primary source of all cosmic radiation. The particles of the cosmic rays would then represent a sample of ions taken from the edge of the solar corona, and since even relatively heavy elements exist there in a highly ionized state these heavy particles would be accelerated as effectively as protons.

Accepting tentatively the assumption that trapping of ions takes place, one can then proceed in two ways. One can suppose that no further acceleration takes place, and that the observed steady flux represents an average of all the "solar flare" particles emitted for the past few million years, with the electrons removed by radiative losses and by the inverse Compton effect. This would imply that some flares cause waves intense enough to accelerate the highest energy particles observed. (If the orbits are distributed uniformly throughout a sphere of radius 50 times the earth-sun distance, the mean life for capture by the planets is about 6 million years. Capture by the sun, if allowed by the solar magnetic field, would reduce this by a factor of 50. Capture by meteoritic matter, because of the large cross section per unit mass of finely divided material, could be even more important but is hard to estimate.)

The second possibility is that the circulating ions receive further acceleration by subsequent passages through "wave bubbles." One bubble with a diameter of 10 wave-lengths of 10-cycle radiation would have a cross section about twice that of the combined planets. The frequency of occurrence of bubbles cannot be inferred from the observed cosmic-ray intensity increases, since they may not all contain waves intense enough to cause such increases, and may not all eject particles in a suitable direction for observation at the earth. Therefore a reasonable estimate of the chance for an ion to undergo repeated traversals through strongly accelerating regions, with an average cumulative gain in energy, cannot be made. Nevertheless a cumulative process for the production of the very highest energies is attractive, and if the regions of strong acceleration are not sufficiently numerous, another source of cumulative acceleration may be found in the action of the non-radiative magnetic fields of the solar corona.

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The Extraordinary Increase of Cosmic-Ray Intensity on November 19, 1949

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Four sudden increases in cosmic-ray intensity associated with solar flares or chromospheric eruptions have so far been observed during more than a decade of continuous registration of cosmic-ray intensity. The last and largest of these increases occurred on November 19, 1949, when such an effect was recorded for the first time at a mountain station at Climax, Colorado. Here the intensity increased to about 200 percent above normal in half an hour. At the sea-level station at Cheltenham, Maryland, the increase was about 43 percent. No increase occurred at the equator. From the increase in the effect with altitude and latitude, it is concluded that the increase was due to the nucleonic component produced by relatively low energy primary charged particles probably accelerated by some solar mechanism.

THE sudden increase in cosmic-ray intensity which began at 10^h45^m GMT, November 19, 1949, was the largest yet recorded during more than a decade of continuous registration of cosmic-ray ionization at several stations (see Table I). Only three other unusual increases had been previously recorded.[1] These occurred on February 28, 1942, March 7, 1942, and July 25, 1946. All were registered with Compton-Bennett ionization chambers completely shielded with 12-cm Pb. Three of the increases began during intense chromospheric eruptions or solar flares.[1] While no solar flare was actually observed during the increase of cosmic-ray intensity on March 7, 1942, a radio fadeout occurred very near the time the increase in cosmic-ray intensity began. The fadeout, which occurred only on the daylight side of the earth, quite definitely indicates the existence of a solar flare.

The terrestrial-magnetic effect of such solar flares is

TABLE I. Location and elevation of Compton-Bennett cosmic-ray meters.[a]

Station	Latitude (degrees)	Longitude (degrees)	Geomagnetic latitude (degrees)	Elevation (meters)	Operation began
Godhavn, Greenland	69.2 N	53.5 W	79.9 N	9	October, 1938
Cheltenham, Maryland	38.7 N	76.8 W	50.1 N	72	March, 1935
Climax, Colorado	39.4 N	106.2 W	48.1 N	3500	
Teoloyucan, Mexico	19.2 N	99.2 W	29.7 N	2285	February, 1937[b]
Huancayo, Peru	12.0 S	75.3 W	0.6 S	3350	June, 1936
Christchurch, New Zealand	43.5 S	172.6 E	48.6 S	8	June, 1936

[a] 12-cm Pb shield around all meters, except that the meter at Climax had, in addition, a slab of Fe 16.5 cm thick directly over the meter.
[b] Not operating after 1945.

[1] S. E. Forbush, Phys. Rev. 70, 771 (1946).

