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Evidence for a Relativistic Electron-Pair Model of Nuclear Particles

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A positroniumlike, relativistic electron-pair model previously found to describe the properties of the pion and hadron resonances is tested for its prediction of the hadron-to-muon production ratio R in high-energy e^+e^- collisions. It is found that the model leads to the observed magnitude of R and its stepwise increase with energy. The model predicts a series of further rises of R as the available energy is increased, beginning at about 7.9 Gev.

The discovery of a series of narrow resonances in the scattering of high-energy electrons against positrons in colliding-beam experiments (Augustin et al., 1974) has led to the suggestion that these collisions may involve the formation of positroniumlike intermediate states composed of pairs of spin-$\frac{1}{2}$ particles such as baryons (Goldhaber and Goldhaber, 1975), quarks (Appelquist and Politzer, 1975), or heavy leptons (Perl et al., 1975) possessing the same quantum numbers as a virtual photon. It is the purpose of the present note to suggest the possibility that such massive intermediate states might represent excited spin-1^- states of electrons and positrons in a relativistic positroniumlike system whose spin-zero ground state was earlier found to reproduce the known properties of the π^0 (Sternglass, 1961), and to indicate the manner in which this hypothesis can be tested by future measurements of the hadron-to-muon production ratio. The principal features of this model (Sternglass, 1961) that relate it to recent "charmonium" models (Appelquist and Politzer, 1975) may be summarized briefly as follows:

(1) A high-mass, positroniumlike bound state of the electron and positron is found to arise when the center-of-mass energy E is highly relativistic and the electrostatic Coulomb force is replaced by the relativistic Coulomb law as measured by an observer at rest with respect to either one of the two

particles. For the case when they are moving in a circular orbit, $F_{el} = \gamma_{12}e^2/r_{12}^2$, where $\gamma_{12} = (1 - \beta_{12}^2)^{-1/2}$ and $\beta_{12} = v_{12}/c$.

(2) Using this law of force, it is found that the relativistic centrifugal force $F_{ce} = \gamma_{12}(m_0/2)r_{12}\omega^2$ can be balanced by F_{el} no matter how large γ_{12} becomes, leading to a new set of orbits that approach a minimum distance between the two charges $r_{min} = \frac{1}{4}(e^2/m_0c^2) = 0.7 \times 10^{-13}$ cm as the energy increases, thereby accounting for "confinement" of these states to subnucleon dimensions (Tryon, 1972).

(3) As a result of the extremely large relativistic velocities, the usually small Sommerfeld precession Ω_p measured by $\frac{1}{2}\alpha^2\omega$, where $\alpha = e^2/\hbar c$ becomes comparable to ω when $\gamma_{12} \gg 1$ according to the expression for the Thomas precession, $\Omega_p = \omega(\gamma_n - 1)/\gamma_{12}$. Thus, the reference frame K_p in which the particles describe their normal, closed Kepler orbits turns out to be a highly accelerated reference frame, so that according to Einstein's principle of equivalence, the rest masses of the two charges are greatly increased above their normal laboratory value. This causes them to behave like massive quarks obeying classical dynamics with respect to radial oscillations, while the mutual forces are increased by a factor far above their normal value, equivalent to a strong coupling constant $g^2 = (\gamma_{12}e^2/\hbar c)$ which exceeds unity as soon as $\gamma_{12} > 137$, thereby accounting for the observed strength of nuclear forces.

(4) Quantization of this system according to the Bohr–Sommerfeld theory leads to an expression for the equilibrium angular momentum $L_{eq} = (\gamma_{12}/\beta_{12})(e^2/c)f_r$, where f_r is a correction factor to account for the relativistic rather than the Galilean addition of velocities, equal to 1 for $v \ll c$ and $\frac{1}{2}$ for $v \simeq c$. This leads to the occurrence of a finite minimum angular momentum $L_{min} \simeq e^2/c$ and two sets of solutions for β_{12}^2. One of these gives the normal, low-energy atomic states of positronium defined by $\beta_{12} = (1/n)\alpha$, and the other a new, high-energy set defined by $\gamma_{12} = n(2/\alpha)$, where n is the principal quantum number of the Bohr–Sommerfeld theory.

(5) The large angular acceleration of the precessing K_p frame, which increases the inertial mass of the charges, when combined with the assumption that the rest masses of the electron and positron are purely electromagnetic in origin, also explains the parton or "pointlike" behavior of the constituents of hadrons as well as the low rate of radiation (Sternglass, 1965a), since the classical shell radius is now reduced to $r_{cl} = (e^2/2\gamma_{12}m_0c^2)$.

