search & discovery

Nobel prize to Richter and Ting for discovery of J/psi

The 1976 Nobel Prize in Physics has been awarded to Burton Richter of SLAC and Samuel C. C. Ting of MIT "for their pioneering work in the discovery of a heavy elementary particle of a new kind." Their surprising and far-reaching discovery of the J/ψ particle was announced in November 1974 (PHYSICS TODAY, January 1975, page 17). The prize of $160 000, to be shared equally by Richter and Ting, was scheduled to be awarded on 10 December in Stockholm.

The J/ψ with a lifetime 1000 times greater than expected for a particle as massive as 3.1 GeV, did not fit into the three-quark classification scheme. Two years after the discovery, nine or ten particles related to the J/ψ have been found. All the members of the J/ψ family of mass below 3.7 GeV (the threshold for the associated production of charmed mesons) have remarkably small widths, typically a few hundred kilovolts or smaller, whereas particles with comparable mass were expected to have widths of several hundred MeV. By now it is widely believed that all the J/ψ particles are bound states of a charmed quark and its antiquark. Further confirmation of the existence of charm has come from the discovery of charmed mesons and charmed baryons.

TING

RICHTER

Richter collaborated on the experiment with a large team of experimenters led by himself, Martin Perl (SLAC), William Chinowsky, Gerson Goldhaber and George Trilling (Lawrence Berkeley Laboratory). The experimenters used the large solenoidal magnetic detector at SPEAR, the electron–positron colliding-beam device at SLAC. It was Richter who led the drive to construct SPEAR, after his pioneering efforts with an electron–electron device done with W. C. Barber, Bernard Gittelman and Gerard K. O'Neill.

The SLAC–LBL team had been studying the behavior of the total cross section for e^+e^- annihilation as a function of energy, varying the total energy in 200-MeV steps. They observed an anomalously high cross section at 3.2 GeV. When the California experimenters returned to this energy region and varied the energy in much finer steps, using a nuclear magnetic-resonance spectrometer to monitor the ring energy, they found[1] a cross section for hadron production at 3.105 GeV that was greater than 100 times the cross section outside the peak. The full width at half maximum was less than or equal to 1.3 MeV.

The actual discovery of the particle the group called "ψ(3105)" took place in one frantic weekend (9–10 November 1974). By the next day the news had traveled far and wide. On 21 November the SLAC–

continued on page 19

Shortest wavelength laser from harmonic generation

Records for the shortest wavelength at which coherent radiation has been achieved in the search for an x-ray laser system are falling with remarkable speed:

- It was only in June that Henry Hutchinson, C. C. Ling and Daniel Bradley (Imperial College, London) reported[1] at the Amsterdam Quantum Electronics Conference that they had extended the range of generation of coherent radiation into the extreme ultraviolet at 570 Å.
- After a preliminary paper in August, at the International Conference on the Physics of X-ray Spectra, John Reintjes, Robert Eckardt, Nicholas Karangelen, Raymond Elton and Ronald Andrews of the Naval Research Laboratory (Washington, DC) and Chiao-Yao She of Colorado State University report in a current Letter[2] that they pushed the record down to 532 Å.
- Now, at the Tucson meeting of the Optical Society in October, the NRL group reported preliminary results indicating they had reached 380 Å.

The methods used by the two groups are quite similar: Both used the nonlinear susceptibilities of noble gases to generate harmonics of an incident laser beam. These methods are extensions of initial work done in 1973 by Stephen Harris and his colleagues at Stanford. The Imperial College group used argon to frequency-triple the radiation from a xenon excimer laser (one in which the active medium consists of excited short-lived Xe_2 molecules). The NRL group obtained the fifth (and, in their latest work, seventh) harmonic of pulses that were already fourth harmonics of Nd–YAG laser light. The noble gases they used were helium, neon and argon, Reintjes told PHYSICS TODAY.

The NRL experiment. The primary radiation wavelength of 2661 Å was obtained from the 1.06-micron output of a Nd–YAG laser by two successive stages of frequency doubling, first in a crystal of potassium dihydrogen phosphate and then in one of potassium dideuterium phosphate. The NRL experimenters then converted this 2661-Å radiation of the fifth harmonic by a process that can be pictured as follows:

A sequence of virtual transitions of a ground-state electron with the absorption of five pumping photons at 2661 Å generates a dipole moment that causes the emission of a single photon at one fifth of the driving wavelength. Such high-order nonlinear processes tend to be inefficient. However, the NRL group took advantage of an accidental near-resonance in neon, which has a 3p [1½], $J = 2$, line located within 12 cm^{-1} of four-photon resonance with the 2661-Å input, which enhanced the five-photon emission process. Although this effect tends to increase the conversion efficiency, the improvement can be offset by absorption resulting from photoionization in the neon gas. A similar situation exists in the Imperial College group's experiment on third-harmonic generation in argon.

