The cross sections for chlorine and barium were calculated from measurements of the inelastic cross sections of NaCl, BaS, Na and S and the assumption of the additivity of cross sections.

The results of the measurements are shown in the Table. They make possible the following conclusions: (1) the inelastic cross sections for 2.5 mev neutrons for most nuclei increase smoothly with a mass number; (2) nuclei having a magic number of nucleons have inelastic scattering cross sections that are significantly smaller than neighboring nuclei. It may be that this is the result of the presence of particularly stable nuclear clouds, whose influence is felt even at neutron energies of 2.5 mev.

In conclusion, I take the opportunity to acknowledge the direction of A. I. Leypounskii in this work and the valuable advice and interest of M.V. Pasechnik.

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Level Shifts in μ-Mesic Hydrogen and the Structure of the Proton

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THE work of Wheeler[1] showed that a study of μ-mesic atoms can serve to give information on the internal structure of the nucleus and to determine some of its properties. The purpose of this note is to call attention to the possibility of using data on the fine structure of the μ-mesic hydrogen system to give information concerning the internal structure of the proton and the limits of the applicability of quantum electrodynamics.

The energy of the stationary state of μ-mesic hydrogen to an accuracy including order $\alpha^3 \times$ ($\alpha = e^2/\hbar c$) can be written in the form

$$E = E_0 + \alpha E_1 + \alpha^2 E_2 + \alpha^3 E_3. \qquad (1)$$

In this equation the main term, E_0, is the energy of the μ^--meson in a Coulomb field of a point proton including the correction for retarded interaction. The correction proportional to α is due to the polarization of the electron vacuum in the neighborhood of the μ-mesic atom and was first pointed out in the work of Galanin and Pomeranchuk[2] (see also Ref. 3). The term proportional to α^2 contains the correction to the "ordinary" fine structure of the level determined by spin orbit interaction and the relativistic dependence of mass on energy, and also the second approximation to the polarization of the electron vacuum. There is also included in the approximation the so-called hyperfine structure of the level determined by the interaction of the magnetic moments of the proton and μ-meson. In the given situation this is comparable to the fine structure. Finally, the term involving α^3 includes the interaction of the μ^--meson with the zero point vibrations of the electromagnetic field, the effect of the polarization of the μ-mesic vacuum and third order corrections to the electron vacuum polarization. It should be emphasized that in all these terms, it is necessary to take into account electromagnetic corrections arising from the finite mass of the proton and retarded potentials.

It is not hard to see, however, that in addition to the electromagnetic terms included above, the terms of order α^2 and α^3 should also contain effects of nonelectromagnetic origin. The term of order α^2 should be strongly affected by the interaction of the proton with the zero point vibration of the π-mesic vacuum. The existence of this interaction should lead to a smearing of the proton charge over a distance of the order of the Compton wavelength of the π-meson. This will result in a deviation of the electric field from the Coulombic in the indicated regions. We will examine some of the effects arising from the existence of the proton in a dissociated state (neutron + π-meson) during a time interval τ. Corresponding to this effect, there exists a correction to the basic energy level of the μ-mesic hydrogen of the order of the quantity

$$\Delta E \sim \tau (\mu / m)^2 \alpha^2 n^{-3} \mathrm{Ry}' (1 + \mu / M)^{-3}, \qquad (2)$$

where m, μ and M correspond to the masses of the π, μ-meson and of the proton; $Ry' = \mu e^4 / 2k^2$. Since the quantity $(\mu/m)^2$ in Eq. (2) is of the order of unity, this effect introduces a significant contribution to the relativistic fine structure of the level of the μ-mesic hydrogen ($\sim \alpha^2$). For ordinary hydrogen, because of the smallness of the quantity $(m_e/m)^2 = (1/273)^2$, the dissociation of the proton has an effect only of the order of electromagnetic corrections proportional to α^4. This is at the borderline of present-day experimental errors. Nonelectromagnetic effects should likewise contribute significantly to corrections to the (ordinary) fine structure of μ-mesic hydrogen (α^3 approximation).

Let us examine, for example, the polarization of the vacuum in μ-mesic hydrogen. Generalizing the results of Vehling[4] for polarization corrections to arbitrary atomic and vacuum particles having masses m_0 and m_V in the case where m_0/m_V is much less than $1/\alpha$, we have:

$$\Delta E = -\frac{8}{15\,\pi}\left(\frac{m_0}{m_v}\right)^2 \frac{\mathrm{Ry}',\alpha^3}{n^3}\left(1+\frac{m_0}{M}\right)^{-3} G. \qquad (3)$$

The factor G in Eq. (3) is determined by the spins of the particles examined and their interaction with the vacuum fields. It follows from Eq. (3) that the polarization of the π-mesic vacuum introduces into μ-mesic atoms terms of the same order as arise from the polarization of the μ-mesic vacuum. For ordinary hydrogen the polarization of the π-mesic vacuum introduces terms of the same order as electromagnetic corrections of order α^5. These are beyond present-day experimental techniques.

At the same time, because the polarization of the π-mesic vacuum by the external electromagnetic field is seriously affected by the strong interaction of virtual π-mesic and nucleon pairs, the nonelectromagnetic additions to the fine structure of the μ-mesic hydrogen have a first order effect. The isolation of these effects might serve to establish the limits of applicability of pure electrodynamics and possibly lead to some tests of present-day ideas of the interactions of nucleons with π-mesons.

In conclusion, I thank Prof. V. L. Ginzburg for discussions of this note and for a series of critical comments.

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The Photoproduction Cross Section for Positronium in an External Field Taking into Account Radiative Corrections

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THE differential cross section $d\sigma$ for the photoproduction of positronoum in an external field, taking into account radiative corrections of any order, is connected with the differential cross section $d\sigma_f$ for the photoproduction of the free products with zero relative velocity by the following relation:[1]

$$d\sigma = [(\bar{\psi}(0)\,\psi(0)) / (\bar{\psi}_f(0)\,\psi_f(0))]\, d\sigma_f. \qquad (1)$$

where $\psi(x)$ is a wave function (in relative coordinates) of the ground state of positronium (with energy E), satisfying a Bethe-Salpeter equation which takes into account the possibility of annihilation[1,2], $\psi_f(x)$ is a wave function of the free particles and is a proper function of the same complete set (but with an energy $E_f = E + \epsilon$, where $\epsilon > 0$ is the binding energy), as is $\psi(x)$. In Eq. (1) it is necessary to evaluate $(\bar{\psi}(0)\psi(0)) = \mathrm{Sp}[\bar{\psi}(0)\psi(0)]$ with the same accuracy as is taken in the calculation of $d\sigma_f$.

If only the first radiative corrections are examined, the multiplier $(\bar{\psi}(0)\psi(0)]$ must be replaced by its nonrelativistic value, since the next correction to $|\psi_{\mathrm{nonrel}}(0)|^2$ is of the order of $(e^2/\hbar c)^2$ [3]. In addition, when positronium is produced in a ground state, the factor $(\bar{\psi}_f(0) \times \psi_f(0))$ can be taken equal to one[3]. Thus, the calculation of the photoproduction cross section of positronium in an external field, taking into account first order radiative corrections, is reduced to the problem of finding the cross sections of either the photoproduction of the free particles or of bremsstrahlung in an external field. This latter has been investigated by Myamlin.[4] However, from his results we cannot immediately write down the cross section $d\sigma_f$, since the author's purpose was to find the radiative corrections to bremsstrahlung,