According to the relativistic pair model whose ground state gives the π^0 mass, the heavy mesons and baryons are assumed to be quasimolecular systems consisting of groups of such relativistic pairs forming "pionic molecules," quite analogous to the "polyelectron systems" composed of low-energy electron–positron pairs examined by Wheeler (1946). Thesé systems are assumed to be produced in a succession of pair-production processes from the intermediate spin 1^- s states[1] of $n > 1$ resulting from a capture process at very high energies, analogous to the formation of excited compound nuclei in low-energy nuclear reactions. Since these models for the hadrons have definite numbers of electrons and positrons, n_{eh}, it is possible to calculate $R(E)$ for a given energy at which hadrons of mass E/c^2 are produced, knowing that the incoherent cross section σ_h for hadron production is determined by n_{eh} or $\sigma_h \propto \sum_i q_i^2 = n_{eh}$ when the charges q_i are integral and the spin is $\frac{1}{2}$.

From this knowledge, R can be calculated if one knows the corresponding quantity for μ-meson pair production. According to the present model (Sternglass, 1965a), the μ meson is composed of $3e^{\pm}$, so that a pair of muons give $n_{e\mu} = 6$. Therefore, if the electron-pair model for the muon and hadron structure is correct and only pions can form strongly bound hadrons, the ratio R must be given by

$$R(E) = \sigma_h/\sigma_\mu = \tfrac{1}{6}n_{eh} \tag{1}$$

Equation (1) indicates that as the energy available for forming increasingly complex hadrons containing increasing numbers of $e^{\pm}$ rises, R must generally increase. Furthermore, rapid rises or resonances in R should take place whenever particularly favorable conditions for the creation of new, relatively stable or long-lived clusters of electron pairs are reached, or whenever important new decay channels possessing the correct quantum numbers become available, in close analogy to the theory of excited compound nuclei.

As shown in Sternglass (1965a), the most important basic cluster unit is that consisting of two strongly bound pions analogous to a diatomic positronium molecule, similar to the pairing of nucleons. Neglecting spin-spin and spin-orbit interactions of the order of 6–10 MeV, this di-pion was found to have a bond length of 1.4 fm and a ground-state mass of 484 MeV for $J = 0$, close to that of the K meson. Thus, whenever the available center-of-mass energy is such that pairs of K mesons of relatively great stability or long life can be produced and rotationally excited to states of $J = 1^-$ as the result of a series of successive pair-production processes, one should observe a rise to higher R values.

Because the strength of the binding between pairs of e^+e^- depends upon the degree of correlation between the orbital motions (Sternglass, 1965a), and because this correlation is greatest when the two electron pairs have exactly equal internal momenta or masses, the most stable clusters will result when-

[1] The relativistic states differ from the normal states with regard to their symmetry properties, owing to the existence of $r_{\min}$ close to r_{12} for any n. Thus, states of $l = 0$ in the relativistic case have an appreciable "zero-point" angular momentum $L_0 = 137\,(e^2/c) = \hbar$ as in the ground state π^0 (Sternglass, 1961). This gives all $l = 0$ states the odd parity of an atomic $n = 1$ p state rather than the even parity of a normal s state, for which $L_0 = e^2/c$.

ever a pair-creation process leads to pairs of equal masses. Furthermore, phase-space considerations tend to favor momenta of equal magnitude for the decay products. Therefore, one would expect particularly strong enhancements to arise whenever the available energy allows the production of integral numbers of K-type di-pions in a succession of "fissionlike" decays of the original pair into equal mass daughter pairs.

The requirement that the preferred number of electrons and positrons is such as to be derivable from a series of successive decays into pairs of equal mass can be expressed by the condition $n_{eh} = 2^N$, where N can take on any integral value greater than 0.

The additional requirement that these electron–positron pairs must be grouped into integral numbers n_k of the most stable K-type di-pion structures each containing $4e^{\pm}$ when sharp rises in R occur leads to the further condition $n_{eh} = 4n_k$. Combining the two requirements gives the critical values of n_k where the sharpest rises in R should take place

$$n_k = 2^N/4 \tag{2}$$

where $N \geqslant 2$.

Equation (2) also fixes the energy where R should rise to its next stable or quantized level since $E_N = n_K M_K c^2$. Beyond this point, the number of pairs forming a stable cluster will remain essentially constant until an energy E_N is reached corresponding to the next value of N, the additional energy going into rotational excitation of the cluster or its internal components to give the required $J = 1^-$, thus leaving R nearly constant to form a plateau.

It follows that if the energy is measured in units of the K-meson energy $E_K = M_K c^2$, one can write a simple expression for the value of R in the region of the Nth plateau following each rise to give

$$R(E) = \tfrac{2}{3}(2^N/4) = \tfrac{2}{3}(E/E_k) \tag{3}$$

The values of R as a function of N and E have been plotted in Figure 1 up to $N = 7$ or $E = 15.8$ GeV together with the values of n_{eh} given by equation (1) for the hadrons formed at each energy.

