Astrophysical tests of atomic data important for stellar Mg abundance determinations

L. Mashonkina\textsuperscript{1,2}

\textsuperscript{1} Universitats-Sternwarte München, Scheinerstr. 1, D-81679 München, Germany\n\textsuperscript{2} Institute of Astronomy, Russian Academy of Sciences, RU-119017 Moscow, Russia
\textsuperscript{e-mail: lm@inasan.ru}

Received / Accepted

ABSTRACT

Context. Magnesium abundances of cool stars with different metallicities are important for understanding the galactic chemical evolution.

Aims. This study tests atomic data used in stellar magnesium abundance analyses.

Methods. We evaluate non-local thermodynamical equilibrium (NLTE) line formation for Mg\textsubscript{i} using the most up-to-date theoretical and experimental atomic data available so far and check the Mg abundances from individual lines in the Sun, four well studied A-type stars, and three reference metal-poor stars.

Results. With the adopted g/f-values, NLTE abundances derived from the Mg\textsubscript{i} 4703 Å, 5528 Å, and Mg\textsubscript{ii} lines are consistent within 0.05 dex for each A-type star. The same four Mg\textsubscript{i} lines in the solar spectrum give consistent NLTE abundances at log N(Mg\textsubscript{i})/N(H) = −4.45, when correcting van der Waals damping constants inferred from the perturbation theory. Inelastic Mg\textsubscript{+}H collisions as treated by Barklem, Belyaev, Spielfiedel, Guitou, and Feautrier serve as efficient thermalizing process for the statistical equilibrium of Mg\textsubscript{i} in the atmospheres of metal-poor stars. The use of Mg\textsubscript{+}H collision data improves Mg abundance determinations for HD 84937 and HD 122563, though does not remove completely the differences between different lines.

Key words. Atomic data – Atomic processes – Line: formation – Sun: abundances – Stars: abundances – Stars: atmospheres

1. Introduction

Magnesium plays an important role in studies of cool stars. It affects atmospheric structure through donation of free electrons and significant contribution of Mg\textsubscript{i} photoionization to the ultraviolet (UV) opacity. Magnesium is a key element for studying the history of α-process nucleosynthesis in the Universe. The Mg/Fe abundance ratio of metal-poor (MP) stars carries on an important role in nuclear astrophysics and its statistical equilibrium (SE) can easily deviate from ther-

diecal calculations of Barklem et al. (2012, hereafter, BBSGF) on Mg\textsubscript{+}H collisions. The role of inelastic collisions with neutral hydrogen atoms in establishing the SE of atoms in cool stars is debated for decades. Steenbock & Holweger (1984) implemented the classical Drawin (1968, 1969) formula to calculate H\textsubscript{i} collision rates, and it suggests that their influence is comparable to electron impacts. Till recent time, laboratory measurements and/or detailed quantum mechanical calculations of collisions with H\textsubscript{i} atoms were only available for Na\textsubscript{i} and Li\textsubscript{i} (see Barklem et al. 2011 for references). Based on these data, the Drawin’s formalism has been criticized for not providing a realistic description of the physics involved and overestimating the collision rates. Interestingly, spectroscopic studies of Na\textsubscript{i} also suggest that the Drawin’s formula strongly overestimates the Na\textsubscript{+}H collision rates. For example, Allende Prieto et al. (2004) reproduced the center-to-limb variation of the solar Na\textsubscript{i} 6160 Å line with pure electronic collisions. At the same time, the need for a thermalizing process not involving electrons in the atmospheres of, in particular, very metal-poor stars, was indicated by many NLTE line-formation studies (see Mashonkina et al. 2011 and references therein).

