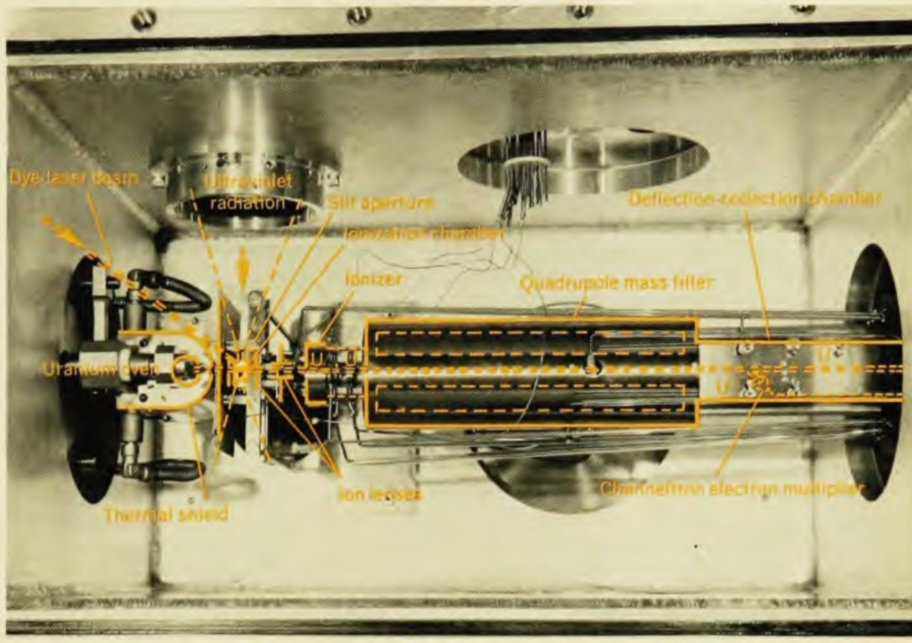
search & discovery

Many groups report laser-induced isotope separation

In an exciting post-deadline session at the Eighth International Quantum Electronics Conference in San Francisco this June five groups reported experimental results on laser-induced isotope separation. One of the groups was able to separate small quantities of U^{235}. A successful method of doing this on a large scale would obviously be of great commercial interest and is undoubtedly the motivation of many workers in the field. It is clear that laser isotope separation will be the focus of considerable attention for quite a while.

In all the laser techniques reported, one tunes the laser to excite one isotope (or molecule containing it) but not the other isotopes. Then the excited atom or molecule must be chemically or physically separated from the unexcited ones before it transfers energy to the unexcited atoms or molecules.



Top view of laser isotope separation chamber used at Lawrence Livermore Laboratory. The atomic uranium source is at left, followed by the active region. A quadrupole mass analyzer measures the mass of uranium ions produced by two-step selective photoionization.

The uranium work, done by Sam A. Tuccio, James W. Dubrin, Otis G. Peterson and Benjamin B. Snavely (Lawrence Livermore Laboratory) used two-step, selective photoionization. A collimated beam of uranium atoms with a mixed isotopic composition was struck by the tunable output of a cw dye laser to excite the U^{235} atoms selectively, promoting a 7s electron to a 7p electron. Simultaneously the uranium atoms were struck by ultraviolet light that ionized the excited U^{235} atoms while leaving the U^{238} unaffected. Then the ions were separated from the neutral atoms by an electric field after the beam had passed through a quadrupole filter for mass analysis. The quantity of U^{235} atoms produced was too small for accumulation in the negatively charged collector cup—10^6 atoms/sec were produced. The Livermore group was able to enrich natural uranium from 0.7% concentration of U^{235} to 60%.

The dye laser had an output power of about 40 mW. Its output wavelength of 5915.4 Å was tuned to 1 part in 10^6 so that one could separate the absorption lines in U^{235} and U^{238}; the separation was about 8 GHz. As a uv source the

continued on page 19

Maybe the Sun is round after all

Many ears pricked up at two recent conferences when Henry Hill of the University of Arizona reported that he and his colleagues had looked for but not found any oblateness in the mass distribution of the sun. Hill announced these results at both the Fifth Cambridge Conference on Relativity held at Cambridge, Mass. on 10 June and the Seventh International Conference on Gravitation and Relativity held at Tel Aviv, Israel from 24 to 28 June. Hill and his colleagues—Paul D. Clayton, Doug L. Patz and Alfred W. Healy of the University of Arizona, Robin L. Stebbins of the High Altitude Observatory and James R. Oleson and Carl A. Zanoni of Wesleyan University—made their measurements at the Santa Catalina Laboratory for Experimental Relativity by Astrometry (SCLERA), a facility near Tucson that is jointly operated by the University of Arizona and Wesleyan University.

