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CALCULATION OF MEAN CHARGES OF SLOW IONS IN A PLASMA WITH A KAPPA DISTRIBUTION FOR THE ELECTRON VELOCITY

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นางสาวสุวิชา วรรณวิเชียร : การคำนวณประจุเฉลี่ยของไอออนความเร็วต่ำในพลาสมาด้วยการกระจายของความเร็วของอิเล็กตรอนแบบแคปปา (CALCULATION OF MEAN CHARGES OF SLOW IONS IN A PLASMA WITH A KAPPA DISTRIBUTION FOR THE ELECTRON VELOCITY) อ. ที่ปรึกษา : รศ. ดร. เดวิด รูฟโฟโล : จำนวนหน้า 70 หน้า ISBN 974-03-0590-3.

ประจุเฉลี่ยของไอออนของธาตุต่าง ๆ ที่จุดสมดุล มีความสำคัญในการศึกษาพลาสมาที่มีอุณหภูมิสูง และช่วยในการทำความเข้าใจลักษณะการกระจายตัวของสถานะประจุของอนุภาครังสีคอส-มิกจากดวงอาทิตย์ สถานะประจุที่จุดสมดุลสามารถหาได้จากการสมดุลกระบวนการการแตกตัวเป็นไอออนกับกระบวนการการรวมตัวใหม่ ในกรณีสำหรับไอออนความเร็วต่ำนั้น การชนระหว่างไอออนความเร็วต่ำกับอิเล็กตรอนที่อยู่รอบ ๆ เป็นกระบวนการที่สำคัญ ดังนั้น การแจกแจงความเร็วของอิเล็กตรอนจึงเป็นส่วนสำคัญของการคำนวณในงานนี้ จากการสังเกตในอวกาศพบว่า ปริมาณที่เพิ่มขึ้นของอิเล็กตรอนพลังงานสูงสามารถจำลองได้ด้วยรูปแบบการแจกแจงความเร็วแบบแคปปา โดยมีแคปปา (κ) เป็นตัวแปรที่ปรับเปลี่ยนลักษณะการแจกแจงความเร็ว เราพิจารณาสมดุลของสถานะประจุของธาตุ ไนโตรเจน ออกซิเจน นีออน แมกนีเซียม กำมะถัน ซิลิกอน อาร์กอน แคลเซียม เหล็ก และ นิเกิล พร้อมกับ สัดส่วนการแตกตัวเป็นไอออนที่เป็นฟังก์ชันของอุณหภูมิและค่า κ เราพบว่าการแจกแจงความเร็วของอิเล็กตรอนสามารถมีผลกระทบต่อประจุเฉลี่ยที่จุดสมดุลได้ โดยที่ประจุเฉลี่ยจะสูงขึ้นเมื่อค่า κ ต่ำลง (จำนวนอิเล็กตรอนพลังงานสูงเพิ่มขึ้น) และที่อุณหภูมิต่ำลงการแจกแจงความเร็วแบบแคปปาจะมีอิทธิพลมากสำหรับทุกธาตุ นอกจากนี้ สำหรับช่วงอุณหภูมิที่พบในบริเวณชั้นบรรยากาศโคโรนา ของดวงอาทิตย์ (ประมาณ 10^6 ถึง 10^7 เคลวิน) พบว่าการเปลี่ยนแปลงค่า κ มีผลกระทบพอสมควรต่อประจุเฉลี่ยที่จุดสมดุล ของธาตุ ไนโตรเจน ออกซิเจน นีออน อาร์กอน และ แคลเซียม

ภาควิชา ฟิสิกส์	ลายมือชื่อนิสิต………………………………………...
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ปีการศึกษา 2544	ลายมือชื่ออาจารย์ที่ปรึกษา………………………………

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KEY WORD: PLASMA/ KAPPA DISTRIBUTION/ EQUILIBRIUM CHARGE - STATES/ IONIZATION FRACTION

SUWICHA WANNAWICHIAN: CALCULATION OF MEAN CHARGES OF SLOW IONS IN A PLASMA WITH A KAPPA DISTRIBUTION FOR THE ELECTRON VELOCITY. THESIS ADVISOR: ASSOC.PROF. DAVID RUFFOLO, Ph.D., 70 pp. ISBN 974-03-0590-3.

The mean equilibrium charges of ions are important as diagnostics of high temperature plasmas and in understanding the charge state abundance of solar energetic particles. The equilibrium charge states are derived from a balance of ionization and recombination processes. For slow ions, only the collisions with surrounding electrons are important; therefore, the electron velocity distribution is important for our calculation. According to space observations, the enhanced number of high-energy electrons is well modeled by a kappa distribution, a distribution function with a parameter, κ. We consider the formation of equilibrium charge states of N, O, Ne, Mg, S, Si, Ar, Ca, Fe, and Ni as well as the ionization fractions as a function of temperature and the κ value. We find that the electron velocity distributions affect the mean equilibrium charges, which can be higher at lower κ values (for a greater number of high-energy electrons). At lower temperature, the kappa distribution has a strong influence on the ionic charge states of all elements. In addition, in the range of coronal temperatures ($\sim 10^6$ - 10^7K), our results show a significant effect of different κ values on the mean equilibrium charges of N, O, Ne, Ar, and Ca.

Department of Physics	Student's signature……………..…………
Field of study: Physics	
Academic year 2001	Advisor's signature……………………….

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In the beginning of this thesis work, I put much effort into learning about the calculation of mean charges by prior methods, and later I worked on our new method. There are my thesis supervisor, Assoc. Prof. Dr. David Ruffolo, and Dr. Julia Kartavykh who stand beside me. No problem could go though our hands as long as we have not tried to solve it. I want to give my sincere thank to them.

In the meantime, there are many people in the Space and Energetic Particles Group who gave me a great deal of help. It seems that there is so much kindness from people around me. To announce their names would require too much space, and would risk leaving out some names unintentionally. Finally, I would like to gratefully thank my parents, the first who taught me in life.

Table of Contents

Page

List of Figures

List of Tables

Chapter 1
Introduction

1.1 Introduction

Solar physics is the one of many fields in astrophysics, concerning the amazing variety of physical phenomena best observed at the Sun. These include the huge explosions of solar flares and coronal mass ejections, known collectively as solar events. At this time solar events are divided into two classes, “impulsive” and “gradual” events, and the resulting solar energetic particle populations can be classified according to their origin and final acceleration sites (Ruffolo, 2001). Many direct measurements, e.g., by detectors on spacecraft and neutron monitors, are used as diagnostics of a solar event.

One type of observed data concerns ionic charge states of the various elements that are present in the Sun as well as in the solar energetic particles (SEP), e.g., Si^{+9} and Fe^{+11}. The charge state abundances serve as diagnostics of the source temperature of solar particles. In that sense, the observed mean ionic charge of solar particles (SEP) indicates their site of origin or initial acceleration. Therefore, the calculation of the mean equilibrium charges of ions of different elements is important in understanding the particle ejection from high temperature plasmas and the charge state abundances of solar energetic particles.

Ionic charge state distributions arise from charge changing processes, which take place when ions collide with other particles in the medium. In this case, the medium is a plasma, which contains ions (protons, alpha particles, and small amounts of ions of all other elements) and electrons. Here we consider only collisions between ions and plasma electrons, whereas we neglect the collisions between ions and other plasma ions, such as protons or alpha particles (He^{+2}). The reason is that the ionization reaction cannot take place if the collision energy is less than the ionization threshold energy. Therefore, because of their higher mass compared with electrons, plasma protons, alpha particles, etc. are too slow to collide with ions and then cause ionization reactions. Ionization reactions include direct ionization and excitation-autoionization (Arnaud and Rothenflug, 1985; Arnaud and Raymond, 1992; Sampson and Golden, 1981). In addition, radiative recombination (Shull and Van Steenberg, 1982; Arnaud and Raymond, 1992) and dielectronic recombination (Mazzotta et al., 1998) reactions are considered. The equilibrium charge distributions of ions are considered in this thesis. In this case ions are taken to be slow, or essentially at rest with respect to the typical electron speed, which is often the case in their source plasma because they are much heavier in comparison with electrons. Therefore, the time-dependent rates depend on the characteristics of the electron velocity distribution.

In the solar corona, the electron distributions are typically assumed to be Maxwellian (Dzifčáková, 1992):

$$f_{max}(E) = \left(\frac{m}{2\pi k_b T}\right)^{3/2} e^{-E/k_b T}, \tag{1.1}$$

where m is the electron mass, k_b is Boltzmann's constant, and T is the temperature characterizing the mean particle energy $< E >= 3k_bT/2$.

However, many observations of the solar wind and other space plasmas show that the number of electrons with a high energy is larger than that estimated by a Maxwellian distribution (Owocki and Scudder, 1983; Maksimovic et al, 1997). Thus here we employ the velocity distribution of the electrons as a kappa distribution (Olbert et al., 1967; Olbert, 1969). The kappa distribution is expressed as (Owocki and Scudder, 1983):

$$f_\kappa(E) = \left(\frac{m}{2\pi k_b T}\right)^{3/2} A_\kappa \Big/ \left(1 + \frac{E}{(\kappa - 3/2)k_b T}\right)^{\kappa+1}, \tag{1.2}$$

where T is temperature, $\Gamma(\kappa+1) \equiv \kappa!$, and $A_\kappa \equiv \Gamma(\kappa+1)/[(\kappa-3/2)^{3/2}\Gamma(\kappa-1/2)]$. The kappa distribution can be closely represented by a Maxwellian distribution at the low-energy "core," but we can vary the power-law parameter κ of the high-energy "tail." This distribution formula is a convenient parameterization that is used to study the effect of an enhanced high-energy tail of the electron velocity distribution.

1.2 The Objectives of This Thesis

Analytical and numerical calculations are used to calculate the influence of the kappa parameter and plasma temperature on the equilibrium charge distribution of N, O, Ne, Mg, Si, S, Ar, Ca, Fe, and Ni. The reason we choose those elements for our calculation is there are the ionic charge states that are best measured in space observations. The results could later be compared with measured data for solar energetic particles such as N, O, Si, and Fe etc., and with some charge state ratios from previous research (Luhn and Hovestadt, 1985; Mazzotta et al., 1998).

We also obtain the ionization fractions, i.e., the relative abundances of charge states of each element as a function of κ and plasma temperature, in order to provide useful information for various applications. The observed ionization fraction, or the presence of a given ion, serves as a diagnostic of the source plasma. Measurements of charge states are widely used in solar physics and astrophysics. An example is the observation of optically forbidden line emission from specific Fe ions during a solar eclipse, or extreme ultraviolet (EUV) lines observed by spacecraft. Another example is the growing field of X-ray spectroscopy to indicate the ionic charge states in laboratory fusion experiments or in hot plasma throughout the universe.

The following chapters in this thesis are organized as follows: The basic knowledge and historical evidence are given in Chapter 2. The methodology of both analytical and numerical calculations are described in Chapter 3. The results of our calculations are presented in Chapter 4. The discussion and conclusions are given in Chapter 5. In the Appendices, we present tables of calculated ionization fractions and mean charges, our newly written computer programs in the C language, Verner's FORTRAN program, and a sample *Mathematica* calculation.

Chapter 2
Theoretical and Observational Background

Space observations of ionic charge states provide evidence about the physical properties of their source regions. In this thesis, we calculate the ionization fractions and equilibrium mean charges of heavy ions as a function of temperature. In the mean time, we study the influence of the electron velocity distribution on the calculated results. Assuming the condition of thermal equilibrium, most astrophysicists employ a Maxwellian distribution function for the electron velocity distribution. However, there are many lines of evidence showing that in actual space plasmas, the electron velocity distribution has a suprathermal tail, i.e., an enhancement of particles at high energy. Several distribution functions have been suggested to find that which is the most suitable for the observed data.

The kappa distribution, a characterized distribution function, is used in our work. It is helpful for explaining different observed data, while the enhanced tail can be changed by the parameter, κ. In our work, this electron velocity distribution is used in the calculation of ionization and recombination rate coefficients. Then, the ionization balance and mean equilibrium charge are calculated.

2.1 Maxwell Distribution

The Maxwell (also called "Maxwellian") distribution function was first obtained by James Clerk Maxwell in 1859 (Tipler, 1978). From basic physics, in the condition of equilibrium, the electron velocity distribution can be approximated by a Maxwell distribution. There is much previous research in astrophysics which employs this distribution function for the electron velocity distribution (e.g., ionization equilibrium calculations by Arnaud and Rothenflug, 1985; Luhn and Hovestadt, 1987; Arnaud and Raymond, 1992; Mazzotta et al., 1998).

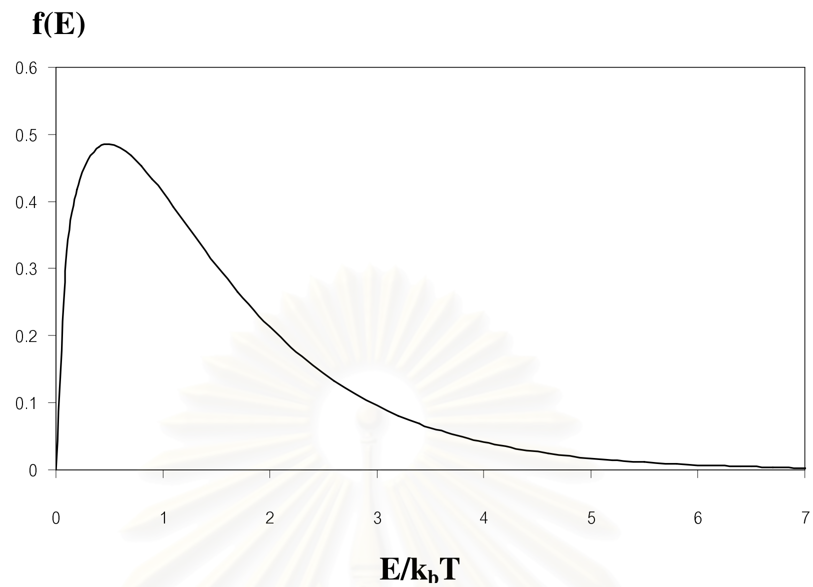

Figure 2.1: An example of the Maxwell distribution function $f(E)$ for the kinetic energy E (in units of k_bT) corresponding to the relative velocity v ($k_bT = 861.71$ eV, $m = 9.1 \times 10^{-31}$ kg).

The Maxwell distribution function is given by

$$f(E) = \frac{2\sqrt{E}}{\sqrt{\pi}(k_bT)^{3/2}} e^{-E/k_bT}, \tag{2.1}$$

where m is the electron mass, k_b is Boltzmann's constant, and T is the temperature characterizing the mean particle energy $\langle E \rangle = 3k_bT/2$. In this thesis, the thermal electron velocity v is that relative to the ions, considered to be at rest because of their greater masses in comparison with those of electrons.

2.2 Kappa Distribution

Astrophysicists have found that observed electron velocity distributions in space have more high energy electrons in comparison with a Maxwellian distribution (Montgomery et al., 1968). It was suggested (Owocki and Scudder, 1983) that non-Maxwellian distributions with an enhanced high energy tail occur as an effect of high gradients in particle concentration or temperature. In previous work (Feldman et al., 1975), the solar wind electron velocity distribution has been expressed as the sum of two distribution functions: a Maxwellian distribution for a low energy 'core' and a power law distribution for a high energy 'tail.'

The kappa distribution function has served primarily as an empirical fit to the observed particle distribution (Collier, 1999). This distribution function characterizes enhanced, power-law tails of particle distributions by a parameter κ (Owocki and Scudder, 1983):

$$f_\kappa(E) = \frac{2\sqrt{E}}{\sqrt{\pi}(k_bT)^{3/2}} A_\kappa \Big/ \left(1 + \frac{E}{(\kappa - 3/2)k_bT}\right)^{\kappa+1}, \tag{2.2}$$

where T is temperature, $\Gamma(\kappa+1) \equiv \kappa!$, and $A_\kappa \equiv \Gamma(\kappa+1)/[(\kappa-3/2)^{3/2}\Gamma(\kappa-1/2)]$. The kappa distribution closely approximates the Maxwell distribution in the low-energy "core" but varies as a power law in its enhanced high energy "tail." Therefore, we employ a kappa distribution to be the more suitable distribution function for modeling the actual electron velocity distribution.

As shown in Figure 2.2, the kappa distribution tends toward a Maxwellian when κ is large, while the enhanced tail is strong at small κ. Considering the peak energy, E_p, for a kappa distribution, we obtain

$$\frac{E_p}{k_bT} = \frac{\kappa - 3/2}{\kappa}. \tag{2.3}$$

According to the above equation, it is seen that κ must be greater than 3/2.

