NONTHERMAL PROCESSES IN LARGE SOLAR FLARES

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Summary. In many small solar flares the $\sim$10–100 keV electrons accelerated during the flash phase contain the bulk of the total flare energy output. In large flares, such as those in the period 1972, August 2–7, the flash phase electrons are present in substantially greater numbers. These electrons can explosively heat the chromosphere-lower corona and eject flare material. The ejected matter can produce a shock wave which will then accelerate nucleons and electrons to relativistic energies. We analyze energetic particle, radio, X-ray, gamma ray and interplanetary shock observations of the 1972 August flares to obtain quantitative estimates of the energy contained in each facet of these large flares. In general these observations are consistent with the above hypothesis. In particular:

(1) From the X-ray emission (van Beek *et al.*, 1973) the energy contained in >25 keV electrons is calculated to be $\gtrsim 2 \times 10^{32}$ erg for the 1972, August 4 event. Since the lower energy cutoff to the electron spectrum is known to be below 25 keV and possibly below 10 keV, the electrons contain enough energy to produce the following interplanetary shock wave, which has by far the bulk of the energy dissipated in the flare. Similar numbers are obtained for the large August 7 flare event.

(2) From the γ-ray emission (Chupp *et al.*, 1973) the energy in protons dumped at the same level of the atmosphere, assuming a thick target situation, is at least a factor of three smaller than the electrons. Moreover the γ-ray emission indicates that the bulk of the protons are accelerated at least several minutes after the electrons. Thus it is more likely that the electrons are responsible for the flare optical (Hα and white light) emissions which occur in the chromosphere.

(3) Approximately 5% of the electrons and $\gtrsim$99% of the protons escape into the interplanetary medium to be observed by spacecraft. This situation is consistent with the hypothesis of shock acceleration of the protons high in the solar corona.

(4) The four most intense X-ray bursts observed during the period July 31–August 11 are the only bursts followed by an interplanetary shock wave and a new injection of energetic protons into the interplanetary medium.

We conclude that the energy source for the interplanetary shock wave and ejected material is the collision loss of the flash phase electrons in the solar atmosphere, and that the energetic protons are likely to be accelerated by the shock wave. Since $\sim 10^{33}$ erg are likely to be contained in the electrons, that is, the bulk of the total flare energy and the equivalent of total conversion of 500 G in a volume of 10^{29} cm^3, it is clear

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that the basic flare mechanism must be able to convert with high efficiency magnetic field energy into fast electrons during the flash phase.

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References

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