IC/73/19
INTERNAL REPORT
(Limited distribution)

International Atomic Energy Agency

and

United Nations Educational Scientific and Cultural Organization

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

ON THE POLARIZATION OF THE RESONANCE LINES OF LITHIUM AND SODIUM ATOMS BY ELECTRON IMPACT †

A.N. Tripathi *
International Centre for Theoretical Physics, Trieste, Italy,

K.C. Mathur ** and S.K. Joshi
Department of Physics, University of Roorkee, U.P., India.

ABSTRACT

The polarization of the resonance lines of ^{6}Li, ^{7}Li and Na, excited by electron impact, are calculated using the Glauber approximation. The present results are in good agreement with experimental values and with other theoretical calculations in the energy range from 2 eV to 5 eV.

MIRAMARE - TRIESTE
February 1973

† To be submitted for publication.

* Permanent address: Department of Physics, University of Roorkee, U.P., India.

** Present address: Department of Applied Mathematics and Theoretical Physics, Queen's University of Belfast, Northern Ireland.

I. INTRODUCTION

The Glauber approximation has been very widely applied by a number of investigators (Franco 1968, 1971, Tai et al. 1969, 1970, Ghosh et al. 1970, Bhadra and Ghosh 1971, Thomas and Gerjuoy 1971, Hidalgo et al. 1972, Yates and Tenney 1972) to study the electron impact elastic and inelastic cross-sections of hydrogen and helium. The success of the Glauber predictions in treating the electron-hydrogen collisions tempted us (1972, 1973) to extend the study to other complex atoms such as the alkali atoms which behave like one-electron systems. The effect of the core electrons in these atoms has been ignored by employing the frozen core approximation. Recently Gerjuoy et al. (1972) have also applied this approximation to study the polarization of Lyman-α resulting from $\bar{e}$ - H(1s) collisions and have obtained very satisfactory agreement with the experimental data. The aim of the present paper is to make use of the Glauber approximation to calculate the polarization of the resonance lines (2s - 2p) of ^{6}Li , ^{7}Li and (3s - 3p) of sodium, following the procedure of Gerjuoy et al. (1972).

II. THEORY

The percentage polarization of the resonance line of lithium, in the direction at right angles to the incident beam, is given by the following formula (Flower and Seaton 1967):

$$P = \frac{300(9\alpha-2)\,(Q_0 - Q_1)}{12Q_0 + 24Q_1 + (9\alpha-2)\,(Q_0 - Q_1)}\,, \qquad (1)$$

where Q_0 and Q_1 are the excitation cross-sections of the 2P level, with respectively, the components $m_\ell = 0$ and $m_\ell = 1$ of the orbital angular momenta. The value of α depends on the ratio of the hyperfine structure energy separation to the natural line width and is 0.413 for ^{6}Li , 0.326 for ^{7}Li and 0.288 for Na .

The total cross-sections Q_0 and Q_1 which appear in (1) for the percentage polarization are evaluated from the scattering amplitude $F^{(a)}_{2p,2s}(q,m_L)$ quantized along the incident electron momentum $\vec{K}_a$. However, the correct ns - np$_m$ (n = 2,3) Glauber amplitudes can easily be computed for a given $\vec{K}_a$ and $\vec{K}_b$, by quantizing along a direction ζ perpendicular to the momentum transfer vector $\vec{q}$. Therefore, one needs the Glauber amplitudes $F^{(a)}_{2p,2s}(q,m_L)$ in terms of the amplitude quantized along ζ . The transformation

required to obtain the desired amplitudes to construct Q_0 and Q_1 is discussed by Gerjuoy et al. (1972) and, according to them, are given by

$$F^{(a)}_{2p,2s}(q,m_L = 0) = -i\sqrt{2}\cos\theta_q F^{(\zeta)}_{2p,2s}(q) \qquad (2a)$$

$$F^{(a)}_{2p,2s}(q,m_L = \pm 1) = \sin\theta_q F^{(\zeta)}_{2p,2s}(q) , \qquad (2b)$$

where $F^{(\zeta)}_{np,ns}(q)$ is defined by Eqs.(4), (7) and (8) of Mathur et al. (1972) and Tripathi et al. (1973), and

$$\cos\theta_q = \frac{\vec{q}\cdot\vec{K}_a}{qK_a} .$$

Finally, the cross-sections Q_0 and Q_1 are constructed from Eqs.(2a,b) in the usual way:

$$Q_{m_L}(E_a) = \frac{1}{K_a^2}\int_{K_a-K_b}^{K_a+K_b} qdq \int_0^{2\pi} d\phi_q \left|F^{(a)}_{np,ns}(q,m_L)\right|^2 .$$

