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Connection between fusion theory of bosons and nonlocal field theory

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TABLE I. Auger line intensities arising from internal conversion of $E1$ radiation.

Auger line	$K-L_IL_I$	$K-L_IL_{II}$	$K-L_IL_{III}$	$K-L_{II}L_{II}$	$K-L_{II}L_{III}$	$K-L_{III}L_{III}$
Calculated intensity	zero	0.87	1.65	0.235	1.46	0.805
Experimental intensity	1.0	1.71	1.20	0.32	1.44	0.805

cients. The $K\alpha_1$ and $K\alpha_2$ x-rays arise from $E1$ transitions between the L_{III} and K levels and the L_{II} and K levels, respectively. Conversion coefficients for these radiations in the L subshells can be obtained from the theoretical computations of Gellman, Griffith, and Stanley.[1] Although these calculations are admittedly approximate, they have been observed[2,3] to describe L-conversion experiments reasonably well.

In Table I, the relative intensities of the L Auger lines for mercury ($Z=80$) have been computed. In these computations it was assumed that the $K\alpha_1$ intensity was twice the $K\alpha_2$ intensity and that the conversion coefficient in a particular subshell was reduced proportionately to the fraction of electrons in the subshell at the instant of conversion. The relative experimental intensities in gold ($Z=79$) due to Mihelich[4] are also given in Table I.

The calculated intensities, except for those lines including an L_I subshell contribution, are in excellent agreement with experiment. The L_I discrepancy can now be somewhat removed by allowing the existence of a small amount of magnetic dipole radiation in the K series x-rays. An $M1$ transition may occur in the "forbidden" electron jump between the L_I and K levels, and on account of the high preferential conversion of $M1$ radiation in the L_I subshell, the $K-L_IL_I$ Auger line can be brought up to the observed strength by assuming only about 1 percent of $M1$ radiation.

TABLE II. Auger line intensities arising from internal conversion of $M1$ and $E1$ radiation.

Auger line	$K-L_IL_I$	$K-L_IL_{II}$	$K-L_IL_{III}$	$K-L_{II}L_{II}$	$K-L_{II}L_{III}$	$K-L_{III}L_{III}$
Calculated intensity	1.0	1.02	1.65	0.235	1.46	0.805
Intensity (theory[a])	1.0	5.5	5.3			
Intensity (theory[b])	1.0	1.14	2.28			
Intensity (expt.[c])	1.0	1.71	1.20	0.32	1.44	0.805

[a] See reference 5.
[b] See reference 6.
[c] See reference 4.

In Table II, the relative Auger line intensities for mercury are given for an $M1$ intensity of 1.47 percent of the total $E1$ x-ray intensity. Other intensities listed in the table are the relativistic theory calculations of Massey and Burhop,[5] the nonrelativistic theory calculations of Burhop,[6] and the experimental values of of Mihelich,[4] all for $Z=79$. With the exception of the $K-L_IL_{II}$ and $K-L_IL_{III}$ lines, for which the calculated intensities are reversed, the agreement with experiment of the calculated values is surprisingly good and superior to that of existing theoretical intensities.

It is uncertain whether the remaining lack of agreement is due to the approximate nature of the conversion coefficients, or to the inaccuracy of the assumptions (for example, the size of the radiation source), or to the experimental uncertainties.

Finally it should be pointed out that Hulubei[7] in 1947 observed satellite x-ray lines on the long wavelength side of the $K\alpha_2$ lines. Although he considered at that time the possibility of L_I to K electron jumps, he believed these lines arose from some process in which the $K\alpha_{1,2}$ x-rays lost energy to electrons in external shells. These and other satellite lines have more recently been observed by Groven and Morlet,[8] who now interpret them as arising from L_I to K jumps modified slightly by different electron screening effects. According to Hulubei, exposures of approximately 100 times those required for the $K\alpha_{1,2}$ lines were needed to bring out the satellite lines. There seems little doubt that the satellite lines are to be identified with the magnetic dipole transitions which give rise to the strong $K-L_IL_I$ Auger line.

