sufficient accuracy to measure the deviation of the matrix element from the first term of (9) would therefore give us information about the $\pi\rightarrow\mu+\nu$ decay mechanism. This accuracy must be $\sim 1/M$ if $C_T\approx C_A$, or $\sim 1/M^2$ if $C_T\approx 0$.

[1] C. Lattes and H. L. Anderson, Nuovo cimento (to be published); J. M. Cassels, *Proceedings of the Seventh Annual Rochester Conference on High-Energy Nuclear Physics* (Interscience Publishers, Inc., New York, 1957).

[2] M. Ruderman and R. J. Finkelstein, Phys. Rev. **76**, 1458 (1949); M. Ruderman, Phys. Rev. **85**, 187 (1952); S. B. Treiman and H. W. Wyld, Phys. Rev. **101**, 1552 (1956).

[3] The fact that parity is not conserved in the weak decays is irrelevant to the calculation, which concerns only total decay rates.

[4] Except for the small amount of C_P required here, this set of couplings is the same as that recently proposed by R. R. Feynman and M. Gell-Mann [Phys. Rev. **109**, 193 (1958)], E. C. G. Sudarshan and R. E. Marshak [Proceedings of the Padua-Venice Conference, September, 1957 (to be published)], and J. J. Sakurai [Bull. Am. Phys. Soc. Ser. II, **3**, 10 (1958)].

[5] This necessitates a two-component neutrino field ψ_ν which satisfies $\gamma_5\psi_\nu=\psi_\nu$.

[6] For a summary of experiments on nuclear β decay, see *Proceedings of the International Conference on Nuclear Structure, Weizmann Institute, Rehovoth, Israel, 1957* (to be published).

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Refraction Effects in Direct Nuclear Reactions

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FOR all bombarding energies in the range 11.8 Mev–96 Mev, the observed angular distributions[1] for the reaction $C^{12}(p,p')C^{12*}$ ($Q=-4.4$ Mev) rise to peaks as the scattering angle approaches $\theta=0°$. Nevertheless this reaction appears to proceed as a direct interaction with angular momentum transfer $l=2$. Elementary theories[2] then all predict that the cross section should be small near $\theta=0°$, rising to appreciable values only at angles approaching those at which $qR=l=2$. Here R is the nuclear radius, and $\mathbf{q}=\mathbf{k}_i-\mathbf{k}_f$ is the difference between the incident and outgoing momenta. The magnitude of $\mathbf{q}$ always increases as $\mathbf{k}_f$ rotates towards larger angles, and for most experiments is quite small when $\theta=0°$. It is clear that the experiments are in striking disagreement with the predictions of the simple theory.

A more sophisticated calculation has been performed by Levinson and Banerjee,[3] treating the same direct-reaction mechanism, but going beyond the use of free-wave functions for the incoming and outgoing particles. Their wave functions are eigenfunctions of an optical potential. It is very interesting that these authors have been able to demonstrate an optical potential which permits reasonable fits to the entire range of the $C^{12}(p,p')$ data. The peak at $\theta=0°$ seems to be a particularly straightforward consequence of their work, appearing for a variety of potential types. We wish to indicate here that one can understand in a simple way why deviations from the elementary theory[2] should be most important near $\theta=0°$, and why these deviations then are such as to produce quite large cross sections.

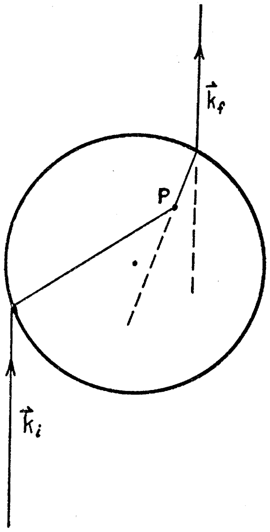

FIG. 1. Mechanism of production of the forward refracted peak in a direct inelastic reaction. Note that each ray is refracted at the nuclear surface in such a way that angular momentum is conserved. The actual change in angular momentum of the nucleus occurs at the point P.

From a semiclassical point of view, and assuming undeviated motion of the incident and outgoing particles through the nucleus, the linear momentum transfer $\mathbf{q}$ corresponds to an angular momentum transfer $|\mathbf{q}\times\mathbf{r}|$, where the reaction which produces the outgoing particle is assumed to be local and to take place at the point $\mathbf{r}$. A definite inelastic reaction requires a definite angular momentum transfer,

$$l=|\mathbf{q}\times\mathbf{r}|,$$

limiting the values of $\mathbf{r}$ at which the reaction can proceed. This is the origin of the selection rule which establishes the location of the first peak of the angular distribution. The minimum possible value of q is that for which $l=qR$, for $r>R$ gives no reaction.