The main goal of this paper is to investigate how the use of recent detailed quantum mechanical calculations of Barklem et al. (2012) for inelastic Mg\textsubscript{+}H collisions influences the NLTE results for Mg\textsubscript{i}. We started from analysis of the solar Mg\textsubscript{i} lines,
for which the departures from LTE are small and the derived abundances are not influenced by \( H i \) collision treatment. It was found that the two lines \( \text{Mg}^0 4703 \) Å and \( \text{Mg}^0 5528 \) Å give significantly lower abundance compared with that from the \( \text{Mg}^0 b \) lines and also compared with the meteoritic value. To understand the source of discrepancies and to separate effects of oscillator strengths and van der Waals broadening, we moved to the hotter A-type stars. The paper is organized as follows. All our results are based on the NLTE line formation for \( \text{Mg}^0 i \). The model atom of magnesium and the used atomic data are described in Sect. 2. In Sect. 3, we derive abundances from individual \( \text{Mg}^0 i \) lines in the solar spectrum and in the spectra of four well studied A-type stars. Section 4 investigates the effects of \( \text{Mg}^0 H \) collisions on the SE of magnesium and NLTE abundances for the two very metal-poor ([Fe/H] < −2, VMP) stars. We compare the NLTE results from calculations using \( \text{Mg}^0 H \) collision data of BBSGF and using the classical Drawinian rates. The NLTE abundance corrections are presented for lines of \( \text{Mg}^0 i \) in the grid of metal-poor model atmospheres. Our conclusions are given in Sect. 5.

### 2. Method of NLTE calculations for magnesium

This study uses a comprehensive model atom that includes 85 levels of \( \text{Mg}^0 i \), 2 levels of \( \text{Mg}^0 ii \), and the ground state of \( \text{Mg}^0 iii \). For \( \text{Mg}^0 i \), we rely on the model atom produced by Zhao et al. (1998), who carefully investigated atomic data on the energy levels, transition probabilities, and photoionization cross-sections. In this study, the calculation of collisional rates was updated. For electron-impact excitation, we used rate coefficients of Mauas et al. (1988), where available, and the same recipes as in Zhao et al. (1998) for the remaining transitions. Ionization by electronic collisions is calculated from the Seaton (1962) formula with a mean Gaunt factor set equal to \( \overline{\gamma} = 0.1 \) for \( \text{Mg}^0 i \) and to 0.2 for \( \text{Mg}^0 ii \). For \( H i \) impact excitations and charge transfer processes \( \text{Mg}^0 i + H i \leftrightarrow \text{Mg}^0 ii + H^+ \), rate coefficients were taken from detailed quantum mechanical calculations of BBSGF.

Singly ionized magnesium is represented in our model atom by the two levels \( 3s^2S \) and \( 3p^2P \). Their energies and \( g-f \) value of the resonance transition were taken from the NIST database. Photionization is treated by utilizing Opacity Project cross-sections as available through the TOPBASE database.

In order to solve the coupled radiative transfer and statistical equilibrium equations, we used a revised version of the DETAIL program (Butler & Giddings 1985). The update was described by Przybilla et al. (2011).

Calculations were performed with plane-parallel (1D), LTE, and blanketed model atmospheres computed for given stellar parameters. These are the MAFAGS-OS models by Grupp et al. (2003) for the Sun and VMP stars, the LMODELS models by Shulyak et al. (2004) by D. Shulyak for the three A-type stars, and the model by R. Kurucz for Sirius.

Table 1 lists the lines of \( \text{Mg}^0 i \) used in abundance analyses for MP stars together with the adopted line data. Oscillator strengths were taken from laboratory measurements of Aldenius et al. (2007) for the \( \text{Mg}^0 b \) lines, calculations of Chang & Tang (1990) for \( \text{Mg}^0 i 4703 \) Å and \( 5528 \) Å, and calculations of Tachiev & Froese Fischer for \( \text{Mg}^0 i 4571 \) Å as presented in the NIST database. An accuracy of predicted \( g-f \) values can only be estimated for the \( \text{Mg}^0 b \) lines, where the difference between calculated values of Chang & Tang (1990) and measurements of Aldenius et al. (2007) amounts to 0.06 dex. The van der Waals broadening constants \( \Gamma_6 \) were computed with cross-sections and velocity parameters from Anstee & O’Mara (1995) and Barklem & O’Mara (1997). Hereafter, these papers by Anstee, Barklem, and O’Mara are referred to as the ABO theory. The quadratic Stark effect broadening constants \( \Gamma_4 \) were taken from Dimitrijevic & Sahal-Brechot (1990), except for \( \text{Mg}^0 i 4571 \) Å, with \( \Gamma_4 \) from the VALD database.

