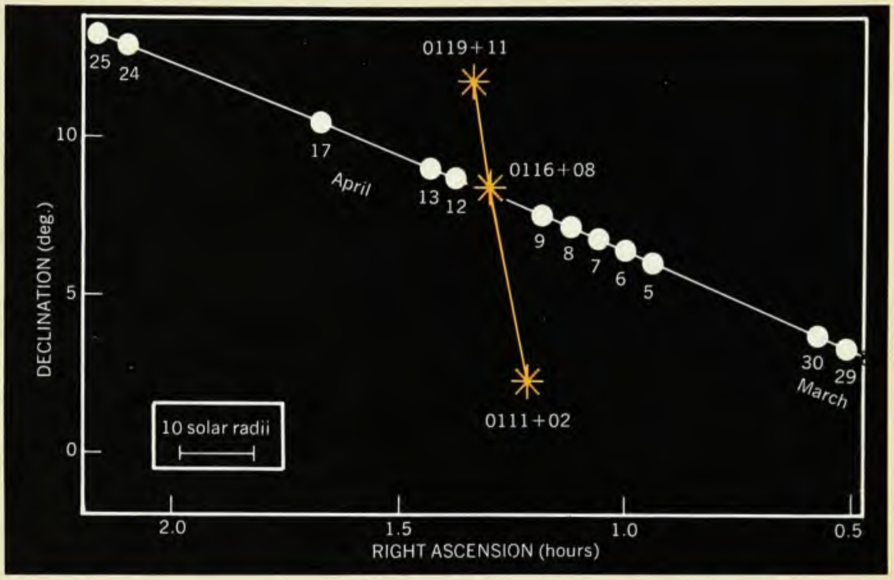
search & discovery

Radio-wave deflection experiments confirm Einstein

Einstein yes, Brans–Dicke no, is the apparent verdict of some recent experiments at the National Radio Astronomy Observatory, Green Bank, West Virginia. Edward Fomalont and Richard Sramek measured the deflection of microwave radiation by the Sun's gravitational field and report results sufficiently precise that they are consistent with Einstein's general relativity but not with scalar–tensor formulations such as Brans–Dicke theory. The remaining uncertainty concerns possible systematic errors in these observations, not the formal statistical error, which appears to be sufficiently small. The experimenters used a 35-km baseline radio interferometer to study three nearly collinear radio sources at two frequencies and found the bending to be 1.015 ± 0.011 times that predicted by general relativity; the Brans–Dicke prediction differs by about seven percent.



Positions of the radio sources and of the Sun at noon are shown here for the NRAO experiment. Because of the small angular separation between the occulted source (0116 + 08) and its calibrator (an average of the outer sources), the observers could correct for transient shifts.

Although studies of solar light bending have been going on since Arthur Eddington's solar-eclipse expedition of 1919, not until about eight years ago did radio-interferometric techniques allow reduction of experimental error down to a few percent, and the NRAO group is now the first to report a sufficiently small experimental error to rule out either one or the other formulation. They described their results in a special experimental session at the VII Texas Symposium on Relativistic Astrophysics, held in Dallas 16 to 20 December. Two other groups have recently reported experiments with errors quite small (about three percent) but not yet small enough to distinguish between the two theories. One group worked at the Westerbork Observatory, The Netherlands (Kurt W. Weiler, Ron D. Ekers, Ernst Raimond, Kelvin J. Wellington) and described their results at the Dallas meeting; the other group (Charles Counselman, Thomas Clark, Hans Hinteregger, Stephan Kent, Curtis Knight, Alan Rogers, Irwin Shapiro and Alan Whitney) used antennas at NRAO and at the Haystack Observatory in Westford, Mass, and reported their results in a recent issue of *Physical Review Letters*.[1]

