even with larger simulation populations.

A possible way out of the dilemma is to abandon the hypothesis that the protogalaxies were in fact uniformly distributed in three dimensions. Yaakov B. Zeldovich at the Institute for Applied Mathematics in Moscow has developed a model in which the galaxies were formed not primarily by gravitational accretion but rather by the complex hydrodynamic interaction of massive gas clouds. In such a model, galaxies are formed preferentially on sheets in space, with regions devoid of galaxy formation between the two-dimensional sheets. In the time since the galaxy formations, these initial sheets would have been smeared out to some extent by gravitational clustering; but large voids might remain as vestiges of the original nonuniform distribution. The Zeldovich model has not yet been worked out in sufficient quantitative detail to permit a meaningful comparison with the observational data, Oemler told us.

One paradox, however, is harder to get around, Oemler points out. If voids like that suggested by the Kirshner group data are common, the 3-K cosmic microwave background ought to be much less uniform than we know it to be. The group quotes an upper limit of $^1/_{10}$ for the ratio of the density of bright galaxies in the Boötes void (if the three samples are representative) to the mean galactic density in normal regions. The 3-K microwave background has its origin at the time of "recombination"—the period when the early Universe first became cool enough to sustain neutral atoms. The Universe has expanded by about a factor of 1000 since the time of recombination. Therefore, the standard argument goes, density fluctuations would have grown by a factor of 1000 in the interim. Thus, today's tenfold depletion in the supervoid would have its origin in a 1% density fluctuation at recombination.

If such 1% density fluctuations were common at recombination, we should be seeing 1% fluctuations from point to point in the blackbody temperature of the cosmic microwave background today. In fact, the 3-K background is observed to be smooth to one part in 10^4. (The well-known anistropy due to our motion toward the Virgo cluster is a large-scale feature unrelated to such local fluctuations.)

The smoothness of the microwave background is a more serious problem, Oemler told us, than the disagreement with specific models such as those of Peebles and Gott. But here too, there are possible ways out. Perhaps the observed depletion of bright galaxies in the Boötes void exaggerates the overall depletion of mass density in such voids. A relatively shallow density trough, the Kirshner group argues, might well have inhibited galaxy formation, producing a void whose depletion of bright galaxies is much more pronounced than its true mass depletion. After all, Oemler says, we can only see the mass that shines brightly.

Another possibility would be a lumpy cosmic distribution of massive neutrinos. If neutrinos do have rest masses on the order of 10 eV, as is now widely speculated (PHYSICS TODAY, July 1981, page 17), they would represent a major fraction of the mass of the Universe. It may be, Oemler told us, that the neutrino spatial distribution exhibits strong fluctuations. If the "normal" matter "fell" into this lumpy neutrino distribution much later than the epoch of recombination, he argues, we would be seeing a microwave background much smoother than the present-day distribution of visible matter.

Note added in proof: Since writing this story we have heard from Davis that his group has recently identified a void they believe to be more than 50 Mpc in diameter. This void is also in Boötes, but at a distance from us of 140 Mpc it is only half as far away as the Kirshner void. The Davis report will be published in the *Astrophysical Journal* in March. —BMS

References

1. R. P. Kirshner, A. Oemler Jr, P. L. Schechter, S. A. Shectman, Astrophys. J. **248**, L57 (1981).
2. G. Chincarini, H. J. Rood, Sky and Telescope **59**, 364 (1980).

