DR, Photoionization and Opacities

Nigel Badnell

Department of Physics
Univerity of Strathclyde
Glasgow, UK

Outline

DR: Methodologies, with particular attention to modelling dynamic finite-density plasmas.

Photoionization: Inner-shell PE and PI, and application to opacity determination.

Opacities: Updated opacities from the Opacity Project and application to the Solar Radiative Interior.

DR

- **Atomic Physics**
  1. Reaction pathways: Fine-structure transitions
  2. Atomic structure: Accurate radiative rates
  3. Coupling scheme: LS, BP, DF
  4. Continuum description: CC vs DW
  5. Interference: Asymmetry in the DR resonance profile.

- **Modelling**
  1. Dynamic plasmas: metastables not in collisional LTE with ground.
  2. Density effects: stepwise ionization
  3. Field effects: l-changing collisions represent dynamic part of plasma microfield

- **Integrated approach**
  1. Determine DR from both the ground and metastable states
  2. Determine DR to all non-LTE final resolved states
  3. Use variable final-state resolution: fully-resolved for low-n where spectroscopic diagnosis takes place. Bundle appropriately for higher n, but resolve by parent still e.g. Jpnl, Jpn.
  4. Determine data uniformly for a wide range of iso-electronic sequences so as to provide good isonuclear coverage.
  5. Atomic Data and Analysis Structure (ADAS) *adf09* datefile format fulfills requirement for Generalized Collisional-Radiative modelling. (Also provides zero-density total...)
  6. Applicable to general Astrophysical and Fusion plasmas.

- **DR Project**

  Using the code AUTOSTRUCTURE, extensive calculations of DR atomic data have been made, using the above approach, for astrophysical and fusion relevant elements viz. He, Li, Be, B, C, N, O, F, Ne, Na, Mg, Al, Si, P, S, Cl, Ar, Ca, Ti, Cr, Fe, Ni, Zn Kr, Mo, Xe.

  Goals and Methodology: Badnell et al A&A 406, 1151 (2003).

Results:

H-like: Badnell

He-like: Bautista and Badnell

Li-like: Colgan et al A&A 417, 1183, (2003)

Be-like: Colgan et al A&A 412, 597 (2003)

B-like: Altun et al A&A 420, 775 (2004)

C-like: Zatsarinny et al A&A 417, 1173 (2003)

N-like: Mitnik et al A&A 425, 1153 (2004)

O-like: Zatsarinny et al A&A 412, 587 (2003)

F-like: Zatsarinny et al A&A To be submitted

Ne-like: Zatsarinny et al A&A 426, 699 (2004)

Na-like: Altun et al A&A To be submitted

Mg-like: Altun et al A&A To be submitted

To Be Continued

Data available from Oak Ridge Controlled Fusion Atomic Data Center website.
www-cfadc.phy.ornl.gov/data_and_codes

Photoionization

Using the code AUTOSTRUCTURE, extensive calculations of inner-shell PE and PI data have been made for the chemical elements He, C, N, O, Ne, Na, Mg, Al, Si, S, Ar, Ca, Cr, Mn, Fe and Ni.

Initial- and final-state resolved (inner- and outer-shell) PE and PI data is available in the ADAS *adf38* and *adf39* file formats for the following sequences.

H-like: Bautista and Mendoza

He-like: Bautista and Mendoza

Li-like: Bautista and Mendoza

Be-like: Palmeri

B-like: Palmeri

C-like: Bautista and Mendoza

N-like: Butler

O-like: Delahaye and Zeippen

F-like: Butler

Ne-like: Butler

Na-like: Butler

Mg-like: Butler

Data will available from Oak Ridge Controlled Fusion Atomic Data Center website.

