the solution in the Sommerfeld-Maue approximation is

$$\psi(\mathbf{r})=\frac{N}{(2\pi)^{\frac{3}{2}}}e^{i\mathbf{k}\cdot\mathbf{r}}\left\{1+\frac{in\beta^2}{2r}\frac{\partial}{\partial k}+O(n^4\beta^4)\right\}L_n(\rho); \tag{9}$$

also

$$\varphi(\boldsymbol{\kappa})=-\frac{N}{2\pi^2}\lim_{\epsilon\to 0}\left[\frac{\partial}{\partial\epsilon}+\frac{in\beta^2}{2}\left(\frac{\partial}{\partial k}+\frac{\mathbf{k}\cdot\mathrm{grad}_\kappa}{k}\right)+O(n^4\beta^4)\right]\frac{[\kappa^2+(\epsilon-ik)^2]^n}{[\epsilon^2+|\boldsymbol{\kappa}-\mathbf{k}|^2]^{1+n}}. \tag{10}$$

The approximation is definitely better than in the Dirac case, since it is correct to third order in $n\beta$ instead of only to first order. The first Born approximations may be obtained from (9) and (10) by putting $n=0$. The result is

$$\psi(\mathbf{r})=\frac{N}{(2\pi)^{\frac{3}{2}}}e^{i\mathbf{k}\cdot\mathbf{r}},\quad \varphi(\boldsymbol{\kappa})=-\frac{1}{2\pi^2}\lim_{\epsilon\to 0}\frac{\partial}{\partial\epsilon}\frac{1}{\epsilon^2+|\boldsymbol{\kappa}-\mathbf{k}|^2}.$$

The second Born approximation is obtained from (9) and (10) by expanding to first order in n:

$$\psi(\mathbf{r})=\frac{Ne^{i\mathbf{k}\cdot\mathbf{r}}}{(2\pi)^{\frac{3}{2}}}\{1+nf(\rho)\}, \tag{11}$$

$$\varphi(\boldsymbol{\kappa})=-\frac{N}{2\pi^2}\lim_{\epsilon\to 0}\frac{\partial}{\partial\epsilon}\left\{\frac{\left[1+n\ln\frac{\kappa^2+(\epsilon-ik)^2}{\epsilon^2+|\boldsymbol{\kappa}-\mathbf{k}|^2}\right]}{[\epsilon^2|\boldsymbol{\kappa}-\mathbf{k}|^2]}\right\}. \tag{12}$$

We have derived explicit expressions for the momentum wave functions because they are of considerable interest for various atomic and nuclear problems.[5]

We have applied these approximations to a number of atomic and nuclear processes, and we intend to communicate our results shortly.

[1] See, for example, A. J. W. Sommerfeld, *Atombau und Spektrallinien* (F. Vieweg und Sohn, Braunschweig, 1939). The explicit Coulomb wave functions for unbound particles obeying the Klein-Gordon equation will be given by us in a paper on meson capture processes to be published shortly.

[2] See, for example, J. C. Jaeger and H. R. Hulme, Proc. Roy. Soc. (London) **148**, 708 (1935), where the exact solution of the Dirac equation in the presence of a Coulomb field is applied to the problem of internal pair creation. The authors are forced to resort almost entirely to numerical integrations. Also, Casimir's trick for effecting spin summation cannot be used with these wave functions. It can, however, be used in conjunction with the wave functions discussed here.

[3] n is defined in Eq. (3). We are using natural units, for which $\hbar=c=1$.

[4] We will refer to this as the Sommerfeld-Maue approximation.

[5] See, for example, the remarks of E. Guth and C. J. Mullin, Phys. Rev. **83**, 667 (1951). These authors gave the momentum wave function in the nonrelativistic approximation.