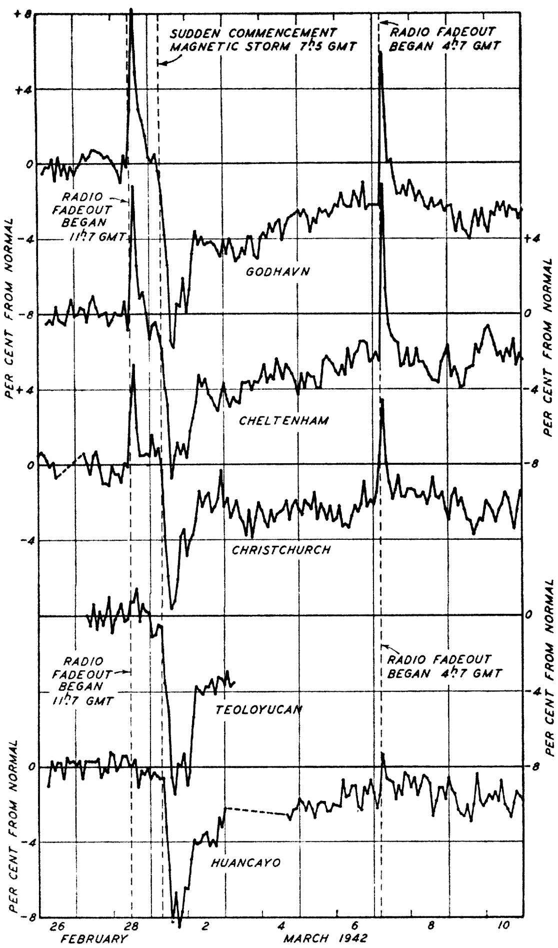

FIG. 1. Increases of cosmic-ray intensity, February 28 and March 7, 1942.

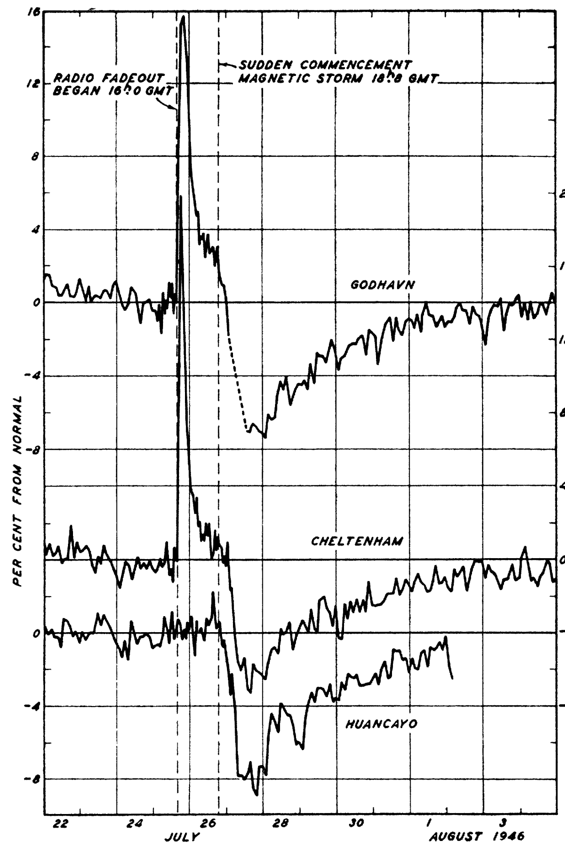

FIG. 2. Increase of cosmic-ray intensity, July 25, 1946.

