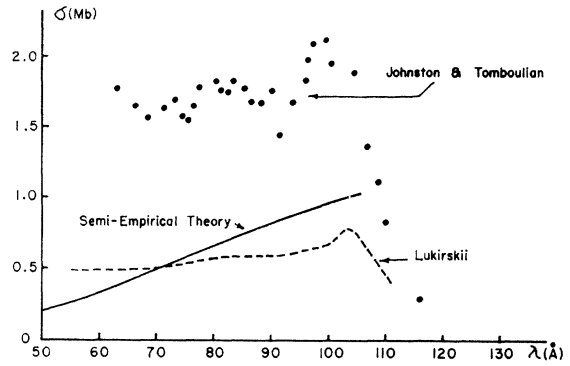

FIG. 3. A comparison of the results of earlier experiments with theory. The Lukirskii curve arbitrarily matched at 70Å is presented for comparison of shape only.

Hence, one can only compare shapes of absorption curves and to do so we have arbitrarily normalized his curve to match the calculated cross section at 70Å. As seen in Fig. 3, the previous experimental results show a wavelength dependence which is at variance not only with that of the present determination but also with the general trend indicated by the results of calculations based on atomic theory.

The evidence suggests that surface contamination has a noticeable effect on the shape of the absorption curve. To verify this point, we carried out a determination of the absorption by the present instrumentation on a sample which intentionally was exposed to air for a short time. The observations indicated that such an exposure increased the magnitude of the individual values of the cross section and the shape of the absorption curve was distorted so as to approach that found in the earlier results.

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Alkali Polarizabilities by the Atomic Beam Electrostatic Deflection Method*†

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The electric dipole polarizabilities of the alkali atoms have been measured by observing the deflection of a collimated beam of neutral atoms in a two-wire-type inhomogeneous electric field. Beam deflection measurements are taken both for the case when s_B, the deflection of atoms with the most probable velocity in the source, is larger than the detector wire width w_d, and for $s_B<0.1w_d$. The results in units of 10^{-24} cm^3 are: $\alpha(\mathrm{Li})=22\pm2$, $\alpha(\mathrm{Na})=21.5\pm2$, $\alpha(\mathrm{K})=38\pm4$, $\alpha(\mathrm{Rb})=38\pm4$, and $\alpha(\mathrm{Cs})=48\pm6$. These values are in reasonable agreement with other recent experimental and theoretical determinations of the alkali polarizabilities.

1. INTRODUCTION

A KNOWLEDGE of the electric dipole polarizability α of atoms is of interest because of the direct relationship to excited state lifetimes, line strengths, and van der Waals interaction forces. Also, a comparison with experimental values affords a test of various approximation methods and wave functions used in the calculation of atomic properties.

The first atomic beam measurement of the dipole polarizabilities of the alkalis was done by Scheffers and Stark. In their measurements[1] a beam of atoms was deflected in a radial electric field and the polarizability was deduced from an analysis of the deflected beam pattern. We had also reported[2] values obtained from the measured deflection of an atomic beam by an electric field which provides a uniform deflecting force for all atoms in the beam. Recently, however, Salop, Pollack, and Bederson have measured α for each alkali in terms of its effective magnetic moment with an atomic beam method in which electric and magnetic forces are balanced in congruent E and H fields, and in which the results are independent of the distribution of velocities in the beam.[3] Their values are noticeably higher than the results from the earlier deflection experiments. Because of this we have done the experiment described here[4] which is an improved version of our earlier work.

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[1] H. Scheffers and J. Stark, Physik Z. **35**, 625 (1934).
[2] G. E. Chamberlain and J. C. Zorn, Bull. Am. Phys. Soc. **5**, 241 (1960).
[3] A. Salop, E. Pollack, and B. Bederson, Phys. Rev. **124**, 1431 (1961).
[4] G. E. Chamberlain and J. C. Zorn, Bull. Am. Phys. Soc. **7**, 70 (1962).

2. PRINCIPLES OF THE EXPERIMENT

A schematic of the apparatus geometry is given in Fig. 1, in which the horizontal x axis is defined by the centers of the vertical source and collimator slits, and the z axis chosen is horizontal. The dipole moment induced in the atom by the electric field E is αE, so the force on the atom in the z direction is $\alpha E\partial E/\partial z$. The deflection s, in the detector plane, of an atom with velocity v and mass m is related to the strength of the deflecting field by

$$s=\frac{\alpha E\partial E/\partial z}{2mv^2}L,$$

where

$$L\equiv l_2(l_2+2l_1)(L_2/L_1).$$

Atoms with the most probable velocity in the source, $v_B=(2kT/m)^{1/2}$, undergo a deflection s_B given by

$$s_B=(\alpha GV^2/4kT)L,$$

in which T is the source temperature in degrees Kelvin, k is Boltzmann's constant, and V is the voltage across the deflecting electrodes. The geometric constant G is defined as $G\equiv E(\partial E/\partial z)/V^2$. Values of α can then be obtained from measured values of s_B, V, T, G, and L. This is done for s_B less than one-tenth the detector wire width w_d (small shifts) and for $s_B\geq w_d$ (large shifts).

