0.258×10^{-5}) and the perturbing effects of the earth, sun, and solar radiation pressure. Tracking data from one nearside pass were used in the orbit determination. I obtained a best mean orbit from the Doppler data by differentially correcting estimates of the satellite position and velocity.

6. The satellite position and velocity are numerically integrated over one orbital period and simultaneously transformed to generate a history of five osculating Kepler elements (a, the semimajor axis; e, eccentricity; I, inclination; Ω, the longitude of the ascending node; and ω, the argument of the perifocus). These osculating elements are averaged over one orbital period to generate a set of mean elements.
7. Each element was fitted with patched cubic polynomials to smooth the data and permit the determination of an accurate time derivative. Analysis shows this method to be very accurate, and the errors introduced are shown to be well within the noise level of the mean elements. Since the time derivative of a due to long-term lunar perturbations is zero, it is not included in the calculation.
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14. The spectrum for each degree of the gravity field is found from the following relationships involving the normalized harmonic coefficients $\bar{C}_{\ell m}, \bar{S}_{\ell m}$ (ℓ-degree, m-order):

$$\sigma_\ell^2 = \sum_{m=0}^{\ell} (\bar{C}_{\ell m}^2 + \bar{S}_{\ell m}^2)$$

$$S_\ell = \sigma_\ell (2\ell + 1)^{1/2}$$

where σ_ℓ^2 is the variance of the ℓth degree and S_ℓ is its spectrum.

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22. The gravity generated from a cylinder of thickness t, density ρ, and radius r at a field point a distance d away is given by:

$$\Delta g = 2\pi G \rho t \left[1 - \frac{d}{(d^2 + r^2)^{1/2}} \right]$$

where G is the universal constant of gravitation.

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25. A limited set of higher-degree harmonic solutions will be attempted in the future. A parallel analysis is currently being pursued by M. Ananda of the Jet Propulsion Laboratory, using a discrete point mass modeling algorithm. A hybrid solution consisting of lower-degree harmonics and point masses will also be attempted.
26. The mean orbital elements for the Apollo subsatellites used in this analysis were generated by W. R. Wollenhaupt of the Johnson Spacecraft Center. I am indebted to N. E. Hamata and R. N. Wimberly of the Jet Propulsion Laboratory for their programming and computer assistance. I am also indebted to W. L. Sjogren of the Jet Propulsion Laboratory for his suggestions and support during this investigation. Contribution No. 2554 of the Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena 91125.

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Psi Particles and Dyons

Abstract. *A hypothetical magnetic model of matter provides a natural setting for the newly discovered psi particles. This supplements a phenomenological description of such particles that had appeared prior to their experimental recognition.*

The first issue of *Physical Review Letters* in 1975 contained nine theoretical contributions that were snap-judgment responses to the dramatic discovery of new particles with unusual properties (*1*). Of these, only one (*2*) cited a previously published (*3*) anticipation of particles with the observed general characteristics (normal electromagnetic coupling and suppressed hadronic interaction). Such particles had been postulated in an attempt to supply a phenomenological (*4*) interpretation for the striking absence of hypercharge-changing neutral processes in the weak interactions, as unified with electromagnetism. By and large, the other letters in that issue proposed various speculative models for the new particles. I have written elsewhere (*5*) of the importance of maintaining a clear distinction between phenomenology and speculation in particle physics. My own contribution was purely phenomenological in character. But, as I have also noticed, thanks to the cool responses of individuals and audiences, phenomenology seems not to be enough; a speculative model is considered superior, or at least more interesting, no matter how logically inconsistent it may be. Accordingly, here is my speculation.

