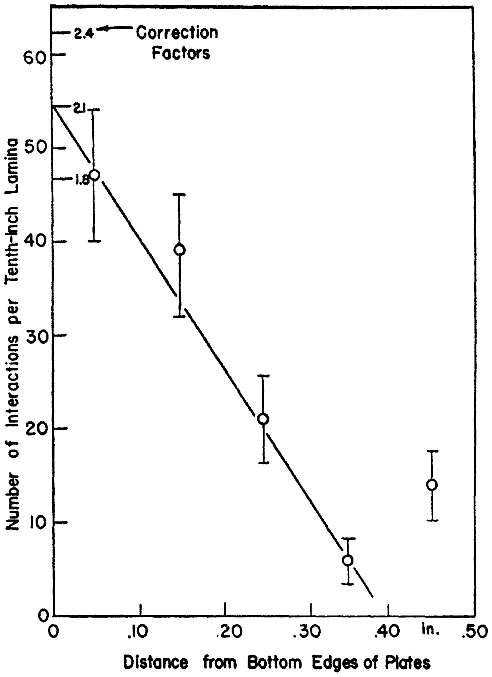

FIG. 2. Distribution of observed nuclear interactions in the lead plates.

to be lost. The factor K by which it is necessary to multiply ΔN_0 in order to obtain the real number of interactions, ΔN, in our case turns out to be $K=2.1\pm0.3$. The uncertainty in K arises from both the statistical errors and the extrapolation. With this correction we deduce λ to be

$$\lambda=172\pm29 \text{ g cm}^{-2} \text{ of Pb},$$

a value quite close to the geometric m.f.p.

The value of K is expected to decrease strongly when the thickness of the absorber is decreased. With plates of $\frac{1}{4}$-in. Pb one can anticipate a value $K=\sim1.1$. In fact, Gregory and Tinlot[3] with plates of $\frac{1}{4}$-in. Pb found $\Lambda=172\pm20$ g cm^{-2}.

In the past years several authors (see bibliography in the paper of Gregory and Tinlot) obtained much higher values for λ in Pb; probably the reason for the discrepancy with the present determination is due to the fact that generally they used thick absorbers inside the chambers and did not select energetic secondaries, hence making the number of missed interactions too high to permit accurate correction. The same conclusion was reached by Lovati *et al.*,[4] who found a value $\Lambda=200\pm50$ g cm^{-2} Pb using plates 0.5 mm thick.

* This work was supported in part by a grant from the Research Corporation.
[1] This prevents consideration of interactions and traversals in the top plate of the lower chamber, but makes the discrimination against electrons and low energy particles more effective than if all single traversals and interactions were counted.
[2] W. W. Brown and A. S. McKay, Phys. Rev. **77**, 342 (1950).
[3] B. P. Gregory and J. H. Tinlot, Phys. Rev. **81**, 675 (1951).
[4] Lovati, Mura, Succi, and Tagliaferri, Nuovo cimento **8**, 271 (1951).

A Dual Cloud-Chamber Study of Extensive Air Showers*

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(Received July 23, 1951)

DURING the fall of 1949 the dual cloud-chamber assembly described in the preceding letter was operated at Echo Lake, Colorado, to obtain photographs of penetrating particles in ex-

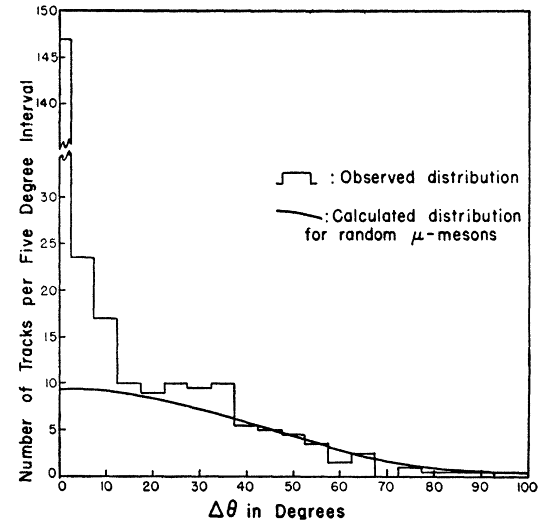

FIG. 1. Distribution of deviations, $\Delta\Theta$, between the projected zenith angles of penetrating particles and their respective extensive air shower axes. Note that the ordinate scale has been broken to show the relatively high peak at small deviations.

