3°K BLACKBODY RADIATION AND LEAKAGE LIFETIME OF COSMIC-RAY ELECTRONS

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Since the first observations of strong background of radio waves at ~7-cm wavelength by Penzias and Wilson,[1] many observations have been reported[2-4] which support the hypothesis of a universal 3°K blackbody radiation.[5] Consequently, many authors have discussed the implications of the interactions of this radiation field with high-energy cosmic-ray particles during their propagation and have made predictions about the high-energy ends of various components of cosmic rays.[6-9]

Recently Daniel and Stephens[10] have reported very interesting results of their measurements on the spectrum of primary cosmic-ray electrons up to a few hundred GeV (see Fig. 1). They have shown that taking the generally accepted lifetime of 100 Myr for primary cosmic rays, the observed intensity of electrons in the 100-GeV regions is too high by a factor of 10 compared with what would be expected from an extrapolation of low-energy spectra if the 3°K blackbody radiation field really exists. They conclude that either the universal 3°K radiation does not exist, or the high-energy (>10 GeV) primary electrons have a very flat source spectrum, quite different from the low-energy spectrum measured directly and also deduced from the shape of the background radio noise.

In this note we would like to take a different viewpoint. We suggest that the presence of a universal 3°K radiation provides an excellent method of putting an upper limit on leakage life of cosmic-ray electrons and hence of primary cosmic rays. As discussed later, the measures made so far on the life of cosmic rays do not contradict the information derived from this analysis.

Calculation of the equilibrium spectrum of cosmic-ray electrons.—Several discussions of the equilibrium spectrum of electrons in the presence of magnetic fields and radiation fields can be found in literature; see, for example, Hayakawa *et al.*[11] For completeness here we give the expressions used by us for these calculations.

The energy loss suffered by high-energy cosmic electrons is mainly due to synchrotron and Compton processes. This is given by[12]

$$dE/dt=-bE^2, \tag{1}$$

and the steady-state differential flux of electrons of energy E would be

$$F(E)dE=\frac{dE}{E^{\gamma+1}}\int_0^{1/bE\tau}(1-bE\tau x)^{\gamma-1}e^{-x}dx, \tag{2}$$

where $1/E^{\gamma+1}$ gives the differential spectrum

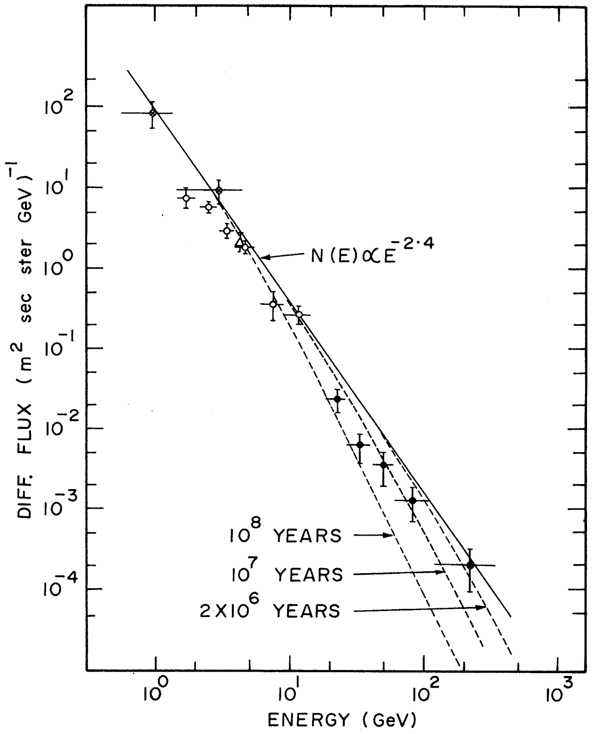

FIG. 1. Calculated equilibrium energy spectra of electrons for the three values of leakage life are shown along with experimental points. Data are from the following sources: circled crosses, C. V. Waddington and P. S. Freier, in Proceedings of the Ninth International Conference on Cosmic Rays, London, 1965 (The Institute of Physics and The Physical Society, London 1966), Vol. 1, p. 339; triangles, P. Agrinier *et al.*, *ibid.*, p. 331; open circles, J. A. M. Bleeker, J. J. Burger, A. Scheepmaker, B. N. Swamenburg, and Y. Tanaka, *ibid.*, p. 327; and closed circles, Daniel and Stephens, Ref. 10. The injection spectrum has been taken to be a power law in energy with a differential slope −2.4, and experimental points in 2- to 5-GeV range have been used for normalization.

for the case of no energy losses, i.e., $b=0$, and τ is the leakage life of cosmic-ray electrons. [The total energy loss is given by a value of $b=1.92\times10^{-3}$ (GeV)$^{-1}$/Myr if the energy densities for 3°K radiation field and starlight are taken as 0.4 eV/cm^3 and 0.1 eV/cm^3, respectively, and the effective value of the magnetic field is taken as 2×10^{-6} G.]