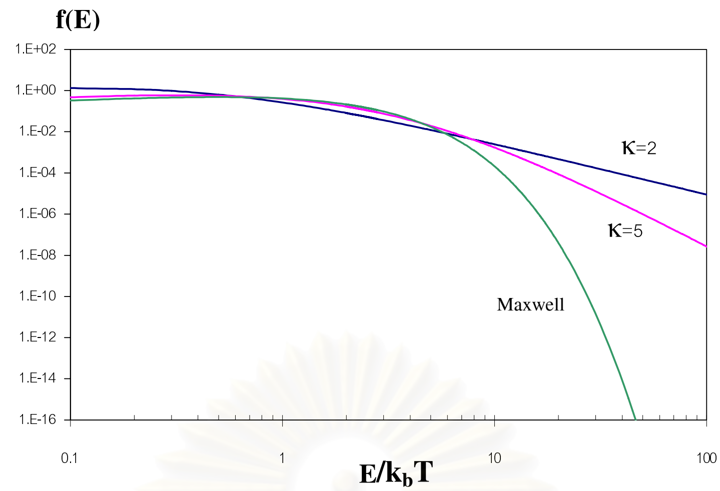

Figure 2.2: Kappa electron distribution function $f_\kappa(E)$ vs. the electron kinetic energy, E, (in units of k_bT) for kappa distributions with $\kappa = 2$ and 5, and a Maxwell distribution ($\kappa \to \infty$). The temperature T is assumed to be equal for all three distributions (k_bT=861.71 eV, m= 9.1×10^{-34} kg).

2.3 Observational Evidence for Kappa Distributions

Direct observations of electron velocity distributions in the solar wind have shown that there are many more particles with high energy than for a Maxwell distribution (Feldman et al., 1975; Owocki and Scudder, 1983; Collier, 1999).

Recently, kappa distributions have been confirmed to be suitable for characterizing the enhanced high-energy tails in observed electron velocity distributions.

As shown in Figure 2.3 (Pierrard et al., 1999), the electron velocity distributions measured by the electrostatic analyzer of the 3DP instrument on the Wind spacecraft are divided into two types. The first type (Figure 2.3a) is the typical slow speed solar wind (v = 320 km/s and n_e = 10 cm^{-3}), and the second distribution (Figure 2.3b) is the typical high speed solar wind (v = 650 km/s and n_e = 4 cm^{-3}).

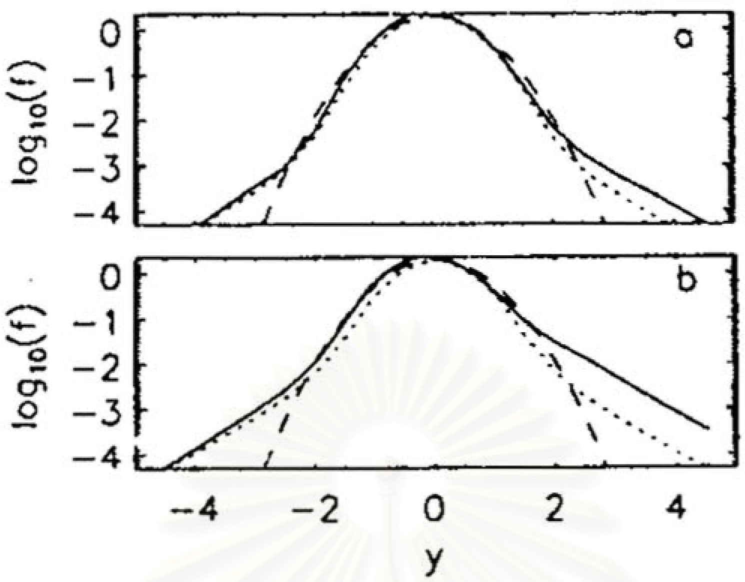

Figure 2.3: Typical electron velocity distribution functions measured by the electrostatic analyzer 3DP on Wind of the (a) low speed solar wind, measured on January 24, 1997, at 1834 UT, and (b) high speed solar wind, measured on January 28, 1997 at 1336 UT. The cross sections of the phase space density are plotted as a function of the normalized velocity parallel $y_{||}$ (solid lines) and perpendicular $y_{\perp}$ to the magnetic field direction (Pierrard et al., 1999). Here y refers to $\Delta v/\sqrt{2k_bT/m}$.

For low speed solar wind, the electron distribution is somewhat anisotropic and exhibits noticeable power-law tails, while for higher speed solar wind, there is an even stronger distinction between the Maxwellian thermal 'core' and a highly anisotropic, hot 'halo' population whose velocity distribution decreases as a power law with the velocity. Fitting with a kappa distribution, Pierrard et al. (1999) find $\kappa \simeq 3.1$ and $\kappa \simeq 2$ for the slow and high speed solar wind, respectively. These extremely low κ values indicate strongly non-Maxwellian distributions.

Furthermore, Maksimovic et al. (1997) have fitted a kappa function to 16,000 electron velocity distributions measured in the solar wind by the electron plasma instrument on board the Ulysses spacecraft. Statistically, the electron distributions are observed to have important high velocity tails in the fast solar wind but are slightly closer to a Maxwellian distribution (with a somewhat higher

Table 2.1: Summary of the statistical analysis of slow solar wind ($V < 550$ km/s) and fast solar wind ($V > 550$ km/s) (from Maksimovic et al., 1997).

	$V > 550$ km/s	$V < 550$ km/s
number of events	3,494	12,393
$\langle \kappa \rangle$	1.90 ± 0.08	2.71 ± 0.56
$\langle \sigma_{fit} \rangle$	0.16	0.11

κ) in the slow wind. The reported data are shown in Table 2.1.

In order to quantify the result, Maksimovic et al. (1997) have split the results into two sets: events (data samples) with a low speed solar wind ($V < 550$ km/s) and high speed solar wind ($V > 550$ km/s). For each of the two populations the mean value $\langle \kappa \rangle$ of the fitted parameter κ are calculated, along with the variances of the fits $\langle \sigma_{fit} \rangle$ (Table 2.1).

2.4 Ionization and Recombination

In this thesis we consider only the collisions between the ions of interest and plasma electrons, whereas the collisions between ions and plasma protons or alpha particles (He^{2+}) are neglected for reasons explained in Chapter 1. We consider two types of collisional processes, ionization and recombination.

Ionization is a process that increases the charge state of an ion. Two types of ionization processes are considered: direct ionization and excitation-autoionization.

A) Direct ionization is a process that can take place after the collision between a free electron and ion. Then an electron in the ion is excited to become another free electron.

B) Excitation-autoionization takes place by a process similar to the direct ionization process. However, it is an electron in an inner shell that is excited. With its high binding energy, the inner shell electron just releases the excitation energy and comes back to the ground state. Fortunately, it is an outer shell electron that receives the energy and becomes another free electron.

Recombination is a type of process that decreases the charge state of an ion. We also consider two recombination processes, radiative recombination and dielectronic recombination.

C) Radiative recombination is the process where a free electron is bound to the ion after the collision. The electron emits its excess energy in the form of electromagnetic radiation.

D) Dielectronic recombination is more complicated than the previous process. After the collision, the initially free electron becomes bound and emits its energy. Then the energy is taken up by another bound electron. After the bound electron receives the energy, it is in an excited state for a moment and comes back to the ground state by emitting energy through electromagnetic radiation. Finally the ion has gained another electron.

2.5 Rate Coefficients

Electrons in a hot plasma can collide with the slow ions, considered as the collision targets. The probability of collision is explained by the cross section (cm^2). If n_e is the electron density (cm^{-3}) and v is the electron velocity ($cm\ s^{-1}$), the rate of collisions is equal to the product of the cross section with n_e and v:

$$\text{rate of collisions per ion} = n_e \times v \times [\text{cross section}] \qquad s^{-1}. \tag{2.4}$$

According to the rate calculation, a rate coefficient can be defined by

$$\text{rate coefficient} = v \times [\text{cross section}] \qquad \text{cm}^3\ \text{s}^{-1}, \tag{2.5}$$

so

$$\frac{\text{rate of collisions}}{\text{unit volume}} = n_i \times n_e \times [\text{rate coefficient}] \qquad \text{cm}^{-3}\ \text{s}^{-1}. \tag{2.6}$$

In the calculations, we used the rate coefficients of ionization, S_q, and recombination, α_q, in the rate equation involving the density of ions at a given charge state, n_q, where q is the charge state. The calculation will be explained further in the next chapter.

2.6 Ionization Fraction and Equilibrium Mean Charge

The ionization fraction is the ratio between the density of a charge state, n_q, and the sum of the density for every charge state of that element, $\sum_i n_i$. In presenting the results, it is more convenient to present the ionization fractions:

$$-\log_{10}\left(\frac{n_q}{\sum_i n_i}\right). \tag{2.7}$$

The equilibrium ionization fractions for N, O, Ne, Mg, Si, S, Ar, Ca, Fe, and Ni are presented in Appendices. The ionization balance is important for understanding how the abundance of a charge state is related to the source temperature.

The equilibrium mean charge is the average charge that is observed at a certain temperature. In our work, we calculate the equilibrium mean charge by using the ionization fraction:

$$\langle Q \rangle = \frac{\sum_q n_q q}{\sum_q n_q}. \tag{2.8}$$

This quantity is useful because some observational data (e.g., for solar energetic particles) are in terms of the mean ionic charge of a given element, e.g., $\langle Q \rangle_{\mathrm{O}}$, $\langle Q \rangle_{\mathrm{Si}}$, etc.

Chapter 3
Methodology

3.1 Calculation Procedure

The charge state distribution of ions is established by two processes, ionization and recombination. The rate equations are taken into consideration, where the contribution of a process to the rate of change of the charge density of charge state q, dn_q/dt, depends on the product of the densities of collision partners (e.g., n_q and n_e) and the ionization (S_q) or recombination (α_q) rate coefficient. The units of dn_q/dt are $\mathrm{cm}^{-3}\mathrm{s}^{-1}$, which is consistent with the product of the units of n_q and n_e (both cm^{-3}) and the rate coefficient ($\mathrm{cm}^3\mathrm{s}^{-1}$). However, the rate equations are not difficult to solve. The difficulty is to calculate the rate coefficients, because there are many cross sections used to calculate rate coefficients. Some cross sections are obtained from several papers in the literature, but others are already presented in terms of rate coefficients which are calculated with a Maxwellian electron velocity distribution. We have to convert such reported rate coefficients into cross sections and then calculate the rate coefficients for a kappa distribution.

Therefore, most of the work of this thesis has been on the source literature and techniques described in this chapter.

3.1.1 Rate Equations

To calculate the mean equilibrium charge vs. temperature for a given element, we consider this system of equations (Luhn and Hovestadt, 1987):

$$\begin{aligned}
\frac{dn_0}{dt} &= n_e(-n_0S_0 + n_1\alpha_1) \\
\frac{dn_q}{dt} &= n_e(n_{q-1}S_{q-1} - n_q(S_q + \alpha_q) + n_{q+1}\alpha_{q+1}) \qquad \text{for } q = 1, 2, ..., Z-1 \\
\frac{dn_Z}{dt} &= n_e(n_{Z-1}S_{Z-1} - n_Z\alpha_Z), \qquad (3.1)
\end{aligned}$$

where n_q is the density (cm^{-3}) of charge state q, n_e is the density of electrons, and Z is the atomic number. In this work, we consider S_q, the ionization rate coefficient from charge q to $q+1$, and α_q, the recombination rate coefficient from charge q to $q-1$. The rate equations present the rate of change of n_q, the density of charge state q, as a function of n_q, n_e, and the rate coefficients, S_q and α_q. The charge state density, n_q, is increased by ionization processes from charge state $q-1$ and recombination precesses from charge state $q+1$. On the other hand, n_q is decreased by ionization processes from charge state, q and recombination processes from charge state, q. For the equilibrium case, the rate equation is reduced to (Luhn and Hovestadt, 1987)

$$\frac{dn_q}{dt} = 0 \qquad \text{and} \qquad n_qS_q = n_{q+1}\alpha_{q+1} \qquad \text{for } q = 1, 2, ..., Z-1. \qquad (3.2)$$

The rate coefficients S_q and α_q are obtained by multiplying the corresponding cross section σ_i or σ_r for direct ionization, excitation-autoionization (Arnaud and Rothenflug, 1985; Arnaud and Raymond, 1992; Sampson and Golden, 1981), radiative recombination (Shull and Van Steenberg, 1982; Arnuad and Raymond, 1992), or dielectronic recombination (Mazzotta et al., 1998) with the relative velocity v between the collision partners and averaging over the relative velocity distribution, $f(v)$:

$$S = \int v\sigma_i(v) f(v) dv,$$

$$\alpha = \int v\sigma_r(v) f(v) dv. \tag{3.3}$$

Using the relation between kinetic energy E and velocity v as $E = mv^2/2$, we obtain

$$S = \frac{8\pi}{m^2} \int E\sigma_i(E) f(E) dE,$$

$$\alpha = \frac{8\pi}{m^2} \int E\sigma_r(E) f(E) dE. \tag{3.4}$$

We consider the formation of the equilibrium charge distribution of thermal or slow ions. For the reasons explained in Chapter 1, ions are taken to be slow, or essentially at rest with respect to the typical electron speed. In this case the rates depend only on the characteristics of the cross section and the electron velocity distribution. Furthermore, we consider the electron velocity distribution $f(v)$ to be kappa distribution.

Finally we can calculate the mean equilibrium charges by the following equation:

$$\langle Q \rangle = \frac{\sum_q n_q q}{\sum_q n_q}. \tag{3.5}$$

3.2 Cross Sections

The probability for a particular reaction can be expressed in terms of its reaction cross section, σ. The cross section for a reaction is the number of reactions per unit time per target particle divided by the incident flux. Because the incident flux is the number of incident particles per unit time per unit area, σ has the dimensions of area (Blatt, 1992).

There are many cross section formulas that we use for various processes. There are several papers in the literature in which cross section or rate coefficient formulas are fitted to experimental data. For ionization processes, each cross section formula is a function of u, the ratio between the electron kinetic energy E and ionization threshold energy (I_j for direct ionization and I_{EA} for excitation-autoionization), $u = E/I$. Because the ionization processes cannot take place if the electron kinetic energy is less than the ionization threshold energy, it is a condition that E must be greater than I_{EA}, or $u > 1$.

3.2.1 Direct Ionization

For the direct ionization (DI), the cross section formula was taken from Arnaud and Rothenflug (1985; this form was also used by Arnaud and Raymond, 1992; Mazzotta et al., 1998; etc.):

$$\sigma_{DI}(u) = \sum_j \frac{1}{uI_j^2}\left\{A_j\left(1-\frac{1}{u}\right) + B_j\left(1-\frac{1}{u}\right)^2 + C_j\ln(u) + D_j\frac{\ln(u)}{u}\right\}\ \mathrm{cm}^2, \quad (3.6)$$

where $u = E/I_j$, E is the energy of the incident electron, and I_j is the ionization potential for the level j. The units of k_bT and I_j are eV, while A_j, B_j, C_j, and D_j are constants in the units of 10^{-14} $\mathrm{cm}^2\mathrm{eV}^2$. In other words, the numbers provided in tables in the literature need to be multiplied by 10^{-14}. Most constants are taken from Arnaud and Rothenflug (1985). Only for Fe are the constants taken from Arnaud and Raymond (1992).

3.2.2 Excitation-Autoionization

- **For all Fe ions**, the cross sections are calculated by following formula (Arnaud and Raymond, 1992):

$$\sigma_{EA}(u) = \frac{1}{uI_{EA}}\left\{A + B\left(1 - \frac{1}{u}\right) + C\left(1 - \frac{1}{u^2}\right) + D\left(1 - \frac{1}{u^3}\right) + F\ln(u)\right\}\ \mathrm{cm}^2, \quad (3.7)$$

where $u = E/I_{EA}$, E is the incident electron energy (in eV), I_{EA} is the excitation-autoionization threshold (in eV) and A, B, C, D, and F are constants (in the units of 10^{-16} cm^{2}eV^2) taken from a tabile (Arnaud and Raymond, 1992).

- **For Ca^{+0} and Ca^{+1}**, cross sections are from Arnaud and Rothenflug (1985):

$$\sigma_{EA}(u) = \frac{a}{u}\Big[1 + b\ln(u)\Big]\ \mathrm{cm}^2, \quad (3.8)$$

where $u = E/I_{EA}$.