#### 3. \( \text{Mg}^0 i \) lines in the Sun and A-type stars

In the galactic chemical evolution studies, stellar sample covers, as a rule, a range of metallicities of more than 3 dex. The lines \( \text{Mg}^0 i 4703 \) and \( 5528 \) Å are favorites for abundance determinations of mildly MP ([Fe/H] > −2) stars, however, these lines cannot be measured in hyper metal-poor stars, with [Fe/H] < −4.5, where one relies on the \( \text{Mg}^0 b \) lines. One needs, therefore, to prove that the use of different \( \text{Mg}^0 i \) lines does not produce a systematic shift in derived abundance between various metallicity stars. In the beginning, we checked whether the lines listed in Table 1 give consistent abundances for the Sun, when employing the most up-to-date theoretical and experimental atomic data available so far. Observed solar spectrum was taken from the Kitt Peak Solar Flux Atlas (Kurucz et al. 1984). We used the MAFAGS-OS solar model atmosphere with \( T_{\text{eff}}/\log g/[\text{Fe/H}] = 5870/4.44/0 \). Microturbulence velocity was fixed at \( V_{\text{mic}} = 0.9 \text{ km s}^{-1} \). Element abundances from individual lines were determined from line-profile fitting using the code SIU (Reetz 1991). The obtained results are presented in Table 2. We find that (i) the NLTE effects are minor for each investigated line, (ii) abundances derived from the \( \text{Mg}^0 b \) and \( \text{Mg}^0 i 4571 \) Å lines are consistent with the meteoritic value \( \Delta \log N_\text{Mg,\text{me}} = -4.45 \) (Lodders et al. 2009), (iii) \( \text{Mg}^0 i 4703 \) and \( 5528 \) Å give significantly lower abundances, by 0.24 dex and 0.15 dex, respectively. These discrepancies can arise from the uncertainty in either \( g-f \) values or/and \( \Gamma_6 \) values. The influence of atmospheric inhomogeneities on derived solar \( \text{Mg}^0 \) abundance was evaluated by Asplund (2005) as −0.03 dex.

To test \( g-f \) values, we choose the three well studied stars Sirius, Vega, and 21 Peg (Table 3), where the \( \text{Mg}^0 i \) lines are insensitive to \( \Gamma_6 \) variation. The departures from LTE are expected to be larger in hot atmospheres than in the solar one. Thus, analysis of the \( \text{Mg}^0 i \) lines in the A-type stars tests also our NLTE method. For each star, its stellar parameters and observed equivalent widths indicated in Table 2 and used to determine element abundances were taken from a common source cited in Table 3. We find that, for each star, (i) the NLTE effects are minor for

| \( \lambda \) (Å) | \( E_{\text{exc}} \) (eV) | \( \log g \cdot f \) | \( \log \Gamma_4/N_4 \) (rad/s·cm\(^{-2}\)) | \( \log \Gamma_6/N_6 \) (rad/s·cm\(^{-2}\)) |
|---|---|---|---|---|
| 4571.10 | 0.00 | -5.62 | -6.46 | -7.77 |
| 4702.99 | 4.33 | -0.45 | 4.17 | -6.69 |
| 5528.41 | 4.33 | -0.50 | 4.63 | -6.98 |
| 5172.68 | 2.71 | -0.45 | 5.43 | -7.27 |
| 5183.60 | 2.71 | -0.24 | 5.43 | -7.27 |

\( \Gamma_4 \) and \( \Gamma_6 \) correspond to 10000 K.

