G. E. Kocharov. *New data on the generation of nuclear particles and radiations during solar flares.*
a) *Solar flares rich in helium-3.* The chief distinctive feature of the class of solar events under consideration is exceptionally strong enrichment of the solar cosmic rays in the rare isotope helium-3. The coefficient of enrichment in helium-3 with respect to helium-4 may even range up to 10^4. There is only one known possible cause for such strong enrichment, and it is based on preferential preacceleration of helium-3 by plasma effects.[1-3] According to the model developed, an electric field appears on intrusion of hot electrons into the cold chromospheric plasma after they have been accelerated in the flare, and a cold-electron current inevitably re-

sults. If the number of high-energy electrons is so large that the current velocity of the cold electrons is higher than the velocity of sound, ion-acoustic turbulence arises in the plasma. High-energy ($E \geq 20$ keV) electrons cross the ion-acoustic front without scattering and, in the region ahead of the front, form a beam that generates Langmuir turbulence efficiently. This turbulence damps rapidly, sharply heating the electrons of the cold plasma. Thus, the ion-acoustic front propagates through a medium that is highly nonisothermal. The ions of the surrounding plasma interact intensively with the ion-acoustic turbulence and are preaccelerated in the process. What is noteworthy here is that the rate at which the ions are heated depends on their charge (Z) and mass (A) and is proportional to $a = Z^4/A^2$, i.e., protons and helium-4 nuclei are heated at the same rate ($a = 1$), while helium-3 is heated more rapidly ($a \approx 1.8$). Enrichment in helium-3 in the superthermal-velocity region occurs as a result. If an accelerating mechanism begins to operate in this region, the fraction of accelerated helium-3 nuclei will be larger than the fraction of accelerated helium-4. The preference for helium-3 will be stronger the higher the threshold velocity (v_{th}) of the accelerating mechanism. If the velocity of sound is taken as v_{th}, the coefficient of enrichment in helium-3 relative to helium-4 will increase with increasing departure from isothermal conditions.

It has been possible to explain all the basic properties of helium-3-rich flares within the framework of the theory of preferred helium-3 preheating: the high ratio of the helium-3 and helium-4 fluxes and the absence of detectable deuterium and tritium fluxes are explained without effort in the framework of plasma theory; experimental data indicate that the coefficient of enrichment in helium-3 with respect to helium-4 decreases with increasing proton and helium-3 nucleus fluxes in accordance with $I(\mathrm{p})^{-0.4}$ and $I(^3\mathrm{He})^{-0.8}$. The plasma theory predicts precisely such a relationship; according to the proposed model, helium-3-rich flares should be accompanied by x-ray and microwave emission. A quantiative relation between the absolute and relative helium-3 and helium-4 fluxes and the flux of x-ray and microwave radiation is predicted. Analysis of all available data indicates that such a relationship does indeed exist. This is of fundamental importance, since it demonstrates a genetic relation between the accelerations of electrons and heavy particles; the plasma mechanism also explains in principle the simultaneous enrichment in heavy nuclei that is observed in experiments, but the specific theory has not yet been worked out. An important prediction of the theory is emission of the helium-3 preheating region in the He II line. Registration of this line would make it possible to see the helium-3 preheating region directly.

b) *Solar γ quanta.* Highly interesting results were obtained in experiments under the Solar Maximum Year program in 1980. Here our chief interest will be in results on x-ray and gamma radiation from the solar flare of 7 June 1980.[4,5]

Analysis of the available data[4-5] points to the following conclusions: there were series of pulsed bursts at the beginning of the event (at about 03^h12^mUT) for all energy ranges from 10 to 350 keV, which were measured with high time resolution (1.02 sec). The first series lasted approximately 70 sec. There were seven subpulses to a series. The percentage modulation was ~4. In addition to the first series, there were two more at 03^h14^mUT and 03^h16^mUT. Comparison of the relationships for the low-energy (≤ 20 keV) and high-energy (≥ 20 keV) x-rays indicates that a slow component was present at low energies and vanished at high energies. This component was evidently of thermal nature. The 4.1–6.5 MeV energy range, which covers the instantaneous gamma lines at 4.43 and 6.15 MeV, was also subject to deep modulation, like the γ rays, at least for the first five bursts.

Thus, high-energy electrons and ions interact simultaneously with the solar atmosphere (within 1 sec) with several subpulses, each of 4-sec duration and with a quasiperiod of 10 seconds between subpulses. This can be explained naturally in terms of an acceleration process that accelerates electrons and ions simultaneously or with a delay of less than 1 sec. This is the most unexpected result. It comes as a surprise in light of the prevailing opinion that a delay (of several minutes) between the instantaneous gamma quanta and the x-radiation had been established experimentally for the solar flare of 4 August 1972. More careful analysis indicates that this was not so. In the flare of 4 August 1972, the intensities of the x-ray, microwave, and gamma radiations all began to increase at the same time. There was a front-time difference, i.e., the gamma intensity built up more slowly. It was pointed out in Ref. 6 that this difference can be explained under the hypothesis of simultaneous acceleration of electrons and heavy particles if the gamma quanta were generated in a region with relatively low particle concentration (for example, 10^9–10^{10} cm^{-3}). Looked at in this way, the rise time of γ-ray intensity decreases with increasing density of the medium, approaching the x-ray rise time (flare of 7 June 1980). We note that the bulk of the accelerated protons escaped into interplanetary space for the flare of 4 August 1972,[7] while only a small fraction of the protons departed the sun in the 7 June 1980 flare.[8] These data are also evidence in favor of the possibility considered above, since γ rays were generated in a region with low density in the flare of 4 August 1972 and in a region of high density in the case of the 7 June 1980 flare.

The possibility examined above does not, of course, mean that the electrons and protons must be generated simultaneously in all flares. We wished only to stress that simultaneous acceleration is a real possibility and that there is no basis for accepting a long time delay between the accelerations of electrons and heavy particles.

The congruence of the x-ray and γ-radiation profiles in the flare of 7 June 1980 indicates that the protons and electrons were accelerated at about the same time and place. The relation between the acceleration of protons that produce γ radiation and the electron fluxes is also confirmed by analysis of the ratio of the proton and

relativistic-electron fluxes observed in interplanetary space.[9]

Thus, the situation resembles that encountered in the helium-3-rich flare, both in the localization of the acceleration region of the protons that produce γ radiation in the sun's atmosphere and in the coupling between the acceleration of these protons and the acceleration of the electrons. In this model, the total number of accelerated particles decreases as the threshold of injection of particles into the acceleration regime rises, and the number of gamma quanta generated decreases accordingly, but the coefficient of enrichment in helium-3 becomes higher. Conversely, the lower the threshold, the greater will be the numbers of accelerated particles and gamma quanta, and the lower will be the coefficient of enrichment in helium-3. Naturally, all these qualitative arguments require quantitative scrutiny and analysis of all their consequences.

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