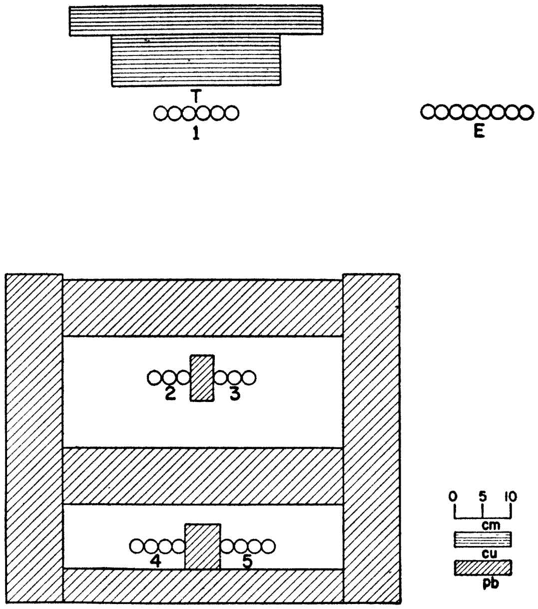

FIG. 1. Arrangement for observing penetrating showers.

with copper over a prolonged period, and the results are presented here.

The apparatus was set up at Ottawa (about 300 ft above sea level) and consisted of a fivefold coincidence set P containing five trays of counters as shown in Fig. 1. Trays 2 and 3 had 4-cm lead between them, and trays 4 and 5, 6-cm lead between them. Ten cm of lead was placed above each of these pairs of trays as shown, and these two groups of trays were surrounded on all sides by lead walls 10 cm thick. Thus the coincidence set P recorded showers of at least two particles of range greater than 20-cm lead. In addition to the set P, an unshielded tray of eight counters (E) was placed at a distance of 50 cm from tray 1 for detecting the presence of air showers and thus separating them from the showers generated in copper.

Besides observing the fivefold coincidences P, records were taken of the coincidences P accompanied by a discharge in any of the counters of the air shower tray E. Such coincidences are called (P, E). The anticoincidences $(P, -E)$, i.e., fivefold coincidences P which were not associated with a discharge of the air shower tray E, are classified as local penetrating showers or simply "local showers," while the coincidences (P, E) are classified as extensive penetrating showers or simply "extensive showers." This is in conformity with the nomenclature already established by previous workers:[1]

The counters were one inch in diameter and have an active length of 16 inches. Each counter group was connected to Neher-Harper type quenching devices. The resolving time of the circuits was of the order of 10^{-5} sec. The individual counter groups were tested once a week during the course of experiment.

TABLE I. Dependence of penetrating showers on the thickness of copper at sea level (Ottawa $\lambda = 56.8°$; $h \sim 300$ ft).

Thickness Inch	Thickness g/cm²	Time t (hr)	Local showers $(P, -E)$ n	Local showers $\frac{n}{t} \pm \frac{\sqrt{n}}{t}$	Extensive showers (P, E) n	Extensive showers $\frac{n}{t} \pm \frac{\sqrt{n}}{t}$
0	0	475	98	0.206 ± 0.02	93	0.196 ± 0.02
1	22.6	476	143	0.30 ± 0.025	111	0.233 ± 0.02
$2\frac{1}{2}$	56.5	475	172	0.362 ± 0.03	124	0.261 ± 0.02
5	113	505	194	0.384 ± 0.03	119	0.235 ± 0.02
$7\frac{1}{2}$	170	423	150	0.354 ± 0.03	91	0.215 ± 0.02
10	226	458	149	0.325 ± 0.027	95	0.207 ± 0.02
$12\frac{1}{2}$	282	408	102	0.25 ± 0.025	76	0.186 ± 0.02

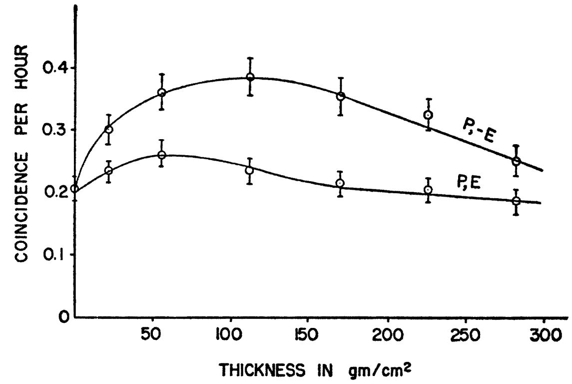

FIG. 2. Transition curves in copper for (a) local penetrating showers (curve $P, -E$), (b) extensive penetrating showers (curve P, E).