The null measurements of solar oblateness contradict the 1966 measurements by Robert Dicke and Mark Goldenberg of Princeton University[1] that have caused speculation about the validity of Einstein's general theory of relativity (PHYSICS TODAY, April 1967, page 63). The solar oblateness, that is, the difference between the equatorial and polar diameters of the sun, was found to be 18.4 ± 12.5 arc msec in the SCLERA experiment whereas the value was 86.6 ± 6.6 arc msec in the Dicke–Goldenberg measurement. The SCLERA group further claims to have observed an excess brightness at the extremities of the equatorial diameter that has sufficient intensity, they feel, to have been interpreted by the Princeton instrument as an intrinsic solar oblateness.

The keen interest in solar oblateness dates back to the end of the 19th century when it was first proposed as a possible explanation for the discrepancy between the observed value for the precession of the perihelion of Mercury and that predicted according to Newtonian theory of gravitation. However, without assuming any mass quadrupole moment for the sun, Einstein's theory of relativity accounts almost perfectly for the excess precession. This prediction constitutes the strongest experimental evidence for the Einsteinian theory. But the solar oblateness reported by Dicke and Goldenberg in 1967 was large enough to account for 7% of the precession, implying that Einstein's value is 7% too high. These results also supported the scalar-tensor theory of gravitation developed by Dicke and Carl Brans[2] that proposes a scalar field in addition to the tensor field required by Einsteinian gravitation. The Dicke–Brans theory predicts a perihelion rotation that is somewhat less than the Einsteinian value by roughly 10%.

The SCLERA team conducted its measurements on a telescope that has been designed to measure the solar deflection of starlight.[3] This telescope is suitable for measurements of the sun's diameter because it uses that value as a scale reference. The instrument is basically a Schupmann telescope that is held in a vertical position and is fed by an elevation–azimuth mirror system. It is enclosed in a tower to provide a controlled thermal environment. The objective lens is an f/100 singlet with a 12.2 m focal strength. The telescope features low scattered light levels. Its construction was jointly supported by the University of Arizona and Wesleyan University.

The basic difference between the SCLERA experiment and the Princeton experiment lies in their different definitions of the solar edge, and their instruments reflect these different definitions. Dicke and Goldenberg project the sun's image onto an occulting disk and take the light that extends beyond the disk's edge as a measure of the amount of projection of the limb. The light falls on a scanning wheel that is rotating at 123 rev/sec and that has two diametrically opposed slits. A photocell detects the total light flux passing through the slits as a function of angle around the solar limb. If the sun is oblate, then the signal from the equatorial region should exceed that from the polar region.

Hill and his colleagues have developed a mathematical definition of the solar edge. It can best be understood with reference to the so-called "limb darkening profile"—a curve of the intensity of the solar limb as a function of distance from the sun's center. This curve starts high but drops rapidly. The SCLERA group takes a finite interval along this curve and convolutes it with a cosine curve. The point at which the convolution equals zero is defined as the edge of the sun. Experimentally, this point is located by sinusoidally scanning the solar limb across a slit that is tangent to the sun's edge. The instrument computes the finite Fourier transform of the observed signal, and a servomechanism adjusts the location of the slit along the radial direction until the transform is zero (see figure). Two such slits are positioned at either end of the sun's diameter and the distance between them is measured with an interferometer. In this way both the equatorial and polar diameters are determined. Hill feels that his definition of the solar edge is far more sensitive to the shape of the limb darkening profile than is the Princeton measurement.