For Ca^{+0}: $a = 6.6 \times 10^{-7}$ cm^2; $b = 1.12$; $I_{EA} = 25$ eV.

For Ca^{+1}: $a = 9.8 \times 10^{-7}$ cm^2; $b = 1.12$; $I_{EA} = 29$ eV.

- **For Other Ions**, an excitation-autoionization cross section (σ_{EA}) is used for various sequences (in all other cases, σ_{EA} is negligible in comparison with σ_{DI}). A "sequence" is defined by the number of remaining electrons, e.g., the lithium sequence refers to ions with three remaining electrons.

A) For the Lithium (Li) Sequence (e.g., Si^{+11}, Mg^{+9}, and Ne^{+7}) the cross section formula is taken from Sampson and Golden (1981), so that the full ionization cross section for Li-like ions is

$$\begin{aligned}\sigma_{ion}(u) &= \frac{\pi a_0^2}{I_{2s}}\left[\frac{4}{Z_{eff}^2(2s)}Q_R^H(2s,u) + \frac{2}{Z_{eff}^2(1s)u}\left(\beta H(u-\xi_2)\left[Z^2\Omega_H(1\to 2)\right]_{eff}\right.\right.\\ &+ \left.\left.\beta\sum_{n=3}^{\infty} H(u-\xi_n)Z^2\Omega_H(1\to n) + \frac{u}{\xi_{1s}}H(u-\xi_{1s})Q_R^H(1s,u/\xi_{1s})\right)\right]\ \text{cm}^2.\end{aligned} \tag{3.9}$$

The terms with $Q_R^H(nl,u)$, the reduced cross section, describe the contribution of direct ionization and $[Z^2\Omega_H(1\to 2)]_{eff}$, the effective scaled collision strength, is the most important term which contributes to the excitation-autoionization. Neglecting the $\Omega_H(1\to n)$ term, the excitation-autoionization cross section for the lithium sequence is

$$\sigma_{EA}(u) = \frac{2\pi a_0^2}{I_{2s}Z_{eff}^2(1s)u}\beta H(u-\xi_2)\left[Z^2\Omega_H(1\to 2)\right]_{eff}\ \text{cm}^2, \tag{3.10}$$

where

$$\begin{aligned}\left[Z^2\Omega_H(1\to 2)\right]_{eff} &= 2.220\ln(u) + 0.669\left(1-\frac{1}{u}\right) + \frac{0.488}{u} + \frac{1.201}{u^2}\ \text{eV},\\ H(x) &= \begin{cases} 0 & \text{if } x<0;\\ 1 & \text{if } x>0,\end{cases}\\ \xi_2 &= I_{EA}/I_{2s},\\ I_{2s} &= 13.6/4(Z-1.679)^2\ \text{eV},\\ I_{EA} &= 13.6\left[(Z-0.835)^2 - \frac{1}{4}(Z-1.620)^2\right]\ \text{eV},\\ Z_{eff}(1s) &= Z-0.43, \qquad Z \text{ is the nuclear charge},\\ u &= \frac{E}{I_{2s}},\end{aligned}$$

$$\beta = \frac{1}{1 + 2 \times 10^{-4} Z^3}, \text{ and}$$
$$a_0 = \text{Bohr radius} = 5.292 \times 10^{-9} \text{ cm.}$$

For $H(x)$, x is the difference between the impact electron energy and the threshold energy for the transition.

B) For the Sodium (Na) Sequence, the observed excitation-autoioinizaiton cross section is (Arnaud and Rothenflug, 1985):

B.1 For Z $\leq$ 16,

$$\sigma_{EA}(u) = \frac{a}{u}\left(1 - \frac{1}{u}\right) \text{ cm}^2, \tag{3.11}$$

where u=E/I_{EA},

I_{EA}=$26(Z-10)$ eV and

$a = 2.8 \times 10^{-17}(Z-11)^{-0.7}$ cm^2.

B.2 For 18 $\leq$ Z $\leq$ 28,

$$\sigma_{EA}(u) = \frac{a}{u}\left(1 - \frac{1}{u^3}\right) \text{ cm}^2, \tag{3.12}$$

where u=E/I_{EA},

I_{EA}=$11(Z-10)^{1.5}$ eV and

$a = 1.3 \times 10^{-14}(Z-10)^{-3.73}$ cm^2.

C) For Sequences from Magnesium (Mg) to Argon (Ar) (Arnaud and Rothenflug, 1985). The excitation-autoionization cross section can be calculated as follows:

$$\sigma_{EA}(u) = \frac{a}{u}\left(1 - \frac{1}{u^3}\right) \text{ cm}^2, \tag{3.13}$$

where $u = E/I_{EA}$,

$$a \times I_{EA} = 4 \times 10^{-13} Z^{-2} \ \text{cm}^2 \ \text{eV},$$

Magnesium sequence	I_{EA}	$= 10.3(Z-10)^{1.52}$ eV,
Aluminum sequence	I_{EA}	$= 18.0(Z-11)^{1.33}$ eV,
Silicon sequence	I_{EA}	$= 18.4(Z-12)^{1.36}$ eV,
Phosphorus sequence	I_{EA}	$= 23.7(Z-13)^{1.29}$ eV, and
Sulfur sequence	I_{EA}	$= 40.1(Z-14)^{1.10}$ eV.

3.2.3 Radiative Recombination

For all elements, the radiative recombination cross section is related to the rate coefficient (for a Maxwellian distribution) from Shull and Van Steenberg (1982). Those authors specify the rate coefficient formula:

$$\alpha_{RR}(T) = A_{rad}(T/10^4 \ \text{K})^{-\eta} \ \text{cm}^{\ 3}\text{s}^{-1}, \tag{3.14}$$

where the coefficients A_{rad} and η are given in a table. Now following Luhn and Hovestadt (1987), we note that if

$$\sigma_{RR}(E) = C_{rad} E^{-a} \ \text{cm}^2, \tag{3.15}$$

then

$$\alpha_{RR}(T) = \frac{4}{\sqrt{2\pi m_e k_b T}} \frac{C_{rad}}{(k_b T)^{a-1}} \Gamma(2-a) \ \text{cm}^{\ 3}\text{s}^{-1}. \tag{3.16}$$

The quantities C_{rad} and a are chosen so that Equation (3.16) matches Equation (3.14). From this we derive

$$\sigma_{RR}(E) = \frac{1.495 \times 10^{-8}}{\Gamma(3/2-\eta)} \frac{[k_b]^{\eta}}{[10^4 \text{ K}]^{-\eta}} A_{rad} E^{-(\eta+1/2)} \text{ cm}^2 \qquad (3.17)$$

as the cross section consistent with the rate coefficient presented by Shull and Van Steenberg (1982).

3.2.4 Dielectronic Recombination

The cross section formulas for all elements are the same. According to Mazzotta et al. (1998), the dielectronic recombination rate coefficient formula (for a Maxwellian distribution) is

$$\alpha_{DR}(E) = \frac{1}{(k_b T)^{3/2}} \sum_{j=1}^{4} c_j \exp\left(-\frac{E_j}{k_b T}\right) \text{ cm}^3\text{s}^{-1}, \qquad (3.18)$$

where k_bT and E_j are given in eV and c_j in $\text{cm}^3\text{eV}^{3/2}\text{s}^{-1}$. Each term in the sum corresponds to a different dielectronic transition. The coefficients c_j and E_j are given in a table from Mazzotta et al. (1998).

Using the same technique as for radiative recombination, we utilize the relation between σ_{RR} and α_{RR} for a Maxwellian distribution according to Luhn and Hovestadt (1987), where

$$\begin{aligned} \sigma_{DR}(E) &= \sum_j C_{di,j} \delta(E-E_j) \text{ cm}^2, \text{ and} \\ \alpha_{DR}(E) &= \frac{4}{\sqrt{2\pi m_e k_b T}} \sum_j \left[C_{di,j} \frac{E_j}{k_b T} \exp\left(-\frac{E_j}{k_b T}\right)\right] \text{ cm}^3\text{s}^{-1}. \qquad (3.19) \end{aligned}$$

The quantity $C_{di,j}$ is a constant which gives the strength of the contribution of level j with energy E_j. Comparing Equations (3.18) and (3.19), we derive the corresponding cross section:

$$\sigma_{DR}(E) = 1.495 \times 10^{-8} \sum_{j=1}^{4} c_j \frac{\delta(E - E_j)}{E_j} \text{ cm}^2. \tag{3.20}$$

3.3 Analytical Calculations

In this section, we only present the results, the rate coefficients, of the analytical calculations, while the quantities are defined as in §3.2. Most of the rate coefficients for kappa distributions can be calculated analytically. In this case Equation (3.3) becomes

$$\begin{aligned} S(T) &= \frac{6.69 \times 10^7}{(k_b T)^{3/2}} \int_0^\infty \frac{E\,\sigma_i(E)}{\left[1 + \frac{E}{(\kappa - 3/2)k_b T}\right]^{\kappa+1}} dE \\ \alpha(T) &= \frac{6.69 \times 10^7}{(k_b T)^{3/2}} \int_0^\infty \frac{E\,\sigma_r(E)}{\left[1 + \frac{E}{(\kappa - 3/2)k_b T}\right]^{\kappa+1}} dE \end{aligned} \tag{3.21}$$

In our calculation of rate coefficients we use the partial fractions expansions:

$$\begin{aligned} \frac{1}{u(1+yu)^{\kappa+1}} &= \frac{1}{u} - \sum_{n=1}^{\kappa+1} \frac{y}{(1+yu)^n} \\ \frac{1}{u^2(1+yu)^{\kappa+1}} &= \frac{1}{u^2} - \frac{(\kappa+1)y}{u} + \sum_{n=1}^{\kappa+1} \frac{(\kappa - n + 2)y^2}{(1+yu)^n}, \end{aligned} \tag{3.22}$$

where u is E/I_{EA} and y is $I_{EA}/[(\kappa - 3/2)k_b T]$. In each case, the calculations by hand have been checked by using the *Mathematica* program (version 4.0, Wolfram Research, Inc., 1999) and also by our own numerical integration (see §3.4) and

Appendix D. Furthermore, we have studied some calculation techniques from previous works, e.g., Dzifčáková (1992). Her technique, like ours, is to find the cross sections by considering the rate coefficients given in the literature (see §3.2.3 and §3.2.4). All cross sections we have considered are calculated directly, while Dzifčáková (1992) had to approximate a formula of the dielectronic recombination rate coefficeint to be less complicated for specification of the cross section.

3.3.1 Direct Ionization

Calculated by Equation (3.6), the direct ionization rate becomes a function of temperature T:

$$\begin{aligned} S_{di}(T) &= \frac{6.69\times 10^{7}}{(K_bT)^{3/2}} A_\kappa \sum_j \left\{ A_j \left[\frac{(1+y)^{-\kappa}}{y\kappa} + \sum_{n=2}^{\kappa+1} \frac{1/(n-1)}{(1+y)^{n-1}} \right] \right. \\ &+ B_j \left[\frac{(1+y)^{-\kappa}}{y\kappa} + (2+\kappa y + y)\ln\frac{y}{y+1} + \sum_{n=2}^{\kappa+1} \frac{\kappa y - ny + 2y + 2}{(n-1)(1+y)^{n-1}} + 1 \right] \\ &+ \frac{C_j}{y\kappa} \left[\ln\left(\frac{1+y}{y}\right) - \sum_{n=2}^{\kappa} \frac{1/(n-1)}{(1+y)^{n-1}} \right] \\ &+ \left. D_j \int_1^\infty \frac{\ln(u)/u}{(1+yu)^{\kappa+1}} du \right\} \ \mathrm{cm^3 s^{-1}}, \end{aligned} \tag{3.23}$$

where $\quad y = I_j/\Big[k_bT(\kappa - 3/2)\Big].$

The last term cannot be calculated analytically (as verified with the *Mathematica* program). Therefore a numerical integration is necessary for this term.

3.3.2 Excitation-Autoionization

\- **For Iron (Fe)**, excitation-autoionization rate calculated by using Equation (3.7) is

$$
\begin{aligned}
S_{EA}(T) \; &= \; c\Bigg\{A\frac{(1+y)^{-\kappa}}{y\kappa} + B\Bigg[\frac{(1+y)^{-\kappa}}{y\kappa} + \ln\left(\frac{y}{y+1}\right) + \sum_{n=2}^{\kappa+1}\frac{1/(n-1)}{(1+y)^{n-1}}\Bigg] \\
&+ \; C\Bigg[\frac{(1+y)^{-\kappa}}{y\kappa} - y\sum_{n=2}^{\kappa+1}\frac{\kappa-n+2}{(n-1)(1+y)^{n-1}} + (\kappa+1)y\ln\left(\frac{y+1}{y}\right) - 1\Bigg] \\
&+ \; D\Bigg[\sum_{n=2}^{\kappa+1}\frac{(\kappa-n+2)(\kappa-n+3)y^2}{2(n-1)(1+y)^{n-1}} - \frac{(\kappa+1)(\kappa+2)}{2}y^2\ln\left(\frac{y+1}{y}\right) \\
&+ \; \frac{(1+y)^{-\kappa}}{y\kappa} + (\kappa+1)y - \frac{1}{2}\Bigg] + \frac{F}{y\kappa}\Bigg[\ln\left(\frac{y+1}{y}\right) - \sum_{n=2}^{\kappa}\frac{1/(n-1)}{(1+y)^{n-1}}\Bigg]\Bigg\} \\
&\qquad\qquad\qquad\qquad\qquad\qquad \text{cm}^3\text{s}^{-1}, \qquad (3.24)
\end{aligned}
$$

where $\quad y = \dfrac{I_{EA}}{(\kappa - 3/2)k_bT} \quad$ and

$$c = \frac{6.69 \times 10^7 A_\kappa}{(k_bT)^{3/2}}.$$

- **For Ca^0 and Ca^{+1}**, the rate coefficient is calculated by using Equation (3.8):

$$
\begin{aligned}
S_{EA}(T) \; &= \; \frac{6.69 \times 10^7}{(k_bT)^{3/2}} A_\kappa I_{EA}^2 a\Bigg\{\frac{(1+B_\kappa)^{-\kappa}}{\kappa B_\kappa} + \frac{b}{\kappa B_\kappa}\Bigg[\ln\left(\frac{1+B_\kappa}{B_\kappa}\right) \\
&- \; \sum_{n=2}^{\kappa}\frac{(1+B_\kappa)^{-(n-1)}}{n-1}\Bigg]\Bigg\} \qquad \text{cm}^3\text{s}^{-1}, \qquad (3.25)
\end{aligned}
$$

where $\quad u = E/I_{EA}$,

for Ca^{+0}: $a = 6.6 \times 10^{-7}$ cm^2; $b = 1.12$; $I_{EA} = 25$ eV and

for Ca^{+1}: $a = 9.8 \times 10^{-7}$ cm^2; $b = 1.12$; $I_{EA} = 29$ eV.

- **For Other Ions**

A) For the Lithium (Li) Sequence, the cross section is from Equation (3.10):

$$
\begin{aligned}
S_{EA}(T) \; = \; & c\Bigg\{\frac{2.220}{\kappa B_\kappa}\left[\frac{\ln \xi_2}{(1+B_\kappa\xi_2)^\kappa} + \ln\left(\frac{B_\kappa\xi_2}{1+B_\kappa\xi_2}\right) - \sum_{n=2}^{\kappa}\frac{1/(n-1)}{(1+B_\kappa\xi_2)^{n-1}}\right] \\
+ \; & 0.669\left[\ln\left(\frac{B_\kappa\xi_2}{1+B_\kappa\xi_2}\right) + \frac{(1+B_\kappa\xi_2)^{-\kappa}}{B_\kappa\kappa} + \sum_{n=2}^{\kappa+1}\frac{1/(n-1)}{(1+B_\kappa\xi_2)^{n-1}}\right] \\
+ \; & 0.488\left[\ln\left(\frac{1+B_\kappa\xi_2}{B_\kappa\xi_2}\right) - \sum_{n=2}^{\kappa+1}\frac{1/(n-1)}{(1+B_\kappa\xi_2)^{n-1}}\right] \\
+ \; & 1.201\left[\frac{1}{\xi_2} - (\kappa+1)B_\kappa \ln\left(\frac{1+B_\kappa\xi_2}{B_\kappa\xi_2}\right) + \sum_{n=2}^{\kappa+1}\frac{(\kappa-n+2)B_\kappa}{(n-1)(1+B_\kappa\xi_2)^{n-1}}\right]\Bigg\} \\
& \mathrm{cm^3 s^{-1}}, \qquad (3.26)
\end{aligned}
$$

where $c = \dfrac{4.20\times 10^8 A_\kappa}{(k_bT)^{3/2}}\dfrac{a_0^2\alpha}{Z_{eff}^2(1s)}I_{2s}$ and

$$B_\kappa = \frac{I_{2s}}{(\kappa-3/2)k_bT}.$$

B) For the Sodium (Na) Sequence, the excitation-autoionization rates can be calculated by using the cross section depending on the atomic mass Z.