The copper absorbers were in the form of plates 6 in.×24 in. ×½ in. and were placed at T close above the top tray 1. Absorbers were placed in a "cyclic manner," changing to a different thickness of copper after every two or three days so as to avoid any instrumental selectivity.

The results of about five month's continuous observation are given in Table I and these are plotted in Fig. 2.

The transition curve for extensive showers (curve P, E) gives an indication of a cascade type maximum showing that in air showers electrons are present along with groups of penetrating particles and that these electrons are responsible for the slight increase in shower intensity. The position of this maximum is near 6- to 7-cm copper corresponding to 4 cascade units in agreement with the result obtained by George and Jason[1] in the case of lead.

The curve for local showers (curve $P, -E$) shows a marked transition effect with signs of a saturation in the vicinity of 80 to 120 g/cm² of copper. The primary radiation producing such showers appears to have a collision length of this order, which corresponds approximately to the geometrical cross section of copper nuclei.

In regard to the number of primary particles responsible for local showers it was found further that there was about one such primary for every 6000 mesons crossing the absorber within the cone formed by the extreme counters, *viz.*, by tray 1 and trays 4 and 5 put together.

The probabilities of knock-on showers were determined by the method adopted by Janossy[2] and found to be 0.008 per hour, a very small contribution compared to the observed shower rate.

In conclusion, the author expresses his sincere thanks to Dr. D. C. Rose for the interest he has taken in this work.

* On leave from the University of Calcutta, India. Holder of a National Research Council postdoctorate fellowship.

[1] E. P. George and A. C. Jason, Proc. Phys. Soc. (London) **A63**, 1081 (1950).
[2] L. Janossy, Proc. Roy. Soc. (London) **A179**, 361 (1942).

High Energy Nucleon-Nucleon Scattering*

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ATTEMPTS[1] to account for high energy nucleon-nucleon scattering by means of a symmetric hamiltonian have met with difficulty. In the Case-Païs work the sign of the spin-orbit term is opposite to that convenient for the shell model. In Jastrow's calculations[1] the connection between the mass of the π-meson and the apparent range of force is hard to maintain. Without a hard core, low energy proton-proton scattering favors a meson mass of $\sim 330\ m$. With a hard core the agreement with the measured mass of the π-meson is even worse. Approximate magnitudes can be estimated by observing that if the scattering length approaches infinity conditions of equivalence for scattering cross section at zero energy and for rate of change with energy give

$$r_0 = r_0' + r_1',$$

where r_0 is the radius of the square well without core, while r_1' is the core radius and r_0' is the outer radius of the modified square well. If $r_0 = 2.7\times10^{-13}$ cm and $r_1' = 1\times10^{-13}$ cm, then $r_0' = 1.7\times10^{-13}$ cm. A shortening of range in the ratio 1.7/2.7 gives an increase of meson mass by the factors $\sim$2.7/1.7, which corresponds to a mass $\sim$500 m. Unpublished calculations of M. H. Hull and A. Herschman support the conclusion that the apparent meson mass is too high. They also find that the p-p and p-n interactions are in slightly poorer agreement with the core than without. An exact agreement with the measured mass is hardly to be expected, and reasons for differences of the order of 10 or 20 percent can be given.[2] The connection with meson theory becomes forced, however, if the disagreement is by a factor of about 2.

The approximate independence of the p-p scattering cross section on the scattering angle is usually made to appear as a result of the superposition of angle dependent effects. For a few Mev bombarding energy it is very probable that one deals with pure S-scattering. No definite effects have been observed which would indicate the setting in of p or d waves between 0.2 Mev and 30 Mev. There is an uninvestigated gap of energies between 30 Mev and 75 Mev. From here on[3] the scattering is again spherically symmetric. The standard reason for assuming that at the higher energies superposition of angle dependent effects takes place is that the cross section is too large for pure S-scattering.

There appears to be no compelling reason for supposing that at energies comparable with the rest mass energy of the π-meson the collision process does not change the nature of the protons. If, after collision, the protons are not identical, they can exist in ^3S as well as ^1S states. A statistical factor 4 is gained and the explanation of angular independence can again be reduced to dominance of S-scattering. The changed state of the proton need not be one of different mass. Any change, even that of an otherwise unobservable internal coordinate, would be satisfactory. It would be of interest to see whether scattered protons are identical with other protons in all respects. Effects depending on symmetry properties of the wave-function would be most decisive. In principle there is the possibility of rescattering. Polarization effects would have to be separated from effects sought for in such tests.

