pected since the Debye temperature for lattice vibrations in the basal plane is higher than for the vibrations transverse to these planes. If the hypothesis of vacancy diffusion is correct, then it would appear that the diffusing atom halfway between two vacancies in the same basal plane is in a position of higher energy than a similar atom halfway between vacancies in adjoining planes. A comparison of the electrostatic energy of the two situations has been made on the assumption that the two valence electrons per atom are uniformly distributed in space. For a close-packed hexagonal lattice the migrating atom would have in each case four nearest neighbors at a distance $\sqrt{\frac{2}{3}}$ times the lattice constant and the difference in energy would be small. The zinc lattice, however, departs considerably from close-packing (c/a is 1.86). The calculations for this case were carried out by the Ewald method[3] and showed that the configuration corresponding to basal diffusion lies higher by $0.055(2e)^2/a$ or 2.7×10^4 cal./mole. This is about two and a half times the difference between the Q values. It might be expected that such simplified considerations would give too large a result, first because the two conduction electrons in metallic zinc probably behave quite differently from free electrons, and secondly because polarization effects will tend to reduce all electrostatic terms and differences between such terms.

[1] P. H. Miller, Jr., and Floyd R. Banks, Phys. Rev. **61**, 648 (1942).
[2] H. B. Huntington, Phys. Rev. **61**, 325 (1942).
[3] P. P. Ewald, Ann. d. Physik **64**, 253 (1921).

Erratum: Simple Method for the Investigation of Secondary Electrons Excited by γ-Rays and the Interference of These Electrons with Measurements of Primary β-Ray Spectra

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(Phys. Rev. **63**, 73 (1943))

ON page 76, first column, the lines which read "for the primary β-particles a range of 0.36-mm Al corresponding to 0.098 g/cm²," should be changed to read "for the primary β-particles a range of 0.36 mm corresponding to 0.13 g/cm²."

Mesotron Mass and Heavy Tracks on Mt. Evans

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April 30, 1943

ABOUT ten fairly reliable observations of the mesotron mass have been published.[1] Most of these are consistent with a mass approximately 180 times the electron mass, but they do not constitute conclusive evidence for uniqueness of the mass. It is thus clearly desirable that more observations of the mass be obtained, both to determine whether it is unique and to fix its value more precisely.

An expedition to Mt. Evans was made for the primary purpose of obtaining such observations. The ionization and momentum of cosmic rays were observed simultaneously in a Wilson cloud chamber by photographing tracks curved by a magnetic field of 2500 oersted, and diffused sufficiently to permit photographic resolution of single droplets. A delay of ~0.15 second between reduction of the clearing field from ~20 v/cm to ~2 v/cm and expansion of the chamber was provided. Most of the photographs were of random expansions, and this time of reduced clearing field corresponds to the interval before expansion during which a track remains to be observed. It has been shown[2, 3] that condensation upon even a small fraction of the negative ions indicates a supersaturation sufficient to give condensation upon substantially all positive ions; and this result is valid for any water-ethyl alcohol mixture in a broad range around the 70 percent alcohol mixture requiring minimum expansion. The number of droplets formed in a positive track with an associated negative is therefore equal to the number of ion pairs. An enlarged section of a typical mesotron track pair is reproduced in Fig. 1.

Mass determination from ionization and curvature depends upon a knowledge of the relation between ionization and speed. The generally accepted form of this relation is expressed in the theoretical equation

$$I=\frac{A}{\beta^2}\left(\log\frac{\beta^2}{1-\beta^2}+K-\beta^2\right).$$

This is the function used by Corson and Brode[4] to obtain mass from ionization and curvature. The experiments of C. T. R. Wilson and E. J. Williams[5] have yielded an experimental relation based upon counts of primary ionization of slow electrons. Their work is summarized by the equation $I=I_0\beta^{-1.4}$, which has been used by Williams and Pickup to derive mass values. For comparison it is interesting to note that the theoretical equation is well represented in the interval $0.20<\beta<0.90$ by $I=I_0\beta^{-1.8}$. Mass values derived from the experimental curve are larger than values from the theoretical curve. This uncertainty in interpretation would be removed and at the same time the possibility of error from inaccurate ionization measurement would be eliminated if one were to observe under identical conditions the curvature and ionization of slow electrons of the same speed as the mesotrons. This procedure would permit an unambiguous mass assignment: Two particles with equal charge ionize equally when moving at the same speed, and their masses are then proportional to their momenta or $H\rho$ values. Experiments to determine the ionization of slow electrons are in progress, but until their completion the mass values are subject to a possible error. For the present, computations from the Corson and Brode nomograph and the Williams curve are both given.