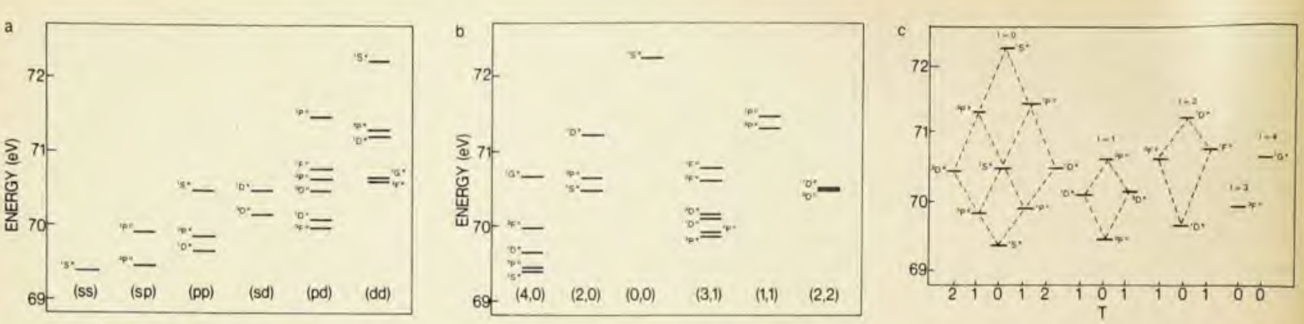
Supermultiplets in doubly excited atoms

Take an excited hydrogen atom, add a second excited electron, and you change the calculation of energy levels from an easy problem to a formidable task. In such doubly excited atoms, the dominance of electron correlations considerably alters the single-particle shell structure. Alternative formulations of the electronic states in terms of hyperspherical coordinates have greatly elucidated the angular and radial correlations. That progress was recently boosted by the insight from dynamical group theory: A supermultiplet classification gives striking order to the energy spectrum and predicts which electron states become mixed. This supermultiplet classification visually depicts the doubly excited atom as a linear triatomic molecule having the electrons across the nucleus from one another and exhibiting collective rotational and bending motions. This new view is compatible with that of the hyperspherical approach. All the varying perspectives were discussed last month at the meeting of the APS Division of Electron and Atomic Physics in New York.

The supermultiplet classification[1] and its interpretation as the spectrum of a rotor-vibrator[2] (ro-vibrator) were proposed by two chemists—David R. Herrick (University of Oregon) and Michael E. Kellman (now at Northeastern University). Their work built on group-theory research done in the early 1970s by Carl Wulfman (University of the Pacific) and by Oktay Sinanoğlu (Yale University) together with Herrick. The application of dynamical group theory to the problem of correlated motion of electrons in atoms has not been extensive in the past, perhaps because the Hamiltonian was known and provided a starting point for calculations of the energy levels or charge distributions.

Historically, the importance of electron correlations was first underscored by the deviation of the observed helium photoabsorption spectrum from that anticipated by independent-electron models. (See the review by Ugo Fano, PHYSICS TODAY, September 1976, page 32.) The need to include electron correlations led Fano and his students at the University of Chicago to adopt hyperspherical coordinates, which describe the positions of the two electrons relative to each other as well as to the nucleus. Joseph Macek (University of Nebraska) constructed a wave function that was approximately separable in the joint-electron radial coordinate R. Chii-Dong Lin (Kansas State University) extended this approach to write a wave function in which both the angular and radial correlations are approximately separable. The separability in hyperspherical coordinates relates to the separability of the rotational and vibrational modes found in the group-theory picture, but the precise correspondence has yet to be established. The nodal patterns calculated by this method infer the same structure as does the recent group-theory computation, although the hyperspherical approach is limited to the comparison of states of a single Russell–Saunders symmetry. One strength of the hyperspherical approach is that it delineates the radial as well as the angular correlations, whereas the dynamical group theory treats only the angular correlations.

The power of the group-theory approach in classifying the energy spectrum of doubly excited (or autoionized) atoms is illustrated in figure 1 for the specific case of the $n = 3$ shell of doubly excited helium. In the figure the energy levels were calculated by a standard



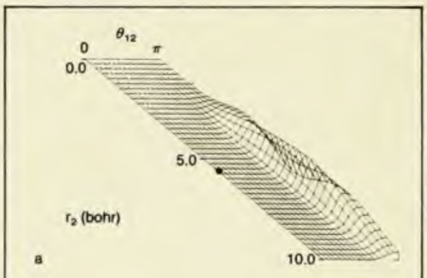
Successive regroupings impose increasing order on the energy spectrum of two electrons in the $n = 3$ shell of helium. No order is seen for the regrouping by single-particle quantum numbers (l,l′) due to mixing of states (**a**). Greater order arises from the O(4) classification, where quantum numbers (P, T) bracket the total angular momentum (**b**). The diamond pattern emerges from the supermultiplet definition of David Herrick and Michael Kellman,[1] where I relates to the revolutions of a rigid rotor (**c**). Figure 1

interaction configuration. Each state is labeled according to the conventional spectroscopic notation $^{2S+1}L^{\pi}$, where $\pi = $ o or e (for odd or even parity). When the levels are grouped (figure 1a) on the basis of the independent-electron angular-momentum quantum numbers (l,l′), no clear pattern emerges. Figure 1b and figure 1c illustrate the successive regrouping, according to the quantum numbers of particular symmetries. The work by Wulfman, and by Sinanoğlu and Herrick was based on the orthogonal group O(4), which characterizes the hydrogen atom. They calculated the coupled O(4) states for two-electron atoms. The levels were classified according to the values (P,T), where P and T refer to irreducible representations of O(4) and are the limiting values of the total angular momentum $L(T \leqslant L \leqslant P)$. The result was the far more regular spectrum shown in figure 1b. Herrick and Kellman later recognized this classification scheme as being similar to the cut-off spectrum of a rigid rotor. Two features of the spectrum remained unexplained: the splitting of levels for the same L in the same multiplet when $T > 0$, and the near-degeneracy of levels even in different multiplets.

