

The Geographical Variation of the Cosmic-Ray Showers

In an effort to determine whether the radiation responsible for the cosmic-ray showers is affected by the earth's magnetic field, observations were taken in the summer of 1935 on a voyage across the Pacific to New Zealand and return. A triple coincidence recording apparatus was built in a form that could be used on ship board. The high voltage for the counters was supplied by batteries while the amplifier was connected to operate on 100 volts a.c. or d.c. The counters used were about 2.5 cm in diameter and 14 cm long. They were filled with a mixture of 80 percent argon and 20 percent air to a pressure of 5 cm.

Data were taken with the counters in two arrangements. For the first they were set in a vertical line with about 13 cm between the top and bottom counters, and with the frame holding the counters swung in gimbals. To measure the showers the arrangement of Fig. 1 was used. The lead

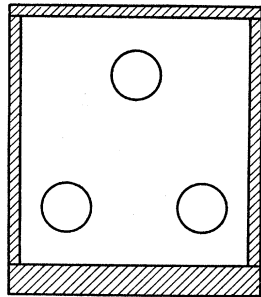


FIG. 1.

above the counters was 1.6 cm thick, that at the sides and below was about 0.6 cm thick. The daily runs were usually divided with the counters vertical for about 4 hours and in the shower position for about 20 hours. From the ship's log data on the position and barometer were obtained.

In Fig. 2 the data for the vertical coincidences are plotted against the geomagnetic latitude. The latitude effect shown is estimated as being about 17 percent.

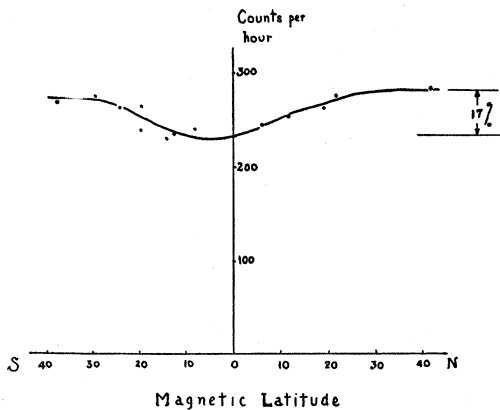


FIG. 2.

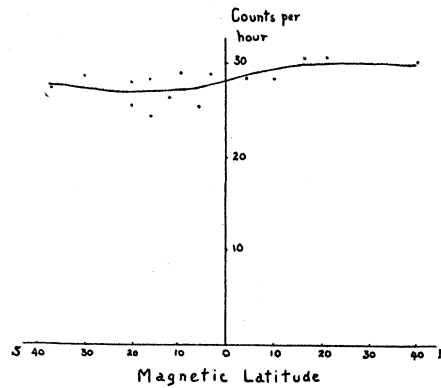


FIG. 3.

In Fig. 3 the data for the shower coincidences are similarly plotted. It is evident that the latitude effect, if any, is much less than for the vertical coincidences. However, the points show a considerable fluctuation partly due to the statistical fluctuations and partly to the instrumental changes in sensitivity. To remove this last source of error the ratio of the vertical counting rate to the shower counting rate on the same day is used. This ratio is plotted as a function of latitude in Fig. 4 and obviously much more consistent points are obtained. Numerically the curve indicates the shower radiation experiences about 11 percent less latitude effect than the vertical radiation. This means that if the latitude effect for the vertical rays is 17 percent that for the radiation responsible for the showers is about 6 percent.

Conclusions based directly upon this difference in latitude effect for the two types of coincidence must be viewed with caution because of the difference in the geometry in the two cases. In the one case only those rays that are approximately vertical will register, in the other case those making a considerable angle with the vertical may still be recorded. That this difference may be significant is shown by the fact that in the Pacific Ocean the

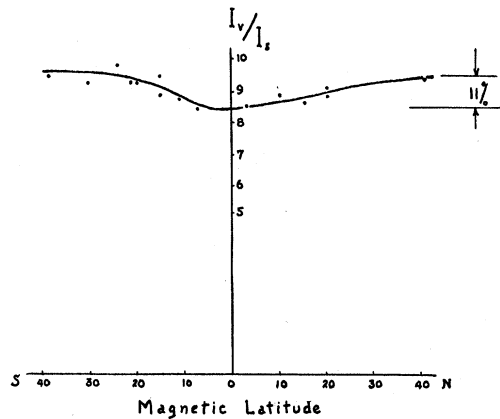


FIG. 4.

latitude effect as measured with electroscopes is about 10 percent.<sup>1</sup> However, the above results indicate that for the shower radiation the latitude effect is even less than this value, and if this is indeed true, then it follows that a part of the showers at sea level must be caused by an incoming photon radiation.

The above experimental result is in substantial agreement with that of Johnson in the Atlantic Ocean.<sup>2</sup>

The pleasant cooperation of the Union Steamship Company and especially the officers of the steamships *Makura* and *Niagara*, made this experiment possible.

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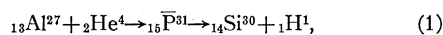
<sup>1</sup> Millikan and Neher, *Phys. Rev.* **47**, 205 (1935).

<sup>2</sup> T. H. Johnson and D. N. Read, *Phys. Rev.* **49**, 639 (1936).

