search & discovery

AEC opens up on laser fusion implosion concept

Interest in laser-produced thermonuclear fusion is increasing rapidly. Until recently almost all discussion in the open literature mentioned only the possibility of using the laser to heat a fusion-fuel pellet, and most observers argued that the laser energy requirement for a fusion reactor would be impracticably high.

In November, in testimony before the Joint Congressional Committee on Atomic Energy, Robert Hirsch (then in the AEC Division of Research), revealed that the laser could also be used to cause an implosion of the pellet. This was apparently the first AEC announcement of the hitherto classified concept.

The following month, at the annual meeting of the American Association for the Advancement of Science, John Nuckolls and Lowell Wood of Lawrence Livermore Laboratory discussed calculations indicating that the laser energy requirement could be reduced by many orders of magnitude if the pellet were imploded to very high densities.

In April Keith Brueckner, vice-president of KMS Fusion, a subsidiary of KMS Industries, gave a talk at the University of Michigan revealing his previously classified calculations of laser-produced implosions. In May, at the Quantum Electronics Conference in Montreal, workers from many laboratories gave reports related to laser-produced fusion. Also in May AEC further declassified the program, although most of it remains classified.

So far there has been no experimental observation of laser-produced implosion, but some experts believe that workers at the Lebedev Institute in Moscow, under Nikolai Basov, are doing implosion experiments right now with their nine-path laser, which delivers 1300 joules in 16 nanosec and 600 joules in 2 nanosec onto a pellet. The Soviet group is apparently two to three years ahead of the rest of the world in development of the type of large lasers needed to implode fusion fuel to efficient thermonuclear burn conditions.

Theory. The work reported in Ann Arbor by Brueckner and in Montreal by the Livermore workers (Nuckolls,

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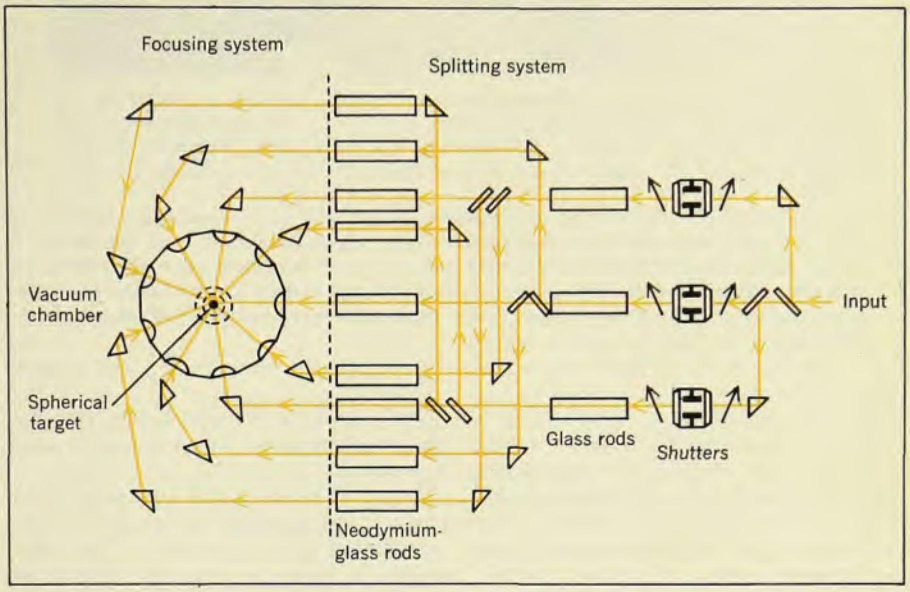

Nine-path laser at Lebedev Institute produces 1300 joules in 16 nanosec and 600 joules in 2 nanosec. The beam is split into three parts, each of which is then amplified by a rod. Then each beam is again divided into three, and each is again amplified. The nine beams than converge onto a single target. A 27-beam laser, now being constructed by the Soviet group, is expected to yield 200 joules in 2 nanosec.

The case of the missing solar neutrinos

The Brookhaven solar-neutrino experiment, after five years of running, is in even worse disagreement with theoretical expectations than it was earlier. While the theoretical value has tended to rise slightly, the experimental limit has dropped and is consistent with zero.

At a conference on neutrino astrophysics held near Budapest in June, Raymond Davis reported the most recent upper limit on the solar neutrino flux—less than 1 solar neutrino unit (1 SNU = 10^{-36} sec^{-1} per target atom). His limit reported in 1968 was less than 3 SNU, and so was his limit reported in 1970. However, some experts say that they will remain somewhat skeptical of the technique, beautiful as it is, until Davis has demonstrated that he can collect argon produced in a beta interaction, for example, Ar^{36} from the decay of Cl^{36}.

Theory. As John Bahcall (Institute for Advanced Study) says, Davis's value is "just not a socially acceptable number in solar-evolution circles. That's a number that cannot be reconciled with the standard theory of stellar evolution," which predicts a lower limit on flux of 1.7 ± 0.3 SNU. This limit would prevail if you assume the decay of B^8 in the solar-evolution process is prevented from taking place somehow or if the heavy-element abundance in the interior is a factor of ten or more below the observed surface abundance.