Notes. \( \text{NIST}^2 \), \( \text{Chang} \& \text{Tang} (1990); \text{Aldenius} \text{et al.} (2007). \)

\( \text{Aldenius} \text{et al.} (2007) \) and measurements of Chang & Tang (1990)
Table 2. Magnesium NLTE and LTE abundances log \( A_{\text{Mg}} \) of the Sun and hot stars.

| \( \lambda \) (Å) | Sun | HD 32115 | Vega | Sirius | 21 Peg |
|------------------|-----|----------|------|--------|--------|
|                  | NLTE | LTE | EW | NLTE | LTE | EW | NLTE | LTE | EW | NLTE | LTE | EW | NLTE | LTE |
| Mg \textit{i} 4571 | -4.38 | -4.42 | - | - | - | - | - | - | - | - | - | - | - | - |
| Mg \textit{i} 4703 | -4.69 | -4.70 | -4.55 | -4.58 | - | -4.93 | -4.94 | 42 | -4.56 | -4.56 | 17 | -4.48 | -4.50 | - |
| Mg \textit{i} 5528 | -4.60 | -4.61 | -4.52 | -4.54 | 27 | -4.93 | -4.95 | 39 | -4.54 | -4.53 | 14 | -4.49 | -4.51 | - |
| Mg \textit{i} 5172 | -4.45 | -4.46 | -4.44 | -4.44 | 106 | -4.88 | -4.87 | 121 | -4.44 | -4.25 | 70 | -4.40 | -4.30 | - |
| Mg \textit{i} 5183 | -4.45 | -4.46 | -4.44 | -4.44 | 124 | -4.84 | -4.62 | 134 | -4.44 | -4.21 | 86 | -4.35 | -4.16 | - |

\[ \Delta \log A(Mg \textit{i} 4703,5528 - Mg \textit{i} 5172,5183) \]

\[ -0.19 \quad -0.10 \quad -0.07 \quad -0.11 \quad -0.11 \]

Note. 1 Equivalent width, \( EW \), in mÅ.

Table 3. Stellar parameters of selected stars.

| Object | \( T_{\text{eff}} \), K | \( \log g \) | \([\text{Fe/H}]\) | \( V_{\text{mic}}^1 \) | Ref. |
|--------|------------------|--------|---------|-------------|------|
| Sun    | 5780             | 4.44   | 0       | 0.9         |      |
| HD 32115 | 7250           | 4.20   | 0.4     | 2.3         | F11  |
| HD 48915 (Sirius) | 9850       | 4.30   | 0.4     | 1.8         | S13  |
| HD 84937    | 6350           | 4.00   | -0.20   | 1.7         | M11  |
| HD 103095    | 5070           | 4.69   | -1.35   | 0.8         | M07  |
| HD 122563    | 4600           | 1.60   | -0.56   | 1.95        | M11  |
| HD 172167 (Vega) | 9550       | 3.95   | -0.5    | 2.0         | P01  |
| HD 209459 (21 Peg) | 10400     | 3.55   | 0.0     | 0.5         | F09  |

Note. 1 Microturbulence velocity, in km s\(^{-1}\).

Ref.: F09 = Fossati et al. (2009); F11 = Fossati et al. (2011); M07 = Mashonkina et al. (2007); M11 = Mashonkina et al. (2011); P01 = Przybilla et al. (2001); S13 = Sitnova et al. (2013).

Mg \textit{i} 4703 Å and 5528 Å, (ii) abundances from these two lines are consistent within 0.02 dex, in contrast to the solar case, (iii) departures from LTE for the Mg \textit{ib} lines are significant, so that the NLTE abundance correction \( \Delta_{\text{NLTE}} = \log \varepsilon_{\text{NLTE}} - \log \varepsilon_{\text{LTE}} \) ranges between \(-0.14\) dex and \(-0.22\) dex for different stars, (iv) the difference in NLTE abundance between the Mg \textit{ib} and Mg \textit{i} 4703, 5528 Å lines is smaller compared to that for the Sun. It is worth noting that it does not exceed \(0.05\) dex, when applying \( g_f \)-values from a single source (Chang & Tang 1990) for all the investigated lines.

