the conversion efficiency is quite insensitive to the choice of numerical values of these parameters. The solar spectrum has been approximated by the distribution from a black body at a temperature of 5760°K with an integrated intensity at the earth's surface of 0.1 watt/cm^2.

Note that the conversion efficiency increases with the degree of doping because of an increase in the height of the potential barrier; that the band separation best matching the solar spectrum is, as noted above, 1.5–1.6 ev; and that the maximum obtainable efficiency (assuming that the saturation solubility of donors and acceptors is of the order of 10^{19}/cm^3) is roughly twenty five percent, corresponding to a power output of about 250 watts/meter^2 in full sunlight. A slight further increase in efficiency may be realized with the use of an optical collection system which increases the radiation intensity at the photocell surface. Note in addition that silicon is clearly a better choice for the present purpose than other materials that have been proposed[2,5,6] such as germanium and cadmium sulfide ($\Delta E=2.4$ ev) but that silicon is in turn surpassed by aluminum antimonide. The superiority of AlSb over Si with respect to conversion efficiency would prevail even if the minority carrier lifetimes were lower by several orders of magnitude in the former material. The possibility of substantially improving the efficiency of experimental units over that heretofore realized[1] appears quite promising.

It is a pleasure to acknowledge several valuable discussions with Dr. F. K. du Pré and with T. R. Kohler.

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Influence of the Geomagnetic Field on the Extensive Air Showers

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RECENTLY, Cocconi[1] published a paper on the influence of the geomagnetic field on the extensive air showers. According to this calculation the shape of the lateral spread of an extensive shower should not be circular, but elliptical, the main axis in the east-west direction being about twice as long as the other one.[2]

In July, 1954, we measured this effect on the top of Lomnický Štít (altitude 2634 m, 48° N geomagnetic latitude). We used two telescopes, each of which consisted of two trays of five argon-ethylene counters (two of them 40×500 mm, three of them 45×600 mm). The distance between these telescopes was 7 m. The separation of the trays of counters in the telescope was 800 mm. The telescopes were at the zenith angle of 45°, successively oriented towards east, west, north, and south; and fourfold coincidences were recorded. The results are as follows:

E: 45.2 ± 2.9 coincidences per hour,
W: 50.1 ± 2.6 coincidences per hour,
N: 38.3 ± 2.3 coincidences per hour,
S: 38.5 ± 2.3 coincidences per hour.

In view of the rather large statistical errors, we would not like to draw any conclusion about the precise value of the influence of the geomagnetic field on the extensive air showers, but it seems that our measurements prove the existence of such an effect. The measurements are being continued. A more complete paper, containing also a discussion of the results, will be published soon in the *Czechoslovakian Journal of Physics.*

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Coulomb Interference Effects in Proton-Proton Scattering*

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COULOMB interference effects in proton-proton scattering should be useful in discriminating between different combinations of phase shifts which equally well describe the cross section and polarization arising from purely nuclear interactions.[1] Calculations have been made of these effects for 200 Mev on the assumption only that s and p waves enter into the interaction.

In order to include the Coulomb interaction, the Møller formula for relativistic electron-electron scattering has been generalized by adding a Pauli term to the interaction Hamiltonian, to account for the proton's anomalous magnetic moment $\mu_a=1.793$. The Coulomb scattering matrix so obtained may conveniently be written, correct through terms of order $1/\theta$,

$$M_c=M_{c+}+M_{c-},\quad M_{c-}{}^S(\theta,\phi)=(-1)^S M_{c+}(\pi-\theta,\pi-\phi),$$

$$M_{c+}=-\frac{\eta}{2k\sin^2(\theta/2)}\left[1-\nu i\left(\frac{\boldsymbol{\sigma}_1+\boldsymbol{\sigma}_2}{2}\right)\cdot\mathbf{n}\sin\theta\right],\quad (1)$$

$$\nu=\frac{(\epsilon-1)}{(2\epsilon^2-1)}[(2\epsilon+1)+2\epsilon(\epsilon+1)\mu_a].\quad (2)$$

Here S is the total spin, $\boldsymbol{\sigma}_1$ and $\boldsymbol{\sigma}_2$ are the Pauli spin matrices for particles 1 and 2, θ and ϕ are the c.m. scattering angles, k is the c.m. momentum/$\hbar$ of each proton, ϵ is the c.m. total energy of each particle/mc^2, $\eta=e^2/\hbar v$, with v the incident velocity in the laboratory system and $\mathbf{n}$ is the unit normal to the scattering plane $(\mathbf{n}=(\mathbf{k}_i\times\mathbf{k}_f)/|\mathbf{k}_i\times\mathbf{k}_f|)$.[2] In order to make M_c reduce to the exact nonrelativistic formula, M_{c+} as given by Eq. (1) was multiplied by the Coulomb phase factor $\exp[-2i\eta\times\ln\sin(\theta/2)]$ for the numerical computations.