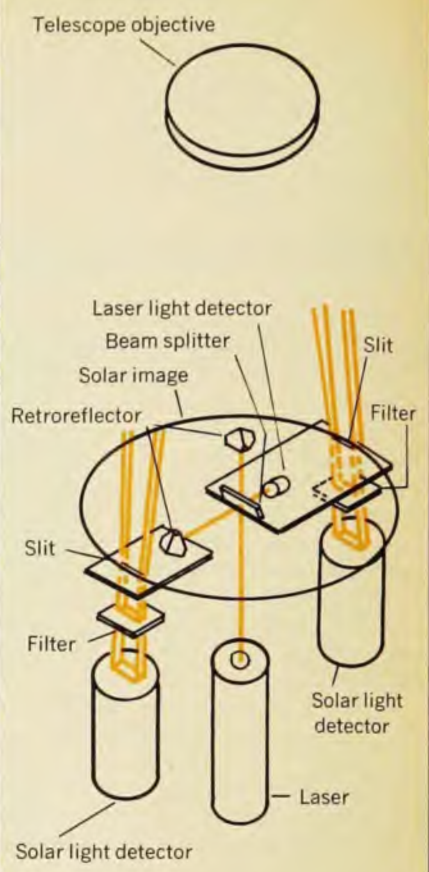
One of the major criticisms of the Dicke–Goldenberg results is the difficulty in distinguishing whether a large signal was caused by intrinsic solar oblateness or by excess equatorial brightness. Dicke feels these objections have been answered[4] by measurements made with three different amounts of solar limb exposed; the oblateness measured is independent of the amount of exposed limb. Dicke and Goldenberg also checked for brightness by using a disk that masked the oblateness signal.

Explicit measurement of the brightness of the equator relative to the pole was one of the objectives of the SCLERA experiment. According to the SCLERA workers, a measure of the brightness was obtained by varying the amplitude of the scan. By varying the amplitude one essentially includes more of the solar limb in the measurement and, claims the SCLERA team, this shows the effect of brightness on the definition of the solar edge. The different values of apparent oblateness obtained for two different values of the amplitude are used as a measure of the excess brightness.

Hill and his associates ran their experiment in June and July, 1972, in September 1973 and in November and December, 1973. They measured an excess brightness in the first and last runs to account, they feel, for the Dicke–Goldenberg results. The brightness was fairly constant except for sudden shifts that could be identified with local solar activity. Because the last run continued for 21 days, or roughly ¾ of the sun's rotation period, the SCLERA group suspects that the brightness represents some global phenomenon. No excess brightness was observed during the September 1973 run, so they conclude that the brightness apparently varies with a period of at least several months. The oblateness was calculated from the September data because it did not require correction for brightness.

Dicke questions how the SCLERA team could predict the effect from their observations, that excess brightness might have on an experiment such as his when their definition of the limb position is so different. Dicke notes that the servo–null that provides the SCLERA definition of limb position is completely independent of limb brightness but is sensitive to the shape of the limb darkening curve. Also, the SCLERA telescope measures at only two points, whereas the Princeton instrument scans the intensity at continuous points all around the limb. Dicke further commented that he would like to see the SCLERA experiment run for at least three months to show the effect of the change in position of the axis of the sun relative to the telescope before he is convinced that the results are free from all possible instrumental distortions.

When questioned about the effect that a null result for solar oblateness would have upon the scalar–tensor theory, Dicke stated that it would make the scalar-field coupling constant (an adjustable parameter) substantially larger and the theory would then be less interesting. Dicke feels that a definitive test of the various theories of relativity will come in the next two or three years from measurements of the deflection of radio waves or from measurement of the Nordtvedt effect on the moon.



Solar-oblateness detector looks at light that passes through each of two diametrically opposed slits. The servomechanism centers slit on mathematically defined edge. Laser interferometer arrangement measures distance between the slits. Two diameters are found.

The question of solar oblateness also relates to the recent measurements of a solar neutrino flux that is considerably lower than what one would expect.[5] This low flux is consistent with models of the sun that give it a rapidly rotating core. Dicke proposed just such a model to account for the solar oblateness observed in his experiment.[4] However, the value for solar oblateness obtained by Hill and his associates is consistent with a value of 15.7 arc msec that one would expect for a uniformly rotating sun. Clearly this new measurement will cause still more speculation in a field that is already alive with questions.

—*Barbara G. Levi*

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NASA asks for more lunar-research ideas

NASA is encouraging qualified scientists not now involved in NASA lunar research to contribute their ideas, techniques and research capabilities. The program's goal is to improve the scientific understanding of the origin, evolution, structure and composition of the Moon and of its relationships to Earth and the solar system. NASA's lunar studies include

- experimental and theoretical research on lunar materials (samples and Surveyor parts),
- lunar data analysis and synthesis, using published or other generally available data and
- supporting research and technology designed to support the general goals of the other lunar programs such as theoretical studies, laboratory simulations, meteorite research and advanced experiment concepts.

