A general wave equation would therefore be,

$$\frac{\partial^2\phi_i}{\partial x_\mu \partial x^\mu}-\kappa^2\phi_i=-\frac{4\pi}{c}(\gamma_1 j_i+\gamma_2 j'_i)$$

with γ_1 and γ_2 as independent constants.

This together with the wave equation for the free heavy particles defines practically uniquely a Lagrangian and Hamiltonian in which the interaction heavy particle-meson field is represented by:

$$-W=\frac{\gamma_1}{c}\phi_\mu j^\mu+\frac{\gamma_2\hbar}{4Mci}\left(\frac{\partial\phi^\nu}{\partial x_\mu}-\frac{\partial\phi^\mu}{\partial x_\gamma}\right)M_{\mu\nu}.$$

Proceeding to the non-relativistic limit for the heavy particles, neglecting terms $\sim v/c$ and leaving out δ-functions, one gets in the usual way the interaction potential:

$$V=\left\{\gamma_1^2+\gamma_2^2\left(\frac{\hbar\kappa}{2Mc}\right)^2\left[\left(\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2-\frac{(\boldsymbol{\sigma}_1\cdot\mathbf{r})(\boldsymbol{\sigma}_2\cdot\mathbf{r})}{r^2}\right)+\left(\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2-\frac{3(\boldsymbol{\sigma}_1\cdot\mathbf{r})(\boldsymbol{\sigma}_2\cdot\mathbf{r})}{r^2}\right)\left(\frac{1}{\kappa r}+\frac{1}{\kappa^2r^2}\right)\right]\right\}\frac{e^{-\kappa r}}{r}.$$

With $\gamma_1=g_1$, $\gamma_2=(2M/\mu)g_2$, (μ = meson mass) this is the form given by Youkawa *et al.*

If we take $\gamma_1=\gamma_2=e$ and let $\kappa\rightarrow 0$, this expression changes continually into its electrostatic counterpart

$$V_{\text{el}}=\frac{e^2}{r}+\left(\frac{e\hbar}{2Mc}\right)^2\frac{(\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2)r^2-3(\boldsymbol{\sigma}_1\cdot\mathbf{r})(\boldsymbol{\sigma}_2\cdot\mathbf{r})}{r^2};$$

that is, the Coulomb interaction + the spin-spin interaction which follows from Breit's operator in non-relativistic approximation.

From the point of view proposed above one would expect $\gamma_1=\gamma_2$ also in meson theory, thus leaving only one constant free for each sort of field. Only then will the difference between electrodynamics and meson theory merely come from the finite rest mass of the mesons. On account of the conservation of the currents it is of course formally possible to choose $\gamma_1\neq\gamma_2$, but this is a separate assumption which cannot be inferred from the analogy with electrodynamics.

[1] H. A. Bethe, Phys. Rev. **57**, 260 (1940).
[2] G. Breit, Phys. Rev. **39**, 616 (1932).
[3] W. Gordon, Zeits. f. Physik **50**, 630 (1928).

On the Gyromagnetic Effects in Ferromagnetic Substances

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September 16, 1941

The refined researches of Barnett and others[1] on the gyromagnetic effects in ferromagnetic substances have revealed positive deviations of the ratio ρ of mechanical to magnetic moment from the spin-only value mc/e. This obviously means that, besides the spins, the orbital motion of electrons also contributes to the mechanical and magnetic moments. But further understanding was blocked by the apparent influence of minor structural differences in the samples upon the magnitude of the deviation. The most striking example was that the deviation mentioned for Yensen electrolytic iron, as observed in the Barnett effect, was three times larger than that for soft Armco or Norway iron. Even more incomprehensible was the difference between the gyromagnetic ratio ρ for Yensen iron and also for an iron-cobalt alloy, observed in the Barnett effect, and the lower gyromagnetic ratio observed in the Einstein - de Haas effect for the same substances.

Now Barnett recently in a footnote[2] sheds doubt upon his own former results on the Barnett effect of Yensen iron and the iron-cobalt alloy, mentioning that a redetermination appears to give much lower values of ρ, in agreement with those obtained in the Einstein - de Haas effect. It is the purpose of this note to point out that this considerably simplifies the situation. Considering Barnett's results and omitting the doubtful data, one sees that the ρ-values seem to split into four different groups, namely, nickel and the alloys containing mainly nickel, cobalt and the alloys consisting primarily of cobalt, iron and the alloys containing mainly iron, and finally Heusler's alloy. The approximate values of $\rho e/mc$ for each group will be found in Table I.

Table I.

Substances	$\rho e/mc$ exp	$\rho e/mc$ calc.	ion
Heusler's alloy	1.01	1.00	Mn^{++}
Iron and alloys	1.03	1.07–1.11	Fe^{++}
Cobalt and alloys	1.08	1.12–1.27	Co^{++}
Nickel and alloys	1.05	1.13–1.18	Ni^{++}

On the other hand, recently the gyromagnetic ratios of bivalent paramagnetic salts have been calculated[3] from the deviations of their susceptibilities from the spin-only values. In the right-hand side of the table these calculated values of $\rho e/mc$ are given.

Apparently there is a parallelism between the two series of numbers, though the theoretical paramagnetic deviations from unity are about three times larger than the experimental ferromagnetic deviations. Does this mean that the ions responsible for ferromagnetism are doubly ionized and subject to an interaction with their surroundings which is similar to (though a few times larger than) that characteristic of the bivalent ions in paramagnetic salts?

[1] S. J. Barnett, Rev. Mod. Phys. **7**, 129 (1935); D. P. Ray-Chaudhury, Ind. J. Phys. **9**, 383 (1935); I. K. Kokoin and S. V. Goobar, C. R. Acad. Sci., Moscow **19**, 249 (1938).
[2] S. J. Barnett, Proc. Am. Acad. **73**, 401 (1940).
[3] C. J. Gorter and B. Kahn, Physica **7**, 753 (1940).