In the NRL team's experimental arrangement, the 2661-Å beam was focussed (by a calcium-fluoride lens) to a spot in a 500-micron hole in the gas–vacuum wall, which took the place of the entrance slit of a 1-m vacuum-uv monochromator. The 30-psec input pulses with a peak power of 330 MW were formed by the lens into a spot 10 microns in radius and with a depth of 2 mm, later reduced, Reintjes said, to a 5-micron spot size with a depth of 0.5 mm (by switching from a lens of 10-cm focal length to a 5-cm lens). The 532-Å radiation was detected both photographically and photoelectrically. Because for the neon the generated radiation is in the ionizing continuum, efficient conversion requires that the interaction length (focal depth) be kept less than the 0.7-mm absorption length for a neon pressure of 40 Torr.

This difficulty was avoided by the NRL team in the helium experiment, because there the generated photon energy lies below the continuum, radiating from a level 1760 cm^{-1} above the 3p state. Although the four-photon resonance is not nearly as exact as in neon, the net conversion efficiency (in the range of 10^{-6}–10^{-5}) was higher in helium. This is because of its transparency at 532 Å, and because its negative dispersion allows phase matching by a tight-focussing procedure. The group has also seen fifth-harmonic conversion in argon at pressures of 10 Torr, Reintjes told us.

The latest result of the NRL group, mentioned above, is the generation of the seventh harmonic of the 2661-Å light in helium. In this experiment, in which the 380-Å output originated from a level in the ionizing continuum of helium, the 5-cm lens was used for focussing. Because the experimental arrangements are the same, the fifth and seventh harmonics are generated simultaneously, but conversion is considerably less for the seventh-order process.

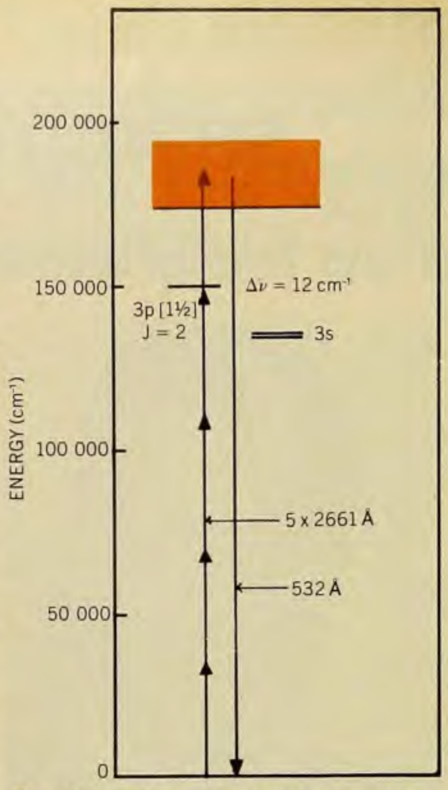
The Imperial College work. Short wavelengths can be obtained not only by going to higher-order processes but also by pumping with a laser of shorter wavelength. The Imperial College group did the latter, making use of the availability of the xenon excimer laser, which at 1710 Å is already in the vacuum-uv region. A single stage of frequency tripling in argon, enhanced by two-photon resonance with the 5p state, was therefore sufficient to produce the coherent extreme-uv radiation at 570 Å. The narrow-band tunability of the Xe_2 laser made accurate tuning to the resonance possible, and the experimenters were able to plot the relative efficiency of the process as a function of the laser's wavelength.

The Imperial College experimenters pumped with 10-nsec, 15-mJ pulses with a bandwidth of 1 Å, from the Xe_2 laser. With a barium-fluoride lens of 3-cm focal length, they focussed the beam just in front of a 250-micron aperture in the focal plane of a 1-m normal-incidence vacuum spectrograph. The bandwidth of the 570-Å coherent radiation was an instrument-limited 0.8 Å. As compared with the NRL pulses, the longer-duration lower-power pulses of the Imperial College experiment make saturation of the resonant transition less serious, Bradley said.

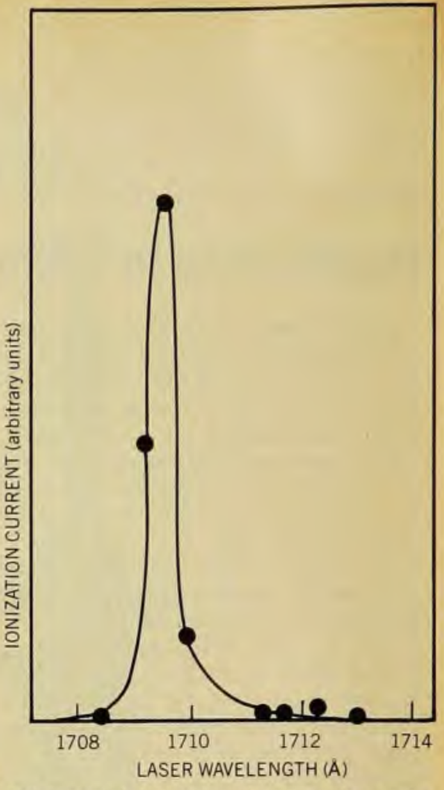
Bradley and his collaborators indicate that coherent radiation at even shorter wavelengths than theirs could be attained with other noble-gas-excimer lasers and appropriate isotropic nonlinear media.

