Letters to the Editor

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Solutions of the Meson-Nucleon Equation in the Adiabatic Limit

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THE relativistic meson-nucleon equation,[1] $[(\gamma p+m)(k^2+\mu^2)-I]\psi=0$, upon reduction to three-dimensional form, may be used to examine the stability of meson-nucleon systems (bound and virtual states) as well as scattering. Such an investigation has been made for the isotopic spin 3/2 state, with lowest order interaction (crossed meson graph) in the adiabatic limit, but keeping both "large" and "small" components in the resulting equation. In momentum space, the three-dimensional equation becomes

$$(K-\omega_p-H)\phi_i(\mathbf{p})=\frac{g^2}{(2\pi)^3}\left[\frac{1}{2\omega_p}-\frac{\Lambda_-}{K+\omega_p+E_p}\right]\tau_j\tau_i \int\frac{\beta m+\boldsymbol{\alpha}\cdot(\mathbf{p}+\mathbf{p}')-(\mu_1-\mu_2)K}{m^2+(\mathbf{p}+\mathbf{p}')^2-(\mu_1-\mu_2)^2K^2}\phi_j(\mathbf{p}')d\mathbf{p}', \quad (1)$$

where $K=m+\mu+E$ is the total energy of the system, $\mu_1=\mu/(m+\mu)$, $\mu_2=m/(m+\mu)$, $H=\boldsymbol{\alpha}\cdot\mathbf{p}+\beta m$, and Λ_- is the negative energy free particle projection operator. Multiplying by $K-H+\omega_p$ (to rationalize the kinetic energy term) and returning to coordinate space, one obtains an equivalent Dirac equation of the form

$$(W-H)\phi_i(\mathbf{r})=\int V_{ij}(\mathbf{r},\mathbf{r}')\phi_j(\mathbf{r}')d\mathbf{r}';\quad W=m+\frac{E(E+2\mu)}{2(m+\mu+E)}, \quad (2)$$

where

$$V_{ij}(\mathbf{r},\mathbf{r}')=\frac{g^2}{4\pi}\frac{\tau_j\tau_i}{4K}[KQ_m(\mathbf{r}+\mathbf{r}')+(K-\beta m-\boldsymbol{\alpha}\cdot\mathbf{p}) \{Q_\mu(\mathbf{r}+\mathbf{r}')-Q_m(\mathbf{r}+\mathbf{r}')\}]\times[\beta m-(\mu_1-\mu_2)K-\boldsymbol{\alpha}\cdot\mathbf{p}']Y(r');$$

$$Y(r)=(1/r)\exp(-r/\rho);\quad Q_\mu(\mathbf{r})=-\frac{1}{2\pi^2}\frac{1}{r}\frac{\partial}{\partial r}K_0(\mu r). \quad (3)$$

The range of the Yukawa well, $\rho^{-1}=[m^2-(\mu_1-\mu_2)^2K^2]^{\frac{1}{2}}$, is energy dependent. The integral operator, $V(\mathbf{r},\mathbf{r}')$, was approximated by a multiplicative exchange potential. In so doing, $mQ_m(\mathbf{r}+\mathbf{r}')$ was replaced by $\delta(\mathbf{r}+\mathbf{r}')$ and the terms proportional to $Q_\mu-Q_m$ were neglected as $Q_\mu-Q_m$ is logarithmic at the origin (and hence not highly singular). The potential for the 3/2 state then becomes

$$V=(g^2/8\pi m)[H-(\mu_1-\mu_2)K]Y(r)P, \quad (4)$$

where P is the exchange operator. The angular parts of the wave function may be separated out in the usual fashion, via the constants of motion J, $K=\beta(\boldsymbol{\sigma}\cdot\mathbf{L}+1)$. The resulting coupled radial equations for the two components u/r, v/r are

$$\left[\frac{d}{dr}-\frac{k}{r}+(-1)^l\frac{g^2}{8\pi m}\frac{\partial}{\partial r}Y\right]u(r) =-\left[W+m-(-1)^l\frac{g^2}{8\pi m}\{2m-\mu-(\mu_1-\mu_2)E\}Y\right]v(r), \quad (5)$$

$$\left[\frac{d}{dr}+\frac{k}{r}-(-1)^l\frac{g^2}{8\pi m}\frac{\partial}{\partial r}Y\right]v(r) =\left[W-m-(-1)^l\frac{g^2}{8\pi m}\{\mu-(\mu_1-\mu_2)E\}Y\right]u(r). \quad (6)$$