In the method of small shifts s_B is about 3×10^{-4} cm. It is shown elsewhere[5] that with an ideal beam velocity distribution, and with the detector positioned for an intensity near $\frac{1}{2}I_0$ (see Fig. 2), a small deflection of the beam causes a change in detector signal given to good approximation by $dI=-\gamma s_B$, where $\gamma\equiv\partial I/\partial z$ is the slope of the beam shape evaluated at the point of observation. Thus, the polarizability of the atom is given by

$$\alpha=(4kT/GV^2L)(dI/\gamma).$$

In the method of large shifts, s_B is about 4×10^{-3} cm. Both undeflected and deflected beam shapes are measured. In order to determine s_B from the deflected beam shape, the undeflected beam shape is approximated by

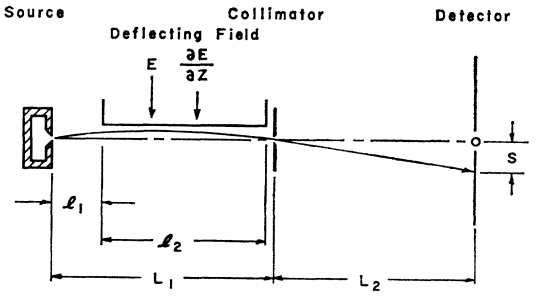

FIG. 1. Schematic of the geometry for deflecting alkali beams. The vertical scale is greatly exaggerated over the horizontal scale. The dimensions are $l_1=16.6$, $l_2=55.9$, $L_1=75.7$, and $L_2=68.5$ cm. The deflection s of a beam atom is discussed in the text.

[5] J. C. Zorn, G. E. Chamberlain, and V. W. Hughes, Phys. Rev. (to be published).

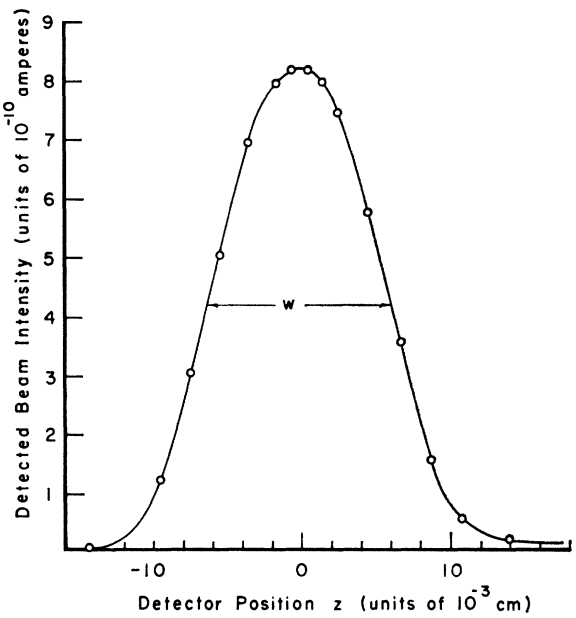

FIG. 2. Typical alkali beam shape in which the solid curve is drawn through the observed points. In the text I_0 refers to the maximum beam intensity, and w is the width at $\frac{1}{2}I_0$.

a trapezoid with the same central intensity, slope, and width at half intensity. Shifted beam patterns are calculated as a function of the parameter s_B with an IBM 650 computer, with the velocity distribution taken into account. These curves are compared graphically with the experimentally observed deflected beam shape, and s_B is determined from the curve giving the best fit to both position and intensity.[6]

3. APPARATUS

A cylindrical brass vacuum chamber is divided into source and main chambers. Oil diffusion pumps maintain an operating pressure of 1.5×10^{-7} mm Hg in the main chamber and less than 10^{-5} mm Hg in the source chamber.

The beam is formed by methods standard in atomic beam measurements.[7] The source has thin slits[8] to reduce distortion of the ideal beam velocity distribution. The oven source used in most of the runs is made from oxygen-free, high-conductivity copper in order to minimize temperature gradients. The source slit is a 0.051-mm wide gap between two steel shims (0.04 mm thick) clamped to the front of the oven with beveled copper strips. A few runs were taken with a 0.025-mm source slit, and some with a nickel oven. Neither of these modifications caused a significant difference in the values of α obtained.

[6] G. E. Chamberlain, Ph.D. thesis, Yale University, 1962 (unpublished).

[7] P. Kusch and V. W. Hughes, in *Encyclopedia of Physics*, edited by S. Flügge (Springer-Verlag, Berlin, 1959), Vol. 37, Part 1.