Another development at Imperial College is the generation of pulses as short as 0.3 psec by[3] I. S. Ruddock and Bradley. The extremely short pulses, practically bandwidth limited, were obtained by mode locking a cw dye laser with two saturable absorbers. The pulses are significant for their hyperbolic-secant-squared intensity profiles, so that they are stationary pulses, that is, solitons. This makes it possible for them to propagate through materials without changing shape, according to Bradley. Because the pulses contain only 150 optical cycles (at 6000 Å), the Imperial College pulses are nearly at the lower limit of pulse duration set by the frequency of the laser. The arrangement used an argon-ion pumping laser, a saturable absorber dye cell and a resonant cavity, near the center of which passed a free-flowing jet of a rhodamine dye. Such short pulses are useful in the study of the interactions of matter on a very short time scale; for example, in ultrahigh-speed photography, stopping the motion of crystals and macromolecules.

As pumping lasers of increasing power are developed, will it become possible to obtain converted coherent radiation of higher and higher orders, and so of shorter and shorter wavelengths? Reintjes answered our question with a qualified yes. It turns out that there are certain effects that may limit conversion, in particular electrical breakdown of the gas. Such a breakdown was already seen in Reintjes's lab, in neon at 60 Torr. In this region an increase in pressure (needed for efficient conversion) lowers the breakdown threshold.



The five-photon process in neon, with a near-resonance at the four-photon level, used to generate 532-Å coherent radiation at NRL.



Efficiency of third-harmonic generation peaks at 1709.4 Å in argon to produce 570-Å coherent output in an experiment at Imperial College.

If soft x rays may be said to begin at 100 Å, some people believe that coherent x rays are likely to become a reality soon. The uses of such radiation would include the study of crystals and biomolecules, and photolithographic techniques for producing super-miniaturized electronic microcircuits. —HRL

References

1. M. H. R. Hutchinson, C. C. Ling, D. J. Bradley, Optics Comm. 18, 203 (1976); D. J. Bradley, M. H. R. Hutchinson, C. C. Ling, in *Tunable Lasers and Applications* (A. Mooradian, T. Jaeger, P. Stokseth, eds.), Springer, New York (1976), page 40.
2. J. Reintjes, R. C. Eckardt, C.-Y. She, N. E. Karangelen, R. C. Elton, R. A. Andrews, Phys. Rev. Lett. (to be published).
3. I. S. Ruddock, D. J. Bradley, Appl. Phys. Lett. **29**, 296 (1976).

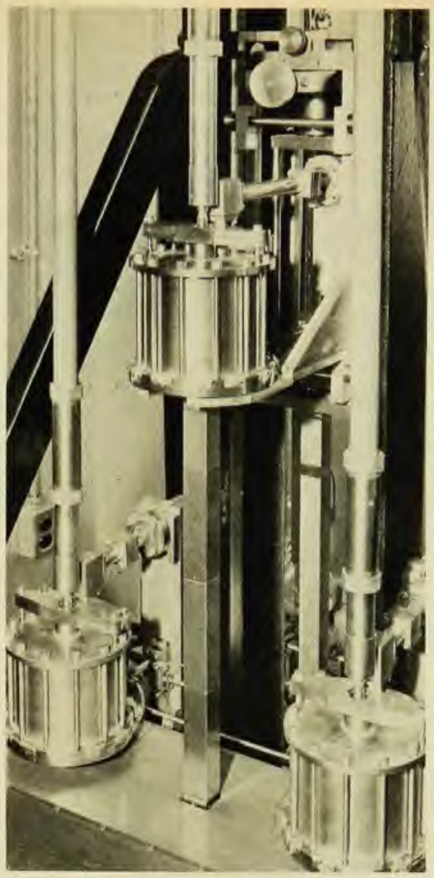
New values for boiling and freezing points

The values assigned to the temperatures of the boiling point of water and the freezing points of tin and zinc on the International Practical Temperature Scale of 1968 appear to be significantly higher than thermodynamic values. The new measurements, done by Leslie Guildner and Robert Edsinger with a very carefully built gas thermometer at the National Bureau of Standards, may lead to a redefinition of the International Practical Temperature Scale.

