From the knowledge that these solar cosmic rays are stored, and from a determination of particle flux incident at the top of the atmosphere over the lifetime of storage, we determine the lower limit for the total kinetic energy in solar produced cosmic rays as $> 10^{30}$ ergs. The steep spectrum in Fig. 2 emphasizes that the main contribution is from particles $\leqslant 2$ BeV, or that $> 3 \times 10^{32}$ relativistic particles were produced and *not* captured by the Sun. Independently various estimates by Parker and others for the total energy released at the flare site based upon observed 'white light' or Hα emission yields $\geqslant 10^{32}$ ergs. Thus relativistic particle production is $\leqslant 1\%$ efficient.

From the volume of the optical flare it is clear that the average energy density available for the flare process exceeds 10^3 ergs/cm^3. Since such a high energy density cannot be created by drawing energy from surrounding regions of the Sun at the time of the flare, this energy must have been *in situ* prior to the flare. The only known energy storage is by magnetic fields. For fields of the order 10^3 gauss, only a portion of the field need be destroyed to provide the necessary energy. (At this conference Severny has shown striking magnetograph evidence for the partial destruction of magnetic fields which occupied the region of a flare.)

The acceleration of the particles in the unstable magnetic fields within the flare remains a major problem, although the Fermi mechanism is the most likely mode. A decision in this matter will come from a study of future flare cosmic ray increases to determine whether He^{++}, carbon, and heavier stripped nuclei are also accelerated to high energies in flares.

Although a solar origin for *all* low-energy cosmic rays is unlikely because of the observed short storage times in the solar system, there remains the question of whether the solar-flare effect contributes a sufficient yield of particles to the galaxy to be typical of the average injection required by stars for sustaining the galactic level of cosmic radiation. From a total kinetic energy for cosmic rays in the galaxy of approximately 10^{55} ergs, an 'average' star must inject nearly 5×10^{28} ergs/second in cosmic rays. The solar flare output is too small by a factor exceeding 10^6. Thus, if particle injection to the galaxy is by a flare mechanism, the Sun is not a typical injector. However, flares may not be the only possible mode of injection by the Sun.

3. DISCUSSION

REMARKS BY T. GOLD

The new results obtained by Van Allen in the U.S. and by U.S.S.R. scientists with the aid of satellites have much relevance to the discussion of magnetic storms and aurorae, and so has the new knowledge obtained by means of the cosmic ray investigations.

Van Allen concludes that there exists a flux of mean energy at least of the order of 10 ergs/cm^2 in the form of particles, probably both electrons and protons, mostly of the order of 50 keV particle energy but with a spectrum extending to several MeV. This flux commences at a height of 400 km and reaches the quoted intensity at the maximum height of the observation, namely 1600 km. At this height the intensity is still increasing with height, and therefore even higher values of the flux are expected. To date the observations have not been carried out for long enough to know much about variations in time; but as the flux is similar to that observed in the auroral regions at a lower level it is very tempting to think of this as associated with the auroral phenomenon, and thus variable in intensity. The occurrence of a bright aurora may then be caused by the flux being temporarily augmented and reaching down to lower levels.

Particles of this sort can be stored in the Earth's field, for there is a family of captured, stable orbits that go from one hemisphere to the other spiralling around the lines of force, and that suffer reflexion in the converging field at a height such that collisions with atmospheric gases is inappreciable. An intensification of such a flux of captured particles would account for the auroral phenomenon. But it is necessary to find the mechanism whereby particles can be put into these orbits.

The suggestion of a secondary cosmic ray process would not meet the case, for then the intensities would be adequate only if the storage times were very long—contradicted by diurnal variations in the flux that have been reported by the Soviet scientists, and, of course, there would be no relation with aurorae.

The requirements are met if one supposes the solar streams that are responsible for aurorae and magnetic storms to cause substantial deformations of the far part of the Earth's field. The small scale of the magnetic disturbances on the Earth in any case forces one to assume an unstable flow where some places are treated very differently from others with fluctuations in the range from one minute to one hour. If this unstable flow is in the form of tongues that penetrate to a height of a few hundred kilometres frequently, then access would be created through them into the otherwise confined orbits. The solar material must draw out what magnetic field threaded it and was anchored in the Sun (and this indeed is also the picture required for the explanation of the cosmic ray events). From this very elongated field in the Earth–Sun space some small tongues in turn stretch in to within a few hundred kilometres of the Earth's surface. All this region therefore becomes accessible to any fast charged particles that may be available on the Sun. These observations would then be an indication of the solar output of such particles.