Return to the Sun. The abundance discrepancies found between different solar lines of Mg \textit{i} can only be owing to van der Waals damping treatment, and they are removed by reducing the \( \Gamma_6(ABO) \) values by 0.3 dex and 0.2 dex for Mg \textit{i} 4703 Å and Mg \textit{i} 5528 Å, respectively. The use of such corrections was justified by analysis of the Mg \textit{i} lines in the cool subdwarf star HD 103095 (Table 3). We obtained the difference (Mg \textit{i} 4703, 5528 - Mg \textit{ib}) = \(-0.18\) dex, when using \( \Gamma_6(ABO) \), and a significantly smaller value of \(+0.02\) dex, with the above corrections. Table 2 presents Mg abundances of the late A-type star HD 32115, where Mg \textit{i} 4703 Å and 5528 Å are less sensitive to \( \Gamma_6 \) variation. Both lines give identical abundances at \( \log A_{\text{Mg}} = -4.51 \), and the difference (Mg \textit{i} 4703, 5528 - Mg \textit{ib}) reduces to \(-0.07\) dex, when employing the corrected \( \Gamma_6 \)-values.

Fig. 1. Departure coefficients for selected levels of Mg \textit{i} as a function of \( \log \tau_{5000} \) in the model atmosphere 4600/1.60/−2.56 from the calculations with pure electronic collisions (top panel) and with H\textit{i} collisions taken into account following BBSGF (bottom panel). Tick marks indicate the locations of line center optical depth unity for the Mg \textit{i} lines 5172 Å (1) and 5528 Å (2).

4. Influence of Mg+H collisions on the NLTE results for metal-poor stars

The departures from LTE for Mg \textit{i} grow toward lower metallicity due to decreasing number of electrons donated by metals and decreasing collision rates and also due to decreasing the UV opacity resulting in increasing photoionization rates. The largest
uncertainties in NLTE results are caused by the uncertainties in collisional data. Here, we evaluate for the first time the effect of applying Mg+H collision data of Barklem et al. (2013) on the SE of magnesium in two well studied VMP stars. HD 84937 represents the hot end of the stars that evolve on time scales comparable with the Galaxy lifetime. HD 122563, in contrast, is a cool giant (Table 5).

Figure 1 shows the departure coefficients \( b_i = \frac{n_{\text{LTE}}}{n_{\text{NLTE}}} \) for the Mg i levels in the model atmosphere 4600/1.60/-2.56 from calculations with two different types of collisional rates. Here, \( n_{\text{LTE}} \) and \( n_{\text{NLTE}} \) are the SE and thermal (Saha-Boltzmann) number densities, respectively. In the line-formation layers, the Mg i levels have less populations compared with the thermal ones, independent of collision treatment, however, the magnitude of departures from LTE is significantly smaller in case of Mg+H collisions included compared with the case of pure electronic collisions. The main NLTE mechanism is overionization caused by superthermal radiation of a non-local origin below the thresholds of the \( 3p \) \( ^1P \) and \( 3p \) \( ^3P \) levels. When taking Mg+H collisions into account, the charge transfer processes \( \text{Mg}^+ + \text{H} \rightarrow \text{Mg} + \text{H}^+ \) establish close collisional coupling of excited terms of Mg i to the ground state of Mg ii and reduce their underpopulation. This effect is redistributed to the lower excitation levels via the bound-bound transitions, including the \( \text{H}^+ \) impact excitation and de-excitation processes.