It is seen that the value of R increases in a series of quantized steps or shells as the energy rises and increasingly massive clusters of pairs of the required J^P can form in a cascade of successive pair-production processes. It is of interest to note that as an energy sufficient to produce eight neutral or charged K mesons is reached, or for $n_K = 8$ and $n_{eh} = 32$–40, the production of two baryon pairs, or a strongly bound alpha-particle-type structure, becomes possible and R rises particularly sharply. This is consistent with the hypothesis that protons are composed of two $K_{2\pi}$-type di-pions, held together by a single e^+ core charge exchanged between them (Sternglass, 1965b), giving a total of $9e^{\pm}$ for the proton.

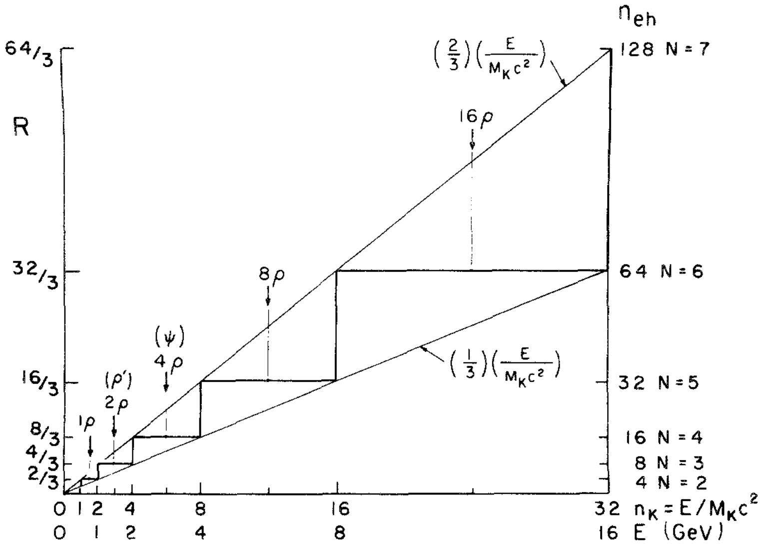

Fig. 1. Plot of R as a function of energy E given by the relativistic electron-pair model.

The degree to which the relativistic electron-pair model fits the most recent measurements of R may be seen by an inspection of Figure 2, where the latest available data obtained at SLAC (Schwitters, 1975) have been plotted together with the predicted steps of R between 2 and 8 GeV. It is seen that the plateau values of R given by the present model fit the observed values in the centers of the 4th and 5th plateaus near $4M_\rho$ and $8M_\rho$ to within the experi-

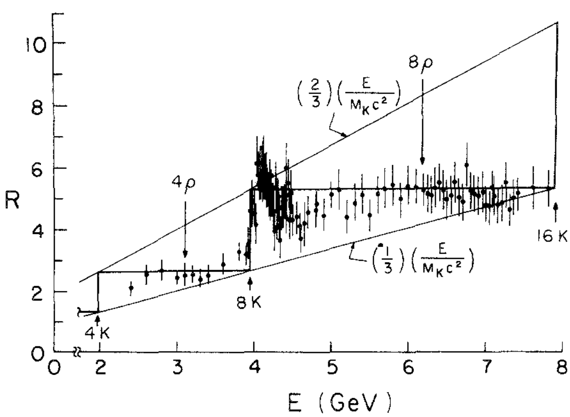

Fig. 2. Comparison of predicted variation of R as a function of energy E with the most recent data obtained at SLAC (Schwitters, 1975).

mental uncertainty. It follows that when the measurements of R can be extended to energies beyond the existing limit of 7.8 GeV, the relativistic pair model will be subjected to a further test since another rise of R should begin at about 7.9 GeV.

In summary, the existing evidence for the absolute magnitude and stepwise doubling of R with energy is consistent with the hypothesis that all nuclear particles, including the muon and the nucleon, are composed of integrally charged electrons and positrons exhibiting a pointlike, massive parton behavior. These charges appear to be grouped into quarklike pairs moving in a relativistically precessing reference frame, which causes their rest mass to increase in a manner somewhat analogous to the rotating or "cranked potential" for nuclei introduced by Inglis (Inglis, 1954). Each basic pair appears to be held together by velocity-dependent, resonance-type forces that increase with the total rotational energy so that the system can sustain indefinitely large internal excitations, thereby explaining the failure to observe free quarks in the laboratory. These positroniumlike systems appear to be capable of forming molecular-type clusters of increasing complexity and widely varying stability that can be excited to individual particle or collective rotational states similar to the case of low-mass nuclei, thus explaining the usefulness of SU_3 symmetry in the classification of hadrons (Bohr, 1976) and encouraging the hope that the dynamics of nuclear particles can be understood along the same lines as was previously so successfully used in the case of atomic, molecular, and nuclear states.

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