Within this set of ideas a natural explanation is found for the average behaviour of magnetic storms during what is called the 'main phase'. There the field strength on the Earth is diminished, and remains depressed for several days. The stable magneto-hydrostatic shapes into which the field can be deformed by gas pressure from its normal curl-free configuration are all of the sort that diminish the surface field, and that 'blow up' and distend the field. An overall compression could only be achieved by a gas whose weight was significant, and this is not the case here. Therefore any 'excited state' in which the Earth's field may be left after a storm will be of the observed sort with a weakened surface field. This state of a magneto-hydrostatic but not curl-free field can best be set up by an expansion of the conducting gases of the outermost atmosphere due to heating. The energetic particle flux of which we are now aware would seem to be the dominant source of heat for this region and rough calculations indicate that it is quite adequate. The decay of the system to the unstressed, curl-free state most probably occurs both through cooling and through dissipation due to the resistivity of the currents responsible for the stressed condition. Both time constants may well be about one day.

REMARKS BY J. A. SIMPSON

In considering the possible origins for the low-energy charged particle radiation recently detected by the Explorer satellites, I wish to point out that there are at present three major possibilities:

(*a*) Albedo effects from the interaction of cosmic rays with the Earth's atmosphere lead to μ-mesons decaying to give electrons and neutrinos—an idea proposed by Neher. More recently slow neutrons which decay in the geomagnetic field to yield protons plus electrons and neutrinos have been suggested by Vernov and others.

(*b*) Particles might be accelerated in the vicinity of the Sun and propagated or transported to the Earth by magnetized clouds or an extension of solar fields which somehow interlink at appropriate times with the geomagnetic field as suggested by Van Allen and Gold.

(*c*) Particles, especially protons, may be accelerated in the vicinity of the Earth by a Fermi mechanism arising from the motions of the magnetic fields derived from the interaction of plasma clouds with the geomagnetic field or, according to Parker, possibly by the solar wind and the geomagnetic field.

The first possibility, (*a*), does not appear promising for the entire effect, due to energy requirements and storage times. Evidence just reported this past week from Explorer IV points towards the existence of high-energy radiation which would not be produced by neutron decay; therefore, at present, possibilities (*b*) and (*c*) are the most likely candidates for the origin and it is most important in forthcoming satellite observations to attempt a decision between these.

REPLY BY T. GOLD

I agree with Dr Simpson that the other possible modes of generation of these energetic particles must be investigated also. I consider the μ-meson decay idea to fall short by a substantial factor, but all injection mechanisms that draw on secondaries from cosmic rays will suffer from the difficulty that a high efficiency and very good storage would be required, because a flux of some hundreds of times the energy content of the cosmic ray flux has to be explained; in terms of particle number the enhancement is very great indeed, of order 10^7. For this reason I think the interpretation in terms of a general solar flux that gains access through suitable configurations of the field at present the most promising. This interpretation agrees with other considerations of the magnetic storm process, and it would allow one to identify an enhancement of this stored flux with the condition that gives rise to aurorae.

So far as the time constants of the decay of a distended magnetic field of the Earth are concerned there is no difficulty in accounting for the observed one of about one day, given by the rate at which the field strength recovers after a disturbance. The individual tongues that stretch in to allow the penetration of gas are of course of much shorter duration, as is shown by the auroral display.

4. THE INHOMOGENEITIES OF SOLAR CORPUSCULAR STREAMS

M. S. BOBROV

As a rule, a typical geomagnetic record obtained near the auroral zone during a magnetic storm shows some separate groups of peaks with intervals between them which are practically the records of an undisturbed field [1].

We consider this picture as observational evidence of the inhomogeneous structure of solar corpuscular streams in the vicinity of the Earth. From this point of view the magnetic storm is caused by a bombardment of the auroral zones and adjacent regions by clouds of solar plasma with some magnetic field frozen into it.

The approach of such a cloud to the point of observation causes a strong peak on the magnetogram.

This conception permitted us to estimate the following quantities:

(1) the number Z of the clouds per unit of time penetrating the ionosphere in the zenith of the point of observation;

(2) the size r of the clouds (by variation of the intensity and phase of disturbances with distance, see [2] and [3]);

(3) and (4) the volume density ρ_V of the clouds in the corpuscular stream and the mean distance R between the clouds.

For the moderate magnetic storm of 1953 November 11–21, with gradual commencement, we obtained the following: $Z \simeq 2\cdot 10^{-4}$ sec^{-1}; $r \simeq 100$–300 km, $\rho_V \simeq 10^{-4}$; $R/r \simeq 40$.

REFERENCES

[1] Nikolsky, A. P. *Terr. Magn. Atmos. Elect.*, 1947.

[2] Pudovkin, I. M. *Izv. Acad. Sci. U.S.S.R., geophys. ser.*, 1956 N 7, 835.

[3] Alexandrov, Pudovkin and Janovsky, report presented at the 5th Meeting of C.S.A.G.I. (Moscow, August 1958).