamak, which differs from other tokamaks by having a noncircular, racetrack-shaped cross section. According to R. Wilhelm, first experiments went well, reaching a Lawson number of about 2.8×10^{10} seconds per cubic centimeter, but at a temperature of 3 million degrees.

A pinch that uses a physical implosion, an imploding liner in the cylinder, is the U.S. Naval Research Laboratory's Linus project, reported by A.E. Robson. Major problems involved in designing such a thing were to avoid destroying the outer magnet coil and to provide for recovery so that the plasma could expand back for another shot. A lead and lithium mixture that provides a rotating implosion may prove best. The method of compressing a magnetic field by spatial implosion is borrowed from ultrahigh-field experiments in magnet laboratories, where there's usually no worry about destroying coils or using the apparatus for more than one shot. The method should produce megagauss fields and a dense hot plasma. Whether the idea can be scaled to practical reactor size depends on the fields that can be achieved and how well specially configured fields can prevent plasma loss through the ends of the cylinder.

Finally there is a mixture of a number of ideas now current in the experiment called LITE at United Technologies Research Center, described by D.H. Polk and several others. This uses laser irradiation of lithium hydride or lithium deuteride particles to make a dense, warm plasma in the field of a magnet shaped like the seams of a baseball. The plasma is then further heated and contained by injection of a beam of neutral atoms. Lawson numbers greater than 10^9 are claimed so far. One plasma physicist, hearing of this device, remarked that this sort of combination of most of the current ideas might prove the way to go for the future. □

Math in the schools: What's wrong?

Recent reports of falling mathematics scores have added new fuel to the public debate over the effect of two decades of major change in school mathematics curricula. A natural inference, which many parents have drawn, is that "New Math" programs are responsible for declining mathematics test scores. But a new nationwide study of content and achievement in school mathematics contradicts this common assumption.

The study, called "Overview and Analysis of School Mathematics," was commissioned by the Conference Board of the Mathematical Sciences—a consortium of 11 mathematics-related professional societies—and carried out over an 18-month period by the National Advisory Committee on Mathematical Education (NACOME). Its major conclusion is that mathematics education in the United States today is incredibly pluralistic. What is true in one school is likely to be false in another; indeed, the committee says, contradictions may often be found in different classrooms of the same school or in the same classroom on different days.

The decline in test scores, for instance, reflects this kaleidoscopic pattern. While the committee did find considerable evidence of a decline of computational ability, it also found some evidence of an increase in comprehension and understanding. Moreover, declines in mathematics test scores, where found, paralleled a general pattern of decline in all scholastic areas. The committee found no evidence that linked changes in mathematics test scores to particular changes in mathematics curricula.

Indeed, the committee said it could hardly recognize the presence of any clearly defined mathematics curricula. Instead of finding some schools using "New Math" and others using "Old Math," it found in most schools an eclectic pattern that severely compromises the curricular reform of the past two decades. The distortion of objectives and the transformation of means into ends—described by one observer as the serving of the icing rather than the cake—has, in the committee's view, been so extensive that the label "New Math" no longer carries any meaning. "New Math versus Old Math is a non-issue," says Ross Taylor, director of mathematics for the Minneapolis public school system. "The real story in mathematics education is the vast difference in perception of the problem between the public and the professional."

One such difference concerns the use of hand calculators in the classroom. Even though many people worry that a massive introduction of calculators will undercut what little remains of students' computational ability, the NACOME report advocates that at least from eighth grade and on, a hand calculator should be available for all work, including all tests, "for each mathematics student for each mathematics class."

Although admitting that injudicious use of a calculator could turn it into a computational crutch, the NACOME mathematicians and educators argued that a properly used calculator will enhance motivation for the learning of arithmetical skills. But Clifford E. Swartz of the State University of New York at Stony Brook reacted with skepticism:

"I'm worried about this because the report also recommends that a lot of research be done on what happens when you have hand calculators in the classroom. We are getting into a situation once again where something is being put into the schools and we don't really know much about what the effect will be. What I am afraid of is that those calculators are going to get out there and will be used in exactly the ways that we don't want them used. All that we will get is the icing again."

Expressions of distress over the lack of coordination between tests and curriculum objectives permeate many aspects of the committee's report. Too often, it says, the content of tests determines the nature of the curriculum. That, noted NACOME chairperson Shirley Hill of the University of Missouri, is really putting the cart before the horse. The committee strongly advocates that both programs and student evaluations be based on tests that are matched to the goals of the curriculum. "This sounds very sensible," commented Hill, "but it isn't always done."

The committee does not advocate any major shifts in curriculum content. Its report agrees with the direction and thrust of the earlier reform programs—that logical structure be the framework for the study of mathematics—but goes on to stress the need for relating mathematics to its applications at all levels in the curriculum. In particular, the report recommends that basic statistical ideas be introduced throughout the school mathematics curriculum. Statistical literacy, the report argues, is more vital to consumer education than, say, elementary algebra or geometry, because it reduces the individual's vulnerability to onslaughts of fancy sounding numbers. □