which seems to be obeyed in nature. We wish to re-emphasize here that the inequality (22) follows from our model only after making the additional assumptions (20) and $y \geq 0$.

The main point of this paper is that of reducing a complicated multiparticle problem to a much simpler two-body problem. Further work, especially at $t \neq 0$, is needed to obtain a full understanding of the Pomeranchuk singularity in this model.[9]

I wish to thank Professor R. Oehme and Professor R. Arnold for valuable discussions.

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*Work supported in part by U. S. Atomic Energy Commission.

[1]This should not be confused with the redundant label R attached sometimes to the A_2 trajectory.

[2]G. F. Chew and A. Pignotti, to be published; A. Pignotti, private communication.

[3]G. F. Chew and A. Pignotti, Phys. Rev. Letters 20, 1078 (1968).

[4]I wish to acknowledge an illuminating conversation with Dr. G. Veneziano on this point.

[5]P. G. O. Freund, Phys. Rev. Letters 20, 235 (1968); in this paper the result is stated in its full generality and not only for the case of $\pi\pi$ scattering [see especially Aachen-Berlin-CERN-London (I.C.)-Vienna Collaboration, Phys. Letters 27B, 336 (1968) and the discussion to which it refers]. A restatement of this result is contained in H. Harari, Phys. Rev. Letters 20, 1385 (1968).

[6]Throughout this paper we disregard factors like $(\ln s)^{\lambda_1}(\ln \ln s)^{\lambda_2}\cdots$ and concentrate only on powers of s and n. Logarithmic factors can always be included by suitably modifying the Ansatz (6).

[7]Assuming the width of the forward peak at fixed s due to R exchange to depend at most logarithmically on n.

[8]Aachen-Berlin-CERN-London (I.C.)-Vienna Collaboration, Ref. 5.

[9]The approach opposite to that taken in this paper and in Refs. 2 and 3 would be a model in which the Pomeranchuk term bootstraps by itself, independently of any lower Regge trajectories. A two-body intermediate-state reduction may prove useful even for such a model but the resonances ought to be of the type that can be produced by diffraction dissociation.

HIGH-ENERGY GAMMA RAYS, COSMIC-RAY ELECTRONS, AND THE FAR-INFRARED BACKGROUND RADIATION*

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It is shown that the observed flux of galactic gamma rays, which is one order of magnitude higher than the theoretical value, can be explained if one assumes the recently detected far-infrared radiation to be galactic or universal. Effects of the infrared radiation on cosmic rays are discussed.

Shivanandan, Houck, and Harwit[1] have recently detected a background infrared radiation with intensity 5×10^{-2} erg/cm^2 sec sr (within a factor of 2) in the spectral range from 0.4 to 1.3 mm. We wish to point out that inverse Compton scattering of such radiation, if it is universal, or at least galactic, would provide a natural explanation of the otherwise unaccountable gamma flux observed recently by Clark, Garmire, and Kraushaar.[2] Some secondary evidence supporting the existence of a background infrared radiation in the galaxy can also be found from the spectrum of cosmic electrons observed at Earth. The gamma-ray data obtained by Clark, Garmire, and Kraushaar can be summarized as follows. A diffuse photon flux of 2×10^{-4} (cm^2 sec rad)$^{-1}$ was detected in coincidence with the plane of the galaxy at energy $E \geq 100$ MeV (the instrumental limit). The intensity of the radiation in this plane has a broad maximum [5×10^{-4} (cm^2 sec rad)$^{-1}$] toward the galactic center. With less certainty an isotropic background intensity of 1×10^{-4} (cm^2 sec sr)$^{-1}$ was also observed.