E.G. of inner-shell data, 6-element mix:

Z	NE	Shells	
2	1	K	
6	1	K	
	2	K	
	3	K	L
8	1	K	
	2	K	
	3	K	L
16	1	K	
	2	K	
	3	K	L
	4	K	L
	5		L
	6		L
	7		L
	8		L
	9		L
	10		L

Z	NE	Shells		
26	1	K		
	2	K		
	3	K	L	
	4	K	L	
	5	K	L	
	6	K	L	
	7	K	L	
	8	K	L	
	9	K	L	
	10		L	
	11		L	M
	12		L	M
	13			M

Updated Opacities from the Opacity Project

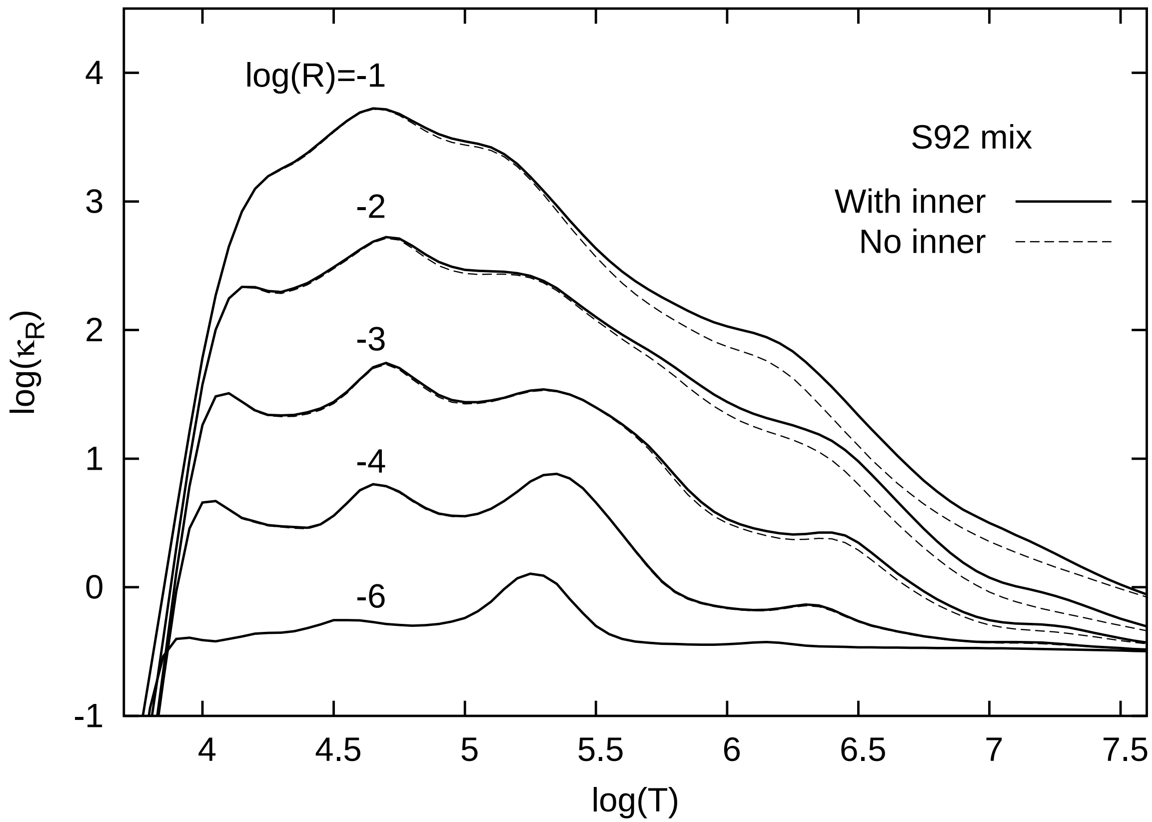

Figure 1. Rosseland-mean opacities from OP for S92 mix (Anders & Grevesse 1989), with and without inner-shell contributions.