III. RESULTS AND DISCUSSION

We have calculated the percentage polarization of the resonance line using Eq.(1). Fig.1 shows the percentage polarization of the resonance lines of ^{6}Li , ^{7}Li . The present calculation has been compared with the recent calculations of Feautrier (1970) and with the experimental values of Hafner and Kleinpoppen (1967). We observe that in the energy region of 2 eV to 5 eV, the present calculation gives good agreement with the close coupling calculations of Burke and Taylor (1967), Karule (1970), modified by Feautrier (1970) by taking into account the full polarizability of the atomic states. The inclusion of dipole polarization terms improves the results near the excitation threshold. Fig.2 shows the plots of the percentage polarization of the resonance line of sodium. Also in the case of sodium the present calculations show good agreement in the range of 2-5 eV with the recent calculations of Moores and Norcross (1972) using a four-state exchange close-coupling approximation. The present calculation is also in reasonably good accordance with the measurements of Enemark and Gallagher (1972) and Gould (1970), but lie well below the values obtained by Hafner and Kleinpoppen (1967).

The modification of the close-coupling calculations introduced by Feautrier for the lithium atom improves the agreement with the experimental data of Hafner and Kleinpoppen. For the case of sodium, the close-coupling calculations do take into account most of the dipole polarizability of the 3p state, and this is in many respects a Feautrier modification. However, in this case it does not succeed in removing the discrepancy between the two state calculations and the results of Hafner and Kleinpoppen. For both cases beyond 5 eV, the percentage polarization decreases as the energy increases. There are no experimental data or any other theoretical calculations available to assess the accuracy of the present calculations at higher energies.

The success of the Glauber approximation in producing results in close agreement with experimental data and other theoretical calculations is not surprising, because the Glauber amplitude includes the effect of polarization and distortion. Byron (1971) and, more recently, Bransden and Coleman (1972) have demonstrated the relationship between the Glauber approximation and the close-coupling and usual impact parameter methods Byron further suggests that the Glauber approximation should be viewed as a close-coupling method in which all channels are included at the cost of making certain approximations in each channel. Further, we observe that although the total cross-section for the resonance transition under close-coupling approximation and the Glauber approximation differ by a factor of two near threshold, but the percentage polarization of the resonance line shows fairly good agreement.

ACKNOWLEDGMENTS

One of us (ANT) would like to thank Professors Abdus Salam, P. Budini as well as the International Atomic Energy Agency and UNESCO for hospitality at the International Centre for Theoretical Physics, Trieste. We also take pleasure in thanking Professor P.G. Burke for many helpful discussions and suggestions and Dr.M.K. Srivastava for discussion at the early stage of the work.

REFERENCES

Bhadra, K. and Ghosh, A.S. (1971), Phys. Rev. Letters 26, 737.

Bransden, B.H. and Coleman, J.P. (1972), J. Phys. B 5, 537.

Burke, P.G. and Taylor, A.J. (1969), J. Phys. B 2, 869.

Byron, F.W., Jr., (1971), Phys. Rev. A4, 1907.

Enemark, E.A. and Gallagher, A. (1972), Phys. Rev. in press.

Feautrier, N. (1970), J. Phys.B 3, L152.

Flower, D.R. and Seaton, M.J. (1967), Proc. Phys. Soc. (London) 91, 59.

Franco, V. (1968), Phys. Rev. Letters 20, 709;

(1971), Phys. Rev. Letters 26, 1088.

Gerjuoy, E., Thomas, B.K. and Sheorey, V.B. (1972), J. Phys. B 5, 321.

Ghosh, A.S., Sinha, P. and Sil, N.C. (1970), J. Phys. B 3, L58.

Gould, G. (1970), Ph.D. Thesis, University of New South Wales.

Hafner, E. and Kleinpoppen, H. (1967), Z. Phys. 198, 315.

Hidalgo, M.B., McGuire, J.H. and Doolen, G.D. (1972), J. Phys.B 5,L70.

Karule, E. (1970), J. Phys. B 3, 860.

Mathur, K.C., Tripathi, A.N. and Joshi, S.K. (1972), Phys. Rev. A5 , 746.

Moores, D.L. and Norcross, D.W. (1972), J. Phys. B 5, 1482.