To explain the remaining irregularities, Herrick and Kellman tried constructing two different supermultiplets. One of these—the I-supermultiplet—is shown in figure 1c. In this picture L denotes the total angular momentum; T denotes the angular momentum associated with the degenerate bending vibration, and $I = L - T$ is related to the number of rigid rotor quanta. This scheme produces a striking diamond-shaped pattern for the spectral lines and manifests the relation between the nearly degenerate states.

The spectral classification according to the alternate, d-supermultiplet is like that of the ro-vibrational progressions familiar to molecular spectroscopists. Kellman and Herrick strengthened this interpretation by fitting each intrashell spectrum using leading-order ro-vibrational energy formulas from molecular spectroscopy, and they obtained qualitatively good agreement. Thus they inferred that the doubly excited states of the helium atom or the negative ion behave as highly nonrigid linear molecules, with rotational and bending motions.

A group at the University of Chicago has calculated[3] several doubly excited-state wave functions for the $n = 2$ shell of helium and found the distribution to be consistent with the rotor-vibrator picture. This work was done by Huoy-Jen Yuh, Gregory Ezra, Paul Rehmus and R. Stephen Berry. They calculated the wave functions for different states from the Hylleraas functions, which are series expansions in which the coordinates are based on the distances of the electrons from each other and from the nucleus. Electron conditional probability distributions for the $^1P^\circ$ state (comprised of electrons in the s and p orbitals) suggest some bending motion coupled with some antisymmetrical stretching motion (see figure 2). Berry told us they have found similar results when they repeated their calculations with Sturmian functions, which show less extreme angular correlations. Similar computations for higher shells have not yet been done.



Conditional probability density for one of two excited electrons in the $n = 2$ shell, $^1P^0$ state of helium. When the radius r_1 of the other electron (black dot) is 5.6 bohrs (**a**), the distribution suggests coupled bending and stretching modes. The most probable configuration for an electron angular separation θ_{12} of 180° occurs when r_1 is 8.0 bohrs (**b**). From reference 3. Figure 2

Herrick points out that the group-theory approach does not directly predict energy levels but that it may guide the direction of calculations in the higher-level states. The main advantage of the group theory, he feels, is to give a simple picture of the angular correlation of the electrons, whereas the hyperspherical technique emphasizes the structure of energy levels within distinct sets of radial channels. For now the complementary aspects appear mutually beneficial.

A more recent application of group theory, with a different scope and objective, was undertaken[4] by Francesco Iachello (University of Groningen and Yale) and A. R. P. Rau (Louisiana State University). Whereas the Herrick–Kellman work aimed to classify all states within the low-lying shells, Iachello and Rau are trying to show that one highly correlated state dominates in the high-lying shells. Their motivation is the parallel they see with collective-pair states in other branches of physics. Indeed, Iachello is a nuclear physicist whose work on the group theory of interacting boson pairs led to the observation of a nuclear supersymmetry (PHYSICS TODAY, September 1980, page 21).

Herrick has also been exploring[5] an approximate pairing symmetry of electrons in the highest levels of each shell that seems to arise in the short-range interactions just as the ro-vibrator structure originates in the long-range correlations. Certainly one of the many questions to explore is the relation between the behavior of electrons in the low-lying states to that in the states near the threshold for ionization. —BGL

References

1. D. R. Herrick, M. E. Kellman, Phys. Rev. **A21**, 418 (1980).
2. M. E. Kellman, D. R. Herrick, Phys. Rev. **A22**, 1536 (1980).
3. H. J. Yuh, G. Ezra, P. Rehmus, R. S. Berry, Phys. Rev. Lett. **47**, 497 (1981).
4. F. Iachello, A. R. P. Rau, Phys. Rev. Lett. **47**, 501 (1981).
5. D. R. Herrick, Phys. Rev. **A21**, 418 (1980).

Crystal Ball to move from SLAC to DESY

The German Electron Synchrotron laboratory (DESY, Hamburg) and SLAC have agreed to a unique intercontinental transfer of a major high-energy-physics detector facility. After more than three years of fruitful operation at SPEAR, the older of the two electron–positron storage rings at SLAC, the "crystal-ball" particle detector will be moved in June to DORIS, SPEAR's opposite number at DESY. The 730 sodium-iodide crystals that make up the seven-foot-diameter hollow crystal ball provide extra-ordinary energy resolution for high-energy photons (PHYSICS TODAY, July 1981, page 21).

DORIS and SPEAR began life in the early 1970s as colliding-beam e^+e^- accelerators of very similar capability, with maximum collision energies of about 8 GeV. But DORIS has been moving to higher energies. Having been pushed beyond 10 GeV two years ago, DORIS is now being upgraded again. By April it is expected to be capable of e^+e^- collisions at center-of-mass energies above 10.55 GeV, the effective threshold for the production of "bare-bottomed" B mesons, which carry the fifth (bottom) quark flavor (PHYSICS TODAY, October 1980, page 19). Until now, CESR at Cornell has been the only e^+e^- machine capable of operating efficiently in this particularly interesting energy region.

