son to assume a large ratio for F^* to decay into muons. A majority of the dimuon events are presumably due to the production and decay of other resonances. We thank A. S. Goldhaber and J. Smith for discussions.

[11]We remark that the Adler sum rule [S. L. Adler, Phys. Rev. 143, B1144 (1966)], which involves the difference $\nu W_2^{\bar{\nu} p} - \nu W_2^{\nu p}$, should be unaffected by these nonscaling effects, as has been previously pointed out (Ref. 2). It is recalled that the Bjorken scaling hypothesis can be actually traced to the Adler sum rule [J. D. Bjorken and S. F. Tuan, Comments Nucl. Part. Phys. 5, 71 (1972)]. Partly for this reason, and partly because we believe that the incoherence assumption of the parton model is valid for small ω, we continue to expect the validity of Bjorken scaling for the structure functions at small ω, and for the difference $\nu W_2^{\nu p} - \nu W_2^{\bar{\nu} p}$ for all ω.

[12]H. W. Kendall, in *Proceedings of the Fifth International Symposium on Electron and Photon Interactions at High Energies, Ithaca, New York, 1971*, edited by N. B. Mistry (Cornell Univ. Press, Ithaca, N. Y., 1972).

[13]Y. Watanabe *et al.*, to be published; C. Chang *et al.*, to be published.

Comments on the Observation of Two-Photon Decay in *n-p* Capture

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Two-photon decay in n-p capture has been reported as having a branching ratio of 10^{-3} relative to single 2.23-MeV γ-ray emission. It is suggested that this result can be explained by crosstalk effects between detectors due to single γ rays, principally that associated with annihilation in flight following pair production. The shape of the observed γ-γ coincidence spectrum is consistent with this type of crosstalk and the apparent two-photon branch is about what is expected from a rough calculation of the magnitude of the crosstalk effect.

From recent measurements two-photon decay in n-p capture has been reported by Dress, Guet, Perrin, and Miller[1] as having a branching ratio of $(1.05 \pm 0.16)\times 10^{-3}$ relative to single 2.23-MeV γ-ray emission. As pointed out by Blomqvist and Ericson[2] and by Barshay[3] this result is about 10^4 times larger than theoretical expectation. The experimental arrangement consisted of two 12-cm$\times$ 12-cm NaI(Tl) crystals on either side of a 2-cm^3 sample of H_2O which was exposed to a collimated beam of subthermal neutrons. Two-dimensional analysis of the γ-γ coincidence spectrum displayed a ridge along the $E_{\gamma 1}+E_{\gamma 2}=2.23$-MeV sum line having an intensity minimum at $E_{\gamma 1}=E_{\gamma 2}$. The yield in this region, i.e., 600 keV $<E_{\gamma 1}$ or $E_{\gamma 2}<1600$ keV, was attributed to two-photon decay after rejecting explanations including the Compton scattering of γ rays from one crystal to the other, or the tails of coincident (511, 1710)-keV peaks.

An effect of this sort has been observed[4] while attempting to detect the two-photon branch in the decay of the 6.05-MeV 0^+ first excited state of ^{16}O. It had been reported[5] that this branch was 2.5×10^{-3} relative to $E0$ positron-electron nuclear pair emission. However, in the Brookhaven National Laboratory experiments[4] it was shown that the yield could be explained by an annihilation-in-flight crosstalk effect due to the presence of unresolved 6.13-MeV γ rays. In this process a single 6.13-MeV γ ray produces a positron-electron pair in either of the NaI(Tl) crystals, the positron annihilates in flight, and the resulting energetic γ ray escapes and is detected as a coincident event by the other crystal. Such an effect would result in a continuum spectrum with an intensity minimum as actually observed at the middle of the $E_{\gamma 1}+E_{\gamma 2}$ line, and it would explain both the magnitude of the effect observed in the Brookhaven experiments[4] and the apparent branch of 2.5×10^{-3} previously ascribed[5] to the 6.05-MeV level of ^{16}O. Even with careful design[4] of the shielding between the two NaI(Tl) detectors it was not possible to eliminate the annihilation-in-flight crosstalk, and the background from this effect was the main limitation in the sensitivity of the search for two-photon decay. An upper limit of 1.1×10^{-4} was found[4] for the two-photon decay of the 6.05-MeV level.

Since the n-p–capture γ rays of 2.23 MeV lie well above the threshold for pair production, the annihilation-in-flight crosstalk effect is still a likely source of background in the experiments reported by Dress *et al.*[1] The magnitude of the effect may be calculated from the theory as presented by Heitler[6] who has derived the total probability of two-quantum annihilation of a positron with an unbound electron, and the differential cross section, both as a function of positron energy. For example, in the production of pairs by 2.23-MeV γ rays the positron can have a maximum kinetic energy of 1.21 MeV (total energy 1.72 MeV or $3.37mc^2$). Figure 32 of Ref. 6 shows that such a positron has a total probability for annihilation in flight of 5.5%. Also shown in that figure is the differential cross section which increases as the positron slows down, reaching a maximum when the kinetic energy is ~0.4 MeV, and thereafter decreasing. For high-energy positrons a major share of the annihilation energy is given to one of the photons and only ~0.5 MeV to the oppositely directed photon. Evidently, if a 1.21-MeV positron annihilates at the very beginning of its path, photons of ~1.7 and ~0.5 MeV are produced. Should the more energetic of these escape, an external detector observing this as a coincidence event can receive more energy than the detector in which the initial interaction took place.

