search & discovery

KMS claims thermonuclear neutrons from laser implosion

The experimental observation of a laser-driven spherical implosion has been reported by a group at KMS Fusion, Inc. in Ann Arbor, Michigan. The KMS group has observed what they believe to be thermonuclear neutrons produced in pellets of both deuterium and deuterium-tritium. Results were announced by KMS Industries in a press release on 13 May; subsequent experiments were discussed with PHYSICS TODAY by Keith Brueckner (who had been serving as chief scientist at KMS Fusion and is now returning to the University of California, La Jolla) and Robert Hofstadter (who is now chief scientist at KMS Fusion but will return to Stanford University in the fall).

In the experiment a pellet of thermonuclear fuel (whose exact construction is classified) was bombarded by light from a neodymium glass laser; the beam was split in two and delivered onto the target on either side by means of two large-aperture elliptical mirrors. The peak laser power was approximately 0.5 terawatt; power per unit area on the pellet was $2\text{–}5 \times 10^{15}$ W/cm^2. The incident laser energy on target was 80–120 joules; the laser efficiency was about 0.1%. Targets were typically 60 to 80 microns in diameter.

Using deuterium-tritium targets the experimenters obtained as much as 3×10^5 neutrons/shot; they also obtained neutron yields from deuterium targets. Because the detector subtends a small solid angle the actual number of neutrons detected is considerably less than 3×10^5, so small that it is not possible to determine the neutron energy spectrum accurately. Such a determination would of course help confirm that the neutrons were thermonuclear. In the past, laser-fusion experimenters both in the US and abroad have observed neutrons that turned out to be produced from sources other than thermonuclear reactions. For example, neutrons can be produced from the exploding target striking deuterium gas in the chamber or in the walls. KMS feels, however, that it has eliminated the obvious sources for false neutrons.

The target is observed by x-ray pinhole cameras that have a resolution of 14 microns, Brueckner told us. In the x-ray picture one can observe the pellet contracted and hot. A time-integrated record of the implosion history of the pellet is obtained. Further analysis of this picture allows one to infer volume compression. However this figure is only a minimum, because one has a time-integrated result and the resolution of the pinhole camera is limited. Brueckner notes that they cannot observe dimensions of 2 microns with the pinhole camera, so that they cannot see what happens in the last 10 picosec of compression. In the early experiments, reported in May, Hofstadter says they obtained a volume compression of 30.

In the figure at the top of page 19, one sees an x-ray pinhole photograph of an imploded pellet. The darker spot in the interior represents the imploded region of high density. The outer fringe shows the approximate shape of the original pellet surface. In the den-

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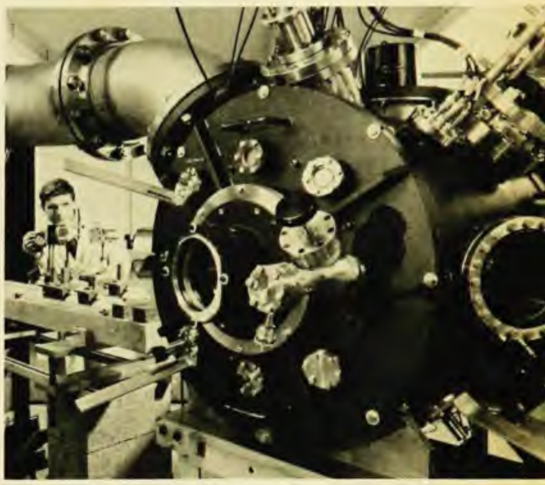


Target chamber used in KMS experiments. At center of chamber is port through which half of laser light enters. The large port at the right is used for optical recording.