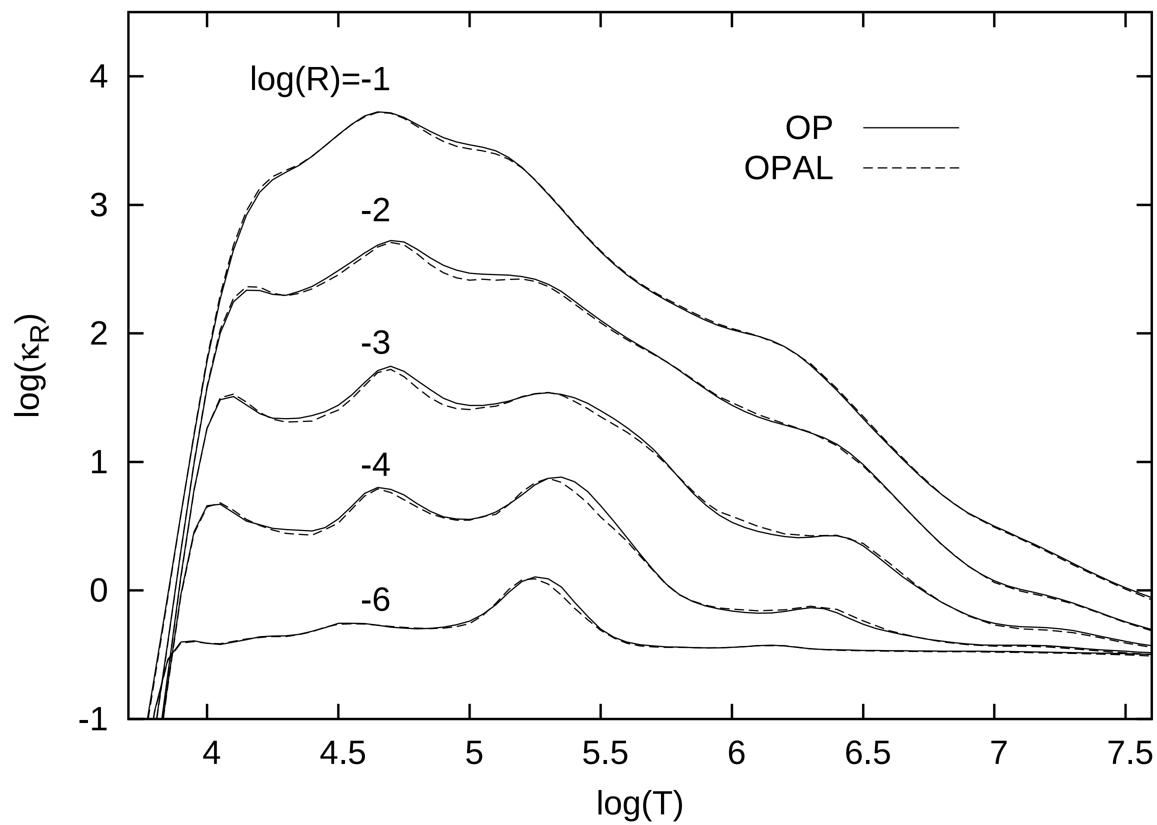

Figure 2. Rosseland-mean opacities from OP and OPAL for the S92 mix.