Theoretically, the primary processes for generating high-energy photons in space are the decay of π^0 mesons produced by cosmic-ray collisions, and the bremsstrahlung and Compton scattering of relativistic electrons.[3] The predicted γ-ray intensity due to π^0 decay and bremsstrahlung are more than one order of magnitude less than the observed intensity. One should notice that $I_{\pi^0}(E_\gamma)$, the γ-ray flux due to π^0 decay, and to a lesser degree $I_B(E_\gamma)$, the bremsstrahlung flux, are closely related to the cosmic-ray positron intensity. They are all proportional to the interstellar mass density. Assuming equal production of π^+ and π^0 in nuclear collisions at high energy, one can deduce an upper limit on the intensity of $I_{\pi^0}(E_\gamma)$ from the observed positron intensity. This upper limit (a part of the positrons could be produced inside discrete sources) is very close to the presently accepted theoretical value. Hence the discrepancy with the observed γ-ray intensity cannot be removed by postulating an increase in the interstellar matter density. Nor can the strong flux be explained by the inverse Compton scattering of the stellar photons or the 3°K blackbody radiation. The Compton flux $I_C(E_\gamma)$ observed at Earth can be calculated from the cosmic-ray electron intensity $I_e(E, \vec{r})$ by[4]

$$I_C(E_\gamma) = E_\gamma^{-1/2} \int A_1 I_e(A_2 E_\gamma^{1/2}, \vec{r}) dl, \qquad (1)$$

where the integration path is along the line of observation. $A_1 = 1.5 \times 10^{-19} W \epsilon^{-3/2}$ eV$^{1/2}$ cm^{-1} and $A_2 = 4.5 \times 15 \epsilon^{1/2}$ eV$^{1/2}$. W (in units of eV/cm^3) is the energy density and ϵ (in units of eV) the average energy of the scattered photons. Using the electron flux observed at Earth[5] as I_e inside the galaxy, we find the intensity of Compton photons $I_C(E_\gamma > 100$ MeV) from 3°K radiation to be $\lesssim 4 \times 10^{-5}$ (cm^2 sec sr)$^{-1}$ toward the galactic center and weaker at other directions in the galactic plane because of the shorter integration path. The contribution from Compton scattering of interstellar photons is less than or equal to that from 3°K photons. The observed line intensity of 5×10^{-4} (cm^2 sec rad)$^{-1}$ at $l^{\rm II} = 0°$ can be made compatible with the local electron intensity by the plausible postulation that the galactic center is a strong cosmic-ray source. Because the electrons which produce $\geqslant$100-MeV photons by scattering 3°K radiation are of energy $E > 100$ BeV, the range they can diffuse in the galaxy before losing most of their energy via radiation is far less than the distance from Earth to the core. Hence the large flux of energetic core electrons required to produce the observed gamma flux does not contribute to the intensity of high-energy electrons at Earth. However, the large gamma intensity observed at other directions in the galactic plane remains unaccountalbe in this model. Observation along $l^{\rm II} = 60°$ would, for example, pass most regions at approximately the same distance from the galactic center as Earth. It is difficult to understand how the average electron flux in these regions can be more than 10 times higher than that at Earth.

If we assume the infrared radiation observed by Shivanandan, Houck, and Harwit exists in the galaxy, a crude estimation using the cosmic-ray electron flux at Earth as the intensity everywhere throughout the galactic disk would give an average Compton flux of 5×10^{-4} photons (cm^2 sec sr)$^{-1}$ above 100 MeV in the galactic plane, which is compatible with the gamma-ray observation. (The experimental results were averaged over a latitude cone of $-15° < b^{\rm II} < 15°$; hence they contain a substantial part of halo even though directed at the galactic plane.) In fact, the existence of a strong infrared radiation field, coupled with a disk source distribution of cosmic-ray electrons with injection energy spectrum E^{-2}, provides a more satisfactory explanation of the observational results related to cosmic-ray electrons than can be given without the radiation. In order to present the argument we shall assume the source of cosmic-ray electrons to be

$$Q(E, \vec{r}) = Q_0 E^{-\alpha} f(\vec{r}),$$

where

$$f(\vec{r}) = (\pi^{3/2} a^3 p)^{-1} \exp\left(-\frac{x^2 + y^2 + z^2/p^2}{a^2}\right) \qquad (2)$$

with the galactic radius $a = 12$ kpc and the thickness of the disk characterized by $p = 10^{-2}$. The equilibrium electron density in the galaxy $N(E, \vec{r})$ is then given by