tensive air showers. The counter tray A, indicated in Fig. 1 of the previous letter,[1] was removed; and two unshielded trays, X and Y, each of about 500-cm^2 area, were placed at distances of about two meters from the cloud-chamber assembly. About 400

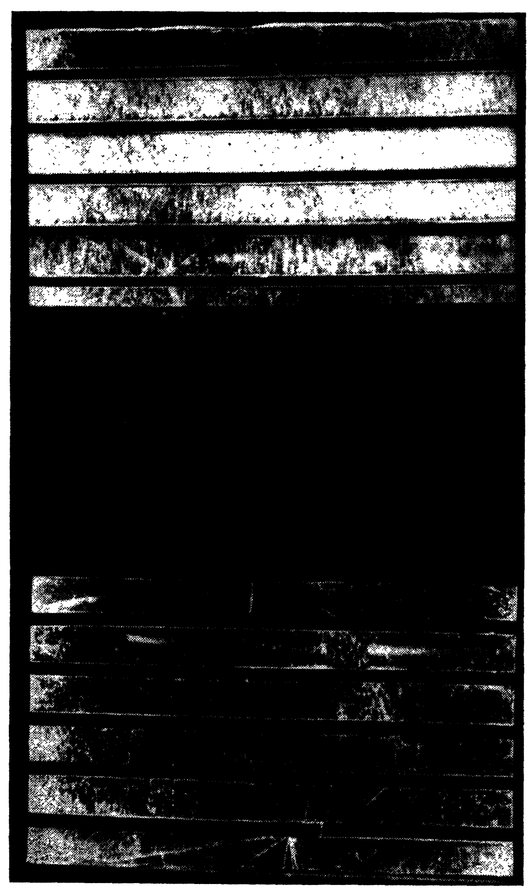

FIG. 2. An extensive air shower containing a coherent particle generating the nuclear cascade beginning in the fifth plate of the upper chamber.

good photographs were obtained with the simple fourfold coincidence $(X+Y+B+C)$, for which only one counter was required to be struck in each tray.

The cloud-chamber photographs demonstrate the occurrence of strongly interacting nucleonic particles in air showers and thus provide qualitative verification of the interpretation of recent counter experiments. These photographs also show that nuclear cascades contributing to the electronic cascade development exist within air showers at mountain altitudes.

The projected angular distribution of penetrating particles relative to their corresponding air shower axes was measured in 173 selected photographs showing air showers of sufficient electron density to indicate the inclination of the shower axis within one degree and showing one or more counter-age penetrating tracks in the lower chamber. The result is shown in Fig. 1. The smooth curve is the calculated shape of the distribution of random mesons which has been fitted to the data at large angles where few penetrating particles associated with air showers are expected to occur. This analysis shows that at angles of less than 10° in projection 92 percent of the observed penetrating particles are coherent with air showers. About three-fourths of the coherent penetrating particles are deviated less than 3° from the shower axis; i.e., they are scattered less than 3° in the air and lead above the lower chamber and hence have momenta greater than 2 Bev/c.

An approximate analysis of the observed flux of charged penetrating particles into a strongly interacting component (protons and pi-mesons) and a weakly interacting component (mu-mesons) can be made from the relative numbers of traversals and nuclear interactions observed in the plates of the lower chamber. (The numerous electron tracks prevent similar consideration of the upper chamber.) In 134 selected photographs, 155±5 coherent externally incident penetrating particles (parallel to the shower axis within 10°) were observed to make 606±20 traversals of lead plates in the lower chamber, producing three local penetrating showers and two local mixed showers. A background of 15±5 random mesons has been subtracted from the total number of penetrating particles observed; the expected number of chance interactions is negligible (<0.01). Assuming that the N-component of energy sufficient to produce local penetrating showers has a geometric collision mean free path in lead, the number of traversals expected to yield the five observed interactions is 53±24, or 8.6±3.8 percent of the total number of traversals. Taking into account the absorption of the N-component in traversing the apparatus to reach the lower chamber by using the interactions mean free path for single energetic N-component particles measured by Walker, Walker, and Greisen,[2] one estimates the fraction of energetic N-component in the flux of air shower penetrating particles incident on the apparatus to be 26±10 percent. Similar results were deduced in shielded counter studies of the penetrating particles in air showers.[3-5]

Examples of photographs of air showers containing strongly interacting particles are given in Figs. 2 and 3. Many of the photographs showed large numbers of energetic electrons in the lower chamber, as in Fig. 3, which could not have developed through the 29 radiation lengths of lead in the intermediate layer by means of pure electromagnetic cascades. The observation of locally generated mixed showers in air showers incident on the apparatus suggests that similar processes occur in the air also.

