not stable. When the Bell experimenters first made it, they measured a high transition temperature. They left the sample lying around for a few days at room temperature and them remeasured the transition temperature. This time it had dropped considerably. A week later the sample had deteriorated still more. When they annealed the sample again at 750 K, the high transition temperature returned. On the other hand, when you remove the sample from the furnace and immediately cool it to helium temperature, the sample retains a high transition temperature and keeps its structure for a long time to come, Matthias explains. This metastability of all high-temperature superconductors is one of their crucial features, he says. Because instability is a rate process, he went on, the deterioration can come in minutes or can cover years.

To make the lithium titanium sulfide, the experimenters first make titanium sulfide in a quartz tube. Then they mix it with the lithium mechanically. It is then brushed with an electric arc in an arc furnace so that the lithium does not evaporate. Finally the sample is put back in a quartz tube and annealed at various temperatures for as much as two or three weeks. The experimenters have achieved their highest value of T_c with the formula $Li_{0.3}Ti_{1.0}S_{1.8}$; they expect that they should still find high-temperature superconductivity with a concentration variation of 10% either way.

"What other compounds will you try?" we asked. "I don't know," Matthias said. "First we have to get over the shock. In essence what this discovery means is that I should reevaluate, remeasure, reanneal and have another look at 8000 compounds. And those are only binaries and pseudobinaries. The ternaries, and this is a ternary, are much more difficult. The question is, out of all those thousands and thousands of compounds which I make, which were not superconducting, how many would be superconducting at high temperature if we had reached the structure that would be favorable and not let them lie at room temperature for days and weeks until they deteriorate. In other words, everything must be reexamined in the following way. You should anneal it at a certain temperature, then not give the crystal much time to relapse into whatever is the structure at room temperature." —GBL

References

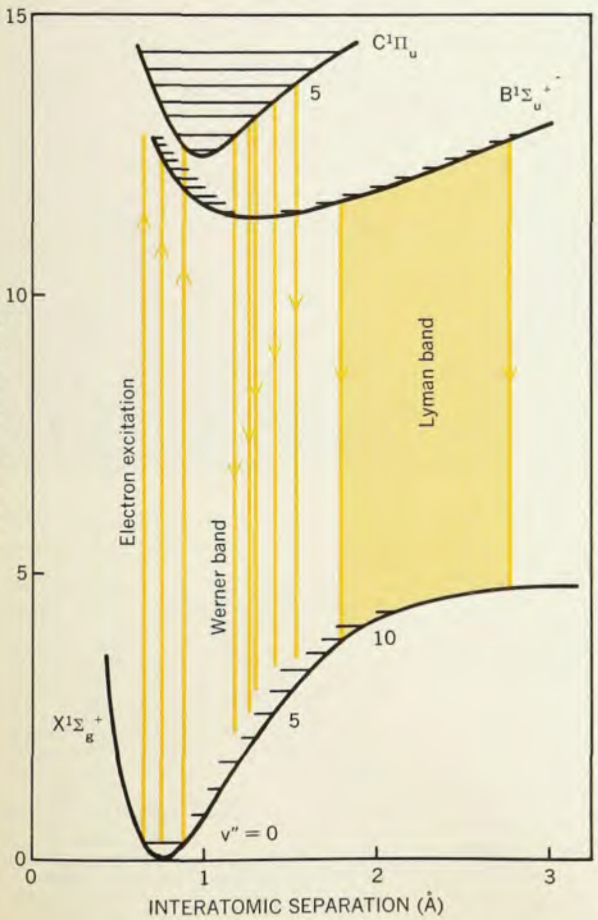
1. G. Arrhenius, E. Corenzwit, R. Fitzgerald, G. W. Hull Jr, H. L. Luo, B. T. Matthias, W. H. Zachariasen, Proc. Natl. Acad. Sci. US **61**, 621 (1968).
2. H. E. Barz, A. S. Cooper, E. Corenzwit, M. Marezio, B. T. Matthias, P. H. Schmidt, Science **175**, 884 (1972).