[8] R. C. Miller and P. Kusch, Phys. Rev. **99**, 1314 (1955).

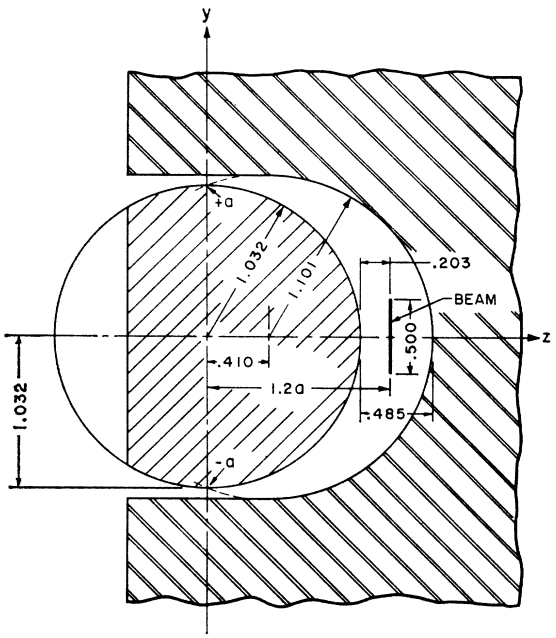

FIG. 3. Cross section of deflecting electrodes. All dimensions are in centimeters.

The oven temperature is measured with Chromel-*P* Alumel thermocouples. Two of these are at the back of the oven near the melt and a third thermocouple is peened into the oven near the front. At 480°K the thermocouples in the copper oven agree to within 5°K, and in the nickel oven a 10°K temperature drop from front to back is observed.

The collimator slit is a 0.051-mm-wide gap between two razor blade edges.

The surface ionization detector[7] has a heated tungsten filament 0.025 mm in diameter. The signal current flows through a $5\times10^{10}\,\Omega$ resistor and the resultant voltage is measured with a Cary model 31 vibrating reed electrometer. The linearity of the electrometer is measured to be better than 1%.

A cross section of the deflecting electrodes is shown in Fig. 3. The trough is machined from an aluminum bar and the inner surface is polished. The bead is a polished, stainless steel rod. The inner electrode surfaces, shaped to produce a two-wire-type electric field,[9] are portions of cylinders that intersect at the lines $z=0$, $y=\pm a$. The usual position of the atomic beam within the electrode gap is at $z=1.2a$. The calculated value of $E(\partial E/\partial z)$ over the beam dimensions varies by less than 0.5%.

The deflecting voltages are supplied by two Hamner model N-413, 0–5 kV regulated high voltage power supplies, and are applied with equal and opposite polarity to the electrodes. The calibration of the supplies is checked against a Leeds and Northrup K-3 potentiometer by means of a voltage divider, and is accurate to within 2%.

A Keuffel and Esser 9092-1A jig transit is used for optical alignment of the apparatus.

[9] N. F. Ramsey, *Molecular Beams* (Oxford University Press, New York, 1956), pp. 431–2.

4. PROCEDURE

A Pyrex plate glass window in the end of the vacuum system permits optical lineup of the apparatus under operating conditions. The beam position relative to the electrodes is determined to within ±0.10 mm before each run, and is generally checked at the end of the run. After alignment a full beam shape is taken (Fig. 2). Typically w is 0.0125 cm and the ratio γ/I_0 is 0.124×10^3 cm^{-1}.

Both large and small shift data are taken during a run. In the large shift work an undeflected beam shape measurement is followed by taking a deflected beam shape with 10 kV across the electrodes. Then a remeasurement of the position of the peak of the undeflected beam is usually made.

In the small shift work γ is determined from a series of measurements of the beam shape taken before and after the measurements of dI. The detector is positioned on the side of the beam where the intensity is near $\frac{1}{2}I_0$ and a change in intensity, dI, on the order of $0.03I_0$ or less is observed when the voltage (1 to 5 kV) is alternately applied and removed from the deflecting fields.

5. EXPERIMENTAL RESULTS AND ERRORS

The values of α obtained from the small and large shift measurements are listed in Table I.

Each small shift value is an average of n individual values of α determined in the course of several runs with varying detector positions, deflecting voltages, and voltage polarities in each run. The error given for the small shift values in Table I includes a standard error of about 2%, as well as an allowance for a 3% error in s_B from the small shift approximation.[6]

Large shift measurements for lithium are not observed because of the low deflecting power available. Not enough large shift data for sodium were obtained for a meaningful comparison to the small shift value. The errors given in Table I for the large shifts results are estimated from the fit of the calculated beam shapes to the observed beam shapes.

TABLE I. Experimental values of α (units of 10^{-24} cm^3) for the alkalis.

