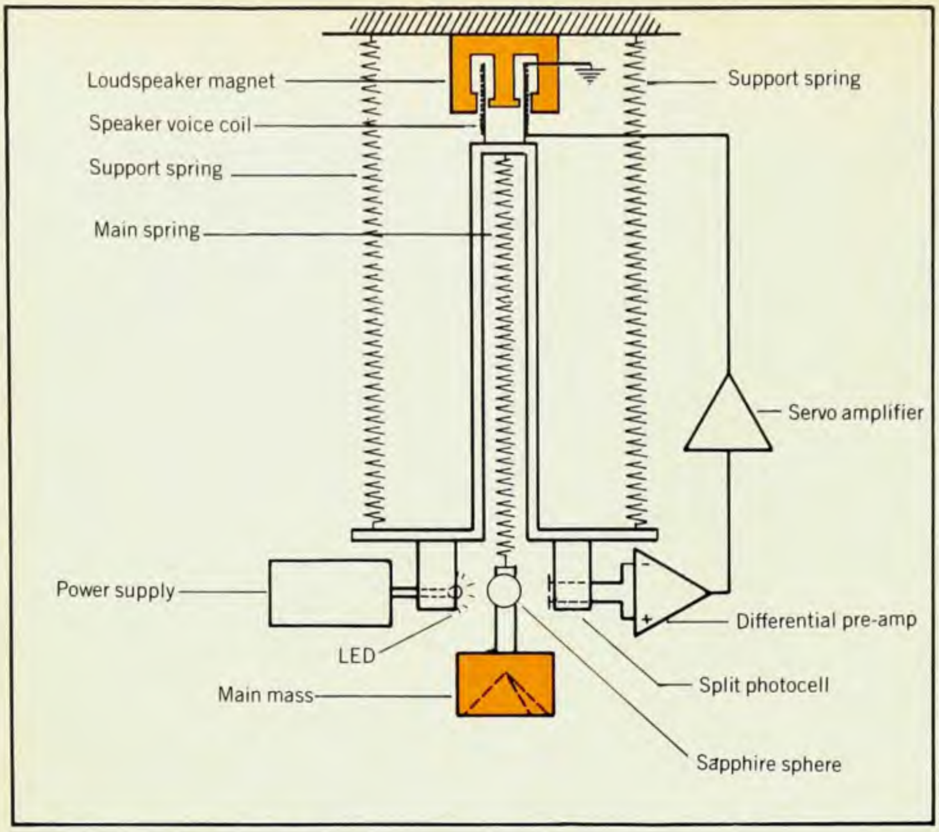


Super spring developed at JILA is a mechanical isolating device with an electroncially achieved length as great as 22 km and a period up to 300 sec, although the "main spring" shown in the drawing is physically only 30 cm long. The device is to be used in a portable absolute gravimeter.

can imagine a mass hanging on the end of a spring that extends 1 km vertically. The mass will oscillate with a 60-sec period, and of course the coils of the spring will also oscillate. The coils close to the mass will have an amplitude roughly equal to the amplitude of the mass; the coils far from the mass will have an amplitude less than that of the mass. In fact, the coils near the top will scarcely be moving at all. If one were to grasp the spring 30 cm above the mass and move that point on the spring just as it moved when the lower mass was in free oscillation, the motion of the mass would not be affected. One could then cut off the top of the spring and be left with a 30-cm long spring that has the same resonance and behaves in all ways as if it were a spring 1-km long. The JILA pair uses a servo system to produce such a virtual point of suspension.

In the JILA system, two side springs (see figure) support a movable bracket from which the mass-supporting spring (of approximately 30 cm length) is hung. The output of a light-emitting diode is focussed through a sphere near the bottom of the spring onto a split photodiode to sense displacements of the central spring. The output from the two halves of the photodiode is amplified and differenced, producing an analog signal that is proportional to the displacement of the mass with respect to this bracket. This signal, processed by a servo-compensated amplifier, drives a loudspeaker voice coil, which in turn supplies the needed force to cause it to (nearly) track the motion of the bottom weight. Because the top of the spring is attached to the bracket, the top moves almost the same amount as the bottom. (The precise degree of tracking is determined by the gain setting of the servo system; thus by changing the gain, the length of the spring and the period can be varied.) Faller and Rinker note that once the various internal modes of the spring have either died down or been damped, using for example, an external magnet, the spring is essentially stationary in inertial space and as a result, the only mode that remains excitable is the fundamental.

The JILA team is unaware of other attempts to make a long-period spring electronically. In principle, periods as long as 55 minutes should be possible, corresponding to a spring length equal to half the Earth's radius. However, at this length the change in force on the mass for a small displacement due to the gradient in the Earth's gravity field is greater than the spring's restoring force, Faller said. As a result, the system would be unstable.