$$-\frac{\partial}{\partial E}\left(\frac{dE}{dt} N\right) - D\nabla^2 N = Q, \qquad (3)$$

where $D \approx 10^{29}$ cm^2/sec.[6] In the presence of the infrared radiation, the Compton scattering dominates all other kinds of energy losses and $dE/dt = -bE^2$, where $b = 8 \times 10^{-26} W$ (eV sec)$^{-1} \simeq 10^{-24}$ (eV sec)$^{-1}$ for $W = 13$ eV/cm^3. The general solution of Eqs. (2) and (3) has been discussed previously[7] and the electron spectrum is reproduced using the new value of b in Fig. 1. To a good approximation the equilibrium density in the disk ($z \leqslant pa$) can be expressed as

$$\begin{aligned} N(E, \vec{r}) &= N_0 E^{-\alpha}, \quad E \ll E_1, \\ &= N_0 E_1^{\frac{1}{2}} E^{-(\alpha + \frac{1}{2})}, \quad E_1 \ll E \ll E_2, \\ &= N_0 (E_1 E_2)^{\frac{1}{2}} E^{-(\alpha+1)}, \quad E \gg E_2. \end{aligned} \qquad (4)$$

In the halo ($z > pa$) $N(E, \vec{r})$ varies as

$$N(E, \vec{r}) \approx N_0 E^{-\alpha} \exp\left(-\frac{z^2}{a^2} \frac{E}{E_1 + p^2 E}\right), \qquad (5)$$

where $E_1 = 4D/ba^2 \approx 200$ MeV, $E_2 = 4D/b(pa)^2 \approx 2$

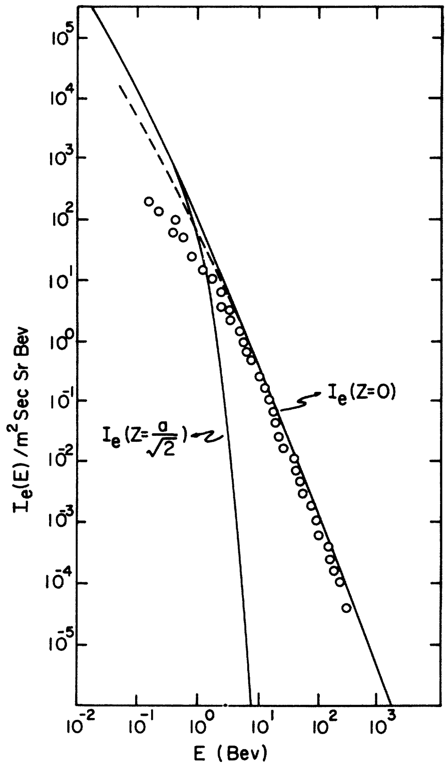

FIG. 1. Sketch of computed equilibrium cosmic-ray electron intensity in the disk $[I_e(z=0)]$ and in the halo $[I_e(z=a/\sqrt{2})]$ in the presence of an infrared radiation field of $W = 13$ eV/cm^3. The circles are the observed intensity of electrons at Earth, summarized by K. C. Anand, R. R. Daniel, and S. A. Stephens, Phys. Rev. Letters 20, 764 (1968). The dashed line results from demodulation of the low-energy electron data at Earth [R. Ramaty and R. E. Lingenfelter, Phys. Rev. Letters, 20, 120 (1968), modulating function f_2].

$\times 10^3$ BeV, and $N_0 = Q_0/Da$. One observes that the intensity and the spectrum of cosmic-ray electrons are approximately the same in the halo and disk for $E < E_1$. Above E_1 the disk spectrum changes by one-half power and the halo spectrum drops exponentially. There are few electrons in the halo with $E >$ a few BeV. It is worthwhile to point out here the connection between the diffusion treatment and the commonly used (but incorrect)[8] confinement-leakage approximation. One could, if one wished, state that for $E < E_1$ the electrons are "confined" in the galactic sphere (including halo and disk), while for $E > E_1$ the electrons are more and more "confined" in the disk. This can be explained in the following way: The radiative lifetime of an energetic electron is $\sim(bE)^{-1}$; within that time the particle can on the average travel a distance $l = (2D/bE)^{1/2}$ from its source via random walk through the irregular galactic magnetic field. For $E < E_1$, $l \geqslant a$, the electrons can in principle fill up the galaxy and the confinement-leakage approach makes some sense. But for higher energy electrons they can only be found near their source, hence "confined" in the disk. It is obvious that in the energy range above E_1 the boundary of the galaxy plays little role since few electrons of that energy can ever reach there.

