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NOTE CONCERNING CLOUD CHAMBER EXPERIMENTS WITH POSITRONS

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1. *Introduction.*

Ho Zah-Wei and W. Bothe[1] have called attention to the interest attached to cloud chamber studies of energetic positron-electron collisions. This interest arises from the possibility of observing energy transfers in excess of 50 per cent, a possibility which is of course nonexistent in the case of the interaction of particles which are completely identical. The results obtained by Ho Zah-Wei[2] seem to confirm in a general way the formula for positron and electron elastic collision cross sections calculated by H. J. Bhabha[3], but in detail there appear deviations both for large and for small energy transfers, the former being especially noteworthy.

It is intended to point out briefly here additional reasons for the desirability of obtaining reliable data on the hard collisions between positrons and electrons [§2], some limitations of the present data of Ho Zah-Wei [§3], and some experimental possibilities for significant extension of these results [§4]. Preliminary measurements bearing partially on the present suggestions have been made with the Brookhaven National Laboratory high pressure cloud chamber[4], and a brief report of the results will be given in the concluding section of this paper.

2. *Significance of Cloud Chamber Experiments on Scattering and Annihilation of Fast Positrons.*

Bhabha's derivation of the differential elastic scattering cross sections of electrons and positrons is based on Møller's quantum-relativistic theory of the collision of two free electrons[5] and on the elementary phase of Dirac's "hole theory" of positrons[6]. A reliable verification of Bhabha's formula is of interest in connection with both of these theories.

The most direct check on Møller's theory would naturally involve experimentation on energetic electron electron collisions. It is somewhat surprising that the only experiment of this nature so far performed dates back to 1932[7]. Champion's results although of interest as providing general

* Part of the work on which this note is based has been done at Brookhaven National Laboratory under the auspices of the Atomic Energy Commission.

1 Fiat Report 1132, May 29, 1947.

2 ibid and C. R. 226 (1948) 1083

3 Proc. Roy. Soc. A 154 (1936) 195–206.

4 Hoke, O'Neill, and Shutt, October 1949, private communication.

5 Ann. der Physik, 14 (1932) 531.

6 A good discussion of this subject is to be found in Heitler's *The Quantum Theory of Radiation*, Chapter IV.

7 F. C. Champion, The Scattering of Fast β-Particles by Electrons, Proc. Roy. Soc. A. 137 (1932) 688.

first-order agreement with theory, cannot, however, be used as conclusive evidence in what concerns the large angle deflections, but it is the results on these energetic deflections that would be crucial in a significant check of Møller's method. Thus it appears quite evident when one examines the essential hypotheses of Bhabha's and Møller's formulations, that careful measurements of the energetic collisions of positrons and electrons especially for sufficiently fast positrons, would also be decidedly worth having by way of confirmation of the relativistic two-body quantum treatment of Møller. It would also appear that the cloud chamber would be the simplest instrument to use for such an investigation, provided, of course, that the technique employed is adequate.

As to Dirac's theory of positrons, at least in what concerns its first approximation, it has been sufficiently successful in all the applications so far made of it, that mistrust in the present case would not be indicated. Nevertheless, the particular application which Bhabha makes of Dirac's positron theory, involving as it does an interesting employment of Pauli's principle, would make a direct check of Bhabha's conclusions based on these ideas, of independent interest.

Of even more immediate interest in connection with Dirac's theory of positrons, is a good quantitative confirmation of the differential cross sections for annihilation of positrons and electrons computed with its aid. Such annihilation (as well as creation) enters also in Bhabha's treatment of positron electron scattering, but only in the *virtual* states. Real annihilation of positrons colliding with electrons is of course a very well established experimental fact, but quantitative experimental determinations of the energy dependent probabilities of its occurrences are very scarce.[8] Quite recently there have been announced some interesting results dealing with a delayed coincidence counter determination of annihilation probabilities for slowed down positrons.[9] Similar determinations for fast positrons do not appear as feasible with simple counter techniques. Again it would appear that a suitable cloud chamber technique, such as the one suggested in this note, for example, would provide the simplest attack on this problem.

3. *Discussion of Ho Zah-Wei's Results.*

Since the main object of this note is to point out ways of significantly extending the present experimental results on positron-electron collisions, it will suffice here to call attention very briefly to a few obvious limitations which attach to the published data of Ho Zah-Wei and which it would be desirable to reduce in further experimentation of this type. The following are the most apparent of these limitations:

i) The average energy of the positrons involved in these data is not as high as would be required for a significant check of the Møller-Bhabha formula.

[8] For theory and experiment see for instance Heitler, loc. cit., especially pp. 208–209 (in the second edition) for the existing experimental evidence.