### Possibility of Selective Phenomena for Fast Neutrons

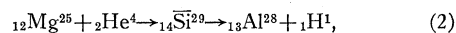
In the experiments on nuclear transformations produced by collisions with fast neutrons no resonance phenomena have yet been observed. Therefore it may be of interest to indicate here that such phenomena can be expected in the region of semi-light nuclei and that, with the evidence at present available on nuclear reactions, one can even in certain cases predict the energy of fast neutrons for which resonance disintegration should be observed.

It is usually accepted that the phenomena of resonance take place when the "intermediate compound" of the reaction (i.e., original nucleus+incident particle with its total energy) possesses the excess of energy corresponding to one of its discrete quantum states. For example from the existence of resonance phenomena in the reaction:



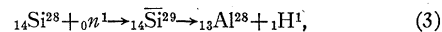
where, for six different resonance velocities of incident  $\alpha$ -particles, the discrete groups of protons with the energy ranging from 6.0 MEV up to 8.6 MEV are emitted,<sup>1</sup> we can conclude that the nucleus  ${}_{15}\text{P}^{31}$  possesses well-defined energy levels for the excitation up to 8.6 MEV above its "ionization potential" for proton (i.e., binding energy of proton in this nucleus). Accepting for this binding energy the value about 10 MEV we come to the conclusion that the nucleus in question has discrete and widely separated levels for the total excitation as high as 18 MEV and that, consequently, Bohr's picture of very close and practically overlapping levels,<sup>2</sup> introduced for the understanding of neutron capture by heavy nuclei, cannot yet be applied in this region of atomic weights.

An analogous case is represented by the reaction:



which, according to Ellis and Henderson<sup>3</sup> shows a strong resonance for the energy of  $\alpha$ -particles somewhat below 5.4 MEV. As far as in this case the energy balance is negative and, according to Duncanson and Miller,<sup>4</sup> has the value -1.16 MEV, the protons emitted in resonance case must have the energy around 4.2 MEV. The same intermediate compound as in (2) can be obtained if one

bombards silicon (most abundant isotope  ${}_{14}\text{Si}^{28}$  present in amount 96 percent) by fast neutrons:



so that choosing the energy of incident neutrons so that  ${}_{14}\text{Si}^{29}$  would have the same total energy as in the resonance case of the reaction (2) one should expect to observe the resonance.

To calculate the necessary energy of neutrons we must know the difference of binding energies of a neutron and a proton in our nucleus. This can be easily estimated from the circular process:

$$\begin{aligned} {}_{14}\text{Si}^{28} + {}_0n^1 &= {}_{14}\text{Si}^{29} + Q_n, \\ {}_{14}\text{Si}^{28} - {}_1\text{H}^1 &= {}_{13}\text{Al}^{28} - Q_p, \\ {}_{13}\text{Al}^{28} &= {}_{14}\text{Si}^{28} + e + E_{\text{max}}, \end{aligned} \quad (4)$$

giving us:  $Q_n - Q_p = [m_r - (m_p + m_e)]c^2 - E_{\text{max}} = 1 \text{ MEV} - 3 \text{ MEV} = -2 \text{ MEV}$ , which means that in this case the proton is bound 2 MEV stronger than the neutron. Thus the intermediate compound of the reaction (3) will have the total energy corresponding to resonance if the energy of incident neutrons will be around 4.2 MEV - ( $Q_n - Q_p$ ) = 6.2 MEV.

It should be interesting to find experimentally such selective phenomena in silicon for the neutrons of this or lower energy.

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May 28, 1936.

<sup>1</sup> W. E. Duncanson and H. Miller, *Proc. Roy. Soc. A* **146**, 396 (1934).

<sup>2</sup> N. Bohr, *Nature* **137**, 344 (1936).

<sup>3</sup> C. D. Ellis and W. J. Henderson, *Nature* **136**, 755 (1935).

### Comments on Robertson's Interpretation

In recent papers in the *Physical Review* Engstrom and Zorn<sup>1</sup> and H. P. Robertson<sup>2</sup> have shown that the only transformations which preserve a Euclidean three-dimensional reference system with constant light velocity are the Lorentz transformation and the constant acceleration transformation discussed in my paper,<sup>3</sup> or a combination of the two. This disposes of my expectation that other such reference systems might exist.

Lest any one should infer from Robertson's paper that my theory is merely a special case of Einstein's general theory, I should like to emphasize the fact that Einstein's theory (both special and general) makes the measured interval between two nearby events as determined by ideal scales and clocks the same for all reference systems, whereas mine does not. Therefore the two theories are quite different in their physical content.

In connection with Robertson's expectation that my procedure must lead to the usual classical expression for the ponderomotive force, I would point out that Adams and I have shown<sup>4</sup> that it may lead to a very different equation of motion.

LEIGH PAGE

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May 26, 1936.

<sup>1</sup> Engstrom and Zorn, *Phys. Rev.* **49**, 701 (1936).

<sup>2</sup> H. P. Robertson, *Phys. Rev.* **49**, 755 (1936).

<sup>3</sup> L. Page, *Phys. Rev.* **49**, 254 (1936).

<sup>4</sup> Page and Adams, *Phys. Rev.* **49**, 469 (1936).