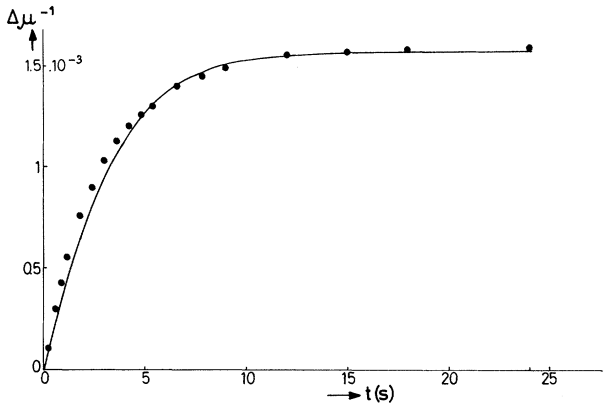

FIG. 3. Change in stiffness as a function of time after switching on light of intensity 9×10^{-5} W/cm^2 (77 °K). Dots: experimental points; drawn curve (calculated): $7.08\times10^{-3}/[1+3.5\coth(0.2t)]$.

should yield a straight line:

$$(\Delta\mu^{-1})^{-1}=1/Cn_s+(\alpha/C)t. \quad (6)$$

In Fig. 2 just such a plot is shown: The experimental points lie on a straight line to a very good approximation. Equation (6) also shows that the slope of this line should be independent of the stationary level n_S from which the recovery starts. This is indeed the case: We cannot show this in Fig. 2, since most experimental points coincide on the scale of that figure. From the slope α/C of the line and from the value C calculated above we find α; this leads directly to β since α/β was also calculated before.

Finally we examine the decrease in μ after the light is switched on. As a test we have in Fig. 3 plotted $\Delta\mu^{-1}$ vs t for a light intensity I_w not used in the calculations above. The dots are experimental points: The drawn curve represents $\Delta\mu^{-1}$ according to Eqs. (1) and (3) with the values of C, α, and β calculated above. A slight deviation for small t might be due to inaccuracy in determining the point $t=0$. In general we observe a very satisfactory agreement between experiment and calculations.

The proposed model does not specify how the difference in contribution to magnetic properties of centers of type I and II arises, what exactly is the mechanism by which light induces a dissociation of a type-I center, or how electrons, once at a type-II center, move back to Ga donors. Further investigation of each of these points should eventually lead to a quantitative prediction of the constants C, α, and β, in that order. However, the excellent agreement between model calculations and experimental results strongly suggests that Eq. (2) correctly describes the essential features of the process, thus justifying the assumed model.

We wish to thank Mr. H. Logmans for his assistance in the measurements.

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ELECTRIC DIPOLE MOMENT OF THE CESIUM ATOM. A NEW UPPER LIMIT TO THE ELECTRIC DIPOLE MOMENT OF THE ELECTRON*

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(Received 12 November 1968)

An atomic-beam magnetic-resonance apparatus has been used in a test of parity and time-reversal invariance in atomic systems. An upper limit to the permanent electric dipole moment of the cesium atom, $|d_{Cs}|<3.7\times10^{-22}e$ cm, has been set. This result leads to an upper limit to the electric dipole moment of the electron, $|d_e|<3\times10^{-24}e$ cm.

An atomic-beam magnetic-resonance technique has been used to set a new upper limit to the electric dipole moment (EDM) of the cesium atom. This upper limit leads in turn to a new upper limit to the EDM of the electron which is a factor of 10 lower than any limit previously reported.

The importance of these experiments lies in the fact that the observation of an EDM in an atomic system of well-defined angular momen-

tum would be direct evidence for a violation of both parity and time-reversal invariance.[1,2]

Extensive experiments have been completed with an apparatus previously described,[3] but modified to include a longer resonance region. This apparatus has improved collimation to reduce possible trajectory effects which may have been significant in earlier work. The additional length of the resonance region reduced the contribution of fringing field effects to the detected signal.

