

By measuring the ratio of three-jet events to two-jet events and using a QCD calculation done⁷ by Ahmed Ali, E. Pietarinen, Gustav Kramer and Juergen Willrodt, the Mark J results yield a value⁸ of $\alpha_s = 0.23 \pm 0.02$ (statistical error) and ± 0.04 (systematic error). According to Schopper, Ali and his collaborators also used Tasso data and obtained a similar result. The Jade group, using the calculations⁹ of P. Hoyer and his collaborators, found a value of $\alpha_s = 0.17 \pm 0.04$.

Schopper noted that the PETRA measurements are a direct determination of α_s , whereas the earlier determinations (with which the new results agree) are less direct because of large theoretical uncertainties. These earlier values were obtained from the level spacing of particles in the ψ family and from deep inelastic experiments involving neutrino or muon scattering on protons.

This spring Schopper expects PETRA to operate with 19 GeV in each beam. He said, "One might hope the experimenters can find the energy variation of α_s . This was not possible earlier because the logarithmic dependence requires either a wide energy range or a more precise determination than is feasible."

Another interesting—but negative—

finding at PETRA is that toponium, a particle containing a top quark, has not been found up to an energy of 31.5 GeV. Many theories had predicted its energy would be in the 28–30-GeV range.

Summing up the situation on QCD, Schopper said, "One of the relevant predictions of QCD is that gluons carry color charge and hence there should be direct interaction between gluons. This has not been demonstrated. But I think the data show that gluons are there." —GBL

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flow of gas into the system generally. The method is limited by the attainable signal-to-background ratio, kept as high as possible by several stages of differential pumping of the gases effusing continuously into the system from the two beams. Another drawback, stemming directly from this need for fast differential pumping, is that the hardware—nested vacuum chambers, pumps and so on—often gets in the way of the experiment, limiting the angular range of differential scattering measurements, for example. The newer, pulsed molecular-beam sources increase the signal-to-background ratio, yet consume so little gas that no differential pumping is required. And the supersonic free expansion of gas from the pulsed source yields cooled molecular beams with rotational temperatures down to a few tenths of a kelvin.

For good resolution the pulse duration should be shorter than the flight time of molecules across the apparatus—particularly if a velocity-distribution measurement of the beam molecules is contemplated. For a light gas, such as helium, and a typical flight path of 50 cm the required pulse duration for 10% velocity resolution works out to be around 20 microseconds. The problem of designing a pulsed molecular-beam source is largely that of designing a valve that will open for 20 microsec, close to make a good seal, and repeat indefinitely.

Gentry and Giese solved the problem by clamping a metal bar across a Viton O-ring to make the seal, and springing the bar away from the O-ring by means of the force between short, intense pulses of electric current (about 20 kiloamps for about 2 microsec) flowing through the bar in one direction and the same current flowing back through a fixed faceplate in

Pulsed molecular-beam sources

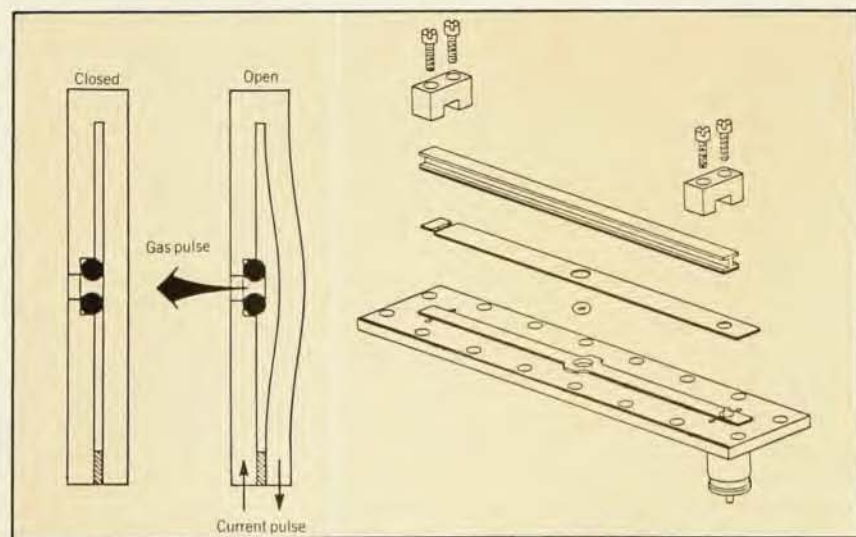
A new type of fast, pulsed molecular-beam source for collision studies and molecular spectroscopy appears to have several advantages over the traditional continuous-flow sources. It improves signal-to-noise in the detectors, produces very "cold" beams with little or no rotational or vibrational excitation, and it allows good time-of-flight measurements to determine velocity spectra. The source was developed by W. Ronald Gentry and Clayton Giese at the University of Minnesota.¹ Their work employs two such sources to investigate collisions between two molecular beams.

