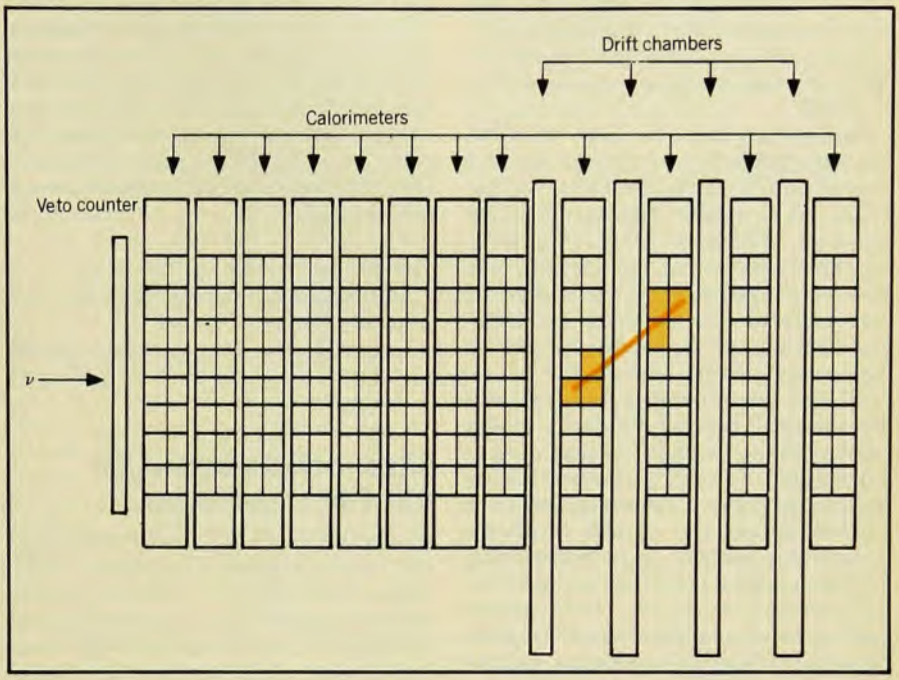
search & discovery

Neutrinos and atoms shed light on neutral currents

Over the past three years, evidence for the existence of neutral currents has grown ever stronger. Such currents are generally required by various gauge theories that have been developed in an attempt to unify the weak and electromagnetic interactions. Many observations of neutrino interactions are consistent with the model proposed a decade ago by Steven Weinberg and by Abdus Salam. However, two experiments cast a small shadow of doubt on the minimal model: the so-called "high-y anomaly" in antineutrino inelastic scattering and preliminary results on parity violation (or lack of it) in atomic physics.

Theory. In a charged-current interaction, the current mediates the transition of either an (charge $\frac{2}{3}$) up or a charmed quark into either a (charge $-\frac{1}{3}$) down or a strange quark so that the quark changes charge by one unit. On the other hand, in a neutral-current interaction, the electric charge does not change so that up quarks remain up quarks, down quarks remain down quarks, and so on. In such a neutral-current process, a lepton scatters off another particle, does not change its charge, and a heavy neutral particle is exchanged between the lepton and the particle from which it scatters.



Side view of apparatus used at Brookhaven National Laboratory to measure neutrino–proton elastic scattering. A typical recoil-proton event is shown in color. Experiment was done by a Harvard–Pennsylvania–Wisconsin collaboration. A single calorimeter module is 2.7 high × 2.5 m deep.

Although the existence of neutral currents is no longer in doubt, Weinberg feels, the detailed properties of neutral currents are still not established. The most important clue here is that the neutral currents are known very accurately to conserve "flavors" such as strangeness. For theories with the SU(2) × U(1) group structure considered by Weinberg and Salam, this requires the existence of at least one additional flavor, such as charm. Sheldon Glashow (Harvard) and Weinberg have recently argued further that, within this general frame-

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Laser frequency switching studies coherent phenomena

A simple way of observing coherent transient effects in the visible and ultraviolet regions has been developed by Richard G. Brewer and Azriel Z. Genack (IBM Research Laboratory, San Jose). The technique, called "laser frequency switching," simplifies the observation of a class of coherent phenomena in atoms, molecules and solids, analogous to the wide-ranging applications of pulsed nuclear-magnetic-resonance techniques. The IBM pair reported their results in *Phys. Rev. Letters*[1] and at the International Tunable Lasers and Applications Conference in Loen, Norway in June.

