

a simple model of the charge separation and transport. In the absence of the secondary acceptor ubiquinone-0 in solution, a transient initial current spike was observed, but it died away quickly, leaving no steady-state current. This spike is essentially a displacement current—analogous to the polarization of a dielectric. It is attributed to the transfer of an electron from the first to the second of the two primary acceptor molecules (ubiquinone-10), made possible by the reduction of the charged chlorophyll by the secondary donor. The decay time constant of this transient is a measure of the intrinsic rates of these charge-transfer reactions.

With the secondary donor (cytochrome c) and acceptor (ubiquinone-0) in solution in their respective compartments on either side of the lipid bilayer, a steady-state current was observed to flow between the shorted electrodes for the duration of the illumination. With a density of about 10^{11} reaction centers per square centimeter of membrane, the steady current is of the order of 50 nanoamps/cm². Together with the equilibrium open-circuit voltage (50 mV), this is a measure of the reaction rate for the slower of the two secondary transfer processes—the acceptance of an electron by the ubiquinone-0.

Before they could regard these photovoltaic observations as clues to the mechanism of photosynthesis *in vivo*, the La Jolla researchers had to convince themselves that they were not laboratory artifacts. The wavelength dependence of the photovoltaic response of the La Jolla cell, peaking near 800 nm with secondary peaks on either side, is almost identical to the optical absorption spectrum of the reaction centers. The group regards this as "unequivocal" evidence that the reaction centers themselves are responsible for the observed photoelectric effect. Furthermore, the photoelectric spectrum closely resembles the wavelength dependence of electron paramagnetic resonance observed in bacterial reaction centers *in vivo*.

The La Jolla results offer direct evidence that the reaction centers span the bacterial membrane, shuttling electrons from secondary donors on one side to secondary acceptors on the other. Because the synthetic bilayer was symmetric, only half the reaction centers imbedded in the membrane had the "right" orientation—with the chlorophyll end near the cytochrome compartment. Presumably *in vivo* all the reaction centers are correctly aligned.

Having demonstrated the photosynthetic transduction of light energy into a transmission electric current, the La Jolla group plans to exploit this technique for the detailed investigation of the chain of physical and chemical

processes that make up bacterial photosynthesis. By using laser-flash techniques similar to those developed by the Penn group, they hope to determine the kinetics and reaction rates for electron transfers inside the reaction center, for example the chlorophyll's donation of an electron to the primary quinone. The steady-state currents and voltages should permit determination of the reaction rates involving the secondary donors and acceptors.

With polarized illumination one can determine the orientation of the reaction centers. The group plans to produce asymmetric lipid bilayers in order to have control over these orientations. They hope to probe the functional roles of the ferrous ion on the primary quinone and the major subunits of the reaction center, "which have this far remained elusive."

Further down the photosynthetic chain, the mechanism for producing ATP remains unclear. The group expects ultimately to use their new techniques to investigate the coupling of the photoinduced electrical potentials to this central energy-storage process.

Penn work. Nigel and Christine Packham, Paul Mueller, David Tiede and Leslie Dutton at Penn have built a photosynthetic voltaic cell very similar to the La Jolla device. Under steady illumination, their cell gave results in good agreement with the La Jolla data. But they have also exposed the membrane to repeated 20-nanosec laser flashes and 6-microsec xenon flash-tube pulses. They expect that this technique will provide additional clarification of electron-transport mechanisms in photosynthesis.

They found, for example, that the first of a sequence of flashes separated by 30 millisecc generated a much smaller transient current than did the subsequent flashes. Dutton explained to us that the weak response to the first flash is really the difference between two larger currents going in opposite directions, corresponding to the two subpopulations of randomly oriented reaction centers—with "right" and "wrong" alignments relative to the cytochrome-c added to the cell. In response to the first flash, the transfer of an electron from the cytochrome to the quinone in properly oriented reaction centers is almost canceled by an opposing current of electrons going from the chlorophyll to the quinone in the wrongly aligned centers. The 30-ms interval before the next flash is long enough for the chlorophyll situated near the cytochrome (correct alignment) to recover its lost electron from the secondary donor. But the chlorophyll in the misaligned population, having no direct access to the cytochrome, takes much longer to regain its lost electron. Thus this population is photochemically inactive during subsequent flashes, leaving a much larger unidirectional response. Results such as this tend to confirm in detail the picture of photosynthetic electron transfer that had evolved from the earlier work.

