*Work supported by the National Science Foundation.

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HIGH-ENERGY γ-RAY ABSORPTION IN SPACE BY A 3.5°K MICROWAVE FIELD

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(Received 13 January 1966)

It is generally accepted[1] that the dominant absorption process for high-energy γ rays in intergalactic space is pair creation[2] through collisions with low-energy photons. This process was first considered by Nikishov[3] in the energy region $E_\gamma \sim 10^{11}$-5×10^{13} eV, for collisions with the thermal photons of intergalactic background starlight, with $kT\sim0.5$ eV. These calculations were then extended[4] into the energy region $E_\gamma\sim10^{18}$-10^{20} eV, for interactions with the nonthermal radio-frequency radiation in the decameter waveband.

It has not hitherto been possible to investigate the γ-ray "window" in the region $E_\gamma\sim10^{15}$-10^{18} eV, owing to lack of information on the background radiation in the microwave and infrared regions of the spectrum. Recently, however, Penzias and Wilson[5] have discovered an isotropic radiation at $\lambda=7.4$ cm, which is believed to be universal and of thermal origin, with a black-body temperature of $T=3.5\pm1.0$°K. One aspect at least of the significance of this discovery to x-ray and γ-ray astronomy has already been noticed,[6,7] namely its role in the inverse Compton effect. The purpose of the present note is to draw attention to another aspect, the absorption of high-energy γ rays.

The threshold γ-ray energy for photon-photon pair creation in a field of quantum energy ϵ is $E_{\gamma0}=(mc^2)^2/\epsilon$. Following Nikishov, the probability P per unit path of a γ-ray absorption is

$$P=\iint\sigma(E_\gamma,\epsilon,\theta)(1-\cos\theta)\cdot\tfrac{1}{2}\sin\theta n(\epsilon)d\theta d\epsilon$$

where σ is the cross section for the process, $n(\epsilon)$ the number density of the low-energy quanta, and θ the angle between the directions of the two quanta. Assuming an isotropic distribution of θ, and a thermal spectrum for $n(\epsilon)$, it is convenient to reduce the expression to

$$P=2\left(\frac{m^2c^4}{E_\gamma}\right)^2A\int\varphi(S_0)(e^{\epsilon/kT}-1)^{-1}d\epsilon,$$

where $S_0=(E\epsilon/mc^2)$, and the function $\varphi(S_0)$ is taken from Ref. 3.

Assuming that the radiation discovered by Penzias and Wilson is indeed universal and thermal in character, its energy density is $u_\gamma=0.71$ eV cm^{-3}, about 100 times higher than the generally accepted density of starlight in intergalactic space. The spectrum peaks at $\lambda\sim1$ mm, $kT\sim3.0\times10^{-4}$ eV, and Nikishov's constant $A=1.37\times10^{13}$ quanta cm^{-3} eV^{-3}. With these assumptions, values of P were computed over the range $E_\gamma\sim10^{14}$-10^{18} eV. These are then compared, Fig. 1, with those obtained previously for the optical and radio-frequency bands, for various values of u_γ, for intergalactic and interstellar space.

The following conclusions result. (1) There is no "window" for γ rays from remote extragalactic objects (i.e., $d>3\times10^7$ parsec) between 10^{14}-10^{19} eV. (2) At the peak of the absorption ($E_\gamma\sim2\times10^{15}$ eV), the microwave absorption coefficient is four orders of magnitude higher than the highest values found for the intergalactic absorption in the other spectral regions. (3) The microwave absorption dominates over that due to intergalactic starlight by a factor ~10 at $E_\gamma\sim10^{14}$ eV, and over that due to extragalactic rf by a factor ~10^3 for $E_\gamma\sim2\times10^{18}$ eV. (4) The most significant result, however, is that this absorption is so strong that it is effective even within the galaxy. E.g., the attenuation of a 2×10^{15}-eV γ ray arising, say, at the center of the galaxy will amount to as much as ~20 at the distance of the solar system (~10 kiloparsec).

