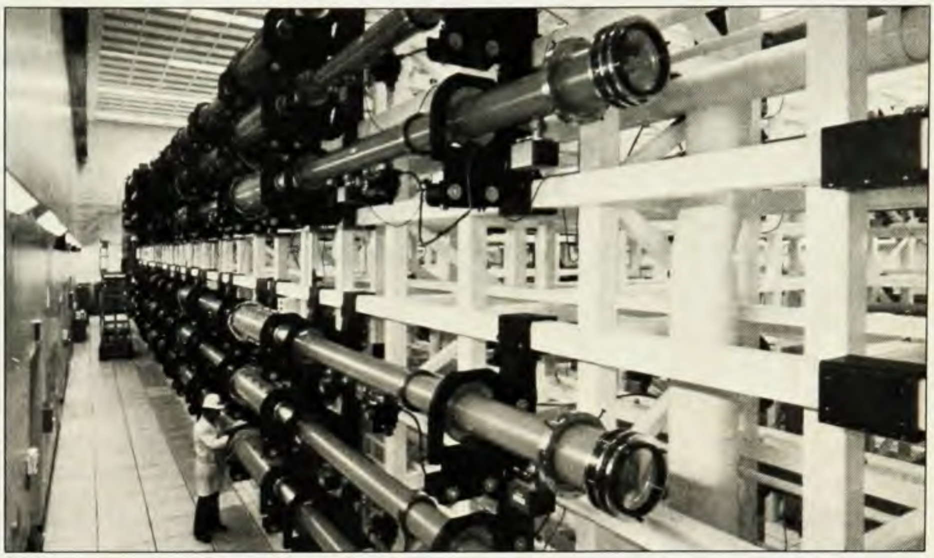
# search & discovery

## Laser-fusion devices at Livermore and Rochester use Nd glass

Fusion research with solid-state lasers entered a higher-power regime recently as the Lawrence Livermore Laboratory began operating its 20-beam, 20–30 terawatt ($10^{12}$ watts) neodymium–glass laser system. The design and current status of the facility were described by the associate director of Livermore, John L. Emmett, and others at the Conference on Laser and Electro-Optical Systems held in San Diego in February. After having successfully fired all twenty arms of the system at 10 kilojoules with a pulse of 1 nanosec, the Livermore group was changing the configuration for shorter (down to 0.1 ns) pulses, installing the final pieces of diagnostics and hardware, and aligning the lasers on a target in groups of five. A photograph of the target chamber appears on the cover of this issue of PHYSICS TODAY. The power of 1.7 TW attained by the first beam had confirmed hopes that all twenty beams would collectively reach the upper limit of the design power.



**The Shiva laser–fusion facility** at Lawrence Livermore Laboratory incorporates twenty neodymium–glass laser beams with total power likely to reach 30 terawatts. The cover of this issue shows the target chamber where all beams will be focussed. This photograph shows six beam lines.

While Livermore is clearly the pioneer at the highest power levels, other groups both in the US and abroad are planning, constructing and operating neodymium–glass lasers of various powers and designs. One such system is expected to be completed late this summer at the University of Rochester. The University's Laboratory for Laser Energetics, directed by Moshe Lubin, is building a six-beam, 3-TW facility, called Zeta, which will constitute the first phase of a 24-beam, 12-TW Omega system, scheduled to be operating by the early 1980's.

**Livermore.** As a very appropriate namesake, the Livermore Laboratory selected the multi-armed Hindu god, Shiva, who has a third eye from which shines a ray of destruction. Just as the god Shiva is associated with both destruction and creation, the new Shiva facility is concerned with the destruction of a deuterium–tritium (D–T) fuel pellet for the ultimate creation of energy. The goal of Livermore's laser fusion program is to achieve both power production and weapons construction. In laser-fusion schemes, the radiant energy ablates the outer layer of a pellet as small as a few microns in diameter. The outward expansion of this layer implodes the D–T fuel inside to densities perhaps a thou-

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## Portable "super spring" has apparent length of 22 km

Mechanical isolation of equipment is a long-standing problem for experimenters. For example, in 1895, Sir Charles Vernon Boys was working in Oxford, determining Newton's gravitational constant. He generally worked on Sunday night between midnight and 6:00 am. According to Boys, "The daytime, of course, is out of the question, owing to the rattling traffic on the stones in St. Giles', about a quarter of a mile away." Boys was also troubled by rail traffic, wind, and even an earthquake.