Results.—The calculated steady-state differential spectrum of electrons is shown in Fig. 1, along with experimental points, for leakage lives of 2, 10, and 100 Myr, respectively. The differential slope of the injection spectrum, i.e., slope under conditions of no energy loss, has been taken as −2.4, which is the value inferred for the low-energy part of the spectrum, from direct observations as well as the observations on radio background, by Felton.[13] The combined losses due to starlight, 3°K radiation, and magnetic fields have been taken as equivalent to the losses in a radiation field of 0.6 eV/cm^3 density [$b=1.92\times10^{-3}$ (GeV)$^{-1}$/Myr]. The spectrum is normalized with experimental points in the range 2 to 5 GeV.

It is seen that the calculated spectrum for a leakage lifetime of 10 Myr gives a good representation of the experimental data. Considering the uncertainties in the slope and amplitude of the source spectrum, a leakage life as low as 2 Myr cannot be excluded; on the other hand, a life of 100 Myr or more gives too low a flux at 100 GeV and beyond. Thus it appears that the leakage life of cosmic-ray electrons, and most probably of other particles also, cannot be much longer than 10 Myr, if the 3°K radiation does exist and if there is only one source of electrons up to a few hundred GeV energy.

Discussion.—The only other direct method used for determining the lifetime of cosmic-ray particles utilizes the fact that Be^{10}, one of the isotopes produced in fragmentation of heavy nuclei, is unstable with a mean life of $\sim4\times10^6$ yr. Thus the value of the ratio Be/B in primary cosmic rays is expected to be ~0.36, if the life of cosmic rays is much longer than the time-dilated life of Be^{10} nuclei, and ~0.51, if it is much shorter than Be^{10} lifetime.[14,15] These numbers are subject to rather large uncertainties on the presently available partial cross sections for production of different Be and B isotopes in collisions of various heavy nuclei with protons.[16] To our knowledge only one statistically significant measurement of the Be/B ratio has been reported so far which gives a value of 0.33 ± 0.02 at energies less than 1 GeV/nucleon.[17] (This is not corrected for 2-6 g/cm^2 of air above the measuring apparatus.) Subject to the uncertainties on fragmentation parameters, this may at best be used to indicate that the cosmic-ray leakage time is equal to or greater than a few million years. Two other measurements of this ratio at higher energy[14,17] are based on balloon measurements, each involving only about half a dozen Be nuclei before atomspheric correction, and hence do not really put much of a lower limit on the cosmic-ray lifetime.

Still another point may be relevant here. It is conceivable that the leakage life of cosmic rays is rigidity dependent, its value increasing with decreasing rigidity over some rigidity range. The considerations of this note apply to electrons of rigidity greater than ~100 GV, while the leakage life determined by the Be/B method, used with an equatorial flight without energy measurements on individual particles, would apply to cosmic-ray nuclei at rigidities ≥16 GV. These two values even if accurately determined need not be necessarily the same. However, if we do take an upper limit of 10 Myr to be applicable to the leakage life of all relativistic cosmic-ray particles, the fact that cosmic rays have traversed about 2.5 g/cm^2 of matter[18] puts a lower limit of ~0.15 hydrogen atoms per cm^3 on the average density along their path. Since an unknown part of the matter traversed could be near the source or in the galactic disk, this information cannot be used to obtain the matter density in the halo region.[19]

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[1] A. A. Penzias and R. W. Wilson, Astrophys. J. 142, 419 (1965).

[2] P. G. Roll and D. J. Wilkinson, Phys. Rev. Letters 16, 414 (1966).

[3] G. B. Field and J. L. Hitchcock, Phys. Rev. Letters 16, 817 (1966).

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[6] F. Hoyle, Phys. Rev. Letters 15, 131 (1965).

[7] J. V. Jelley, Phys. Rev. Letters 16, 479 (1966).

[8] R. J. Gould and G. Schrēder, Phys. Rev. Letters 16, 253 (1966).

[9] K. Greisen, Phys. Rev. Letters 16, 748 (1966).

[10] R. R. Daniel and S. A. Stephens, Phys. Rev. Letters 17, 935 (1966).

[11] S. Hayakawa, H. Okuda, Y. Tanaka, and Y. Yamamoto, Progr. Theoret. Phys. (Kyoto) Suppl. No. 30, 153 (1964).