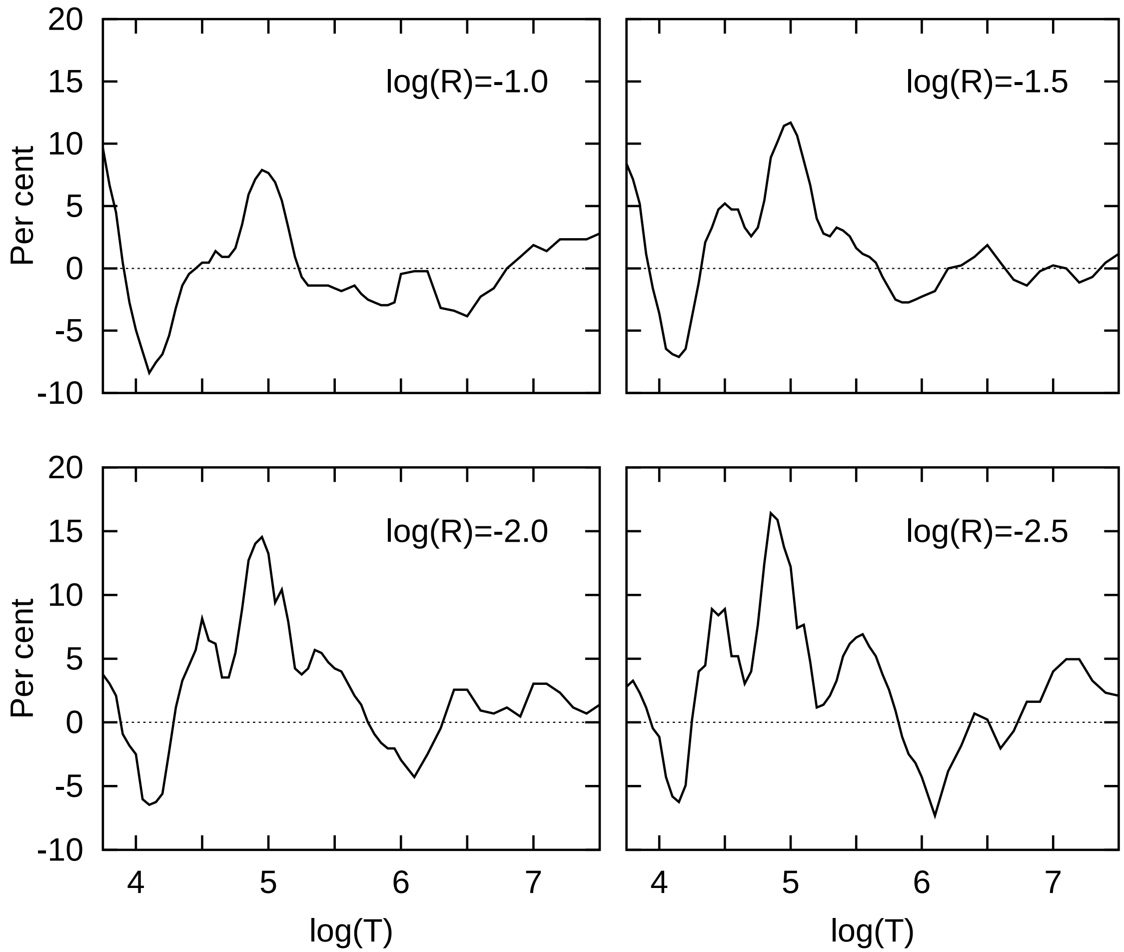

Figure 3. Percentage differences, OP–OPAL, for the S92 mix: $\log(R) = -1$ to -2.5.