Continuous cooled beams have been in use for some years in single-beam spectroscopy; in a few cases a form of pulsed source had already been adopted to reduce the gas load on the system. Among the spectroscopists who have turned to the Gentry-Giese source for this purpose, in single-beam experiments, are Richard Smalley and his group² at Rice University and J. D. McDonald's group³ at the University of Illinois at Urbana-Champaign.

Gentry summarized some of the latest work in a paper delivered at the 11th International Conference on the Physics of Electronic and Atomic Collisions in Kyoto, Japan, last September.

Technique. For many years the standard technique for studying single-collision cross sections in atoms and molecules

has used crossed molecular beams of the reactants. "Chopping" of one or both beams provides an amplitude modulation to help resolve signal from background; each chopper is a rotating or vibrating vane that interrupts the line-of-sight path of the beam but does not stop the effusive



Pulsed gas valve designed by Ronald Gentry and Clayton Giese at the University of Minnesota. The two schematic sketches on the left show how a pulse of electric current flowing in two parallel but opposite directions flexes a metal bar and admits a burst of gas through the O-ring seal. On the right we show an exploded view of the construction. This valve generates 10-microsec pulses of light gases (hydrogen and helium) with a 20-pulse-per-second repetition rate. (From ref. 1.)

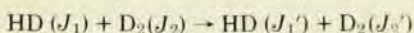
the opposite direction. Each time the bar lifts off the O-ring it releases a pulse of gas, the center of the ring (inside diameter 0.6 mm) forming the expansion nozzle for the supersonic jet. The bar is made of copper-plated spring steel, 1.5 mm $\times$ 1.75 mm $\times$ 3.8 cm, and is shaped like an I-beam.

The Gentry-Giese source currently delivers pulses of light gases—hydrogen and helium—of about 10 microsec duration (full width at half maximum) and a repetition rate of up to 20 pulses per second. With heavier gases the pulse duration is longer, because gas-flow properties through the O-ring limit the effusion rate; the geometrical length of the beam pulse remains approximately constant at 1 to 2 cm for all gases. Although the duty factor is small, compared with steady-state beams, the instantaneous gas pressures while the pulse is "on" are much higher, and signal-to-background is thereby increased.

Background signal is further reduced in Gentry and Giese's experiments by closing off the detector from the rest of the system by a guillotine-type shutter, which opens briefly, shortly after the two colliding beams have fired. This arrangement also allows measurement of time-of-flight spectra of the collision products.

At the University of Minnesota the pulsed molecular-beam apparatus has been used by Gentry, Giese and Mark Hoffbauer to study state-resolved rotational excitation in He + HD, He + D₂, HD + H₂ and HD + D₂ collisions and also for laser photodissociation studies of dimer molecules held together by van der Waals forces.

