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Electric Polarizabilities of the 4^2p Level of Potassium*

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ABSTRACT

The atomic beam technique has been used to study the Stark effect in the 4p level of potassium. The results, expressed in terms of three polarizabilities, are found to be in good agreement with the Bates and Daamgard calculation of oscillator strengths.

The study of the Stark effect of atomic levels is important in that the Stark shifts are directly determined by the oscillator strengths connecting the level under study to near-lying levels of opposite parity. Hence the measurement of these shifts serves as a direct test of theoretical calculations of oscillator strengths. Perhaps the simplest of the available theoretical methods for predicting oscillator strengths is the Coulomb approximation of Bates and Daamgard,[1] which is easily made to yield numerical values. Recently we have begun a program for checking the applicability of the Bates and Daamgard oscillator strengths to the Stark effect of the first excited p level of the alkalis by studying the Stark effect in the D-lines of cesium and rubidium.[2] In this paper we report the extension of these measurements to the 4p level of potassium.

The basic method employed is the atomic-beam method for studying the Stark effect that was used in the cesium and rubidium.[2,3] However, because of the small hyperfine structure (hfs) of the potassium ground state, it is necessary to employ an absorption cell to obtain narrow absorption lines in the broad lamp emission line.[4] This modification can be understood with reference to Fig. 1, where a schematic diagram of the basic apparatus is shown. Light from a ^{39}K resonance lamp is passed through a filter which will pass either the D_1 ($4^2p_{1/2} \rightarrow 4^2s_{1/2}$) or D_2 ($4^2p_{3/2} \rightarrow 4^2s_{1/2}$) line. Because the hfs of all these states is substantially smaller than the Doppler width, the light passing through the filter is a single line with a width of about 1500 MHz. This light is now passed through an absorption cell consisting

of an optically dense ^{39}K absorption beam. The effect of the absorption beam is to remove a doublet from the lamp line. The two components of the doublet are separated by the hfs of the $4^2s_{1/2}$ ground state (≈462 MHz) and each component has a width of about 400 MHz. The hfs of the excited p states is sufficiently small that it plays no role in these experiments and is henceforth ignored. This light is now allowed to fall incident on the C region of an atomic-beam apparatus with flop-in magnet geometry. The C region also contains a pair of electric-field plates capable of sustaining fields up to 0.5×10^6 V/cm.

The Stark effect signals observed with a ^{39}K beam can be understood with reference to the energy level diagram of Fig. 2. Consider the case where D_1 light is passed. It is well known[2] that for the case where J = 1/2, all of the states of a hyperfine multiplet are shifted equally under the action of an electric field except for small (and, for the purposes of this experiment, negligible) hyperfine and higher order effects. Therefore at zero electric field, where the absorption lines of atoms in the beam overlap the absorption lines of atoms in the cell, a minimum is observed in the signal intensity. As the electric field is turned on, and the Stark shift "detunes" the two absorption lines, the signal increases. Eventually, however, the Stark effect is sufficient to shift the absorption lines through an amount equal to the ground state hfs and a second absorption minimum is observed. In Fig. 3 is plotted the difference in signal intensities with no absorption cell present and with the absorption cell in, hence the overlap positions appear as maxima in the curves.

In the case where irradiation is by D_2 light, the effect of hfs in the $4^2p_{3/2}$ state on the observed Stark pattern can be considered in the following way. Recent measurements[5] have shown that the overall hyperfine separation between the F = 3 and the F = 0 states of this line is about 33 MHz. This is a factor of 14 smaller than the ground state hfs, which is the magnitude of the Stark shift at the position of the non-zero field overlaps of the absorption lines of atoms in the atomic beam with those in the absorption cell. Under this condition an electric field analogue of the Paschen-Back effect exists wherein m_J and m_I become good quantum numbers. Levels of the same m_J but different m_I are separated by an amount of order of the excited state hfs. Hence it is possible to analyze this situation by ignoring the $p_{3/2}$ hfs in the calculation. The hfs will give rise to a width of the same order as the hyperfine splitting on the calculated intensity pattern and can be taken into account in this way. Therefore, under the action of an electric field the $4^2p_{3/2}$ state will split into a doublet corresponding to $m_J = \pm 3/2$ and $m_J = \pm 1/2$. Apart from the absorption maximum at zero field, there will be two higher field maxima corresponding to the relative positions of the energy levels indicated in Fig. 2. The observed signal shown in Fig. 4 confirms the prediction of two high-field minima.