An article published a number of years ago in these pages (*6*) described a predominantly electromagnetic model of the subnucleonic world. It was based upon the concept of symmetry between electric and magnetic fields, as embodied in certain hypothetical spin ½, Fermi-Dirac particles, called dyons, that carry both electric and magnetic charges. These charges independently occur as fractional multiples, ⅔, −⅓, and −⅓, of the corresponding units of pure charge. All hadrons thus far known are considered to be magnetically neutral composites of dyons. The neutral combination of three dyons, with the respective magnetic charges ⅔, −⅓, and −⅓, is a Fermi-Dirac particle and a baryon, while a pairing of dyon with antidyon of the same magnitude of magnetic charge is a Bose-Einstein particle and a meson. It is also imagined, paralleling the electric charge exchange mediated by weak interactions, that magnetic charge is rapidly exchanged among the dyon constituents of a magnetically neutral hadron, in such a way that even a quite short time average of a particular dyon's magnetic charge would be zero. And it was pointed out, consistently with the previous remark, that conflict with the Fermi-Dirac statistics of dyons is avoided for the low-lying states of baryons, which seem to be symmetrical in space and spin variables, by invoking the physical degree of freedom of magnetic charge and placing these quantum numbers in a total antisymmetric state. Incidentally, this idea resurfaced later (*7*) with the physical identification in terms of magnetic charge deleted, and an empty, but sexy label substituted—color.

We have now reached the jumping-off point. Through the mechanism of rapid magnetic charge exchange, magnetically neutral hadronic systems acquire an approximate dynamical symmetry that can be expressed as an invariance with respect to a group of operations on the three-valued magnetic charge indices. The group has the structure of the unitary group in three dimensions, U_3. The total antisymmetry remarked on for low-lying hadrons is an invariance of these states under the special subgroup SU_3(mag.). That such states are not invariant under the full group U_3(mag.), but form one-dimensional representations of it, expresses their possession of the property of nucleonic charge, as commented on in (*6*). The low-lying mesons, which do not carry nucleonic charge, are invariant under the full magnetic group. It is now natural to envisage the existence of excited states that are not invariant under SU_3(mag.) but constitute members of certain multiplets, which are analogous to, but distinct from the SU_3 multiplets that are familiar in connection with the electric charge quantum numbers. To the extent that U_3(mag.) invariance is an accurate one, transitions between SU_3 (mag.)-invariant and -noninvariant states will occur slowly. Hence we identify the 1^- neutral particles ψ(3.1 Gev) and ψ(3.7 Gev) as members of a noninvariant magnetic multiplet.

The eight-dimensional representation that presents itself for mesons is labeled by magnetic analogs of isotopic spin T and hypercharge Y. Of the various pairs

$(T,Y) = (0,0)$, $(\frac{1}{2}, \pm 1)$, $(1,0)$, it is $(0,0)$ that contains no magnetically charged state and therefore is a natural candidate for the lowest-lying type of excitation. If both long-lived ψ particles are labeled $T(\text{mag.}) = Y(\text{mag.}) = 0$, they must be distinguished by quantum numbers associated with the group $U_3(\text{el.})$, in analogy with the well-known 1^- neutral particles ρ^0, ω, and ϕ. We indicate these options for the ψ particles as $\rho^{0\prime}$, ω', ϕ'. At the moment, I favor the view that $\psi(3.1)$ is a mass-degenerate superposition of $\rho^{0\prime}$ and ω' (ρ^0 and ω differ in mass by only 14 Mev), while $\psi(3.7)$ is identified with ϕ'. The latter assignment is attractive in the following way. Although transitions of $\psi(3.1)$ and $\psi(3.7)$ to "normal" hadrons are largely forbidden by $U_3(\text{mag.})$ invariance, this would not inhibit the decay $\psi(3.7) \rightarrow \psi(3.1)$ + normal hadrons, except that the same mechanism which restrains the decay of ϕ into pions should also operate here. That mechanism was long ago (*8*) interpreted within the framework of U_3 invariance as signifying the unity of 9 rather than 8+1 unit spin mesons. The degeneracy of $\rho^{0\prime}$ and ω' is also quite important in attaining a thorough suppression of this coupling. Another point on behalf of the ϕ' status of $\psi(3.7)$ is the absence of appreciable production in proton-nucleon collisions (*9*), as compared with $\psi(3.1)$, which seems to be produced by hadronic rather than electromagnetic interactions (*10*).

