

Acknowledgments

I am very grateful to Prof. Charlotte Froese Fischer, who proposed and initiated this work and also provided her B-spline library and suggested many useful improvements to the code. I would like to thank Prof. K. Bartschat for many useful discussions, extensive testing of the code, and careful reading of the manuscript. This work was supported by the United States National Science Foundation under grant PHY-1520970.

References

- Ait-Tahar S, Grant I. P, and Norrington P H 1996 *Phys. Rev. A* **54** 3984
Electron scattering by Fe XXII within the Dirac R-matrix approach.
- Allan M, Zatsarinny O and Bartschat K 2011 *J. Phys. B* **44** 065201
Electron impact excitation of the (4p55s) states in krypton: High-resolution electron scattering experiments and B-spline R-matrix calculations
- Bachau H, Cormier E, Decleva P, Hansen J E and Martin F 2001 *Rep. Prog. Phys.* **64** 1815.
Applications of B-splines in atomic and molecular physics
- Badnell N R 2008 *J. Phys. B* **41** 175202
Dirac R-matrix with pseudo-states.
- Balance C, private communications
- Bartschat K, Hudson E T, Scott M P, Burke P G and Burke V M 1996 *J. Phys. B* **29** 115
Electron scattering by complex atoms and ions at intermediate energies
- Bartschat K 1998 *Comp. Phys. Commun.* **114** 168.
The R-matrix with pseudo-states method: Theory and applications to electron scattering and photoionization
- Berrington K A, Burke P G, Butle K, Seaton M J, Storey P J, Taylor K T and Yan Yu 1987 *J. Phys. B* **20** 6379
Atomic data for opacity calculations: 11. Computational methods.
- Berrington K A, Eissner W B and Norrington P H 1995 *Comp. Phys. Commun.* **92** 290.
RMATRX1: Belfast Atomic R-matrix codes
- Burke P G and Robb W R 1975 *Adv. At. Mol. Phys.* **11** 143
The R-matrix theory of atomic processes
- Burke P G, Francken P, and Joachain C J 1991 *J. Phys. B* **24** 761
R-matrix-Floquet theory of multiphoton processes.
- Burke P G and Berrington K A 1993 *Atomic and Molecular Processes: R-Matrix Approach*
(Bristol: Institute of Physics Publishing)
- Burke P G and Burke V M 1997 *J. Phys. B* **30**, L383
Time-dependent R-matrix theory of multiphoton processes
- Burke P G 2011 *R-Matrix of Atomic Collisions: Application to Atomic, Molecular, and Optical Processes*
(New York : Springer)
- Burke P G and Scott M P 1996 *Electron and Positron Scattering from Atoms and Ions*, in:
Computational Atomic Physics, editor K. Bartschat (Heidelberg and New York: Springer)