If collisions produce isomeric states it would be natural to suppose that the formation occurs through an intermediate state of the two-nucleon system, requiring for its formation a relative kinetic energy of the order of the meson mass energy. The observed flatness of the cross-section energy curve for p-p scattering would be the result of compensation of the decrease in scattering of identical protons and an increase in scattering of nonidentical ones. The view discussed above has been presented in part at the Chicago International Conference on Nuclear Physics and Fundamental Particles.

* Assisted by the joint program of the ONR and AEC.
1 Chamberlain, Segrè, and Wiegand, Phys. Rev. **83**, 923 (1951). This paper contains a discussion of theoretical work and references to articles quoted in present note.
2 G. Breit and M. C. Yovits, Phys. Rev. **81**, 416 (1951).
3 Birge, Kruse, and Ramsey, Phys. Rev. **83**, 274 (1951).

Limitations on Mass Changes of Scattered Nucleons*

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In connection with the preceding note[1] it is of interest to determine the degree to which scattering experiments performed by the coincidence method exclude changes in mass of protons on scattering. The collision of two particles of equal mass M is considered. After the collision the mass of one of the particles is taken to be M and of the other M_1. In the reference system of zero momentum (rest system) the scattering angle for the particle of mass M is taken to be θ. The angle between the directions of motion of the two particles when observed in the reference system in which one of them is at rest before the collision (laboratory system) is denoted by

$$\chi = (\pi/2) - \delta.$$

For small values of $\Delta M/M = (M_1 - M)/M$ and small velocities, conservation of energy and momentum gives the approximate value

$$\tan\delta = (\beta^2/2)\sin\theta + \cdots + (\Delta M/2M)(1-\beta^2)^{\frac{1}{2}}[(\beta^{-2}/\sin\theta) + \cot\theta - \tfrac{1}{2}\sin\theta] + \cdots,$$

where $\beta = v/c$ and v is the velocity in the rest system before the collision. The first term is an approximation to the relativistic effect which makes χ differ from $\pi/2$ even if the masses are equal. The second term shows the effect of changing one of the masses. The incident energy in the laboratory is $2Mc^2\beta^2/(1-\beta^2) = T$. Introducing $\epsilon = T/(2Mc^2)$, one has $\beta^2 = \epsilon/(1+\epsilon)$ and the effect of ΔM on $\tan\delta$ is

$$\delta' = [\Delta M/(2M\epsilon\sin\theta)]\{1+\epsilon[\cos\theta + \tfrac{1}{2}\cos^2\theta]\}.$$

Terms of relative order ϵ have been kept. For $T = 300$ Mev the factor in braces is close to 1, and one has the approximation

$$\delta' = c^2\Delta M/(T\sin\theta).$$

If δ' is allowed to be 1°, then at 100-Mev bombarding energy one may suppose $c^2\Delta M = 0.87$ Mev; while at 300-Mev, bombarding energy $c^2\Delta M = \pm 2.6$ Mev would not be excluded for $\theta = 30°$. This scattering angle corresponds to $\Theta = 15°$. It is not clear from the publications on high energy scattering whether the relativistic angle relation is obeyed to better than 1°. The more significant tests are those having to do with small scattering angles. Presumably these are the least favorable for good geometry. Tests at $\Theta \cong 45°$, $\theta = 90°$ to 1° would limit the mass within $\sim\pm 1.7$ Mev for 100-Mev incident energy. In either case the change in mass is not so small as to discourage tests.

* Assisted by the joint program of the ONR and AEC.
1 G. Breit, Phys. Rev. **84**, 1053 (1951).

Thermal Expansion and Specific Heat of Tungsten Oxide at High Temperatures

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We have previously reported[1] that tungsten oxide has ferroelectric properties and that its Curie point seems to be situated at about 710°C; these results followed from our observations of many of its properties, i.e., domain structure, hysteresis loop, permitivity, thermal expansion, specific heat, etc. Afterwards it was ascertained, by x-ray analysis,[2] that the crystal structure changes from orthorhombic to tetragonal ($a=b$) at 700$\sim$750°C. In addition to our previous investigations, we shall now report briefly the quantitative results of our observations of thermal expansion and specific heat above room temperature.

The thermal expansion was measured by a dilatometer of the rotating-rod type with a sensibility of $\Delta l/l = 4\times10^{-6}$. Figure 1 shows the linear thermal expansion coefficient, measured by heating at a rate of about 2°C/min. A rather gradual expansion is observed at 330°C and a remarkable contraction at 755°C, the latter amounting to about $\Delta l/l = 1.2\times10^{-3}$. On cooling, a temperature hysteresis exists for one anomaly but not for the other; that is, the anomalies of the thermal expansion coefficient in the cooling process are observed at 725°C and 330°C, respectively. We measured the specific heat by a vacuum calorimeter of the same type as the ones used by Bantle[3] for KH_2PO_4