[9] James W. Shearer and Martin Deutsch, The Lifetime of Positrons in Matter, Phys. Rev. 76 (1949) 462 (a).

ii) The statistics are not sufficiently ample for the purpose of making the desired deductions from the data.

iii) The possible sources of error in the energy determinations do not appear to have been sufficiently accounted for, at least as far as can be surmised from the actual published description of the experiments.

Regarding point i) two observations need to be made. In the first place, since the radioactive sources used for the experiments in question were Mn^{52} in one set and F^{18} in the other, the mean β^+ energies available were of the order of only 0.2 to 0.3 Mev. at most. Indeed the highest estimates of the maximum end points of the spectra of these two nuclides are 0.75 Mev. and 0.95 Mev. (to 20%) respectively.[10] On the other hand, an examination of Bhabha's theoretical results discloses that only at considerably higher energies and for large percentage energy transfers do the specific relativistic and "exchange" terms in the formula in question begin to have a sensible effect upon the scattering cross sections.[11]

What has been said above applies also in part to the observation under ii). The interesting information is to be gotten from the collisions with high percentage energy transfers and these, if Bhabha's formula is at all correct, are relatively few in number. It becomes, therefore, necessary as can be seen by a simple calculation involving the probabilities and percentages in question, to have available statistics at least by an order of magnitude more than the 323 meters of total usable length (reduced to normal conditions) that were obtained in the experiments under discussion. This point is made quite clear in connection with the question of annihilation cross sections of positrons in flight. The three photographs of such annihilation found by Ho Zah-Wei are obviously not enough to serve as a reliable quantitative check on the theory of this process. But an increase by one or more orders of magnitude of the total equivalent track length coupled with some positron energy selection could be expected to provide evidence of at least a preliminary nature on the quantitative validity of the differential cross sections for the annihilation process.

Little can be said in elaboration of remark iii), since the experiments in question have so far been written up in a rather sketchy manner. Nevertheless, the absence of any mention of such considerations, for instance, as the effect of multiple scattering on energy calculations using track curvature in a magnetic field, in the papers under discussion, would lead one to the presumption that such effects were perhaps neglected in the energy calculations. That such effects are not at all negligible for the range of pressures and magnetic field strengths that were employed, is a rather well established fact. An interesting paper to consult in this connection is Bethe's "Multiple Scattering and the Mass of the Meson."[12]

[10] G. T. Seaborg and I. Perlman, Table of Isotopes, Rev. of Mod. Phys. 20 (1948) 585.

[11] In connection with a critical analysis of questions related to these points, I am indebted to Dr. S. Goudsmit of Brookhaven National Laboratory for enlightening discussion.

[12] Phys. Rev. 70 (1946) 821.

4. *Some Suggestions for Obtaining Higher Positron Energies and Increased Statistics.*

There exist at present a number of possibilities for obtaining positron sources with mean energies near or in excess of 1 Mev. The source of fastest positrons available at present would appear to be the pairs from the X-rays generated by the 100 Mev. betatron. A rough preliminary calculation of the positron intensity to be expected from such X-ray conversion, based on an estimate of the X-ray spectral intensity distribution for the 100 Mev. betatron made by G. C. Baldwin and G. S. Klaiber[13] points to the feasibility of such a source. However, from a practical point of view, it would be hardly expected that one could count on the availability of the 100 Mev. betatron for the experiments under discussion when it is the only one now in existence. The availability of a 20 Mev. betatron would of course be an easier possibility. Unfortunately, the question of the adequacy for the experiment under discussion of the positron flux intensity obtainable in this way becomes rather critically dependent upon the X-ray intensities that can be produced with these instruments. One would require knowledge of this intensity and perhaps also rather careful estimates regarding the various cross sections and geometric factors which enter in a determination of the beam intensity of the positrons which actually enter the cloud chamber.

Another possibility for obtaining high energy positrons is provided by the gammas from the $Li^7 - H^1$ reaction at the resonance energy of about ½ Mev. Positrons from the pairs created by such gammas have indeed been used in scattering experiments.[14] But here again, the positron beam intensity that could be made available for the type of setup that is being suggested in this note, becomes a matter requiring closer scrutiny.

What appears to be the simplest practicable procedure for obtaining a satisfactory source of energetic positrons is to make a proper choice of radioactive substance. The requirements are obvious. This substance should be readily producible in a number of laboratories and in suitable form and activity, and its positive beta decay should have as large an energy maximum as possible together with a proper half-life. An examination of the Seaborg and Perlman Table of Isotopes[15] discloses that the radioactive arsenic isotope As^{72} appears to come closest to satisfying the above requirements. It can be made with cyclotron bombardment in a number of practicable ways, its positive beta maximum lies at about 2.8 Mev, and it has a quite convenient half-life of 26 hr.