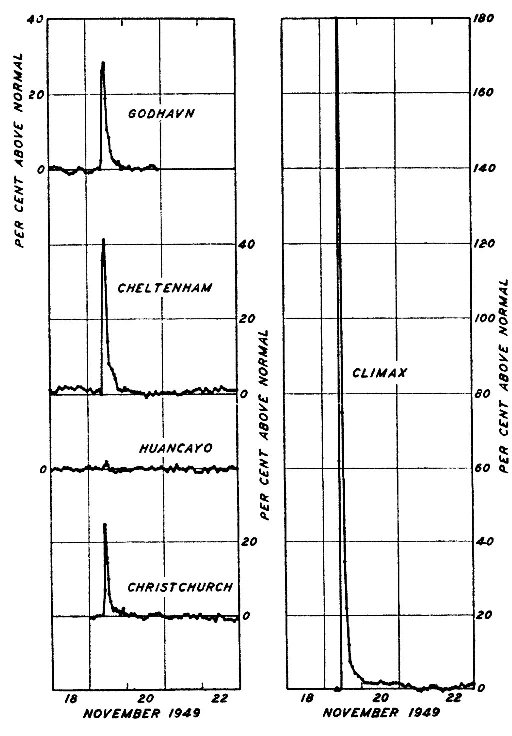

FIG. 3. Increase of cosmic-ray intensity, November 19, 1949.

an increase, on the daylight side of the earth, in the normal diurnal variation in the earth's field.[2] The known small diurnal variation[3] in cosmic-ray intensity excludes the possibility that the increases were due to changes in the earth's external magnetic field resulting from an augmentation of the magnetic diurnal variation. The evidence thus indicates[1] that the four increases in cosmic-ray intensity were probably due to charged particles accelerated by some mechanism[4] on the sun. Unless the particles responsible for the increases were charged, it would be difficult to explain either the simultaneous occurrence of the increases on both the daylight and dark hemispheres or the absence of the increases at the equator.

The sudden increases in cosmic-ray intensity on February 28 and March 7, 1942, are shown in Fig. 1, in which the curves are drawn through the bihourly means, after correcting these to constant barometric pressure. It is evident that neither increase occurred at

[2] A. G. McNish, Terr. Mag. **42**, 109 (1937).
[3] S. E. Forbush, Terr. Mag. **42**, 1 (1937).
[4] Forbush, Gill, and Vallarta, Rev. Mod. Phys. **21**, 44 (1949).

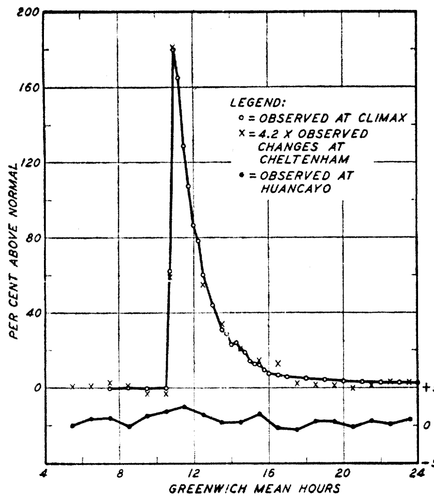

FIG. 4. Cosmic-ray intensity, November 19, 1949.

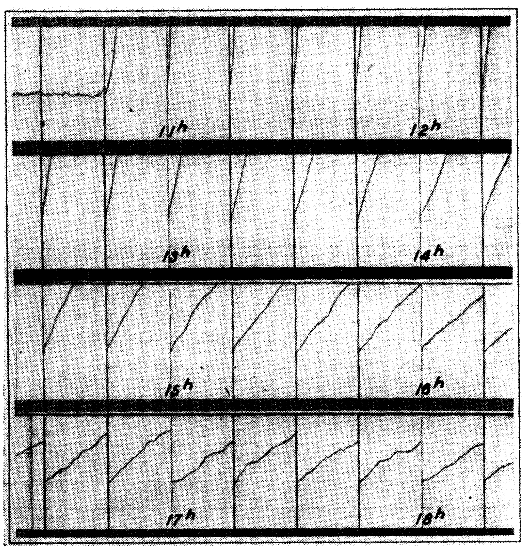

FIG. 5. Cosmic-ray records for Climax, Colorado, showing increase beginning at 10 hr. 45 min. GMT, November 19, 1949.

Huancayo and that the increase on February 28 did not occur at Teoloyucan. The decrease in cosmic-ray intensity during the magnetic storm following the sudden commencement on March 1 is evident at all the stations. The sudden increase in cosmic-ray intensity on July 25, 1946, is shown in Fig. 2. No data for this period were available from the other stations in Table I. Again, no increase occurred at Huancayo although the decrease during the subsequent magnetic storm is evident there.