Details on where and how to propose may be obtained from N. W. Hinners, Lunar Programs Office, Code SM, NASA, Washington, D. C. 20546.

Table of fundamental constants is updated

An adjusted set of values for the fundamental constants has been recommended for international adoption by E. Richard Cohen and Barry N. Taylor. These values were worked out under the auspices of the International Council of Scientific Union's CODATA Task Group on Fundamental Constants; they therefore represent the first internationally "official" adjustment ever carried out. The complete Taylor–Cohen report appears in the *Journal of Physical and Chemical Reference Data*[1]; a card listing the recommended values may be found opposite page 81. Both Cohen (Rockwell International, Thousand Oaks, California) and Taylor (US National Bureau of Standards, Gaithersburg, Maryland) have previously done semiofficial and widely used adjustments; the most recent work of Cohen and Jesse W. M. DuMond appeared in 1963 and that of Taylor, William H. Parker and Donald N. Langenberg in 1969.

The new values improve on the 1969 recommendations in several ways, among them the availability of two precise, compatible values for the proton magnetic moment in nuclear magnetons (μ_p/μ_N); inclusion of the now well known value of $2e/h$, known to a few parts in 10^8 because of Josephson junction measurements; and a resultant overall reduction in assigned uncertainties. The new recommendations have not yet resolved inconsistencies in various measurements of the Faraday or of the fine-structure constant.

A major problem in the 1969 adjustment was the discrepancy between two groups of measurements for μ_p/μ_N. The mean values of the two groups differed by more than three times the standard deviation of their difference, a clear indication that either the "high" or the "low" group had to be discarded. Taylor, Parker and Langenberg decided, after careful consideration, to discard the high values. But new, extremely accurate measurements (to less than 1 ppm) by B. A. Mamyrin, N. N. Aruyev and S. A. Alekseenko (A. F. Ioffe Physico-Technical Institute, Leningrad, USSR) and by B. W. Petley and K. Morris (National Physical Laboratory, Teddington, UK) indicate that these higher values were the more nearly correct ones. Then, comparing these sub-ppm *direct* measurements with the *indirect* values that may be calculated from an equation that includes the Faraday constant F, they found large discrepancies. Since all other quantities in the equation are relatively well known, the two previously accepted measurements of F must be assumed incorrect. The new recommendation for μ_p/μ_N also leads to changes in the value for the Avogadro constant N_A.

Taylor and Cohen feel that the greatest need for improvement is in measurements of γ_p, the gyromagnetic ratio of the proton. Two techniques are used to measure γ_p, one at low magnetic field and the other at high field. The four available low-field measurements have uncertainties of the order of six ppm, with a somewhat unsatisfactory degree of scatter. The two high-field measurements are not apparently discrepant but have larger uncertainties. An important feature of the 1969 adjustment was the comparison of the value of α, the fine-structure constant, calculated without quantum-electrodynamic-dependent quantities (the so-called "WQED value"), with its QED counterpart. Although there is no indication now of any basic discrepancies in quantum electrodynamics, Cohen points out to us that this is more a result of the relatively large uncertainty assignment for the spectroscopic data than of good agreement between QED and WQED values. Thus, a critical test of QED theory is not available.

Improved accuracy in both the low-field and high-field measurements of γ_p would not only give us a better value for α but also for K, the ampere conversion factor and for N_A as well as an independent verification of the value of F. Several groups are working on this problem and on remeasuring F. And the recently completed work of Richard Deslattes and his coworkers at NBS[2] who measured the Avogadro constant with x-ray interferometry, could give us another way to reduce the uncertainty in these values.

—*Marian S. Rothenberg*

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Isotope separation

continued from page 17

experimenters used a 2500-watt mercury arc lamp. Uranium atom density in the active region was about 5×10^{10} cm^{-3}. For a commercial process, Tuccio told us, one would prefer a laser to do the ionization. It must be energetic enough to raise the U^{235} atoms that are in an excited state to the ionization continuum. However if it is too energetic it will also ionize the U^{238}. In the experiments reported at the conference, light with a wavelength shorter than 2100 Å was removed by a doped quartz filter in front of the mercury arc. This prevented ionization of the unexcited U^{238}. The experimenters were also able to resolve the eight hyperfine components of the 5915.4-Å line in the U^{235} ion current.

The Livermore workers note that scaling of the separation process they used is difficult, at best. They feel that their experiment, however, represents a logical first step in the evaluation of this class of processes. The laser uranium separation work at Livermore, insti-