τ has to be divided by four. On the other hand, the mean life of the system $\mathrm{Cl}(e^-e^+)$ should be of the same order of magnitude as that of positronium, i.e., 10^{-10} sec. However, inasmuch as the time necessary for the emission of light is of the order of 10^{-8} sec and as the probability of annihilation and of catching an M electron is small in the higher states of the system $(\mathrm{Cl}e^-)e^+$, the conclusion must be made that the spectrum given in Table I is to be expected.

A more detailed account of this work will be presented in *Societas Scientiarum Fennica Commentationes Physico-Mathematicae* in the near future.

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The Formation of a Compound Nucleus in Neutron Reactions*

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IN the theory of nuclear reactions with particles of moderate energy (<50 Mev), one generally makes the following assumption: The incident particle, upon entering the target nucleus, immediately forms a compound nucleus in which its motion is completely integrated into a complicated collective motion of the entire system. There are some reasons to doubt the validity of this assumption. The success of the shell model of nuclear structure suggests that nucleons do not interact very strongly with each other when moving inside the nucleus. The motion is rather like that of an independent particle in a potential well. Recent measurements by Barschall[1] and co-workers of the total cross sections for neutrons on various nuclei as a function of energy have brought some new evidence corroborating the latter point of view.

A theory for total neutron cross sections was developed by Feshbach and Weisskopf[2] under the assumption that the incident neutron and the target nucleus immediately form a compound nucleus. The resulting total cross sections decrease *monotonically* with increasing energy,

$$\begin{aligned} \sigma_t &\approx 4\pi/(kK) \qquad (\bar{\lambda} \gg R) \\ &\approx 2\pi(R+\bar{\lambda})^2 \qquad (\bar{\lambda} \ll R). \end{aligned} \tag{1}$$

Here $k=\bar{\lambda}^{-1}$ is the wave number of the incident neutron; $K \approx 10^{13}\ \mathrm{cm}^{-1}$ is the wave number of the neutron in the interior of the nucleus; and R is the nuclear radius. These results are at variance with the experiments which are shown in a three-dimensional plot in the upper part of Fig. 1.

The regular maxima and minima exhibited by the experimental results seem to indicate an interference of the incident wave with an outgoing one, suggesting that the neutron wave is not completely absorbed into collective motion in one passage through the nucleus. We therefore have recalculated the total neutron cross section with the following model. The nucleus is replaced by a potential well with a complex potential,

$$\begin{aligned} V(r) &= -V_0(1+i\zeta) \quad \text{for} \quad r<R \\ &= 0 \qquad\qquad\quad\ \text{for} \quad r>R, \end{aligned} \tag{2}$$

