In addition to the data presented in Figs. 1 and 2, we have measured the corresponding differential cross sections for $B^{10}(\alpha,p)C^{13}$ ground state,[4] $Na^{23}(\alpha,p)Mg^{26}$ first excited state, and $Al^{27}(\alpha,p)Si^{30}$ first excited state.[5] Qualitatively different from the other results are the $C^{12}(\alpha,p)N^{15}$ ground-state results.[4,6]

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[1] S. T. Butler, Phys. Rev. **106**, 272 (1957).
[2] W. B. Cheston and A. E. Glassgold, Phys. Rev. **106**, 1215 (1957).
[3] C. A. Levinson and M. K. Banerjee, Bull. Am. Phys. Soc. Ser. II, **2**, 229 (1957).
[4] C. E. Hunting and N. S. Wall, Bull. Am. Phys. Soc. Ser. II, **2**, 181 (1957).
[5] Reported orally at 1957 Washington meeting of the American Physical Society in conjunction with reference 4.
[6] R. Sherr and M. Rickey, Bull. Am. Phys. Soc. Ser. II, **2**, 29 (1957).

Large Auroral Effect on Cosmic-Ray Detectors Observed at 8 g/cm² Atmospheric Depth*

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We have observed a large increase in the rate of a single Geiger counter and ionization chamber at high altitude during an intense auroral display on July 1, 1957, at Minneapolis. The equipment was operating at 8 g/cm² atmospheric depth on a constant level plastic balloon when the aurora began at about 0330UT. A large initial burst occurred (see Fig. 1), lasting about ten minutes, followed by a second, less intense, of about fifteen minutes duration and a third, still less intense, peaked at 0420UT. Fluctuations were seen until 0630UT in both instruments. The large initial effect was associated with auroral arcs near the zenith, and the increases in rates were roughly correlated with visual observations of increased brilliance near the zenith. (See arrows in Fig. 1.) It was also observed that strong auroral curtains and other phenomena continued in the north after the instruments had returned to normal cosmic-ray rates. The relative increase is much larger in the ionization chamber, which is of the integrating type containing argon at 8 atmospheres pressure, although the pattern of bursts is similar in both instruments. A clue to the type of radiation causing the increase may be obtained by plotting the ratio of the two instruments which give the relative mean ionization per count (upper graph of Fig. 1). This ratio has the value 0.2 as the balloon rises through the atmosphere from about 0100 (launch) to 0230, and increases to 0.26 above the single counter maximum. The value 0.2 is characteristic of fast singly-charged particles in the lower atmosphere, while the increase at higher

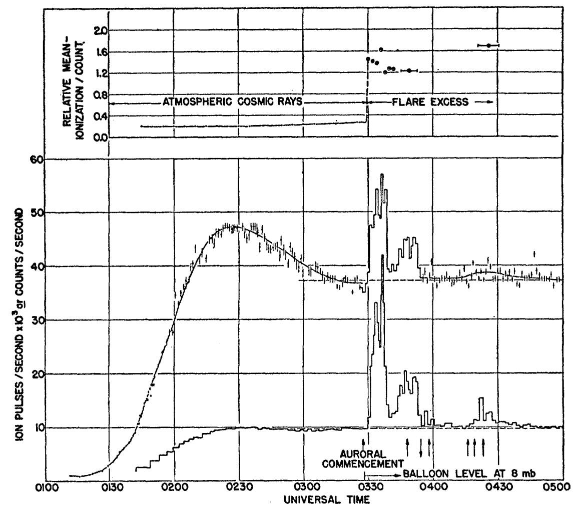

Fig. 1. In the lower section is plotted the counting rate of a single Geiger counter (upper curve), and pulsing rate of an integrating ionization chamber (lower curve), during the auroral display of July 1, 1957. Between 0130 and 0330 the two instruments show the normal transition curves as the balloon rises to altitude. In the upper section is plotted the ratio of the counting rate of the ionization chamber to that of the single counter. The flare effect has a relative mean ionization per count which is 7 times that of fast cosmic-ray particles.

altitude may be attributed to the increased flux of heavy primary nuclei. The ratio for the burst excess, however, is 1.3 to 1.4, and remains reasonably constant despite the large intensity fluctuations of both instruments. A ratio of 1.4 corresponds to a proton with relative ionization seven times minimum, of energy 45 Mev and residual range 2 g/cm². Such protons above the atmosphere have a range of 10 g/cm², an energy of 120 Mev, and $\beta = 0.45$ assuming vertical incidence. The peak measured flux is 1.0 particle/cm² sec.

The ratio of ionization per count has also been measured in the laboratory for x-rays of various energies and for γ rays. In the range 500–1000 kev, the ratio 0.2 characteristic of minimum ionizing particles is obtained. The ratio rises rapidly below 100 kev due to the somewhat greater absorption of the Geiger counter brass wall than the 0.025-in. steel of the ion chamber. However, the sensitivity of both the ion chamber and counter drops very rapidly below 40 kev. The response is thus peaked in the region of 50–70 kev, and both the ratio 1.4 and the observation under 8 g/cm² of atmosphere are consistent with x-rays in this energy range. These x-rays must be attributed to electrons of $\beta \approx 0.5$ emitting bremsstrahlung in the higher atmosphere. The peak x-ray flux at the equipment is 5 mr/hr.

