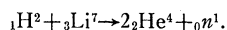


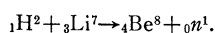
### Evidence for the Formation of ${}^8_4\text{Be}$ in the Disintegration of Lithium by Deuterons

From the determination of the range of the alpha-particles produced by the reaction



Oliphant, Kempton and Rutherford<sup>1</sup> found the energy released in the disintegration to be  $14.6 \pm 0.25$  MEV. By measuring the ranges of the recoil protons which had sufficient energy to penetrate a mica sheet (stopping power 114 cm) which was placed in the center of a high pressure cloud chamber, we have investigated the energy distribution of the neutrons in this reaction which were emitted with energies over 11 MEV. The chamber was operated at expanded pressures of 11.9 and 14.7 atmospheres. Otherwise, the experimental procedure was identical to that described in our article which appears in this issue. We have taken over 9000 pictures in which 86 tracks penetrated the mica and satisfied our requirement of being projected in the forward direction.<sup>2</sup>

Fig. 1 shows the energy distribution of these measured tracks. The points on the lower curve represent the actual number of tracks observed in an energy interval of 0.4 MEV, while the points on the upper curve have been corrected according to the varying probability, due to the geometry of the apparatus, of observing tracks of different lengths. Both curves show a pronounced maximum near 13 MEV. We believe that this increase is due to neutrons from the reaction



Evidence that  ${}^8_4\text{Be}$  is formed in other nuclear reactions has been presented by Kirchner and Neuert,<sup>3</sup> and by Crane, Delsasso, Fowler and Lauritsen.<sup>4</sup> A preliminary investigation of the number of neutrons emitted with energies lower than 10 MEV shows that there is a much larger number with energies in the neighborhood of 2 or 3 MEV.

The maximum energy of the neutrons emitted at  $90^\circ$  appears to be 13.4 MEV. The calculated value of the energy of disintegration is  $14.3 \pm 0.5$  MEV. From the value  $14.6 \pm 0.25$  MEV obtained by Oliphant, Kempton and Rutherford, we have calculated that the mass of  ${}^8_4\text{Be}$  is  $0.3 \pm 0.75$

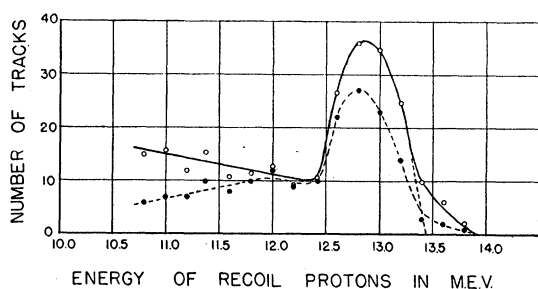


FIG. 1. Energy distribution curve of recoil protons projected in forward direction.

MEV greater than that of two alpha-particles. A recalculation of Kirchner's mass of  ${}^8_4\text{Be}$  with Bethe's<sup>5</sup> new values gives a mass just equal to that of two alpha-particles; Crane and Lauritsen's mass of  ${}^8_4\text{Be}$  is  $1.5 \pm 0.5$  MEV greater than that of two alpha-particles. These agree with our results within the rather large limits of error.

Such a mass of  ${}^8_4\text{Be}$  gives evidence for a resonance level in the interaction of two alpha-particles. This may be an important factor in the anomalous scattering, as pointed out by Beck and Horsley.<sup>6</sup>

Thanks are due Professor C. C. Lauritsen and Dr. H. R. Crane for the use of the high potential apparatus, and for valuable suggestions. We are indebted to the Seeley W. Mudd fund for the financial support of this work.

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May 4, 1935.

<sup>1</sup> Oliphant, Kempton and Rutherford, Proc. Roy. Soc. **A149**, 406 (1935).

<sup>2</sup> See article by Bonner and Brubaker in this same issue.

<sup>3</sup> Kirchner and Neuert, Physik. Zeits. **35**, 293 (1934).

<sup>4</sup> Crane and Lauritsen, Phys. Rev. **47**, 420 (1935); Crane, Delsasso, Fowler and Lauritsen, Phys. Rev. **47**, 887 (1935).

<sup>5</sup> H. Bethe, Phys. Rev. **47**, 633 (1935).

<sup>6</sup> G. Beck and L. H. Horsley, Nature **135**, 430 (1935).

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### The Correlation of Wave Functions with the States of Physical Systems

In their recent article, *Can Quantum-Mechanical Description of Physical Reality be Considered Complete?*<sup>1</sup> Einstein, Podolsky and Rosen arrive at the conclusion that the question put by the title of their paper must be answered in the negative. In the writer's opinion their argument is not sound.

The essential feature of their reasoning is the purported demonstration by means of an example that "it is possible to assign two different wave functions . . . to the same reality." If this were true, it would mean that quantum-mechanical description is erroneous as well as incomplete, for each different wave function involves a different prediction regarding the future behavior of the system described and the authors of the above paper clearly intend the phrase "the same reality" to refer to the same system in the same physical state. Actually, however, the demonstration cited is incorrect.