—BMS

References

1. M. Schonfeld, M. Montal, G. Feher, *Proc. Nat. Acad. Sci.* **76**, 6351 (1979).
2. N. K. Packham, C. Packham, P. Mueller, D. M. Tiede, P. L. Dutton, *FEBS Lett.* **110**, 101 (1980).

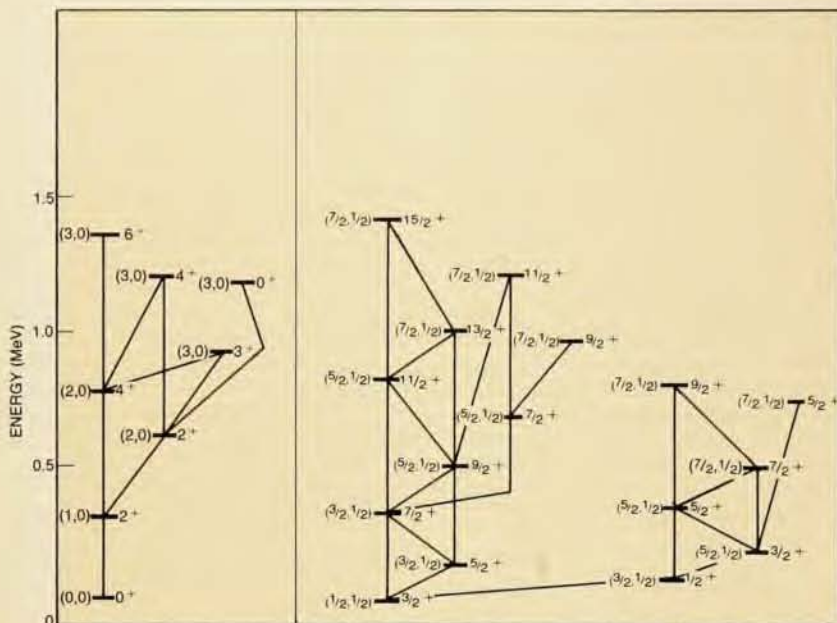
Nuclei may exhibit supersymmetry

Are there any interactions under which bosons and fermions behave similarly? Such a query lies at the heart of the current search for supersymmetry. A supersymmetry might be described somewhat more formally as the invariance of a Hamiltonian under a transformation operator that changes bosons into fermions and vice versa. Although the search is being most hotly pursued by particle and gravitational theorists, the first evidence for a supersymmetry in nature has surfaced in nuclear physics—as manifested in the energy spectra of some complex nuclei. This application of supersymmetry is largely phenomenological, but it has nonetheless intrigued the many theorists interested in the field.

The supersymmetry was identified¹ by Francesco Iachello (Yale University and University of Groningen) as part of his ongoing work with the interacting boson model. This nuclear model,

which is based largely on group theory (see *PHYSICS TODAY*, July 1978, page 17), has emerged in recent years as an alternative to the collective model of Aage Bohr and Ben Mottelson, both of Copenhagen. The interacting boson model depicts the nucleus as an inert core, corresponding to the last magic shell, surrounded by valence nucleons. Pairs of these nucleons act as bosons with angular momentum equal to either $L = 0$ or $L = 2$ (S and D bosons).

The interacting boson model was originally applied to nuclei with even numbers of protons and neutrons, but Iachello in his recent work extended the approach to odd-A nuclei by adding one fermion. He was able to find a group accommodating both the bosons and the fermion and to assign quantum numbers associated with this group to many of the observed low-lying energy levels (with positive parity) of the iridium-191 nucleus. (See figure.) Sub-



Predictions of supersymmetric structure in complex nuclei agree well with observed energy levels of the positive parity states of an even- A (Pt^{192}) nucleus (left) and an odd- A (Ir^{191}) nucleus. Iachello's group-theoretic model of the nucleus predicts each level to be one state with a particular set of quantum numbers—two of them are shown in parentheses, the third is the angular momentum. The model predicts energy levels in reasonable agreement with observation. The lines between levels denote observed electromagnetic transitions (E2 and M1).

sequently John Wood (Georgia Tech) extended the same approach to the positive parity states of gold-193, as he reported at the APS meeting in Washington in April.

