ever, neglected the influence of pair formation, and more recently by Jean,[3] using methods similar to those developed independently by us.[4]

We would like to point out that, within this framework, bound state problems can be treated in a manner which yields in a natural fashion a somewhat better perturbation calculus than the usual one. The method consists in retaining only a limited number of particle-wave functions in configuration space, and thus can only be formulated in a configuration space treatment of field theory. The method is applicable in either coordinate or momentum space. We shall, however, work in momentum space since one then deals with algebraic rather than differential equations.

Consider first the one-body problem in scalar or pseudoscalar meson theory. We restrict ourselves to a Fock configuration space wave function which includes all the effects caused by the presence of a single meson and a single pair. Thus

$$\Phi^{(1\ \text{particle})}=\left\{\begin{array}{l} f^{(1,0;0)}(p^{(1)}s^{(1)}) \\ f^{(1,0;1)}(p^{(1)}s^{(1)};\,k^{(1)}) \\ f^{(2,1;1)}(p^{(1)}s^{(1)},\ p^{(2)}s^{(2)};\ q^{(1)}t^{(1)};\ k^{(1)}) \end{array}\right\} \tag{1}$$

where $p^{(1)}s^{(1)}\cdots$ are the momentum and spin coordinates of the nucleons, $q^{(1)}t^{(1)}\cdots$ those of the antinucleons and $k^{(1)}\cdots$ those of the mesons. The superscript $(l, m; n)$ on the particle-wave functions refers to the eigenvalue of the number operator for the nucleons, antinucleons, and mesons, respectively. In the Schroedinger representation the equation of motion of the system is given by

$$\left\{P_0^{(0)}+\int d^3x\mathcal{H}(x)+H_0\right\}\Phi=E\Phi \tag{2}$$

$$(\hbar=c=1),$$

where $P_0^{(0)}$ is the fourth component of the energy-momentum vector of the free field. $\mathcal{H}(x)$ is the interaction energy given by

$$\mathcal{H}(x)=\tfrac{1}{2}g[\bar{\psi}(x)\mathcal{O},\,\psi(x)]\phi(x)+\tfrac{1}{2}\delta\kappa[\bar{\psi}(x),\,\psi(x)], \tag{3}$$

where g is the coupling constant, $\delta\kappa$ an infinite constant designed to cancel the divergent self energy, $\psi(x)$ and $\phi(x)$ the usual nucleon and meson operators, respectively,

$$\begin{aligned} \mathcal{O}&=i\gamma_5 \quad \text{for pseudoscalar mesons} \\ &=1 \qquad \text{for scalar mesons.} \end{aligned}$$

The infinite constant H_0 defines the zero level of energy of the interacting fields. The equations of motion for the individual wave functions can easily be written down using methods analogous to those of Fock,[5] care being taken that phase factors are included so that all operators obey the proper commutation rules. One then readily finds that $f^{(1,0;0)}(p^{(1)}s^{(1)})$ satisfies the equation,

$$(P_0^{(1)}-E)f^{(1,0;0)}(p^{(1)}s^{(1)})=0, \tag{4}$$

if $\delta\kappa$ in Eq. (3) is equal to[6]

$$\delta\kappa=\pm\kappa g^2[(3/2\pi)\log(1/\gamma\omega_0)+\text{finite terms}], \tag{5}$$

$$\kappa=\text{nucleon mass.}$$

An infinite term [proportional to $\delta(0)$] is canceled by the H_0 term. The latter [$\delta(0)$] term corresponds to the shift in the zero level of energy as a result of the interaction and implies nothing of physical interest. The minus sign in Eq. (5) occurs in the scalar meson theory, whereas the plus sign occurs in pseudoscalar meson theory.

This whole procedure in configuration space is made relativistically invariant using the momentum space integration techniques of Umezawa and Kawabe.[7]

To the same approximation the two-particle wave function is taken to be

$$\Phi=\left\{\begin{array}{l} f^{(2,0;0)}(p^{(1)}s^{(1)},\ p^{(2)}s^{(2)}) \\ f^{(2,0;1)}(p^{(1)}s^{(1)}p^{(2)}s^{(2)}k^{(1)}) \\ f^{(3,1;1)}(p^{(1)}s^{(1)}p^{(2)}s^{(2)}p^{(3)}s^{(3)};\ q^{(1)}t^{(1)};\ k^{(1)}) \end{array}\right\}. \tag{6}$$