Analysis of the data can be done in the following way. If the polarizability of a level $\alpha(n^2\ell_J m_J)$ with the quantum numbers n, ℓ, j, m_J is defined by the usual relation:

$$\Delta W(n^2\ell_J m_J) = -\frac{1}{2}\,\alpha(n^2\ell_J m_J)\,E^2 ,$$

where ΔW is the energy shift induced by the electric field E, then the position of the three non-zero field maxima indicated in Figs. 2 and 3 can be described by

$$\frac{E_1^2}{2}\left[\alpha(4^2p_{1/2} \pm \tfrac{1}{2}) - \alpha(4^2s_{1/2} \pm \tfrac{1}{2})\right] = 461.72 \text{ MHz} ,$$

$$\frac{E_2^2}{2}\left[\alpha(4^2p_{3/2} \pm \tfrac{1}{2}) - \alpha(4^2s_{1/2} \pm \tfrac{1}{2})\right] = 461.72 \text{ MHz} ,$$

$$\frac{E_3^2}{2}\left[\alpha(4^2p_{3/2} \pm \tfrac{3}{2}) - \alpha(4^2s_{1/2} \pm \tfrac{1}{2})\right] = 461.72 \text{ Mhz} .$$

If our measured values are employed for E_1, E_2, and E_3 and if the result of Salop et al.[6] is used for the polarizability of $\alpha(4^2s_{1/2} \pm 1/2)$, then these equations determine the three polarizabilities characterizing the 4p level. These are tabulated in Table I along with the predictions of the Bates and Daamgard theory. The agreement is seen to be good.

An interesting point arises from the fact that in the limit of zero spin-orbit coupling it can be shown[2] that

$$\alpha(4^2p_{1/2} \pm \tfrac{1}{2}) = \frac{1}{2}\left[\alpha(4^2p_{3/2} \pm \tfrac{3}{2}) + \alpha(4^2p_{3/2} \pm \tfrac{1}{2})\right] .$$

This relationship is seen to be very well satisfied by the actual measurements, in contradistinction to the case of the first excited p state in cesium, which shows marked spin-orbit effects.

FOOTNOTES AND REFERENCES

*Work supported by the U. S. Atomic Energy Commission.

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[6] A. Salop, E. Pollack, and B. Bederson, Phys. Rev. 124, 1431 (1961).

Table I. Polarizabilities in the 4^2p level of potassium (units of 10^{-24} cm^3).

	$\alpha(4^2p_{1/2}\pm1/2)$	$\alpha(4^2p_{3/2}\pm1/2)$	$\alpha(4^2p_{3/2}\pm3/2)$
This experiment	87 (13)	114 (16)	68 (10)
Bates and Daamgard	93	109	80

