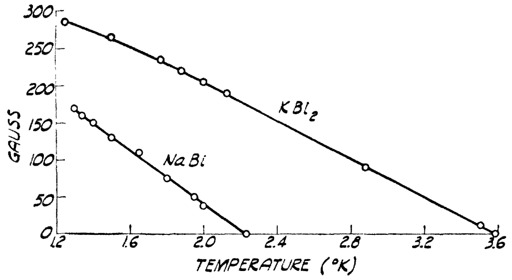

FIG. 3. Critical threshold curves for the two alloys.

which is particularly useful for "zero field" transition studies. The alloys were prepared from spectroscopically pure Bi, Na, and K by synthesis.

Figure 1 shows the very sharp zero field transitions; approximately 0.05°K for NaBi and 0.07°K for KBi_2. Figure 2 shows an isothermal magnetic transition for KBi_2 at 2.0°K. An almost complete lack of hysteresis is evident. Figure 2 is typical of 16 curves for both NaBi and KBi_2 at a whole series of temperatures between about 1.2°K and the normal transition temperatures.

Figure 3 shows the threshold curves for the two alloys these being evolved from data such as Fig. 2 by taking the saturation value of field as the critical threshold. The initial slopes are approximately 180 gauss/°K for NaBi and 130 gauss/°K for KBi_2. Such values would be considered small even for pure elementary superconductors of the soft variety. The measuring method used by us does not necessarily reveal information about the completeness of the Meissner effect, but in all other respects the results seem to give strong support to the Mendelssohn-Shoenberg hypothesis.

* Part of a dissertation presented by Joseph M. Reynolds to the Faculty of the Graduate School of Yale University in candidacy for the degree of Doctor of Philosophy.

† Now at Louisiana State University, Baton Rouge, Louisiana.

‡ Assisted by the ONR.

[1] de Haas, van Aubel, and Voogd, Leiden Comm. 197a (1929).

[2] N. E. Alekseyevsky, J. Phys. U.S.S.R. **9**, 350 (1945).

[3] N. E. Alekseyevsky, J. Exper. Theor. Phys. U.S.S.R. **18**, 101 (1948).

[4] N. E. Alekseyevsky, J. Exper. Theor. Phys. U.S.S.R. **19**, 671 (1949).

[5] K. Mendelssohn, Proc. Roy. Soc. **A152**, 34 (1935).

[6] D. Shoenberg, Nature **142**, 874 (1938).

[7] Webber, Reynolds, and McGuire, Phys. Rev. **76**, 293 (1949).

A Convergent Non-Linear Field Theory

J. C. WARD
Clarendon Laboratory, Oxford, England
April 24, 1950

NON-LINEAR field theories of the interaction of similar particles have been proposed by several authors, but only recently has it become possible to discuss whether or not they give rise to divergencies. It is interesting to note that a very simple theory of the interaction of scalar particles, which may be made convergent solely by the device of mass renormalization, can be constructed in the following way.

Consider the field theory, taken as a neutral theory for convenience, derivable from the Lagrangian

$$L=-\tfrac{1}{2}\{(\partial\phi/\partial x_\mu)^2+K^2\phi^2\}+\lambda\phi^3,$$

where λ is a small interaction constant.

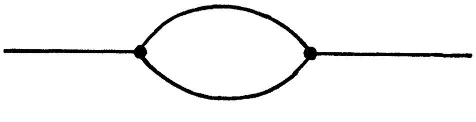

FIG. 1. Feynman diagram for $E=2$, $n=2$.

In the interaction representation the Schrödinger equation becomes

$$i\hbar c\delta\Psi(\sigma)/\delta\sigma(x)=\{\lambda\phi^3-\tfrac{1}{2}\delta K^2\phi^2\}\Psi(\sigma)$$

with δK^2 the logarithmically infinite change in mass due to the interaction. It will be shown that the S-matrix which follows from this equation contains no divergencies. Using the techniques of Feynman and Dyson, it is easy to show that a sufficient condition for the primitive convergence of a matrix element connected with a graph having n vertices, at which the term $\lambda\phi^3$ operates, and E external lines is

$$E+n\geqslant 5.$$

Hence, the only divergence arises from $E=2$, $n=2$ which is the simplest possible self-energy graph, shown in Fig. 1. It is clear that, whever this appears as part of a graph, the corresponding logarithmic divergence will be canceled by the self-energy term $-\tfrac{1}{2}\delta K^2\phi^2$ in the interaction, leaving a finite result.

Mixtures of charged and uncharged particles can, of course, be treated in a similar fashion.