Table 4 presents abundances determined from individual lines of Mg i under different assumptions for line formation. It is worth noting that results for Mg i 4703 Å and 5528 Å do not depend on van der Waals damping treatment because both lines are weak. For each star, NLTE leads to depleted absorption in the lines at 4571, 4703, and 5528 Å due to overall overionization of Mg i in the atmospheric layers, where they form. As expected, the inclusion of Mg+H collisions leads to weaker NLTE effects compared with that for pure electronic collisions, such that \( \Delta N_{\text{LTE}} \) reduces by 0.06-0.23 dex for different lines. For HD 122563, the NLTE effects have different sign for Mg i 4703 Å and Mg i 5528 Å, resulting in a remarkable consistency of abundances derived from these two lines.

Despite the low Mg abundance, the Mg ii lines are rather strong in both VMP stars. For each line, its core forms in the layers, where departure coefficient of the upper level \( 4s \) \( ^1S \) drops rapidly (Fig. 1) due to photon escape from the Mg ii triplet lines themselves resulting in dropping the line source function below the Planck function and enhanced absorption in the line core (Fig. 2). NLTE leads to depleted absorption in the line wings due to overall overionization in deep atmospheric layers. However, this effect is predominated by NLTE strengthening for the line core, such that the obtained NLTE abundances are lower compared with the corresponding LTE ones and lower compared with those from the other lines, independent of collisional rate treatment. The difference \( \Delta \log e(\text{Mg} i 4703, 5528 - \text{Mg} ii) \) is smaller in the case of Mg+H collisions included than in the case of pure electronic collisions and amounts to 0.09 dex and 0.12 dex for HD 84937 and HD 122563, respectively. For LTE abundances from the Mg ii lines, we used \( \text{EWs} \), because their profiles cannot be fitted at the LTE assumption. Despite the latter fact, the obtained LTE abundances are consistent within 0.05 dex with those from the other lines.

Our calculations show that inelastic collisions with \( \text{H}^+ \) atoms as treated by BBSGF produce significant thermalization effect on the SE of Mg i in the atmospheres of VMP stars and improve Mg abundance determinations compared with the case of pure electronic collisions. To understand remaining discrepancies between different lines, one, probably, needs to go beyond the 1D analysis. The models based on hydrodynamical calculations (3D models) show, on average, lower temperatures outside log \( T_{\text{5000}} \) = -1 compared with those in the corresponding 1D model, for example, by 1 000 K at log \( T_{\text{5000}} \) = -2 in the 4858/2.2/-3 model, according to Collet et al. (2007). For VMP giants, these are exactly the layers where line core of the Mg ii lines forms.

For most atoms, formalism of Drawin (1968, 1969) is still widely applied to simulate an additional source of thermalization in the atmospheres of cool stars by parametrized \( \text{H}^+ \) collisions. For Mg i, Barklem et al. (2013) compared in their Fig. 1 the quantum scattering rate coefficients at \( T = 6000 \) K with the results of the Drawin formula for five common bound-bound transitions. The Drawin/BBSGF rate ratio is close to unity for the \( 3p \) \( ^3P \rightarrow 4s \) \( ^1S \) transition, but the Drawinian rates are one to four orders of magnitude larger for the remaining transitions. However, relatively large departures compared to those for excitation were obtained by BBSGF for the charge transfer processes. We find that they are larger compared to the Drawinian rates for ionization from the excited levels above \( 3p \) \( ^3P \), especially from the \( 4s \) \( ^1S \) state, where the difference is about four orders of magnitude at \( T = 6000 \) K. It is worth noting that the Drawin/BBSGF rate ratios are only weakly sensitive to temperature variation.

We employed the Drawinian rates scaled by a factor of \( S_{\text{HI}} = 0.1 \) to determine magnesium abundances of the investigated stars (Table 4). The changes in collisional rates result in different effects for different lines in different stars. For example, the use of accurate Mg+H collision data and scaled Drawinian rates leads to very similar results for Mg i 4571, 4703, and 5528 Å in the model 6350/4.09/-2.08. For the cool giant model, the departures from LTE are larger when applying the BBSGF rates. However, nowhere the difference between using these two recipes exceeds 0.1 dex. This is smaller or similar to a line-to-line scatter for stellar abundance determinations including the present one.
Table 4. Magnesium LTE and NLTE abundances of HD 84937 and HD 122563 from calculations with different treatment of H\textsc{i} collisions.