Many total cross sections are rising

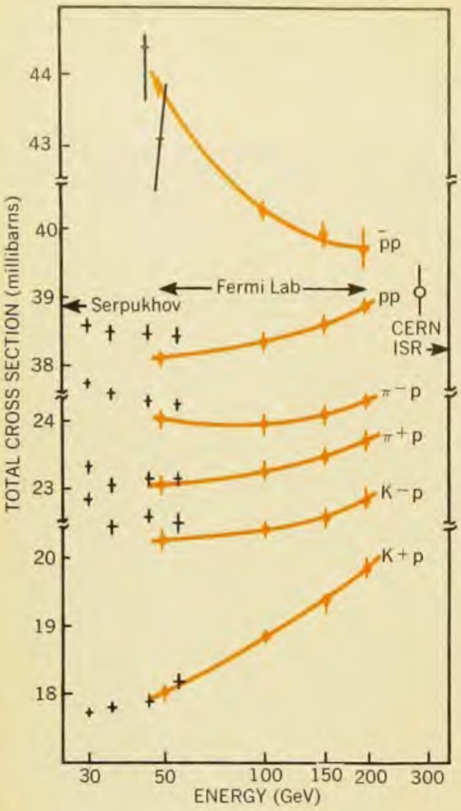
When experiments last year at the CERN Intersecting Storage Rings showed that the total cross sections for proton–proton collisions were rising about 10% as center-of-mass energies increased from 23 to 53 GeV, there was great excitement and considerable surprise. Now a tripartite team working at the Fermi National Accelerator Laboratory has investigated total cross sections from targets of protons and deuterons where the incident particles were protons, antiprotons, positive and negative kaons and positive and negative pions; incident energies ranged from 50 to 200 GeV in the laboratory system. By comparing the proton and deuteron cross sections, neutron cross sections were deduced.

In all cases except for the antiprotons, the total cross sections were found to be rising, just as the ISR had found for p–p scattering. And by extrapolation the experimenters believe that the antiproton cross sections, which now appear to have flattened out, will begin rising at higher energy.

Thus it appears that both the proton and the neutron show a rising total cross section to all the strongly interacting particles; it is probably a universal phenomenon, according to the experimental group. The data are also consistent with the Pomeranchuk theorem in that each of the pairs of particle and antiparticle cross sections are tending to come together.

The results were reported by Thaddeus F. Kycia (Brookhaven) in July at the XVII International Conference on High-Energy Physics held in London. The experiment was done by a team consisting of Alan S. Carroll, I-Hung Chiang, Kycia, Kelvin K. Li, Peter O. Mazur, Paul M. Mockett and David C. Rahm (Brookhaven National Laboratory), Winslow F. Baker, David P. Eartly, Giorgio Giacomelli, Peter F. M. Koehler, Klaus P. Pretzl, Roy Rubinstein and Alan A. Wehmann (Fermi Lab), Rodney L. Cool and Orrin D. Fackler (Rockefeller University).

The experiment, done at the Fermi Lab, used a so-called "good geometry transmission technique," in which one measures the transmission of the beam through an empty target and a full target. Incident particles were defined by scintillation counters and identified by two differential gas Cerenkov counters, allowing cross sections of two different particles to be determined simultaneously. The targets of liquid hydrogen or deuterium were ten feet long. Transmission through the targets was measured by 12 scintillation counters



Total cross sections on protons measured a Serpukhov, Fermi Lab and CERN Intersecting Storage Rings (where the equivalent lab energies went as high as 1500 GeV).

of different diameters, with 11 independent channels being formed by coincidences between each counter and the next largest counter. The experimenters believe they have achieved an accuracy of 1 part in 500 in the cross section determination, an accuracy considerably higher than that reported last year by two groups using the ISR (PHYSICS TODAY, May 1973, page 17). By the beginning of next year the Fermi Lab team expects that they will have extended their measurements for antiprotons to 300 GeV and for pions and protons to about 400 GeV.

Results for the proton–proton total cross sections show a rise of 2% as incident momentum increases from 50 to 200 GeV/*c*, a result consistent with those reported last year from the ISR. In the ISR experiments (done by a collaboration between Sezione di Pisa of INFN, the Istituto de Fisica of the University of Pisa, the Scuola Normale Superiore and the State University of New York at Stony Brook and by a second collaboration between the Physics Laboratory of the Istituto Superiore di Sanità, the Sezione Sanità of the INFN, Rome and a group at CERN), the observations were made at equivalent laboratory momenta between about 300 and 1500 GeV/*c*.