The portable absolute gravimeter being developed at JILA uses the method of free fall, in which one element of an optical interferometer is dropped. The super spring will be used to isolate the gravimeter (or one element in it) and thereby permit measurements at the level of a part in 10^9. If the instrument were not isolated from the environment, the resulting accuracy would be parts in 10^7, limited by the Earth's surface motion (which appears as noise).

Relative gravimeters that measure differences in g but not g itself have been used to establish values of g at a variety of positions to locate ore deposits and so forth; the LaCoste-Romberg gravimeter and the Warden gravimeter, both of which are available commercially, use a so-called zero-length spring in a hinged mechanical system to achieve a weak restoring force on a test mass. Therefore, they could be (and have been) used as the basis of a mechanically (as opposed to electronically) synthesized isolator. Mechanical gravimeters have been used to determined vertical tectonic movements occurring over short periods of time (weeks) in relatively confined areas (tens of kilometers) both in Japan and Canada. In such cases, relative readings are sufficient. However, Faller said, by the nature of their construction they are subject to both abrupt changes and drift.

He told us that the absolute gravimeter being developed at JILA, which is supported—so to speak—by a super spring, uses the fundamental standards of length and time in its method of measurement. Thus, he said, it will have the dc stability necessary to study directly long-term geophysical processes. At the same time, he feels the instrument will provide a stable reference for relative devices.

—GBL

Panel promotes electron-beam studies of nucleus

Noting new technical developments and consequent new opportunities for research, a panel has recommended increased funding over the next few years for the field of nuclear research using intermediate-energy electron accelerators. The Study Group on the Role of Electron Accelerators in US Medium Energy Nuclear Science, headed by Robert S. Livingston (Oak Ridge), has also recommended that the nuclear-physics community give serious consideration to the construction (beginning as early as 1981 or 1982) of a new national electron accelerator with a 100% duty cycle, energy of 1 to 2 GeV and electron-beam current of approximately 100 μA.

The panel's report is a follow-up to studies made in 1974 by the joint AEC–NSF Committee to Review US Medium-Energy Science headed by Roger H. Hildebrand (PHYSICS TODAY, December 1974, page 77) and in 1977 by the NAS–NRC Ad-Hoc Panel on the Future of Nuclear Science headed by Gerhart Friedlander. The report was presented at the first meeting last October of the newly organized DOE–NSF Nuclear-Science Advisory Committee (NUSAC) (PHYSICS TODAY, February 1978, page 77).

The study group recalled that the US had an early lead in studies using electrons in nuclear physics. Programs begun in the early 1950's at the University of Illinois and Stanford University established the usefulness of electron beams as precise nuclear probes. Since then, however, the US has gradually lost much of its initial lead, in the opinion of the panel, and now two new major electron accelerators are under construction in Europe: the Amsterdam linear accelerator (500 MeV with 2.5% duty cycle and 250 MeV with 10% duty cycle) and the University of Mainz room-temperature linac structure (800 MeV, 100% duty cycle and 100 μA beam current).

Despite these developments, the panel is convinced that the US can regain a position of leadership as a result of several recent technical developments. The MIT Bates linear accelerator and its energy-loss spectrometer with excellent energy resolution has been successfully operated. The possibility of studying the nucleon–nucleon system at extremely small interparticle distances (as well as studying the subnucleon structure of nucleons) has been encouraged by very high momentum transfer electron scattering from d, He^3 and He^4 at very high energies at SLAC.[1,2]

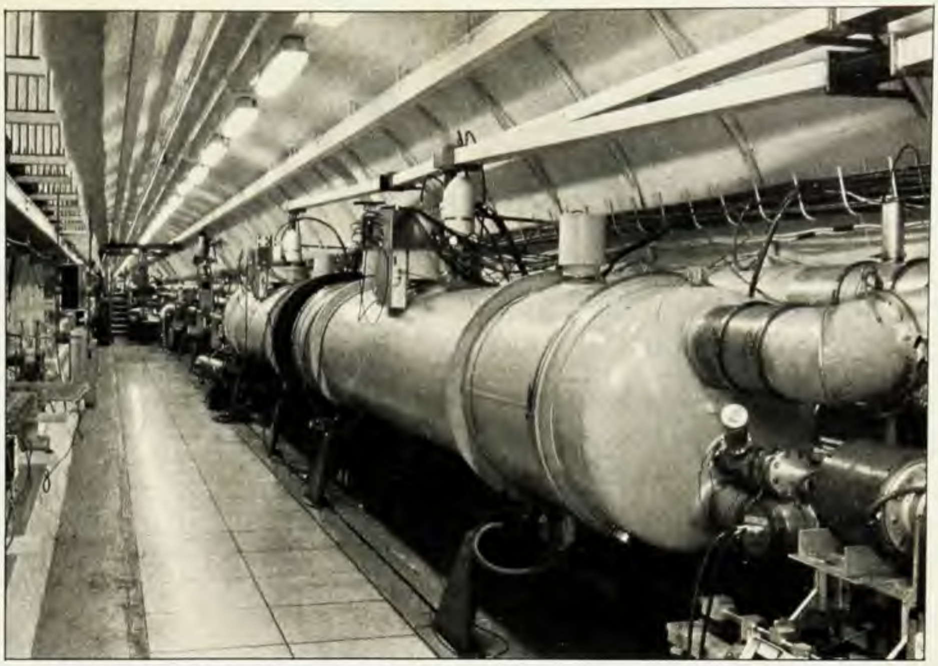
In addition, the panel noted that successful demonstrations of recirculation techniques at Stanford and the University of Illinois may permit expansion of electron energy capability at modest cost, and that researchers at Stanford have gained an improved understanding of the technology of radio-frequency superconductivity.[3]