The auroral display was probably associated with the passage across solar meridian of an active region (039 *C* on the Boulder report)[1] on June 30th and the transit time from sun to earth is about 20 hr. The β for the beam is thus about 0.01. This β is quite consistent with the velocity of incident auroral protons of energies below 100 kev measured by Meinel[2] by the H_α doppler shift in the auroral spectrum.

We must therefore account for the presence in the auroral beam of particles much greater in velocity than the beam itself. If these particles are protons then they must be approaching the earth in very flat spirals in magnetic fields locked in the solar gas cloud. It should be noted that such protons of 120 Mev are not inconsistent with Meinel's Doppler shift, as the H_α line is emitted only near the end of their range. However, an analysis of Meinel's H_α line shape and the angular distribution of incident auroral protons by Chamberlain[3] seems more consistent with protons of much lower energy than can be reconciled with the present observation. We rather favor the assumption that the observed effect originates from 60-kev electrons, and if these electrons cannot be contained in the auroral beam itself some mechanism must be devised for transferring energy from the auroral protons to the electrons. Kellogg[4] has suggested the charge separation of the neutral beam on entry into the earth's magnetic field as a means of accelerating the electron component from its beam-velocity energy of 30 ev to the observed 60 kev.

Extensive observations of soft radiation above the atmosphere in the auroral zone have been made by Van Allen and co-workers.[5] The authors conclude that the radiation consists of x-rays in the range 10–40 kev and is probably from electrons of auroral origin. However, the radiation was not observed as deep as 8 g/cm^2 in the atmosphere. We believe that the present observation is possibly the same phenomenon as Van Allen's soft radiation, but for the first time is directly correlated with visual aurora, and in addition appears to be a more energetic process. This is in agreement with evidence that auroral displays like the one on July 1st which exhibit zenith arcs which occur well below the auroral zone, and in which H_α radiation is observed, are a higher energy phenomenon than the more abundant aurorae at higher latitudes where H_α emission is not observed.[6]

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[1] Report TR 305, July 5, 1957, High Altitude Observatory, Boulder, Colorado (unpublished).
[2] A. B. Meinel, Astrophys. J. **113**, 50 (1951).
[3] Joseph W. Chamberlain, Astrophys. J. **120**, 350 (1954).
[4] P. J. Kellogg, Phys. Rev. (to be published). We are indebted to Professor Kellogg for discussions of this matter.
[5] Meredith, Gottlieb, and Van Allen, Phys. Rev. **97**, 201 (1955).
[6] *Belfast Symposium, 1955*, edited by Armstrong and Dalgarno (Pergamon Press, London, 1956).

Time-Reversal Invariance in Beta Decay*

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SEVERAL experiments have been suggested[1] which, in principle, lead to a test of time-reversal invariance (hereafter abbreviated as TRI) in beta decay. These experiments were designed to measure a quantity which depended on Im $C_XC_Y^*$. Recent experiments indicate a complete (i.e., $\pm v/c$) polarization of electrons in pure Fermi and Gamow-Teller transitions,[2] which implies that S-V, T-A, S-A, and V-T interferences do not occur. Since this eliminates many of the simpler tests of TRI, it becomes appropriate to test TRI in experiments which measure Re $C_XC_Y^*$. It is the purpose of this letter to consider one example of this type, based on the beta spectrum of RaE.

Terms involving Re $C_XC_Y^*$ appear, for example, in the beta spectrum, beta-gamma directional correlation, beta-gamma circular polarization correlation, and in the beta-nuclear polarization correlation. The principal difficulty involved in this means of testing TRI, is that in the absence of a reliable means of calculating nuclear matrix elements, we must treat them, as well as the coupling constants, as unknown parameters. The experiments then must give sufficient information to determine *both* matrix elements and coupling constants, and in particular must prove unambiguously that matrix elements from different forces are present, since only then does a test of TRI arise. One easily sees that the beta-gamma directional correlation and the beta-gamma circular polarization correlation experiments alone do not determine enough information to provide a test. For example, measurement of the circular polarization of a gamma gives, together with the lifetime, only two parameters, while there are three unknowns, M_F, M_{GT} and Re $C_XC_Y^*$. Here, and in the following, we treat $|C_F|^2$, $|C_{GT}|^2$ as known,[3] and assume the validity of TRI for the strong forces,[4] which fixes the relative phase of the nuclear matrix elements.

On the other hand, experiments with polarized nuclei provide enough independent experiments to determine all the unknowns, in an allowed transition.[5] Experiments with Co^{58} are an example[6]; when analyzed with an S-T interaction, there are three unknowns (M_F, M_{GT}, and Re $C_SC_T^*$), and there are three (or more) experiments which can be done. Unfortunately, the results are all consistent with $M_F=0$, which means that no test of TRI is possible. Other nuclei, notably Mn^{52}, may provide a test along these lines.

Lastly, we wish to consider the evidence from the shapes of beta spectra. Allowed spectra, and most first forbidden spectra, do not determine the matrix elements, since all matrix elements give rise to the same (allowed) shape. Only spectra showing deviations from this shape give a means of determining the matrix