SOVIET PHYSICS JETP VOLUME 14, NUMBER 2 FEBRUARY, 1962

ABSORPTION OF HIGH-ENERGY PHOTONS IN THE UNIVERSE

A. I. NIKISHOV

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor March 8, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **41**, 549-550 (August, 1961)

The probability per unit length of path that a 10^{12}-ev γ quantum is converted into an electron pair as a result of a collision with a thermal photon is calculated. If the energy density of thermal photons in intergalactic space is taken as 0.1 ev cm^{-3}, the probability turns out to be 7×10^{-27}. Thus if the distance traversed is greater than 10^{26} cm, the attenuation of the γ-quantum flux may be appreciable.

THERE has recently been increasing interest in the possibility of observing point sources of high energy photons.[1] In this article, we shall consider the role of the reaction $\gamma + \gamma \rightarrow e^{+} + e^{-}$ in the propagation of $10^{-12} - 10^{13}$-ev photons from sufficiently distant objects outside our galaxy.

The cross section for the conversion of two γ quanta into an electron pair is given by the expression* (see [2])

$$\sigma(s) = \tfrac{1}{2}\pi r_0^2 (1 - v^2)\left\{(3 - v^4)\ln\frac{1+v}{1-v} + 2v(v^2 - 2)\right\},$$

$$v = \sqrt{1 - 1/s},$$

$$r_0 = 2.8 \cdot 10^{-13}\ \mathrm{cm},\quad s = (E\varepsilon/2m^2)(1 - \cos\vartheta),$$

where s is the square of the c.m.s. γ-quantum energy, m is the mass of the electron, c = 1, E and ϵ are the energies of the colliding γ quanta in the laboratory system, θ is the angle between their momenta; $\sigma(s) \approx 10^{-25}\ \mathrm{cm}^2$ in the region of s of interest to us. At present, it is assumed that the density of photons with mean energy ~ 1 ev in intergalactic space is $1/3$ to $1/10$ the density in our galaxy. The density of light energy in the galaxy is $W_{\mathrm{gal}} = 0.3 - 1$ ev.[3] It is thus readily seen that if the path traversed by high energy photons is $R \gtrsim 10^{26}$ cm, then the photon flux can be appreciably attenuated. Similar estimates indicate that the contribution to the attenuation of the photon beam as a result of interactions with nuclei or magnetic fields is much smaller.

We proceed to quantitative estimates. The probability per unit length of path that a quantum of energy E is converted into an electron pair in a collision with a thermal photon is

$$P = 2\int_0^\infty d\varepsilon\, n(\varepsilon) \int_0^1 z\sigma(s)\, dz,\quad z = \tfrac{1}{2}(1 - \cos\vartheta),$$

$n(\epsilon)$ is the density of thermal photons in the energy interval $d\epsilon$. Replacing the integration over z by integration over $s = E\epsilon z/m^2$, we find that

$$P = 2\left(\frac{m^2}{E}\right)^2 \int_0^\infty n(\varepsilon)\, \varepsilon^{-2}\varphi(s_0)\, d\varepsilon,\quad \varphi(s_0) = \int_1^{s_0} s\sigma(s)\, ds,$$

$$s_0 = \frac{E\varepsilon}{m^2}.$$

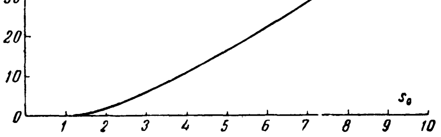
The values of $\varphi(s_0)$ in the interval $1 \le s_0 \le 10$ are shown in the figure. For larger s_0

$$\varphi(s_0) = 25 \cdot 10^{-26}\{s_0(\ln 4s_0 - 2) + 3\}.$$

For the numerical estimate, we set

$$n(\varepsilon) = A\varepsilon^2/(e^{2\varepsilon} - 1).$$

This is a spectrum of the solar type, where kT = 0.5 and the photon energy is measured in electron-volts. To consider a specific case, we shall assume that the energy density of thermal photons in the universe is 0.1 ev cm^{-3}. Then the normalization factor is A = 0.22. Shown in the table are the numerical values of P for different γ-quantum energies and, as an example, the values of PR for an interesting star, Cygnus A (at a distance[4] $R_C = 6.6 \times 10^{26}$ cm). It is seen from the table that



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*It is readily seen that $\sigma(s)$ is obtained by multiplication of the inverse reaction by $2v^2$; the factor 2 results from the fact that the particles in the final state are not identical and v^2 results from the difference in the flux and statistical weight of these channels of the reaction.

10^{-12} E, ev	0.1	0.5	1	5	10	50
10^{27} P, cm^{-1}	0.05	5	7	4	2	0.7
PR_c	0.03	3	4.6	2.6	1.3	0.5

the maximum attenuation of the beam is e^{-PR} for $E = 10^{12}$ ev.

In principle, the effect can be used for an experimental estimate of the mean density of thermal photons in intergalactic space. The numerical value of this density is of interest for a number of astrophysical problems (see, e.g., [5], where the photodisintegration of high energy heavy nuclei in intergalactic space is discussed).

In conclusion, the author expresses his gratitude to V. L. Ginzburg for interesting discussions.

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[2] A. I. Akiezer and V. B. Berestetskii, Kvantovaya élektrodinamika (Quantum Electrodynamics), 2nd ed., Fizmatgiz, 1959, p. 359.

[3] E. Feenberg and H. Primakoff, Phys. Rev. **73**, 449 (1948); C. W. Allen, Astrophysical Quantities, University of London, Athlone Press, 1955, pp. 228, 245.

[4] I. S. Shklovskii, Astronomicheskii zhurnal, **37**, 945 (1960), Soviet Astronomy **4**, 885 (1961).

[5] N. M. Gerasimova and I. L. Rozental', JETP **41**, 488 (1961), Soviet Phys. JETP **14**, 350 (1962).

Translated by E. Marquit
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