distances. Also, as for shock-waves, first sound velocities would ultimately be observed for second sound pulse front arrivals (but dependent upon geometry rather than heat current input).

As first observed by Pellam and Scott[9] at 0.75°K and later by Atkins and Osborne[1] at lower temperatures, the received signals were found to be very much broadened, suggesting a dispersion effect.[1,9] If this represents a true property of liquid helium, independent of the apparatus, then predictions which take no account of dispersion must be theoretically inadequate. We shall give quantitative information in our final publication showing that, on the dispersion hypothesis, frequencies corresponding to the tail of the pulse travel at velocities several times slower than those constituting the pulse-front. Appreciable differences persist even at temperatures as high as 0.9°K. Clearly monochromatic velocity measurements are needed for the low temperature region.

Actually the results reported here were obtained by applying pulsed CW 22.5 kc/sec electrical signals to the heater generating the second sound. Since we employed no receiver frequency-discrimination, however, the resultant 45 kc/sec second sound signals were indistinguishable above the background dc component of the signal resulting from the current-squared (i.e., I^2R) heater output. Accordingly the measurements of Fig. 1 correspond to the wave-front velocity of the associated square wave pulses (our 80-μsec and 250-μsec duration pulses, bracketing Atkins' and Osborne's 100-μsec pulse duration, gave consistent pulse front velocities at the lowest temperatures).

On the other hand, when employing pulsed CW 7.5 kc/sec electrical signals (250-μsec duration), a "hump" appeared superposed on the mid-portion of this dc background envelope. The leading edge of this hump would correspond to a velocity for the associated 15-kc/sec second sound of the order of 100 m/sec (at the lowest temperatures).

Prior to publication of the final paper, wave velocities will be remeasured in the 0.02°K–0.4°K range at lower pulse input levels, in order to clarify the situation regarding possible shock-wave effects.

Note added in proof: Professor Kramers,[10] in a final paper just published, had concluded that the decrease in second sound velocity should occur "at the same temperature as the increase above aT^3 of the specific heat" (i.e., in neighborhood of 0.65°K). The results reported above appear to substantiate Professor Kramers' viewpoint very well.

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Negative Primaries as Part of Cosmic Radiation

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THE low value of the observed east-west asymmetry has always raised suspicion concerning the existence of negatively charged particles in the primary cosmic radiation. Since mesons are absent because of their unstability, and experimental evidence[1,2] is available to show the absence of any significant amount of electrons, the presence of a negative heavy component would raise a very fundamental question, i.e., the existence of anti-matter. From a critical analysis of the experimental data on the azimuthal intensity variation, we find that these data are consistent with the primary radiation containing 20 percent negatively charged particles.

Table I. Azimuthal variation at $\lambda=0°$, $Z=40°$.

Magnetic azimuth α	$E(\alpha Z)$ milli-stormer	$I(\alpha Z)$ A calculated $\gamma=2.2$ $\sigma=\infty$	B calculated $\gamma=2.2$ $\sigma=4$	C observed at height of 24 g cm^{-2}	D calculated $\gamma-m=1.686$ $\sigma=\infty$
0	528	10.000	10.000	10.000	10.000
30	578	8.048	8.952	8.889	8.833
60	625	6.670	8.296	8.222	7.932
90	642	6.255	8.052	8.000	7.647
120	625	6.670	8.296	8.444	7.932
150	578	8.048	8.952	9.333	8.833
180	528	10.000	10.000	10.667	10.000
210	480	12.570	11.666	11.778	11.400
240	448	14.800	13.174	12.884	12.510
270	443	15.240	13.443	13.334	12.720
300	448	14.800	13.174	13.111	12.510
330	480	12.570	11.666	12.222	11.400

We assume the differential energy spectrum to be $K/E^{\gamma}dE$, in conventional units, and we denote by σ the ratio of the positive to the negative primary radiation. The latitude effect and the north-south asymmetry depend entirely on γ and are independent of σ. We take $\gamma=2.2-2.1$ from the latitude effect of the primary particles observed by Winckler *et al.*[3] In Table I the calculated

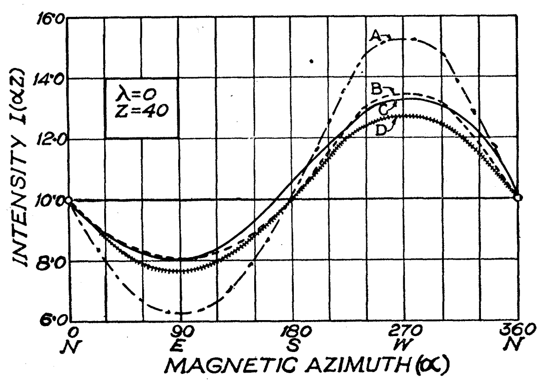

Fig. 1. Azimuthal variation of primary cosmic rays at $\lambda=0$, $Z=40°$. The theoretical curves are A: $\gamma=2.2$, $\sigma=\infty$; B: $\gamma=2.2$, $\sigma=4$; and D: $\gamma-m=1.686$, $\sigma=\infty$. C is the experimental curve at a depth of 24 g cm^{-2}.

intensity $I(\alpha Z)$ for a given magnetic azimuth α and zenith angle Z is given,[4] taking the minimum energy of arrival for the main cone.[5] The intensity due north is taken as 10.000, and all the experimental data are reduced accordingly for convenience of comparison.