The technique traces its origins to the nmr studies using the spin-echo method of Erwin L. Hahn (University of California, Berkeley) and using the transient nutation effect by H. C. Torrey (Rutgers University) about 1950. The optical analog of the spin echo, the photon echo, was observed in 1964 at Columbia University by Sven Hartmann, Isaac Abella and Norman Kurnit. In 1973 the Columbia group extended their technique by electronically gating a cw ruby laser, thereby allowing wide versatility in excitation conditions. They were able to observe free induction decay, multiple pulse echos, spin-locked and notched echos, and so on. In addition, they developed a photon-echo nuclear double-resonance technique. Meanwhile, in 1971, Brewer and Richard L. Shoemaker (PHYSICS TODAY, December 1971, page 17) had used Stark switching to study optical coherence phenomena. Instead of using pulsed laser light, as in the Columbia experiments, Brewer and Shoemaker irradiated a molecular sample with a continuous infrared beam from a cw CO_2 laser. Coherent absorption or emission transients appeared in the transmitted beam when electronic pulses applied to the sample tuned the molecules into or out of resonance with the fixed laser frequency. Tuning was achieved because the electric field acts on the electric dipole moment of the molecules to split their vibrational energy levels through the Stark effect.

In the new approach, which in a sense is the exact opposite of Stark switching, Brewer and Genack use a stable, tunable cw dye laser that is frequency switched while the sample's transition frequency remains constant. The sample is kept external to the laser system so its performance will not be affected. Coherent transient signals appear in the forward beam. An electro-optic crystal of ammonium dihydrogen phosphate is inserted into the dye-laser cavity and is driven by a sequence of low-voltage pulses. The laser frequency follows the variations in refractive index induced in the crystal. Thus the experiment is controlled electronically.

As Brewer points out, Stark switching has been limited to the several discrete lines of the CO_2 laser. Furthermore, it is restricted to samples that have a dipole moment. The new technique is more universal because one can tune the laser over a broad spectral region, bringing the measurements into the visible and ultraviolet region, and one is no longer limited to samples with dipole moments.

Since its development five years ago, Brewer says, Stark switching has been applied to the identification and quantitative study of specific molecular collision mechanisms that previously had been hidden within the optical lineshape. Brewer and Stephen B. Grossman have now done optical pulse Fourier-transform spectroscopy, where very high spectral resolution is possible without the complication of Doppler broadening, and the relaxation or dephasing processes can be examined simultaneously for each line as in nmr. This work has now progressed to the point where the force laws that operate during elastic or inelastic molecular collisions can be obtained independently, Brewer said. Thus Stark switching has now been used to observe effects such as optical nutation, photon echoes involving two or more pulses, optical free induction decay, coherent Raman beats, optical adiabatic fast passage, and so on.

With laser frequency switching, Hahn told us, one can expect to obtain clearer measurements of damping and collision dynamics of optical systems among various levels. The technique will reveal the nature of transient coupling and damping connected with hyperfine and other higher-order degrees of freedom. In the solid state, he went on, one can measure dynamic processes, monitoring the local fields. Many other experiments previously possible with pulsed nmr should be now feasible in the visible and uv.

In general, Brewer said, with the technique one can study time-dependent phenomena of either coherent or incoherent processes in the optical region—in solids, atomic and molecular gases. Already Brewer and Genack have measured directly phase-interrupting collisions in molecular iodine. They have observed photon echoes, free induction decay and nutation effects in many lines of the visible electronic transition of molecular iodine, similar behavior on the sodium D lines, and with Roger Macfarlane (IBM) did free induction decay in a lanthanum trifluoride crystal having 0.1% Pr^{3+} at 1.5 K temperature.