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[1] Gellman, Griffith, and Stanley, Phys. Rev. **85**, 944 (1952).
[2] J. W. Mihelich, Phys. Rev. **87**, 646 (1952).
[3] J. B. Swan and R. D. Hill, Phys. Rev. **91**, 424 (1953); Australian J. Phys. (to be published).
[4] J. W. Mihelich, Phys. Rev. **88**, 415 (1952). Other experimental results are summarized by E. H. S. Burhop, *The Auger Effect* (Cambridge University Press, Cambridge, 1952).
[5] H. S. W. Massey and E. H. S. Burhop, Proc. Roy. Soc. (London) **A153**, 661 (1936).
[6] E. H. S. Burhop, Proc. Roy. Soc. (London) **A148**, 272 (1935).
[7] H. Hulubei, Compt. rend. **224**, 770 (1947).
[8] L. Groven and J. Morlet, Acad. roy. Belge, Classe sci., Mem. **37**, 630 (1951).

Connection between Fusion Theory of Bosons and Nonlocal Field Theory

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FOLLOWING the original idea of de Broglie,[1] the quanta of a pseudoscalar field and a vector field are considered as composite particles resulting from the "fusion" of a spinor particle and its antiparticle. As Heisenberg emphasized,[2] we have to assume an attractive force of yet unknown nature between the constituent particles in order that such a fusion theory may become physically meaningful. If the pair of component fermions are thus performing relative motion, it is to be expected that the resulting boson field can be described as a kind of nonlocal field in the sense of Yukawa's theory.[3] The aim of the present work is to demonstrate by an example the mathematical feasibility of such correlation of the fusion theory with the nonlocal field theory.

The two-particle wave function $\Psi_{rs}(x', x'')$ (r, s: Dirac indices) is assumed to transform like $\psi_r(x')\bar{\Psi}_s(x'')$ for the Lorentz transformation and to obey a relativistic two-body wave equation,[4]

$$(D(x')+mE_5)\Psi(x', x'')(D(x'')-mE_5) = g^2W(x', x'')O'^{\alpha}\Psi(x', x'')O''^{\alpha}, \quad (1)$$

with

$$D(x') = -i(\partial/\partial x'_\mu)E_\mu, \quad O'' = J\bar{O}'J^{-1}, \quad (2)$$

where the ordinary rule of matrix multiplication is assumed for the 4-4-Dirac indices. $W(x', x'')$ is an invariant "potential," which may be a function or an operator.[5] The O's are some matrices with Dirac indices ($\hbar=c=1$).

In addition to (1), $\Psi(x', x'')$ is assumed to satisfy

$$(D(x')+D(x'')+\kappa E_5)\Psi(x', x'')=0, \quad (3)$$

which amounts physically to a condition for formation of a pseudoscalar or vector particle.[6] The compatibility of (1) and (3) is indirectly verified by the existence of a common solution. The mass κ of the composite particle must be $2m$ plus a certain term due to the interaction.

We now expand Ψ with the help of the 16 units of the E system,

$$\Psi = (iU + U^\mu E_\mu E_5) + (VE_5 + V^\mu E_\mu + \tfrac{1}{2}iV^{\mu\nu}E_\mu E_\nu E_5). \quad (4)$$

By virtue of the transformation property of Ψ, the quantities in the first pair of parentheses transform like pseudoscalar field quantities and those in the second pair like vector field quantities. Equations (1) and (3) can now be rewritten as a set of nonlocal equations for the U's and V's with respect to the variables

$$X^\mu = (x^{\mu\prime}+x^{\mu\prime\prime})/2, \quad r^\mu = x^{\mu\prime} - x^{\mu\prime\prime}. \quad (5)$$

