Feshbach Resonances and Virtual States
In Electron Scattering by Rb, Cs, and Fr Atoms at Low-Energies

Cristian Bahrin*, Uwe Thumm*, and Ilya I. Fabrikant†

*Department of Physics, Kansas State University, Manhattan, KS 66506–2604, USA
†Department of Physics and Astronomy, University of Nebraska, Lincoln, NE 68588-0111, USA

In the last decades, negative ions have attracted much interest from both theorists and experimentalists and some reviews have been devoted to this subject. Nevertheless, the spectra of many negative ions, especially the heavy anions, have not been investigated in detail. Based on the Dirac R–matrix method, we analyze the spectra of Rb−, Cs−, and Fr− anions below the first np excitation thresholds of Rb(5p), Cs(6p), and Fr(7p), 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 gas–like core3. The available data provided by both theory and experiment suggest that the low–lying spectra of different negative alkali–metal ions are similar1. Recently, we have confirmed in elaborate Dirac R–matrix calculations that the lowest 3P0 excited state for Rb− and Cs+ ions is a shape resonance rather than a bound state, in excellent agreement with electron scattering and photodetachment measurements3. We have predicted that the lowest 3P0 state of Fr− is also a resonance, at 32 meV above the detachment threshold3.

Our new relativistic Dirac R–matrix calculations for electron scattering at energies below the Rb(5p), Cs(6p), and Fr(7p) excitation thresholds allow to identify the 3Pc and 1P1 Feshbach resonances4. For Cs and Fr targets, our calculation indicates the presence of a new 1D2 resonance at a few meV below the lowest npn2 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 3Pc, 1P1, and 1D2 Feshbach states is investigated. Comparison with available experiments is done4. We find that the splitting ΔEk(J, J − 1) between adjacent fine–structure components J of the same triplet resonance located below the first Rb(5p2), Cs(6p2), and Fr(7p2) thresholds, increases linearly with Z^4/n^4, as in the case of hydrogenic ions. Here n is the principal quantum number which defines the dominant n l nl 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 3P0 shape and 3Pc Feshbach states of Rb−, Cs−, and Fr−.

Figure 1. The splitting ΔEk(1, 0) between the J = 0 and J = 1 terms of the 3P0 (triangles) and 3Pc (circles) resonances vs. Z^4/n^4.

Based on the relativistic version of the modified effective range theory5, which extrapolates eigenphases provided by the Dirac R–matrix calculations toward energies below 1 meV, we compute highly accurate 3S0 and 3S1 scattering lengths in e− + Rb(5s), Cs(6s), and Fr(7s) elastic collisions.

Acknowledgements: Supported by Office of Fusion Energy Sciences, Office of Energy Research, U.S. DOE, under grant no. ER 54511.

References

E-mail: bahrinc@phys.ksu.edu