The total scattering matrix is $M=M_c+M_N$, where M_N is the nuclear scattering matrix which can be expressed in terms of phase shifts in the manner of Ashkin and Wu,[3] except that each factor $[\exp(2i\delta_L{}^J)-1]$ has been multiplied by $\exp 2i(\eta_L-\eta_0)$, where $\eta_L=\arg\Gamma(1+L+i\eta)$. The scattering matrix M so expressed may be substituted into the formulas of Wolfenstein and Ashkin[4] for the unpolarized cross section $\sigma(\theta)$ and the polarization $P(\theta)$:

$$\sigma(\theta)=\tfrac{1}{4}\,\mathrm{Tr}MM^+,\quad \sigma(\theta)P(\theta)\mathbf{n}=\tfrac{1}{4}\,\mathrm{Tr}MM^+\boldsymbol{\sigma}_1, \qquad (3)$$

giving expressions for σ and P in terms of the phase shifts.

This has been done for the case where only s and p phase shifts are supposed to exist, yielding expressions for σ and P in terms of the following $\delta_L{}^J$; $\delta_0{}^0$, $\delta_1{}^0$, $\delta_1{}^1$, and $\delta_1{}^2$. Calculations reported previously[5] enable one to select, subject to the restriction to $L<2$, all phase shifts consistent with isotropy of the unpolarized cross section and any given values of σ and P in the angular region where Coulomb effects are negligible. For such angles experimental data gives $\sigma(\theta)=3.56$ mb/sterad, $P(45)^\circ=0.22$, at 213 Mev.[6–7] By the use of these values the possible $\delta_L{}^J$ are limited to values lying on a one-parameter curve with four branches, in the space of the four $\delta_L{}^J$. These branches differ from each other in the sign of $\delta_0{}^0$ and of the $\delta_1{}^J$. Thus, if a certain point on one branch is $\delta_0{}^0$, $\delta_1{}^J$ the corresponding points on the other branches are $\pm\delta_0{}^0$, $\pm\delta_1{}^J$ (all of the $\delta_1{}^J$ preserve the same sign relative to each other). For the present calculation the values of the phase shifts given in Table I of the previously published letter[5] (which are representative points on one of these branches corresponding to 200 Mev) have been revised to fit the lower value of $\sigma(\theta)$ quoted above.

Of all possible phase shifts so determined, seven sets were found which also give $\sigma(\theta)$ in accord with the small-angle measurements,[8–9] where Coulomb effects are important. These are given in Table I, along with values of the corresponding polarization at 15°, where the Coulomb interference effect is strongest.[10]

TABLE I. Phase shifts $\delta_L{}^J$ for 213 Mev chosen to fit the following data: $\sigma(\theta)=3.56$ mb/sterad independent of θ with no Coulomb interference, $\sigma(15°)=1.02\sigma(90°)$, $|P(45°)|=0.22$. The last column gives the polarization at 15°.

Set	$\delta_0{}^0$	$\delta_1{}^0$	$\delta_1{}^1$	$\delta_1{}^2$	$P(15°)$
a	29	48	−7	−7	−0.133
b	20	−13	25	−12	−0.106
c	0	−69	5	4	0.065
d	37	−37	6	10	0.103
e	−36	41	−6	−8	−0.120
f	−38	−31	4	12	0.112
g	−30	10	−16	17	0.132

It turns out that the spin-dependent term in the Coulomb scattering matrix, Eq. (1), plays a negligible role in the unpolarized cross section, while for the polarization it is of about the same importance as the spin-independent term.

Recent experiments at Harwell[11] at 133 Mev indicate that $P(\theta)$ does not vary as $\sin(2\theta)$ between 30° and 45° c.m. The Coulomb effects are not large enough at these angles to explain the divergence, so that there appears to be some contribution from other than s and p waves at this energy.

Further details about these and related calculations will be published later. The author wishes to thank Professor Lincoln Wolfenstein, who suggested looking into Coulomb interference effects, for his interest and valuable advice. He is also grateful for helpful discussions with Professors Gian-Carlo Wick and Julius Ashkin.

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High-Energy Electron Pair Produced by 113-Mev Positive Pion*

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A HIGH energy pair of electrons has been found in a nuclear emulsion exposed to the 122-Mev positive pion beam of the University of Chicago synchrocyclotron.

During measurements on positive pion-proton scattering,[1] 600-micron Ilford G-5 plates were scanned for "possible hydrogen events," that is, all stars which in addition to the incident pion had a single black prong in the forward hemisphere. The average energy of the pions in the plate is 113±2 Mev. These "possible