In Fig. 1 the results are shown graphically for $\lambda=0$, $Z=40°$. The experimental data of Winckler *et al.* at a depth of 24 g cm^{-2} (curve C) shows poor agreement with the calculated intensity for primary radiation which is entirely positively charged (curve A). The

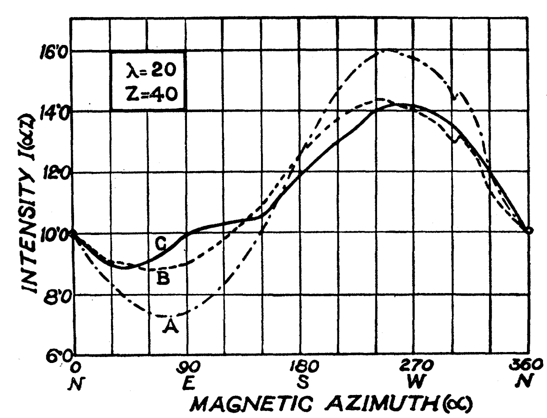

Fig. 2. Azimuthal variation of primary cosmic rays at $\lambda=20$ N, $Z=40°$. The theoretical curves are A: $\gamma=2.1$, $\sigma=\infty$; B: $\gamma=2.1$, $\sigma=4$. C is the experimental curve at a depth of 15 g cm^{-2}.

calculated intensity for $\sigma=4$ (curve B) shows excellent agreement. One can assume, however, that the multiplicity in the atmosphere is given by $M=JE^m$. This reduces the effective value of the exponent to $\gamma-m$. We choose $\gamma-m=1.686$ to get agreement with the observed east-west asymmetry. The curve D for $\sigma=\infty$ obtained after introducing multiplicity does not show good agreement with the experimental curve B, though both the curves D and B have same east-west asymmetry.

For $\lambda=20$, because of the asymmetry of the allowed cones about the east-west plane, the superposed azimuthal curve for mixed primaries is very much different from the curve for primary radiation which is entirely positively charged. In Fig. 2 we show the results of our calculations for $Z=40°$ and compare them with the experimental data of Winckler *et al.* As before, the agreement with the experimental curve (C) is excellent for 20 percent negatively charged primaries (B) and is very poor for primaries which are entirely positively charged (A).

In Fig. 3(a) we plot the azimuthal effect at sea level calculated after introducing multiplicity in the atmosphere (dotted line). As already pointed out, the north-south asymmetry is independent of σ, and this is a guide to the estimation of $\gamma-m$. For $\lambda=20$ N, $Z=20°$, we take $\gamma-m=1.35$–1.60 and $\sigma=4$. The agreement with the unpublished data of Bhowmik and Bajwa[6] for $\lambda=19$ N is very good. The hump at 285° is the result of the contribution from the penumbra.[7]

In Fig. 3(b) the results calculated for $\lambda=20$ N, $Z=40°$, after taking into account the absorption in the atmosphere, have been

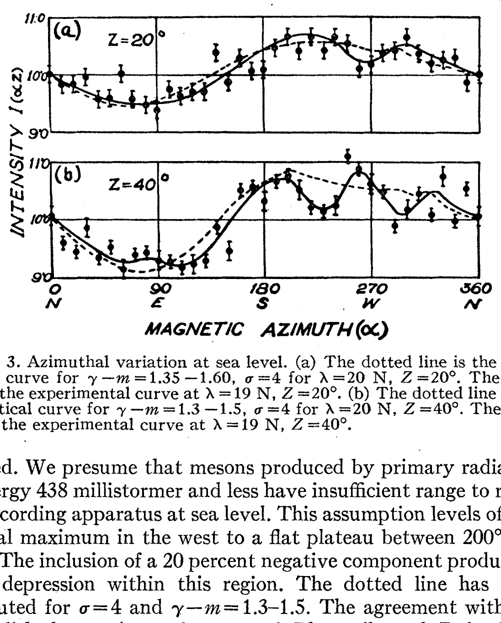

FIG. 3. Azimuthal variation at sea level. (a) The dotted line is the theoretical curve for $\gamma-m=1.35-1.60$, $\sigma=4$ for $\lambda=20$ N, $Z=20°$. The solid line is the experimental curve at $\lambda=19$ N, $Z=20°$. (b) The dotted line is the theoretical curve for $\gamma-m=1.3-1.5$, $\sigma=4$ for $\lambda=20$ N, $Z=40°$. The solid line is the experimental curve at $\lambda=19$ N, $Z=40°$.