The special problem discussed by Einstein, Podolsky and Rosen is that of a compound system whose two component systems  $\alpha$  and  $\beta$  are assumed to interact during a limited time interval  $0 < t < T$ . (We may suppose that the interaction is a collision between an atom and a free electron which takes place during this time interval.) After the interaction it is possible to measure any physical property of the system  $\alpha$  without disturbing  $\beta$ . According to the usual quantum-mechanical procedure the wave function to be assigned to the system  $\beta$  after the observation of  $\alpha$  depends on the type of observation made and on

its result. But since  $\beta$  has not been disturbed by the observation of  $\alpha$ , Einstein, Podolsky and Rosen argue that it cannot be affected by that observation and must in all cases constitute "the same physical reality." In other words, they assume it to be in the same "state" in all cases. Here lies a fallacy, however, for whenever two systems interact for a short time there is a correlation between the subsequent behavior of one system and that of the other. Thus in the case of a pair of systems with a definite total energy or definite total linear momentum we can infer from the measured value of the energy or momentum of one system after a collision what the value of the corresponding quantity for the other system must be. In the Compton effect each photon scattered at a definite angle from a unidirectional monochromatic primary beam is correlated with a recoil electron driven off at a definite corresponding angle. The process of reducing the wave packet<sup>2</sup> is the orthodox procedure for taking this correlation into account and, *of course*, it yields a different wave function for the recoil electrons correlated with photons scattered at one angle from that for recoil electrons whose photons have been scattered at another angle. If our mathematics did not work out that way we should have to revise it.

It is quite true, as pointed out by E., P. and R., that the act of observing the system  $\alpha$  can hardly be supposed to change the state of a system  $\beta$  which may be widely separated from it in space, but it can and does reveal something about the state of  $\beta$  which could not have been deduced from the initial wave function of the combination system without such an observation. Thus each possible wave function for system  $\beta$  gives a correct description of the corresponding state of that system.

These remarks would hardly clear up the whole question if no specific mention were made of the interpretation of quantum mechanics as a statistical mechanics of assemblages of like systems. This point of view most clearly formulated by Slater<sup>3</sup> seems the only way of solving the paradoxes of the average presentation of elementary quantum theory. It asserts that the wave functions of the Schrödinger theory have meaning primarily as descriptions of the behavior of (infinite) assemblages of identical systems similarly prepared. When we say that the "state" of an electron in motion is described by  $\psi(x, t)$  we mean that an assemblage of a very large number of similarly prepared electrons would have statistical properties described by this function, and that we cannot know more about an individual electron than the fact that it belongs to a suitably chosen potential assemblage of this character. Every analysis of a wave function into a linear combination of orthogonal functions can be interpreted as a resolution of the complete assemblage into a collection of sub-assemblages. The expansion set up by E., P. and R. of the complete wave function  $\Psi(x_\alpha, x_\beta)$  for the combination system into eigenfunctions of a dynamical variable  $A$  of the system  $\alpha$  shows that in each sub-assemblage we have a correlation between a particular pure state of the variable  $A$  and a corresponding state of the system  $\beta$ . The act of measuring the variable  $A$  is the physical

counterpart of this mathematical expansion and when successful<sup>4</sup> shows which sub-assemblage a particular pair of systems  $\alpha, \beta$  belongs to. The "reduction of the wave packet" is the process of substituting the wave function of the sub-assemblage for that of the original complete assemblage which must accompany the transfer of one's attention from an arbitrary member or members of the original assemblage to systems known to belong to said sub-assemblage.

There seems no reason to doubt the completeness of the quantum-mechanical description of atomic systems within the frame of our present experimental knowledge.

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Harvard University,  
May 25, 1935.

<sup>1</sup> A. Einstein, B. Podolsky and N. Rosen, Phys. Rev. **47**, 777 (1935).

<sup>2</sup> Reference 1, p. 779.

<sup>3</sup> J. C. Slater, J. Frank. Inst. **207**, 449 (1929).

<sup>4</sup> In most measurements of the properties of atomic systems we do not get a definite result for every system in the group under investigation.

#### The Dielectric Constant and Resistance of Colloidal Solutions

It has been noticed by various investigators<sup>1-6</sup> that the dielectric constant of aqueous colloidal solutions is often considerably higher than that of water. It has usually been assumed that this increase results from the colloidal particles acting as dipoles, but there is evidence<sup>3, 4</sup> that this is not the essential principle involved, and the following experiments throw further light on the situation.

Over a range of frequencies from 0.25 to 2000 kilocycles/sec. measurements were made with a Wheatstone bridge by a substitution method, comparison being made with potassium chloride solutions taken to have a dielectric constant equal to that of water and resistances independent of the frequency. Electrode polarization is a difficulty at low frequencies, but can be eliminated by measuring at different electrode distances.

Coarse suspensions are particularly suitable for study and we have used Nujol, sulfur, ferric oxide and kaolin, in sodium oleate and gelatin; cream (natural and homogenized); and cellulose in water, with mean particle size ranging from  $10\mu$  down to  $0.5\mu$ . For all these, we find high dielectric constants at the lower frequencies, generally increasing with the total internal surface and increasing rapidly as the frequency decreases, so that values as high as 40,000 are obtained in certain cases. As is to be expected,<sup>7</sup> the resistance simultaneously increases with decreasing frequency.

That we are dealing with the same effect in all cases is indicated by the characteristic fashion in which the dielectric constant and the resistance vary with the frequency (Fig. 1). Over a wide range of frequencies the values of  $(D - D_\infty)$ , where  $D_\infty$  is the constant value of the dielectric constant obtained at high frequencies, vary as