Comparison of $N(z=0)$ calculated from Eq. (3) with the experimental points observed at Earth finds no inconsistency if we take $\alpha = 2$. This is especially true now that the predicted "break" of the spectrum has moved back to the energy range below 1 BeV, while without the existence of the infrared radiation field (but with the 3°K photons) E_1 is expected to be around 10 BeV. No change in slope was found in the observed electron spectrum around that energy. However, the moderate flattening of the interstellar energy spectrum at a few hundred MeV predicted in the present model is completely masked by solar modulation[9] when they reach Earth. Any meaningful discussion regarding this point has to wait until we know more about the modulation effect.

On the other hand, the inverse Compton flux generated from the assumed infrared radiation can be now calculated rigorously by substituting $N(E, \vec{r})$ into Eq. (1). The results are plotted in Fig. 2 for 10^4 eV $< E_\gamma < 10^9$ eV; the corresponding energy for electrons producing them is 1 BeV $< E <$ 300 BeV, a range for which the electron intensity is accurately measured at Earth. The computed galactic gamma-ray intensity toward the halo is quite low, since the half-width of the "high-energy electron disk" is $\sim(2D/bE)^{1/2}$, much smaller than the radius of the galaxy at $E = 100$ BeV. Hence the diffuse x-ray and gamma-ray radiation must still be explained by inverse Compton radiation of metagalactic electrons.[10] If the infrared radiation also exists in metagalactic space, the observed x-ray flux implies a very low metagalactic electron intensity $\approx 50E^{-3.6}$ (cm^2 sec sr MeV)$^{-1}$. The isotropic background component at $E_\gamma \geqslant 100$ MeV could result from the same mechanism as the x rays. An alternative explanation was suggested by Stecker.[11] We might mention here that the apparent depletion of high-energy electrons in the halo due to the existence of the infrared radiation does not contradict the background radio data. The synchrotron radiation in the frequency range where it is separable from the 3°K microwave background is produced by electrons of energy less than 10

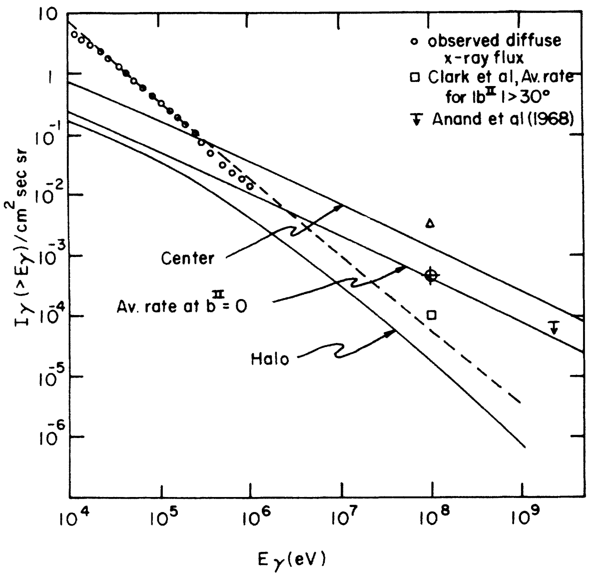

FIG. 2. Expected integral spectra of Compton photons from the scattering of infrared radiation of $W = 13$ eV/cm^3 and $\epsilon = 2\times10^{-3}$ eV. The dashed curve represents the contribution from metagalactic electrons of assumed intensity $I_{e,\,\mathrm{meta}} = 50E^{-3.6}$ (cm^2 sec sr MeV)$^{-1}$. The solid curves represent contributions from galactic electrons (1) observed toward the galactic center, (2) averaged over all directions in the galactic plane, and (3) observed toward the halo. The two points Δ (galactic center) and ⊕ (average rate at $b^{\mathrm{II}} = 0$) are converted from the data of Clark, Garmire, and Kraushaar using Eq. (9).

