PROPOSED EXPERIMENTAL TEST FOR THE MASS SHIFT AND THE PECULIAR MOTION OF AN ELECTRON IN A LASER BEAM*

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Using the technique of an electron beam crossing a laser beam, an experiment is proposed not only for resolving the controversy of the electron mass-shift effect, but also for confirming the peculiar longitudinal and transverse motion of an electron in an electromagnetic traveling wave.

Since Sengupta[1] first suggested the possibility of observing the mass increase of a free electron in an intense electromagnetic wave, there have been many theoretical investigations on this subject and much controversy has arisen.[2] Therefore, the existence of this mass-shift effect has been a focus of interest in recent years and a number of proposed experiments for a possible measurement of this effect were published.[3] According to the proposal of Reiss,[4] this effect manifested itself as a change in transition frequency of a hydrogenic atom. Mowat, Johnson, Ehlers, and Shugart[5] of the Berkeley Atomic Beam Group have performed an excellent experiment using a Cs^{133} atom beam interacting with a microwave. Their apparatus was sensitive enough to detect effects which were three orders of magnitude less than the mass-shift effect expected. Unfortunately, the final result of this experiment is negative.[6] However, it is very difficult, based on this negative result, to conclude that the mass-shift effect is nonexistent because there are a number of possible reasons contributing to the zero effect for an electron in an atom.[6] Most of the theoretical calculations of the mass-shift effect were based upon a system consisting of a free electron and a traveling wave. Naturally, the best experimental system to be used at present is an electron beam interacting with a laser beam. Of course, the main problem is how.

When the relativistic equation of motion of an electron in an electromagnetic wave is solved in terms of the observer's time instead of the retarded time,[7] the solution reveals that the total momentum of the electron as seen by the observer has two components of entirely different characteristics. The component in the direction of wave propagation $\vec{n}$, $\vec{p}_n$, is expressed as a momentum of a wave (Compton electron); whereas the one in the direction perpendicular to $\vec{n}$, $\vec{p}_m$, is as a momentum of a particle (photoelectron). The relative magnitude of these two components depends on the energy of the interaction. The average momentum of the electron is not zero and, hence, the electron will be scattered by the wave into a direction depending upon the magnitudes of the two momentum components. In the case of a linearly polarized wave with its electric vector $\vec{\mathcal{E}} = \mathcal{E}\vec{m}$, and $\vec{n}$ perpendicular to the velocity of an electron beam $\vec{V}_0$, the energy absorbed from the wave by an electron and the two momentum components are given by[7]

$$\epsilon = E - E_0 = (e^2/2m_0\omega^2)(\vec{\mathcal{E}} - \vec{\mathcal{E}}_0)^2, \tag{1}$$

$$p_n = \epsilon/c, \quad p_m = (2m_0\epsilon)^{1/2}, \tag{2}$$

and

$$(p_n/p_m)^2 = \epsilon/2m_0c^2, \tag{3}$$

where $m_0 = m\gamma_0$ and $\gamma_0 = (1 - \vec{V}_0^2/c^2)^{-1/2}$. (Notice that the average energy absorbed by the electron does not depend, in general, on the time duration of the interaction, as if the electron collided with another particle.) For a laser beam of $\lambda = 7000$ Å and $\mathcal{E} \simeq 10^8$ V/cm, $\bar{\epsilon} \simeq 1$ eV. If we define $\langle \Delta m \rangle = \bar{\epsilon}/c^2$, we have

$$\langle \Delta m \rangle / m_0 = 2(\bar{p}_n/\bar{p}_m)^2 \simeq 2\times 10^{-6}. \tag{4}$$