For antiprotons hitting protons the Fermi Lab experimenters find that, as they had at lower energies, the cross sections continue to fall but the rate is decreasing. Furthermore, above 150 GeV/*c*, the cross section becomes nearly constant. A plot of antiparticle–particle differences in cross section, namely $\sigma_{\bar{p}p}$-σ_{pp} and $\sigma_{\bar{p}d}$-σ_{pd} shows that the differences become smaller with increasing momentum. The differences show a power-law dependence, with momentum variation going approximately as $(P_{lab})^{-n}$ with n in the range 0.5 to 0.6. By extrapolating these curves the experimenters find that the antiproton cross sections will probably begin to rise around P_{lab} of about 300 GeV.

For both positive and negative pions and positive and negative kaons on protons and on deuterons, the experimenters find rising total cross sections. All the cross-sectional differences can be fit by a form $A(P_{lab})^{-n}$ with n varying as 0.5 to 0.6 for kaons and n varying as 0.4 to 0.5 for pions. A similar pion behavior had been predicted by S. J. Lindenbaum (Brookhaven) and his collaborators in 1967. Using the unsubtracted dispersion relations and measured total cross sections from 8 to 29 GeV they calculated that the difference between the π^+p and π^-p cross sections would vary as $(P_{lab})^{-0.6}$ at sufficiently high energy (and somewhat more slowly at intermediate energies), Lindenbaum told us.

Earlier experimental indications of rising total cross sections had also come from the 76-GeV Serpukhov accelerator. In 1971 S. P. Denisov (Serpukhov) and his collaborators reported that the K^+p total cross sections were increasing with energy, but that the K^-p cross sections were tending to go down. And the π^+p cross section section had flattened out and might be interpreted as going up.

In 1972, by analyzing some earlier cosmic-ray data, G. B. Yodh (University of Maryland), Yash Pal (Tata Institute) and J. S. Trefil (University of Virginia), had concluded that the total cross section rises with $(\log s)^2$, but many considered the cosmic-ray data too inaccurate.

Earlier Serpukhov experiments had also caused some observers to question whether or not the Pomeranchuk theorem was in trouble. Subsequently, more extensive and more accurate Serpukhov experiments were found to be consistent with predictions of the theorem. In 1958 Isaak Ya. Pomeranchuk had predicted that in the high-energy limit the cross section for a particle hitting a given target will be equal to that for an antiparticle hitting the same target. The theorem is based on the dispersion relations and assumes that a given cross section becomes a relatively smooth function of energy (instead of having many oscillations) at sufficiently high energy. The new Fermi Lab results are consistent with the Pomeranchuk theorem.

Another consistency shown by the Fermi Lab data is that they are in agreement with charge symmetry within less than 0.2%. That is, π^+d and π^-d cross sections are equal within experimental error.

What does it all mean? The Fermi Lab experiment shows the great fundamental unit of hadronic matter, according to Valentine Telegdi (University of Chicago), who remarks that as we know the p–p cross sections are rising, rising meson-nucleon cross sections are a necessary (but not sufficient) condition for the quark picture to hold. The Brookhaven–Fermi Lab–Rockefeller experimenters note that their data up to 200 GeV/*c* show agreement with predictions made by quark and Regge-pole models.

Some observers feel that the Fermi Lab results show we are very far indeed from asymptopia. There is a limit to how fast the total cross sections can rise, and that is the Froissart bound, which says that the cross section cannot rise faster than $(\log s)^2$ where s is the square of the center-of-mass energy.