The sudden increase in cosmic-ray intensity at the time of the solar flare on November 19, 1949, is shown in Fig. 3. This is the first instance when an increase in bosmic-ray intensity accompanying a solar flare has ceen recorded at a mountain station and at sea-level stations. The increase, in percent of the total cosmic-ray ionization, is obviously very much greater at Climax than at Cheltenham. In fact, if the ordinates on the curve showing the increase at Cheltenham are multiplied by 4.2, the resulting points, shown in Fig. 4, lie on the curve for Climax. It may also be noted in Fig. 3 that the increase on November 19 was not followed by a decrease in cosmic-ray intensity during the magnetic storm which began about 18^h GMT on November 19.

The rapid increase on November 19, 1949, is evident beginning at 10^h45^m GMT in Fig. 5, which is a reproduction of part of the cosmic-ray record for Climax on that date. The electrometer is grounded every 15 min. The large increase in intensity caused the image of the electrometer needle to go off scale during the first few minutes in several of the 15-min. intervals. Departures of cosmic-ray intensity from the balance-value (electrometer trace horizontal) in percent of the total intensity are obtained by multiplying the slope by 9.8.

Figures 6 and 7 permit more detailed comparison of the solar-flare effects observed at several stations than

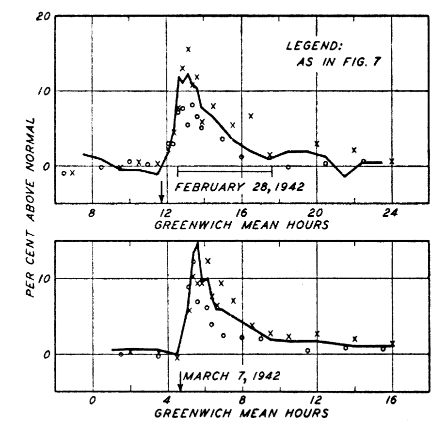

FIG. 6. Increases in cosmic-ray intensity during two solar flares, for different stations.

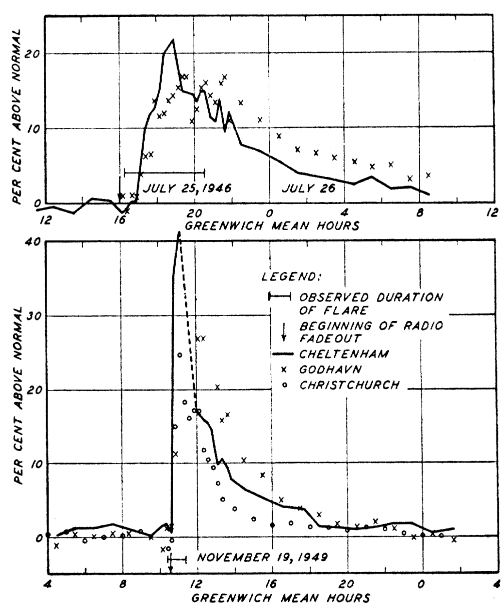

FIG. 7. Increases in cosmic-ray intensity during two solar flares, for different stations.

is possible in Figs. 1, 2, and 3. The observed durations of the solar flares are also indicated as well as the times of commencement of the radio fadeouts.

In addition to complete shielding by 12-cm Pb, the meter at Climax was under a rectangular iron shield 4 ft. long, 1 ft. wide, and 16.5 cm thick. The absorption mean free path for nucleons of medium energy in iron is approximately 240 g cm^{-2}. Taking the dimensions of the shield into account and figuring the zenith angle distribution for a radiation exponentially absorbed with an absorption coefficient of about 145 g cm^{-2}, it is estimated that the increase at Climax on November 19, 1949, would have been 15 percent greater without the iron shield. Thus it is estimated that the maximum of the increase on November 19 at Climax would have been about 207 percent without the iron shield, instead of the uncorrected 180 percent as shown in Figs. 3 and 4. This correction also results in a factor of 4.8 for the ratio of the percentage increase at Climax on November 19 relative to that at Cheltenham, instead of 4.2 as is indicated in Fig. 4.