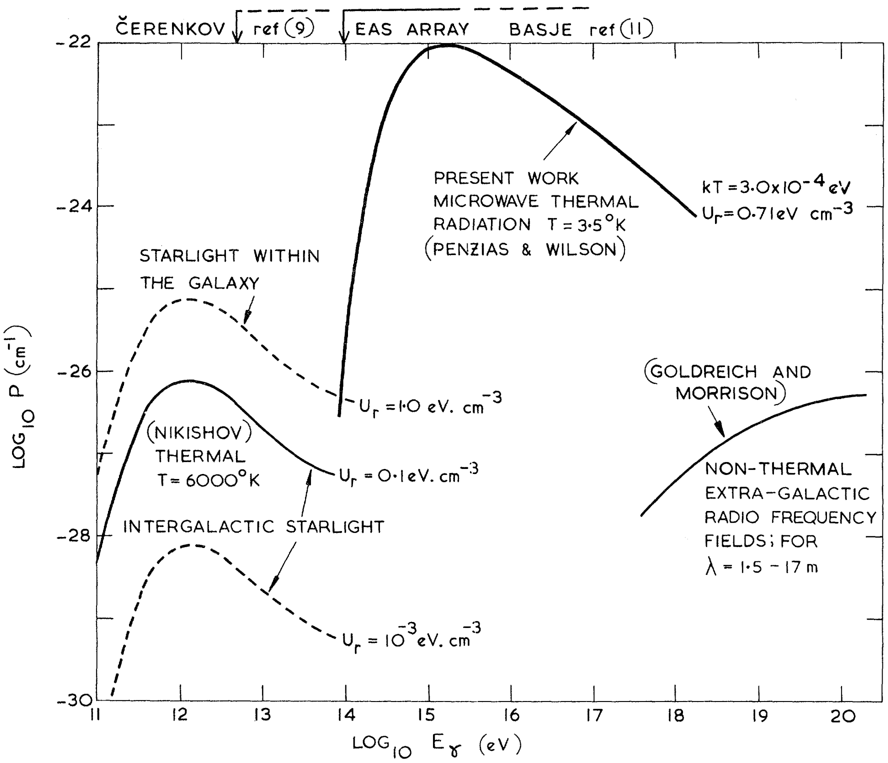

FIG. 1. The probability P (cm^{-1}) for the absorption of γ rays of energy E_γ by photon-photon pair production, in a universal thermal microwave field of temperature 3.5°K at an energy density of 0.71 eV cm^{-3}, and in intergalactic and interstellar optical and radio-frequency fields. The lowest curve represents the intergalactic absorption of diluted 6000° radiation with a revised photon density {V. L. Ginsburg and S. I. Syrovatskii, Zh. Eksperim. i Teor. Fiz. 45, 353 (1963) [translation: Soviet Phys.—JETP 18, 245 (1964)]}.

Strong though it is, the microwave absorption appears to be negligible at the threshold of the Cherenkov technique,[8] $\sim 5\times 10^{12}$ eV, and will not therefore influence the upper-limit fluxes[9] obtained thereby, even for remote quasars. The absorption, however, falls in precisely the energy band covered by the BASJE array[10] and could result in a dimming of all but nearby galactic sources. The Crab nebula, at a distance 1.1 kiloparsec, would not, however, be obscured, even at $E = 2\times 10^{15}$ eV.

The existence of such an absorption at these energies has an impact on a number of problems. For example, in Clark's study[11] of the relationship between 10^{14}-eV γ rays, the 3-Å x rays, and galactic magnetic fields, some revision of the ratio of the fluxes may be necessary. Likewise, an additional factor is introduced in the relationship of the various components of the high-energy radiations in and without the galaxy, as discussed in detail by Gould and Burbidge.[12] For example, the pair-produced electrons and positrons will themselves partake in synchrotron radiation and inverse Compton scattering.

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ANALYSIS OF THE B ENHANCEMENT*

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(Received 14 January 1966)

The reactions $\pi^{\pm}+p\to\pi^{\pm}+\omega+p$ in the region 3 to 4 GeV/c have been studied by several groups. In each case the effective-mass distribution for the $\pi^{\pm}\omega$ system showed a strong enhancement (referred to as the B meson) centered at $M_{\pi^{\pm}\omega}\simeq 1220$ MeV; estimates for the full width, Γ, vary between 80 and 160 MeV.[1,2] The origin of the enhancement has remained obscure since (a) it has not been possible to determine whether the B represents a state of definite spin and parity, (b) no corresponding peak has been observed in any other final state, (c) evidence for a possible anomaly in ω's associated with the B has been reported by Goldhaber et al.,[2] and (d) the enhancement has been observed only in $\pi^{\pm}p$ interactions. Recently, in extending a suggestion due to Deck,[3] Maor and O'Halloran[4] have pointed out that virtual dissociation of the incident pion, $\pi\to\omega+\rho$, followed by the strongly asymmetric inelastic process, $\rho+p\to\pi+p$, should result in a broad enhancement in the region $M_{\pi^{\pm}\omega}\simeq 1200$ MeV. In the present Letter it is shown that such a model accounts naturally for the essential features of the B enhancement as observed in our data. Difficulties associated with interpretation of the B as a resonant state are also discussed.

In a continuing study of π^-p interactions in the Lawrence Radiation Laboratory 72-inch hydrogen bubble chamber, 5112 events[5] representing the final state $p\pi^+\pi^0\pi^-\pi^-$ have been measured at 3.2 GeV/c and 3792 events at 4.2 GeV/c. The Chew-Low plot for single-ω events (either neutral pion triplet, but not both,[6] lies in the ω interval, 760 to 800 MeV) is shown in Fig. 1(a); a strong concentration in the B region occurs only for events with low Δ_p^2 (squared four-momentum transfer to the proton). This feature is emphasized further in Fig. 1(b). The $M_{\pi^{\pm}\omega}$ distribution for single-ω events shows the characteristic B enhancement in the region near 1220 MeV; a negligible reduction in the peak occurs when events with $\Delta_p^2<0.35$ (GeV/c)^2 are plotted separately. We conclude that if the B represents a resonant state, production occurs in highly peripheral collisions.

It is widely recognized that Δ^2 distribution observed in peripheral interactions cannot be interpreted by using unmodified exchange models.[7] Nevertheless, in most experiments involving resonance production, Δ^2 distributions for reactions mediated by π exchange are concentrated at significantly lower values than those proceeding through ρ or ω exchange.[8] The observed Δ^2 distribution in the B region suggests resonance production through π exchange [inset in Fig. 1(a)]. If this were the case, possible spin-parity assignments would be $J^P=1^-$, 3^-, etc.,[9] and decay into $\pi+\pi$ and $K+\bar{K}$ should occur.[10] If the absence of these decays is due to the sequence $J^P=0^-$, 1^+, $2^{\pm}$, 3^+, etc., the B can be produced only through ω exchange; in this case a broader Δ_p^2 distribution would be expected.

A further difficulty arises in attempting to analyze the B as a resonant state. The Dalitz plot for the $\pi^-\omega p$ final state is shown in Fig. 1(c) for events with $\Delta_p^2<0.35$ (GeV/c)^2. It is ap-