Group-theory approach. In the interacting boson model, the one state of the S boson and the five states of the D boson determine the six-dimensional basis for the symmetry group $\text{SU}(6)$. In 1975 Akito Arima (State University of New York at Stony Brook and University of Tokyo) together with Iachello showed² that in three cases the Hamiltonian for an even-even nucleus could be written in terms of the Casimir invariants of subgroups of $\text{SU}(6)$. Such situations are called dynamical symmetries and result only because of special properties of the interparticle forces. The subgroups of $\text{SU}(6)$ in this instance describe special cases where certain terms in the Hamiltonian dominate over others. Two of these correspond to the extreme cases of nuclear motion first treated by the Bohr and Mottelson model—the anharmonic vibrator and the axial rotor, both well known experimentally. The third of these dynamical symmetries was subsequently observed in heavy nuclei.

Following this success with even-even nuclei, Iachello attacked the problem of odd nuclei, which requires both bosonic and fermionic degrees of freedom. One of the dynamical symmetries in the boson case was the orthogonal group $\text{O}(6)$. The boson states were classified according to the tensor representations of the group.

To treat odd- A nuclei, Iachello used the group $\text{Spin}(6)$, which maps onto $\text{O}(6)$, and which includes both spinor representations (to classify fermions) and the $\text{O}(6)$ tensor representations (to classify bosons). Joseph Ginocchio (Los Alamos) has developed³ a similar model for odd- A nuclei, which uses the spinor representations associated with $\text{O}(6)$. The angular momentum associated with the fundamental spinor representations of the group $\text{Spin}(6)$ is $3/2$; so the simplest realization of fermion structure is for a fermion with angular momentum of $3/2$.

The group structure determines a set of quantum numbers that define the various states, as seen in the energy levels of the nucleus. At the suggestion of Wood and Charles Vieu (Orsay), Iachello looked for the spectra he had predicted among the odd- A nuclei in the platinum region. Indeed his labels worked both for the even- A platinum nucleus and the neighboring odd- A iridium nucleus.

Because of the dynamical symmetry, the Hamiltonian can be written as the sum of invariants with their coefficients adjusted to fit the experimental data. (The invariants are eigenvalues of the Casimir operators of the group, where a Casimir operator is one that, like J^2 , commutes with all other operators.) The energy levels predicted by Iachello agree reasonably well with the observed spectra. The model also allows one to predict the allowed and forbidden electromagnetic transitions

between the states. Wood reported that in the gold nucleus he studied all transitions expected from the model to be forbidden were at least strongly inhibited.

One problem with the structure adapted by Iachello is that it is not a true supersymmetry: It uses a group based on a Lie algebra—an algebra that is defined only in terms of ordinary commutators of the transformation generators. A more complex supersymmetry must be based on a graded Lie algebra which allows both commutation relations (satisfied by boson operators) and anticommutation relations (satisfied by single fermion operators). Iachello comments in his paper that one might investigate the embedding of $\text{Spin}(6)$ into a graded Lie algebra; this has been done recently by Itzhak Bars and Baha Balantekin (Yale University).

Supersymmetry is only one of several active areas involving the interacting boson model. Some groups are trying to introduce more details into the model. Others are tempting to derive it from the shell model. Still others are studying⁴ the relation between the interacting boson model and the collective model; debate continues on the relative merits of the two approaches.

—BGL

References

1. F. Iachello, *Phys. Rev. Lett.* **44**, 772 (1980).
2. A. Arima, F. Iachello, *Phys. Rev. Lett.* **35**, 1069 (1975).
3. J. N. Ginocchio, *Annals of Physics* **126**, 234 (1980).
4. J. N. Ginocchio, M. W. Kirschen, *Phys. Rev. Lett.* **44**, 1744 (1980); A. E. L. Dieperink, O. Scholten, F. Iachello, *Phys. Rev. Lett.* **44**, 1747 (1980).

in brief

A satellite link between the Lawrence Livermore Laboratory and the Princeton Plasma Physics Laboratory will become operational the first of next year. The hookup will allow the two labs to transmit fusion data and information at the rate of 56 kilobits per second, initially, and ultimately at 1000 kilobits per second. The satellite link is the first phase of a plan to link all of the major magnetic fusion labs by satellite. MIT plans to build a \$5-million integrated-circuit fabrication facility at its Cambridge campus. The facility will serve a major role in MIT's effort to solve design and miniaturization problems associated with the development of very-large-scale integrated systems. □