In a related development, Chung L. Tang and John M. Telle (Cornell University) reported[2] last year that they had electronically switched a dye laser 15 Å in a few nanoseconds and more recently 150 Å in a few nanoseconds, although they did not try to obtain coherent transients at that time. Brewer notes that this result exceeds the IBM tuning range by about five orders of magnitude. He feels the Cornell method appears promising for extending the IBM laser frequency-switching technique to the sub-nanosecond time scale. —GBL

References

1. R. G. Brewer, A. Z. Genack, Phys. Rev. Lett. **36**, 959 (1976).
2. J. M. Telle, C. L. Tang, Appl. Phys. Lett. **26**, 572 (1975).

Laser assists excitation transfer in collisions

In an experiment that introduces a completely new approach to inelastic collisions, the transfer of excitation from one atom to another has been enormously enhanced by resonant optical irradiation. Incident laser light was tuned to a wavelength corresponding to the energy difference between the final and initial states of the colliding atoms. The experiments, in which the 5p strontium atoms transferred their excitation energy to 6s calcium atoms, was performed at Stanford University by Stephen Harris, Roger Falcone, William Green, Derek Lidow, Jonathan White and James Young.[1]

The feasibility of such an experiment had been predicted theoretically. In 1972 L. I. Gudzenko and S. I. Yakovlenko of the Lebedev and Kurchatov Institutes predicted high probabilities for the closely related inverse process, radiative collision, in the presence of a resonant electromagnetic field.[2] In 1974–75 Harris and Lidow independently predicted[3] the effect they observed.

When the Stanford experimenters illuminated with laser light a cell containing a gas of 5p strontium atoms and 4s (ground-state) calcium atoms, the Sr transferred its excitation energy to the Ca by the reaction

$$\mathrm{Sr}(5p\ {}^1P^0) + \mathrm{Ca}(4s^2\ {}^1S) + \hbar\omega(4977\ \text{Å}) = \mathrm{Sr}(5s^2\ {}^1S) + \mathrm{Ca}(6s\ {}^1S)$$

If no radiation is present the cross sections for reactions such as this are vanishingly small unless the two excitation energies match to within several kT. When Falcone and his co-workers irradiated the system with 4977-Å light from a tunable laser at a power density of about 10^6 W/cm^2, they found a cross section somewhat greater than 10^{-17} cm^2 for the inelastic collision.

The Sr–Ca cell, which was of the heat-pipe type, was operated at about 875 deg C. The Sr and Ca densities were about 10^{15} atoms/cm^3. The 5p storage state of Sr was populated by single-photon pumping. Excitation of the Ca(6s) level was detected by measurement of 5513-Å fluorescence that accompanies its spontaneous decay to the Ca(4p) state. The measured cross section was linear in the incident power density of the transfer laser. The Stanford group expects to use this linearity to attain cross sections as high as 3×10^{-13} cm^2, by a thousandfold increase in laser power.

Earlier this year the Stanford group reported[4] the apparent observation of this effect in a mixture of Sr and Ca. Further work indicated that because of the presence of an overlapping transition frequency within the Sr triplet series, the conclusions were in error. In the subsequent months two new successful experiments, which led to the results reported here, were accomplished.

Harris and his collaborators consider three theoretical points of view. In one, the effect is viewed as a virtual collision, followed by an electromagnetic transition. Another viewpoint considers the process as a transition between states of a quasimolecule. Calculations of this type indicate that, for dipole–dipole and dipole–quadrupole interactions, the cross section for inelastic collision peaks when the laser is tuned to correspond to the energy defect of the infinitely separated atoms. This is in agreement with experimental results to within an experimental uncertainty of 0.2 Å. The third, *ad hoc*, viewpoint considers the effect as resulting from the near electromagnetic field of the interacting atoms.

A number of theoreticians, including Marvin Payne, C. W. Choi and Munir H. Nayfeh of the Oak Ridge National Laboratory, Sydney Geltman of the Joint Institute for Laboratory Astrophysics, and Thomas George and his collaborators[5] at the University of Rochester, have already submitted follow-up papers.

Future applications of the new technique may include

- a radiative-collision laser using the inverse process discussed by Gudzenko and Yakovlenko;[2]
- extending the Stanford experiment to multiphoton processes to reach states in the 100-Å (vacuum-uv) region of the spectrum, and
- coherent Raman processes induced by collisions, for up-conversion of long-wavelength radiation.

Other possible experiments include spin-exchange and charge-exchange versions of this process.