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Abstract: The effects of vacuum polarization on the "line shape" of the $^1S_0$ p-p state are calculated and shown to be measurable with present experimental techniques.

Vacuum polarization effects (VPE) have in the past provided remarkable confirmation of predictions of quantum electrodynamics (QED), like the correction of the Lamb shift$^{1)}$. More recently, however, the validity of QED at small distances was questioned by experiment$^{2)}$. Later work by the collaboration Hamburg-Columbia$^{3)}$ proved to be in contradiction with the work of reference 2) and confirmed the validity of QED to momentum transfers up to 400 MeV/c.

The VPE on p-p scattering, and hence on p-p interaction, have been calculated in the past by Foldy and Eriksen$^{4)}$ and also by Heller$^{5)}$. Both calculations are in agreement except for minor differences due to the alternate methods used in the computation. The absolute accuracy or validity of the corrections due to the VPE on p-p interaction has not been established yet$^{6)}$. This point is important for the determination of the shape parameters of the effective range expansion, or equivalently for a proper choice of a potential describing the S-wave interaction. Very low energy scattering experiments (below 300 keV in the laboratory system) may provide clues concerning this point. However, no accurate data exist at present and the experimental difficulties are considerable.

Recent experiments have shown that reactions involving two protons and a third particle in the final state are dominated by the $^1S_0$ nucleon-nucleon interaction. This is the case for $^3He(d,t)2p$ 7,8) or $^3He(^3He,\alpha)2p$ 9). So far a reasonable agreement has been found in fitting the spectra with formulas based in the Watson-Migdal final-state interaction theory 10,11). The center of mass spectra are given by

$$\frac{d^2\sigma}{dE_0 d\Omega} = |g(\phi)|^2 \frac{C(\eta)\rho(E_0)}{C^2(\eta)E_{2p} + (\hbar^2/M_p)[-1/a_p - h(\eta)/R + \gamma_p E_{2p}]^2} \qquad (1)$$

where $C(\eta) = 2\pi\eta/(e^{2\pi\eta} - 1)$ and $h(\eta) = \mathrm{Re}\left[\frac{\Gamma'(-i\eta)}{\Gamma(-i\eta)}\right] - \ln(\eta)$, $\eta = e^2/\hbar v$ (v is the relative velocity of the p-p system, E_{2p} the relative energy), $\gamma_p = r_e M_p/\hbar^2$ (r_e is the effective range), $\rho(E_0)$ is the phase space factor, $|g(\phi)|^2$ is a reaction mechanism dependent factor, function of the momentum transfer. The factorization of the transition matrix element into terms dependent on the nucleon-nucleon pole and the momentum transfer pole is valid for direct or peripheral nucleon transfer reactions, as it corresponds to the assumptions of the Watson-Migdal theory. Expression (1) does not include VPE, as it is simply obtained from the linearized effective range expansion of the function

$$K = RC^2(\eta)k \cot\text{an}\, \delta_0 + h(\eta) \qquad (2)$$

where $R = \hbar^2/M_p e^2$, δ_0 is the $^1S_0$ phase shift. Foldy and Eriksen 4) calculated the corrections ΔK on the basis of first order perturbation theory

$$\Delta K = M_p C^2(\eta) R/\hbar^2 \int_0^\infty V_{vp}(r) u^2(r) dr \qquad (3)$$

V_{vp} is the vacuum polarization potential. The corrections are highly non-linear at low relative energies. Using the values of ΔK of Foldy and Eriksen$^{4)}$ one can correct the "line shape" of the $^1S_0$ state of two protons for VPE, including a term $\Delta K/R$ in the effective range expansion. Figures 1a), 1b) and 2 summarize the results of the computation and its application to the ^{3}He(d,t)2p reaction. Laboratory spectra are shown for obvious practical considerations.

Some discussion is in order concerning the actual observability of the effect. A spectrum shape measured with high statistical accuracy (0.1%) and high energy resolution and precision (down to a few keV) should provide a good test of the correctness of the calculated VPE. However it is not yet known if the third particle spectra are described theoretically to that accuracy by expression (1). If such accurate investigation proved to depart from both, the corrected and uncorrected line shape, it may be due to the neglect of other interactions, but not necessarily due to a breakdown of QED. The following more lengthy experimental path may then prove useful to further pursue the point. The reactions T(d,^{3}He)2n and T(T,^{4}He)2n performed with the same degree of experimental accuracy could provide the spectrum shape when the electrostatic field is switched off. Subsequently, turning on the electrostatic interactions, and properly handling the electromagnetic corrections$^{12)}$, the spectrum of the mirror reactions can be calculated both with and without VPE.

Clearly, agreement would mean another brilliant confirmation of QED, disagreement could be blamed on its failure or to other unknown factors related to charge asymmetry of nuclear forces.

FOOTNOTE AND REFERENCES

[*] This work was done under the auspices of the U.S. Atomic Energy Commission.

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Figure Captions

Fig. 1a) Line shape due to $^1S_0$ p-p state. The calculation corresponds to the ^{3}He(d,t)2p reaction near 30 MeV at 8° in the laboratory system.

Fig. 1b) Highly expanded view of the high energy end of the spectrum and correction factor calculated as described in the text. Note the shift of about 10 keV of the spectrum endpoint.

Fig. 2) Overall view of the corrections of the line shape and correction factor. Note the sizeable range over which the correction is nonlinear.