B.1 For $Z \leq 16$, from the cross section in Equation (3.11):

$$S_{EA}(T) = \frac{6.69\times 10^7}{(K_bT)^{3/2}}A_\kappa I_{EA}^2 a\left\{\frac{(1+B_\kappa)^{-\kappa}}{\kappa B_\kappa} + \ln\left(\frac{B_\kappa}{1+B_\kappa}\right) + \sum_{n=2}^{\kappa+1}\frac{1/(n-1)}{(1+B_\kappa)^{n-1}}\right\}$$

$$\mathrm{cm^3 s^{-1}}, \qquad (3.27)$$

$$\text{where } B_\kappa = \frac{I_{EA}}{(\kappa - 3/2)k_bT},$$
$$I_{EA} = 26(Z-10) \text{ eV} \qquad \text{and}$$
$$a = 2.8 \times 10^{-17}(Z-11)^{-0.7} \text{ cm}^2.$$

B.2 For 18$\leq Z \leq$28, from the cross section in Equation (3.12):

$$S_{EA}(T) = c\Bigg\{\frac{(1+B_\kappa)^{-\kappa}}{\kappa B_\kappa} + (\kappa+1)B_\kappa - 0.5(\kappa+1)(\kappa+2)B_\kappa^2 \ln\left(\frac{B_\kappa+1}{B_\kappa}\right)$$
$$+ \sum_{n=2}^{\kappa+1}\frac{0.5(\kappa-n+2)(\kappa-n+3)B_\kappa^2}{(n-1)(1+B_\kappa)^{n-1}} - \frac{1}{2}\Bigg\} \quad \text{cm}^3\text{s}^{-1}, \qquad (3.28)$$

where $B_\kappa = \dfrac{I_{EA}}{(\kappa - 3/2)k_bT}$,

$$c = \frac{6.69 \times 10^7}{(K_bT)^{3/2}} A_\kappa I_{EA}^2 a,$$
$I_{EA} = 11(Z-10)^{1.5}$ eV and

$a = 1.3 \times 10^{-14}(Z-10)^{-3.73}$ cm^2.

C) For Sequences from Magnesium (Mg) to Argon (Ar) from the cross section in Equation (3.13):

$$S_{EA}(T) = c\Bigg\{\frac{(1+B_\kappa)^{-\kappa}}{\kappa B_\kappa} + (\kappa+1)B_\kappa - 0.5(\kappa+1)(\kappa+2)B_\kappa^2 \ln\left(\frac{B_\kappa+1}{B_\kappa}\right)$$
$$+ \sum_{n=2}^{\kappa+1}\frac{0.5(\kappa-n+2)(\kappa-n+3)B_\kappa^2}{(n-1)(1+B_\kappa)^{n-1}} - \frac{1}{2}\Bigg\} \quad \text{cm}^3\text{s}^{-1}, \qquad (3.29)$$

where $B_\kappa = \dfrac{I_{EA}}{(\kappa - 3/2)k_bT}$,

$$c = \frac{6.69 \times 10^7}{(K_b T)^{3/2}} A_\kappa I_{EA}^2 a,$$

$$a \times I_{EA} = 4 \times 10^{-13} Z^{-2} \qquad \text{cm}^2 \text{ eV},$$

Magnesium sequence	I_{EA}	$= 10.3(Z-10)^{1.52}$ eV,
Aluminum sequence	I_{EA}	$= 18.0(Z-11)^{1.33}$ eV,
Silicon sequence	I_{EA}	$= 18.4(Z-12)^{1.36}$ eV,
Phosphorus sequence	I_{EA}	$= 23.7(Z-13)^{1.29}$ eV, and
Sulfur sequence	I_{EA}	$= 40.1(Z-14)^{1.10}$ eV.

3.3.3 Radiative Recombination

The rate corresponding to Equation (3.17) is

$$\alpha_{RR}(T) = A_{rad} A_\kappa \frac{\Gamma(\kappa+\eta-1/2)}{\Gamma(\kappa+1)} \frac{(\kappa-3/2)^{-\eta+3/2}}{T^\eta (10^4\text{K})^{-\eta}} \qquad \text{cm}^3\text{s}^{-1}. \tag{3.30}$$

3.3.4 Dielectronic Recombination

From the cross section in Equation (3.20), the rate is:

$$\alpha_{DR}(T) = \frac{A_\kappa}{(k_b T)^{3/2}} \sum_{j=1}^{4} c_j \left(1 + \frac{E_j}{(\kappa-3/2)k_b T}\right)^{-(\kappa+1)} \qquad \text{cm}^3\text{s}^{-1}. \tag{3.31}$$

3.4 Numerical Techniques

In this thesis, numerical methods are used to solve rate equations and integrate rate coefficients. The integration step is the most complicated. At first we employed **Simpson's Method**, a high-accuracy integration method, to integrate the last term of the direct ionization rate coefficient as shown in Equation (3.23). However the upper limit of integration, infinity, led to a difficult decision as to when we should stop integrating. A newly developed **Robust Integration Method** is used to deal with that difficulty, while the **Bisection Method** (Johnson and Riess, 1982) is also used.

3.4.1 Simpson's Method

Generally, the integration of a function $f(x)$ along an interval between a and b is considered:

$$I = \int_a^b f(x)dx. \tag{3.32}$$

In Simpson's rule, an integral path from a to b is divided into two parts indicated by three points x_0, x_1, and x_2. Next, $f(x)$ between three adjacent grid points is approximated by a quadratic function like the curved line in Fig (3.1):

$$f(x) = ax^2 + bx + c. \tag{3.33}$$

Since the values of x_0, x_1, x_2, $f_0(x)$, $f_1(x)$, and $f_2(x)$ are known, we obtain a, b, and c from

$$\begin{aligned} x = x_0: \quad f(x_0) &= ax_0^2 + bx_0 + c, \\ x = x_1: \quad f(x_1) &= ax_1^2 + bx_1 + c, \text{ and} \\ x = x_2: \quad f(x_2) &= ax_2^2 + bx_2 + c. \end{aligned} \tag{3.34}$$

Substituting a, b, and c, Equation (3.33) becomes :

$$f(x) = L_0(x)f(x_0) + L_1(x)f(x_1) + L_2(x)f(x_2), \tag{3.35}$$

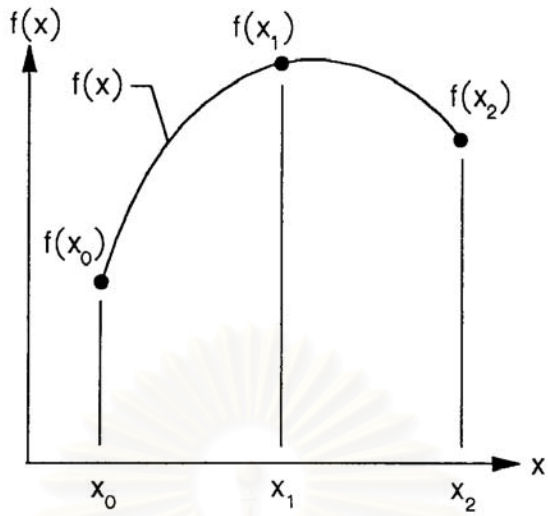

Figure 3.1: Function $f(x)$ between three adjacent grid points x_0, x_1, and x_2.

where

$$L_0(x) = \Big[(x_2 - x)(x_1 - x)\Big] / \Big[(x_2 - x_0)(x_1 - x_0)\Big],$$

$$L_1(x) = \Big[(x_2 - x)(x_0 - x)\Big] / \Big[(x_2 - x_1)(x_0 - x_1)\Big], \text{ and}$$

$$L_2(x) = \Big[(x_1 - x)(x_0 - x)\Big] / \Big[(x_1 - x_2)(x_0 - x_2)\Big].$$

After substituting function $f(x)$ into Equation (3.32), we get

$$\begin{aligned} I \;\approx\; & \int_a^b \left[\frac{(x - x_1)(x - x_2)}{(x_0 - x_1)(x_0 - x_2)} f(x_0) + \frac{(x - x_0)(x - x_2)}{(x_1 - x_0)(x_1 - x_2)} f(x_1) \right. \\ + \; & \left. \frac{(x - x_0)(x - x_1)}{(x_2 - x_0)(x_2 - x_1)} f(x_2) \right] dx. \end{aligned} \qquad (3.36)$$

Therefore we can directly integrate the above equation, where $x_2 - x_1 = x_1 - x_0 = h$:

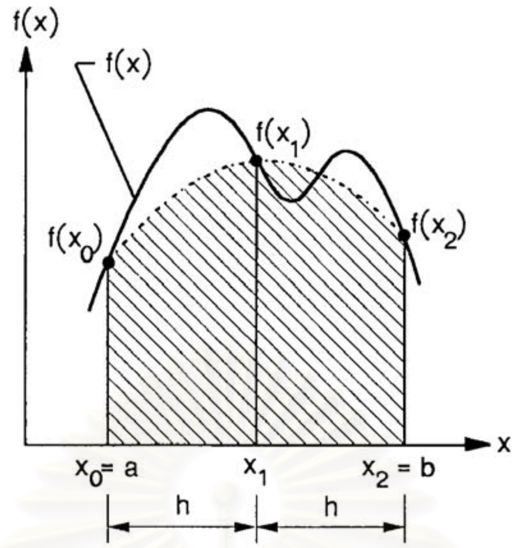

Figure 3.2: An example of Simpson's method for integrating a function $f(x)$ when we know $f(x)$ at x_0, x_1, and x_2.

$$I \approx \frac{h}{3}\Big[f(x_0) + 4f(x_1) + f(x_x)\Big]. \tag{3.37}$$

Equation (3.37) is Simpson's 1/3 rule, a name which refers to the coefficient 1/3. More generally, we can write

$$I \approx \frac{(b-a)}{6}\Big[f(x_0) + 4f(x_1) + f(x_x)\Big]. \tag{3.38}$$

- **Many intervals of Simpson's rule** are used when $b-a$ is broad. Using only one interval might cause an inaccurate integration, where the error of integration will be presented later.

From Figure (3.3), we divide the interval from a to b into n parts. Thus the width h is

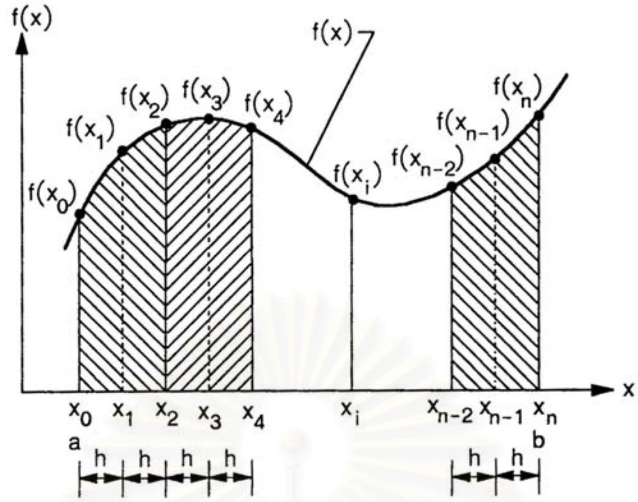

Figure 3.3: Simpson's method for the case where the integration interval is broad. The interval is divided into n parts.

$$h = \frac{b-a}{n}, \tag{3.39}$$

and the x-coordinate of each point i is

$$\begin{aligned} x_0 &= a, \\ x_i &= x_0 + ih \qquad\qquad i = 1, 2, \ldots, n-1, \text{ or} \\ x_n &= b. \end{aligned} \tag{3.40}$$

Next the integration in Equation (3.32) will be divided into $n/2$ pairs of intervals. It will begin with the intervals $x_0 \le x \le x_2$ and $x_2 \le x \le x_4$ and continue until $x_{n-2} \le x \le x_n$, where n must be an even number:

$$I = \int_{x_0}^{x_2} f(x)dx + \int_{x_2}^{x_4} f(x)dx + \ldots\ldots + \int_{x_{n-2}}^{x_n} f(x)dx. \tag{3.41}$$

For all intervals we use Simpson's rule as in Equation (3.38). Thus we obtain an integration method for our numerical calculation:

$$I = \frac{h}{3}\Big[f(x_0) + 4f(x_1) + f(x_2)\Big] + \frac{h}{3}\Big[f(x_2) + 4f(x_3) + f(x_4)\Big]$$

$$+ \quad \ldots\ldots + \frac{h}{3}\Big[f(x_{n-2}) + 4f(x_{n-1}) + f(x_n)\Big]$$

$$I = \frac{h}{3}\Big[f(x_0) + f(x_n) + 4\sum_{\substack{i=1 \\ i \text{ odd}}}^{n-1} f(x_i) + 2\sum_{\substack{j=2 \\ j \text{ even}}}^{n-2} f(x_j)\Big]. \tag{3.42}$$

- **The error of Simpson's rule** can be calculated by using a polynomial expansion for $f(x)$, $f(x_i)$, $f(x_{i+1})$, and $f(x_{i+2})$. For $n/2$ pairs of intervals, the error for Simpson's rule is

$$E_a = -\frac{(b-a)^5}{180n^4}\overline{f}^{(4)}. \tag{3.43}$$

Here $\overline{f}^{(4)}$ is defined as

$$\overline{f}^{(4)} = \frac{2}{n}\Bigg(\sum_{\substack{i=0 \\ i \text{ even}}}^{n-2} f^{(4)}(\eta_i)\Bigg). \tag{3.44}$$

The fourth-order derivative $f^{(4)}(\eta_i)$ is approximated at a position η_i between x_i and x_{i+2}. However, the value of each η_i is not known, so we can only find a limit on the error $|e|$:

$$|e| \leq \frac{(b-a)^5}{180\ n^4}\overline{f}^{(4)}. \tag{3.45}$$

According to the above equation, in any case we cannot calculate the exact value of $\overline{f}^{(4)}$. We define that

$$\overline{f}^{(4)} = \max\{f^{(4)}(x) : x \in [a,\, b]\}. \tag{3.46}$$

3.4.2 Bisection Method

This method is used to solve an equation in the form $f(x) = 0$. For example, in Figure 3.4, $f(x)$ is positive where x is greater than a solution, $\overline{x}$, but $f(x)$ is negative if x is less than $\overline{x}$. It is also possible for other functions $f(x)$ to have different curves, but they are no more difficult to solve than this example, if our goal is to find at least one root.

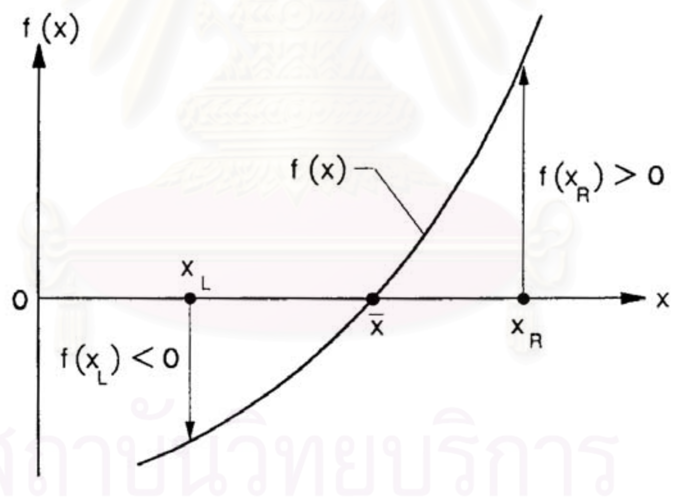

Figure 3.4: Example of a function $f(x)$, where $\overline{x}$ is a root, i.e., a solution of $f(x) = 0$. The goal is to better constrain the location of a root between x_l and x_r. The existence of a root is guaranteed if $f(x)$ is continuous and $f(x_l)f(x_r) < 0$.

From Figure 3.4, a solution $\overline{x}$ can be estimated by decreasing the width of the interval between x_l and x_r, while maintaining $f(x_l)$ and $f(x_r)$ with opposite signs. It is necessary to ensure that $f(x)$ is continuous for x between x_l and x_r. We have to check that $f(x_l)f(x_r) < 0$ first, because it lets us know that there is at least one solution in the selected interval. Furthermore, there could be many roots in one interval.

