Absorption Mean Free Path of the Nucleonic Component of Cosmic Radiation

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(Received June 19, 1961)

The absorption mean free path L of star-producing radiation was determined by means of the local production of neutrons in condensed materials; for that purpose a neutron monitor was installed in an aircraft, and two flights were performed at the geomagnetic latitudes 23.3°S (Buenos Aires, República Argentina) and 15°S (Asunción, República del Paraguay). The results show an increase in L of about 20% for an altitude increase of 6000 m in Buenos Aires, and of 40% in Asunción, for the same altitude increase; the total L value in Asunción was found to be 175 g cm^{-2}, while in Buenos Aires it was 163 g cm^{-2}, that is, approximately 8% lower.

INTRODUCTION

MANY experiments with different methods of detection have been carried out by several authors,[1–6] in order to establish a relationship between the nucleonic intensity and the production of stars in the atmosphere, and thereby to draw conclusions about the primary cosmic radiation. In the equilibrium region of the atmosphere (200–600 gcm^{-2}) the intensity varied approximately according to the exponential law $I=I_0e^{-x/L}$, where x is the atmospheric thickness, and L the absorption mean free path of star-producing radiation.

These experiments have shown that the absorption mean free path depends on the geomagnetic latitude and altitude and becomes independent of the first for atmospheric thickness higher than 600 gcm^{-2}. The fundamental purpose of this work is to confirm experimentally these conclusions for the southern hemisphere, where there are practically no available data on the absorption mean free path of the nucleonic component. Two flights were performed; the first one took place on August 3, 1959, from Buenos Aires ($\lambda=23.3$°S) to Asunción, Paraguay ($\lambda=15$°S), reaching a top altitude of 10 000 m. The second flight took place in the same year on November 27, over Buenos Aires, and a top altitude of 12 400 m was then reached.

APPARATUS AND SYSTEM OF MEASUREMENT

A neutron monitor pile was used, of the type adopted by Simpson and other investigators, specially designed to perform experiments on aircraft. Therefore, our method of observation consists in the measurement of the nucleonic component of cosmic radiation, by recording the neutrons produced in the nuclear reactions generated by that component in condensed materials. The neutrons were detected by means of two BF_3 proportional counters, enriched to 96% of the B^{10} isotope, surrounded by paraffin as moderator, and using lead as generating material. The two BF_3 counters were connected in parallel, their Amphenol ends being joined by means of a conductor; from these ends an internal connection leads to the input of an amplifier placed upon the pile; the connection was made by means of a stiff conductor placed in the axis of a pipe, as shown in Fig. 1, so as to be perfectly insulated by approximately 3 cm of air; the pipe was joined by a screw end to the connection box, it ran through a paraffin box, and reached the amplifier's base with the other screw end. This disposition avoids the use of moving connectors, which are unsatisfactory because of the spurious pulses that may arise from sudden motions. The amplifier's output was connected to the recording circuit or scaler. Two automatic counters and a clock were installed on a panel which was photographed with a film camera, automatically operated every minute; this frequency was found to be sufficient for good statistics.

INSTALLATION ON BOARD THE AIRCRAFT

In order to simplify the installation, the whole set, was placed into a wooden box whose front part could be

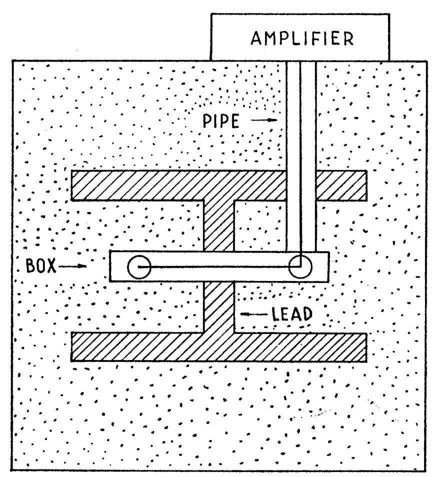

FIG. 1. Shows the rigid connection to avoid spurious pulses that may arise from sudden motions.