Carrying out the same operations as before, one obtains for the $f^{(2,0;0)}$ an equation which after the $f^{(2,0;1)}$ and $f^{(3,1;1)}$ have been eliminated has the following structure:

$$(P_0^{(1)}+P_0^{(2)}-E)f^{(2,0;0)}(ps^{(1)}ps^{(2)}) \tag{7}$$

$=$Møller interaction terms$+$self-energy terms for nucleon 1 and 2, for system in state characterized by energy eigenvalue $E+$a term corresponding to shift of zero energy level [$\propto\delta(0)$]$+$terms proportional to $\delta\kappa$ corresponding to the self energy$+H_0$ term. The term corresponding to the shift of zero level of energy [$\propto\delta(0)$] is again cancelled by the H_0 term. We note that the self energy terms encountered are of the form,

$$\begin{aligned} &\Delta E^{(SE)}(\text{particle 1}) \\ &\sim\frac{g^2}{[2(2\pi)^3]^{\frac{1}{2}}}\int\frac{d^3k}{\epsilon(k)}\sum_{j=1,2}\bar{u}_{s^{(1)}}(p^{(1)})\mathcal{O}\left(\frac{\gamma_\mu(p^{(1)}-k)_\mu-\kappa}{2\omega(p^{(1)}-k)}\right)\mathcal{O}u_j(p^{(1)}) \\ &\times\frac{1}{\Delta E+\omega(p^{(1)})-\omega(p^{(1)}-k)-\epsilon(k)}f^{(2,0;0)}(p^{(1)}j;\ p^{(2)}s^{(2)}) \end{aligned} \tag{8}$$

$+$a similar term arising from pair production.

Here

$$\begin{aligned} \omega(p)&=[p^2+\kappa^2]^{\frac{1}{2}}=p_0 \quad (\kappa=\text{nucleon mass}) \\ \epsilon(k)&=[k^2+\mu^2]^{\frac{1}{2}} \qquad\quad (\mu=\text{meson mass}) \end{aligned}$$

and

$$\Delta E=E-\omega(p^{(1)})-\omega(p^{(2)}). \tag{9}$$

Using the algebraic identity

$$\frac{1}{\Delta E+\Omega(p^{(1)},k)}=\frac{1}{\Omega(p^{(1)},k)}-\frac{1}{\Omega(p^{(1)},k)}\,\frac{\Delta E}{\Delta E+\Omega(p^{(1)},k)} \tag{10}$$

with $\Omega(p^{(1)},k)=\omega(p^{(1)})-\omega(p^{(1)}-k)-\epsilon(k)$, we recognize that the first term gives rise to the universal self mass (i.e., independent of the state of motion) of the nucleons and thus is canceled by the $\delta\kappa$ terms. The second term in Eq. (10), the difference between the self energy of a free and a bound nucleon, corresponds to a part of the Lamb shift. In the present perturbation calculus a contribution to the Lamb shift thus already appears in a "second-order" calculation. It is therefore seen that the present approximation method does not correspond to a power series expansion in $g^2/\hbar c$ and thus may be of value in situations where power series expansions in the coupling constant are not applicable.

Calculations of the deuteron energy levels using this formalism are now in progress. A detailed paper presenting the relativistic configuration space methods and the relevant renormalization program will appear shortly in collaboration with Professor Wightman.

The author wishes to express his sincerest gratitude to Professor A. Wightman for his valuable advice.

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Influence of the Chemical State on the Lifetime of an Isomer*

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A TRANSITION from a nuclear isomeric state may occur by internal conversion or by gamma-ray emission. The observed decay constant, λ, is related to the decay constant for gamma-ray emission alone, λ_γ, by the relation $\lambda=\lambda_\gamma(1+\alpha)$, where the conversion coefficient α equals the ratio of the number of electrons to the number of gamma-rays emitted per second.

As the internal conversion coefficient is influenced by the "electronic environment" of an isomer, one might expect changes in the decay constant when this environment is altered. This

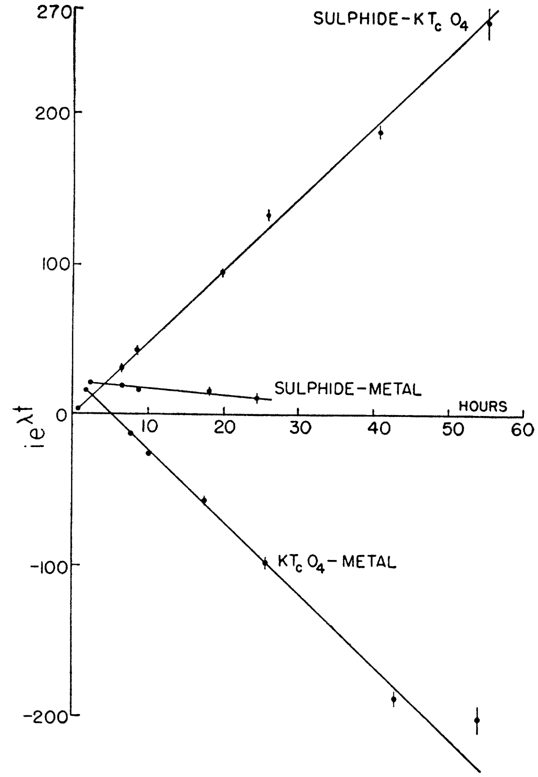

FIG. 1. $ie^{\lambda t}=i_0-\Delta\lambda I_0t$ (divisions) plotted against t. The statistical errors of each point are shown. The lines indicate the least-squares fit to the points. $I_0=15030$ divisions for sources sulfide-$KTcO_4$, 12350 for sulfide-metal, 13270 for $KTcO_4$-metal. The initial time points, $t=0$, for each curve are 0.75, 2.45, and 1.83 hours, respectively.