A means for obtaining adequate statistics is provided by the combination of an arrangement for magnetically focusing a collimated beam of positrons through a thin window of the cloud chamber and into a large arc across the full length of the chamber, with an anticoincidence setup which would permit the photographing of an event only if it consists in either a large angle scattering or in the annihilation of the positron in the chamber.

[13]Phys. Rev. 71 (1947) 3.

[14]Fowler and Oppenheimer, Scattering and Loss of Energy of Fast Electrons and Positrons in Lead, Phys. Rev. 54 (1938) 320.

[15]Loc. cit.

The magnetic focusing arrangement can be designed for instance along the lines of H. R. Crane's setup in his electron scattering experiments at the University of Michigan.[16]

It would obviously be pointless to enter here into any specific suggestions regarding the choice of geometry, cloud chamber gas and pressure, magnetic field strengths, and anticoincidence scheme, that would be suitable for the experiments under discussion, beyond the mere statement that preliminary calculations indicate that such a choice is indeed possible. It may perhaps also be helpful to call attention to the possible advantage of using in connection with the anticoincidence setup a triggering device that actuates not the chamber expansion, but the supply of light for the photographing of the tracks, thus permitting steady operation of the cloud chamber. Although the author is under the impression that such a triggering scheme may already have been utilized at the very beginning of cosmic ray counter work, its employment in connection with scattering experiments seems to have been made only recently.[17]

It hardly needs to be pointed out that the possibility of selecting positron energy bands in the suggested setup would be an aid in the study of the energy dependence of the cross sections under investigation. Moreover, since such energy dependence studies can only be of rather limited scope, owing to inherent cloud chamber limitations, it would not become necessary to keep the width of these bands below comfortably practicable limits.

5. *Preliminary Results with the Brookhaven High Pressure Cloud Chamber.*

Owing to the availability at Brookhaven National Laboratory of the high pressure cloud chamber while filled with helium during part of the fall of 1949, R. Hoke, G. O'Neill, and R. P. Shutt took some photographs of tracks obtained in the chamber upon the introduction of a minute trace of radioactive arsenic. The radioarsenic was introduced into the chamber in liquid solution, this being the only means of getting readily into the interior of such a type of cloud chamber.[18] Because it was not feasible to operate this cloud chamber with a pressure below 70 atmospheres while at the same time it was of course necessary to employ a low magnetic field (700 gauss were actually used), it was expected that excessive track distortion by scattering in the gas would preclude the drawing of reliable quantitative conclusions from the photographs, and therefore only a rather limited number of these were taken.

A set of these cloud chamber photographs were kindly sent by Dr. Shutt to the author for examination, and in spite of their limited scope, two

[16]A valuable paper to consult in connection with this and related problems of cloud chamber technique and analysis is "The Single Scattering of Electrons in Gases," R. B. Randels, K. I. Chao, and H. R. Crane, Phys. Rev. 68 (1945) 64.

[17]The Scattering of Fast Beta-particles through Large Angles by Nitrogen Nuclei, F. C. Champion and R. R. Roy, Proc. Phys. Soc. 61 (1948) 532.

[18]Its construction is described in: A Hydrostatically Supported Cloud Chamber of New Design for Operation at High Pressures, T. H. Johnson, S. DeBenedetti, and R. P. Shutt, Rev. Sci. Inst. 14 (1943) 265.

interesting though qualitative observations could be deduced from rough measurements made on the clearly visible tracks.

First, it was found that the photographs contained a considerable proportion of positron tracks corresponding to energies in excess of 1 Mev. and well into the 2 Mev. region, thus definitely establishing the suitability of radioactive arsenic as a high energy positron source. Because of the limitations to which many of the photographed tracks were subject[19], it was not possible to construct a significant energy distribution curve for the positrons, but the following rough distribution found among 40 tracks of positrons having energy in excess of 0.75 Mev. may be of some interest:

Energy interval (in Mev.)	0.75 – 1.25	1.25 – 1.75	1.75 – 2.25
Number of tracks	25	9	6

The other observation concerns the proportion of collisions with energy transfers in excess of 50 per cent that could be observed in these photographs. Although it was not possible, owing to the aforementioned limitations, to obtain a result of quantitative significance, it could nevertheless be inferred upon careful examination of the data and of the relevant probabilities, that this proportion was definitely smaller than that to be expected from a comparison with the results of Ho Zah-Wei, and more nearly of the same order as predicted by Bhabha's theory. This tentative result indicates at least the desirability of repeating Ho Zah-Wei's experiments with some significant extension of method.

[19] In addition to the aforementioned scattering, contributing causes were also the originating of tracks at the bottom of the vertically placed chamber where the dissolved radioactive substance was to be found, and the strong curving action of the magnetic field whose strength of 700 gauss chosen as a compromise for the minimizing of the gas scattering was still otherwise too high by about a factor of 2.