PROTON-PROTON SCATTERING AT LOW VELOCITY

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ABSTRACT. It is shown that Kar's formula for proton-proton scattering explains the angular variation of 'departure from Mott's formula' as observed by Ragan and others for low velocities, if it is assumed that the short range Yukawa force is due to the formation of mesons having mass 152 e.u. and short range charge ½ or other submultiple of its mass. The mass thus determined is different from the mass 110 e.u. obtained previously by applying Kar's formula to high velocity proton-proton scattering.

Recently one of us (Kar, 1942) derived a formula for proton-proton scattering assuming the short range interaction potential to be of Yukawa type $V = -(A/r)e^{-ar}$. The formula was found to be in very good agreement with the observations of Heydenburg, Hafstad and Tuve (1939) at high velocity of incidence. The values of a and A in Yukawa potential for which there is agreement with the above experiment give for the mass of meson $m = 110$ e.u. (approx.) and for the short range meson charge $\sqrt{A} = 6e$ (approx.). These identical values of mass and charge of mesotron have more recently been obtained by Kar and Roy (1943) by applying the above Kar's formula (modified for the absence of Coulomb repulsive force) to neutron-proton scattering at high velocity of incidence. Again, Kar and Roy (1943) have shown that the binding energy of deuteron may be correctly determined by their self-consistent method, if it is assumed that the energy is due to a meson field of mass 110 e.u.

Thus, it follows from Kar's theory of scattering that whenever a proton, due to its high velocity, comes very near a neutron or a second proton, a short range field is developed due to the *temporary* creation of mesons, of mass 110 e.u., within neutron and proton. It has been pointed out before on several occasions that the mesons are only temporarily created; for otherwise there would have been some cases for which the short range meson field is found to be repulsive. Actually, however, we find the meson field to be always attractive, although positive and negative mesons are found in nature.

Now, in the different experiments referred to above, on neutron-proton and proton-proton scattering, the absolute values of the intensity of scattering are never given. Only the ratio of the observed intensity to the Mott's value for Coulomb interaction is given for different scattering angles. This ratio is evidently considered as a measure of the departure from Coulomb scattering given by Mott's formula. It is found experimentally that the observed value of the departure as defined above becomes maximum at 45° for proton-proton scattering at incident velocities 867 k.e.v., 776 k.e.v. and 670 k.e.v. The departure decreases with the angle of scattering and attains a value nearly ·5 for very small angle. These characteristic changes with the angle for different incident velocities are completely explained by Kar's theory of scattering cited above.

Recently, however, Ragan, Kanne and Taschek (1941) have studied proton-proton scattering at low velocity of incidence. They find that, for incident velocities between 200 k.e.v. and 300 k.e.v., the departure attains a minimum value at 45°, instead of a maximum as before. It is evident from Fig. 1 that the departure rises symmetrically on either side of 45°. For smaller angles the rise continues up to very small angle, whereas for larger angles the rise is followed by a decrease in the departure (D) at about 57°, which appears to continue up to 90°. Thus the experimental $D-\theta$ curve, which is drawn dotted in Fig. 1, is not symmetrical about 45°. This asymmetry, it appears, is due to multiple scattering at small angles. And, at low velocity of incidence, the Wenzel angle, giving the limit of multiple scattering, may be as large as 35° as in Fig. 1.

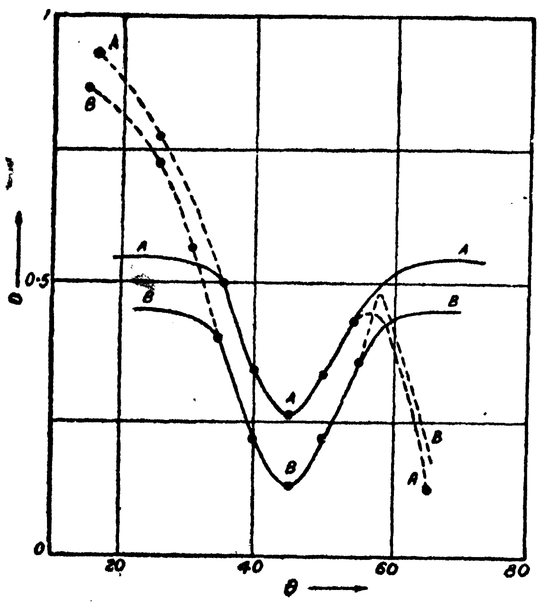

FIG. 1

Curve A—Incident Velocity 249.5 k.e.v.
Curve B— „ „ 298.3 k.e.v.