Tai, H., Bassel, R.H., Gerjuoy, E. and Franco, V. (1970), Phys. Rev. A1, 1819.

Thomas, B.K. and Gerjuoy, E. (1971), J. Math. Phys. 12, 1567.

Tripathi, A.N., Mathur, K.C. and Joshi, S.K. (1973), J. Chem. Phys. (in press).

Yates, A.C. and Tenney, A. (1972), Phys. Rev. A6, 1451.

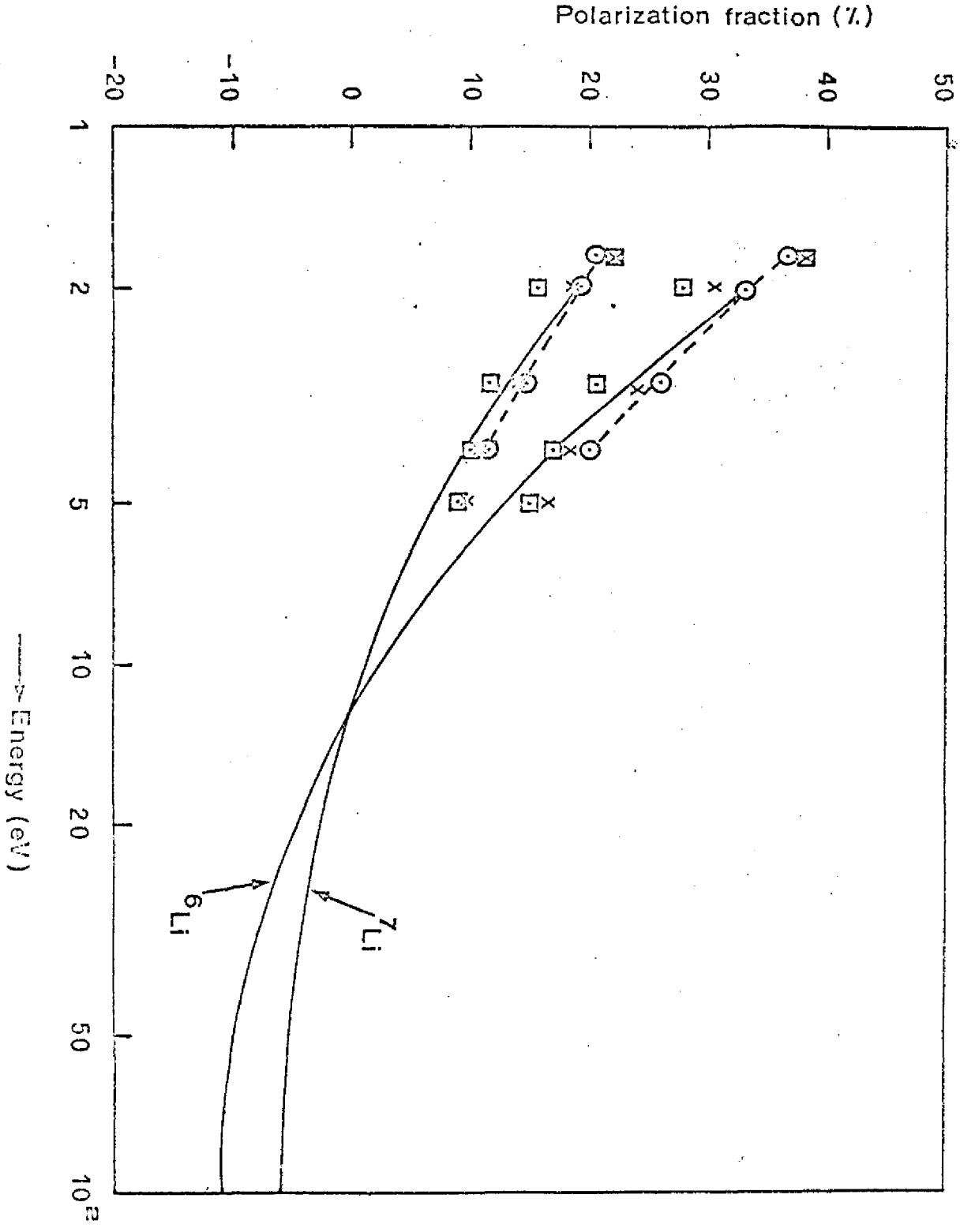

Fig.1 Polarization of resonance line of ^{6}Li and ^{7}Li lines: ——— present calculations; xx calculations of Feautrier using the close-coupling method incorporating the dipole polarizability of atomic states; ⊡ close-coupling calculations of Burke and Taylor; ⊙···⊙ experimental data of Hafner and Kleinpoppen.

