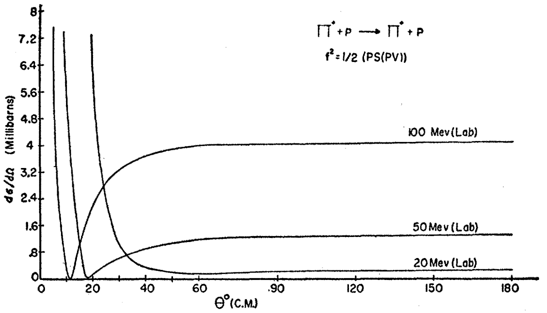


FIG. 2. Differential scattering cross section in the center-of-mass system for the reaction $\pi^+ + P \rightarrow \pi^+ + P$ including electromagnetic effects for the $PS(PV)$ theory. The π meson-nucleon coupling constant $f^2 = \frac{1}{2}$. The curves are labeled according to the π-meson kinetic energy in the laboratory system.

any event, one should be able to obtain useful information concerning the meson-nucleon scattering amplitude by observations on the interference effects with the electromagnetic scattering.

The consideration of this problem arose from a discussion with Professor R. E. Marshak and Mr. A. Messiah. I am indebted to Professor Marshak for further discussion.

* This research supported by the AEC.
[1] H. A. Bethe and R. R. Wilson, Phys. Rev. **83**, 690 (1951).
[2] These interference effects have also been considered by Dr. M. H. Johnson as a possibility of distinguishing between the various spin 0-meson theories (private communication from Dr. M. H. Johnson).
[3] R. E. Marshak, Revs. Modern Phys. **23**, 137 (1951).
[4] Clark, Roberts, and Wilson, Phys. Rev. **83**, 649 (1951).
[5] R. P. Feynman, Phys. Rev. **76**, 749 (1949).
[6] At higher meson energies the sign of the nuclear scattering amplitude is determined by the second term of the nuclear matrix element, while at very low meson energies the nuclear amplitude for both processes I and II is $\sim +1/2M$. The change of sign of the amplitude for process I occurs at such low meson energies that it is probably not experimentally detectable due to the extremely large electromagnetic scattering in this energy region.

The Velocity of 170-Mev Gamma-Rays*

DAVID LUCKEY AND JOHN W. WEIL†
Cornell University, Ithaca, New York
(Received January 31, 1952)

AS a test of a high resolution coincidence circuit for experiments utilizing monoenergetic gamma-rays selected from bremsstrahlung,[1] we have measured the velocity of 170-Mev gamma-rays. A bremsstrahlung gamma-ray is counted in delayed coincidence with the electron producing it. 310-Mev electrons in the circulating beam of the Cornell synchrotron strike a thin target and are analyzed after radiation by the magnetic guide field (Fig. 1). A stilbene crystal is located so as to intercept electrons of about 140 Mev. The energy spectrum of the gamma-rays in coincidence with these electrons was measured by use of the Cornell pair spectrometer[2] and was found to correspond to a peak at 170 Mev with a full width at half-maximum of twenty percent or less.[1] The velocity of the coincident gamma-rays was determined by measurement of relative delay time *versus* position of a movable, external, scintillation counter. Transit time differences were measured for four positions (extreme positions had a separation of thirteen meters) using a coincidence circuit with a resolving time of 4×10^{-9} second. The peak of the resolution curve at each position could be determined within 2×10^{-10} second. Cable delay times were calibrated by observing their resonant frequencies under shorted termination in the frequency range from 10 to 500 megacycles.[3] The error in cable calibration is of the order of one-half percent. A plot of distance *versus* transit time gives a straight line whose slope is the velocity of the 170-Mev gamma-rays. A least squares fit gives a value of 2.974×10^{10} cm/sec, with estimated probable error of one percent. This agrees within the experimental uncertainties with the value of c obtained for 0.5-Mev gamma-rays,[3] and with the most probable value of c obtained from measurements at lower frequencies to be 2.998×10^{10} cm/sec.[4]

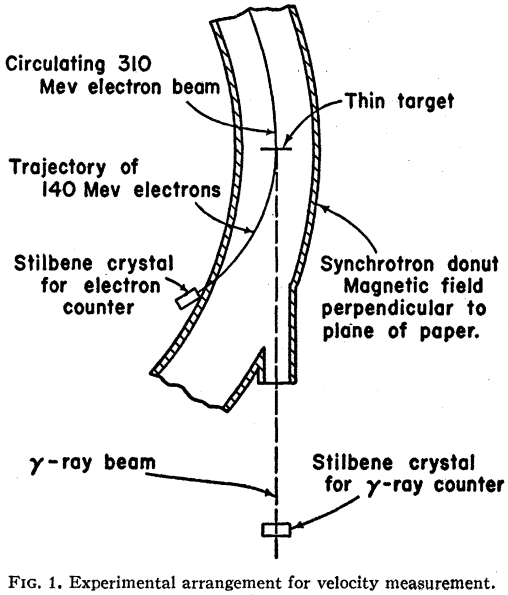


FIG. 1. Experimental arrangement for velocity measurement.