| \( \lambda \) (Å) | HD 84937     | HD 122563   |
|---------------|--------------|-------------|
|                | LTE pure \( e^0 \) | +H(BBSGF) | +H(D0.1) | LTE pure \( e^0 \) | +H(BBSGF) | +H(D0.1) |
| 4571          | -6.38        | -6.24      | -6.30    | -6.33    | -6.80        | -6.60      | -6.67    | -6.77    |
| 4703          | -6.36        | -6.15      | -6.29    | -6.37    | -6.86        | -6.59      | -6.82    | -6.84    |
| 5528          | -6.34        | -6.15      | -6.30    | -6.27    | -6.77        | -6.61      | -6.83    | -6.76    |
| 5172          | -6.35\(^i\)  | -6.39      | -6.39    | -6.46    | -6.87\(^i\)  | -6.74      | -6.94    | -6.94    |
| 5183          | -6.34\(^i\)  | -6.39      | -6.39    | -6.46    |

\[ \Delta \log \nu(Mg \, i \, 4703, 5528 \rightleftharpoons Mg \, i \, 5172, 5183) \]

Notes. \(^i\) Mg+H collisions following BBSGF; \(^i\) Drawinian rates with \( S_H = 0.1 \); \(^i\) from EW.

Table 5. NLTE abundance corrections (dex) for lines of Mg\textsc{i} from calculations with Mg+H collision rates of BBSGF and with the Drawinian rates scaled by a factor of \( S_H = 0.1 \) (D0.1).

| Model | 3829 Å | 5172 Å | 4571 Å | 4703 Å | 5528 Å | 5711 Å |
|-------|--------|--------|--------|--------|--------|--------|
|       | BBSGF  | D0.1   | BBSGF  | D0.1   | BBSGF  | D0.1   | BBSGF  | D0.1   | BBSGF  | D0.1   | BBSGF  | D0.1   |
| 6000/4.0/1.0 | 0.05  | 0.02  | 0.04  | 0.02  | 0.08  | 0.05  | 0.01  | 0.04  | -0.03 | 0.04  | 0.04  | 0.07  |
| 6000/4.0/2.0 | 0.04  | 0.01  | 0.02  | -0.04 | 0.08  | 0.04  | 0.03  | 0.06  | -0.02 | 0.06  | 0.03  | 0.05  |
| 6000/4.0/3.0 | 0.08  | 0.02  | 0.05  | -0.04 | 0.07  | 0.07  | 0.07  | 0.08  |
| 5811/4.0/4.5 | 0.22  | 0.17  | 0.17  | 0.19  |
| 6180/3.7/4.0 | 0.25  | 0.19  | 0.26  | 0.21  |
| 5000/2.0/0.0 | 0.06  | 0.05  | 0.06  | 0.05  | 0.13  | 0.13  | -0.07 | 0.00  | -0.16 | -0.07 | -0.05 | 0.06  |
| 5000/2.0/1.0 | 0.06  | 0.04  | 0.03  | 0.00  | 0.16  | 0.10  | -0.02 | 0.07  | -0.12 | 0.03  | 0.03  | 0.09  |
| 5000/2.0/2.0 | 0.06  | 0.01  | -0.06 | -0.10 | 0.29  | 0.11  | 0.18  | 0.16  | 0.10  | 0.16  |
| 5100/2.0/5.0 | 0.40  | 0.39  | 0.34  | 0.37  |

The NLTE calculations were performed for a small grid of model atmospheres with hydrogenic collisions taken into account following BBSGF and Drawin [1968, 1969]. The obtained NLTE corrections are presented in Table 5. Their inspection will help the user to decide whether the Mg abundances determined earlier using the Drawinian rates should be revised. This depends on which spectral lines were employed in analysis and what was the range of stellar parameters.

5. Conclusions

We summarize our findings.

