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LAWRENCE LIVERMORE LABORATORY
University of California/Livermore, California

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V. R. Brown and J. Franklin

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V. R. Brown* and J. Franklin
Lawrence Livermore Laboratory, Livermore, California and
Temple University, Philadelphia, Pennsylvania

Coplanar asymmetric neutron-proton bremmstrahlung (npγ) is calculated at 130 MeV to compare to the experiment of Edgington et al.[1]. The coupling of the electromagnetic field to the nucleon currents includes, in addition to the usual terms $V_{em}^{(1)}$ arising from the kinetic-energy part of the Hamiltonian, terms $V_{em}^{(2)}$ induced by the nuclear potential. These latter terms are required to preserve gauge invariance when the nuclear potential has momentum dependence or an exchange nature. The potential $V_{em}^{(1)}$ gives rise to all of the external radiation and that part of the internal radiation previously called the rescattering term.[2,3] The T matrix for npγ, treating the nuclear interaction exactly within the framework of a potential model and the electromagnetic interaction to first order, can be written (omitting spin indices) as

$$T = \left\langle \psi_{k_f}^{-} \middle| V_{em}^{(1)} + V_{em}^{(2)} \middle| \psi_{k_i}^{+} \right\rangle , \qquad (1)$$

where $\psi_{k_i}^{+}$ ($\psi_{k_f}^{-}$) is the exact scattering state of the np system corresponding to outgoing (incoming) spherical wave boundary conditions; k_i (k_f) is the relative momentum in the initial (final) two-body system. The electromagnetic potential $V_{em}^{(1)}$ has been given previously.[2,3]

The terms arising from the nuclear potential are introduced in the momentum-space formulation by the usual replacement $\vec{p} \to \vec{p} - e\vec{A}$.[4] To lowest order in the photon momentum K this prescription is unambiguous, and the contribution to the T matrix from $V_{em}^{(2)}$ can be written

$$\left\langle \psi_{k_f}^{-} \middle| V_{em}^{(2)} \middle| \psi_{k_i}^{+} \right\rangle = ia/2 \ \hat{\varepsilon}\cdot\int d\vec{r}\ \psi_{k_f}^{-\,*}\left[(\overleftarrow{\nabla}^2+k_f^2)\vec{r}-\vec{r}(\vec{\nabla}^2+k_i^2)\right]\psi_{k_i}^{+} , \qquad (2)$$

where $a = e/m\sqrt{2\pi/K}$, and $\hat{\varepsilon}$ is the polarization of the photon. The left- (right-) hand arrow in eq. (2) indicates an operation on the final (initial) state wave function, and the initial and final state wave functions must have different isospin. This result includes momentum-dependent and spin-orbit effects as well as exchange contributions, all to lowest order in K. In a previous calculation[3] only exchange effects were included.

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The additional momentum-dependent and spin-orbit terms contribute a few percent in those cases tested.

The coplanar asymmetric differential cross section $d\sigma/d\Omega_n d\Omega_p$ for $np\gamma$ has been calculated at 130 MeV and various neutron (θ_n) and proton (θ_p) exit angles to compare to the experiment of Edgington et al.[1] The results for the Hamada-Johnston[5] (HJ) and the Bryan-Scott III[6] (BS) potentials as compared to experiment are shown in table 1.

Table 1

$d\sigma/d\Omega_n d\Omega_p$ in $\mu b/(sr)^2$ at 130 MeV

(θ_p,θ_n)	BS	HJ	Experiment (Set I of ref.[1])
(20,23)	38.5	40.1	135 ± 50
(20,29)	42.8	44.4	98 ± 37
(32,23)	23.3	23.5	81 ± 38
(32,29)	30.6	30.6	83 ± 26

The coplanar asymmetric cross section $d\sigma/d\Omega_n d\Omega_p d\theta_\gamma$ for 2 sets of nucleon exit angles taken from table 1 has been calculated with BS and is shown in fig. 1. We adopt the convention that the photon angle θ_γ is measured from zero degrees in the beam direction to $+180°(-180°)$ on the side of $\theta_p(\theta_n)$.

It can be seen from fig. 1 that the inclusion of the internal radiation considerably enhances the $np\gamma$ cross section; most of this enhancement is due to the exchange contribution. There is still a significant difference between theory and experiment, however, as can be seen from table 1. A preliminary investigation indicates that the higher order terms in $V_{em}^{(2)}$ probably would not account for this large discrepancy. Agreement between theory[3] and experiment[7] in the coplanar symmetric geometry at 200 MeV (30°,30°) is much better, however. Our calculated cross section using BS is 35 $\mu b/(sr)^2$ as compared to the experimental result of Brady et al.[7] of 35 ± 14 $\mu b/(sr)^2$.