Since the experiments of Boys, gravitational and high-precision experiments have become considerably more sophisticated, but for many, mechanical isolation is still a problem. At the Joint Institute for Laboratory Astrophysics, James E. Faller, Robert L. Rinker and Mark A. Zumberge are developing a portable absolute gravimeter, which they hope will have an accuracy of a few parts in $10^9$. This corresponds to a height sensitivity of about 1 cm. The group feels that this type of gravity-measuring capability will, in addition to complementing leveling and extraterrestrial methods in the study of tectonic deformation, prove valuable for earthquake prediction, goethermal exploration, volcano surveillance and subsidence studies.

**Super spring.** One essential component of the new gravimeter is a mechanical isolating device developed by Faller and Rinker that they call a "super spring," which has an electronically achieved length of as much as 22 km, giving a period of 300 sec; the super spring provides mechanical isolation from disturbances above 0.003 Hz.

The super spring isolator makes use of the fact that a mass suspended from a long spring is effectively isolated (from vibrations) for all frequencies higher than the system's natural resonance, and for any given frequency, the lower the resonance of the mass and spring, the better the isolation. But to isolate against the Earth's natural microseismic background spring lengths are required to be 1 km or more.

As Faller and Rinker explain their electronically generated super spring, one

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supported before the proposed 1 to 2 GeV accelerator is built. —CBW

### References

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2. S. J. Brodsky, B. T. Chertok, Phys. Rev. D14, 3003 (1976).
3. C. M. Lyneis, H. A. Schwettman, J. P. Turneaure, Appl. Phys. Lett. 31, 541 (1977).

## Laser fusion

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sand times that of water. The aim is to sustain the high densities and temperatures for a sufficiently long time to initiate fusion reactions.

In funding the $25-million Shiva project, the Department of Energy has selected it to achieve one milestone in the DOE program aimed at demonstrating the scientific feasibility of inertial-confinement fusion. Joel Weiss of DOE told us that the specific goal for Shiva is to attain 1% of scientific breakeven. This condition would imply significant thermonuclear burn.

The next milestone in the program would be to reach scientific breakeven—when the thermonuclear energy release equals laser energy input to the pellet. This goal will probably not be met by Shiva but by its successor. Livermore has already begun to plan the first of the next generation—Nova—a 200–300 kJ, 200–300 TW facility three times the physical dimensions of the recently completed system.

The Shiva system is based on silicate-glass lasers and attains high power gains with disk amplifiers. Important components of the beam chain are the spatial filters, which eliminate the instabilities caused by small-scale self-focussing. (These instabilities occur when a laser signal is strong enough locally to produce an increase in the index of refraction, which in turn focusses the brighter portions of the beam still more, and so forth.) The alignment, diagnostic and power-conditioning systems of the large Shiva complex are controlled by an extensive system of microprocessors. Shiva will fire only a few times a day. The limit is imposed primarily by the time to set up diagnostics for each experiment; the system was not designed for fast repetition rates.

John Nuckolls, who heads the nuclear-design portion of the laser-fusion program at Livermore, outlined the current experimental plans to us. The first targets will be of the exploding pusher type, in which the D–T fuel at low density is surrounded by a glass shell. With such targets in the two-beam, 4.6-TW Argus laser system, the Livermore team had obtained neutron yields of $2 \times 10^9$ and ion temperatures of 8 keV. They hope to better these numbers on Shiva by summer. During the fall, the experiments will use high-density targets, in which the aim is to compress most of the fuel isentropically, without substantially raising its temperature, while heating the central core to multi-keV temperatures. The fuel pellets for these trials will be multilayered. Significant thermonuclear burn will require that the targets be compressed to 1000 times liquid density.