Next, here is the procedure of calculation:

Step 1 Find the average value x_m between x_l and x_r:

$$x_m = \frac{x_l + x_r}{2}. \tag{3.47}$$

Thus the interval between x_l and x_r is divided into two intervals, where $f(x_m)$ could be positive or negative. In Figure 3.5, we see two possible cases.

Step 2 Since a solution $\overline{x}$ could be in one of two divided intervals, we can choose the right one that contains a solution by multiplying $f(x_m)$ with $f(x_r)$.

Case A: if $f(x_m) \cdot f(x_r) > 0,$ then $x_l < \overline{x} < x_m$.

Case B: if $f(x_m) \cdot f(x_r) < 0,$ then $x_m < \overline{x} < x_R$.

Step 3 We adjust x_l or x_r for a narrower interval.

Case A: We use x_m as the new x_r.

Case B: We use x_m as the new x_l.

Step 4 Repeating steps 1, 2, and 3, we find that the difference between x_r and x_l decreases continually. To be ensured that a solution $\overline{x}$ is very close to x_m, we check by the condition that the difference between x_r and x_l should be less than an acceptable error, ε_s:

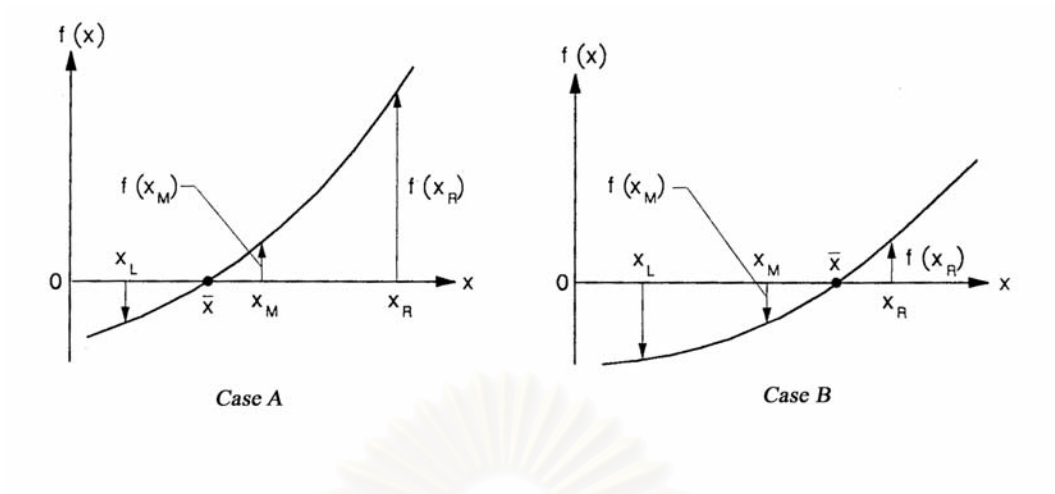

Figure 3.5: Two simple cases with A) $\overline{x} \in (x_l, x_m)$ and B) $\overline{x} \in (x_m, x_r)$. Checking whether $f(x_m)f(x_r)$ is positive or negative lets us choose the right interval in which there is a solution $\overline{x}$.

$$\left|\frac{x_r - x_l}{2}\right| \times 100\% \qquad < \qquad \varepsilon_s. \tag{3.48}$$

In this thesis, the program will stop when ε_s is less than $10^{-9}\%$.

This method is easy to program. After checking that $f(x_l)f(x_r) < 0$, we can be ensured that we will obtain at least one root easily. However, the bisection method is a slowly converging method, though for the speed of the computer and nature of the problem at hand, this is not a concern.

3.4.3 Robust Integration Program

In this thesis, we encounter integrations of the form:

$$I = \int_1^\infty f(u)du, \tag{3.49}$$

where $f(u)$ has a maximum value and monotonically declines thereafter. From a previous section, we see that we need to find

$$\int_1^{\infty} \frac{ln(u)/u}{(1+yu)^{\kappa+1}} du. \tag{3.50}$$

That integrand is plotted in Figure 3.6 for a sample case ($\kappa = 1000$). Using **Simpson's Method** to integrate the above integrand, we must have a finite upper limit. For the curve plotted in Figure 3.6, it is possible for us to choose a suitable upper limit.

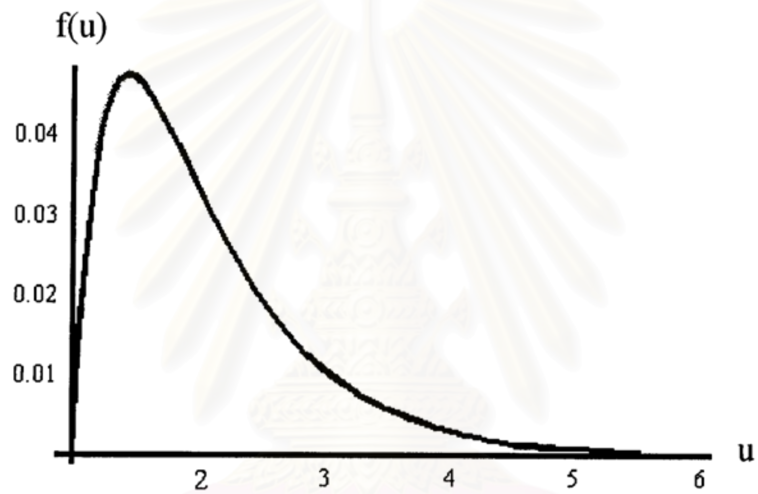

Figure 3.6: The function $f(u) = \ln(u)/[u(1+yu)^{\kappa+1}]$, plotted as a function of u in the case that $\kappa = 1000$.

The calculation procedure of our newly developed robust integration method is as follows:

- **Step 1** The **Bisection Method** is used to find u_0 such that $f(u_0)$ is a maximum point, f_{max}, as shown in Figure 3.7.

- **Step 2** Calculate u_i such that

$$u_i = \frac{f(u_0)}{2^i} = \frac{f_{max}}{2^i}. \tag{3.51}$$

- **Step 3** With N=2, the two-interval **Simpson's Method** ($n = 2$) is used to integrate

$$\begin{aligned} I_{tot} &= \int_1^{u_0} f(u)du + \sum_{i=0}^{N-1} \int_{u_i}^{u_{i+1}} f(u)du \\ I_{N+1} &= \int_{u_N}^{u_{N+1}} f(u)du \end{aligned} \tag{3.52}$$

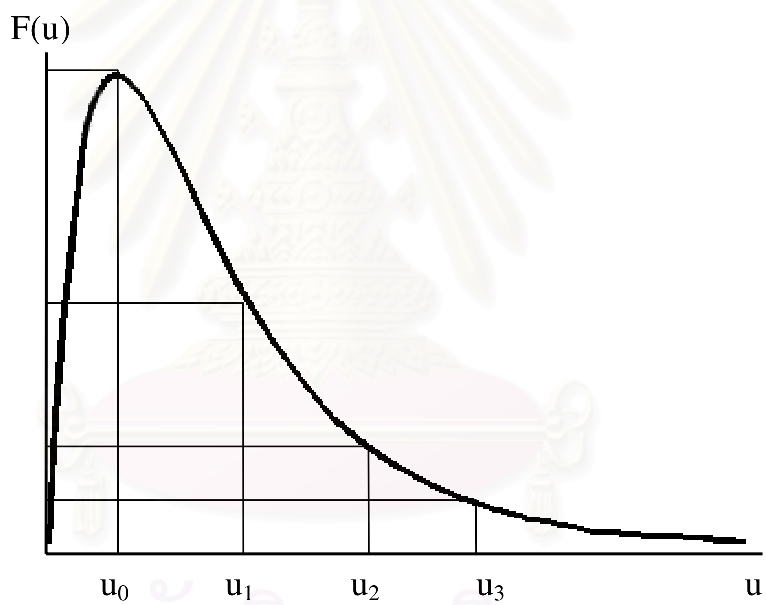

Figure 3.7: The bisection method is used in the integration of function $f(u)$ to find the suitable upper limit u_N. The value of each u_i is calculated from $f(u_0) = f_{max}$ and $f(u_i) = f(u_{i-1})/2$.

Next, we repeat Step 3 for increasing N and stop when the last integrand, I_{N+1}, is very small compared with the whole integral, I_{tot}:

$$\left|\frac{I_{N+1}}{I_{tot}}\right| \quad < \quad 10^{-4}. \tag{3.53}$$

- **Step 4** Now that we have found the suitable upper limit u_N, we directly solve

$$I_n = \int_1^{u_N} f(u)du \tag{3.54}$$

by Simpson's method for n intervals, starting with $n = 2$. Then we increase n by steps of 2 until the tolerance (ε) is less than 10^{-4}, where

$$\varepsilon \quad = \quad \left|\frac{I_{n+1} - I_n}{I_n}\right|. \tag{3.55}$$

- **Step 5** Finally we have both a suitable upper limit, u_N, and a suitable number of intervals, n. We approximate the integration in Equation (3.49) by

$$I \quad = \quad \int_1^{\infty} f(u)du \approx \int_1^{u_N} f(u)du,$$

$$I \quad \approx \quad \frac{h}{3}\Big[f(1) + f(u_N) + 4\sum_{\substack{i=1 \\ i \text{ odd}}}^{n-1} f(x_i) + 2\sum_{\substack{i=2 \\ i \text{ even}}}^{n-2} f(x_i)\Big], \tag{3.56}$$

where $\quad h = \dfrac{u_N - 1}{n}.$

Chapter 4
Results and Discusssion

In this thesis, we obtain the ionization fractions and mean charges for ions of various elements, presented as a function of temperature and the κ value, including the limiting case of a Maxwellian distribution. The charge fraction is defined by

$$\text{charge fraction of charge state } q = \frac{n_q}{\sum_i n_i}, \tag{4.1}$$

where n_q is the density of the charge state q and the sum of charge state densities of a given element is $\sum_q n_q$. The ionization fractions for N, O, Ne, Mg, Si, S, Ar, Ca, Fe, and Ni are presented in Tables A1.1 - A10.4 for κ values of 3, 5, and 10 and a Maxwellian distribution. Such ionization fractions have never been presented before.

For each element and each temperature, we check our calculation for a kappa distribution by proving that, at the limit of large κ, our results for $\kappa =$ 1000 are similar to the case of a Maxwellian. As another check of our calculations, we compare our results for the case of a Maxwellian distribution with those of previous work (Mazzotta et al., 1998). In fact, we mostly used the same formulas of the cross sections as Mazzotta et al. (1998). The only differences (except for Fe, which we will discuss shortly) are for radiative recombination to H, He, Li, and Na sequences, where we use different formulas. We use the older formulas of Shull and Van Steenberg (1982), while Mazzotta et al. (1998) use more recent fits by Verner and Ferland (1996). The reason is because the latter fitted rate coefficients are in a complicated form that is not obviously related to an analytic cross section formula, which we need for calculation in the case of kappa distributions. Checking quantitatively, we have downloaded the calculation program of Verner (1997; http://www.pa.uky.edu/∼verner/fortran.html), which was cited by Mazzotta et al. (1998). Then we compiled Verner's FORTRAN program to obtain their rate coefficients for ionization and radiative recombination at a chosen temperature. We can also compare our ratios α_q/S_{q+1} to those of Mazzotta et al. (1998) by using their published ionization fractions and the formula $\alpha_q/S_{q+1} = n_{q+1}/n_q$ (Equation 3.2).

For almost all elements, our results for a Maxwellian electron velocity distribution are consistent with those of Mazzotta et al. (1998), differing in $-\log(n_q/\sum_i n_i)$ by at most 2.0 for the most abundant ion, over the entire temperature range of $T = 10^4$ to 10^8 or 10^9 K. The only substantial differences are for Fe, where Mazzotta et al. (1998) have used the updated but less physical rate formulas of Arnaud and Raymond (1992). As in the cases mentioned above, the latter authors have chosen an empirical form for the rate coefficients that is not related to any cross section formula. We find that our calculated ionization rate coefficients for Fe are higher at very low charge states but radiative recombination rate coefficients are slightly lower at very high charge states. Anyway, in the range of coronal temperatures ($\sim 10^6$ K), our ionization fractions are very consistent with those of Mazzotta et al. (1998). Therefore, in the range of $T \sim 10^5 - 10^7$ K, our results for Fe are acceptable.

We have also obtained the equilibrium mean charges for different electron velocity distributions, parameterized by $\kappa = 3$, 5, and 10 and a Maxwellian. In Figures 4.1 - 4.10, we compare results for different κ values, showing the influence of the κ parameter on the mean equilibrium charges, $\langle Q\rangle$, as a function of plasma temperature, T. Results are presented for N, O, Ne, Mg, Si, S, Ar, Ca, Fe, and Ni. It is clear that at a given temperature, the mean equilibrium charges are constant or increasing for lower κ. This is because the ionization processes take place more frequently due to the enhanced numbers of high energy electrons.

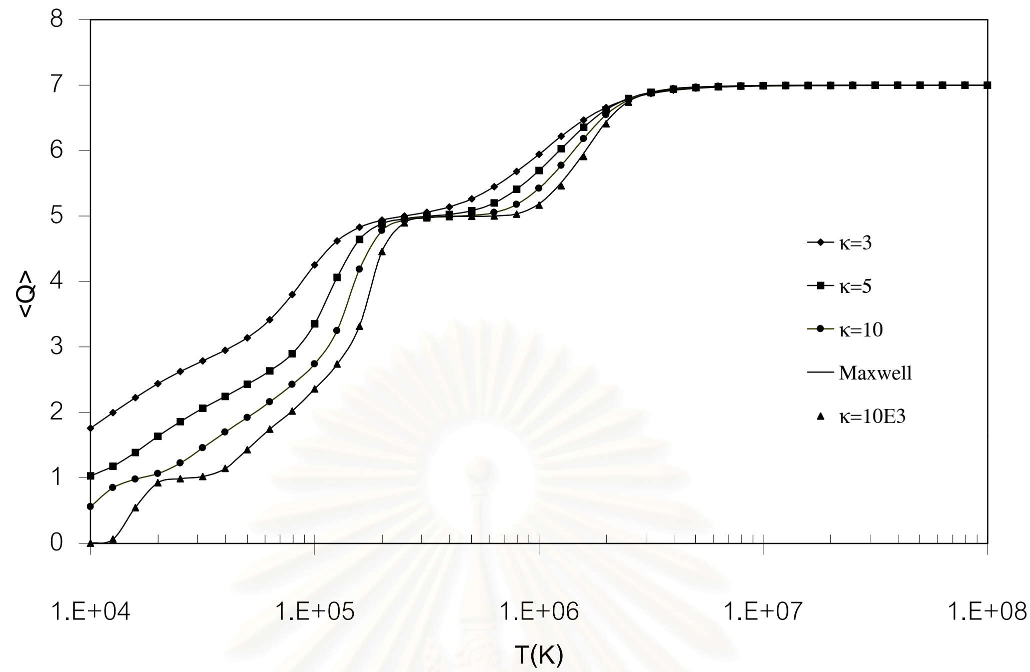

Figure 4.1: Mean equilibrium charge as a function of electron temperature for N.

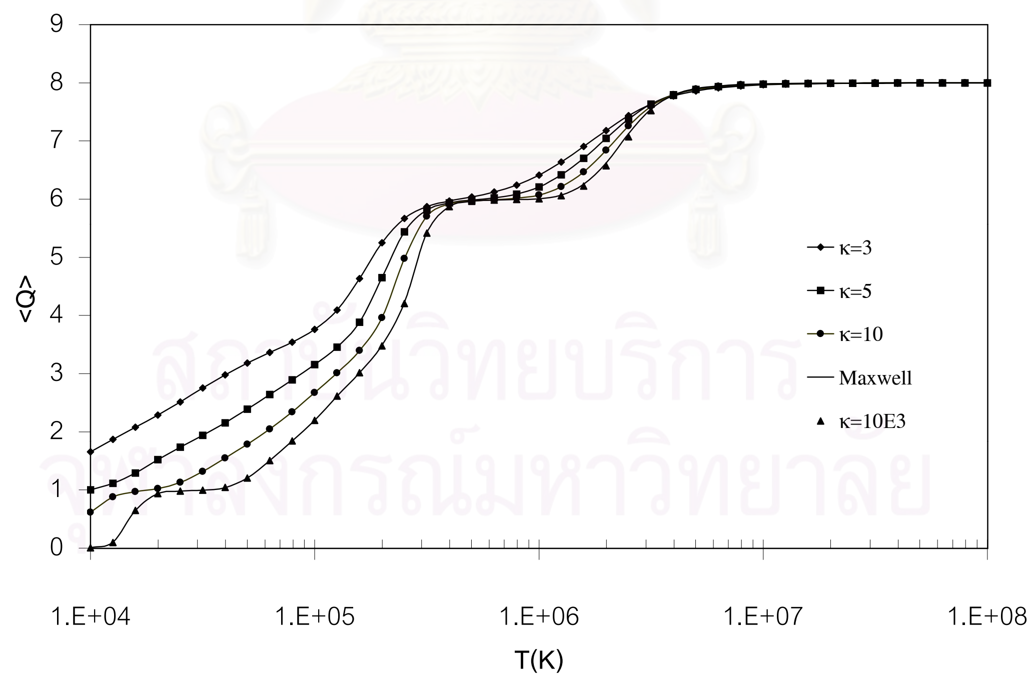

Figure 4.2: Mean equilibrium charge as a function of electron temperature for O.