Although experimenters have made temperature measurements for many years with classical gas thermometers, Ralph P. Hudson, chief of the Bureau's Heat Division, says "They were polishing a slightly rotten apple. We decided to do it right." The project began about 20 years ago, with both Guildner and Edsinger working on it almost from the beginning. Their first determination was the thermodynamic temperature of the steam point, which they found to be 99.975 °C, a discrepancy with the IPTS-68 (the most recent revision) of −0.025 °C. Subsequently they found the tin and zinc freezing points to be 231.924 °C and 419.514 °C, which are lower than the values on the IPTS-68 by 0.045 °C and 0.66 °C, respectively.

The 1968 revision is based primarily on gas thermometry, the work most immediately preceding being done at the Physikalische Technische Bundesanstalt in Braunschweig by Helmut Moser and Wilhelm Thomas and at the National Research Council in Ottawa by Hugh Preston-Thomas and Chris Kirby.

The NBS results differ from and are thought to be more accurate than earlier gas-thermometry values for two reasons: First, the NBS group developed instrumentation to allow the highest level of metrology for the measurement processes such as thermal expansion, thermomolecular pressure and the realization of pressure ratios, Hudson told us. For example, the precision mercury manometer has a total uncertainty in pressure ratios of only 1.5 ppm. Second, the effect of sorption, which is thought to be the principal source of systematic bias between the NBS work and earlier gas thermometry, is believed to be insignificant in the new results because of a comprehensive effort to minimize it.



NBS precision mercury manometer has a total uncertainty in pressure ratios of 1.5 ppm.

The next step for the NBS team will be to measure the freezing point of aluminum, near 660 °C. Eventually they are aiming for measurement at the gold point near 1064 °C to incorporate in a new version of the IPTS. The latter was revised in 1948, 1968, and will be revised again in the not-too-distant future, perhaps as early as 1983, according to one member of the Advisory Committee on Thermometry; this group reports to the International Committee of Weights and Measures. —GBL

Nobel prize

continued from page 17

LBL group found a second narrow resonance decaying to hadrons, simply by scanning the entire region in 1-MeV steps. The new resonance had a mass of 3.695 GeV.

Much later, Richter said,[2] "It has been particularly satisfying to have witnessed the birth of a new class of particles; the ψ's with their unexpected properties. Every experimentalist dreams of making the great discovery—a discovery which will change the direction of scientific thought. I don't know yet if the colliding-beam machines and the new particles we have discovered with them will cause a sharp change in that direction, but surely they have bent it a bit."

Ting and his Brookhaven–MIT collaborators (Ulrich Becker, Min Chen and others) had been studying quantum electrodynamics, photoproduction of vector mesons and e^+e^- pair decay of vector mesons for the last ten years at DESY, where they developed techniques to identify electron–positron pairs from a background of millions of hadrons. They started their experiment at the Brookhaven AGS, searching for new particles in the reaction $p + Be \rightarrow e^+ + e^- + X$ with a precise pair spectrometer that had a mass resolution of 5 MeV. They saw a sharp peak at 3.1 GeV with a width consistent with zero (consistent with their mass resolution). They called it the "J" particle. The peak was first observed in August 1974, Ting recalls.[3] The group decided to make many experimental checks, such as decreasing the magnet current. They then spent late October and the first week in November measuring the anomalous $e^\pm/\pi^\pm$ ratio, hoping that the J could explain this number.

On 6 November Ting decided to publish[4] the work on the J. On 11 November Ting, who was visiting SLAC for a Program Advisory Committee meeting, went to W. K. H. Panofsky's office and told him and Richter of the MIT results. Richter reciprocated with the SLAC–LBL results. Within a short time the Adone storage ring in Frascati also discovered the J/ψ particle. "It was the shot heard 'round the world," at least in the circles traveled by particle physicists.

Biographies. Richter earned his BS and PhD at MIT. In 1956 he went to Stanford University and in 1963 joined the staff of SLAC, where he has been a professor since 1967.

Ting got his bachelor's and doctorate at the University of Michigan. In 1963 he went to CERN and then joined Columbia University's physics department the following year. He went to MIT in 1967, where he became a professor in 1969. Since 1966 Ting has been doing experiments at DESY. —GBL

References

1. J.-E. Augustin, A. M. Boyarski, M. Breidenbach, F. Bulos, J. T. Dakin, G. J. Feldman, G. E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie, R. R. Larsen, V. Luth, H. L. Lynch, D. Lyon, C. C. Morehouse, J. M. Paterson, M. L. Perl, B. Richter, P. Rapidis, R. F. Schwitters, W. M. Tanenbaum, F. Vannucci, G. S. Abrams, D. Briggs, W.