The supersonic beams have low rotational temperatures, consisting almost entirely of ground ro-vibrational states. So rotational transitions of the type



may be studied for low values of rotational levels of J_1 and J_2 . Ugo Buck of Hans Pauly's group at the Max-Planck Institute in Göttingen examined the $J_1 = 0$ to $J_1' = 1$ transition about two years ago with a continuous-beam apparatus, and the transition probability measured at the University of Minnesota with the pulsed-beam system is in good agreement with Buck's. Because of the better signal-to-background ratio in the pulsed-beam experiment, the Minnesota group was able to observe the much weaker $J_1 = 0$ to $J_1' = 2$ transition.

The pulsed-beam technique is very suitable for investigations involving pulsed laser excitation, Gentry says, because the entire beam pulse can be excited when the spatial dimensions of the two pulses are appropriately matched. This is important in the dimer experiments, where the molecules of interest—the dimers—make up only a very small fraction of the total beam intensity.

In a van der Waals dimer, for example two molecules of ethylene coupled by van der Waals forces, the coupling between the two monomer units is so weak that the vibrational-excitation frequencies of these monomers are not expected to be affected strongly by the dimerization. In other words, one expects the dimer to absorb a photon of frequency near any one of the monomer modes. These frequencies are so far removed from the monomer-to-monomer vibration frequencies (two or three orders of magnitude) that one also expects a long predissociation lifetime—the relaxation time for energy pumped into the monomers to find its way to the van der Waals bond and break it—and hence a narrow absorption linewidth.

Surprisingly the behavior of the ethylene dimer turns out to be mode-specific, according to Gentry, in the following way: If one pumps the in-plane vibration mode of the monomer the linewidth is indeed narrow, as predicted. But when the out-of-plane vibration is excited, the linewidth becomes extremely broad, implying strong coupling between these monomer modes and the van der Waals coupling modes.

Molecular spectroscopy. The value of Gentry and Giese's valve, in the form they use themselves, lies in the rapidity with which it opens and closes. Not so important for their work is that there is insufficient time, during each pulse, for true hydrodynamic flow to develop; almost certainly the jet does not undergo full adiabatic cooling. Spectroscopists working with molecular beams have known for some years of the advantages to be gained by "freezing out" the rotational and vibrational states of their molecules in supersonic expansion jets, and some forms of pulsed jets had been adopted as long as twenty years ago in attempts to reduce the gas loads on the vacuum systems.

At the University of Chicago, where Don Levy and Lennard Wharton were doing spectroscopy on cold beams with a continuous jet, Stuart Rice introduced about three years ago a modified solenoid valve for his own molecular-beam work—partly because he was interested in isotopic forms of gases not readily available in large quantities. This valve opens and closes much more slowly than that of Gentry and Giese (the "open" time is about 200 microsec) but the repetition rate is higher (100 pulses per second). With such a valve, Rice has been studying collisions, within a single beam, between helium or neon and excited iodine. He finds a large cross section at near-zero kinetic energy, suggesting the possibility of orbiting resonances.

Also using a modified solenoid valve in a pulsed source is Philip Johnson, of SUNY at Stony Brook. He studies multiphoton ionization in a molecular beam, and the multichannel electron multiplier that detects electrons from the ionization

requires a very low background pressure close to the interaction region. To avoid differential-pumping problems Johnson decided to go to a pulsed source, and he selected a solenoid with a similar performance to Rice's. He has studied nitric oxide and benzene, cooling out the rotational structure and looking at line widths in intrastate coupling.

Other molecular spectroscopists with similar problems of cooling and pumping have chosen instead to adapt Gentry and Giese's design to their needs.

At Rice University Smalley (who has worked with Levy and Wharton in Chicago) and his colleagues have built a pulsed molecular-beam source, but by designing it with a nozzle that opens slower and more completely than Gentry and Giese's they have been able to push the rotational temperature in polyatomic beams down to 0.2 K or less. Smalley tells us that the absence of uncooled rotational and vibrational states in any of the 30 to 35 molecules he has studied so far is of "crucial importance" for polyatomic spectroscopy.