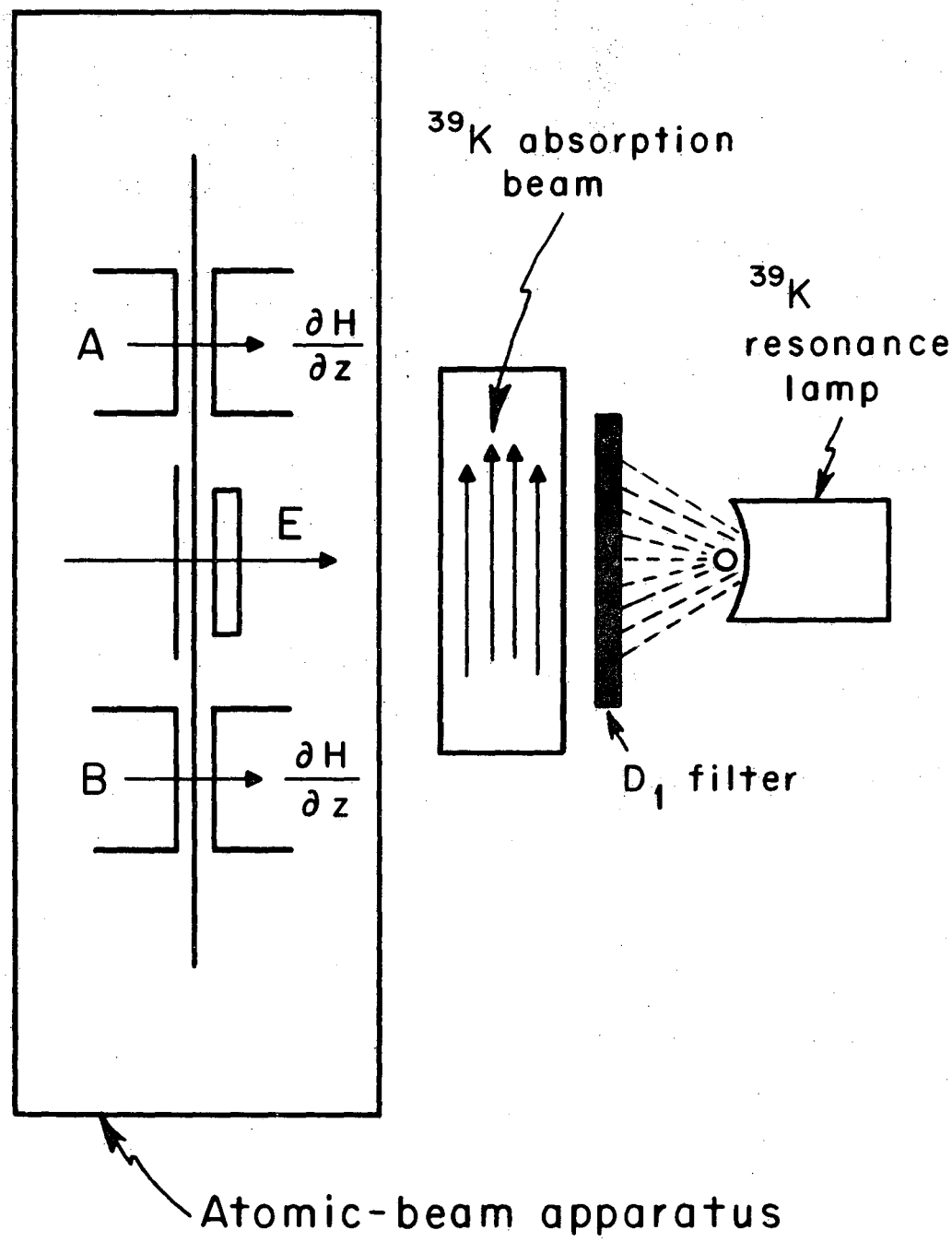
FIGURE CAPTIONS

Figure 1. Schematic diagram of apparatus.

Figure 2. Schematic diagram of energy levels. The lines A and B are almost completely resolved by the atomic beam absorption cell. At zero electric field, the absorption lines 1 and 2 of atoms in the beam coincide with absorption line B of atoms in the cell. Absorption is also maximized at electric fields such that the lines 1 and 2 are made to resonate with the line A.