As radiation passes by the Sun on its way toward an earthbound detector, it is bent by the solar gravitational field; all relativistic theories agree here. The amount of bending, in seconds of arc, is predicted by metric theories of gravity to be

$$\delta\theta \approx (1/2)(1+\gamma)(1.75/d)$$

where d is the distance of closest approach of the ray path to the center of the Sun in solar radii and γ is one of the so-called "PPN" (Parametrized Post-Newtonian) parameters that are often used to distinguish among the various theories of gravitation. According to Einstein's theory, γ equals one. For

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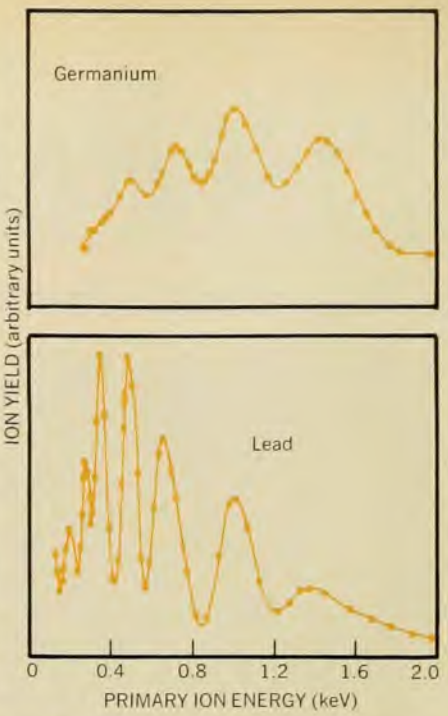
Ion–surface scattering reveals unexpected oscillations

A series of ion-surface scattering studies has revealed surprising oscillatory cross sections that some atomic physicists are hailing as macroscopic evidence of quantum-mechanical phase interference phenomena. Robert Erickson and David Smith (Central Research Laboratories, 3M Company, St. Paul) saw[1] the pronounced regularly spaced oscillations when they measured scattering cross sections as a function of primary energy for the elastic scattering of low-energy noble-gas ions from a number of solid surfaces. Although similar oscillations are well known in ionic collisions in gases, this is the first report of such oscillations in scattering from surfaces. Erickson and Smith explain their results in terms of binary collisions (as in a gas) between an incident ion and a surface atom, and a resulting quasimolecular state with shared electrons. Although not everyone is satisfied that the experimental data are yet sufficient to rule out other likely explanations, most agree that the results are exciting if this interpretation is borne out.

Low-energy ion scattering has been used for the past few years to study surfaces, because the elastically scattered ions have energies characteristic of the surface atoms. In such analyses, however, little attention is given to scattering cross sections. Erickson and Smith were spurred on to their studies, Erickson told us, by conversations with John Leys, an analytic chemist at the 3M Company, who had noticed some irregularities when he measured peak heights as a function of energy. In their own experiments, Erickson and Smith worked at a much finer energy scale. They bombarded a target surface (usually a transition metal) with noble-gas ions at a 45-degree angle and detected the ions that were scattered 90 deg. The fine structure was discovered by varying the energy of the incoming ion (usually He^+) between 0.2 keV and 2 keV, at each step tuning the detector to the energy associated with scattering from the target surface. The resulting plots of scattered-ion current versus energy show a series of peaks, with a pattern of oscillations that is characteristic of the target surface in both amplitude and location. The plots also show some evidence of chemical shift.

Why do the scattering cross sections vary with the energy of the incoming particle? According to Erickson and Smith, the velocity of the incoming ion affects the collision interaction time—the time during which the incident ion and the surface share their electrons, when the incident ion can capture one of the electrons of the surface atom before the ion scatters away. If the ion velocity is sufficiently large, the collision time will be of the right magnitude for a capture to occur, and the resulting neutralization is seen as a decrease in the detected ion yield. For a somewhat lower velocity, the electron can transfer to the ion and back again, with no decrease in the yield. At progressively lower velocities, a succession of charge-transfer events takes place, with ion-yield minima resulting at those velocities for which the end result is a neutral particle. This mechanism is fairly well established as accounting for oscillatory cross sections in gas collisions; the novelty here is its application to collisions at a surface. To test the velocity dependence, Erickson and Smith used $(He^3)^+$ and $(He^4)^+$ ions; both species gave the same result when scaled for mass difference.