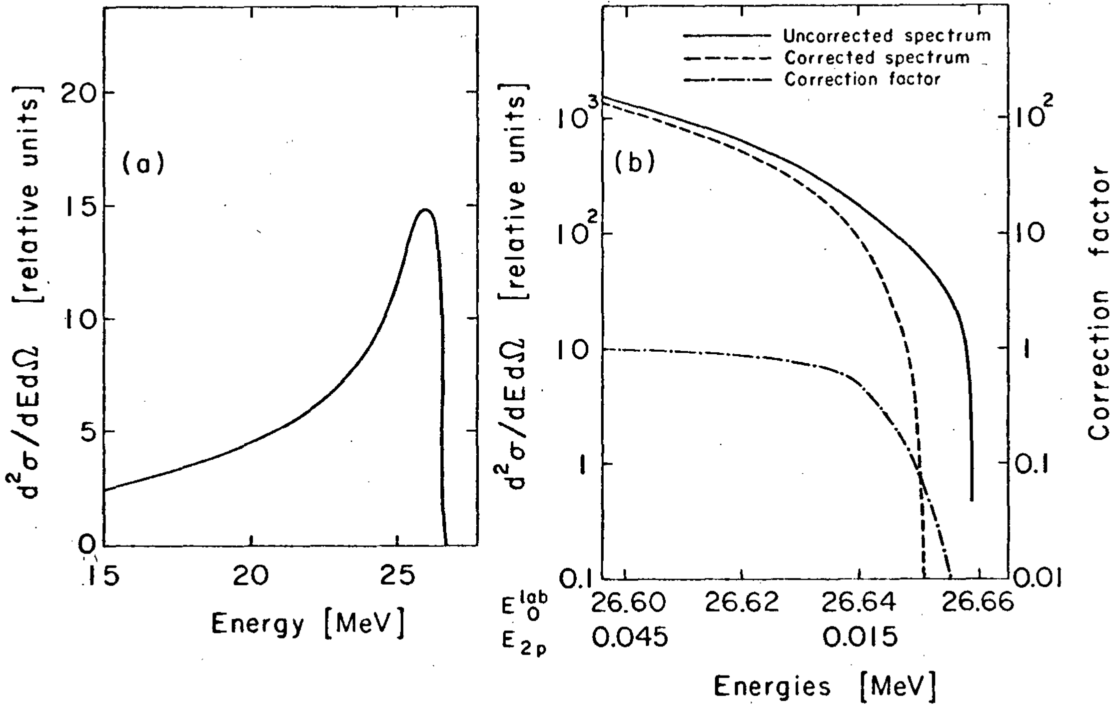

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Fig. 1.

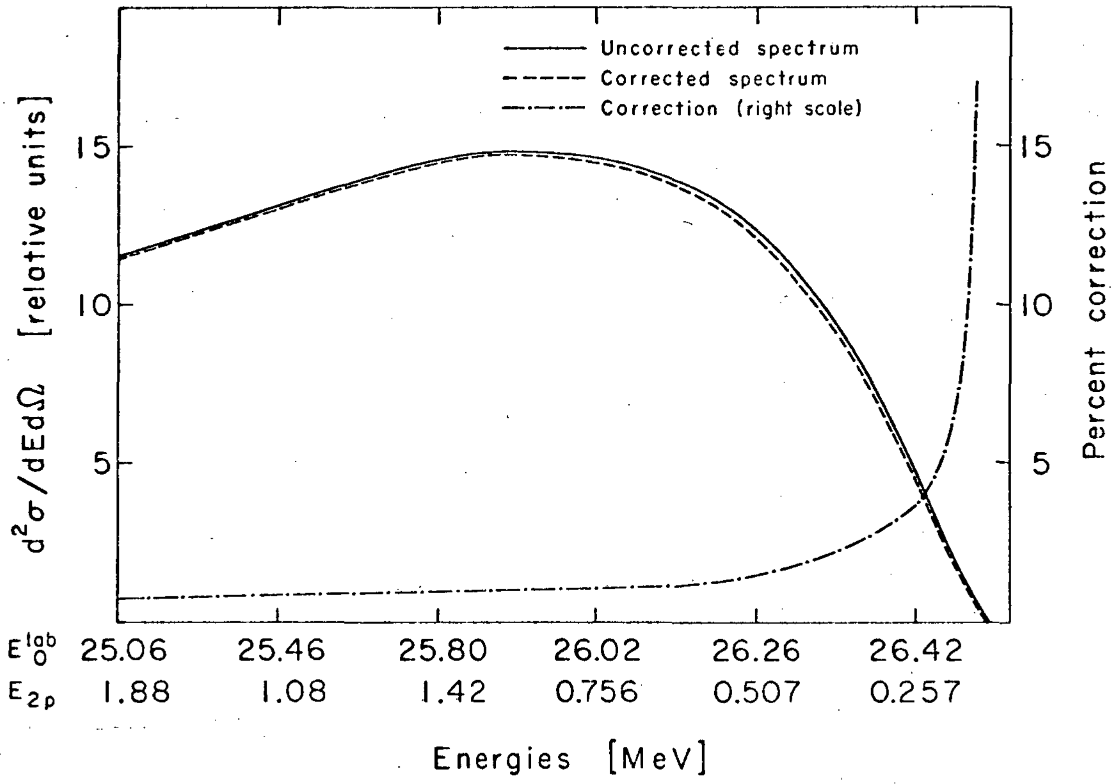

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Fig. 2.