Emulsion Studies of Cosmic-Ray Stars Produced in Metal Foils*

IAN BARBOUR AND LAWRENCE GREENE†
Kalamazoo College, Kalamazoo, Michigan
June 6, 1950

IN this investigation cosmic-ray induced disintegrations of nuclei of several elements are studied with metal foils placed between nuclear emulsions, in order to determine the dependence on atomic weight of the star-production cross section, and to observe the configurations typical of various target nuclei. It also appears probable that analysis of the cross section, multiplicity, and angular distribution of groups of minimum-ionization particles, shown to include predominantly mesons,[1] especially in comparison between heavy and very light nuclei, will throw light on whether meson production is mainly multiple or plural (simultaneous or successive nucleon-nucleon interactions). Our experimental method is described here and some preliminary cross-section results are given.

Perkins[2] and Harding[3] have poured emulsions with alternated layers of pure gelatin to compare star production in gelatin and emulsion, finding a ratio consistent with a geometrical cross section. In another possible method, comparing loaded with unloaded emulsions, very good statistics are required if the differences are to be reliable. Inclusion of small particles of metals within the emulsion is also possible, but quantities in excess of about one-half percent by volume interfere with subsequent scanning.[4]

In this experiment, foils of various metals were "sandwiched" between pairs of Ilford G-5 emulsions placed face-to-face, so that after development tracks could be observed in the emulsions and those originating in disintegrations of foil nuclei could be projected back to common centers outside the emulsion. Several difficulties revealed by preliminary experiments required special attention. If the two emulsion surfaces are too far apart during exposure, prongs from a given star in the foil may be separated from each other by considerable distances when they enter the emulsion, thus making it difficult to associate all those track segments attributable to one common disintegration. Thus, if the two emulsion surfaces are 75μ apart and the distribution of prongs from a disintegration in the foil is isotropic, eight percent of the tracks would enter the emulsion at a distance from the star center greater than 470μ, which at a scanning magnification of 200× is the diameter of our field of view and hence the maximum distance of definite identification. To insure a maximum emulsion separation of 75μ, it is *not* sufficient merely to use a thin foil, for it was

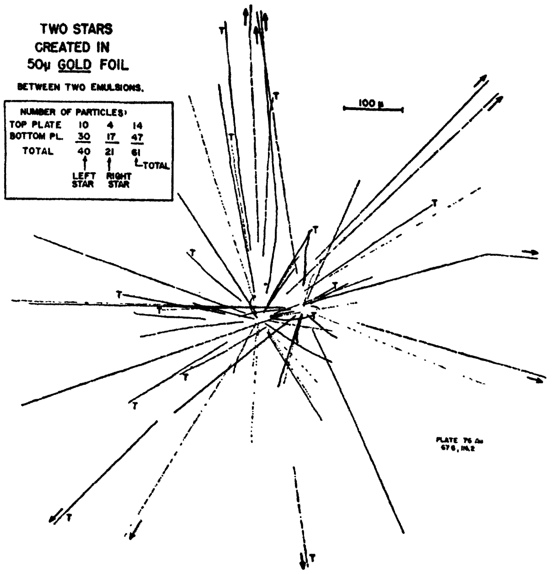

FIG. 1. Microprojection of tracks from two neighboring stars caused by the disintegration of gold nuclei. All the tracks can be seen to radiate from two points between the emulsions; the central portion of each track, representing the portion of the trajectory within the foil, is not observable. Tracks marked "*T*" were in the top plate, others in the bottom plate; arrows indicate tracks continuing beyond this field of view in the emulsion.

found that a new metal foil, even under moderate pressure, will not lie completely flat during exposure. It was found necessary to heat each foil to its annealing temperature to render it malleable, and then subject it to high pressure between two very flat steel surfaces. Finally the flattened foil is placed between 10μ sheets of cellulose acetate (or better, coated with a very thin layer of plastic) to prevent the interaction of the metal atoms with those of the emulsion. Clamped between pairs of nuclear plates, foils of Au, Pt, Ni, Cu, Sn, and Al were flown together in a flight of 6 hr. at 93,000 ft.[5]