There is a different argument pointing to the possibility that some suppression of quadratic ψ couplings with normal hadrons is a general feature. Through the direct coupling of the ψ particles to photons, such a quadratic ψ interaction implies the decay of a ψ particle to a photon and normal hadrons. This decay will occur too rapidly if the quadratic ψ interaction is of normal strength; the appropriate coupling constant must be roughly an order of magnitude smaller. Here is an indication that the internal rearrangements necessary to convert the magnetic states of two ψ particles to an invariant configuration occur with some difficulty. A suggestion of confirmatory evidence appears in photoproduction experiments, which can be interpreted to show that the ψ-nucleon scattering cross section is quite small on the normal hadronic scale (*11*). Finally, we remark that ψ particles more massive than $\psi(3.1)$ and $\psi(3.7)$ are unlikely to be as long-lived as the latter two. If they are members of a similar multiplet, the decay down to either $\psi(3.1)$ or $\psi(3.7)$ is impeded only by the magnetic rearrangement effect. Or, if they are magnetically neutral members of a multiplet other than (0,0), the large splittings anticipated within such a multiplet should lead to a considerable violation of $U_3(\text{mag.})$ symmetry, with a consequent loosening of the restraints against direct decay into normal hadrons.

A speculative model, such as the one we have outlined, can be useful if the impressionistic picture that it paints suggests more sharply focused phenomenological descriptions. Since we have already provided a phenomenology of the ψ particles in the areas of electromagnetic and weak interactions, the challenge is posed to establish contacts with the speculative model that could be broadened into specific hints concerning, for example, the forms of symmetry-breaking interactions, including charge and parity (CP) violation, and also guide the search for magnetically charged particles.

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Picosecond Kinetics of Events Leading to Reaction Center Bacteriochlorophyll Oxidation

Abstract. *A transient absorption spectrum has been measured in* Rhodopseudomonas spheroides *R26 reaction centers. Its salient features indicate that both the bacteriopheophytin and bacteriochlorophyll chromophores play a role in the excited state. Decay of this state yields a rise time for oxidation of the reaction center complex of about 150 picoseconds.*

Much of the work on our basic concepts of how photosynthetic systems may handle incident light energy and convert it into electrochemical potential energy within the photosynthetic membrane has come from studies on photosynthetic bacteria (*1–3*).

In the photosynthetic bacterium, *Rhodopseudomonas spheroides*, an array of light-harvesting bacteriochlorophyll (antennas) and carotenoid molecules function to capture photons. The energy contained in the excited "antenna" molecules is funneled into a special bacteriochlorophyll complex generally called the reaction center protein. This protein in photosynthetic bacteria is readily isolatable from the membrane and from the other pigments by use of detergents. Current investigations in several laboratories reveal that the reaction center protein is comprised of four magnesium porphyrins (bacteriochlorophyll), two hydrogen porphyrins (bacteriopheophytin), a ubiquinone, and an iron (nonheme) moiety (*4–6*). The principal absorption bands are found at 865, 800, 760, 600, and 530 nm; the bands at 865, 800, and 600 nm are generally considered to arise from bacteriochlorophyll absorption, while those at 760 and 530 nm seem to come from bacteriopheophytin absorptions. However, the possible existence of exiton interaction (*2*) makes a unique assignment of these bands difficult.

Excitation of the reaction center bacteriochlorophyll complex results in the transfer of an electron to the primary acceptor. Removal of the electron or the chemical oxidation of the reaction center bacteriochlorophyll complex results in major changes in the spectrum. These include bleaching of the bands at 865 and 600 nm and a small hypsochromic (blue) shift of the 800-nm band; there is also a small optical increase apparent at 1250 nm (*7*). Thus far no detectable optical changes have been identified with the primary electron acceptor in photosynthetic bacteria (*8*).

We have reported the bleaching of the 865-nm band after excitation into the 530-nm bacteriopheophytin band (*9*); this indicates rapid energy transfer between the two reaction center chromophores. We