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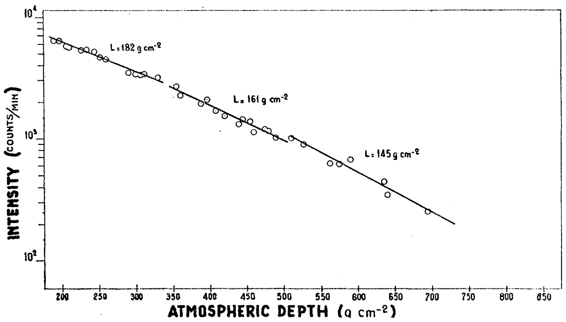

FIG. 2. Data obtained for Buenos Aires (λ=23.3°S) during the second flight on November 27, 1959.

easily taken apart, so as to allow quick inspection or repairing. All the electronic attachments, as well as the highly balanced (1/10 000) source of power supplying the proper voltage, were placed above the cover. The installation was made in the freight cabin of the aircraft. A converter was employed to change voltage from 18 v dc (aircraft power) to 220 v ac, 50 cps, as required for operating our equipment. The altitude data were obtained every minute by direct reading from the altimeter.

CORRECTIONS

The first correction was due to possible losses in the automatic counter; the well-known relation $N=N_0/(1-N_0T)$ was applied, where N_0 represented the recorded counting and T, the dead time of the counter.

The second correction was the zero adjustment of the altimeter. During the first flight, Buenos Aires–Asunción, the pressure was 1021 millibars in Buenos Aires, and 1013 in Asunción; in the second flight (Buenos Aires) the pressure was 1010 millibars. All the data were referred to the normal pressure of 1013 millibars. The adjustment was performed by applying Simpson's[2] pressure coefficient (0.96%/mm Hg).

Variations of fuel consumption by the aircraft had no influence on the intensity measurements, which remained constant for different consumption at constant altitude. Finally, there was no need of a correction due to variations in the primary cosmic radiation, as the average intensity during both flight periods proved to be constant according to the measurements of intensity and pressure recorded the days before, during, and after the flights, in the ground cosmic radiation laboratory in Buenos Aires.

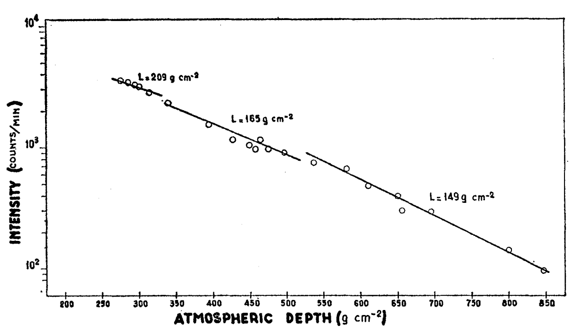

FIG. 3. Data obtained for Asunción del Paraguay (λ=15°S) during the first flight on August 3, 1959.

RESULTS AND CONCLUSIONS

The corrected data have been plotted in Fig. 2 for Buenos Aires and Fig. 3 for Asunción del Paraguay. The intensity per minute is represented against the atmospheric thickness. The results obtained from the graphs are shown in Table I. Considering this table, it is seen that the absorption mean free path changes with altitude from 145 gcm^{-2} for an average altitude of 4900 m up to 182 g cm^{-2} for an average altitude of 10 400 m, in Buenos Aires. In Asunción, L changes from 149 g cm^{-2} at 3600 m, up to 209 g cm^{-2} for an altitude of 9500 m; furthermore, a variation of the absorption mean free path maybe observed as a function of geomagnetic latitude λ: for Buenos Aires (λ=23.3°S) the total L was found to be 163 g cm^{-2}, While in Asunción (λ=15°S), it amounts to 175 g cm^{-2}. Another conclusion that may be drawn from Table I is that the absorption mean free path is independent of the geomagnetic latitude λ for atmospheric thickness higher than 600

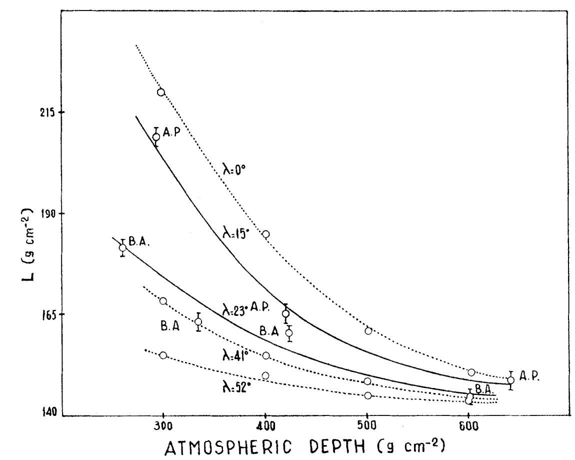

FIG. 4. Curves obtained by Simpson in the Northern Hemisphere. Included are the curves mentioned in this paper.