The distance between the separated oscillatory fields is now 90 cm and the length of the electric field plates is 71 cm. The increased length gives narrower linewidths (300 cps for cesium) and hence greater sensitivity. This greater sensitivity enables us to make a detailed study of certain very small systematic effects.

With the technique of observing resonance shifts with the radio frequency adjusted to the point of maximum slope on the side of the resonance, shifts as small as 1 ppm of the linewidth can be observed with several hours' integration time.

The experiments consist of looking for a resonance shift, linear in an applied electric field (E), in the Zeeman transition ($F = I + \frac{1}{2}$, $m_F = -I - \frac{1}{2}) \rightarrow (I + \frac{1}{2}, -I + \frac{1}{2})$ in the alkali atoms. Such a shift could be interpreted as arising from an atomic EDM interacting with the external electric field. A significant systematic effect in such experiments is the presence of another signal, linear in E, due to the motional magnetic field effect. As the atom moves with velocity $\vec{v}$ through the electric field it experiences a motional magnetic field $\vec{v} \times \vec{E}$. A resonance shift, linear in E, due to the interaction of the atom's magnetic dipole moment with this motional magnetic field, will result if $\vec{E}$ is not parallel to the magnetic field $\vec{H}$ in the resonance region. For this reason, the resonance region contains two perpendicular magnetic fields produced by rectangular Helmholtz coils mounted on a cylindrical form enveloping the electric field plates and rf loops (see Fig. 1). Adjustment of the current in one pair of coils (the current in the other coils held constant) allows one to vary the alignment of $\vec{E}$ and $\vec{H}$ electronically, and thus manipulate the $\vec{v} \times \vec{E}$ effect. The entire resonance region is magnetically shielded by three concentric Hypernom cylinders to minimize noise due to fluctuations in the ambient field.

The signal linear in E is studied as a function of the angle between $\vec{E}$ and $\vec{H}$ and the point of zero signal (intercept) in different elements is determined. The intercepts of sodium and cesium were compared. The importance of making comparisons between different elements stems from the fact that the initial misalignment of $\vec{E}$ and $\vec{H}$ is not known a priori. If only one element is studied, this information would be required to determine whether linear effects other than $\vec{v} \times \vec{E}$ are present. In a comparison, however, the initial misalignment subtracts out. If the intercepts are not the same for different elements, then an interaction other than $\vec{v} \times \vec{E}$ (such as an EDM) is also contributing to the signal.

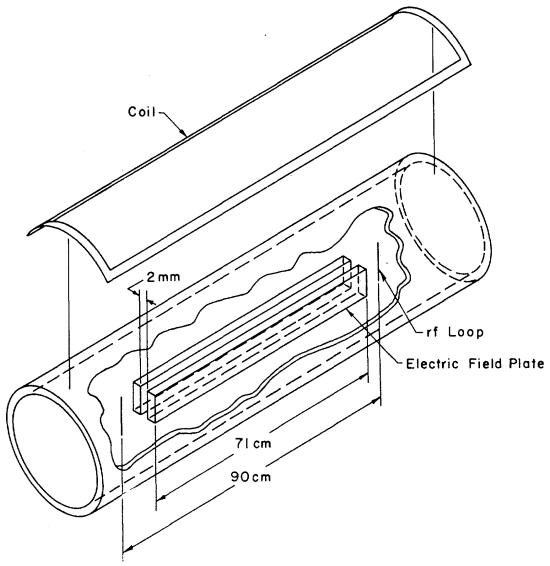

FIG. 1. The resonance region. Four coils including the one shown are placed at 90° increments around the cylinder.

We found 28 independent sodium-cesium comparisons such as the one shown in Fig. 2 to result in an average intercept difference that was zero within the experimental error.