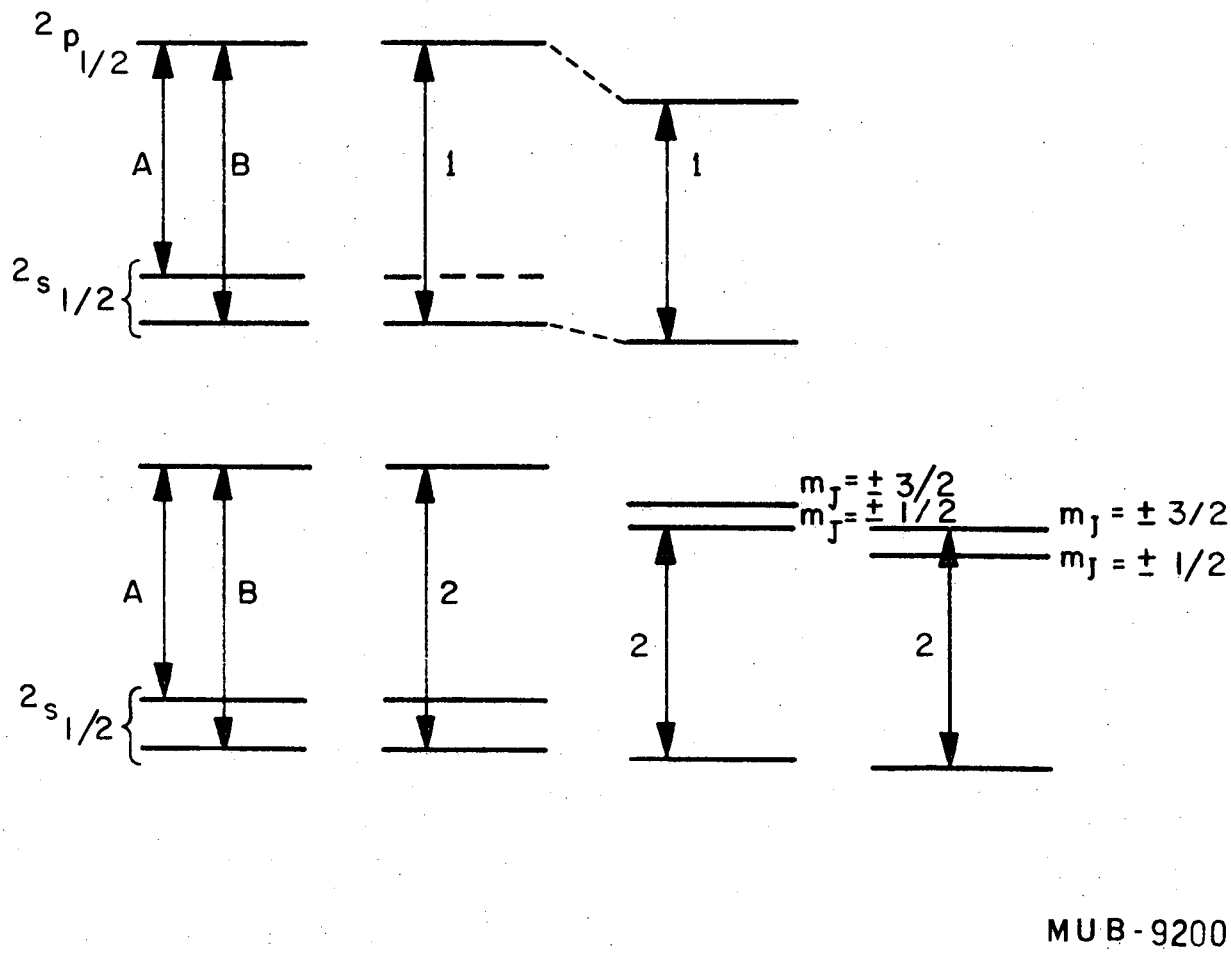
Figure 3. Observed absorption signal with D_1 light incident.

Figure 4. Observed absorption signal with D_2 light incident.