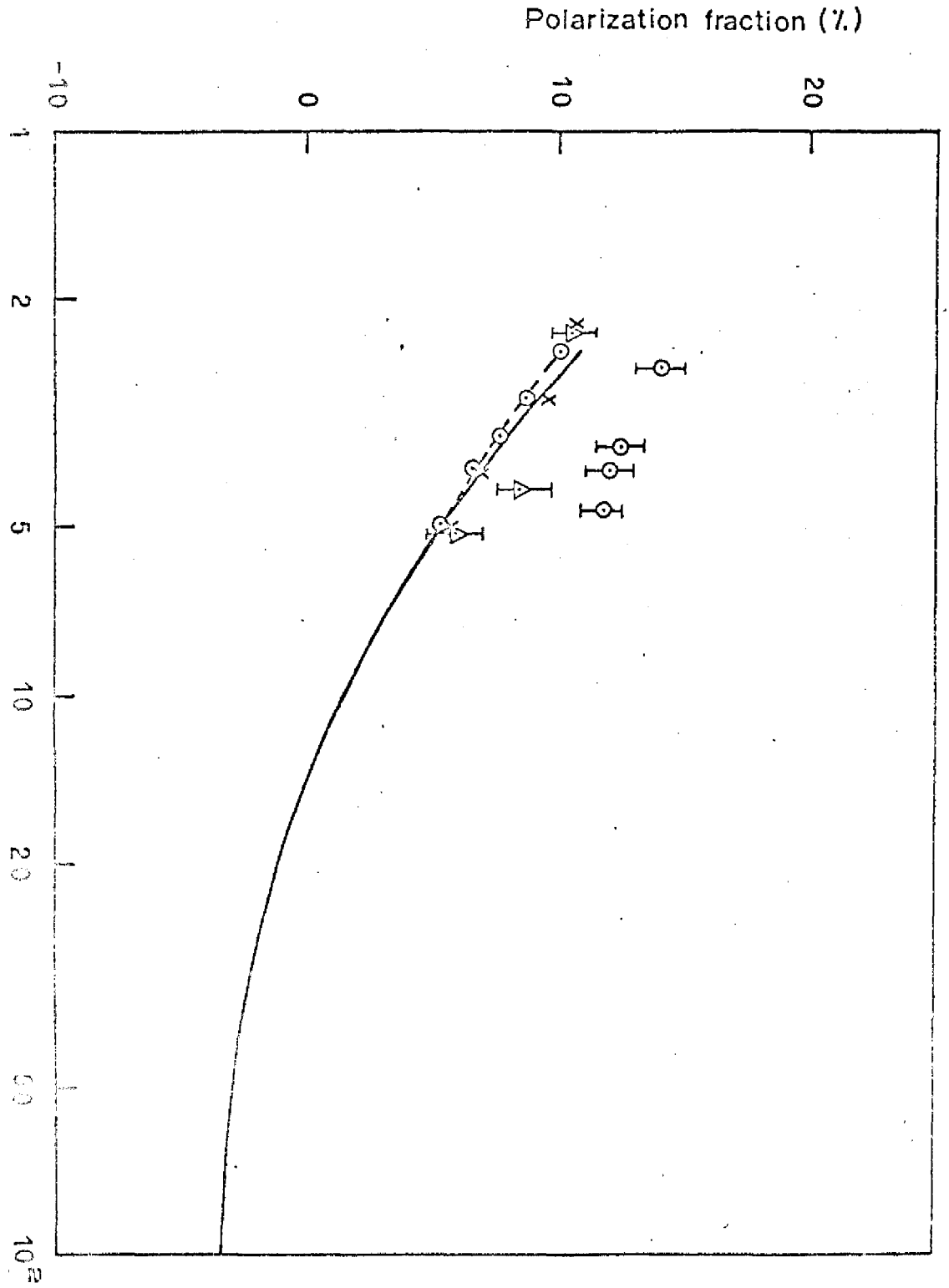

Fig.2 Polarization of resonance line of Na line.
——— present calculations; xx calculations of Moores and Norcross using a four-state exchange approximation.
Experimental data: ⊖ data of Hafner and Kleinpoppen;
⊙···⊙ data of Enemark and Gallagher; ⊖ data of Gould.