Approximately 7000 photographs were taken on Mt. Evans, 14,100 ft. and 1800 were taken at Summit Lake, 12,700 ft. The photographs show numerous heavily ionizing tracks with negligible curvature produced by particles —presumably protons—much heavier than mesotrons. These heavy tracks were present in about eight percent of the pictures at 14,100 ft. and in about four percent of the pictures at 12,700 ft. Each picture records events in an interval ~0.3 sec., and in a volume ~1500 cm³. Only six heavily ionizing mesotrons have yet been identified. Since

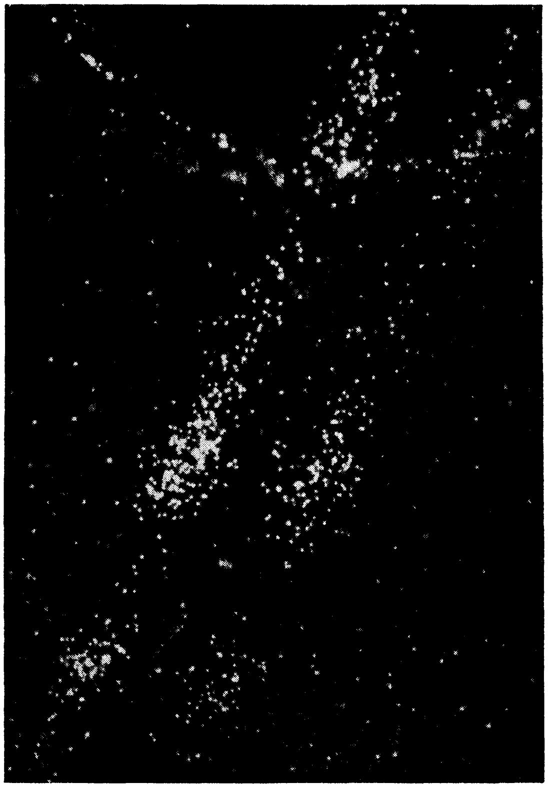

FIG. 1. Section of mesotron track 6949, enlarged to about three times its size in the cloud chamber. Ion pairs are separated into positive and negative columns, with the positive on the left side. At the top a sharp electron track crosses the picture.

they are quite conspicuous it is probable that not many more will be found by additional study of the pictures. Most of the heavy tracks thus do not represent slow mesotrons;[6] in fact, the fraction of slow mesotrons may not greatly exceed the figure of 0.001 found by E. J. Williams at sea level.

Four of these slow mesotrons yield mass values as follows:

Track	Ionization	$H\rho$	Mass: C. & B.	Mass: Williams[5]
8–21, 2	$2.5\times I_0$	2.26×10^5	210 ± 20	230 ± 20
1621	6.0	1.08	180 ± 20	225 ± 20
6941	6.2	1.11	190 ± 15	240 ± 15
6949	2.4	1.6	145 ± 30	155 ± 30

The probable errors are estimated to include chamber distortion of curvature and statistical uncertainty deriving from the finite number of droplets counted. Curvature was measured by plotting micrometer readings of coordinates along the track and fitting a curve to the points by the method of least squares. The curvature of the first track, for example, was determined from 13 points, with a probable error in fitting of 3.5 percent. The ionization of this track was determined by a count of 335 droplets, hence the statistical error is $\sim$5 percent (or more, since each ion is not the result of a single independent event).

We are grateful to all who have assisted with this experiment, and to the Carnegie Institution of Washington, the Fund for Astrophysical Research, and the Rumford Fund of the American Academy of Arts and Sciences for generous financial support.

* Guggenheim Fellow at the time of preparing and assembling the apparatus.

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[2] R. B. Brode and G. D. Bagley, Phys. Rev. **56**, 209A (1939).
[3] C. E. Nielsen, Phys. Rev. **61**, 202A (1942).
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[5] E. J. Williams, Proc. Roy. Soc. **A172**, 194 (1939).
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X-Ray Line Broadening by Cold-Working Alpha-Brass

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NIEMANN and Stephenson have reported[1] that the x-ray diffraction line broadening produced by small amounts of cold-working of alpha-brass is enhanced by speed of working, while the internal friction thus introduced is not. The first of these facts, which might be of great importance to practical metal forming, is not confirmed by our observations.

Three like-tensile specimens of cartridge brass having sections 6.3 by 0.53 mm, sealed in nitrogen, were annealed for ninety minutes at 400°C, and showed fine-grained strain-free diffraction by back-reflection. Each was then cold-stretched about 7.5 percent, one by a falling weight at a speed exceeding 30 ft./sec., one by a hammer-blow of somewhat less speed, and one slowly in a small tensile stressing frame. The back-reflection patterns from these three strained specimens show no significant difference of line broadening. In each the Ni $K\alpha$ doublet has become nearly irresolvable visually. If any difference can be found it is that both fast-worked specimens gave traces of coarse-grain irregularity in the photographs, as the other did not.

These observations seem to remove the disparity between line broadening and internal friction effects of cold work. The earlier observations may have been effected by initial differences between the specimens.

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The Forces Between Hydrogen Molecules

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THE difficult part in an *a priori* calculation of intermolecular forces is the determination of the repulsive exchange forces. For this reason, complete interaction curves have hitherto been obtained for a few simple spherical atoms only. Yet to understand even the most elementary properties of molecules, such as their size and shape, and also to locate the position of the minimum of their van der Waals forces, a knowledge of the exchange forces is required. Attracted by the fundamental nature of the problem, I have undertaken to calculate them for the simplest molecule and herewith report the results.

FIG. 1. Section of mesotron track 6949, enlarged to about three times its size in the cloud chamber. Ion pairs are separated into positive and negative columns, with the positive on the left side. At the top a sharp electron track crosses the picture.