Upper Limit of the Electric Dipole Moment of the Electron*

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A new upper limit on the electric dipole moment of the electron is established by measurements of the scattering of electrons by He^4 at 180° where the charge scattering is zero. The experiment was performed at a momentum transfer of $q=0.44\times10^{13}$ cm^{-1} and indicate that the electric dipole moment of the electron is $\lesssim10^{-15}$ e cm, where e is the charge of the electron.

UPPER limits on the electric dipole moment of the electron have been established by several methods; Table I summarizes the available information. Most measurements were made for momentum transfers $q\approx0$. Burleson and Kendall,[1] however, measured the differential cross section for the elastic scattering of high-energy electrons. This cross section is given by the expression

$$\frac{d\sigma(\theta)}{d\Omega}=\sigma_{\text{charge}}+\sigma_{\text{magnetic}}$$

$$=\sigma_M|F(q)|^2\left[1+\alpha^2(q)\left(\frac{\hbar q}{m_0c}\right)^2\frac{1}{\cos^2(\frac{1}{2}\theta)}\right]. \quad (1)$$

σ_M is the Mott scattering cross section, $F(q)$ is the nuclear structure form factor; as in the case of the proton the charge form factor of the electron cannot be separated from that of the α particle, θ is the angle of scattering, m_0 is the electron rest mass, and $\alpha^2(q)=\lambda^2(q)+\mu^2(q)$ are the structure form factors of the electric and anomalous magnetic dipole moments of the electron measured in units of $e\hbar/m_0c$; elastic scattering measurements place limits on $\alpha(q)$ and not on $\lambda(q)$ or $\mu(q)$ separately.

Burleson and Kendall measurements were made for q between 1.5 and 2.5; they measured the ratio of cross sections at 2 angles (60° and 135°).

TABLE I. Upper limits on the electric dipole moment λ of the electron.[a]

Method	λ	Reference
Lamb-shift experiments	$<3\times10^{-8}$	Feinberg[b]
Absence of non-parity-conserving atomic transitions	$<3\times10^{-2}$, $<2\times10^{-2}$, $<5\times10^{-2}$	Salpeter[c]
g factor of free electron	$\lesssim8\times10^{-5}$	Nelson *et al.*[d]
Scattering of electrons by He^4	$<2\times10^{-4}$	Burleson and Kendall[e]
Scattering of electrons by He^4	$<3\times10^{-5}$	Present experiment

[a] λ is the electric dipole moment in units of $e\hbar/m_0c$.
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We measured the elastic scattering cross section of 41.5-MeV electrons on He^4 at 180° which corresponds to $q=0.44\times10^{13}$ cm^{-1}. At 180° the Mott cross section is zero and the magnetic scattering is very strongly enhanced by the $[\cos^2(\frac{1}{2}\theta)]^{-1}$ factor. This more than compensates the lower q used in this experiment as compared to Burleson and Kendall.

The experimental arrangement was described before[2] but a sketch is shown in Fig. 1. Electrons from the Stanford Mark II Linear Accelerator are deflected ~10° by an auxiliary magnet before striking the target and the ones that undergo 180° scattering are deflected again by another 10° in the same magnet before entering a magnetic spectrometer. Helium gas at six atmospheres was used as a target. The apparatus was fully checked on measurements of the magnetic scattering of nuclei such as H, D, Li^7 and several others.[3] The solid angle of the spectrometer set at 180° was such that a cross section of 2.8×10^{-33} cm^2/sr is expected from the charge scattering of helium. Our results give

$$d\sigma(\theta=180°)/d\Omega=(3\pm3)\times10^{-33}\text{ cm}^2/\text{sr}.$$

Assuming that the maximum positive error corresponds to a magnetic contribution to the cross section, one gets from (1)

$$\alpha\lesssim3\times10^{-5}e\hbar/m_0c \quad \text{for} \quad q=0.44\times10^{13}\text{ cm}^{-1}.$$

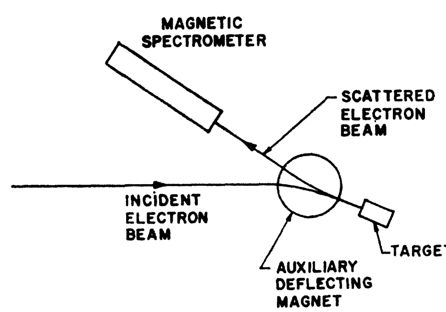

FIG. 1. Sketch of the experimental arrangement used for 180° electron scattering.

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The effects of the internal structure of the He^4 on this type of experiments have been calculated by Goldberg and found to be very small.[4]

The electron anomalous magnetic moment which has origin in electromagnetic corrections is not seen in these high-energy electron scattering experiments because it has a spatial structure of length determined by the Compton wavelength and consequently a form factor that decreases very rapidly for high q.[5] The electron scattering method investigates structures of much smaller size. If one asumes α to be independent of q,[6] the limit established by our experiment for an electric dipole moment of the electron is $\leq 10^{-15}$ e cm. If α is a function of q it must decrease from $\lesssim 8\times 10^{-5}$ (at $q\sim 0$) to $\leq 3\times 10^{-5}$ for $q=0.44\times 10^{13}$ cm^{-1}.

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Alternate Method of Measurement of the Polarization of Light Emitted by Helium Atoms Excited by Energetic Electrons*

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Previous measurements on the polarization of helium light emitted by atoms excited by an electron beam have resulted from the observation of the intensity of the light at right angles to the direction of the electron beam. Polarization was determined in terms of the relative intensities of the components of this light whose electric vectors were oriented parallel to and at right angles to the direction of the electron beam. Because of the disagreement between experiment and theory, an alternate method in which the angle θ between the line of observation and the electron beam could be altered was used. After correcting the effective volume of the reaction region observed, the total intensity of light at a given angle is related to that observed at 90° by the relationship, $I_\theta=I_{90}(1-\pi\cos^2\theta)$, where π is the polarization. Results given show that for $\lambda=4922$ Å, relative changes of polarization with electron energy are similar to those observed with the previously described more sensitive method. The trend of the polarization toward zero at the onset of excitation was again observed.

INTRODUCTION

Earlier work[1–6] on the measurement of the polarization of light emitted by helium atoms excited by an electron beam has produced three distinct anomalies, involving zero polarization at threshold, magnetic field dependence of the diffuse singlet transitions, and the unexpected energy dependence of polarization of the $\lambda=3889$ Å line. Because of these unexpected results, it was considered desirable that a different method be used for making a confirmative measurement. All of the above references utilized observations made at right angles to the electron beam. The relative intensities of the emitted light with electric vectors oriented parallel and perpendicular to the electron beam were measured; the percentage polarization π was then computed by use of the equation,

$$\pi=[(I_{\parallel}-I_{\perp})/(I_{\parallel}+I_{\perp})]\times 100\%. \quad (1)$$

In the experiment to be described, use was made of the relationship,

$$I_\theta=I_{90}(1-\pi\cos^2\theta). \quad (2)$$

This relates the intensity I_θ of light from a point source and observed at an angle θ to the direction of the electric vector to that observed at 90°.

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† Presently employed by the University of Massachusetts, Amherst, Massachusetts.
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EXPERIMENTAL METHODS AND RESULTS

Figure 1 illustrates the procedure used in this measurement. An electron gun was mounted in a solid block of soft iron machined to provide an interaction chamber and ports for observation of the intensity of light at selected angles. Light was channeled from the interaction region through $\frac{3}{8}$-in. diameter drilled and reamed light pipes $4\frac{1}{2}$ in. long. The electron beam was collimated by 0.06-in.-diam holes in the accelerating electrode