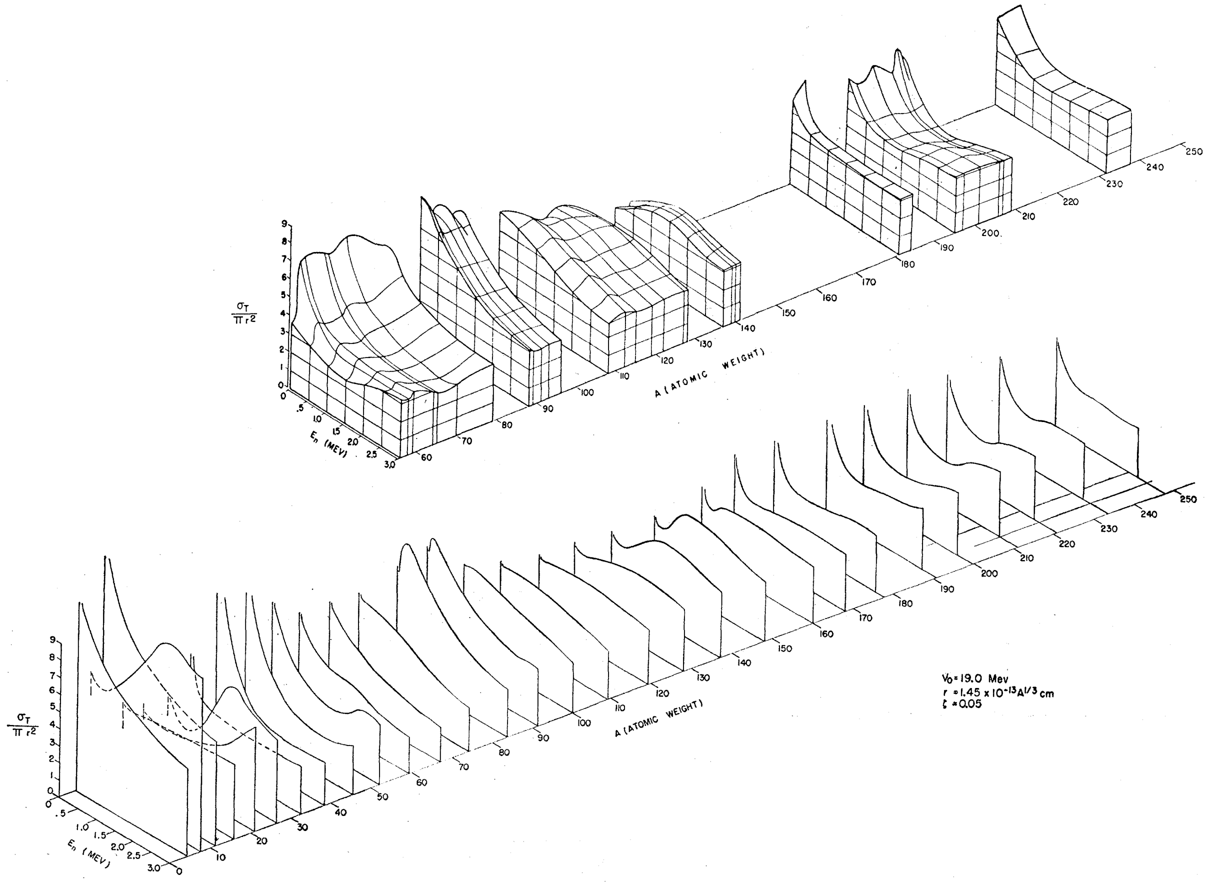

FIG. 1. Total neutron cross section as a function of energy and atomic number. Upper profile: experimental results (reference 1). Lower profile: theoretical results with the constants as indicated.

where V_0 is a real number giving the depth of the well, and ζ is a parameter which indicates an "absorption" for neutrons within nuclear matter. This absorption is introduced in order to describe the formation of the compound nucleus. The distance l in nuclear matter, within which the neutron intensity is reduced by this absorption by $(1/e)$, is given by $(\zeta K)^{-1}$. If (R/l) is small, part of the neutron wave emerges from the nucleus and causes interference with the incoming beam. If $\zeta \gg (KR)^{-1}$, no neutron wave emerges, and the results are equivalent to those of Feshbach and Weisskopf, quoted above.

The calculation of the total cross section arising from the potential of Eq. (2) is a straightforward problem of wave theory, and the results are shown in the lower half of Fig. 1 for the following choices of constants: $V_0 = 19$ Mev, $R = 1.45 \times 10^{-13} A^{\frac{1}{3}}$ cm, $\zeta = 0.05$. It is evident that this simple model reproduces all the main features of the experimental results. If this agreement is not fortuitous, we must conclude that in the energy range considered the neutron penetrates a distance l of about 2×10^{-12} cm into nuclear matter before it is incorporated into a collective compound motion.

It should be mentioned that the experimental curves are averaged over many narrow resonances which the simple model employed here will not predict. They are resonances of the compound system which is formed after "absorption" of the neutrons. The relatively large value of l given above does not preclude the existence of such resonances. A more elaborate theory which also includes these resonances has been developed and will be submitted for publication in the near future.

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Direct Experimental Evidence for the Existence of a Heavy Positive *V* Particle*

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VARIOUS workers have shown[1,2] that some, if not all, charged *V* particles observed in cloud-chamber experiments can be identified with the *K* particles[3] (κ- and χ-mesons) found in nuclear emulsions. Direct mass measurements have been made on primary *V* particles of both signs of charge. These measurements have in all cases given values, somewhat lighter than a proton mass, which are entirely consistent with the known masses of *K* particles. The question arises, therefore, as to whether charged *V* particles exist whose mass is considerably greater than that of a *K* particle, and which perhaps decay into a nucleon and π-meson, in a manner analogous to the decay of the neutral V_1^0 particles.