New accelerator. If the proposed high-energy, 100% duty-cycle electron accelerator is constructed, the study group envisions several "exciting" possibilities for research. Such a device would permit:

- precise determination of charge and magnetism densities in nuclei throughout the periodic table;
- determination of unambiguous properties of the nucleon–nucleon force through a systematic study of the two- and three-particle systems;
- study of single-particle wave functions in nuclei, particularly their high-momentum components; and
- studies of clustering phenomena in nuclei.

All of these types of experiments would be aimed at providing more accurate information on certain fundamental aspects of traditional nuclear physics (such as the assumption of a nuclear shell model and the form of the nucleon–nucleon potential) and would take advantage of the potential lack of ambiguity of electromagnetic-interaction experiments.

In addition, the panel expects that the proposed facility would also permit a fifth class of experiments in the so-called "new nuclear physics" at and beyond the meson threshold. Possible areas of investigation include:



Stanford Superconducting Electron Accelerator. Prominent in this view of the beam line is a 40-foot cryogenic vessel containing two 6-meter superconducting Nb accelerator structures.

- elastic scattering off meson-exchange currents at high momentum transfer;
- photo- and electroproduction of pions in the nuclei to study pion–nuclear interactions at low meson energies in the nuclear interior; and
- photoabsorption measurements for gamma energies up to and above 1 GeV, from which properties of the isobar–nucleus interaction might be inferred.

Facility improvement. In addition to its long-range recommendation for a new facility, the panel recommended more immediate improvements at existing facilities. They supported funding at an early date for the proposed recirculation of the beam at the Bates linac. This technique will double the peak energy to approximately 750 MeV and will allow important experiments to be carried out in the areas of charge and magnetic-field distributions, inelastic scattering transition densities, multipole resonances, quasi-elastic scattering, and will permit systematic study of high-momentum components of single-particle wave functions. The cost of this improvement in energy range is estimated to be less than \$2 million; to obtain the same increase by the direct addition of more accelerating sections and microwave power sources, the panel observed, would cost substantially more.

Continuation of programs at the University of Illinois and at the High-Energy Physics Laboratory of Stanford University was also recommended by the study group. Full-energy operation (60 MeV) was obtained in January 1978 at an Illinois microtron that uses a 6-m Stanford-produced superconducting linac, together with a slightly modified version of a six-traversal, recirculation system that was developed for an earlier microtron built by the Illinois group (headed by Peter Axel and Alfred O. Hanson). The panel recommends (and NSF has just authorized) the further construction of a new two-stage microtron that is now planned to provide 288-MeV electrons; these would be obtained by injecting the 60-MeV beam into a second microtron stage that would include a second 6-m Stanford-produced superconducting linac and a pair of 6-ft-wide end magnets for beam recirculation. The addition of 19 traversals (with 12 MeV per traversal) would add an energy of 228 MeV.

Completion (by the end of 1978) of the Stanford High Energy Physics Laboratory's program (headed by Mason R. Yearian and H. Alan Schwettman) of accelerating an electron beam through four sections of superconducting accelerator structure with four turns of beam recirculation was also recommended by the panel. Beam energies of 260 to 280 MeV are expected if the program proves successful. Microwave beam blowups during beam recirculation have recently been observed at relatively low currents, however, and their impact on the progress of the program is not yet fully known, according to the study group.

The panel believes that many important parts of a research program detailed at length in the panel's report can be carried out with these facilities; in particular, they would allow study of the detailed character of collective states, both bound and in the continuum, through both singles and coincidence experiments.

Finally, the panel, noting that it is not yet clear which technology, room-temperature or superconducting, is most cost-effective in the construction of high-energy continuous-wave machines, recommended that research and development in both areas be substantially supported before the proposed 1 to 2 GeV accelerator is built. —CBW

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1. R. G. Arnold, et al, Phys. Rev. Lett. 35, 776 (1975).
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 2×10^9 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 νN 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.