The system at Rice has a single molecular jet crossing a pulsed tunable laser beam, and a detector for fluorescent radiation emitted perpendicular to the jet-beam plane. Smalley's group has used it to study vibrational relaxation in large polyatomic molecules. The many vibrational modes are all coupled—"like the springs in a bedframe" says Smalley—and the technique is to excite just one mode with a well-resolved laser frequency and then watch the fluorescence radiation to see how quickly the excitation communicates to other modes. "Give just one spring a tweak," says Smalley, "and see for how long it bounces."

They chose n-hexylbenzene, a molecule consisting of a long alkane chain attached to a benzene ring, for one of the experiments, because there are reasons to expect excitation transfer between ring and chain in this molecule to be relatively slow. Surprisingly, excitation of the "breathing" mode in the rings turns out to be transferred entirely to chain vibrations within a nanosecond. The result is very troubling for mode-specific laser chemistry, according to Smalley, because lasers currently in use excite for periods longer than a nanosecond.

Other chemical-physics questions attacked by the Rice University group include laser photoionization and dissociation. The aniline molecule, for example, when excited by a pulsed uv laser tuned to the lowest allowed electronic absorption frequency, produces almost entirely parent ions, while with metal carbonyls (iron pentacarbonyl, molybdenum hexacarbonyl, and so on) the bare metal ion dominates. In both cases the photoionization is found to be nearly 100% efficient. Besides enabling details of molecular structure and dynamics to be worked out, these observations may have

practical applications; the metal carbonyl ionization produces copious quantities of cold metal ions, which may, Smalley suspects, be useful in technologies such as ion implantation.

At the University of Illinois at Urbana-Champaign, McDonald and his group use an apparatus similar to that of Smalley. They have detected quantum beats in fluorescence of the molecules methyl glyoxyl and biacetyl—the first quantum beats due to vibrational structure to be observed, McDonald pointed out to us. The beats occur by mixing of states of the first excited singlet and vibrationally ex-

cited levels of the first excited triplet. The Illinois group chose these two molecules because they have the right density of states in the triplet, and sufficiently long radiative lifetimes to show beats.

—JTS

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New assessments of ozone depletion

A National Academy of Sciences-National Research Council panel has doubled its earlier estimate of stratospheric ozone depletion by halocarbons, though a British government report says that our present understanding of ozone depletion is limited and makes such estimates of doubtful significance. The NRC panel on stratospheric chemistry and transport, headed by Harold Schiff of York University, Toronto, concluded that continued world-wide use of halocarbons will result in ozone depletion that is calculated to reach 16.5%, half of which will occur in the next 30 years. A 1976 NRC report estimated the eventual ozone reduction at 7.5% (*PHYSICS TODAY*, November 1976, page 101).

The small amount of ozone in the stratosphere acts as an ultraviolet shield for the Earth and plays a role in determining the climate of the planet. Chlorofluoromethanes (CFM's), the primary focus of this and past studies, rise to the stratosphere and are dissociated by ultraviolet radiation into ClO_x fragments that enter into catalytic chain reactions in which one molecule can destroy many ozone molecules.

The increased predicted ozone depletion resulted from new values for some of the rate constants for the chemical reactions that govern ozone levels. Recent improvements in the computer models used to simulate the chemical reactions going on in the atmosphere and the air currents and more and better laboratory and atmospheric measurements that can be used to check the validity of the models have reduced the uncertainty range of the estimates as well.

