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On the Sidereal Time Variation of the Cosmic Radiation

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If it is supposed that the positive and negative cosmic-ray particles are not equal in number, the resulting space charge will be neutralized by slowly moving ions which should follow the motion of the stars. If the cosmic-ray particles are not isotropic relative to the stellar system, as for example if they do not share the motion of galactic rotation, the relative motion of the slow ions and the cosmic-ray particles of opposite sign produces in effect an electric current. Calculation shows that the resulting magnetic field may become as great as 10^{-1} gauss if there is a considerable difference between the number of positive and negative particles. It is shown that the anisotropy corresponding to even a small sidereal time variation of the cosmic radiation would imply such great magnetic fields as to bend the paths of cosmic-ray particles in curves of radii small compared with interstellar distances. Therefore, the high degree of isotropy of the cosmic radiation is a necessary consequence of the fact that it consists mainly of charged particles and does not tell us anything about the place of origin of the radiation.

THE sidereal diurnal variation of the cosmic radiation is usually considered to be of fundamental importance for the problem concerning the origin of cosmic radiation. Especially, the absence of a marked intensity variation with the position of the Milky Way has been thought to exclude the generation of the radiation within our galaxy. This opinion would no doubt be correct if the cosmic radiation consisted of uncharged particles, which always travel rectilinearly through space. But as it has been shown that at least the main part of the radiation consists of charged particles, we must take into consideration that their path is rectilinear only in the absence of electric and magnetic fields, or in other words, only if the mutual interaction between the particles is negligible.

In interstellar space there is a multitude of charged particles with energies ranging from thermal to cosmic-ray energies. In order to distinguish between the slow particles and the cosmic rays we shall call a charged particle in space a "cosmic-ray particle" if the probability that it is deviated considerably when passing a thin sheet of matter (let us say 0.001 g cm^{-2}) is small. In another case we call it a "slow particle."

As the density of interstellar matter in our galaxy is about 10^{-25} g cm^{-3} the interaction between a cosmic-ray particle traveling for example 10^4 light years ($=10^{22}$ cm), and interstellar matter is negligible. On the other hand the slow particles, most of which are likely to be electrons and ions with thermal energies, collide so frequently with interstellar matter that they must share the motion of this matter, at least to a considerable extent. Thus, in our galaxy the slow particles take part, more or less, in the galactic rotation.

Now the east-west effect indicates that there are more positive than negative particles in cosmic radiation. As Swann[1] has pointed out, an excess of positive particles in cosmic radiation gives rise to an enormous charge in interstellar space if not neutralized by particles of the opposite sign. We must therefore assume that there is an excess of negative slow particles which has almost exactly the same value as the excess of positive cosmic-ray particles.

As now the slow particles within our galaxy take part in the galactic rotation we have (in a fixed system) a rotating negative space charge. If the cosmic radiation is *isotropic in a system moving with the galactic rotation*, it constitutes a positive rotating space charge exactly neutralizing the effect of the negative charge. But if the cosmic radiation is anisotropic in the rotating system, i.e., if on our earth we measure a sidereal time variation, the difference in motion between the positive and negative charge constitutes a current through space. The current density is no doubt very small, but as the cross section of the current is likely to be enormous, the magnetic field of the current is not at all negligible.

In order to show that even a small sidereal time variation of the cosmic radiation gives rise to enormous magnetic fields, let us assume that the

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[1] W. F. G. Swann, Phys. Rev. **44**, 124 (1933).

Compton-Getting theory[2] is correct. For convenience we approximate the galactic system to a uniform circular disk with the radius $R=5\cdot 10^{22}$ cm and the thickness $b=10^{22}$ cm, and which is rotating uniformly with the angular velocity $\omega=10^{-15}$ sec.$^{-1}$. According to Compton-Getting an observer moving with the system and situated at the distance r from the center would measure a relative excess of $4r\omega/c$ particles in the direction of the motion as compared with the opposite direction. If as a mean n negative and $n(1+\eta)$ positive particles (singly charged) hit a unit surface per second, the current density is

$$i=4r\omega n\eta e/c, \text{ e.m.u. cm}^{-2}$$

where $$e=1.6\cdot 10^{-20} \text{ e.m.u.}$$

We assume that our observer finds no other current than this in space and no resultant space charge. This means that the excess of negative slow particles takes part in the galactic rotation and, to an observer in a fixed system, constitutes a current i with the same direction and magnitude (but for a small relativity correction). This is in accordance with the relativity theory: because the resultant space charge is zero (in the moving system) the current in the fixed and in the moving system must be equal to the first approximation ($v \ll c$).

It is now easy to calculate the magnetic field of the current. As the thickness of the disk is small compared with the radius, the magnetic field in the center is approximately

$$H=2\pi\int_0^R \frac{ibdr}{r}=\frac{8\pi n\eta ebR\omega}{c}.$$

Putting $n=0.2$ cm^{-2} sec.$^{-1}$ and $\eta=0.1$, we find

$$H\sim 0.1 \text{ gauss!}$$

Hence, the consequence of a sidereal time variation as predicted by the Compton-Getting theory is that there must exist a magnetic field of the order of magnitude of one-tenth of a gauss in galactic space. This field is strong enough to bend the path of a 10^{10} ev particle to a circle with a radius smaller than that of our earth!

Against this argument may be objected that the excess of positive particles might be smaller than 10 percent ($\eta=0.1$) as assumed here. This objection is quite reasonable as our definition of cosmic radiation also includes smaller energies than those accessible to measurements. Moreover, the magnetic field might be compensated to a certain extent by other currents. But even if for example the positive excess were only 0.001 percent ($\eta=10^{-5}$) and moreover some unknown currents reduced the magnetic field by a factor of let us say 10^{-5}, the field would amount to 10^{-10} gauss, and this is enough to give a 10^{10} ev particle a radius of curvature of only 0.3 light year. As the magnetic field is perpendicular to the galactic plane it is impossible that a certain direction in this plane is favored by an excess of particles; in other words, a sidereal time variation of the Compton-Getting type is impossible.

Even a more local anisotropy of the charged particle component of the cosmic radiation seems to be very improbable. If the relative amplitude of the sidereal time variation is α, and we assume that this anisotropy is constant within a long cylinder with a radius of only 0.1 light year and the axis points in the direction of the anisotropy, the current within this cylinder generates a magnetic field

$$H\sim 4\cdot 10^{-4}\alpha \text{ gauss}$$

at the surface of the cylinder. A measurable sidereal time variation ($\alpha>10^{-4}$) gives a magnetic field $H>4\cdot 10^{-8}$ gauss, so that a 10^{10} ev particle has a radius of curvature of <0.001 light year. This seems to be very improbable.

Consequently, a measurable sidereal time variation of the charged particle component of the cosmic radiation seems to be excluded. The experimentally found sidereal time variation must therefore be due either to a neutral component or, which perhaps is most probable, of secondary origin.

As the isotropy of the cosmic radiation is a mere corollary to the fact that most part of the radiation consists of charged particles, it is impossible to draw conclusions about the place of origin of the radiation from its isotropy. Consequently, the radiation may very well be generated within our galaxy, as predicted by the double star theory.[3]

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[2] A. H. Compton and I. A. Getting, Phys. Rev. **47**, 817 (1935).

[3] H. Alfvén, Zeits. f. Physik **105**, 319, 633 (1937); **107**, 579 (1937); Ark. f. mat. astron. fys. **B25**. No. 29. April (1937).