Alford and Leighton[4] have suggested that the observed charged *V* particles may be of two or more types, of quite different lifetimes. This suggestion was based upon an observation of the distribution of the decay points of the particles in their cloud chamber. The upper chamber appeared to favor the detection of a relatively long-lived particle (i.e., $\tau \sim 10^{-9}$ sec) formed in the lead blocks above the chamber, while the lower chamber seemed to show a number of particles of relatively short life ($\tau \sim 10^{-10}$ sec) formed in the lead plate between the chambers.

TABLE I. Classification of charged *V* particles according to place of origin and sign of charge.

Sign Origin	Positive	Negative	Total
Above plate	8	18	26
In plate	18	9	27
Total	26	27	

TABLE II. Measured data pertaining to two positive *V* particles with heavy charged secondary particles.

Case	Sign	P_{pri} (Mev/c)	I_{pri} (×min)	M_{pri} (m_e)	P_{sec} (Mev/c)	I_{sec} (×min)	M_{sec} (m_e)	θ	P_T (Mev/c)
1	+	–	3–7	–	360±60	3–7	1300–2300	20°	125±25
2	+	–	2–4	–	520±75	2–4	1300–2200	18°	160±40

Additional data have been obtained with the same apparatus, and an analysis has been made, based upon this apparent difference in sensitivity of the two chambers. In this way there was found a striking charge asymmetry between the charged *V* particles produced in the lead plate and those produced elsewhere (mainly in the lead blocks above the chamber). This is indicated in Table I.

A rough calculation reveals that, if the relative population of positive and negative *V* particles in the two chambers is actually the same, the statistical probability of observing the above charge asymmetry, or a greater one, is about 0.007. This result thus tends to substantiate the conclusions drawn on the basis of the distribution of the observed decay points, but it should, of course, be emphasized that the number of events is still comparatively small.

A possible interpretation of these asymmetries in terms of a mixture of long-lived and short-lived *V* particles might be made as follows: Because the lead blocks above the chamber are rather far away from the illuminated region, the *V* particles observed to decay in the upper chamber are predominantly of the long-lived type. From the charge asymmetry of this fairly pure sample of particles, we may tentatively conclude that they are produced with a negative excess of about two to one. On the other hand,

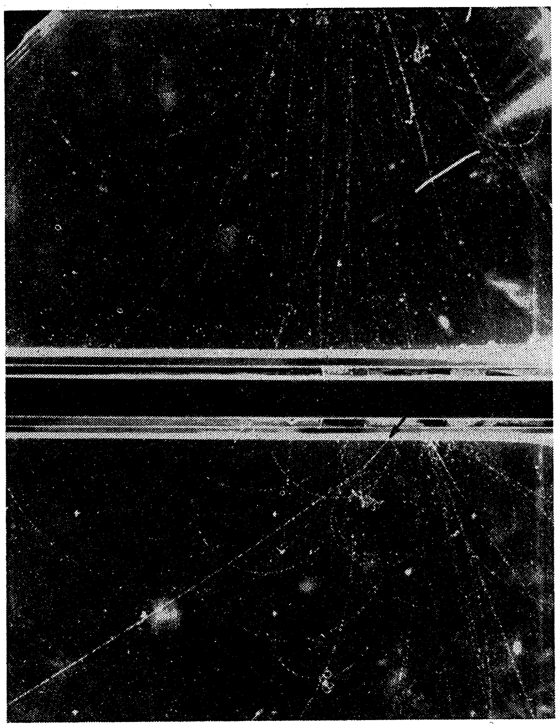

FIG. 1. Cloud-chamber photograph showing a charged *V* particle originating in an interaction in the lead plate and decaying into a heavy secondary particle. The *V* particle travels diagonally downward toward the left from the interaction and decays after having traversed only a short distance in the chamber. The heavy secondary particle proceeds almost in the same direction as the *V* particle. Both the primary and secondary particles are heavily ionizing.