influence can best be tested by using an isomer in different chemical states which has a highly converted low energy isomeric transition.

We have carried out a series of experiments with Tc^{99m} (6 hours), an isomer with a 2-kev highly converted isomeric transition followed promptly by a 140-kev partially converted gamma-ray[1,2] which can be conveniently measured. We find that the decay constant of the 2-kev isomeric transition does assume different values which are dependent on the chemical state of the element.

When long-lived Tc^{99} is used as a carrier, λ for Tc^{99m} in $KTcO_4$, as the dry salt, is $1+0.0030\pm0.00010$ times greater than λ for Tc^{99m} electrolytically deposited on copper.[3] In another experiment the same value, within the expressed error, was found for $KTcO_4$ in basic aqueous solution.

The experimental data for the dry salt $KTcO_4$ and the sulfide[3] (Tc_2S_7) compared with electrolytically deposited Tc^{99m} are shown in Fig. 1. λ for Tc^{99m} as the sulfide is $1+0.00031\pm0.00012$ times greater than λ for Tc^{99m} electrolytically deposited on copper. The radiations from the long-lived Tc^{99} carrier, ~25 micrograms for an individual source, have a negligible effect on these measurements.

The measurements were made by the balance method introduced by Rutherford[4] in which two identical ionization chambers housing the sources under comparison are connected to collect ions of opposite sign. Thus the difference current produced by two closely matched sources is small and can be measured with a precision[4-7] approaching that defined by the statistics of the number of separate ionization events which have occurred during an observation.[6,8] The difference current is $i=i_0e^{-\lambda t}-I_0\Delta\lambda te^{-\lambda t}$ at any time t, where i_0 is the initial unbalance current, I_0 is the initial intensity of the stronger source whose transition constant is λ, and $\lambda-\Delta\lambda$ is the transition constant of the other source.

The observed effect is discussed theoretically by Slater in an accompanying letter.

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The Effect of Chemical Combination on the Internal Conversion in Tc*

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BAINBRIDGE, Goldhaber, and Wilson[1] have shown experimentally that the probability of a certain internal conversion in Tc^{99m} depends on the state of chemical combination. In this conversion, the nucleus loses about 2 kev of energy, undergoing an electric octopole transition of $\Delta l=3$. This energy is only enough to remove an M or N electron from the Tc atom, and since these electrons lie toward the outside of the atom, it was thought that their wave functions might be appreciably affected by chemical combination, with consequent appreciable effect on the conversion probability. In the reference just cited, it was found in fact that there is such an effect, of the order of three-tenths of a percent, and that furthermore, $KTcO_4$ has a somewhat greater conversion probability than Tc metal. It is the purpose of this note to show that this is not unreasonable theoretically.

In the first place, a very rough calculation has been made of the relative contributions of the various electronic shells to the internal conversion probability. The matrix component which has to be computed is the integral of the product of the wave function of the bound electron in the Tc atom or crystal, the wave function of an electron in the continuum with an energy 2 kev greater than the bound electron, and a quantity representing the potential of the nuclear octopole. Since the electromagnetic wavelength of a gamma-ray of 2 kev is about 6A, and the distances concerned in the integral are a rather small fraction of an angstrom, we are justified in representing this potential electrostatically, so that it is given by a spherical harmonic of $l=3$, times $1/r^4$. The integral then involves a product of three spherical harmonics, one from each wave function and one from the potential. Such integrals are zero unless certain relations exist between the l values, resulting in selection principles, which in the present case result in possible transitions from the bound s states to an f state in the continuum, from a bound p state to a d state in the continuum, and from a bound d state to a p state in the continuum. The functions of angles are easily computed, and the matrix component, whose square is proportional to the transition probability, reduces to an integral over r, of the product of the radial wave functions of bound and continuum states, times $1/r^4$, times the volume elements r^2dr.

To compute these radial integrals, a very rough numerical integration for both the bound and continuum wave functions has been made, using as a potential the Fermi-Thomas potential for Tc, corrected for exchange. The integrand in each case proves to start for small r's proportionally to r (the singularity in the