Hence the motivation for so prodigious a moving job. At the upgraded DORIS, the crystal-ball detector system will be operated by a consortium of 15 American and European high-energy groups, looking primarily at B mesons and bound states of the bottom quark and its antiquark (the upsilon mesons). PEP, the newer e^+e^- storage ring at SLAC, has more than enough energy to produce these exotic new mesons. But with a design energy of 36 GeV, PEP can operate in the B-upsilon region only with much reduced luminosity.

Moving the $2.5-million crystal-ball detector facility from California to Germany will not be easy. Great care must be taken to prevent exposure to atmospheric moisture, which would dissolve the sodium-iodide crystals. The current plan is to move the detector aboard a C54 aircraft.

Among the important accomplishments of the crystal ball during its three years at SPEAR have been the discovery of the η_c (the charmed analog of the eta meson) and a possible excited η'_c state, and evidence for the production of two gluonium states (quarkless bounds states of gluons) in the radiative decay of the J/ψ. The conjecture that the $KK\pi$ resonance at 1420 MeV is indeed a "glueball" (PHYSICS TODAY, July 1981, page 20) has recently been strengthened by the conclusion, from additional crystal-ball data, that it is a spin-zero object of negative parity. —BMS

Financial pinch kills British RFX pinch

The British Atomic Energy Authority has cancelled the Reversed Field Experiment. The £20-million RFX magnetic-confinement-fusion facility, planned for the Culham Laboratory in Oxfordshire, was to have been the world's most ambitious reversed-field-pinch machine to date. With its cancellation, for budgetary reasons, American plans for full participation in the RFX have come to a sudden and disappointing end (PHYSICS TODAY, September 1981, page 20).

The toroidal RFX was to have had a plasma-current capacity of 2 megamps, almost four times that of the Los Alamos ZT-40, the largest American reversed-field-pinch machine. With no prospect of a US machine on this scale in the foreseeable future, the Los Alamos group had been participating for three years in design studies for the RFX. Last July, a DOE technical review panel recommended full US participation in the RFX project.

The decision that Britain could not afford the RFX comes despite the fact that the US, Italy and the European Economic Community had agreed to finance 60% of the facility's cost between them. The RFX fell victim to the needs of JET, the £180-million Joint European Tokamak, under construction at Culham. The Atomic Energy Authority was forced to kill the RFX when the UK Department of Energy refused to provide £10 million to upgrade JET to a deuterium–tritium experiment. The necessary funds would have come from the Authority's own fusion budget, leaving nothing for the RFX. "It is now clear that as a result of the government's public expenditure cuts . . . , we must reluctantly conclude that there is little prospect of . . . provision for the RFX in our program," the Atomic Energy Authority told its prospective American and European partners.

Edwin Kintner, who heads the US magnetic-fusion program at DOE, views the cancellation of the RFX with concern that goes beyond the needs of any specific experimental program. "It repeats the unfortunate precedent set by the German cancellation of Zephyr," he told us. After several years of active American participation, this compact tokamak planned for Garching was abruptly cut out of the Federal Republic's budget last spring (PHYSICS TODAY, May 1981, page 18). "I am concerned that we in the West do not seem to be able to muster the resources for the fusion experiments that need to be done—even when we share the cost." The implications for INTOR, the big international tokamak under discussion for the 1990s, are discouraging, he suggests. "You'd have to stay in such a marriage for 20 or 30 years, to get any use out of it." —BMS

in brief

Donald N. B. Hall has become the deputy director of the Space Telescope Science Institute. Hall had been Astronomer with Tenure and the head of the Next Generation Telescope and Gratings Laboratory at Kitt Peak National Observatory, where he had worked since 1970.

The Smithsonian Institution's observatory at Mt. Hopkins, Arizona, which was dedicated in May 1979, has been named after Fred Lawrence Whipple in recognition of "his great scientific achievements and outstanding leadership of the Smithsonian Astrophysical Observatory." Whipple, who selected the site and led the construction and development of the observatory, is professor emeritus at Harvard University.

Harwood Academic Publishers is publishing a new journal, *Soviet Journal of Remote Sensing*, a cover-to-cover translation of *Issledovania Zemli iz Kosmosa*, edited by Alexander V. Sidorenko. A year's subscription of bimonthly issues is available for $350 from Harwood, P. O. Box 786 Cooper Station, New York, N. Y. 10276.

A new quarterly journal, *Mass Spectroscopy Reviews*, will begin publication next Spring. Published by John Wiley & Sons, its coverage will be interdisciplinary. The editors are George Waller and Otis Dermer, both at Oklahoma State University. Subscriptions are $100 per year. □