1. For each of four investigated A-type stars, the use of \( g_f \)-values of Chang & Tang [1990] provides consistent within 0.05 dex NLTE abundances from Mg\textsc{i} 4703 Å, 5528 Å, and Mg\textsc{ib}. The difference between different lines increases up to 0.11 dex, when employing experimental \( g_f \)-values of Aldenius et al. [2007] for the Mg\textsc{ib} lines.

2. We recommend to apply the corrections \( \Delta \log \nu = -0.3 \) and \(-0.2 \) for Mg\textsc{i} 4703 Å and 5528 Å, respectively, to the ABO van der Waals damping constants, to remove the abundance discrepancy between different solar Mg\textsc{i} lines.

3. Inelastic collisions with H\textsc{i} atoms as treated by Barklem et al. [2012] serve as efficient thermalizing process for the SE of Mg\textsc{i} in the atmospheres of metal-poor stars. The use of new collisional data improves Mg abundance determinations for HD 84937 and HD 122563, though does not remove completely the difference in abundance between different lines.

Acknowledgements. L. M. thanks Paul Barklem for initiating this study and providing the \( \Gamma_\nu \) value for Mg\textsc{i} 4571 Å. This study is supported by the Ministry of education and science of Russian Federation, project 8529 and the RF President with a grant on Leading Scientific Schools 3602.2012.2.

References

Aldenius, M., Tanner, J. D., Johansson, S., Lundberg, H., & Ryan, S. G. 2007, A&A, 461, 767
Allende Prieto, C., Asplund, M., & Fabiani Bendicho, P. 2004, A&A, 423, 1109
Anstee, S. D. & O’Mara, B. J. 1995, MNRAS, 276, 859
Asplund, M. 2005, ARA&A, 43, 481
Athay, R. G. & Canfield, R. C. 1969, ApJ, 156, 695
Barklem, P. S., Belyaev, A. K., Guitou, M., et al. 2011, A&A, 530, A94
Barklem, P. S., Belyaev, A. K., Spielfiedel, A., Gutou, M., & Feautrier, N. 2012, A&A, 541, A80
Barklem, P. S. & O’Mara, B. J. 1997, MNRAS, 290, 102
Butler, K. & Giddings, J. 1985, Newsletter on the analysis of astronomical spectra, No. 9, University of London
Carlsson, M., Rutten, R. J., & Shchukina, N. G. 1992, A&A, 253, 567
Chang, T. N. & Tang, X. 1990, J. Quant. Spec. Radiat. Transf., 43, 207
Collet, R., Asplund, M., & Trampedach, R. 2007, A&A, 469, 687
Dimitrijevic, M. S. & Sahal-Brechot, S. 1996, A&AS, 117, 127
Drawin, H.-W. 1968, Zeitschrift fur Physik, 211, 404
Drawin, H. W. 1969, Zeitschrift fur Physik, 225, 483
Fossati, L., Ryabchikova, T., Bagnulo, S., et al. 2009, A&A, 503, 945
Fossati, L., Ryabchikova, T., Shulyak, D. V., et al. 2011, MNRAS, 417, 495
Frebel, A., Aoki, W., Christlieb, N., et al. 2005, Nature, 434, 871
Gigas, D. 1988, A&A, 192, 264
Gratton, R. G., Carretta, E., Eriksson, K., & Gustafsson, B. 1999, A&A, 350, 955
Grupp, F., Kurucz, R. L., & Tan, K. 2009, A&A, 503, 177
Idiot, T. & Thévenin, F. 2000, ApJ, 541, 207
Kupka, F., Piskunov, N., Ryabchikova, T. A., Stempels, H. C., & Weiss, W. W. 1999, A&AS, 138, 119
Kurucz, R. L., Furenlid, I., Brault, J., & Testerman, L. 1984, Solar flux atlas from Kurucz, R. L., Furenlid, I., Brault, J., & Testerman, L. 1984, Solar flux atlas from 1999, A&AS, 138, 119.