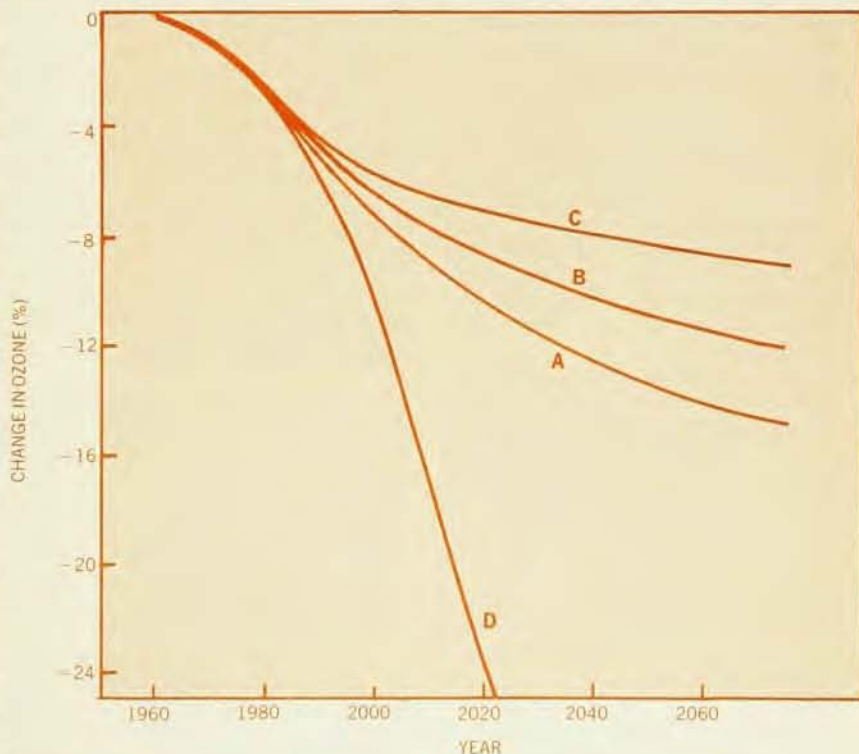
The primary conclusion of the report, *Stratospheric ozone depletion by halocarbons: chemistry and transport*, is that "continued release of halocarbons into the atmosphere will result in a significant decrease in the amount of stratospheric ozone." The NRC group chose to consider only the effects of two halogens, F-11 (CFCl_3) and F-12 (CF_2Cl_2), because they are produced and released in large quantity and, to the best of our

knowledge, are not removed in the troposphere (the region between the surface and the stratosphere). "The present study estimates an eventual decrease of 18.6% in the total amount of ozone for continued release of F-11 and F-12 at the 1977 rates . . ." The group reduced this "best estimate" for the eventual ozone decrease to 16.5%, however, taking into account the possibility of tropospheric "sinks" that can remove some CFM's below the stratosphere and the effects of thermal feedback mechanisms. The

temperature changes in the stratosphere and the troposphere resulting from ozone destruction can alter the rate at which ozone is created and destroyed.

Uncertainties. The NRC group isolated two potential sources of error in their calculations: uncertainties in the rate constants used, and uncertainties as to the validity of the one-dimensional model used. They worked with a model that considers only the vertical motions of chemical substances because they believe that when all the motions of the atmosphere are summed over all latitudes and longitudes, the effects of horizontal motions of substances largely cancel and the vertical movements dominate. "Combination of all these sources of error amounts to a range of a factor of 6. Thus our best estimate is that for continued CFM values at 1977 levels there is one chance in 40 that ozone depletion will be less than 5% and 1 chance in 40 that it will be greater than 28%."

The panel also pointed out that there are two possible sources of error that cannot be quantified. One is that some important chemical reaction has been overlooked; the other is that some systematic error exists in the chemistry, such as the assumption that the reaction rate is independent of pressure. They placed rough uncertainty estimates on these



Ozone reduction estimated for four different scenarios of CFM release: continued release of F-11 and F-12 at the 1977 rates (case A); continued release at the 1977 rate until 1983, followed by a 25% reduction at that time, then continuation at the reduced level (case B); the same reduction assumed in case B plus an additional 25% reduction in 1988, with constant release thereafter at half the 1977 level (case C); constant release rate at the 1977 level until 1980, a 7% per annum growth rate until 2000, and a constant release rate at the year 2000 level beyond that date (case D). (From the National Research Council report on stratospheric ozone depletion.)