TABLE I. Values of absorption mean free path for Buenos Aires and Asunción del Paraguay at several atmospheric depths.

λ	Atmospheric depth (m)	L(g cm^{-2})
15° S	1650–5650	149±5
	5800–8400	165±3
	9000–10 000	209±3
23°3 S	3200–5700	145±4
	5950–8200	161±3
	8250–9675[a]	163±5
	8625–12 100	182±2

[a] This value corresponds to the first flight in Buenos Aires.

g cm^{-2}; the value of L is found to be 145 g cm^{-2} for Buenos Aires, and 149 g cm^{-2} for Asunción.

Finally, Fig. 4 shows the curves obtained by Simpson in the northern hemisphere for the variation of the absorption mean free path as a function of the atmospheric thickness, with the geomagnetic latitude λ as a parameter; we have there introduced our own values for $\lambda=23.3°$S (Buenos Aires) and $\lambda=15°$S (Asunción). They show a good agreement within our experimental errors.

Our results are thus consistent with Simpson's suggestions[2,3] that the variation of the absorption mean free path with geomagnetic latitude and with altitude must be a consequence of the average energy of the primary nucleons as they start the nucleonic shower and of the degradation of the energy through collision and nuclear interaction phenomena along the penetration of the nucleons into the depths of the atmosphere.

ACKNOWLEDGMENTS

We are indebted to Aerolíneas Argentinas, that kindly allowed us to install our equipment and to perform the measurements on board a Comet IV during two of its experimental flights, and to Commander O. Sundt and Commander C. M. Moreno Pacheco and the staff of Aerolíneas Argentinas, who made this research possible. We also acknowledge the cooperation of the technical expert in electronics, Mr. Pedro Waibel.

PHYSICAL REVIEW VOLUME 124, NUMBER 4 NOVEMBER 15, 1961

Estimate of the Nucleon Mass Difference from Hofstadter's New Form Factors

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(Received June 19, 1961)

It is shown that the set of isotopic form factors recently proposed by Hofstadter and Herman seems favorable for an explanation of the observed nucleon mass difference in terms of the electromagnetic self-energy, if an extended core radius is suitably introduced.

An attempt has been made[1] to explain the observed nucleon mass difference, $M_n-M_p=1.29$ Mev, by assuming trial form factors which deviate from Hofstadter's old form factors determined by the electron scattering experiments at rather small values of the momentum transfer q. Meanwhile, according to the new experimental data[2,3] on the electromagnetic structure of the proton and neutron, Hofstadter and Herman[4] have recently presented a tempting unified interpretation of the nucleon form factors. They have found the four isotopic form factors of the Clementel and Villi (C–V) form.[5] Although the C–V form is interesting from the viewpoint of the dispersion relations, their form factors do not give a convergent result for the nucleon mass difference.[1] It should be noted, however, that the signs of the core terms in the Hofstadter new isotopic form factors just satisfy the previously conjectured condition under which the nucleon mass difference can be explained.[6] In the present report it is shown that, if a suitably extended core is assumed with its radius smaller than the nucleon Compton wavelength, then the Hofstadter new form factors, thus modified, can reasonably explain the observed mass difference.

For simplicity a common parameter r_c is introduced into the core terms of Hofstadter's new isotopic form factors as follows:

$$F_{1S}=\frac{0.44}{1+r_c^2q^2}+\frac{0.56}{1+0.214q^2}, \tag{1}$$

$$F_{2S}=\frac{4.0}{1+r_c^2q^2}-\frac{3.0}{1+0.214q^2}, \tag{2}$$

$$F_{1V}=F_{2V}=-\frac{0.20}{1+r_c^2q^2}+\frac{1.20}{1+0.10q^2}. \tag{3}$$

As has been estimated in reference 1, the strong interaction correction to the nucleon mass difference seems to be less than 0.2 Mev, and so the major contribution may be regarded as coming from the direct electromagnetic effect. The e^2-order self-energy thus gives the

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[6] See (3.8′) of reference 1. Note that the normalizing constants of the isotopic form factors are differently defined in references 1 and 4. In the present report, the choice of Hofstadter's normalization in reference 4 is used.