In order to examine the structure of the solutions, the Yukawa potentials were replaced by "equivalent" square wells, $\bar{V}$, defined by $\int_0^\infty Vr^2dr=\bar{V}\int_0^\rho r^2dr$.[2] Eliminating $v(r)$ from the equations, one obtains a Schrödinger equation for u of the form

$$\left[\frac{d^2}{dr^2}-\frac{k(k-1)}{r^2}-\frac{2k}{r}a\frac{g^2}{4\pi}+b\left(\frac{g^2}{4\pi}\right) +c\left(\frac{g^2}{4\pi}\right)^2+W^2-m^2\right]u(r)=0,\quad r<\rho \quad (7)$$

$$\left[\frac{d^2}{dr^2}-\frac{k(k-1)}{r^2}+W^2-m^2\right]u(r)=0.\quad r>\rho \quad (8)$$

The coefficients a, b, c are energy dependent. The appearance of a g^4 term in Eq. (7) reflects the elimination of v from Eqs. (5) and (6). Replacing the $1/r$ term in (7) by a square well, one obtains a total well which is repulsive for $j=1/2, 5/2, \cdots$ and attractive for certain ranges of $g^2/4\pi$ for $j=3/2, 7/2\cdots$.

Assuming the V_1^0 particle to be a virtual state of the p, π^- system at an energy $E\sim 40$ Mev, with isotopic spin 3/2 and an angular momentum of $l=5$, a lifetime of 2×10^{-10} second was obtained. The allowed values of the coupling constant that give this result are $g^2/4\pi=9.0, 13.5$. For the latter case no other virtual or bound states can form in the low-energy region.

The above equations were also applied to calculate the total π^+-p cross section at 37 Mev. The result (for $g^2/4\pi=13.5$) is 19.3 mb.[3]

First-order nonadiabatic corrections to the potential have been examined and appear not to change the results qualitatively. More detailed calculations are now in progress.

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[1] S. Deser and P. Martin, Phys. Rev. **90**, 1075 (1953).
[2] The $1/r$ and $1/r^2$ singularities were smoothed to a $\ln r$ and $1/r$ respectively near the origin, as suggested by the integral operator Q_m.
[3] This result may be compared with the experimental values of 10.9 ± 3 mb and 11.8 ± 1.0 mb at that energy obtained by C. E. Angell and J. P. Perry [Phys. Rev. **91**, 1289 (1953); **92**, 835 (1953)], and the value 7.9 ± 2.2 mg obtained at 33 Mev by S. L. Leonard and D. H. Stork [Bull. Am. Phys. Soc. **28**, No. 4, 19 (1953)].

Production of Acceptor Centers in Germanium and Silicon by Plastic Deformation

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PLASTIC deformation of germanium and silicon by bending and in tension has been reported by Gallagher[1] and by Treuting.[2] In recent experiments compression has been used to deform N-type germanium crystals of 5 and 26 ohm-cm resistivity about 5 percent at 500° and 650°C, respectively. X-ray studies showed that the deformation produced a range of orientations grouped about the principal one for the crystal. In both specimens the conductivity was changed to P-type, and the resistivity values for the deformed germanium were 1.5 and 3 ohm-cm, respectively. These changes correspond to the introduction of about 10^{15} acceptor centers/cm^3.

Control germanium specimens that were only heated, and not compressed, were included simultaneously in the furnace. No, or insignificantly small, changes in resistivity were obtained for the controls. This is considered conclusive evidence that the acceptor centers have an origin in the deformation. They may be at dislocations, introduced into the small regions, or on the small angle boundaries between regions, in the deformed structure. Dislocation models in deformed germanium have been discussed by Seitz[3] and by Shockley.[4]