The predictions of current solar models (such as those by Zulema Abraham and Icko Iben Jr, MIT and Roger Ulrich and Bahcall, UCLA) are all about 9 ± 3 SNU, however, a factor of nine times greater than the Brookhaven upper limit. Recent work by M. Gari and A. H. Huffman at Cal Tech on the meson exchange correction to the proton–proton reaction reduces this

Jubilation at the Los Alamos Meson Physics Facility. LAMPF achieved its first proton beam at full design energy of 800 MeV on 9 June. Gathered at the computer control console are, in foreground from left, Harry Williams, Kenneth Crandall, Donald Swenson, Thomas Putnam, Robert Jameson and Louis Rosen (clapping hands).

In the initial operation the Los Alamos workers achieved approximately 0.1 microamp average current and 4 milliamp peak current. Rosen explained to us that such a high peak intensity indicates that they probably will not have trouble with beam blow-up. Still to be demonstrated is that they can avoid beam loss and achieve an average current of 1 milliamp on a regular basis (with a peak intensity of about 17 milliamp).

value to 7 ± 3 SNU.

There is another limit, of 0.3 SNU, which one would get if the sun shines only as a result of nuclear-fusion reactions in its interior and has no stellar evolution. The Brookhaven result does not disagree with this limit, but it strongly disagrees with the general wisdom. It is clear that something has to give.

The answer may lie in nuclear physics, in astrophysics or in neutrino physics. A. G. W. Cameron (Belfer Graduate School) points out that there is a tendency for workers in any one of these fields to feel that chances are slim that the fault lies in their own speciality; so one of the other fields must be involved, they believe.

A variety of explanations have been offered. Bahcall, Nicola Cabibbo and A. Yahill (Institute for Advanced Study) suggest that the reason you don't see any neutrinos is that they decay on their way from the sun, with a halflife less than 8 minutes for a 1-MeV neutrino (which is the energy to which the Brookhaven detectors are sensitive). Although he admits the hypothesis is "not pretty," Bahcall told us such a decay is not ruled out by terrestrial neutrino experiments, which deal with distances of the order of meters and with neutrinos of much higher energy than those coming from the sun. The hypothesis would require a finite mass for the neutrino. An experiment to test this hypothesis would be the reaction $Li^7 + \nu \rightarrow Be^7 + e$. This reaction is primarily sensitive to the very low-energy neutrinos from the so-called "pep" reaction, in which two protons and an electron go into a deuteron plus a neutrino.

Some theorists have suggested that the sun is changing its temperature on a cycle of 10^4–10^5 years. The solar radiation takes ten million years or so to diffuse up from the center to the surface and we observe the average energy produced during that time; so the cyclic variation would not be detectable. Unfortunately it is difficult to see why the sun would oscillate with such a period, since damping mechanisms are quite strong. However, since the sun is near convective instability transient mixing is possible with effects that will last for a period of the order of the Kelvin–Helmholtz time of approximately 10^7 years. William A. Fowler of Cal Tech has shown that the neutrino flux can be reduced to well below the observed limit for comparable periods, and this has been confirmed in detailed calculations by Robert Rood at Cal Tech and by F. W. W. Dilke and Z. O. Gough at the Institute of Theoretical Astronomy, Cambridge, UK.

Another suggestion, this time in nuclear physics, comes from Fowler. He says it is possible that there is a very narrow, excited state in Be^6, and it occurs where it would cut out the Be^7 and B^8 neutrinos by terminating the proton–proton chain at the $He^3 + He^3$ reaction. Current nuclear-physics ideas suggest such a narrow resonance is unlikely.

The Brookhaven experiment, done by Davis, John C. Evans, Veljko Radeka, Lee Rogers and John Galvin, is conducted a mile underground in the Homestake Gold Mine in Lead, South Dakota. The detector is a 100 000-gallon tank of perchlorethylene. Neutrinos are absorbed in Cl^{37}, forming Ar^{37}, which has a halflife of 35 days. The tank is exposed for two to three halflives (by the end of three months the production rate is equal to the decay rate) and then the Ar^{37} is removed by bubbling helium through the liquid. Helium is circulated through a cryogenically cooled charcoal trap to collect Ar^{37}. A small quantity of Ar^{36} is used as a carrier to make sure argon is recovered efficiently from the tank. The sample is then purified and placed in a very small gas proportional counter; one measures the 2.8-keV x rays coming from the decay of Ar^{37} back to Cl^{37}.

Besides measuring the energy of the decay, the Brookhaven group measures the rise time of the pulse, to distinguish between the Ar^{37} Auger electrons and pulses coming from various background processes. This added discrimination for Ar^{37} events lowers the counter background for Ar^{37}-like events, thus permitting more sensitivity to solar neutrinos.

An additional improvement to the experiment has been the addition of a water shield with an average thickness of about 2 meters; this eliminates the effect of fast neutrons from the surrounding rock. —GBL

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Wood, Albert Theissen and George Zimmerman) is quite similar. Both groups talk about time-tailoring the laser pulse to maximize the implosion effect, but the details of tailoring differ. And both groups consider not only solid spherical pellets but also hollow spherical shells, a geometry that further reduces the required peak laser power and the complexity of the laser pulse form but requires about the same total laser pulse energy.

KMS Fusion is conducting classified research (without AEC funds) on the laser-implosion method, and it hopes to spend \$50 million on the program in the next four years. The company has applied for patents on some of Brueckner's ideas, originated three years ago. (However these patent applications are being contested by AEC.) This is approximately the time when the AEC laboratories, Livermore and Los Alamos, began to rapidly expand their efforts in laser-produced fusion.

In a statement by Keeve M. Siegel, chairman of the board of KMS Industries, prepared for the Joint Committee, he said that if a significantly larger effort is mounted a "proof of principle"