As an illustration, a particular type of "oscillator potential" is considered,

$$O' = -O''E_5,$$
$$g^2 = 4/\lambda^4, \quad (6)$$
$$W = -[(r_\mu r_\nu \partial^2/\partial X_\mu \partial X_\nu)/(\partial^2/\partial X_\lambda \partial X^\lambda)].$$

The resulting equations for the pseudoscalar field are[7]

$$\{(\partial^2/\partial X_\mu \partial X^\mu) - \kappa^2\} U = 0, \quad (7)$$
$$\{(\partial^2/\partial r_\mu \partial r^\mu) - (\kappa - 2m)^2/4 - 4(r_\mu r_\nu \partial^2/\partial X_\mu \partial X_\nu)/(\kappa^2\lambda^4)\} U = 0, \quad (8)$$
$$\{(\partial^2/\partial X_\mu \partial r_\nu) - (\partial^2/\partial X_\nu \partial r_\mu)\} U = 0, \quad (9)$$
$$U^\mu = (1/\kappa)(\partial U/\partial X_\mu). \quad (10)$$

Equations (7), (8), and (9) can certainly be satisfied by a U which is a plane wave with respect to X^μ and an oscillator function with argument $K_\mu r^\mu$, where K^μ is the momentum four-vector of the composite particle. The possible values of the mass κ of the composite particle are determined by Eq. (8). For instance, the simplest solution

$$U(X, r) = \int (\alpha K)^4 U(K) \exp(iK_\mu X^\mu) \delta(K_\mu K^\mu + \kappa^2) \times \exp[-(K_\mu r^\mu)^2/(\kappa^2\lambda^2)]. \quad (11)$$

gives

$$\kappa = 2m \pm 2\sqrt{2}/\lambda. \quad (12)$$

The vector field is completely separated from the pseudoscalar field and can be dealt with in a similar fashion.

More importance should be attached to the method presented here than to the particular type of nonlocal field derived by it.

[1] L. de Broglie, Compt. rend. **198**, 135 (1934) and subsequent papers and monographs.
[2] W. Heisenberg, Z. Naturforsch. **5a**, 251 (1950); **5a**, 367 (1950); **6a**, 281 (1951); his article in the monograph: *Louis de Broglie* (Paris, 1952), p. 284. See also L. de Broglie, J. phys. et radium **12**, 509 (1951); M. A. Tonnelat, J. phys. et radium **12**, 516 (1951).
[3] H. Yukawa, Phys. Rev. **77**, 219 (1950); **80**, 1047 (1950).
[4] $\bar{\psi} = -\psi^\dagger\gamma_5$, $E_a = i\gamma_5\gamma_a$ $(a = 1, 2, 3)$, $E_0 = -J = \gamma_4\gamma_5$, $E_5 = \gamma_5$. $\bar{O}$ means the Hermitian conjugate of O. For the notations see S. Watanabe, Phys. Rev. **84**, 1008 (1951).
[5] If the "force" is produced through the intermediary of another field, W will become in the lowest approximation Δ_F and Eq. (1) will reduce to Nambu's equation, the charge conjugate representation being used for one of the particles. Y. Nambu, Prog. Theoret. Phys. **5**, 614 (1950), Eq. (82). However, we should rather expect, with Heisenberg (Ref. 2) that W is not of such a type.
[6] Regarded as an equation with respect to X^μ, condition (3) becomes identical with the wave equation used by the author in his 4×4-matrix formalism of meson theory. S. Watanabe, Sci. Papers Inst. Phys.Chem. Research (Tokyo) **39**, 157 (1941), Eq. (5.2) through Eq. (5.5).
[7] Reasoning from a different point of view, H. Yukawa also has come to consider a type of equation similar to (8) [private communication from Professor Yukawa, and also Phys. Rev. **91**, 415, 416 (1953)].