At first sight the observations of Ragan and others (1941) appear to be anomalous and to go against the theory of scattering given by Kar (1942). However, on close examination we find that Kar's theory, which is perfectly rigorous, is also applicable to low velocity proton-proton scattering. The fitting values of the parameters A and a in Yukawa potential are, however, different in this case. It is found that for meson mass $m=152$ e.u. and short range meson charge $\sqrt{A}=\frac{1}{2}\times 152\,e$, there is very good agreement for the angular range between 35° and 55°, for incident velocity 249.5 k.e.v., while for incident velocity 298.3 k.e.v., there is very good agreement for the above angular range for meson mass $m=152$ e.u. and short range meson charge $\sqrt{A}=\frac{1}{4}\times 152\,e$.

It is significant that the short range meson charges are submultiples of the same meson mass in both the cases. Further, for higher incident velocity the fraction rapidly decreases. This suggests that there must be some interesting relation between the meson mass and its short range charge. Ragan and others (*loc. cit.*) have not studied the angular variations for other incident velocities. Consequently it is not possible for us to find out if the meson of mass $m=152$ e.u. have other submultiple values for its short range charge. Fortunately, however, Ragan, Kanne and Taschek have given the values of the departure at 45° for a number of incident velocities. We find that for incident velocities 275.3 k.e.v. and 321.4 k.e.v. the values of the departure at 45° are correctly given by Kar's formula if we take the meson mass $m = 152$ e.u. but short range charges $\frac{1}{3} \times 152$ e.u. and $\frac{1}{5} \times 152$ e.u. respectively. In the following table, the theoretical values thus obtained are compared with the experimental values given by Ragan and others.

TABLE I

Incident Proton energy	Angle of Scattering	I/I (Mott) (Expt.)	I/I (Mott.) (Theoretical)	m	$\sqrt{\Lambda}/e$
176.5 k.e.v.	45°	0.544	...	...	...
200.2 ,,	,,	0.448	...	...	...
225.9 ,,	,,	0.353	...	...	...
249.5 ,,	,,	0.256	0.2565	152	$\frac{1}{2} \times 152$
275.3 ,,	,,	0.177	0.178	,,	$\frac{1}{3} \times 152$
298.3 ,,	,,	0.118	0.1154	,,	$\frac{1}{4} \times 152$
321.4 ,,	,,	0.0703	0.0819	,,	$\frac{1}{5} \times 152$

It follows from the above table that up to proton energy 321.4 k.e.v., the mass of meson formed due to the virtual fission of proton is 152 e.u., while its short range charge is as low as 30 e.u. So it is quite likely that at higher incident energy, the charge may be still lower and may be so low as 6 e.u. obtained theoretically for incident energies between 670 k.e.v. and 867 k.e.v. It is, however, significant that for such high incident energies, the mass of meson obtained theoretically is 110 e.u. while for lower energies the mass is greater, being 152 e.u. Without commenting on the law of fission of proton, it may be said that the mesons formed within a neutron or a proton have variable mass and charge And it is highly probable that this formation of bound mesons of variable mass is intimately connected with the widely varying masses of free mesons yet determined by different experimenters.

In conclusion, we may remark that the downward bend in the $D-\theta$ curve at 57° degrees may be explained if it is assumed that, within the protons, mesons of different mass and charge are formed at this distance. The mass and charge are such that $D-\theta$ curve has a maximum at 45°. Thus the curve between 57° and 90° may be considered as a portion of the above curve having maximum at 45°. Investigations in this direction are still in progress.

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