Cosmic Rays from Supernovae

Among a number of effects which would seem to be capable of generating cosmic rays in supernovae a particularly simple one may here be sketched.

From direct observations we know[1, 2] that the total energy E_t liberated in a supernova outburst is at least 10^{48} ergs to 10^{49} ergs. We may assume with a high degree of probability that in the course of such an outburst the mass M of the original star is split into a number of component parts. It is not essential for our considerations to know the exact details of this fission. For the sake of definiteness we picture M to be divided into a stellar remnant M_1 and an expanding shell of gases of mass M_2, where $M_1+M_2 \cong M$ and $M_2=\gamma M$ with, presumably, $\gamma \geqslant 10^{-4}$.

Since M is made up of electrically charged particles, the two parts M_1 and M_2 cannot be expected to emerge uncharged from the fission. All distributions of atoms, ions and electrons must be admitted as equally probable, as long as the electric potential energy characteristic for these distributions is small compared with E_t. We set $M=Nm_p$ and $M_1=N_1m_p$ where m_p is the mass of a proton. For simplicity we assume that all of the atoms involved are singly ionized. The numbers of the positively and negatively charged particles in the stellar remnant will be, respectively, $n_1^+=Np_1+\delta_1^+$ and $n_1^-=Np_1+\delta_1^-$ where $Np_1=NM_1/M$ is the most probable value of n_1^+ or n_1^-, and δ_1^+, δ_1^- are the actual deviations in a given distribution. The stellar remnant then carries a total charge $(\delta_1^- - \delta_1^+)e$, where e is the charge of an electron. Setting $\Delta=\delta_1^- - \delta_1^+$ we are consequently interested in the value of Δ^2 averaged over all possible distributions of positively and negatively charged particles e over M_1 and M_2. A simple calculation shows that

$$\langle\Delta^2\rangle_{\text{Av}}=4Np_1(1-p_1). \tag{1}$$

The most probable charge on M_1, or on M_2, is therefore

$$\bar{E}=e\langle\Delta^2\rangle_{\text{Av}}^{\frac{1}{2}}=2e[Np_1(1-p_1)]^{\frac{1}{2}}, \tag{2}$$

which has its maximum for $p_1=1/2$, $(M_1=M_2)$, namely

$$\bar{E}_{\text{max}}=eN^{\frac{1}{2}}. \tag{3}$$

With $\gamma=10^{-4}$ we may expect to get a lower limit for E, namely

$$\bar{E}_{\text{min}}=eN^{\frac{1}{2}}/50. \tag{4}$$

If the stellar remnant has a radius R_1, the electric potential between it and the shell of ejected gases is of the order

$$\Phi \geqslant \bar{E}_{\text{min}}/R=e(M/m_p)^{\frac{1}{2}}/50R. \tag{5}$$

We write $M=\mu M(\odot)$ and $R=rR(\odot)$, where $M(\odot)=2\times 10^{33}$g and $R(\odot)=7\times 10^{10}$ cm are the mass and the radius of the sun, and we obtain

$$\Phi=4.7\times 10^6\mu^{\frac{1}{2}}/r \tag{6}$$

or in volts, for $\mu=1$ and $r=1$

$$\Phi \geqslant 300\times 4.7\times 10^6=1.4\times 10^9 \text{ volts}. \tag{7}$$

The breakdown of these potentials will take place at an advanced stage of the supernova outburst when the expanding gaseous shells are of a density sufficiently low to permit the free escape of the initially trapped excess charges. The total electric potential energy $\bar{E}\Phi/2$ turns out to be very small compared with E_t and our assumption regarding equally probable distributions is therefore justified.

Although considerations of the above type appear sufficient to demonstrate that cosmic-ray particles are generated in supernovae, the fact that $e\Phi/2 \ll E_t$, in combination with previously derived results,[1] indicates that the numbers of cosmic-ray particles produced in this way fall far short from accounting for the total observed intensity of the cosmic rays. The discussion of processes in supernovae which can produce a sufficient number of cosmic-ray particles will be given in a more detailed paper.

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[1] W. Baade and F. Zwicky, Proc. Nat. Acad. Sci. **20**, 254 (1934) and **20**, 259 (1934); Phys. Rev. **46**, 76 (1934).

[2] W. Baade and F. Zwicky, Astrophys. J. **88**, 411 (1938).

On the Structure of Solid Solutions

During the last few years quantitative x-ray investigations of crystals have been carried out at the Physical Institution of the University of Helsingfors, Finland. Certain results have been achieved which are of interest with regard to the present theories for mixed crystals and alloys. A short communication of these results is given below.

We consider a mixed crystal (KCl+KBr). An analysis of the experimental results regarding the intensities of the x-ray reflections from different faces of the crystal shows that the actual mean distances of the ions from the theoretical positions in a face-centered lattice cannot be entirely explained by thermal vibrations. Consequently, the actual positions of equilibrium of the ions do not agree with the theoretical lattice points. The mean square of the displacements of the ions, i.e., of the distances from the actual positions of equilibrium to the theoretical lattice points is greater for K than for Cl and Br. The negative results of similar earlier investigations are easily explained. By means of such more or less qualitative investigations it was indeed impossible to detect the displacements in question.

The experimental results may be explained as follows. The structure of the mixed crystal can be realized through the exchange of Cl and Br ions in an originally completely ordered reference lattice, with alternating Cl and Br ions in the directions of the crystal axes. Because of the differences between the forces K-Cl and K-Br, every such exchange causes a displacement of the surrounding K ions and this displacement is transmitted to all ions in the lattice as a waning long distance disturbance. This long distance disturbance results in a certain average displacement of the ions, the mean square of which may be denoted by $\langle t^2\rangle_{\text{Av}}$. However, a K ion is surrounded partly by Cl and partly by Br ions. This asymmetry among the neighbors causes a local displacement, s, of the K ions, which appears also in the completely ordered reference lattice, where $\langle t^2\rangle_{\text{Av}}=0$. As regards direction, this local displacement is independent of the long distance disturbance. The total mean square of