For $\bar{\epsilon} \simeq 1$ eV, $\bar{p}_n/\bar{p}_m \simeq 10^{-3}$. Hence, the motion of the electron is predominantly nonrelativistic and particlelike and we have $\bar{v}_n \simeq 6\times 10^4$ cm/sec and $\bar{v}_m \simeq 6\times 10^7$ cm/sec. When a laser beam is focused perpendicular to a 1-keV electron beam ($V_0 \simeq 2\times 10^9$ cm/sec) with its electric vector perpendicular to $\vec{V}_0$, one would expect that the electron beam could be deflected in the direction of $\vec{n}$ by an angle $\theta_n \simeq \bar{v}_n/V_0 \simeq 3\times 10^{-5}$ rad; whereas, in the direction perpendicular to both beams, it could be $\theta_m = \pm\bar{v}_m/V_0 = \pm 3\times 10^{-2}$ rad. Now we may write

$$\langle \Delta m \rangle / m = 2(\theta_n/\theta_m)^2 = \tfrac{1}{2}(V_0/c)^2\theta_m^{\,2}, \tag{5}$$

with at least 1% accuracy.

After the great success of the observations for the famous Kapitza-Dirac effect by both Bartell, Thompson, and Roskos[8] and Schwarz, Tourtellotte, and Gaertner,[9] there will be no experimental problems imposed on the experiment proposed here. The sensitivity of the apparatus in both groups is about 10^{-5} rad. With minor modifications of the optics and the detecting system, and replacing the reflecting mirror by a light trap, both groups should have no difficulty in performing this experimental test. Since $\bar{v}_n \propto \mathcal{E}^2$ and $\bar{v}_m \propto \mathcal{E}$, it may be difficult to observe θ_n if $\mathcal{E} < 10^8$ V/cm. However, there is always a good chance to measure θ_m. Even for $\mathcal{E} \simeq 10^6$ V/cm, $\theta_m \simeq \pm 3 \times 10^{-4}$ rad.

There have been some difficulties in acquiring a good estimation for the $\mathcal{E}$ value of a laser beam in a small region.[9] If the result of this proposed experiment turns out to be positive, the idea of this experiment will have a practical meaning. Further development of this apparatus may be used as an instrument to map the electric field in a laser beam. Undoubtedly, this is a crucial experiment. If the result turns out to be negative, it may mean a disaster in the present concept of classical fields, as all the calculations are a consequence of classical electrodynamics.

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CONTINUOUS BREAKING OF CHIRAL SYMMETRY*

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Continuity arguments for transitions between various subgroups of the chiral-symmetry group are presented. Some interesting sum rules are obtained in this way.

Recent investigations[1] have led to the suggestion that the physical manifestation of a chiral-invariant Lagrangian lies in the existence of Goldstone bosons, degenerate vacua, and nonperturbative solutions. In this note we utilize this idea within the framework of the Gell-Mann model[2] studied more recently by Gell-Mann, Oakes, and Renner (GMOR),[3] and investigate the general properties of the two-point functions. This approach leads in a natural manner to the introduction of many interesting subgroups of the chiral-symmetry group for different possible values of the symmetry-breaking parameter. We discuss the possibility of continuous transitions among different subgroups which leads to some interesting mass formulas and relations between other physically relevant quantities in a nonperturbative way. Especially, the relation[3] obtained by GMOR for the symmetry-breaking parameter is reproduced in this manner.

We start with the strong-interaction Hamiltonian density given by

$$H(x) = H_0(x) + \epsilon_0 S^{(0)}(x) + \epsilon_8 S^{(8)}(x), \tag{1}$$

where $H_0(x)$ is assumed to be invariant under the chiral group $W(3) \equiv \mathrm{U}^{(+)}(3) \otimes \mathrm{U}^{(-)}(3)$, broken by the scalar density terms. We assume[2,3] that the scalar density nonet $S^{(i)}(x)$ together with the nonet $P^{(i)}(x)$ ($i = 0, 1, \cdots, 8$) transforms according to the $(\underline{3}, \underline{3}^*) \oplus (\underline{3}^*, \underline{3})$ representation, satisfying the usual algebra.[2,3] These algebraic relations and the local generalization of the usual equations[3] of motion lead to