Since the total ionization at Climax (under 12-cm Pb) is about 2.5 times that at Cheltenham, and since the percentage increase on November 19, 1949, was about 4.8 times that at Cheltenham, the actual magnitude of the increase on that date at Climax was about 12 times greater than at Cheltenham. Since the difference in the atmospheric layer is equivalent to 340 g cm^{-2}, the radiation responsible for the increase during the flare has an absorption coefficient of about 137 g cm^{-2}. This is just about the rate at which the nucleonic component, responsible for star production, increases with altitude.[5] The increase in total ionization under 12-cm Pb by a factor of 2.5 from Cheltenham to Climax is mainly due to mesons. It is thus evident that the magnitude of the flare effect increases too rapidly with altitude to be ascribed to ordinary mesons. The latitude effect in chambers under 12-cm Pb, due principally to mesons, is small, whereas the flare effect exhibits a strong dependence on latitude (being zero at the equator). This also indicates that ordinary mesons contribute negligibly to the flare effect.

The results of Conversi[6] and those of Simpson[7] on the latitude variation of the proton and neutron intensity suggested that the cross section for nucleon production relative to that for meson production decreases rapidly with increasing energy of primary particles. This is in accord with the conclusion that the increase in intensity during the solar flare of November 19, 1949, was due principally to the nucleonic component or to local radiations originating from it, and not to ordinary mesons.

At Climax, under 12-cm Pb, probably not more than about 10 percent of the total ionization is normally due to local radiation originating from the nucleonic component. If we assume that this radiation is produced entirely by particles in the same band of energy as those responsible for the increase of 207 percent in ionization on November 19, 1949, then the number of primary particles, reaching there per unit time, in that band of energy, must have increased to at least 20 times the normal value.

Three sets of triple coincidence counters and one set of fourfold coincidence counters, located above the meter at Climax and arranged to record air showers, were in continuous operation during the period of the increase in ionization on November 19, 1949. There was no evidence of any significant increase in the rate of air showers during this period.

[5] J. J. Lord and Marcel Schein, Phys. Rev. **75**, 1956 (1949).

[6] Marcello Conversi, Phys. Rev. **76**, 444 (1949).

[7] J. A. Simpson, Jr., Phys. Rev. **76**, 569 (1949).

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Ratio of Cross Sections for Electron Capture and Electron Loss by Proton Beams in Metals

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Measurements have been made of the ratio of the charged to the neutral component (protons to hydrogen atoms) in hydrogen ion beams of energies between 20 and 400 kv, passing through the metallic media beryllium, aluminum, silver, and gold. The data show that this ratio is the same, within the accuracy of the experiment, for the three lighter elements, but is slightly less in gold above 100 kv. The curves depicting this ratio as a function of ion speed cannot be fitted by a power law over the entire energy range, but the high energy end of the data can be fitted fairly well in this way. At 350 kv, the slopes correspond to a dependence on ion speed v of the form v^9 in the case of the lighter elements, and v^7 in the case of gold.

The cross sections for electron capture and electron loss are found to be equal at an ion energy of 26 kv. The ion then has a speed 0.95 times that of the hydrogen orbital electron ($e^2/\hbar$).

I. INTRODUCTION

FOR several reasons there is interest in the capture and loss of electrons by light ions as they pass through matter: the phenomena themselves are fundamental atomic processes; the charge of these ions influences their slowing down; and furthermore, in the case of the light ions it is possible to test present ideas about electron capture and loss which apply to the

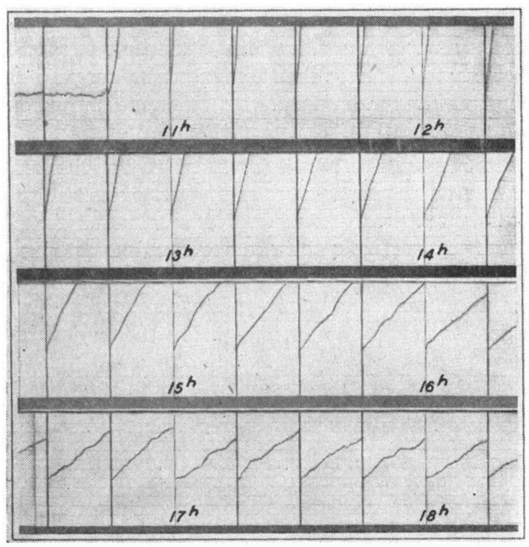

FIG. 5. Cosmic-ray records for Climax, Colorado, showing increase beginning at 10 hr. 45 min. GMT, November 19, 1949.