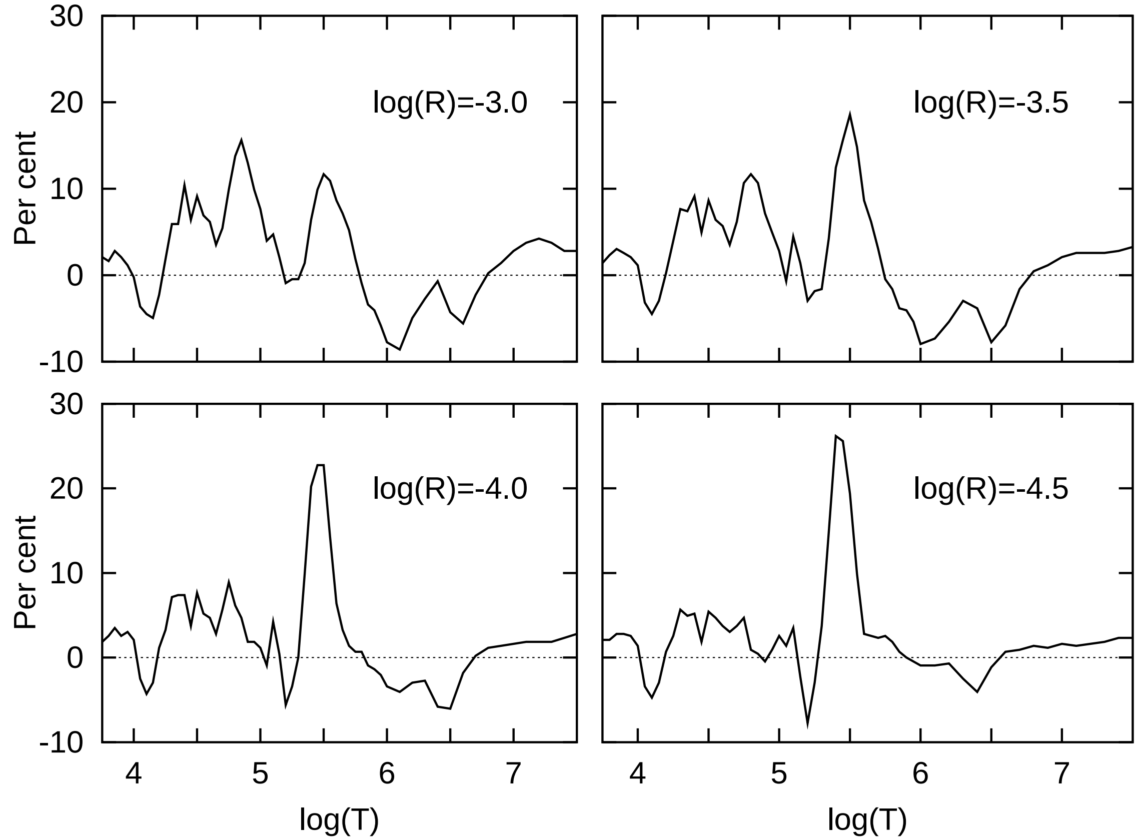

Figure 4. As Figure 3, for $\log(R) = -3$ to -4.5.

Solar Radiative Interior

Helioseismology provides remarkably accurate values for the depth, R_{CZ}, of the solar convection zone (CZ).

With the earlier estimates of solar element abundances (Anders & Grevesse 1989), values of R_{CZ} and other data from helioseismology were found to be in good agreement with results from solar models computed using OPAL opacities.

With recent downward revisions in metal abundances (Asplund et al 2004) it is found in two recent papers to be necessary to increase opacities in the vicinity of R_{CZ}, by 19% according to Basu and Antia (2004) and by 21% according to Bahcall et al. (2004a).

Furthermore, Bahcall et al. (2004b) show that there are also discrepancies for the solar profiles of sound speed and density and of helium abundance. They argue that all such discrepancies would be removed if the opacities were larger than those from OPAL by about 10% in the region of 2×10^6K $\leq T \leq 5 \times 10^6$K ($0.7$ to $0.4 R_{sun}$).