We wish to thank Professor B. D. McDaniel for his helpful advice and encouragement.

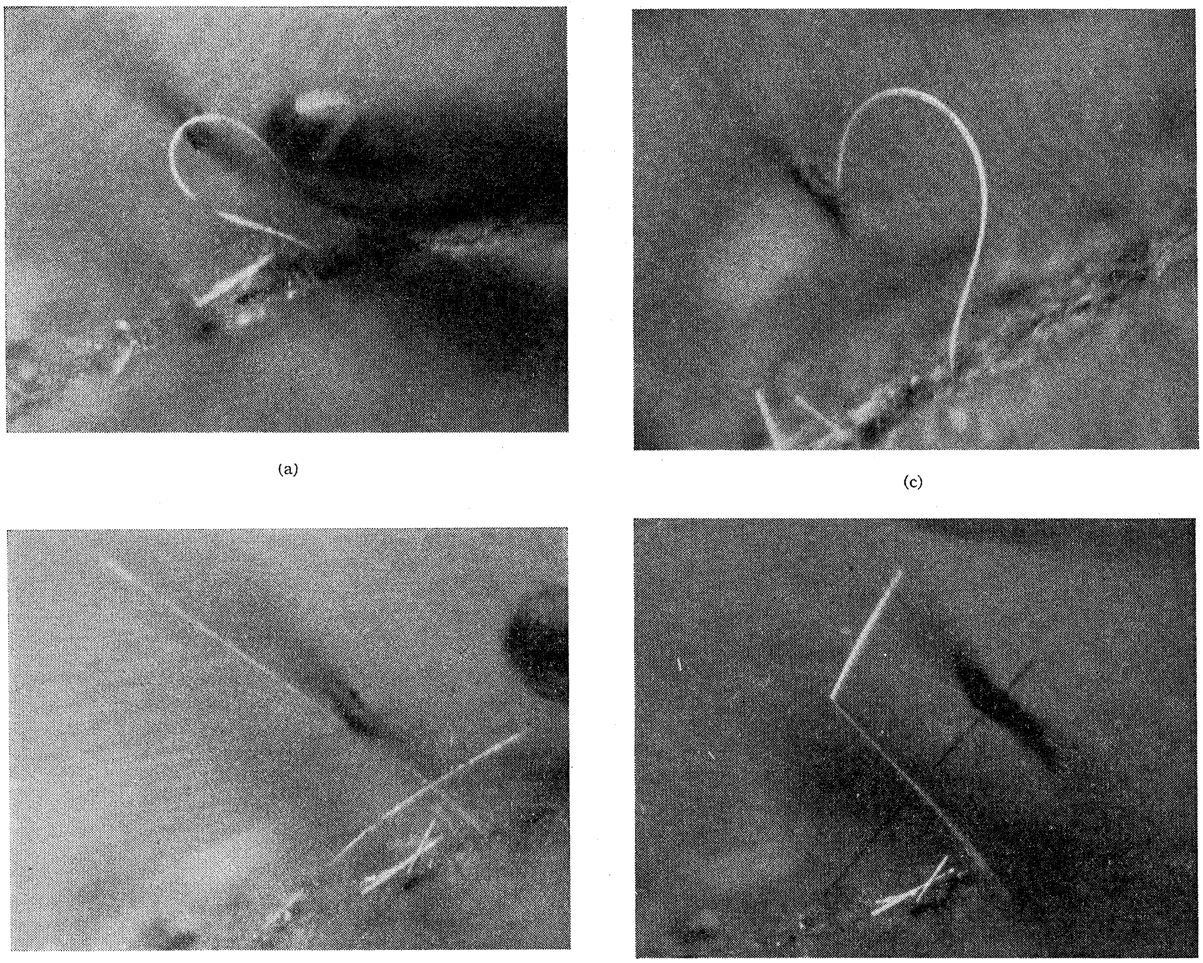
* Supported in part by the ONR.
† AEC Predoctoral Fellow.
[1] J. W. Weil and B. D. McDaniel, Bull. Am. Phys. Soc. **27**, No. 1, 7 (1952).
[2] DeWire, Ashkin, and Beach, Phys. Rev. **83**, 505 (1951).
[3] M. R. Cleland and P. S. Jastram, Phys. Rev. **84**, 271 (1951).
[4] J. W. DuMond and E. R. Cohen, Phys. Rev. **82**, 555 (1951).