Element	Temperature (°K)	Large shift results s_B (mm)	α	β	Small shift results n	α	β
Li	857				10	21.9	±0.9
Na	556				11	21.7	±0.6
K	480	0.03	38	±3	19	37.9	±1.2
Rb	460	0.035	42	±4	23	37.4	±0.8
Cs	437–482	0.05	52.5	±4.5	23	43.9	±1.3

TABLE II. Experimental and theoretical values of alkali polarizabilities (in units of 10^{-24} cm^3).

Investigators	Method	Li	Na	K	Rb	Cs
Present work	Atomic beam deflection	22 ±2	21.5±2	38 ±4	38±4	48 ±6
Salop *et al.*[a]	Atomic beam *E-H* balance	20 ±3	20 ±2.5	36.5±4.5	40 ±5	52.5±6.5
Sheffers and Stark[b]	Atomic beam deflection	12 ±0.6		34 ±1.7		42 ±2.1
Drechsler and Müller[c]	Field emission microscope	16 ±3				
Haun and Zacharias,[d] and Mizushima[e]	Cs hfs Stark effect					51
Dalgarno and Kingston[f]	Theoretical, from oscillator strength data	24.5±1.2	24.6±1.2	41.6±2.1	43.8±2.2	53.7±5.4
Parkinson[g]	Theoretical, Hartree-Fock functions	25.0				
Sternheimer[h]	Theoretical, valence wave functions	24.9	22.9	44.4	49.1	67.7

[a] Reference 3.
[b] Reference 1.
[c] M. Drechsler and E. W. Müller, Z. Physik **132**, 195 (1952).
[d] R. D. Haun and J. R. Zacharias, Phys. Rev. **107**, 107 (1957).
[e] M. Mizushima, National Bureau of Standards Report 6009, 1958 (unpublished).
[f] Reference 11.
[g] Reference 12.
[h] Reference 13.

In both the small and large shift results, β reflects only the error in determining s_B from the deflection measurement on the assumption that the velocity distribution is ideal, and does not include the systematic errors which will now be discussed. The effective length of the deflecting electrodes is uncertain to about two gap widths because of fringing effects, and this is the main contribution to a 3% uncertainty in L. The error in G, due to uncertainties in the cross-sectional geometry of the electrodes, is 4.2%. The error in V^2 is 4%. There is no observed effect of the magnitude or polarity of the applied voltage on the polarizability values. The temperature error is less than 1.5%. The statistical total of these errors is 6.7%.

The alkali metals used to load the oven are obtained commercially, and the effects of impurities are expected to be negligible.

Interpretation of the present experiment depends on a knowledge of the velocity distribution of atoms in the beam. The loss of low velocity atoms in a beam of potassium from a thin slit source, as found by Miller and Kusch,[8] does not seem large enough to affect the present potassium measurement. On the other hand, Estermann, Simpson, and Stern[10] found a substantial loss of slow cesium atoms under somewhat different experimental conditions; they attribute this loss to Cs-Cs scattering near the oven slit. An estimate[6] based on their results indicates that such a distortion of the velocity distribution could make the polarizability of cesium, as measured in a beam deflection experiment, appear as much as 10% low for both the large and small shift measurements. We find, however, that the small shift value for α(Cs) is appreciably smaller than the large shift value and that the deflected beam shapes of the large shift Cs measurements are somewhat broader than expected. Such features are present to a much lesser extent, if at all, in the lighter alkalis. It is felt that the α(Cs) discrepancy probably arises from scattering processes in the beam, although its exact nature is not understood.

The final results of the present experiment are listed in Table II. For lithium and sodium the small shift values are given. The potassium results from both methods are effectively the same. The rubidium value is a weighted average, and the cesium value is an unweighted average of the large and small shift results. In all cases the enumerated 6.7% systematic error is combined quadratically with the errors derived from Table I. For Li, Na, K, and Rb the total uncertainty is increased to 10% because of the possible distortion of the velocity distribution. Allowance for the large difference in the two Cs values in Table I gives a 12% error in our value for the polarizability of cesium.

The results of the present experiment are in reasonable agreement with the experimental values of Salop *et al.* and with recent theoretical calculations[11–13] of the alkali dipole polarizabilities.

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[10] I. Estermann, O. C. Simpson, and O. Stern, Phys. Rev. **71**, 238 (1947). See also P. M. Marcus and J. H. McFee, in *Recent Research in Molecular Beams*, edited by I. Estermann (Academic Press Inc., New York, 1959), pp. 43ff.

[11] A. Dalgarno and A. E. Kingston, Proc. Phys. Soc. (London) **A73**, 455, (1959).

[12] D. Parkinson, Proc. Phys. Soc. (London) **A75**, 169 (1960).

[13] R. M. Sternheimer, Phys. Rev. **127**, 1220 (1962).