One noted theorist is not surprised that the total cross sections are rising. After all, he told us, the very fundamental consideration of unitarity requires that there must be a drastic change in the present theory of weak interactions at center-of-mass energies in the range 100–1000 GeV. Weak interactions have been shown to be getting progressively stronger with increasing energy. And there is some hope that there will be ultimately a unification of the strong, weak and electromagnetic interactions at high energies. If so, he said, like the weak interaction, the so-called strong interaction may also undergo drastic changes at a much higher energy scale, hitherto unreached. What we are witnessing now may well be a glimpse into that unknown region, he concluded.

—GBL

KMS Fusion

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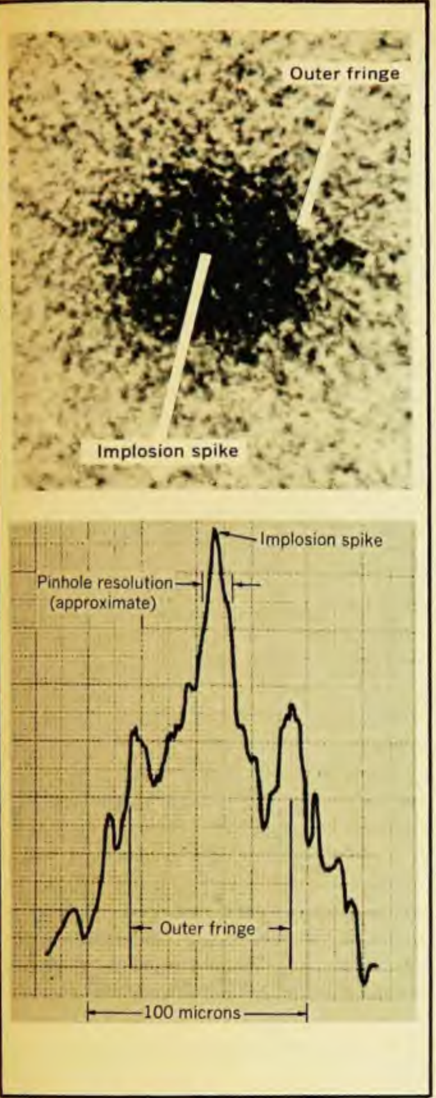
sitometer trace, one can see more exactly the extent of the implosion and make an estimate of the change in pellet size, Hofstadter explained. The central maximum, he said, results from x-ray emission from the pellet center, which has been compressed and heated by a series of convergent shocks. The secondary maxima, he went on, apparent in the x-ray picture as a diffuse outer ring, are produced by x-ray emission from the conduction zone around the dense pellet center, heated by electron conduction from the laser deposition region.

By using a one-dimensional computer code, Brueckner was able to infer



Implosion of thermonuclear pellet observed in x-ray pinhole photograph (top) and densitometer trace made by KMS Fusion. The initial pellet diameter was 73 microns, and the laser energy on target was 53 joules, delivered in an approximately square pulse lasting 250 picosec. This corresponds to an average laser power per unit area at the initial pellet surface of 1.4×10^{15} W/cm^2. Electron temperature in the pellet corona, as inferred from the x-ray intensity and the spectrum was approximately 1 keV.

that they had achieved in various shots densities of deuterium–tritium of between 10 and 20 grams/cm^3, which corresponds to compressions from the solid density of factors of 50 to 100. [However, a solid was not used.] From the computer code they calculate that the temperatures reached peaked briefly at 1 keV, although these temperatures do not last long nor do they extend through the bulk of the material, Brueckner said. These are ion temperatures, he said, but the electron temperatures are very similar, he remarked. To get a significant thermonuclear yield, one would need densities about an order of magnitude higher, Brueckner told us.

From a sequence of x-ray pinhole pictures taken under different conditions one can learn something about the rising velocity of the emitting surface and can see that within the resolution of the camera the implosion is symmetrical, Brueckner said. He is enthusiastic about the results because they eliminate several problems that had worried the KMS workers: coupling, corona instabilities, failure of conduction flow to equilibrate the corona, ablation flow being wrong, hydrodynamic instabilities in the acceleration and deceleration phase of the shocks and ability to achieve final convergence.