To guard against the possibility that our null result arose from a fortuitous cancellation of competing effects, numerous checks for, and precautions against, possible systematic errors were made. The usual procedure of taking data on opposite slopes of the resonance curve was followed in order to average out any resonance-independent contributions to the detected signal.

Digital signal-processing techniques were used. The direction of the E field was reversed every 0.57 sec and the resonance signal accumulated in two counters (one for each direction of the electric field) gated synchronously with the switching frequency. In this way, the quadratic Stark ef-

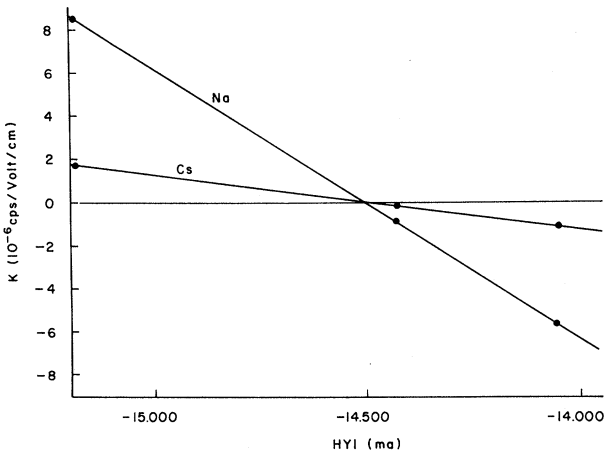

FIG. 2. Typical sodium-cesium comparison. The integration time for each data point was approximately $\frac{1}{2}$ h. $k=\Delta\nu(E)/E$ versus *HYI*, the current in the vertical C-magnet coil, is plotted. A change of 1 mA in *HYI* produces a change in the angle between $\vec{E}$ and $\vec{H}$ of approximately 0.08°.

fect subtracts out and any remaining signal indicates the presence of an effect which is linear in E. By introducing the appropriate delays into a counting cycle, a steady E field is insured during the time when data are taken. This eliminates possible transient effects (e.g., those caused by a displacement current).

A source of systematic error could result from the quadratic Stark effect. If the electric field does not reverse exactly when the high voltage is switched, the quadratic Stark signal will not be subtracted out by our data-processing technique. Measurements of contact potentials and experiments with $|V_1|\neq|V_2|$, but $|V_1-V_2|$ held constant (where V_1 and V_2 are the voltages on each electric field plate), have shown that such effects were negligible within the sensitivity of the experiments. Similarly, measurements of the leakage current have shown that magnetic effects arising from these currents were negligible.

Another possible source of systematic error results if the average misalignment between $\vec{E}$ and $\vec{H}$ is different for sodium and cesium. This could occur if the spatial distribution of velocities were different for each element and there were sufficiently large inhomogeneities in the electric and/or magnetic fields. In this case, the initial misalignment would not be the same for each element and would not entirely be accounted for in a comparison. For example, consider the situation where the inhomogeneities of the fields resulted in a variation in the angle between $\vec{E}$ and $\vec{H}$ of 1 part in 10^4. Furthermore, assume that all sodium and cesium atoms travel in such a way as to experience the maximum possible difference in alignment of the fields. This extreme case would give rise to an intercept difference (not more than) a factor of 10 larger than the present experimental error.

In order to minimize the possibility of such an effect, both beams were formed simultaneously in the same oven using a charge of CsCl and Na. Furthermore, the magnetic field strength in the focusing magnets was 8 kG so that the effective magnetic moments of the relevant states for both elements were identical to better than 7%.

In an attempt to change the spatial distribution of velocities, experiments were also performed with the oven rotated about its axis of symmetry from the position that gave the maximum resonance signal. This had the effect of selecting atoms from different portions of the emitted velocity distribution, i.e., the average detected velocities increased by approximately 5%. The null result was found to be independent of the oven rotation. These results are summarized in Table I.