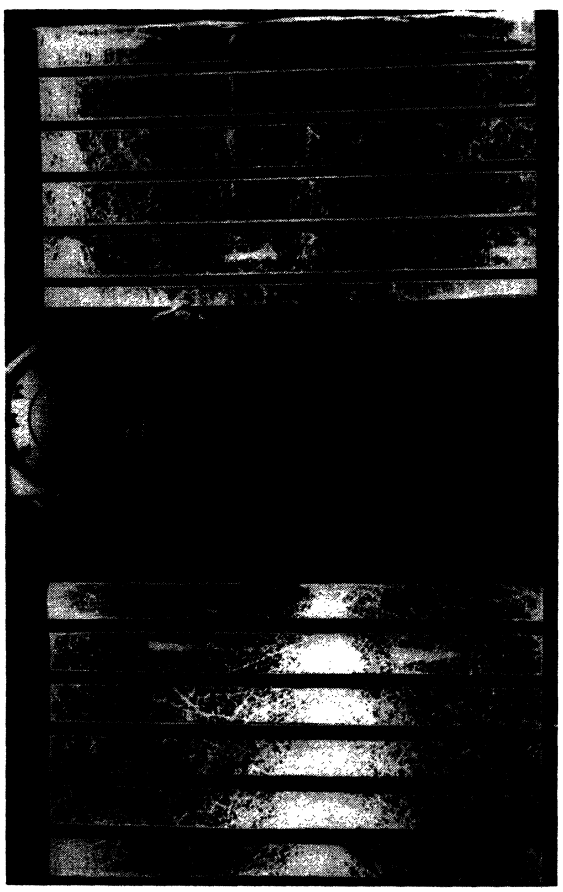

FIG. 3. Large numbers of electrons and slow heavy particles emerge from each of the lead plates in the lower chamber along the axis of this mixed shower. The primary of this local mixed shower traveled parallel to the energetic electrons in the air shower and passed through the upper chamber.

* This work was supported in part by a grant from the Research Corporation.

[1] G. M. Branch and G. Cocconi, Phys. Rev. **84**, 146 (1951).
[2] Walker, Walker, and Greisen, Phys. Rev. **80**, 546 (1950). This measurement gives the appropriate mean free path for the present application, since here as well as in their experiment the detected particles were required to emerge from the absorber singly. Coherent groups of penetrating particles diverging from some point of generation in the absorber were not considered.
[3] K. Sitte, Phys. Rev. **78**, 721 (1950).
[4] Greisen, Walker, and Walker, Phys. Rev. **80**, 535 (1950).
[5] C. B. A. McCusker, Proc. Roy. Soc. (London) **A63**, 1240 (1950).

Diffuse X-Ray Scattering by Disordered Binary Alloys. II

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THE analysis of diffuse x-ray scattering in disordered binary alloys presented recently[1] may be extended as follows. Let k, L denote the kth site in the Lth unit cell, and denote by $[kk', M]$ the set of site-pairs, k, L and k', $L-M$, where M remains fixed, while L assumes all possible values (L and M represent number triples). The sets $[kk', M]$ and $[k'k, -M]$ are identical, since the ordering of the pairs is immaterial. The two types of atoms will be denoted by A and B, while X will be used to represent either an A or a B atom. The atom symbol will be primed if the atom is at the k'th site, unprimed if at the kth site. Let $w_{XX'}^M$ be the fraction of site-pairs in the set $[kk', M]$ for which the kth site is occupied by X and the k'th site by X'. There are four such parameters, $w_{AA'}^M$, $w_{AB'}^M$, etc., and their sum is, of course, unity. It is evident that these parameters satisfy the additional identities,

$$w_{XA'}^M + w_{XB'}^M = x_X^k, \quad w_{AX'}^M + w_{BX'}^M = x_{X'}^{k'}, \qquad (1)$$

where x_X^k is the fraction of all sites of the kth type (kth sublattice) which are occupied by atoms of type X ($X=A$ or B), and similarly for $x_{X'}^{k'}$. In the present discussion, we regard the x_X^k as known, either from measurements of long-range order, or from the stoichiometry of the crystal, in the absence of long-range order. Of the four relations, Eqs. (1), three are independent, so that one additional independent relation is required to determine the four