After removal of the foils and development of the emulsions, the corresponding plates were placed face-to-face, the original alignment being reconstructed by x-ray dots[6] at the ends of the plates and by exact alignment of through tracks, and the edges were cemented, so that the pair of emulsions could be scanned together and observed with a magnification of 450×. Figure 1 is a microprojection of tracks from the disintegration of two gold nuclei which happened to be quite near each other. The weight and area of each foil were accurately measured, so that it was possible to calculate from the number of stars observed the cross section for star production per target nucleus. The correction for tracks missed outside the field of view was computed after determining the original emulsion separation by geometrical consideration of through tracks; a small correction for star tracks which never leave the foil must also be applied. Figure 2 shows values found for relative cross sections *per target nucleus* for the production of stars of various sizes in four materials. The data on very small stars (3, 4, and even 5 prongs) in the foils must be considered less reliable, because of the possibility that tracks, from a 4-prong star, for instance, could be so oriented in the two emulsions that the scanner might overlook their association with a common origin. The values for the emulsion stars are greater than anticipated, though the variety of elements present and uncertainty as to density and shrinkage factor make an exact interpretation difficult. Analysis of the complete data indicates a maximum at about 8 prongs per star for Au, and 6 for Sn, whereas for Cu and emulsion it occurs for smaller values. As an insert in Fig. 1 the integral cross section for stars of more than 4, 8, 6, and 10 prongs have been plotted on a log-log graph against the atomic weight, A, of the target nucleus. Approximate linearity indicates a dependence of the form $\sigma_r = kA^s$, where for values of r (the minimum number of prongs considered) of 10, 8, 6, and 4, the corresponding values of the exponent, s, are 2.0, 1.5, 1.0, and 0.7. Estimating the extrapolation to include stars of 2 or 3 prongs, the total cross section for stars of all sizes is quite close to an $A^{\frac{2}{3}}$ law. This data refers to all observed star tracks and therefore includes, for each star, particles from both initial nucleon-nucleon collision processes and from subsequent "evaporation." A separate analysis of the groups of energetic particles ("meson showers"), their angular distribution and cross section as a function of the atomic weight, together with completion of the data on other metal foils, is in progress.

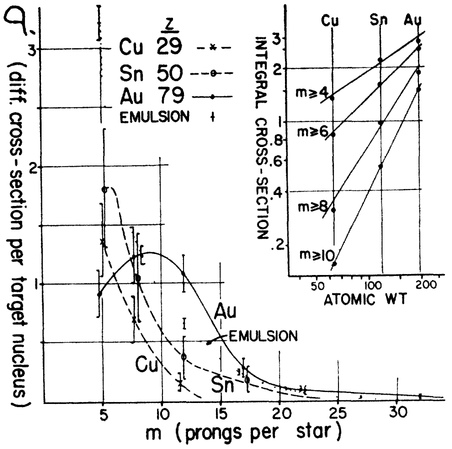

FIG. 2. Differential cross section (number of stars of m prongs observed per target nucleus $\times 10^{-21}$) *vs.* number of prongs (m) for four target materials. Insert at upper right shows a log-log plot of integral cross section (for stars of more than 4, 6, 8, and 10 prongs) *vs.* the atomic weight of the target foil.

---

* This work has been aided by a Cottrell Grant from the Research Corporation.

† Now at Ohio State University, Columbus, Ohio.

[1] Camerini, Fowler, Lock, and Muirhead, Phil. Mag. **41**, 413 (1950).

[2] D. H. Perkins, *Cosmic Radiation* (Butterworth's Ltd., London, 1949).

[3] J. B. Harding, Nature **163**, 440 (1949).

[4] As a check on the present experiment, we are exposing such a suspension of Pb powder prepared by E. Hones of Duke University.

[5] Arranged through the kindness of the ONR and the General Mills Company.

[6] I. Barbour, Phys. Rev. **78**, 518 (1950).

Mesons Produced in Proton-Proton Collisions*

VINCENT Z. PETERSON
Radiation Laboratory, University of California, Berkeley, California

June 5, 1950

A FUNDAMENTAL problem in the study of mesons is that of their production in the collisions of protons with free protons, since the analysis is unhindered by considerations of the internal dynamics of complexed nuclei. Such an experiment can be performed by using a subtraction technique[1] employing C and CH_2, or a pure hydrogen target can be used to study the production directly. We have chosen to construct a liquid hydrogen target and have studied the meson energy distribution at various angles with respect to an incident beam of 345-Mev protons from the Berkeley 184-inch cyclotron.

Since the threshold for meson production in proton-proton collisions is very high (292 Mev in the laboratory system), the maximum kinetic energy available to the meson in the center-of-mass system is only about 25 Mev (for 345-Mev protons incident). Such a meson will have a velocity only slightly greater than the center-of-mass velocity, and hence the meson flux may be expected to be emitted in a predominantly forward direction in the laboratory system. Furthermore, the upper limit of meson energy decreases rapidly with angle, from 74 Mev at 0° to 7 Mev at 90°.