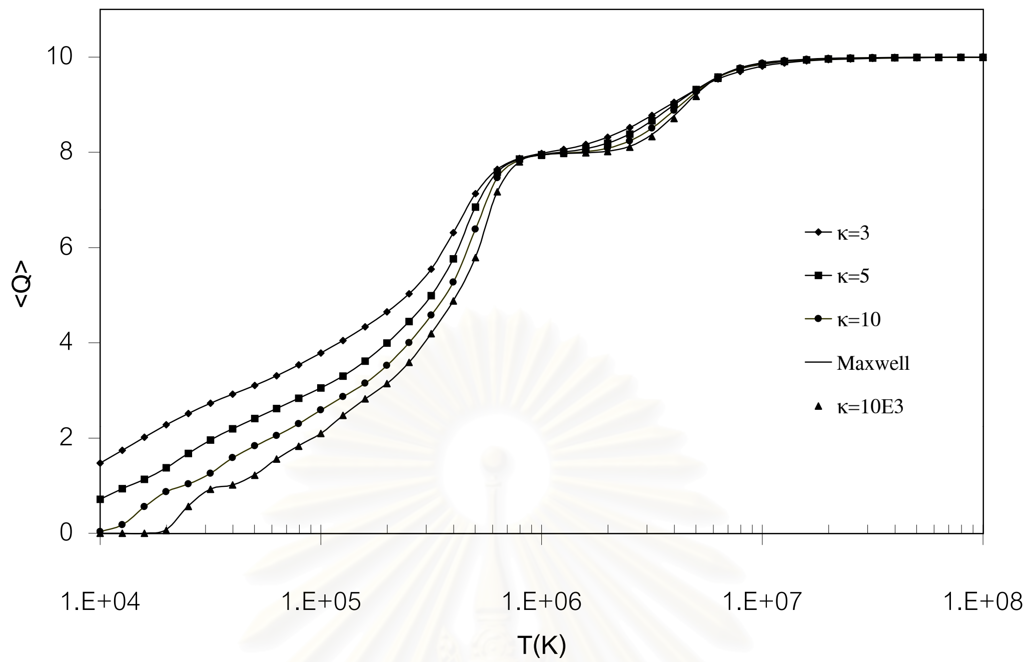

Figure 4.3: Mean equilibrium charge as a function of electron temperature for Ne.

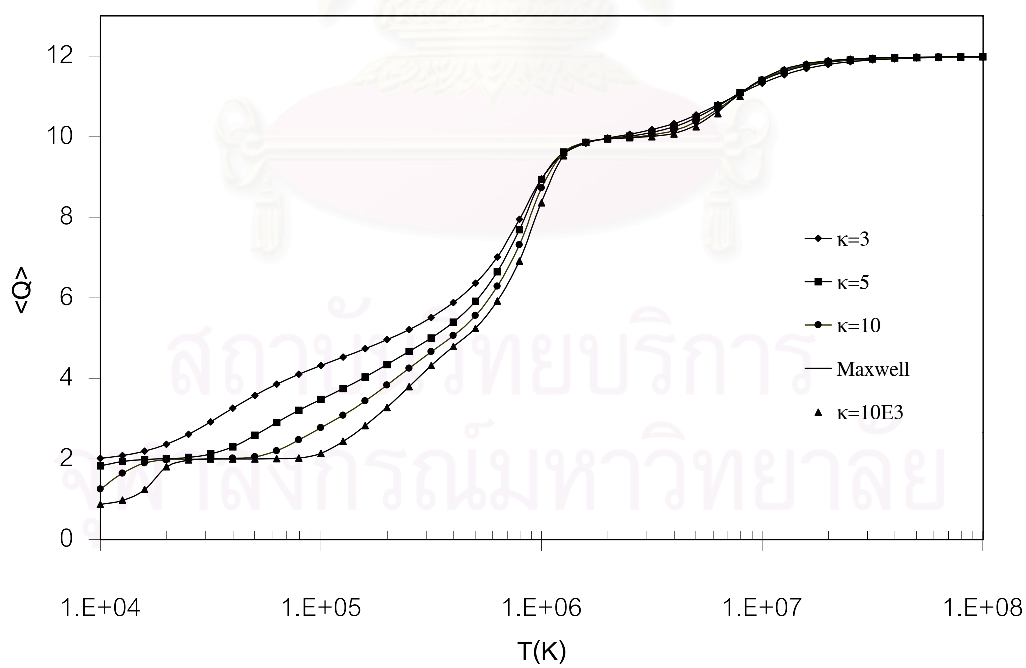

Figure 4.4: Mean equilibrium charge as a function of electron temperature for Mg.

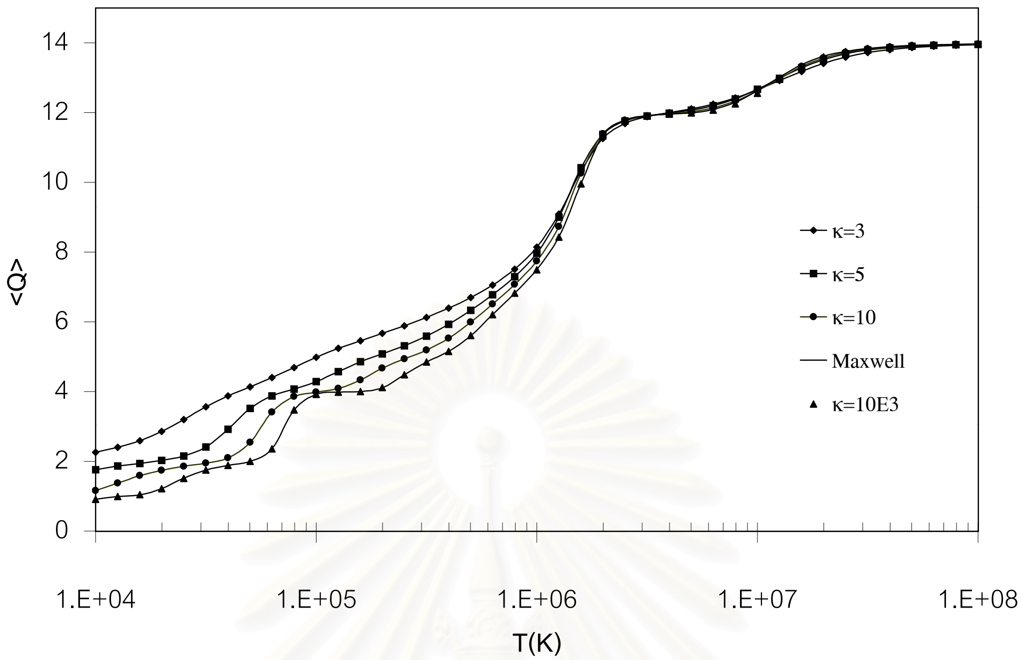

Figure 4.5: Mean equilibrium charge as a function of electron temperature for Si.

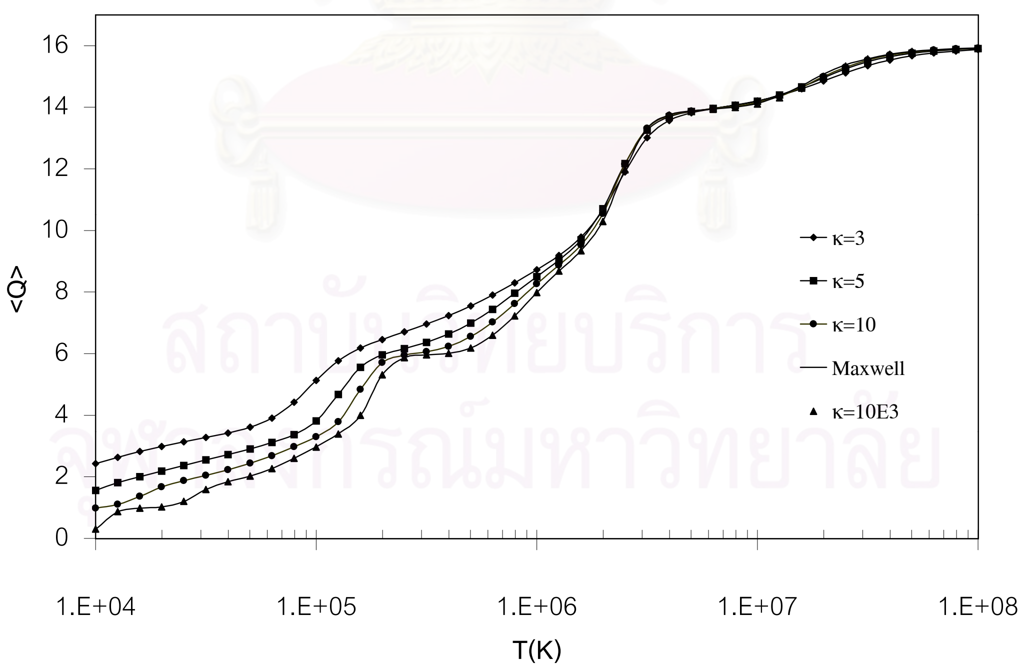

Figure 4.6: Mean equilibrium charge as a function of electron temperature for S.

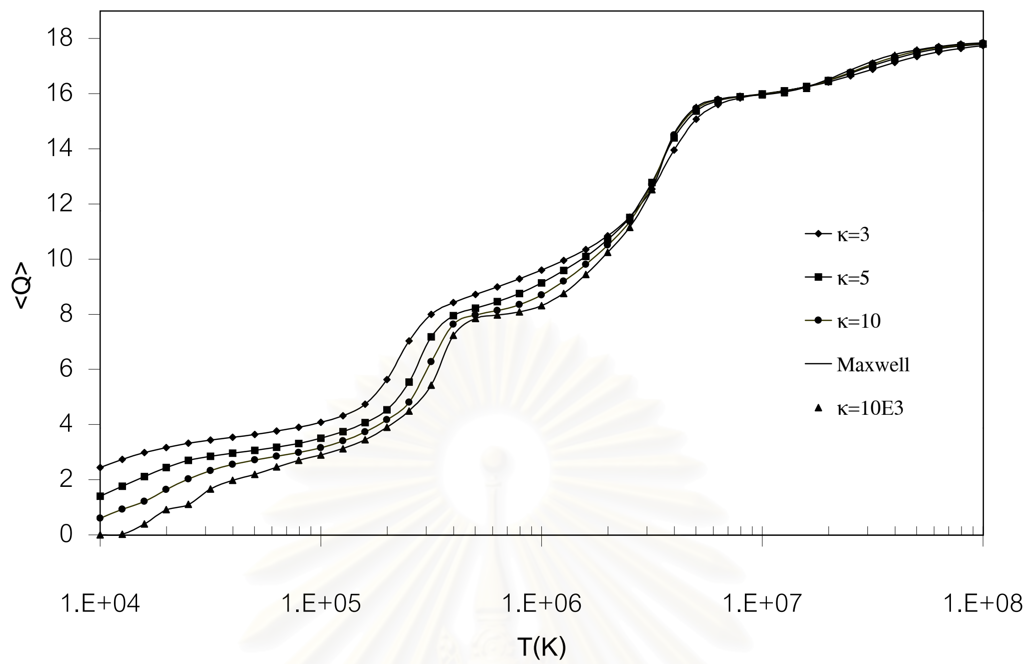

Figure 4.7: Mean equilibrium charge as a function of electron temperature for Ar.

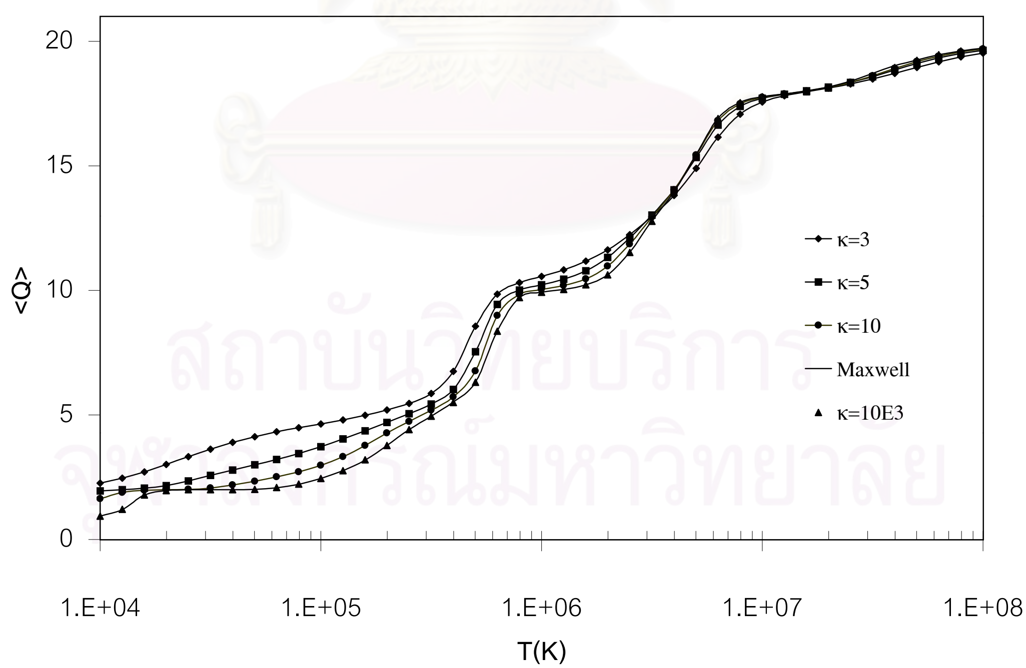

Figure 4.8: Mean equilibrium charge as a function of electron temperature for Ca.

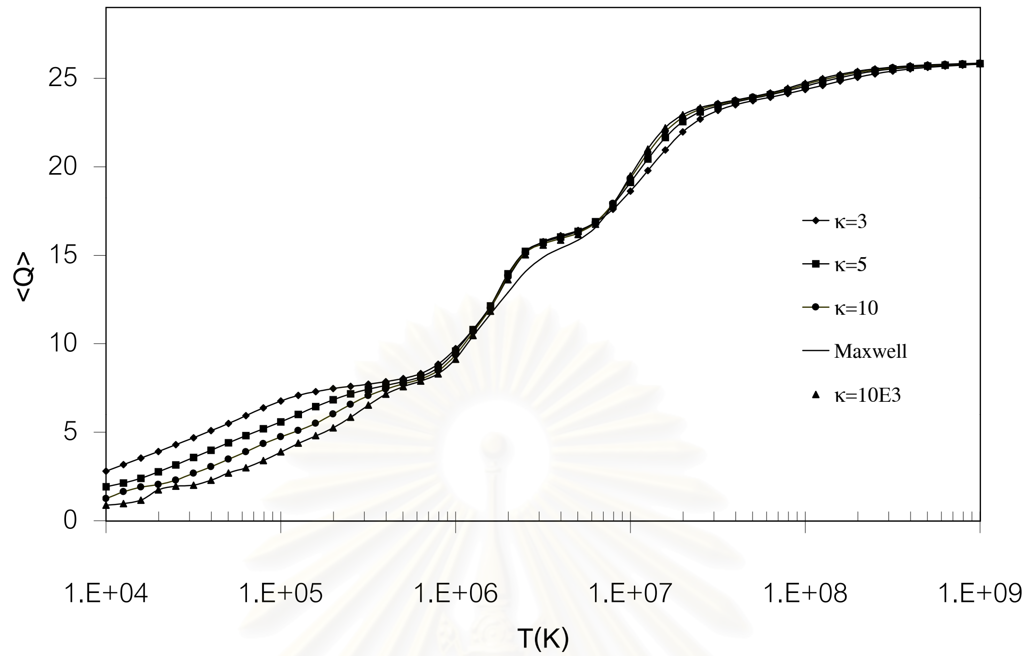

Figure 4.9: Mean equilibrium charge as a function of electron temperature for Fe.