BeV. At that energy the half-width $(2D/bE)^{1/2}$ of the electron disk is ~2 kpc, which is 10 times wider than the so-called radio disk. The electrons contained inside this thick disk are sufficient to create a radio halo (though slightly anisotropic). This point can be seen clearly in Fig. 2, where without the metagalactic background one would expect an "x-ray halo" for photons of energy less than 1 MeV (which are produced by electrons of energy less than 10 BeV). A more detailed calculation taking into account the variation of magnetic field will be published elsewhere.

The computed gamma-ray flux toward the galactic plane, however, cannot be used for direct comparison with the results of Clark, Garmire, and Kraushaar. The observed flux in the galactic plane is, because of the poor resolution of the apparatus, presented in terms of an equivalent line source of dimensions (cm^2 sec rad)$^{-1}$. This could be calculated from

$$I'(E_\gamma)\ [\text{in units of (cm}^2\text{ sec rad)}^{-1}] = E_\gamma^{-1/2}\int_{-\theta_0}^{+\theta_0} d\theta \int_0^{L'} A_1 I_e(A_2 E_\gamma^{1/2}, \vec{r})dr, \quad (6)$$

where $\theta_0 \approx 15°$ is the latitude half-width of the band over which the data were summed, and L is the path length of integration (to the edge of the galaxy). A simple conversion formula relating the line flux $I'(E_\gamma)$ to the solid-angle flux $I(E_\gamma)$ computed in this Letter can be derived by assuming

$$I_e(E, \vec{r}) = I_e(E, Z=0) \text{ for } z \leq (2D/bE)^{1/2}, \quad (7)$$

and

$$I_e(E, \vec{r}) = 0 \text{ for } z > (2D/bE)^{1/2}. \quad (8)$$

With this approximation (which introduces an error of less than 20%), Eq. (6) gives, for $1 \gg \theta_0 > Z_0/L$,

$$I'(E_\gamma) \simeq (2Z_0/L)[1 + \ln(L\theta_0/Z_0)]I(E_\gamma), \quad (9)$$

where $Z_0 = (2D/bA_2E_\gamma^{1/2})^{1/2}$. For 100-MeV photons $Z_0 \cong 2\times10^{21}$ cm; hence Z_0/L is smaller than the beam width for most directions in the galactic plane. The predicted line intensity by the scattering of background infrared radiation by cosmic-ray electrons is ~2×10^{-4} photons (cm^2 sec rad)$^{-1}$ in the galactic plane with only a slight (about 50%) increase toward the galactic center. This agrees well with the data of Clark, Garmire, and Kraushaar except that their results show a maximum, by a factor of more than 2, in the direction of the galactic center. This excess flux of gamma rays could be due to the existence of an intense infrared source in the galactic center. As reported recently by Hoffmann and Frederick[12] an excess flux of 6×10^{-2} erg (cm^2 sec sr)$^{-1}$ in a bandwidth between 80 and 120 μ is detected in the direction of the galactic center. The extension of the source is more than 6.5° along the galactic plane but less than 2° perpendicular to it. This excess infrared flux is not sufficient to produce a Compton flux comparable with that observed by Clark, Garmire, and Kraushaar, but future observations covering a wider spectrum range on the absolute intensity of the infrared source might change the above conclusion. Another possible explanation for the observed gamma-ray maximum is that the galactic center is a stronger cosmic-ray source than as indicated by Eq. (2). For further discussions on this rather interesting point one has to wait for more complete experiment data.