Scintillations Produced by Alpha Particles in CsI

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CRYSTALS of CsI (without activator) at 77°K show an abnormally high absolute efficiency of luminescence under α-particle bombardment, of about 35 percent, and the individual light pulses have a short decay time of 0.5 μsec.[1] Such crystals are colorless, emit light in the blue region of the spectrum, and are nonhygroscopic. Moreover they have a high density (4.5 g/cm^3) and constituents of high atomic number ($Z = 55$ and 53), resulting in a relatively large absorption coefficient (per cm) for γ and x-rays. CsI crystals used in combination with an RCA photomultiplier 5819 and a pulse-height selector are therefore suitable for energy measurements of charged particles and γ rays. It should be mentioned that CsI is a quasi-monoatomic substance. Some results with α particles will be presented here.

The surface of a CsI crystal (5×5×2 mm) is irradiated with collimated α particles. The α source, mounted on a Pt foil, is located at a distance of 1 mm from the crystal surface. There is a space between the crystal and multiplier cathode and no "light contact" is provided. An Al mirror serves as a light reflector. The complete assembly is mounted on the upper end of a copper rod, which is immersed in liquid nitrogen.

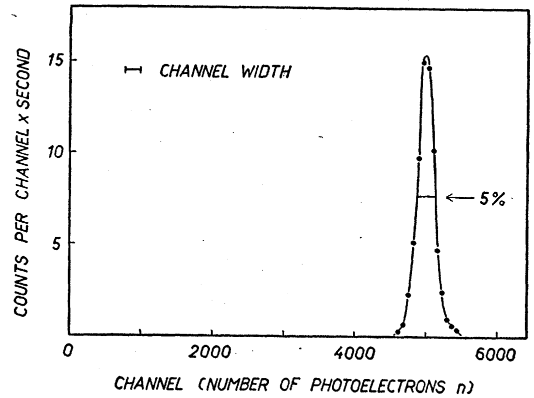

FIG. 1. Pulse spectrum for Po alpha line.

The pulse spectrum, which corresponds to the Po α line, is shown in Fig. 1. The pulse height is expressed in terms of the number n of photoelectrons liberated at the multiplier cathode during one scintillation (about 1000 photoelectrons per Mev). The channel width of the single-channel pulse-height selector used in this experiment is indicated in the figure. The resulting full width at half-maximum of the distribution is 5 percent, being only about 20 percent larger than the minimum width expected from the formula:

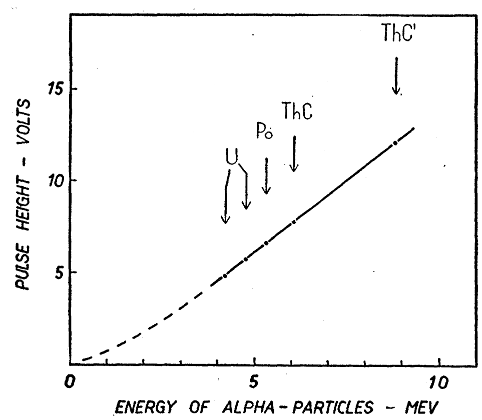

FIG. 2. Energy response of CsI for alpha particles.

$$x_h = 2.34\left\{\frac{1}{n}(1+\delta_g^2)\right\}^{\frac{1}{2}},$$

where δ_g means the relative standard deviation of the tube multiplication.

With the aim of investigating the energy response of CsI crystals to α particles, a thin source composed of U, Po, and ThB mounted on the same Pt foil, was used. Consequently the α lines

TABLE I. Ratio of the pulse heights for the α particles from ThC and ThC′.

Crystal	$h_{ThC}/h_{ThC'}$	References
Anthracene	0.53	a, b
Stilbene	0.52	a
Naphtalene	0.53	a
NaI(Tl)	0.57	b
KI(Tl)	0.60	a
CsI	0.64	
Energy ratio	0.69	

[a] Harding, Flowers, and Eppstein, Nature **163**, 990 (1949).
[b] Taylor, Remley, Jentschke, and Kruger, Phys. Rev. **83**, 169 (1951).