Oscillations in ion yields resulted when helium ions were scattered from a variety of surfaces including lead (bottom) and germanium (top). The experimenters, Robert Erickson and David Smith (3M Company) attribute these oscillatory cross sections to the formation of quasimolecular states with electron transfer during the scattering. (From reference 1.)

Critics of the results note that the experimenters neither give an estimate of the expected cross sections nor say much about the nature of the resonant state. What Erickson and Smith do say is that their systems satisfy the initial-state–final-state degeneracy condition required in order to have quasiresonant charge transfer occur: Those elements that show the oscillatory cross sections (gallium, germanium, indium, tin, antimony, lead and bismuth) all have d-electron energy levels within 10 eV of the helium first-ionization energy (24.6 eV), whereas those elements with greater separation show no such structure. The critics comment that it is difficult to picture a quantum-mechanical phase interference (leading to crossover between energy levels of the two particles) occurring with such a low-energy projectile. Alternative explanations include multiple (as opposed to binary) scattering or ion losses through channeling. But Norman Tolk (Bell Laboratories, Murray Hill), who has done work in gas collisions,[2] tells us that he and John Tully have done some preliminary calculations for level crossing in systems similar to those studied at 3M and have found answers of the right order of magnitude.

Questions about the oscillations can most likely be cleared up with further experiments. These might include doing an angular scan—keeping the energy of the incident particle constant while varying the scattering angle; detecting the scattered neutrals, which may come off in an excited state; looking at the Auger electrons that could be given off by the surface atom when neutralization occurs; changing the incoming particle to vary the ionization energy. —MSR

References

1. R. L. Erickson, D. P. Smith, Phys. Rev. Lett. 34, 297 (1975).
2. N. H. Tolk, C. W. White, S. H. Neff, W. Lichten, Phys. Rev. Lett. 31, 671 (1973).

Excitation-transfer nitrogen lasers

A high-power, high efficiency laser with a wavelength in the visible or near-ultraviolet would be very desirable for such proposed applications as laser-induced fusion and isotope separation. Demonstration models of systems that might lead to this goal have been recently reported from the Naval Research Laboratory, Northrop Corporation, the University of Texas at Dallas and the Lebedev Physics Institute in Moscow. All these systems employ electron-beam energy deposition; they all use rare-gas and nitrogen mixtures, and they lase at wavelengths in the 3000–5000 Å range with efficiencies around 2%. At Los Alamos work is proceeding on a somewhat different approach that attempts to increase the output pulse length of lasers of this type.

The big question for all these systems is, Can the demonstration models be scaled up in size and pressure to produce the necessary output-energy per pulse (10^4–10^6 joules/pulse for laser-induced fusion, for example) without losing efficiency?

Pulsed electron-beam sources with power outputs of many gigawatts, electron energies around 1 MeV and pulse widths measured in nanoseconds are available commercially, off-the-shelf. Such an electron beam provides a particularly efficient way of storing energy in a gas (by electron ionization), and, if a reasonable fraction of this stored energy can be directed toward populating an appropriate energy level, an efficient pulsed laser should be the result.

The rare gases give very favorable energy-conversion efficiency, and there is a further advantage that their reactions have been well studied and have accurately known kinetics. The gas chosen is argon for the NRL, Northrop and Lebedev lasers and helium at UTD. In each case a high pressure, up to 7 atmospheres, provides a sufficiently dense target to the electron beam that a large part of its energy is deposited in the ionized gas; about half of the energy from the electron beam goes to produce dimerized rare-gas ions and excited states of atoms.

Molecular nitrogen has excited states suitably spaced for stimulated emission in the wavelength range desired—3000 to 5000 Å. So the next step is to add a little nitrogen and find the best mechanism for transferring the excitation energy from the ionized rare gas to molecular nitrogen, populating the upper state of the laser levels as efficiently as possible. It is at this stage that opinions diverge as to the best excitation-