Two new lasers share short-wavelength record

The shortest-wavelength laser light yet obtained has been produced by stimulated emission in the molecular-hydrogen Werner bands. These 1160–1240-Å transitions in the vacuum ultraviolet correspond to photon energies of about 10 eV, which are suitable for photochemical, photodissociation and photoionization experiments in most molecules. Lasers with output in this frequency range have been reported independently and nearly simultaneously by two different groups—Ronald W. Waynant of the Naval Research Laboratory, and Rod Hodgson and Russell Dreyfus of the IBM Thomas J. Watson Research Center. Both publications are in the 28 February issue of *Physical Review Letters* (pages 533 and 536 respectively).

Recently both labs reported[1,2] success in achieving Lyman-band stimulated emission at about 1600 Å, which was the previous record for short-wavelength laser light. The pumping energy came from a traveling-wave discharge system in the NRL laser and from direct injection of a high-energy electron beam in IBM's device. In each case with recent improvements in the pumping system they can now initiate the Werner-band transitions as well as get increased power from the Lyman-band lines.

In the NRL laser, the traveling-wave discharge system produces total peak powers of several megawatts in a nanosec pulse. Several lossy optical components, present in the vacuum optical transmission path during the Lyman-band work, were removed to generate the shorter-wavelength Werner-band lines. IBM's laser uses a pulsed beam of 400-kV electrons (5×10^9 watts in a 3-nanosec pulse), which is accelerated through a 0.001-inch-thick titanium foil into an atmosphere of hydrogen at a pressure of 20–100 torr. A pulsed 6-kG magnetic field confines the beam as it passes along a 2.3-meter tube, 1 cm in diameter. Upward transitions in the hydrogen molecule can then be induced by the high-energy primary electrons, by secondary electrons and by cascade electrons.



Potential-energy curves for molecular hydrogen. Stimulated emission in the Werner band represents the shortest-wavelength laser light yet obtained; the photons have about 10-eV energy.

Transitions between the ground electronic state of hydrogen ($X^1\sum_g^+$) and excited electronic states ($C^1\pi_u$ and $B^1\sum_u^+$, see figure) can be induced in either of the two new lasers. The pulse is of such high power and short duration that a large inversion density builds up in the upper level before spontaneous-emission transitions can populate the upper vibrational levels of the ground state. When the inversion density is great enough, stimulated emission, that is, lasing, occurs without the need for the mirrors customary in conventional lasers.

Proof that stimulated emission is occuring can be obtained from an examination of the Werner-band spectrum, obtained with an ultraviolet spectrograph at 0.25-Å resolution. The relative intensities of the lines in the band are in agreement with what is calculated for stimulated emission, and are completely different from the normal spontaneous-emission intensities. Waynant has an extra (and, he maintains, a better) check for stimulated emission with his travelling-wave discharge. The propagation velocity of the excitation wave down the laser channel can be varied, and maximum laser output (for earlier nitrogen and Lyman-band hydrogen lasers) is obtained when the excitation wave velocity is less than *c*. The Werner-band lines only appear when the phase velocity of the wave is less than *c*; this effect is taken as evidence that stimulated-emission gain is occurring.

Hodgson and Dreyfus reported the energy in their Werner-band output as 5 erg/cm^2, but Hodgson tells us that he has now revised the figure upwards to 100 erg/cm^2; he discovered that the lithium-fluoride window he was using had become absorbent, apparently because color centers were formed during the intense ultraviolet exposure. —JTS

References

1. R. W. Waynant, J. D. Shipman Jr, R. C. Elton, A. W. Ali, Appl. Phys. Lett. **17**, 383 (1970).
2. R. T. Hodgson, Phys. Rev. Lett. **25**, 494 (1970); R. T. Hodgson, R. W. Dreyfus, Phys. Lett. **38A**, 213 (1972).

Weak-interaction theory

continued from page 17

specifically predicts a charged intermediate vector meson with a mass greater than 37.3 GeV and a neutral intermediate vector meson with a mass greater than 74.6 GeV as well as a photon of zero mass.