Schiff[4] has shown that it is not possible to observe an EDM in an electrically neutral nonrelativistic system. However, Salpeter,[5] and elsewhere Sanders,[6] have shown that it is possible to observe such a moment in a relativistic system. Attributing the lack of an observed intercept difference between sodium and cesium as a statement about the EDM of the much more relativistic cesium atom, we find that $|d_{Cs}|=(0.8\pm1.8)\times10^{-22}e$ cm. Furthermore, a calculation by Sandars[6,7] has shown that if the electron possesses an EDM, then the EDM of the cesium atom is ap-

Table I. Summary of oven rotation experiments.

Oven position	Average Na velocity (10^4 cm/sec)	Average Cs velocity (10^4 cm/sec)	No. of experiments	Cs EDM ($10^{-22}e$ cm)
Maximized	11.829 ± 0.031	4.585 ± 0.031	19	0.9 ± 2.1
Rotated	12.427 ± 0.097	4.959 ± 0.042	9	0.7 ± 3.5

proximately 120 times larger, whereas that of the sodium atom is 0.3 times as large. This result together with the above value for the EDM of the cesium atom leads to a new upper limit to the EDM of the electron (at 90% confidence level) of

$$|d_e| < 3 \times 10^{-24} e \text{ cm}.$$

Work on this experiment is continuing and an apparatus with an even longer distance between the oscillatory fields is under development. It is hoped that the experimental error can be reduced by at least a factor of 10 with the new apparatus and certain other improvements.

The authors wish to thank A. T. Ramsey and R. Golub for many helpful discussions.

*Work supported by the National Science Foundation.

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OBSERVATION OF OPTICAL PULSE SHAPING BY THE SELF-FOCUSING EFFECTS*

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We report the observation of time distortion of intense laser pulses due to the self-focusing effect. The on-axis shape of pulses propagating in nitrobenzene was measured and compared with a computer solution of the nonlinear wave equation.

We have observed pronounced distortion of the time contour of intense light pulses propagating through nitrobenzene. This effect, which occurs for peak powers below the level required to form trapped light filaments within the liquid cell, is a consequence of the dynamical self-focusing of intense optical beams.[1-3] Previous measurements[4] of optical self-focusing phenomena have relied upon determination of the input power threshold for the onset of stimulated inelastic scattering. However, most such scattering is known to occur within the complicated and poorly understood region of "small scale" or filamentary self-trapping.[5] The measurements reported here are independent of filament formation mechanisms and can be compared directly with numerical solutions of the nonlinear wave equation thought to describe self-focusing.

A simple analysis[6] of the time dependence of the on-axis intensity of a pulse propagating in a medium with positive nonlinear refractive index shows that substantial sharpening of the time contour can occur. The effect is largest for path lengths near the self-focusing length. This prediction was verified by detailed measurements on the shapes of intense optical pulses passing through a 18.8-cm cell of nitrobenzene. The source was a passively Q-switched ruby laser operating in a single axial and transverse mode with a peak power of 1 MW in a single pulse. The time contour of the laser pulse was nearly Gaussian with a 10-nsec full pulse width at half-intensity. The nitrobenzene cell was sufficiently removed from the laser (0.4 Rayleigh distance) so that the spatial intensity profile of the beam at the cell entrance window had nearly a Gaussian distribution with a variance of 0.45 mm. This profile was accurately determined by scanning the beam with a pinhole. Every portion of the input beam had the same time dependence.

A fraction of the laser beam was sent through an optical delay path (30 nsec) so that the incident pulse was detected by the same photodiode (ITT F4000-S1) and displayed on the same oscilloscope trace (Tektronix 519) as the pulse transmitted through the nitrobenzene. A pinhole aperture (0.12-mm-diam) was located on axis in the beam transmitted through the nitrobenzene. As expected, no pulse shaping occurred without this exit pinhole aperture. Thus, the time evolution of the pulse as it entered the material was compared with that of the axial intensity of the pulse after it had passed through the material. A typical oscilloscope trace is drawn in Fig. 1, where