When one considers that particles i and f can travel along rays which might be refracted at the nuclear surface, it is seen that $qR<l$ at $\theta=0°$ no longer need imply a small cross section. Examination of Fig. 1 shows that the refraction at the surface of an optical potential, in combination with a direct reaction in the interior, is able to produce an outgoing ray which while parallel to the incoming ray nevertheless has a quite different impact parameter. Thus the necessary angular momentum transfer is achieved, and the cross section will peak at $\theta=0°$. Naturally, this effect is enhanced by the fact that the basic interaction in any direct process always is strongest for small q.

Most of the rays which contribute for scattering angles much greater than $\theta=0°$ have the property that the incoming and outgoing rays exterior to the nucleus intersect at a point which is not very far from that at which the refracted rays in the interior also intersect. Thus refraction does not produce important changes at large scattering angles.

The semiclassical ideas discussed in this Letter show why an accurate quantum-mechanical calculation using distorted waves is able to produce a refracted forward peak. The shape and strength of the refracted peak are influenced by the range and depth of the optical potential. It seems interesting to us that many of the rays which enter into producing the refracted peak have had to pass through the deep interior of the target nucleus. Thus refracted forward peaks are to be expected only for fairly light and transparent nuclei. It is possible that the systematic study of such peaks will yield detailed information about the imaginary part of the optical model potential.

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Geomagnetic Coordinates and Cosmic Radiation

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WADDINGTON,[1] McDonald,[2] and Fay[3] have found that the geomagnetic cutoff in North America and in Europe does not agree with the values calculated from standard geomagnetic theory, but rather with those corresponding to a change of geomagnetic latitude of the order of 4° to 5°. Independent evidence has been adduced by Simpson and the Chicago group as well as by Rose and the Ottawa group[4] and has led them to propose a new system of "effective geomagnetic coordinates" for cosmic radiation. They have also given theoretical arguments to support their proposal.

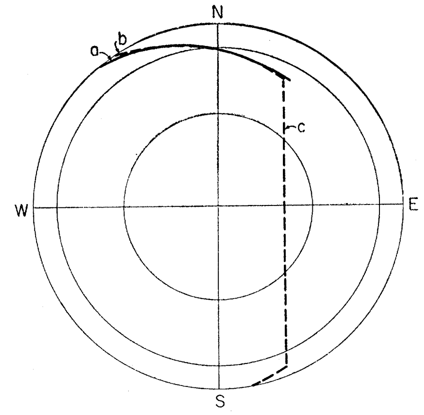

FIG. 1. The simple shadow cone for protons of energy 8.61 Bev at 30° north geomagnetic latitude and 8° 46′ west geographic longitude. (a) Present work with eccentric dipole and quadrupole magnetic field; (b) Schremp's simple shadow cone; (c) Störmer's cone. Zenith angle and azimuth are geomagnetic.

As early as 1935, Vallarta[5] pointed out that there are discrepancies in the position of the earth's magnetic center as determined from magnetic measurements on the earth's surface and from cosmic-ray observations. Further, the longitude effect due to the eccentricity of the earth's magnetic center is unable to account completely for all the experimental facts.[6] It now seems likely that, although the distant albedo due to secondary particles produced at some point of the earth and returned to some other point, undoubtedly contributes to the observed intensity, it cannot account completely for the observed discrepancies.[7]

At low latitudes (less than 25° geomagnetic) the intensity is determined essentially by the main cone,[8] which is bounded by trajectories asymptotic to the outermost family of periodic orbits, whereas at high latitudes it is fixed essentially by the shadow cone. The latter was calculated by Schremp,[9] taking into account the field of the magnetic dipole only. Now the simple shadow trajectories which determine the shadow cone have the property that, between their point of tangency and their point of impact, they stay at a distance from the earth's surface of the order of magnitude of the earth's radius. Since the magnetic quadrupole of the earth contributes as much as 15%, of the total field, depending on latitude, it was felt that the influence of the quadrupole on the simple shadow trajectories was not negligible. It was therefore decided to integrate the equations of motion taking into account both the eccentric dipole and quadrupole terms.

This integration has now been carried out[10] and preliminary results are given in Figs. 1 to 3. It is seen (Figs. 1 and 2) that at intermediate latitudes there is a marked longitude effect and at high latitude (Fig. 3)