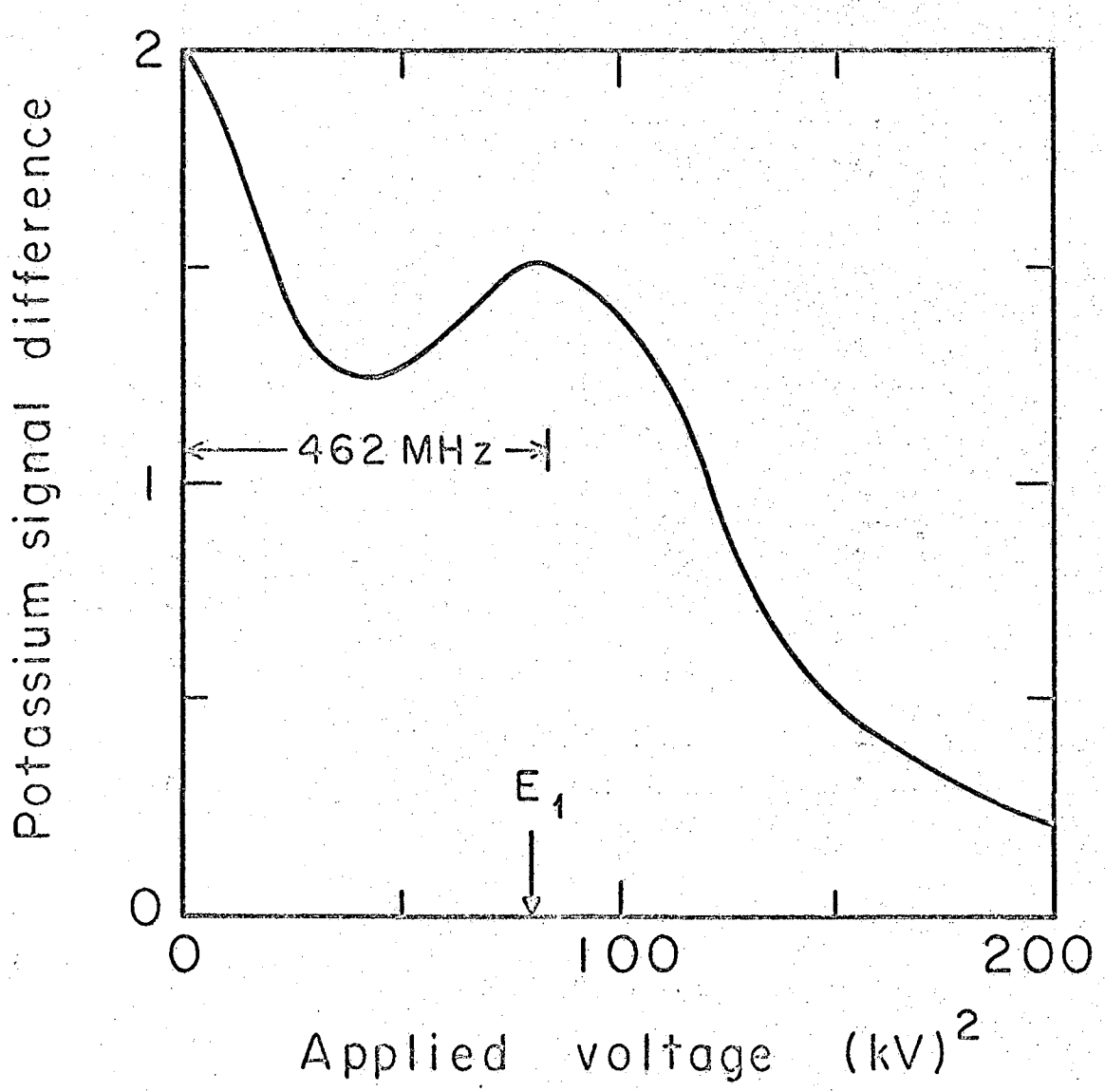
XBL675-3192B

Fig. 1



MUB-9200

Fig. 2



XBL 687-3316

Fig. 3

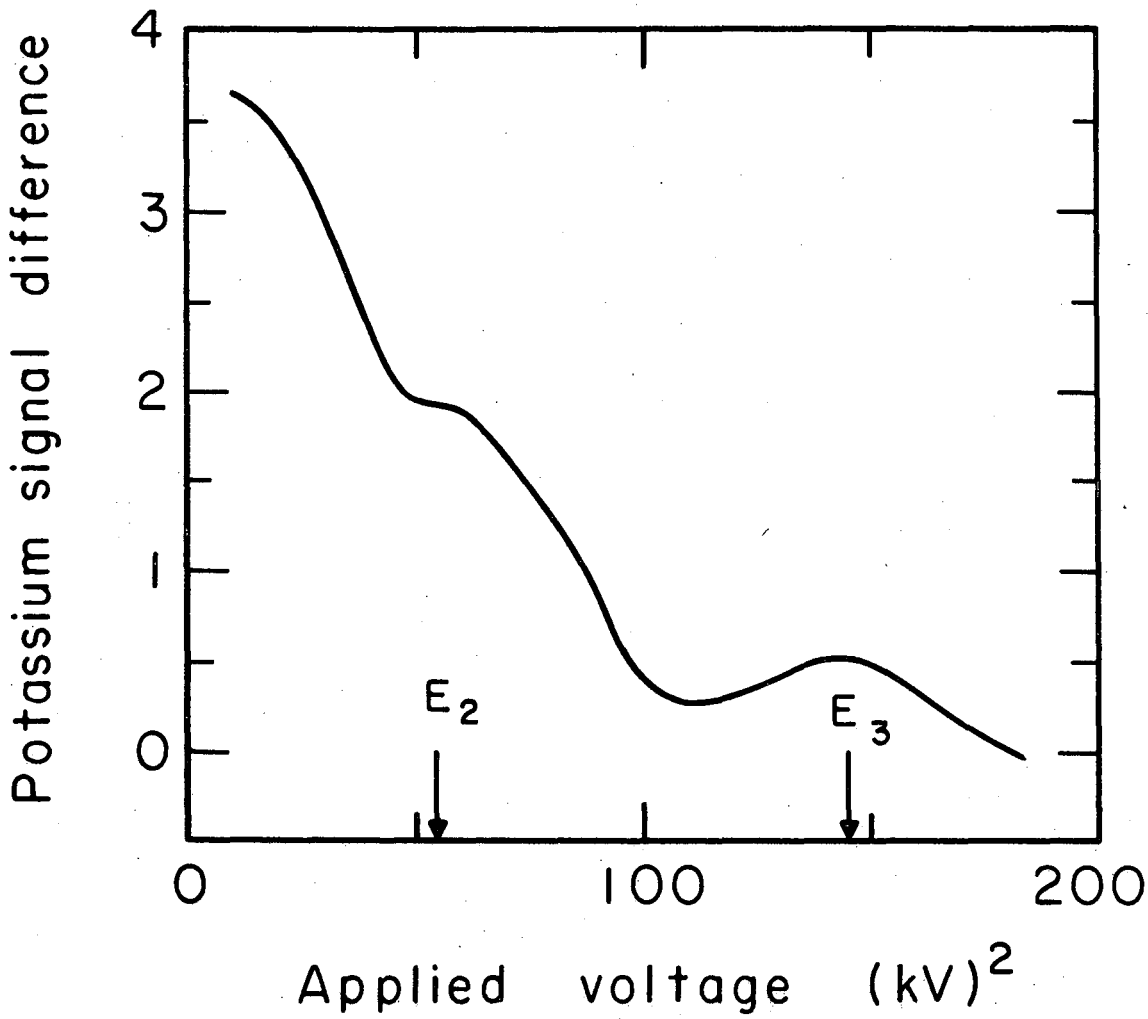


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Fig. 4

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