Fig. 2. Rather surprisingly, results obtained with different aerial systems fit in well, with a few exceptions, in the whole frequency range of 18·3–404 Mc/s. Over this very large frequency range the spectral index is calculated, $\beta = 2{\cdot}65 \pm 0{\cdot}15$. Furthermore the shape of the spectrum can best be interpreted to be a straight line with no turnover point down to the frequency of 18·3 Mc/s.

Further observations are planned at a frequency near 10 Mc/s as well as a new scaled aerial series with improved resolution.

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PHYSICS

Fields of Moving Multipoles

IN free space the electromagnetic potential φ^μ of Maxwell's equations is related to the sources of the field j^μ by the equation $\Box\varphi^\mu = j^\mu$. If the source of the field is an arbitrarily moving charge, the retarded solution for φ^μ may be expressed as an integral over the world line of the charge ($z^\mu = z^\mu(\tau)$):

$$\varphi^\mu_{\text{ret}} = 4\pi e \int_{-\infty}^{\infty} \dot{z}^\mu(\tau)\, D_{\text{ret}}(x - z(\tau))\, d\tau \qquad (1)$$

where D_{ret} is the four-dimensional retarded Green's function. Concise expressions for the fields $F^{\mu\nu} = \varphi^{\mu,\nu} - \varphi^{\nu,\mu}$ can then be obtained by differentiating under the integral sign in (1). The same processes may be applied to the calculation of the radiation fields $F^{\mu\nu}_{\text{rad}} = F^{\mu\nu}_{\text{ret}} - F^{\mu\nu}_{\text{adv}}$ (by changing the Green's function) and the method affords an effective means of evaluating the radiation field on the world line of the charge[1]. The latter fields have the value:

$$F^{\mu\nu}_{\text{rad}}(z(0)) = \frac{4}{3} e\, [\dot{z}^\mu \dddot{z}^\nu - \dot{z}^\nu \dddot{z}^\mu] \qquad (2)$$

Recent work[2] has shown how these processes may be extended by methods of induction to arbitrarily moving electromagnetic multipoles. By integrating by parts successively until the Green's function emerges undifferentiated in the integrands and then carrying out the integration, concise and explicit expressions have been obtained for the potentials and fields of a generally moving 2^m-pole. When $m = 1$ the expressions for the fields bear full agreement with those recently found by G. N. Ward[3] for a dipole. By expanding the integrand as a power series in τ the radiation fields have been calculated for a point $x^\mu = z^\mu(0)$ on the world line of the dipole. An interesting special case has been studied when the moment vector of an electric dipole undergoes Fermi–Walker propagation along the world line of the motion. This represents in a relativistic way the notion of a non-rotating dipole. It has been found that the radiation field measured along the world line vanishes for hyperbolic motion in particular, and in general only if the dipole centre suffers constant acceleration ($\ddot{z}^\mu \ddot{z}_\mu = $ const.). A parallel can be drawn here with an accelerating charge. The expression (2) also vanishes for hyperbolic motion.

Although it is not known whether the derived radiation fields for a moving dipole are continuous with the values at events not lying on the world line, they are certainly continuous along it, and for moving 2^m-poles in general, the world line radiation is finite only so long as $m \leqslant 4$, that is, for singlets, dipoles, quadrupoles, octupoles and 2^4-poles. When $m > 4$, this radiation is apparently infinite. The radiation potential φ^μ_{rad} satisfies the homogeneous equation $\Box\varphi^\mu = 0$ everywhere; however, the method used for evaluating the field gives rise to a singularity along the world line. This singularity in $\Box\varphi^\mu_{\text{rad}}$ is removable (finite) when $m \leqslant 3$, but when $m > 3$ it is non-removable there (infinite). It seems worth mentioning that the situation could in some way be a reflexion on the number 3 of spatial dimensions, in the non-degenerate construction of infinitesimal multipoles by means of rigidly connected charges[4] according to the progression: rod, parallelogram, parallelepiped, where alternating charges occupy the positions of adjacent vertices.

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Upper Limits on Galactic Cosmic Ray Antiproton Intensities

KNOWLEDGE of the abundance of antiprotons in cosmic rays and in interstellar space could have important implications for cosmic ray theory, γ-ray astronomy and certain cosmological theories. For these reasons, attempts have been made both experimentally to measure the intensity of antiprotons in cosmic radiation and theoretically to estimate what antiproton densities might be expected in space. A recent communication[1] by Brooke and Wolfendale, which stimulated the calculation presented in this communication, has placed an experimental upper limit of about 5 per cent on the concentration of antiprotons ($\bar{p}$) in the primary cosmic radiation near the Earth with energies of the order of 1,000 GeV.

For theoretical estimates, the sources of $\bar{p}$ which have been proposed are: (*a*) primeval, (*b*) continuous creation, (*c*) cosmic ray collisions. The first two are speculative, but the third source can be estimated. In a previous calculation[2,3] of the production of antiprotons in the galaxy by collisions of cosmic rays with interstellar gas, Fradkin used the Fermi statistical model of high-energy nucleon–nucleon collisions, assumed a power law spectrum for the $\bar{p}$ produced, and assumed that the antiproton lifetime in the galaxy was limited by annihilation. The calculations gave upper limits of 0·05 per cent[3] and 0·04 per cent[2] for the relative concentration of $\bar{p}$ in cosmic radiation having total energies greater than 1·7 and 9·3 GeV respectively. More recently, without giving details, Hayakawa[4] estimates about 10^{-4} for the ratio of antiprotons to protons in galactic cosmic rays.

In the light of more recent laboratory measurements of proton–proton collision cross-sections, and emulsion measurements of the mean amount of interstellar matter traversed by cosmic ray nuclei, it is possible now to improve the basis on which the earlier theoretical estimates of galactic antiprotons were made, although these improved estimates cannot be compared directly with the measurements of Brooke and Wolfendale. We consider here the production of antiprotons in the reaction:

$$p + p \rightarrow p + p + p + \bar{p} \qquad (1)$$