Elastic and Plastic Properties of Very Small Metal Specimens

CONYERS HERRING AND J. K. GALT
Bell Telephone Laboratories, Murray Hill, New Jersey
(Received January 29, 1952)

THE elastic and plastic behavior of bulk tin has been investigated by several workers. As a result, quite detailed data are available on the yield stress and creep rate. The yield stress varies, of course, with the crystal plane across which stress is applied and its direction in that plane, but the values for the principal cases of interest are all shears of approximately 0.15 kg/mm^2 [1] resolved shear stress. From the elastic constants of tin we are thus led to a maximum yield strain of about 10^{-4} before slip occurs in a simple tension experiment. The minimum creep rates observed are about 2×10^{-8}/sec at tensions of about 0.1 kg/mm^2.[2] This behavior is usually explained in terms of the motion of imperfections, especially of dislocations, since on any reasonable model of a perfect crystal one expects the yield strain[3] to be of the order of 10^{-1}.

It has often been presumed[4] that specimens of very small dimensions ought to have a much larger range of elastic strain than the bulk metal, either because they are free of dislocations, or because the few dislocations present cannot multiply sufficiently to give an observable amount of slip. It occurred to us that this hypothesis could be tested by performing experiments on the thin whiskers which have been observed to grow out from the surfaces of a number of low-melting-point metals.[5] We have therefore made observations on some tin whiskers grown from a tin-plated surface by Mr. S. M. Arnold of these laboratories. Electron microscope observations of many such whiskers, carried out by Mr. C. J. Calbick, of these laboratories, have shown their diameters to be



(a) (c) (b) (d)

FIG. 1. Bending and recovery of tin whiskers. (a) Radius of curvature 0.009 cm. (b) Same whisker after removal of constraining probe. (c) Creep experiment, radius of curvature 0.015 cm. (d) Typical bend produced by excessive stress. In all pictures the whiskers have been manipulated to be in the plane of the picture or close enough to it so that angles and radii of curvature may be read with reasonable accuracy from the pictures.

remarkably uniform and equal to $1.8\pm0.1\times10^{-4}$ cm. They range up to several millimeters in length. Our experiments have consisted in bending a number of these whiskers; the results indicate an elastic and plastic behavior not far different from that to be expected from a truly perfect crystal.