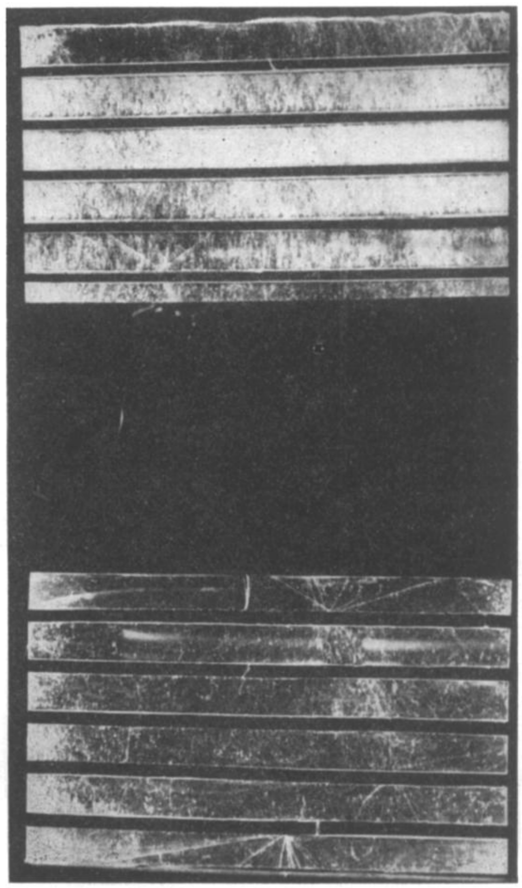

FIG. 2. An extensive air shower containing a coherent particle generating the nuclear cascade beginning in the fifth plate of the upper chamber.

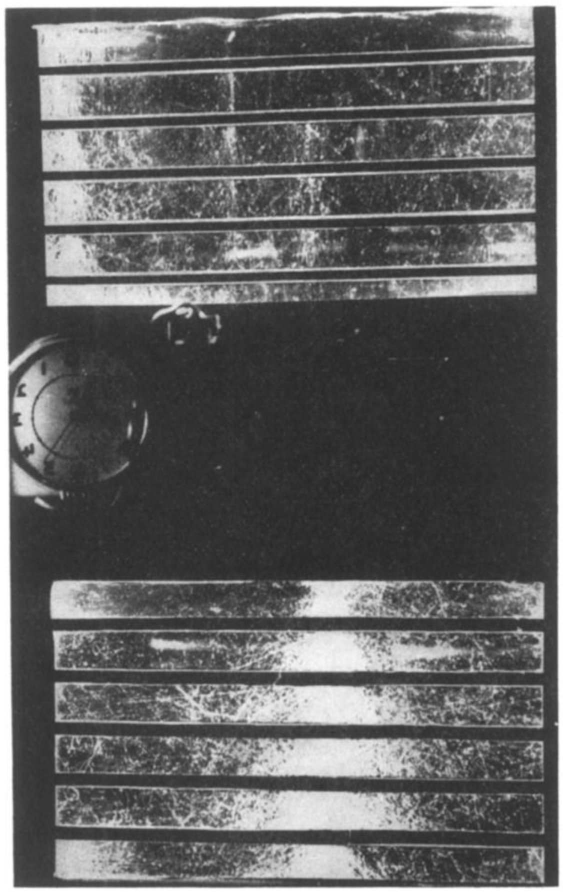

FIG. 3. Large numbers of electrons and slow heavy particles emerge from each of the lead plates in the lower chamber along the axis of this mixed shower. The primary of this local mixed shower traveled parallel to the energetic electrons in the air shower and passed through the upper chamber.