

Comparison of Majorana-Heisenberg and Velocity-Dependent Forces

Breit has recently shown¹ that the specific interaction between like particles required to account for proton scattering in 1S states and has the magnitude which one deduces independently from the energies of the 1S (virtual) and 3S states of the deuteron and the binding energies of H^3 and He^4 . That three constants, a , B_1 , and B_3 (giving the range of nuclear forces and the strength of the interaction in singlet and triplet states) can be adjusted to give a satisfactory fit to the four experimental values $E_1(H^2) = -2.15$, $E_3(H^2) = +0.13$, $E(H^3) = -8.3$, $E(He^4) = -27.6$, furnishes the best available support for present nuclear theory.

We wish to point out that this agreement with experiment does not furnish a specific argument for the Majorana-Heisenberg type of force on which the derivation was based. This fact is illustrated most simply by assuming that the heavy particle interaction is not of the M-H form but has a different dependence on velocity, given by² $J_0(r, \rho) = -B(2/a)e^{-(r+\rho)/a}$ ($B=B_1$ or B_3 according as the wave function is symmetric or antisymmetric in the spins of the two particles). B_1 and B_3 in the table are obtained for various values of a by exact solution of the wave equation which determines $E_1(H^2)$ and $E_3(H^2)$. With these values of the B 's, the binding energies of $E(H^3)$ and $E(He^4)$ are calculated by a modified equivalent two-body method.³ We obtain the best agreement with experiment for $a = 1.17 \times 10^{-13}$ cm, $B_1 = 26.2$ MEV, $B_3 = 48.3$ MEV. The fit (to five percent for H^3 , three percent for He^4) is of the same order as given by the Majorana-Heisenberg theory for an interaction $-Be^{-r^2/a^2}$ (with $a = 2.32 \times 10^{-13}$, $B_1 = 21.0$ MEV, $B_3 = 34.1^4$), and is within the probable error of the equivalent two-body method.

The order-of-magnitude agreement of the constants derived on the M-H theory and on the basis of a simple form of velocity dependent interaction, gives some justification for concluding that estimates of the magnitude

TABLE I. *Strength and range of velocity-dependent forces required to account for the virtual and stable levels of H^2 and the binding energies of H^3 and He^4 . Energies in MEV; E' , uncorrected for Coulomb forces; C , Coulomb correction; a in units of 10^{-13} cm.*

a	B_1	B_3	$-E(H^3)$ (8.3 exp.)	$-E(He^4)$ (27.6 exp.)		
				$-E'$	C	$-E$
2.86	3.52	13.7	3.7	11.1	0.55	10.5
2.33	5.66	17.8	4.2	13.2	.67	12.5
2.03	7.85	21.5	4.7	15.2	.76	14.4
1.66	12.3	28.5	5.6	19.2	.92	18.3
1.44	16.9	35.3	6.4	22.7	1.04	21.7
1.28	21.5	41.8	7.1	26.0	1.15	24.8
1.17	26.2	48.3	7.9	29.7	1.22	28.5
1.08	31.0	54.5	8.7	33.2	1.28	31.9
1.01	35.6	60.9	9.4	36.8	1.34	35.5

(and to a lesser extent, the range) of nuclear forces are essentially independent of the special assumption one makes as to the *type* of these forces.

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¹ Reported at the Gibson Island Conference on Nuclear Structure, June, 1936.

² Cf. John A. Wheeler, this issue for notation and discussion of velocity dependent forces.

³ Cf. Bethe and Bacher, *Rev. Mod. Phys.* **8**, 143 (1936) for a description of the general procedure. We follow a method similar to method (a), p. 144.

⁴ Bethe and Bacher, reference 3, Table III p. 111 and Eq. (128) (these values are based on the value $E=0$ for the virtual level of H^2 and do not assume exact equality of the like particle ($B_1=21.0$) and unlike particle ($B_1=20.5$) interaction in singlet states).

Energy Levels in Crystals of Samarium Salts

It was reported at the Washington meeting of the Physical Society in April that many of the absorption lines of solutions and crystals containing rare earth ions may be identified as forbidden transitions from the ground states to higher multiplets of the normal electronic configurations, ($4f^2$). It was further shown that the *structure* of the Gd groups ($^8S_{3/2}-^6I$) observable in crystal absorption¹ is interpretable in terms of the expected splitting of the atomic levels by the internal crystal field.

An analysis of the published data² on the absorption of salts of Sm has now been partially completed. The more than fourfold increase in the number of lines in a close group in Sm over the number in similar groups of Gd, especially at liquid hydrogen temperatures, at once suggests that some other agency is here effective in addition to crystal field splitting. The successive repetition of the pattern of the strong lines at the bottom of a group as sets of weaker lines displaced about 20, 40, 60, 80 and 100 cm^{-1} to the violet points to the coupling of a set of vibrational (?) levels to the crystal field levels. Evidence for this fundamental frequency of about 20 cm^{-1} is to be found in each of the four Gd salts for which data are available and also in europium sulphate.³ Its origin is still uncertain. In addition, higher coupling frequencies are present which seem to be different for each compound. Thus the strongest of these for samarium ethylsulphate (hydrated) is about 345 cm^{-1} . In a given group of the spectrum only certain ones of the coupling frequencies are observable; rarely is the complete set present at once.

A detailed discussion of the absorption of the Gd, Sm and Eu ions in crystals will be presented shortly.

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¹ Spedding and Nutting, *J. Am. Chem. Soc.* **55**, 496 (1933).

² Spedding and Bear, *Phys. Rev.* **46**, 308 (1934).

³ Meehan, *J. Chem. Phys.* **3**, 621 (1935).