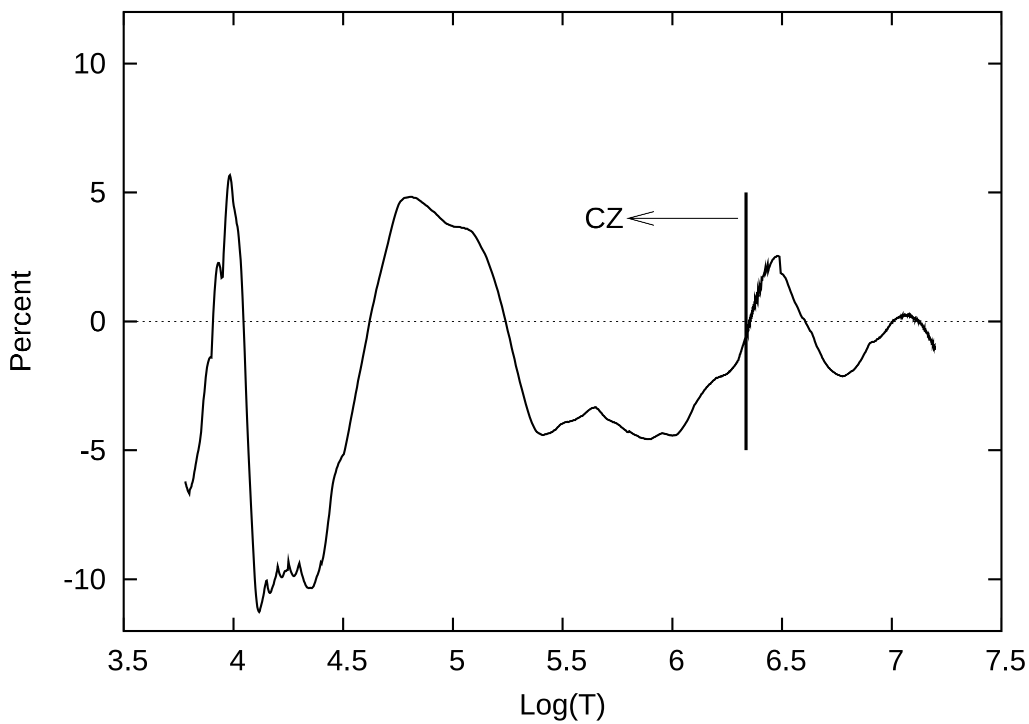

Figure 7. Percentage differences, (OP-OPAL), between opacities for a solar model from Bahcall and Pinsonneault (2004). The convection zone is the region with $\log(T) \leq 6.34$.

Summary OP opacities have been up-dated by inclusion of all contributing inner-shell processes.

Comparisons with OPAL show agreement generally to within 5 to 10%.

In the region just below the base of the solar convection zone, $R_{\rm CZ}$, we find $\kappa_{\rm R}$(OP) never to be larger than $\kappa_{\rm R}$(OPAL) by more than 2.5%.

A 10% increase in $\kappa_{\rm R}$ is required by Bahcall et al. (2004b) to restore agreement between computed solar models and results obtained from helioseismology for $R_{\rm CZ}$.

Opacity Data
Monochromatic opacity data, together with all codes required for the calculation of mean opacities and radiative accelerations for any required chemical mixture, temperature and mass-density, will be made available on CD.

Papers:

I. "Opacities for Stellar Envelopes",
Seaton, Yu Yan, Mihalas and Pradhan, MNRAS, 266, 205 (1994)

II. "On the importance of inner-shell transitions for opacities",
Badnell and Seaton, J.Phys.B, 36, 4367 (2003)

III. "A comparison of Rosseland-mean opacities from OP and OPAL",
Seaton and Badnell, MNRAS, 354, 457 (2004)

IV. "Up-dated opacities from the Opacity Project",
Badnell, Bautista, Butler, Delahaye, Mendoza, Palmeri, Zeippen and Seaton,
Submitted to MNRAS (astro-ph/0410744)

V. "OP data on CD for mean Opacities and Radiative Accelerations",
Seaton
Submitted to MNRAS (astro-ph/0411010)

Collaborators

DR:
Zikri Altun, Manuel Bautista, James Colgan, Tom Gorczyca, Kirk Korista, Stuart Loch, Dario Mitnik, Martin O'Mullane, Mitch Pindzola, Daniel Savin, Allan Whiteford, A. Yumak, Oleg Zatsarinny and Hugh Summers.

PI:
Manuel Bautista, Keith Butler, Franck Delahaye, Claudio Mendoza, Patrick Palmeri, Claude Zeippen and Mike Seaton.

Opacities:
Mike Seaton

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