- Burke V M and Noble C J 1995 *Comp. Phys. Commun.* **85** 471
FARM – A flexible asymptotic R-matrix package
- Fano U and Lee C M 1973 *Phys. Rev. Lett.* **31** 1573
Variational calculation of R-matrices. Application to Ar photoabsorption
- Froese Fischer C and Zatsarinny O 2009 *Comp. Phys. Commun.* **180** 879
A B-spline Galerkin method for the Dirac equation
- Gorczyca T W and Badnell N R 1997 *J. Phys. B* **30** 3897
Photoionization-excitation of helium using an R-matrix with pseudostates method
- Gorczyca T W, Robicheaux F, Pindzola M S, Griffin D C and Badnell N R 1995 *Phys. Rev. A* **52** 3877
Elimination of electron-ion pseudoresonances associated with approximate target wave functions
- Grant IP 2007 *Relativistic Quantum Theory of Atom and Molecules* (Springer)
- Guan X, Zatsarinny O, Bartschat K, Schneider B I, Feist J and Noble C J 2007 *Phys. Rev. A* **76** 053411
A general approach to few-cycle intense laser interactions with complex atoms
- Guan X, Noble C J, Zatsarinny O, Bartschat K and Schneider B I 2008 *Phys. Rev. A* **78** 053402
Time-dependent R-matrix calculations for multi-photon ionization of argon atoms in intense laser pulse
- Hibbert A and Froese Fischer C 1991 *Comp. Phys. Commun.* **64** 417
A general program for computing angular integrals of the non-relativistic hamiltonian with nonorthogonal orbitals
- Plummer M and Noble C J 1999 *J. Phys. B* **32** L345
Multichannel atomic scattering calculations using Lagrange mesh bases and the R-matrix method
- Sunderland A G, Noble C J, Burke V M and Burke P G 2002 *Comp. Phys. Commun.* **145** 311
A parallel R-matrix program PRMAT for electron-atom and electron-ion scattering calculations
- van der Hart H W 1997 *J. Phys. B* **30** 453
B-spline methods in R-matrix theory for scattering in two-electron systems
- van der Hart H W, Lysaght M A, and Burke P G 2007 *Phys. Rev. A* **76** 043405
Time-dependent multielectron dynamics of Ar in intense short laser pulses
- Young I G and Norrington P H 1994 *Comp. Phys. Commun.* **83** 215
[*Solution of the relativistic asymptotic equations in electron-ion scattering*](#)
- Zatsarinny O and Froese Fischer C 1999 *Comp. Phys. Commun.* **124** 247
A general program for computing angular integrals of the Breit-Pauli hamiltonian with non-orthogonal orbitals
- Zatsarinny O and Froese Fischer C 2000 *J. Phys. B* **33** 313
The use of basis splines and non-orthogonal orbitals in R-matrix calculations: application to Li photoionization.
- Zatsarinny O and Bartschat K 2004 *J. Phys. B* **37** 2173
B-spline Breit-Pauli R-matrix calculations for electron collisions with neon atoms.
- Zatsarinny O 2006 *Comp. Phys. Commun.* **174** 273
BSR: B-spline atomic R-matrix codes
- Zatsarinny O and Bartschat K 2008 *Phys. Rev. A* **77** 062701
Relativistic B-spline R-matrix method for electron collisions with atoms and ions: Application to lowenergy electron scattering from Cs
- Zatsarinny O and Bartschat K 2011 *Phys. Rev. Lett.* **107** 023203
Nonperturbative treatment of ionization and excitation of helium by electron impact

Berrington K A and Seaton M J 1985 *J. Phys. B* **18** 2587
 Buttle P J 1967 *Phys. Rev.* **160** 719
 Chang J J 1975 *J. Phys. B* **8** 2327
 Chang J J 1977 *J. Phys. B* **10** 3335
 Crees M A, Seaton M J and Wilson P M H 1978 *Comput. Phys. Comm.* **15** 23 IMPACT
 Fritzsche S, Froese Fischer C and Gaigalas G 2002 *Comput. Phys. Comm.* **148** 103
 Fullerton L W and Rinker Jr G A 1976 *Phys. Rev. A* **13** 1283
 Grant I P 2008 *J. Phys. B* **41** 055002
 Igarashi A 2006 *J. Phys. Soc. Jpn.* **75** 114301
 Igarashi A 2007 *J. Phys. Soc. Jpn.* **76** 054301
 Johnson W R, Blundell S A and Sapirstein J 1988 *Phys. Rev. A* **37** 307
 Jönsson P, He X, Froese Fischer C and Grant I P (2007) *Comput. Phys. Comm.* **177** 597
 Mohr P J 1974 *Ann. Phys. (N.Y.)* **88** 52
 Mohr P J 1983 *At. Data Nucl. Data Tables* **29** 453
 Mohr P J and Kim Y-K 1992 *Phys. Rev. A* **45** 2723
 Norrington P H and Grant I P 1981 *J. Phys. B* **14** L261
 Norrington P H and Grant I P 1987 *J. Phys. B* **20** 4869
 Sapirstein J and Johnson W R 1996 *J. Phys. B* **29** 5213
 Seaton M J 1985 *J. Phys. B* **18** 2111
 Shabaev V M, Tupitsyn I I, Yerokhin V A, Plunien G and Soff G 2004 *Phys. Rev. Lett.* **93**,
 130405
 Szmytkowski R and Hinze J 1996 *J. Phys. B* **29** 761
 Uehling E A 1935 *Phys. Rev.* **48** 55