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A COVARIANT THEORY WITH A CONFINED QUANTUM *

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It has been shown by Lindesay[1], by Noyes and Lindesay[2], and by Lindesay and Markevich[3] that by using a simple unitary two particle driving term in covariant Faddeev equations a rich covariant and unitary three particle dynamics can be generated, including single quantum exchange and production. The basic observation on which this paper rests is that if the two particle input amplitudes used as driving terms in a three particle Faddeev equation are assumed to be simply "bound state poles" with no "elastic scattering cut", they generate rearrangement collisions, but breakup is impossible. Extracting the double poles arising from the binding of the quantum m_Q to each particle and assuming no particle-particle scattering we find the elastic scattering and rearrangement amplitudes $H_{ab}(\vec{k}_a, \vec{k}_{b_0}; M) = \Delta_{ab}(\vec{k}_a, \vec{k}_{b_0}) = -\int d^3k'_{\bar{a}} \Delta_{a\bar{a}}(\vec{k}_a, \vec{k}'_{\bar{a}})[\epsilon'_{\bar{a}}\epsilon'_{\mu_{\bar{a}}}(\epsilon'_{\bar{a}} + \epsilon'_{\mu_{\bar{a}}} - M - i0^+)]^{-1} H_{\bar{a}b}(\vec{k}'_a, \vec{k}_{b_0}; M)$. Here $\vec{k}_a$ is the 3-momentum of spectator particle m_a in the three particle zero momentum system, $\epsilon_a(k_a^2) = (k_a^2 + m_a^2)^{1/2} = \epsilon_{\mu_{\bar{a}}}(k_a^2)$, and $\Delta_{ab}(\vec{k}_a, \vec{k}_{b_0}) = (1-\delta_{ab})\Gamma_a\Gamma_b[\epsilon_Q(k_Q^2)(\epsilon_{\mu_a}(k_a^2) - \epsilon_{b_0}(k_{b_0}^2) - \epsilon_Q)]^{-1}$ with $\vec{k}_Q = \vec{k}_{\mu_{b_0}} - \vec{k}_a$ where $\vec{k}_{\mu_{b_0}} = -\vec{k}_{b_0}$. The residue at the bound state pole, or coupling constant, is required by unitarity (exactly three particles with m_a, m_b, and m_Q present) to be $\Gamma_a^2 = (\mu_a/4\pi)/\int_0^\infty k^2 dk[\epsilon_{\bar{a}}\epsilon_Q(\epsilon_{\bar{a}} + \epsilon_Q - \mu_a)^2]^{-1}$ with $\mu_a \equiv m_{\bar{a}}$ and $a \neq \bar{a}$. It is easy to see that these equations have fully covariant recoil kinematics and have as their leading term the usual t-channel single quantum exchange, but reduce in the non-relativistic on shell kinematic region to the Lippmann-Schwinger equation for scattering by a Yukawa potential. Compared to a scalar theory with interaction Lagrangian $g_a\phi_a^* A_Q \phi_a$ in the weak coupling limit we find that $\Gamma_a\Gamma_{\bar{a}} = g_a g_{\bar{a}}/(2\pi)^3$.

Looking at the energy of the lowest bound state (assuming $m_a = m_{\bar{a}} = m$) $\epsilon_3^0 = 2m - M^0$ as a function of m_Q/m we find that the deepest binding occurs at about $m_Q \sim 1.82m$ and is about $\epsilon_3^{max} \sim 0.75m$. As m_Q increases above this value the binding energy decreases monatonically to zero, and above $m_Q \sim 4.35m$ there are no bound states, other than our two body kinematic input.

For m_Q below this value the binding again decreases monatonically toward zero at $m_Q = 0$, but for small values of m_Q this $\epsilon_3^0(m_Q/m)$ curve provides an envelope for a

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sequence of more weakly bound state trajectories starting with zero binding at $m_Q = 0.1m, 0.05m, \ldots$. For $m_Q \ll m$ the coupling constant is bounded by $[m^2/4\pi ln(m/m_Q)] < \Gamma^2 < [m^2/\pi ln(m/m_Q)]$. Hence if we fix the coupling constant using Rutherford scattering and our weak coupling limit by $\Gamma^2 = (m^2/2\pi^2)e^2/\hbar c$, the corresponding quantum mass(numerically) is $m_\gamma \sim me^{-137\pi^2/5}$. Since the best upper limit on the photon mass from Pioneer 10 data[4] is $m_\gamma > 8 \times 10^{-48} gm$, we can clearly apply our theory as a first approximation to scalar QED. Since our quantum is confined, this necessitates our taking the Wheeler-Feynman point of view that all radiation is ultimately absorbed.

If we consider two scalar particles of nucleonic mass exchanging a scalar quantum and fix m_Q/m at the mass for a Yukawa potential that fits low energy $p-p$ scattering, the coupling constant given by our formula is much too large and the "deuteron" is bound with about 98 Mev. It is not surprising that this crude model is not a good average representation of nuclear forces. Brayshaw and Noyes[5] showed that if we use a pseudoscalar isovector pion with a pion-nucleon p_{11} bound state representing the nucleon pole we must also include the inelastic channels which open up above pion production threshold. If these are represented by a singular core boundary condition fitted to empirical data in this region, the deuteron binding energy *is* correctly predicted to about 1 % with no free parameters.

The large quantum mass limit, ignoring spin, is also of interest. The rigorous limits on the coupling constant are now $mm_Q/4\pi < \Gamma^2 < 4\pi mm_Q$, and numerical evaluation gives a value for large m_Q/m of $\Gamma^2 \simeq 0.24mm_Q$. Once we have introduced spin properly, which has already been done in the companion theory[3], we will have an estimate for the weak boson mass, but we have not seen a compelling way to compare with experiment using our scalar theory. In order to obtain a more realistic model we must introduce antiparticles and the various discrete quantum number symmetries in addition to spin; eventually we must extend the theory to Faddeev-Yakubovsky equations. But we feel that these preliminary results and the conceptual simplicity of the approach will justify a lot of hard work along these lines. Whether the theory can be extended from the Yukawa-type couplings used to date to non-abelian gauge theories and hence to a new way to approach the quark-gluon confinement problem is very speculative at this point. However, we hope others will be encouraged to think along these lines.

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1 J.V. Lindesay, Ph.D. Thesis, Stanford, 1981; see SLAC Report No. 243.
2 H.P. Noyes and J.V. Lindesay, *Australian J. Phys.* (in press).
3 J.V. Lindesay and A. Markevich, contributed to Few Body X.
4 L. Davis, A.S. Goldhaber and M.M. Nieto, *Phys. Rev. Lett.* *35*, 1402 (1975).
5 D.D. Brayshaw and H.P. Noyes, *Phys. Rev. Lett.* *34*, 1582 (1975).