In most recent experiments, Hofstadter told us, KMS experimenters have obtained a volume compression of 88 as measured by the geometric change of the x-ray pinhole picture. This factor of 88, Hofstadter remarks, is only the visible compression. The actual compression is presumably much higher. He prefers not to make a theoretical extrapolation because it is possible that instabilities are occuring during such a large compression. In these new experiments, the same incident laser energy is used and neutron yields and plasma temperatures are the same as in the earlier shots.

There is some evidence that the pioneering laser-fusion effort at the Lebedev Institute in Moscow has also produced a laser-driven implosion. Last year at the Third Workshop on Laser Interaction and Plasma Phenomena at Rensselaer Polytechnic Institute Oleg N. Krokhin, Nikolai Basov and their collaborators reported they had used their nine-beam laser system to bombard a sphere of deuterated polyethylene sitting in a vacuum. At that time they said they had obtained a central compression to a density of about 30 gm/cm^3. Temperatures were several eV. The numbers were inferred from measurement of conditions in the surrounding atmosphere, rather than by direct imaging, and are thus probably not as convincing as the KMS results. —GBL

Solar-energy collector accepts diffused sunlight

Harvesting the sun's bounty of energy is a nontrivial problem—the sun is a nonstationary and often a poorly concentrated source of energy. Another attempt to overcome these difficulties is resulting from a collaboration between workers at the University of Chicago and Argonne National Laboratory. The project, with recently announced funding from the Atomic Energy Commission ($140 000), has reached the stage where prototype collectors have been constructed. These collectors do not need to be redirected during the day and can collect isotropic light more effectively than many earlier designs.

Roland Winston (University of Chicago) is the designer of the collector, which grew out of work he performed when designing sensitive detectors for Cerenkov radiation. The original Cerenkov detector was designed to study the beta decay of the Λ hyperon. Winston's principal collaborators on the solar project are Riccardo Levi-Setti (University of Chicago) and John Martin (Argonne). An important aspect of the solar collector is that there is no image production. Conventional imaging techniques allow approximately a three-fold concentration of light without diurnal tracking of the sun; this nonimaging collector in certain configurations can concentrate up to a factor of ten without tracking.

Collector description. The collector is trough-shaped with parabola-shaped sides made, in prototypes, of a highly reflecting metallic surface. The shape of the collector trough is governed by several geometric and optic considerations. In the course of developing the Cerenkov-counter collector, an axially symmetric "cone" with a parabolic cross-sectional profile was used. The maximum possible concentration factor (the ratio of the entrance-pupil diameter d_1 to the exit-pupil diameter d_2) is

$$\frac{d_1}{d_2} = \frac{n_1}{n_2}\frac{1}{\sin\,\theta_{\max}}$$

where n_1 and n_2 are the indices of refraction at the entrance and exit and $\theta_{\max}$ is the half angle of maximum beam divergence. The minimum length of the cone-shaped collector is

$$L = \frac{d_1 + d_2}{2}\cot\,\theta_{\max}$$

The solar collector is trough-shaped rather than cone-shaped, with the longitudinal axis of the trough parallel to the arc of the sun. Its cross-sectional shape, however is still governed by these equations.

The ideal collector optimizes the concentration factor with the largest possible $\theta_{\max}$. A collector with a $\theta_{\max} = 6$ deg can yield a concentration factor of 9.6 and can collect direct sunlight for a year-round average of about eight hours per day. A $\theta_{\max} = 7$ deg (concentration factor of 8.2) collector receives direct light for approximately nine hours per day.

Diffused light. The field of acceptance of diffused light as viewed from any point on the entrance aperture resembles an elliptical cone with the minor axis perpendicular to the trough and subtending an angle 2 $\theta_{\max}$. The major axis of the elliptical cone runs parallel to the trough and subtends an angle approaching 180 deg as the trough becomes very long or is terminated by reflecting ends. The solid angle for receiving diffused light is 4