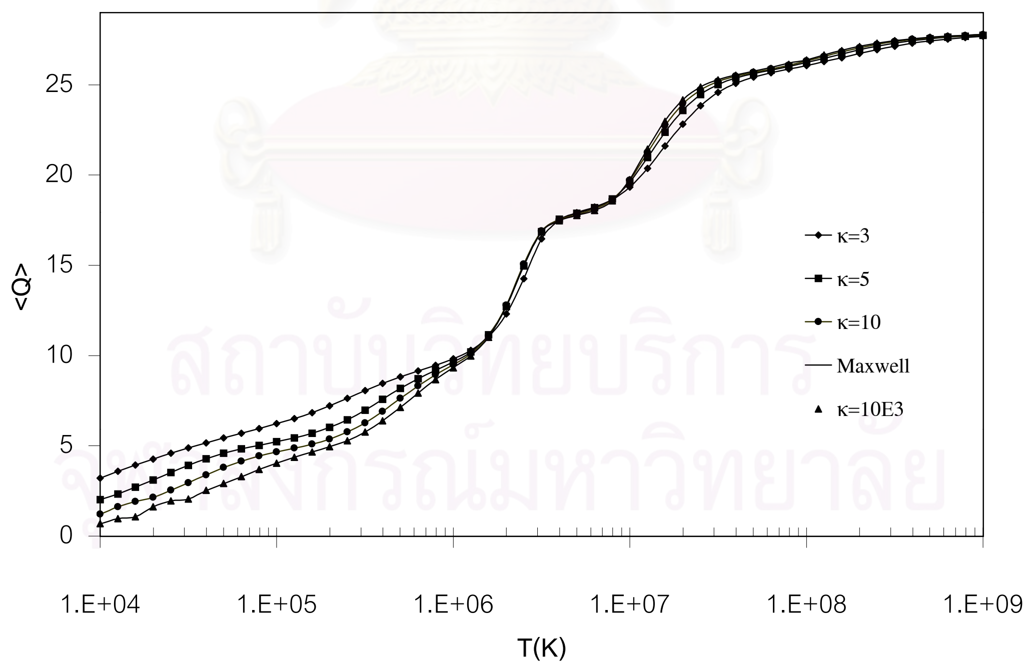

Figure 4.10: Mean equilibrium charge as a function of electron temperature for Ni.

Figure 4.11 shows the relation between mean equilibrium charges and the plasma temperature for all considered elements in the case where $\kappa = 5$. In a conference paper by Luhn and Hovestadt (1985), for C, N, O, Ne, Mg, Si, and S, kappa distributions were also used to calculate mean equilibrium charges, but with different (older) formulas for the cross sections. Note that they did not present ionization fractions, thus limiting the applicability of their work. Comparing their results with ours for the equilibrium mean charges, the results are similar at $\kappa =$ 5 for S, Si, Mg, Ne, O, and N, as shown in Figures 4.12 and 4.13. The results are qualitatively similar, and we ascribe the quantitative differences to the different assumed cross sections. Nevertheless for the elements with high atomic masses (e.g., Ne), the results are more different than those for the lower atomic masses (e.g., N and O).

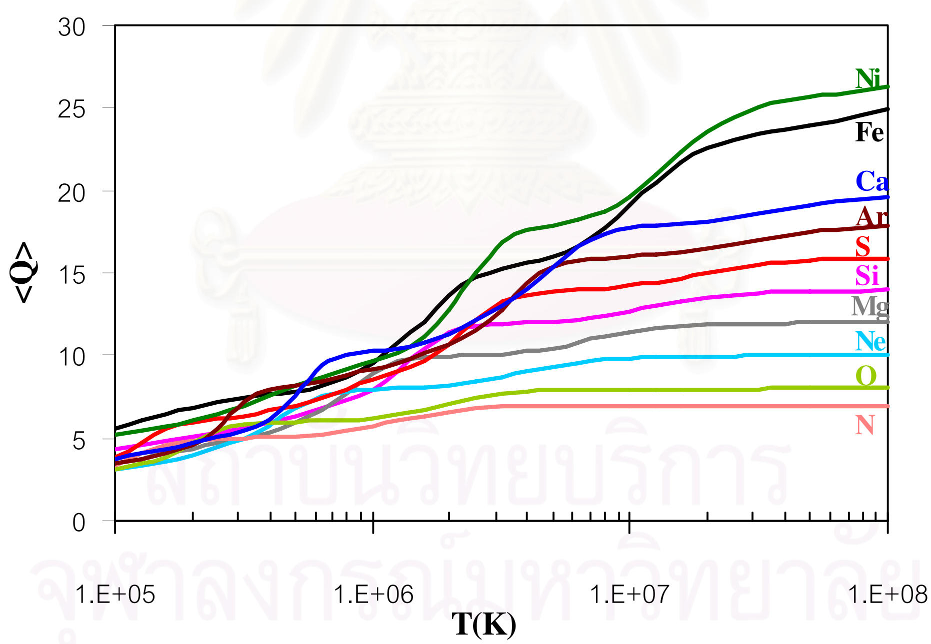

Figure 4.11: Mean equilibrium charge as a function of electron temperature for a kappa distribution with $\kappa = 5$.

Note that the equilibrium mean charges change rapidly when the thermal energy is close to the threshold ionization energy of an atomic shell. For example, the ionization energy for the direct ionization process from N^{+4} ($1s^2$ $2s^1$) to N^{+5} ($1s^2$) is 97.9 eV, corresponding to a temperature of 1.136×10^6 K, as shown in Fig 4.1. Thus, the effect of an enhanced tail is particularly important at temperatures where the ion can lose electrons easily, i.e., not at a closed shell. In addition, the effect of the kappa distributions is obvious for the lighter elements, N, O, and Ne at the temperatures for which atoms are losing the last two electrons, in the K-shell.

At the range of coronal temperatures ($\sim 10^6$ K), the effect of different κ values on the mean equilibrium charges of ions is significant for N, O, Ne, Ar and Ca. However, at temperatures less than the order of 10^6 K, the influence of non-thermal electrons is more significant. According to our results in Figs 4.1 - 4.10, we find that the κ parameter affects the mean ionic charges, which are often used as diagnostics of the plasma temperature.

What our work does for the first time is to show the relation between the mean equilibrium charges (and ionization fractions) and plasma temperature for different electron velocity distributions described by the parameter κ. This is important for applications, since the electron velocity distributions observed in space plasmas are better defined by kappa distributions, i.e., such distributions can characterize the observed high-energy tails. The temperature inferred for a Maxwellian distribution (as typically used) could be much higher than the actual temperature of a plasma with a kappa distribution of electrons.

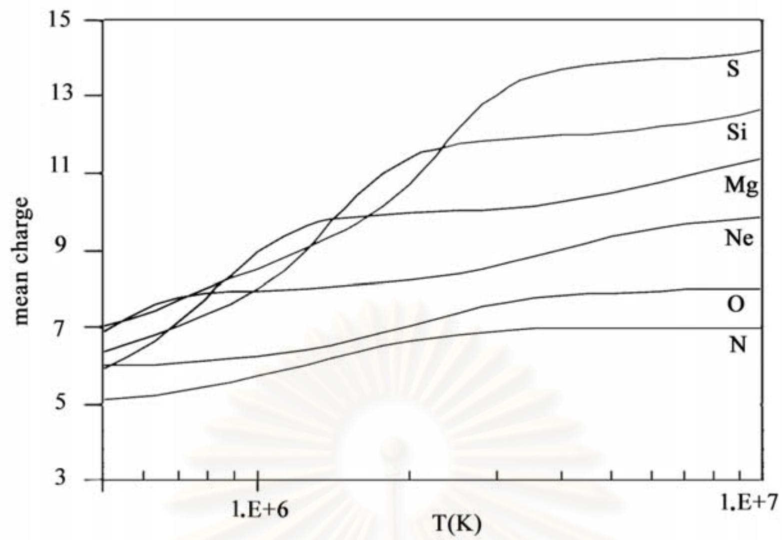

Figure 4.12: Mean equilibrium charges as a function of electron temperature for a kappa distribution with $\kappa = 5$ for several elements. This figure is used to compare the results from Luhn and Hovestadt (1985).

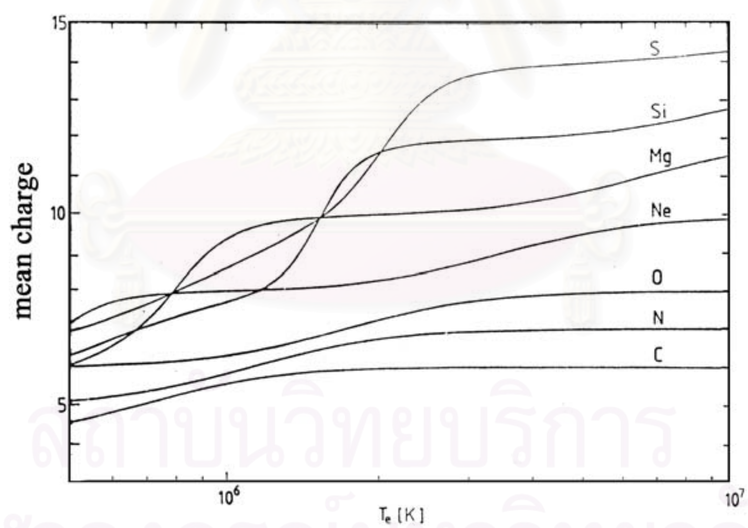

Figure 4.13: Mean equilibrium charge as a function of electron temperature for κ distribution with $\kappa = 5$ (Luhn and Hovestadt, 1985).

Chapter 5
Conclusions

Our work presents the first results for both the mean equilibrium charges and the ionization fractions as a function of plasma temperature for N, O, Ne, Mg, Si, S, Ar, Ca, Fe, and Ni for kappa distributions of electron velocity at various κ values (3, 5, and 10) and a Maxwellian distribution over a temperature range of 10^4 to 10^8 or 10^9 K (conditions under which astrophysical plasmas can be found). In performing our calculations, we tried to use the most updated cross section and rate coefficient formulas from several papers in the literature. If only rate coefficients (for a Maxwellian electron velocity distribution) were available, we first converted those into cross sections. Then we analytically derived ionization and recombination rate coefficients for a kappa distribution, except for one term which we integrated numerically. All analytic formulas were verified by numerical integration and in some cases with the *Mathematica* program. Anyway, we still faced some obstacles because of the complicated rate formulas for radiative recombination to H, He, Li, and Ne sequences and some sequences for Fe; therefore, we have been unable to use the latest formulas in the literature for such rates.

Quantitatively, we have checked our results in the limit of large kappa (at $\kappa = 1000$) against results calculated separately for a Maxwellian distribution. The latter results are also checked against previous work (Mazzotta et al., 1998). We find that substantial differences occur for Fe at very low temperature ($\sim 10^4$ K) or very high temperature ($\sim 10^8$ K), while there are more consistent results at intermediate temperatures ($\sim 10^5 - 10^7$ K). Note that the discrepancy between our Maxwellian results and those of Mazzotta et al. (1998) at extreme temperatures merely reflects the use of different formulas in the calculation. We interpret the comparison as an indicator of the level of systematic error expected from such calculations.

In comparing results for kappa distributions and a Maxwellian distribution, we find that the enhanced tails can cause greater mean equilibrium charges. The lower the κ value, the stronger the influence, because of more frequent ionization caused by the greater number of high energy electrons. From the concept of the shell model, the effect of a kappa distribution is more distinctive at a temperature approximately corresponding to an ionization threshold energy. From the above conclusion and according to Figures 4.1 - 4.10, we see that the effects of the kappa distribution are always strong at low temperatures, where the effects of high energy tails are more pronounced. In addition, at the range of T $\sim 10^6$ to 10^7 K, there are obvious effects for N, O, Ne, Ar, and Ca. We expect that unlike the absolute mean charge, the incremental effect of a kappa distribution should be only weakly affected by any errors in the cross section and rate formulas obtained from the literature.

In conclusion, we offer new results showing the mean equilibrium charge and ionization fractions of astrophysically abundant elements as a function of plasma temperature for different electron velocity distributions. In particular, we consider both a Maxwellian (thermal) distribution and kappa distributions with enhanced high-energy tails. This is practical information for the interpretation of observed ionic charge state data from the solar wind, solar energetic particles, or spectroscopic observations of the cosmos. Our results are necessary for such interpretation of data because an enhanced number of high energy electrons is apparently present in all low-density space plasmas.. Furthermore, we can state that if the kappa distributions are more suitable for the electron velocity distributions in space plasmas, the temperatures inferred for a Maxwellian distribution should overestimate the actual plasma temperatures. For various applications, our results will enable other space physicists to evaluate whether enhanced high energy tails need to be considered when they interpret observed ionic charge states.

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Appendices

Appendix A

Charge Fraction Tables

We show tables of charge fractions for kappa distributions with $\kappa = 3$, 5, 10, and a Maxwellian distribution for N, O, Ne, Mg, Si, S, Ar, Ca, Fe, and Ni. The first column gives $\log_{10}(T/\mathrm{K})$, the last column gives the mean ionic charge, $\langle Q \rangle$, and intermediate columns give $-\log_{10}(m_q)$ where m_q is the fractional abundance of charge state q. The symbol *** is used when $m_q \leq 10^{-5}$.

Table A1.1: The charge abundance for N with Maxwellian distribution.

log T	N^{+0}	N^{+1}	N^{+2}	N^{+3}	N^{+4}	N^{+5}	N^{+6}	N^{+7}	$\langle Q \rangle$
4.0	0.001	2.818	***	***	***	***	***	***	0.002
4.1	0.025	1.247	***	***	***	***	***	***	0.057
4.2	0.343	0.263	***	***	***	***	***	***	0.546
4.3	1.122	0.034	4.229	***	***	***	***	***	0.925
4.4	1.799	0.008	2.698	***	***	***	***	***	0.986
4.5	2.118	0.015	1.590	***	***	***	***	***	1.018
4.6	2.318	0.070	0.844	4.295	***	***	***	***	1.139
4.7	2.593	0.249	0.364	2.754	***	***	***	***	1.433
4.8	3.020	0.555	0.155	1.676	***	***	***	***	1.741
4.9	3.595	0.982	0.112	0.911	4.047	***	***	***	2.018
5.0	4.266	1.502	0.235	0.417	2.499	4.868	***	***	2.358
5.1	***	2.156	0.527	0.185	1.390	2.619	***	***	2.734
5.2	***	2.978	1.027	0.227	0.682	0.984	***	***	3.320
5.3	***	4.274	2.027	0.822	0.667	0.204	***	***	4.455
5.4	***	***	3.364	1.815	1.131	0.041	***	***	4.894
5.5	***	***	4.622	2.759	1.626	0.011	***	***	4.973
5.6	***	***	***	3.597	2.051	0.004	***	***	4.991
5.7	***	***	***	4.284	2.407	0.002	3.710	***	4.996
5.8	***	***	***	4.862	2.681	0.002	2.443	***	5.001
5.9	***	***	***	***	2.842	0.016	1.452	4.331	5.034
6.0	***	***	***	***	2.930	0.089	0.743	2.632	5.184
6.1	***	***	***	***	3.086	0.280	0.358	1.446	5.510
6.2	***	***	***	***	3.382	0.611	0.259	0.690	5.958
6.3	***	***	***	***	3.832	1.076	0.403	0.284	6.436
6.4	***	***	***	***	4.408	1.640	0.693	0.111	6.751
6.5	***	***	***	***	4.997	2.188	1.003	0.049	6.888
6.6	***	***	***	***	***	2.707	1.299	0.023	6.946
6.7	***	***	***	***	***	3.181	1.561	0.012	6.971
6.8	***	***	***	***	***	3.502	1.798	0.007	6.983
6.9	***	***	***	***	***	3.889	2.000	0.004	6.990
7.0	***	***	***	***	***	4.243	2.181	0.003	6.993
7.1	***	***	***	***	***	4.562	2.332	0.002	6.995
7.2	***	***	***	***	***	4.864	2.471	0.001	6.997
7.3	***	***	***	***	***	***	2.594	0.001	6.997
7.4	***	***	***	***	***	***	2.705	0.001	6.998
7.5	***	***	***	***	***	***	2.799	0.001	6.998
7.6	***	***	***	***	***	***	2.893	0.001	6.999
7.7	***	***	***	***	***	***	2.983	0.000	6.999
7.8	***	***	***	***	***	***	3.052	0.000	6.999
7.9	***	***	***	***	***	***	3.124	0.000	6.999
8.0	***	***	***	***	***	***	3.191	0.000	6.999

