FESHBACH RESONANCES AND VIRTUAL STATES
IN ELECTRON SCATTERING BY Rb, Cs, AND Fr ATOMS AT LOW–ENERGIES

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In the last decades, negative ions have attracted much interest from both theorists and experimentalists and some reviews have been devoted to this subject[1]. Nevertheless, the spectra of many negative ions, especially the heavy anions, have not been investigated in detail. Based on the Dirac $R$–matrix method[2], we analyze the spectra of $Rb^-$, $Cs^-$, and $Fr^-$ anions below the first n$p$ excitation thresholds of Rb(5$p$), Cs(6$p$), and Fr(7$p$), in electron scattering calculations.

The model potential we use to describe the electrostatic interaction between the projectile electron and the atomic targets (Rb, Cs, and Fr) is based on an effective two–electrons approach, in which the valence and scattered electron of the electron–alkali atom system move in the field of a polarizable noble–gas–like core[2,3]. The available data provided by both theory and experiment suggest that the low–lying spectra of different negative alkali–metal ions are similar[1]. Recently, we have confirmed in elaborate Dirac $R$–matrix calculations that the lowest $^3P^o$ excited state for $Rb^-$ and $Cs^-$ ions is a shape resonance rather than a bound state, in excellent agreement with electron scattering and photodetachment measurements[3]. We have predicted that the lowest $^3P^o$ state of $Fr^-$ is also a resonance, at 32 meV above the detachment threshold[3].

Our new relativistic Dirac $R$–matrix calculations for electron scattering at energies below the Rb(5$p$), Cs(6$p$), and Fr(7$p$) excitation thresholds allow to identify the $^3P^e$ and $^1P^o_1$ Feshbach resonances[4]. For Cs and Fr targets, our calculation indicates the presence of a new $^1D^o_2$ resonance at a few meV below the lowest n$p_{3/2}$ atomic excitation threshold. We provide the positions, widths, and shape for all these resonances in both partial and total elastic cross sections. The influence of the long-range electrostatic interaction and the short-range electron correlations on the $^3P^e$, $^1P^o_1$, and $^1D^o_2$ Feshbach states is investigated. Comparison with available experiments is done[4]. We find that the splitting $\Delta E_r(J, J{-}1)$ between adjacent fine–structure components $J$ of same triplet resonance located *below* the first Rb(5$p_{1/2}$), Cs(6$p_{1/2}$), and Fr(7$p_{1/2}$) thresholds, increases linearly with $Z^4/\mathrm{n}^3$, as in the case of hydrogenic ions. Here n is the principal quantum number which defines the dominant n$l$ n$'l'$ configurations (n = 5(Rb), 6(Cs), and 7(Fr)) for each resonance, and $Z$ is the charge of the nucleus.

Figure 1 shows this linear dependence for the $^3P^o$ shape and $^3P^e$ Feshbach states of $Rb^-$, $Cs^-$, and $Fr^-$.

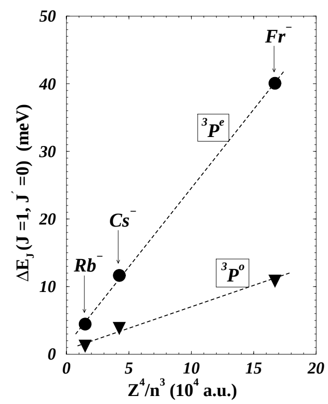


Figure 1. The splitting $\Delta E_J(1,0)$ between the $J=0$ and $J=1$ terms of the $^3P^o$ (triangles) and $^3P^e$ (circles) resonances *vs.* $Z^4/\mathrm{n}^3$.

Based on the relativistic version of the modified effective range theory[5], which extrapolates eigenphases provided by the Dirac $R$–matrix calculations toward energies below 1 meV, we compute highly accurate $^3S^e$ and $^1S^e$ scattering lengths in $e^-$ + Rb(5$s$), Cs(6$s$), and Fr(7$s$) elastic collisions.

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References

1. S.J. Buckman and Ch.W. Clark, Rev. Mod. Phys. **66**, 539 (1994); T. Andersen, H.K. Haugen, and H. Hotop, J. Phys. Chem. Ref. Data **28**, 1511 (1999).

2. U. Thumm and D.W. Norcross, Phys.Rev.A **45**, 6349 (1992).

3. C. Bahrim and U. Thumm, Phys. Rev. A **61**, 022722 (2000).

4. C. Bahrim, U. Thumm, and I.I. Fabrikant, Phys. Rev. A, *in press*

5. C. Bahrim, U. Thumm, and I.I. Fabrikant, J. Phys. B, *in press*

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