A detailed calculation of the continuum crosstalk yield due to the annihilation-in-flight effect would require a Monte Carlo treatment and would be very complex. However, a simplified estimate can be made by numerical integration methods, ignoring angular-correlation effects. One starts with the fraction of 2.23-MeV γ rays that produces positron-electron pairs in one detector. The intensity-versus-energy distribution of the positrons (see Ref. 6, Fig. 16) may be divided into energy intervals for each of which there is an average total probability for annihilation in flight and an associated spectrum of photon intnesity versus energy that may be derived approximately from the annihilation-in-flight differential cross section. Photons lying between 0.6 and 1.6 MeV can escape and be absorbed by a second detector thereby contributing counts in the region where they could be mistaken for genuine two-photon emission from the source. For a representative point where the initial interaction occurs inside the first detector the efficiency times solid angle for detection of a photon by the second detector is found from standard efficiency tables, with an allowance for absorption loss of the photon in escaping from the first detector. This computation is carried out for all energy intervals of the primary positron. The overall effect resulting in counts along the 2.23-MeV line of total energy absorption in the coincidence spectrum, lying between 0.6 and 1.6 MeV, may be equated to the yield that would have been caused by genuine two-photon emission from the source with a branch $B = N_{\gamma\gamma}/N_\gamma$. Because of the increasing cross section for annihilation in flight with decreasing positron energy, and the fact that the initial interaction can take place in either detector, a symmetrical detecting system is expected to produce an intensity minimum at the center of the 2.23-MeV sum-energy line in the γ-γ coincidence spectrum.

An estimate of the annihilation-in-flight crosstalk effect has been made for a system consisting of two 12-cm× 12-cm NaI(Tl) detectors each 5.0 cm from a source of 2.23-MeV γ rays and at 180° with no shielding between them. The result for the apparent branch B is $\sim 5\times 10^{-4}$. This is consistent with an earlier estimate[4] as noted above, which was made in a similar way and which satisfactorily explained the apparent two-photon branch[5] of 2.5×10^{-3} at a transition energy of 6 MeV. It should be pointed out that there are alternative processes such as those involving bremsstrahlung which can also result in a crosstalk yield in the 0.6–1.6-MeV energy region. Thus, the above estimate, which is probably good to no better than a factor of 3, could well err on the low side with respect to the total effect.

Crosstalk is of course reduced by shielding, but the exact details of the shielding were not given by Dress *et al.*[1] Thus, in view of the order-of-magnitude agreement of the above estimate with the observed effect, it is suggested that crosstalk, principally that due to annihilation in flight associated with single γ rays of 2.23 MeV, may well account for both the yield and the shape of the coincidence spectrum observed in the n-p-capture experiment. Data taken with gross changes in the bulk shielding between detectors would help to establish whether crosstalk is indeed responsible for these observations.

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Interpretation of "Nondivergent Radiation of Discrete Frequencies in Continuous X-Ray Spectrum"

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The observation of "hot spots" and "hot rings" in continuous x-ray spectra from targets with cylindrical bores is acknowledged but has a simple explanation. Hot spots appear purely as a result of the geometry of the arrangement; in addition, hot rings are an optical illusion. There is no need to introduce parametric coupling between electron and photon wavelengths and there is no experimental evidence for discrete frequencies in the bremsstrahlung spectrum.

In recent papers[1,2] Das Gupta reported the observation of nondivergent radiation of discrete frequencies in a continuous x-ray spectrum. Repeating the experimental part of this work with a glass tube target of 13-mm i.d. and 140 mm length, and a brass tube target of 10-mm i.d. and 120 mm length, the observation of the introduced "hot spots" and "hot rings" was possible. Electrons of 400 keV and 20 μA and a focal spot diameter of 4 mm from a Van de Graaff were used for the studies of this effect. Several photographs were taken and it can be verified that the diameter of the hot spot does not vary significantly with the distance from the target, but that the reciprocal square distance law is still valid for the hot spot.

We also observed a hot spot using a tantalum target of 1 mm thickness for bremsstrahlung production in front of the glass tube target. In this case the electron beam was focused by two orthogonal magnetic fields (Lissajou figure) on a ring comparable and concentric to the inner diameter of the glass tube target. The divergence and the sharpness of the hot spot depends on the scanning diameter and disappears without scan in agreement with Ref. 1. This suggests that (1) the origin of the radiation forming the hot spot is the inner surface of the target tube; (2) the assumption of interaction between electrons and photons is not necessary for the interpretation of the nondivergent effect; and (3) a straightforward geometrical interpretation of the effect is possible.

Taking spectra from the hot spot in the same way as was reported in Ref. 1, including exactly the same arrangement and type of filter materials and geometry, we have observed a similar spectral distribution of the bremsstrahlung. Figure 1 shows spectra for different electron energies. The peak labeled 1 in Fig. 3 of Ref. 1 corresponds to the main peak in Fig. 1 of this work. According to our experience with bremsstrahlung we expected to observe filtered bremsstrahlung having the same spectral distribution. Our assumption was verified as the energy of the peak maximum depends on the electron energy which

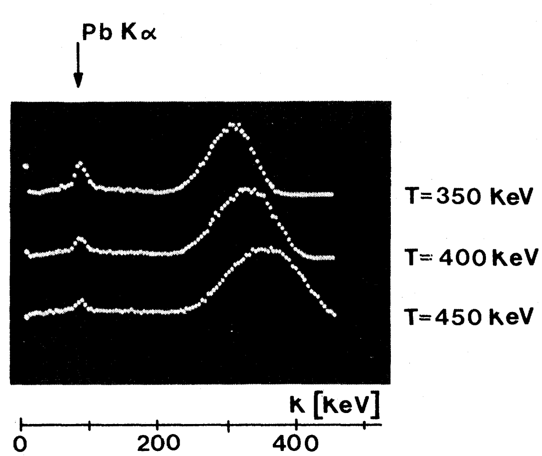

FIG. 1. Spectral distribution in the hot spot for different electron energies taken with a 2 in. × 2 in. NaI(Tl) detector.