plotted. We presume that mesons produced by primary radiation of energy 438 millistormer and less have insufficient range to reach the recording apparatus at sea level. This assumption levels off the general maximum in the west to a flat plateau between 200° and 290°. The inclusion of a 20 percent negative component produces a little depression within this region. The dotted line has been computed for $\sigma=4$ and $\gamma-m=1.3$–1.5. The agreement with the unpublished experimental curve of Bhowmik and Bajwa[8] for $\lambda=19$ N is very good. The hump at 310° is the result of the penumbra, and the agreement in this part is excellent. However, there are two other humps at 190° and 260°, with a minimum at 230° in the experimental curve. The inclusion of a negative component explains only this depression, qualitatively.

The present analysis clearly indicates a very powerful method of deciding about the existence of negative primaries. A detailed account of the present work will be published shortly in the *Indian Journal of Physics*.

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Relation Between the Photoproduction and Scattering Cross Sections for π-Mesons in Complex Nuclei*

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THE cross sections for photoproduction of charged π-mesons in nuclei of mass number $A\geqslant 10$ have been experimentally found to vary as $A^{2/3}$.[1,2] Furthermore, several experimental studies[3,4] of the inelastic scattering and absorption cross section of π-mesons in nuclei have indicated that this is nearly equal to nuclear area for the same range of values for A. These results suggest a short mean free path λ for nuclear interaction of the pion; however, a careful analysis by Byfield *et al.*[3] and by Steinberger[5] of their own scattering experiments have indicated that $\lambda=8\times10^{-13}$ cm. Consequently, the question has been raised[6,7] whether the A-dependence of the photo cross section can be interpreted as due to the reabsorption of produced mesons.

Such analyses (as well as the concept of a mean free path) and interpretations have been based on the "optical model." Our present purpose is to argue that the A-dependence of the photo and scattering cross sections does not seem to be inconsistent with the optical model. We do not consider the question of the validity of the optical model.

The optical model describes the interaction of the meson with the nucleus by the complex potential,

$$V=[V_0-iv_\pi/2\lambda]\rho(\mathbf{z}), \tag{1}$$

where V_0 is the "real well depth" and $\rho(\mathbf{z})$ is the density of nucleons in the nucleus normalized to

$$\int\rho(\mathbf{z})d^3z=V_A, \tag{2}$$

the volume of the nucleus. v_π is the velocity of the meson. The Schrödinger equation to describe the scattering of the meson is

$$[h+V]\varphi_q(\mathbf{z})=E\varphi_q(\mathbf{z}), \tag{3}$$

where q is the momentum of the incoming meson and h is the kinetic energy operator for the meson.

The solution to the complex conjugate of Eq. (3) is $\varphi_q^-(\mathbf{z})$, where

$$\varphi_q^-(\mathbf{z})=\varphi_{-q}^*(\mathbf{z}) \tag{4}$$

("$-q$" means "$-\mathbf{q}$"). φ_q^- and φ_q have the same initial boundary conditions, but φ_q^- has converging whereas φ_q has diverging scattered waves.

We describe the photoproduction of a meson from the lth nucleon by

$$H_l'=N_l\delta(\mathbf{z}-\mathbf{z}_l), \tag{5}$$

where $\mathbf{z}$ is the meson coordinate and $\mathbf{z}_l$ is the coordinate of the lth nucleon. N_l is assumed independent of $\mathbf{z}$ and to depend upon $\mathbf{z}_l$ through a phase factor only. This assumption localizes the photoproduction to the vicinity of the lth nucleon and enables us to apply the optical model in a simple manner.

Treating H_l' as a small perturbation, the transition operator for the photoproduction of a meson with momentum $\mathbf{q}$ is[8]

$$T_l=(\varphi_q^-(\mathbf{z}),H_l'(\mathbf{z}))=N_l[\varphi_q^-(\mathbf{z}_l)]^*. \tag{6}$$

The cross section for photoproduction from the entire nucleus is

$$\frac{d\sigma_\pi}{d\Omega}=2\pi\rho_f\sum_l\int|T_l|^2\frac{\rho(\mathbf{z}_l)}{V_A}d^3z_l, \tag{7}$$

where ρ_f is the density of final meson states and $|T_l|^2$ is averaged over the *probability distribution* of the positions of the lth nucleon in the nucleus. We neglect interference between meson waves produced by *different* nucleons in Eq. (7). To compare $d\sigma_\pi/d\Omega$ with the data of Littauer and Walker,[2] we take this to be the sum of the positive and negative pion cross sections.