Normally, as in recent work on chiral symmetry, the spontaneous breaking of symmetries is accompanied by massless Goldstone bosons. Peter Higgs (University of Edinburgh) had pointed out in 1964 that the spontaneous breaking of an exact gauge invariance was an exception and did not necessarily entail Goldstone bosons. Therefore in Weinberg's theory there are no massless scalar mesons.

Weinberg's paper was allowed to sink into obscurity for the next four years while he struggled to prove that the theory was renormalizable, that the infinities could be reabsorbed like they are in quantum electrodynamics into redefinitions of the fundamental parameters such as electric charge.

Last summer a graduate student at the University of Utrecht, Gerhard 't Hooft, studying the kind of theory in which gauge invariance is exact but broken spontaneously, developed a method[2] of dealing with the theory that indicated the theory was probably renormalizable. Then Benjamin W. Lee (State University of New York at Stony Brook) offered a proof[3] that theories of this class, in particular Weinberg's weak-interaction theory, are indeed renormalizable.

Now Weinberg has published a new paper[4] that shows how his theory escapes some of the divergence difficulties present in conventional models. In the usual weak-interaction theory, with or without the presence of an intermediate vector meson, you find that the cross section for certain processes grows without bound and you get a violation of unitarity. It was generally believed that there would have to be some modification of the theory that would set in at about 300 GeV that would bring everything into agreement with unitarity. Weinberg has shown that in his model the cross sections behave quite well and that the theory heals itself considerably before you reach the 300-GeV limit. This self-healing may explain why the theory is renormalizable, if indeed it is. In the process of a neutrino and an antineutrino producing a pair of intermediate vector mesons, one obtained a scattering amplitude that increased proportionally to energy, whereas unitarity predicts a proportionality to the reciprocal of energy. The Weinberg theory gives an amplitude that is indeed proportional to reciprocal energy.

Since then Thomas Appelquist and Helen Quinn (Harvard) have done some calculations[5] that verify that in a particularly simple version of Weinberg's theory, the conjectured higher-order renormalizations are in fact possible, that is, the theory gives finite results for physical processes.

Weinberg told us that two things remain to be done: to find the right model and then to find experimental evidence for the validity of the model. He emphasized that although his 1967 model has so far received most attention, it is only one of a much larger class of renormalizable models based on various gauge groups. One is looking for a model that incorporates the weak and electromagnetic interactions not only with the leptons but also with the hadrons, he said. This problem is exceedingly difficult, he went on, because there are so many constraints. One of the constraints is that you must not allow the gauge invariance to be broken at all by any term in the Lagrangian. This is difficult to reconcile with accepted belief, which was that some of the effects seen in the strong interactions, such as the finite mass of the pion, arise from an actual breaking of the symmetry in the equations of motion.

Although the 1967 Weinberg model predicts lower bounds for the mass of the intermediate vector meson, the meson is not likely to be found soon, he notes. But there is some indirect experimental evidence that can be examined. Frederick Reines (University of California at Irvine) has done a reactor experiment on scattering of antineutrinos by electrons. If its accuracy can be improved by an order of magnitude it could serve as a test between the Weinberg theory and that of Richard Feynman and Murray Gell-Mann (Cal Tech). An improved experiment on the scattering of muon neutrinos on electrons could also test both theories. Calculations by Weinberg and Roman Jackiw (MIT) show that if the measurement of the anomalous magnetic moment of the muon can be improved by two orders of magnitude, this could also serve as a check on the theories.

"Right now there's not a grain of experimental evidence that this general idea is right. But it solves so many theoretical problems all at once, that it smells right," Weinberg says. —GBL

References

1. S. Weinberg, Phys. Rev. Lett. **19**, 1264 (1967).
2. G. 't Hooft, Nucl. Phys. **B33**, 173 (1971); Nucl. Phys. **B35**, 167 (1971).
3. B. W. Lee, Phys. Rev., to be published; B. W. Lee, J. Zinn-Justin, to be published.
4. S. Weinberg, Phys. Rev. Lett. **27**, 1688 (1971).
5. T. W. Appelquist, H. Quinn, Phys. Lett., to be published. □