The most startling implication on cosmic-ray theories resulting from the cosmic infrared radiation is perhaps the required rate for production of high-energy electrons. The observed intensity ratio of electrons to nuclei is $\sim 10^{-2}$ from 1 to 300 BeV and they both have the same spectral index of ~2.6. But in this energy range the electron spectrum has already steepened by one-half power because of radiative losses. Therefore the injection ratio $Q_e(E)/Q_p(E)$ increases progressively for higher energy and already approaches unity at the present observational limit if one accepts the existence of the infrared field. This conclusion holds independent of other details as long as the electrons and nuclei of cosmic rays are produced in the same source and diffuse in the same manner. One would then have to look for mechanisms which accelerate electrons more efficiently than nuclei.[13]

In conclusion, one cannot claim that the current data on cosmic-ray electrons and high-energy radiation have "proved" the existence of a cosmic (or at least galactic) infrared flux, but they are certainly compatible with the presence of such a radiation field. The origin of the radiation, which we have made no attempt to discuss in this Letter, is still an open question at present. The author wishes to thank Professor G. W. Clark for helpful discussions.

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[2]G. W. Clark, G. P. Garmire, and W. L. Kraushaar, Astrophys. J. 153, L203 (1968).

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[5]K. C. Anand, R. R. Daniel, and S. A. Stephens, Phys. Rev. Letters 20, 764 (1968).

[6]The source Q and the isotropic diffusion equation used here are, of course, gross approximations for propagation of cosmic rays in the galaxy. As pointed out by J. R. Jokipii and P. Meyer [Phys. Rev. Letters 20, 752 (1968)], D should increase toward the halo where the magnetic field is weaker. In the disk one also expects diffusion along the spiral arms to be faster than across the lines of force. The distribution of sources, while likely to be confined in the galactic plane, may not lie as evenly as suggested by a Gaussian. Nevertheless, refinements along the above lines (C. S. Shen and G. Berkey, to be published) do not alter the essential features presented here.

[7]C. S. Shen, Phys. Rev. Letters 19, 399 (1967). There is a typographical error in Eq. (7) of this paper. The exponential factor should be $\exp[-\{\xi+4/9(1+2\xi)\}]$.

[8]A detailed discussion was given by Jokipii and Meyer, Ref. 6.

[9]R. Ramaty and R. E. Lingenfelter, Phys. Rev. Letters 20, 120 (1968).

[10]J. E. Felten and P. Morrision, Astrophys. J. 146, 686 (1966).

[11]F. W. Stecker, Nature 220, 675 (1968).

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THEORIES WITH TOO MUCH SYMMETRY

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It is shown that a class of theories, of which Sugawara's theory of currents and certain Yang-Mills type theories are examples, possess a particular symmetry which is not, even approximately, present in the observed strong interactions. The symmetry would imply that all mesons and all massive fermions have partners with opposite parity and opposite charge conjugation.

There is a class of possible strong-interaction theories, of which Sugawara's theory of currents[1,2] is perhaps the most interesting, in which the energy-momentum tensor $\theta^{\mu\nu}$ can be written as

$$\theta^{\mu\nu}=\theta_{(+)}{}^{\mu\nu}+\theta_{(-)}{}^{\mu\nu}, \tag{1}$$

where $\theta_{(+)}{}^{\mu\nu}$ and $\theta_{(-)}{}^{\mu\nu}$ are two (independently) conserved tensors which commute with each other at equal times and are interchanged by parity, i.e., $P\theta_{(\pm)}{}^{\mu\nu}P^{-1}=\theta_{(\mp)}{}^{\mu\nu}$. The existence of these two independent, conserved tensors leads in the usual way to a symmetry group $\mathcal{P}_{(+)}\otimes\mathcal{P}_{(-)}$, where $\mathcal{P}_{(+)}$ and $\mathcal{P}_{(-)}$ are two commuting Poincaré groups. This is to be contrasted to the usual case where there is only one conserved tensor and (apart from internal symmetries) the theory is invariant only under the usual Poincaré group $\mathcal{P}$.

It will be shown below that the possible existence of a $\mathcal{P}_{(+)}\otimes\mathcal{P}_{(-)}$ symmetry is in conflict with