References

1. J. A. Edgington et al. (contribution to this conference and private communication from F. P. Brady).
2. V. R. Brown, Phys. Lett. 32B (1970) 259.
3. V. R. Brown and J. Franklin, Proceedings of the Gull-Lake Symposium on the Two-Body Force in Nuclei, Gull Lake, Michigan, 1971, Eds. S. M. Austin and G. M. Crawley. (Plenum Press, New York, 1972) p.123
4. This prescription can be ambiguous beyond lowest order in K because equivalent momentum representations of the nuclear potential can lead to different results for $V_{em}^{(2)}$, all satisfying gauge invariance. This will be discussed in detail elsewhere (V. R. Brown and J. Franklin, to be published.) This type of ambiguity is also discussed by L. Heller from a different point of view in ref.[3] p. 79.
5. T. Kamada and I. D. Johnston, Nucl. Phys. 34 (1962) 382.
6. R. A. Bryan and B. L. Scott, Phys. Rev. 177 (1969) 1435.
7. F. P. Brady and J. C. Young, Phys. Rev. C 2 (1970) 1579.

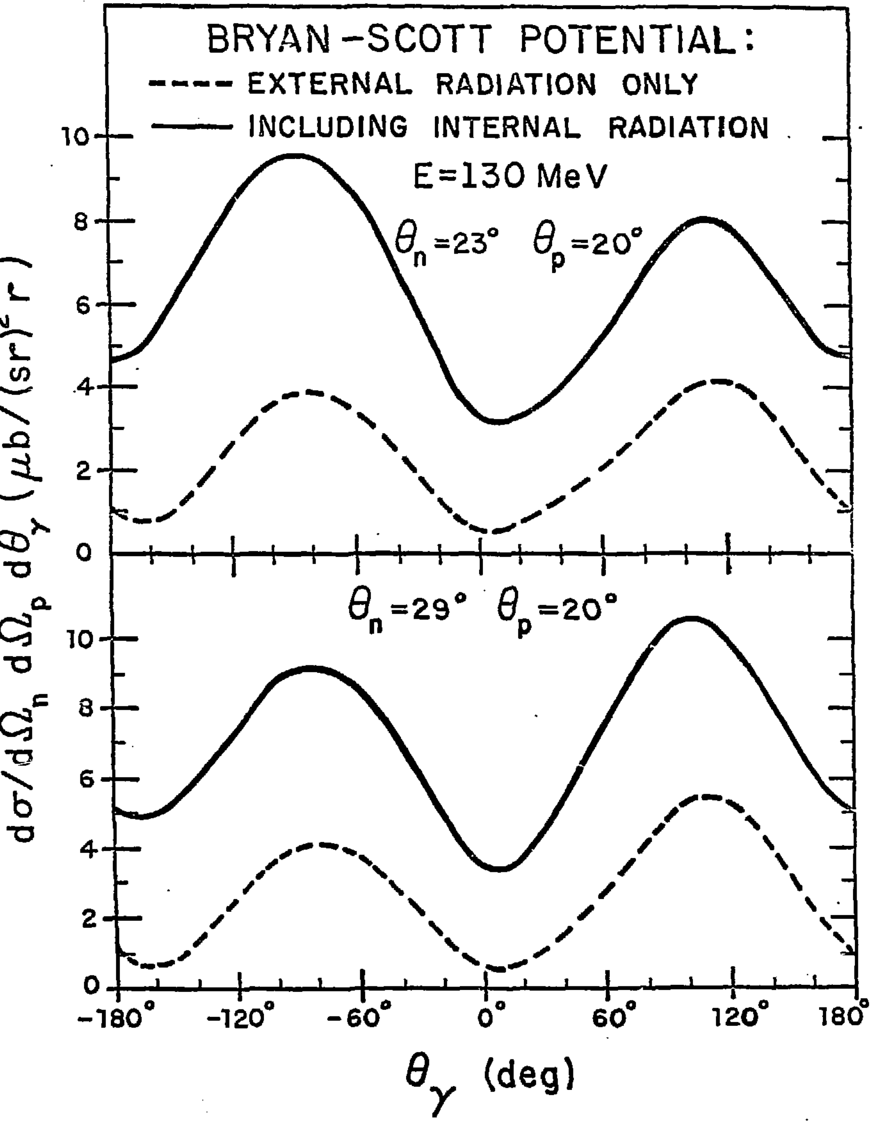

Fig. 1 Coplanar asymmetric npγ cross sections $d\sigma/d\Omega_n d\Omega_p d\theta_\gamma$ for E = 130 MeV with the Bryan-Scott III potential, where θ_γ is negative on the neutron (θ_n) side of the beam. The comparison of external radiation scattering alone and that including internal radiation is made for two sets of nucleon asymmetric angles.