Production of Polarized Particles in Nuclear Reactions

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SCHWINGER[1] has shown that polarized neutrons may be obtained by the elastic scattering of neutrons from He^4. We wish to point out that this result is a special case of a more general theorem to the effect that, under suitable conditions, the products of *any* nuclear reaction will be polarized. As a result it should be possible to use resonant charged particle reactions to obtain directly (rather than by an intervening elastic scattering) high intensity beams of polarized neutrons, with energies variable over a considerable range.

We have obtained a general expression for the polarization resulting from nuclear reactions. The original expression contains a number of sums over magnetic quantum numbers, since we must average over the incident unpolarized beam. However, these sums are essentially geometrical in character and may be reduced to their most elementary form by use of the formalism developed by Racah.[2]

The following general results have been obtained: (1) The polarization is always perpendicular to the plane formed by the directions of the incident and emitted particles. (2) If only S waves are effective in the reaction, for either the incident or the final states, there can be no polarization. (3) If only levels of the compound nucleus having $J=\frac{1}{2}$ (or 0) and a single parity are effective, there will be no polarization. (4) Polarization results from the interference of different subchannels (i.e., partial waves or final channel spins) contributing to the reaction. (The state of the residual nucleus must always be the same, of course.) Hence, if there is only a single incident subchannel leading to a single level and breaking up into a single final subchannel, the polarization will vanish. (5) If there is no spin-orbit coupling, the polarization is zero.

The final result yields the following expression for the dependence of the intensity of polarization upon the angle between the incident and emitted beam:

$$P=\sum_{L=1}^{\infty}A_LP_L^1(\cos\theta), \tag{1}$$

where P_L^1 is the associated Legendre function and A_L is a complicated expression involving several Racah functions and the scattering matrix for the reaction. The results have a formal similarity to the expression previously obtained for the angular dependence of reaction cross sections.[3] In particular, a maximum value of L in Eq. (1) is given by a set of rules which are quite similar to the rules for the limitation of the complexity of angular distributions[4] and which follow from the requirements for the nonvanishing of the Racah coefficients.

It is interesting to note that even a single level of definite $J(\neq\frac{1}{2}$ or 0) and parity will produce polarization if more than one subchannel (1-value or final channel spin) contribute. Several known reactions offer promise. In particular, analyses[5] of the angular distribution of (p,n) neutrons resulting from resonances in C^{13}, B^{11}, Li^7, and H^3 indicate that P waves or higher and opposite parities are interfering. In fact, it seems likely that many neutron sources, hitherto considered unpolarized, may actually exhibit partial polarization.

Details of the above and further calculations will appear in a paper to be submitted to this journal in the near future.

[1] J. Schwinger, Phys. Rev. **69**, 681 (1946).
[2] G. Racah, Phys. Rev. **62**, 438 (1942).
[3] C. N. Yang, Phys. Rev. **74**, 764 (1948).
[4] J. M. Blatt and L. C. Biedenharn, Phys. Rev. **82**, 123 (1951).
[5] H. A. Willard, private communication.

Relativistic Contribution to the Magnetic Moment of $^3S_1$ Helium

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THE nonquantum electrodynamic contribution of order $\alpha^2\sim(137)^{-2}$ to the magnetic moment of helium in the lowest energy triplet (metastable) state $^3S_1$ has been calculated. This contribution arises because the bound two-electron system has a Dirac type rather than a Schrödinger-Pauli type Hamiltonian. The purpose of the calculation was to isolate to order α^2 the quantum electrodynamic radiative contributions to the magnetic moment of a bound two-electron system, for comparison with experiment.[1]

The method of calculation was to reduce the Dirac sixteen-component form of the matrix of external magnetic interaction energy for two electrons to a four-component form in terms of Pauli-approximation wave functions, which could then be evaluated by use of the angular and spin symmetry properties of the Russell-Saunders coupled $^3S_1$ state. This procedure was practicable because L-S coupling could be shown to yield rigorous results to order $\alpha^2\mu_0H$. Breit's prescription for treating the Breit interaction was followed.[2]