[12] Compton loss saturates at some energy, depending on the photon energy, but for the 3°K radiation this saturation energy is very much higher than a few hundred GeV and the Compton loss due to starlight is anyway a small fraction of the total loss if the electrons spend most of their life outside the galactic disk.

[13] J. E. Felton, Astrophys. J. 145, 589 (1966).

[14] N. Durgaprasad, in *Proceedings of the International Conference on Cosmic Rays, Jaipur, India, 1963*, edited by R. R. Daniel *et al.* (Commercial Printing Press, Ltd., Bombay, India, 1964-1965) Vol. 3, p. 17.

[15] R. R. Daniel and N. Durgaprasad, Progr. Theoret. Phys. (Kyoto) 35, 36 (1966).

[16] The large uncertainty in the cross sections which are generally used is exemplified by the following: (i) A direct measurement of the cross sections for reaction $p+C^{12}\rightarrow Li^{6,7}$, which has become available recently, gives a value of ~18 mb in the range 50 to 500 MeV of proton energy [R. Bernas, M. Epherre, E. Gradsztajn, R. Klapisch, and F. Yiou, Phys. Letters 15, 197 (1965)] whereas G. D. Badhwar, R. R. Daniel, and B. Vijayalakshmi [Progr. Theoret. Phys. (Kyoto) 28, 607 (1962)] had used for this a value of 40 mb. (ii) Badhwar, Daniel, and Vijayalakshmi (*loc. cit.*) use a value of 48 mb for $p+C^{12}\rightarrow B^{10,11}$, whereas the experiment from which they have derived most of the information of C^{12} fragmentation indicates a value of 118 ± 13 mb; they argue that this value is too high to be correct.

[17] W. R. Webber, J. F. Ormes, and T. Von Rosenvinge, Proc. Int. Conf. Cosmic Rays (London) 1, 407 (1965).

[18] Badhwar, Daniel, and Vijayalakshmi, Ref. 16.

[19] The implications of the arguments presented in this paper for various models of cosmic-ray production and storage will be discussed by Daniel and Stephens in a forthcoming detailed paper (to be published).

SPONTANEOUSLY BROKEN SYMMETRIES AND CURRENT CONSERVATION*

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It is often argued that spontaneously broken symmetry (SBS)[1-3] theories cannot explain the approximate symmetries of hadron[4,5] and high-energy lepton[6,7] physics because the expected conserved currents (and their Goldstone bosons or long-range interactions) are not observed. The purpose of this Letter is to show that this argument is probably incorrect because it appears that a SBS current is in general not conserved.

We consider the quantum electrodynamics of "electrons" and "muons" without bare masses.[8-11] In a two-component notation for the electron-muon field, this theory is invariant under the group SU(2)⊗SU(2)⊗U(1), containing the $\vec{\tau}$, $\gamma^5\vec{\tau}$, and γ^5 gauge transformations.[10] In the Landau gauge, the lowest order Dyson-Schwinger equation for the fermion propagator has finite solutions for which nearly the whole group, the τ_3 symmetry excepted, is spontaneously broken (in agreement with the experimental situation) and for which the mass renormalizations are finite.[10-13] As in the present approximation all renormalizations are finite,[12] we will use the unrenormalized coupling constant and propagators.

Because the field operators are unbounded, one has to define the currents by a limiting procedure.[14,15] We smear out the lepton field operators in the equal-time plane:

$$\psi^{(\epsilon)}(x)=\int f(\vec{x}-\vec{x}')\psi(\vec{x}',x_0)d^3x' \tag{1}$$

with

$$\int f(\vec{y})d^3y=1,$$

and take

$$f(\vec{y})=\epsilon^{-3}\pi^{-\frac{3}{2}}e^{-\vec{y}^2/\epsilon^2},$$

$$\tilde{f}(\vec{p})=\int e^{i\vec{p}\cdot\vec{y}}f(\vec{y})d^3y=e^{-\vec{p}^2\epsilon^2/4}. \tag{2}$$

The details of the smearing function are unimportant, as long as it is spherically symmetric and sufficiently localized. Only relations which remain finite and become independent of ϵ for sufficiently small ϵ will have a physical significance.

Consider the lepton-changing current

$$j_\nu^{(\epsilon)+}(x)=i\bar{\psi}_m^{(\epsilon)}(x)\gamma_\nu\psi_e^{(\epsilon)}(x), \tag{3}$$

m and e denoting muon and electron. The matrix element of the divergence between momentum eigenstates of the muon and electron is