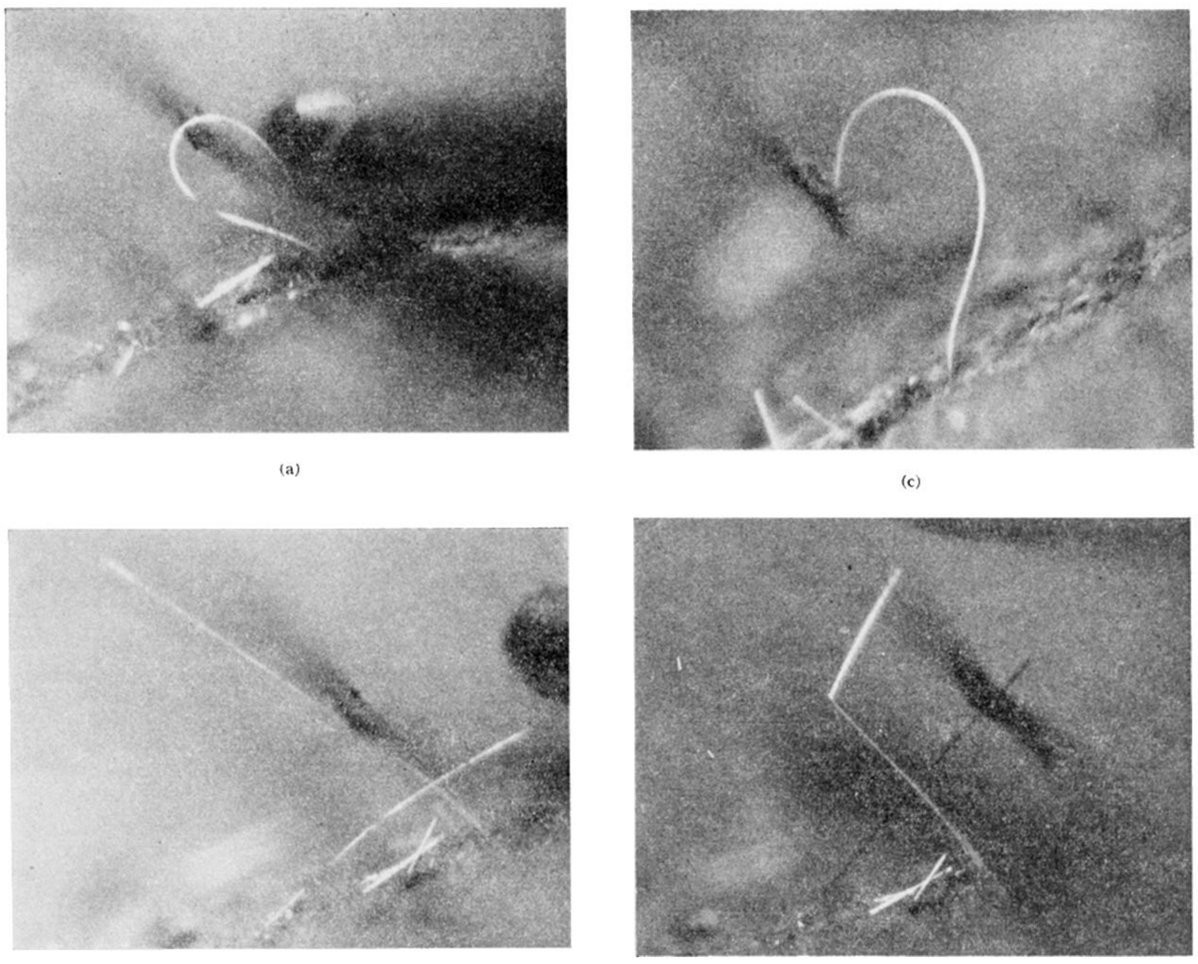
In the first place, very large strains can be tolerated in these whiskers without slip. Figure 1(a) shows a whisker bent sharply (radius of curvature $r_c=0.009$ cm) about a No. 44 formex copper wire (running perpendicular to the plane of the picture and only in focus over a short part of its length) by a 0.010-in. music wire probe. Figure 1(b) shows the same crystal straightened out (running upward from right to left). The strain varies across the cross section from a large positive value at the outer surface through zero to a large negative value on the inner surface of the curved whisker. The maximum strain in Fig. 1(a) is thus the ratio of whisker radius to radius of curvature, or 10^{-2}.

These whiskers also sustain large strains without creep. Figure 1(c) shows a whisker bent to a radius of curvature $r_c=0.015$ cm. The strain is thus 6×10^{-3}. After a week in this position, this whisker straightened out perfectly, as nearly as we were able to tell, when the restraining probe was removed. From the minimum strain which we could observe, we deduce that the strain rate in this experiment was certainly less than 5×10^{-10} sec^{-1}. In comparing this value with the value given above for the minimum creep rate in tin it should be borne in mind that the stresses occurring in our experiment are much higher. From the product of strain and elastic constant we deduce that stresses of the order of tens of kg/mm^2 were present in our sample.

When these whiskers are bent until the maximum strain in them is about 2 or 3 percent they do deform, but in a rather unusual way. A bend which seems to be perfectly sharp occurs in the whisker. Such a bend is shown in Fig. 1(d). It should be emphasized that the whisker has considerable strength at these bends. This has been determined by manipulating them, and by observing the fact that the part of the whisker beyond the bend can be supported by them. Other bend angles have been observed, but values near the one shown in Fig. 1(d) seem to be the most common.

We wish to express our gratitude to Mr. S. M. Arnold for providing us with samples, and to Mr. H. G. Hopper for technical assistance.

[1] J. Obinata and E. Schmid, Z. Physik **82**, 224 (1933); K. Bausch, Z. Physik **93**, 479 (1935).
[2] B. Chalmers, Proc. Roy. S. (London) **A156**, 427 (1936).
[3] L. Bragg and W. M. Lomer, Proc. Roy. Soc. (London) **A196**, 171 (1949); W. M. Lomer, Proc. Roy. Soc. (London) **A196**, 182 (1949).
[4] See for example C. Herring, Chap. 8 of *The Physics of Powder Metallurgy*, edited by W. E. Kingston (McGraw-Hill Book Company, Inc., New York, 1951).
[5] Compton, Mendizza, and Arnold, Corrosion **7**, 327 (1951).



(a) (c) (b) (d)

FIG. 1. Bending and recovery of tin whiskers. (a) Radius of curvature 0.009 cm. (b) Same whisker after removal of constraining probe. (c) Creep experiment, radius of curvature 0.015 cm. (d) Typical bend produced by excessive stress. In all pictures the whiskers have been manipulated to be in the plane of the picture or close enough to it so that angles and radii of curvature may be read with reasonable accuracy from the pictures.