Emmett stressed to us that his team at Livermore regards the neodymium–glass lasers more as a tool for investigating the complex physics of fusion target implosion than as eventual candidates for power production. Solid-state lasers have been selected at this stage because of their high peak power, but Emmett feels that their poor efficiencies and low repetition rates make them only marginally acceptable for fusion power plants. Livermore and other laboratories are continuing to screen a variety of laser types thay may be attractive.

**The Rochester facility** plays a different role from that of the Livermore system. It has been designated as a user's facility and must allocate a minimum of 32% of its scheduled operations to outsiders. Thus it will not only produce some useful laser-fusion physics but also will train physicists in this field. Unlike the Livermore program, none of the experiments at Omega will concern classified targets. Another unique feature of the laboratory at Rochester is the broad base of its financial support: Government funds from DOE will provide the $20 million for construction of the 12-TW Omega system. Private sources such as General Electric Co, Exxon Corp, Empire State Electric Energy Research Co and Northeast Utilities Service Co have financed the $41.5-million operating budget (for five years through 1981). Finally, the New York State Government and the University of Rochester funded construction of the building that houses the laboratories.

The Omega system is being constructed with the more recently developed phosphate-glass lasers. In contrast to the silicate glass used at Livermore, phosphate has a higher specific gain (0.26 compared to 0.16) but inferior thermal properties. The Rochester facility will rely on large-aperture (up to 90-mm diameter) rod amplifiers for high power gain. For future systems the Rochester group is interested in an active-mirror amplifier. First studied at General Electric Co, the device consists of an array of flash tubes at the back surface of a 17–20-cm diameter disk of laser glass. The dielectric coating on this surface transmits the flash-tube light but reflects the laser light. This design increases the gain by having the beam traverse the glass twice, and it also facilitates cooling. Because the active mirror may enable them to reach higher power levels at the same repetition rates of one per half hour, the group at Rochester plans to request an additional $7 to $8 million from DOE to boost Omega's capacity above 30 TW.

Although the highest power levels to date for laser-fusion experiments have been produced by neodymium–glass lasers, such systems do not constitute the only approach being pursued. Another direction is being taken by Los Alamos Scientific Laboratory, where ground was broken last August for a High-Energy Gas Laser Facility, scheduled for completion in 1982. The experimental complex within this new facility will be Antares, a 100-KJ system (pulse durations as short as 0.25 ns) composed of 6 modules and a total of 72 beams. The system is based on a carbon-dioxide laser. Its advantages over the solid-state lasers include its higher efficiencies and repetition rates. Its major disadvantage has been the longer wavelength, which many felt might not couple as successfully with the fusion pellet. Recent experiments at Los Alamos have, however, indicated significant potential for gas lasers in fusion (see PHYSICS TODAY, September 1977, page 19). —BGL□

### Form for writing an "original" paper on gauge models

*Theorist J. J. Sakurai of UCLA recently offered a form that should simplify the writing of papers on gauge models. At the Conference on Leptons and Quarks held at Irvine in December, he presented the following form:*

We present a new gauge theory of weak and electromagnetic interactions based on the group. . .

Under (     ) the left- and right-handed quark multiplets transform as. . .

We now specify the Higgs sector. . .

The mass formulas for the gauge bosons can be readily obtained as follows. . .

Triangular anomalies are cancelled by postulating additional heavy leptons. . .

The inclusive $\nu N$ and $\bar{\nu} N$ cross sections calculated using the interaction (     ) agree with the predictions of the Weinberg–Salam model if we identify. . .

Trimuon events are possible in our model because. . .

The bismuth puzzle is resolved by considering. . .

We wish to thank the Aspen Center for Physics for its hospitality. This work was supported in part by. . .

1. S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967); A. Salam in "Elementary Particle Physics" (ed. N. Svartholm, Stockholm 1968), p. 367.