Table A1.2: The charge abundance for N with κ=10.

log T	N^{+0}	N^{+1}	N^{+2}	N^{+3}	N^{+4}	N^{+5}	N^{+6}	N^{+7}	⟨Q⟩
4.0	0.353	0.255	3.503	***	***	***	***	***	0.557
4.1	0.816	0.074	2.526	***	***	***	***	***	0.850
4.2	1.378	0.027	1.747	***	***	***	***	***	0.976
4.3	1.844	0.042	1.113	3.946	***	***	***	***	1.063
4.4	2.228	0.115	0.648	2.857	***	***	***	***	1.222
4.5	2.552	0.262	0.356	2.053	***	***	***	***	1.456
4.6	2.877	0.475	0.201	1.460	4.666	***	***	***	1.697
4.7	3.234	0.742	0.144	0.995	3.631	***	***	***	1.919
4.8	3.673	1.076	0.169	0.628	2.707	4.941	***	***	2.155
4.9	4.188	1.477	0.282	0.365	1.899	3.412	***	***	2.425
5.0	4.821	1.982	0.499	0.218	1.229	2.075	***	***	2.738
5.1	***	2.619	0.866	0.237	0.751	0.979	***	***	3.247
5.2	***	3.567	1.560	0.600	0.643	0.307	***	***	4.186
5.3	***	4.844	2.588	1.318	0.926	0.080	4.952	***	4.778
5.4	***	***	3.691	2.128	1.329	0.024	4.075	***	4.938
5.5	***	***	4.729	2.891	1.720	0.009	3.288	***	4.979
5.6	***	***	***	3.588	2.076	0.005	2.549	***	4.994
5.7	***	***	***	4.202	2.379	0.008	1.868	4.881	5.009
5.8	***	***	***	4.732	2.624	0.026	1.260	3.588	5.053
5.9	***	***	***	***	2.816	0.084	0.766	2.471	5.177
6.0	***	***	***	***	3.010	0.221	0.431	1.563	5.424
6.1	***	***	***	***	3.246	0.453	0.282	0.903	5.772
6.2	***	***	***	***	3.569	0.786	0.311	0.459	6.183
6.3	***	***	***	***	3.987	1.208	0.483	0.215	6.547
6.4	***	***	***	***	4.469	1.680	0.738	0.099	6.775
6.5	***	***	***	***	4.974	2.154	1.015	0.047	6.889
6.6	***	***	***	***	***	2.605	1.283	0.024	6.943
6.7	***	***	***	***	***	3.031	1.527	0.014	6.968
6.8	***	***	***	***	***	3.425	1.748	0.008	6.981
6.9	***	***	***	***	***	3.788	1.943	0.005	6.988
7.0	***	***	***	***	***	4.126	2.118	0.003	6.992
7.1	***	***	***	***	***	4.443	2.275	0.002	6.995
7.2	***	***	***	***	***	4.735	2.413	0.002	6.996
7.3	***	***	***	***	***	***	2.540	0.001	6.997
7.4	***	***	***	***	***	***	2.653	0.001	6.998
7.5	***	***	***	***	***	***	2.756	0.001	6.998
7.6	***	***	***	***	***	***	2.850	0.001	6.999
7.7	***	***	***	***	***	***	2.935	0.001	6.999
7.8	***	***	***	***	***	***	3.013	0.000	6.999
7.9	***	***	***	***	***	***	3.086	0.000	6.999
8.0	***	***	***	***	***	***	3.154	0.000	6.999

Teble A1.3: The charge abundance for N with κ=5.

log T	N^{+0}	N^{+1}	N^{+2}	N^{+3}	N^{+4}	N^{+5}	N^{+6}	N^{+7}	⟨Q⟩
4.0	1.292	0.060	1.112	3.496	***	***	***	***	1.027
4.1	1.732	0.103	0.721	2.640	***	***	***	***	1.176
4.2	2.172	0.214	0.432	1.916	4.875	***	***	***	1.387
4.3	2.595	0.391	0.261	1.364	3.939	***	***	***	1.632
4.4	2.985	0.609	0.190	0.974	3.208	***	***	***	1.859
4.5	3.336	0.850	0.182	0.703	2.634	***	***	***	2.061
4.6	3.672	1.098	0.220	0.509	2.151	4.158	***	***	2.244
4.7	4.017	1.363	0.296	0.366	1.711	3.235	***	***	2.428
4.8	4.421	1.692	0.416	0.265	1.313	2.367	***	***	2.633
4.9	4.884	2.066	0.598	0.221	0.960	1.551	***	***	2.897
5.0	***	2.558	0.891	0.280	0.695	0.846	***	***	3.353
5.1	***	3.254	1.388	0.540	0.631	0.361	4.214	***	4.064
5.2	***	4.213	2.139	1.047	0.812	0.126	3.486	***	4.645
5.3	***	***	3.011	1.677	1.117	0.046	2.917	***	4.880
5.4	***	***	3.897	2.326	1.450	0.020	2.410	***	4.959
5.5	***	***	4.765	2.958	1.776	0.013	1.935	4.828	4.993
5.6	***	***	***	3.557	2.081	0.018	1.486	3.919	5.024
5.7	***	***	***	4.112	2.360	0.041	1.074	3.050	5.082
5.8	***	***	***	4.637	2.620	0.096	0.719	2.258	5.200
5.9	***	***	***	***	2.874	0.210	0.450	1.567	5.408
6.0	***	***	***	***	3.141	0.396	0.300	1.015	5.694
6.1	***	***	***	***	3.441	0.660	0.273	0.606	6.028
6.2	***	***	***	***	3.778	0.985	0.361	0.337	6.357
6.3	***	***	***	***	4.170	1.371	0.538	0.176	6.625
6.4	***	***	***	***	4.583	1.777	0.763	0.091	6.794
6.5	***	***	***	***	***	2.189	1.008	0.048	6.889
6.6	***	***	***	***	***	2.584	1.247	0.027	6.938
6.7	***	***	***	***	***	2.967	1.474	0.015	6.964
6.8	***	***	***	***	***	3.330	1.683	0.009	6.978
6.9	***	***	***	***	***	3.671	1.873	0.006	6.986
7.0	***	***	***	***	***	3.995	2.047	0.004	6.991
7.1	***	***	***	***	***	4.300	2.203	0.003	6.994
7.2	***	***	***	***	***	4.590	2.346	0.002	6.995
7.3	***	***	***	***	***	4.860	2.475	0.001	6.997
7.4	***	***	***	***	***	***	2.591	0.001	6.997
7.5	***	***	***	***	***	***	2.698	0.001	6.998
7.6	***	***	***	***	***	***	2.795	0.001	6.998
7.7	***	***	***	***	***	***	2.883	0.001	6.999
7.8	***	***	***	***	***	***	2.965	0.000	6.999
7.9	***	***	***	***	***	***	3.040	0.000	6.999
8.0	***	***	***	***	***	***	3.111	0.000	6.999

Table A1.4: The charge abundance for N with $\kappa = 3$.

log T	N^{+0}	N^{+1}	N^{+2}	N^{+3}	N^{+4}	N^{+5}	N^{+6}	N^{+7}	$\langle Q \rangle$
4.0	2.471	0.483	0.239	1.047	2.964	***	***	***	1.756
4.1	2.926	0.712	0.209	0.740	2.370	4.966	***	***	1.994
4.2	3.375	0.977	0.240	0.515	1.882	4.150	***	***	2.225
4.3	3.799	1.259	0.315	0.368	1.505	3.441	***	***	2.437
4.4	4.168	1.528	0.417	0.281	1.211	2.818	***	***	2.622
4.5	4.516	1.796	0.529	0.236	0.989	2.269	***	***	2.786
4.6	4.830	2.044	0.650	0.224	0.814	1.769	***	***	2.946
4.7	***	2.302	0.792	0.242	0.673	1.310	4.927	***	3.139
4.8	***	2.604	0.975	0.304	0.575	0.889	4.186	***	3.414
4.9	***	2.980	1.233	0.436	0.543	0.542	3.516	***	3.802
5.0	***	3.479	1.608	0.678	0.597	0.291	2.947	***	4.254
5.1	***	4.112	2.108	1.033	0.759	0.141	2.476	***	4.620
5.2	***	4.841	2.697	1.467	0.984	0.070	2.087	4.948	4.830
5.3	***	***	3.339	1.942	1.244	0.039	1.744	4.293	4.937
5.4	***	***	4.010	2.439	1.515	0.033	1.421	3.654	5.000
5.5	***	***	4.699	2.948	1.791	0.043	1.122	3.044	5.059
5.6	***	***	***	3.455	2.066	0.072	0.851	2.463	5.139
5.7	***	***	***	3.971	2.348	0.132	0.611	1.924	5.264
5.8	***	***	***	4.494	2.638	0.232	0.426	1.436	5.446
5.9	***	***	***	***	2.943	0.384	0.309	1.023	5.680
6.0	***	***	***	***	3.257	0.588	0.269	0.692	5.944
6.1	***	***	***	***	3.595	0.855	0.302	0.443	6.220
6.2	***	***	***	***	3.938	1.154	0.404	0.271	6.465
6.3	***	***	***	***	4.287	1.478	0.558	0.161	6.657
6.4	***	***	***	***	4.646	1.817	0.744	0.095	6.789
6.5	***	***	***	***	***	2.156	0.946	0.056	6.873
6.6	***	***	***	***	***	2.496	1.156	0.033	6.924
6.7	***	***	***	***	***	2.827	1.360	0.020	6.953
6.8	***	***	***	***	***	3.142	1.550	0.013	6.970
6.9	***	***	***	***	***	3.459	1.738	0.008	6.981
7.0	***	***	***	***	***	3.759	1.909	0.005	6.987
7.1	***	***	***	***	***	4.046	2.066	0.004	6.991
7.2	***	***	***	***	***	4.327	2.213	0.003	6.994
7.3	***	***	***	***	***	4.593	2.345	0.002	6.995
7.4	***	***	***	***	***	4.851	2.470	0.001	6.997
7.5	***	***	***	***	***	***	2.584	0.001	6.997
7.6	***	***	***	***	***	***	2.688	0.001	6.998
7.7	***	***	***	***	***	***	2.784	0.001	6.998
7.8	***	***	***	***	***	***	2.872	0.001	6.999
7.9	***	***	***	***	***	***	2.953	0.000	6.999
8.0	***	***	***	***	***	***	3.028	0.000	6.999

Table A2.1: The charge abundance for O with Maxwellian distribution.

log T	O^{+0}	O^{+1}	O^{+2}	O^{+3}	O^{+4}	O^{+5}	O^{+6}	O^{+7}	O^{+8}	$\langle Q \rangle$
4.0	0.001	2.474	***	***	***	***	***	***	***	0.003
4.1	0.046	0.999	***	***	***	***	***	***	***	0.100
4.2	0.456	0.187	***	***	***	***	***	***	***	0.650
4.3	1.222	0.027	***	***	***	***	***	***	***	0.940
4.4	1.735	0.008	3.577	***	***	***	***	***	***	0.982
4.5	2.010	0.007	2.259	***	***	***	***	***	***	0.996
4.6	2.210	0.023	1.333	***	***	***	***	***	***	1.040
4.7	2.474	0.105	0.676	3.627	***	***	***	***	***	1.208
4.8	2.845	0.304	0.304	2.213	***	***	***	***	***	1.507
4.9	3.390	0.660	0.142	1.221	4.276	***	***	***	***	1.841
5.0	4.077	1.153	0.179	0.577	2.660	***	***	***	***	2.199
5.1	4.900	1.781	0.415	0.245	1.523	4.596	***	***	***	2.612
5.2	***	2.544	0.821	0.172	0.767	2.795	4.877	***	***	3.017
5.3	***	3.442	1.392	0.328	0.341	1.509	2.560	***	***	3.485
5.4	***	4.539	2.185	0.765	0.278	0.734	0.959	***	***	4.219
5.5	***	***	3.457	1.719	0.816	0.670	0.212	***	***	5.422
5.6	***	***	***	3.009	1.718	1.072	0.048	***	***	5.874
5.7	***	***	***	4.207	2.582	1.506	0.015	***	***	5.963
5.8	***	***	***	***	3.348	1.896	0.006	4.353	***	5.986
5.9	***	***	***	***	3.978	2.199	0.003	3.020	***	5.994
6.0	***	***	***	***	4.480	2.412	0.006	1.964	***	6.007
6.1	***	***	***	***	4.868	2.545	0.033	1.155	3.430	6.068
6.2	***	***	***	***	***	2.649	0.127	0.615	2.055	6.258
6.3	***	***	***	***	***	2.856	0.341	0.336	1.094	6.621
6.4	***	***	***	***	***	3.227	0.713	0.312	0.498	7.123
6.5	***	***	***	***	***	3.752	1.216	0.484	0.214	7.549
6.6	***	***	***	***	***	4.350	1.773	0.753	0.093	7.790
6.7	***	***	***	***	***	4.961	2.325	1.042	0.044	7.900
6.8	***	***	***	***	***	***	2.822	1.303	0.023	7.947
6.9	***	***	***	***	***	***	3.154	1.535	0.013	7.969
7.0	***	***	***	***	***	***	3.563	1.739	0.008	7.981
7.1	***	***	***	***	***	***	3.930	1.919	0.005	7.988
7.2	***	***	***	***	***	***	4.258	2.074	0.004	7.991
7.3	***	***	***	***	***	***	4.560	2.213	0.003	7.994
7.4	***	***	***	***	***	***	4.842	2.339	0.002	7.995
7.5	***	***	***	***	***	***	***	2.451	0.002	7.996
7.6	***	***	***	***	***	***	***	2.553	0.001	7.997
7.7	***	***	***	***	***	***	***	2.645	0.001	7.998
7.8	***	***	***	***	***	***	***	2.731	0.001	7.998
7.9	***	***	***	***	***	***	***	2.805	0.001	7.998
8.0	***	***	***	***	***	***	***	2.877	0.001	7.999

Table A2.2: The charge abundance for O with $\kappa = 10$.

log T	O^{+0}	O^{+1}	O^{+2}	O^{+3}	O^{+4}	O^{+5}	O^{+6}	O^{+7}	O^{+8}	⟨Q⟩
4.0	0.414	0.212	3.967	***	***	***	***	***	***	0.614
4.1	0.922	0.056	2.966	***	***	***	***	***	***	0.881
4.2	1.445	0.019	2.132	***	***	***	***	***	***	0.971
4.3	1.859	0.023	1.416	4.948	***	***	***	***	***	1.025
4.4	2.165	0.068	0.860	3.642	***	***	***	***	***	1.132
4.5	2.441	0.169	0.499	2.607	***	***	***	***	***	1.318
4.6	2.746	0.335	0.284	1.813	4.670	***	***	***	***	1.549
4.7	3.104	0.560	0.180	1.204	3.527	***	***	***	***	1.786
4.8	3.522	0.858	0.167	0.750	2.592	***	***	***	***	2.044
4.9	4.061	1.241	0.253	0.433	1.817	4.831	***	***	***	2.342
5.0	4.717	1.734	0.451	0.249	1.190	3.534	***	***	***	2.675
5.1	***	2.324	0.758	0.203	0.722	2.443	3.927	***	***	3.013
5.2	***	3.024	1.183	0.296	0.404	1.543	2.389	***	***	3.397
5.3	***	3.863	1.759	0.566	0.288	0.897	1.160	***	***	3.958
5.4	***	***	2.653	1.172	0.529	0.653	0.385	***	***	4.975
5.5	***	***	3.900	2.152	1.172	0.852	0.105	4.631	***	5.703
5.6	***	***	***	3.225	1.927	1.208	0.034	3.765	***	5.913
5.7	***	***	***	4.246	2.652	1.566	0.013	3.002	***	5.969
5.8	***	***	***	***	3.302	1.885	0.008	2.302	***	5.991
5.9	***	***	***	***	3.873	2.157	0.013	1.669	4.336	6.014
6.0	***	***	***	***	4.360	2.370	0.036	1.123	3.159	6.072
6.1	***	***	***	***	4.789	2.551	0.103	0.697	2.156	6.212
6.2	***	***	***	***	***	2.740	0.242	0.419	1.354	6.468
6.3	***	***	***	***	***	2.998	0.478	0.307	0.761	6.839
6.4	***	***	***	***	***	3.357	0.825	0.357	0.386	7.260
6.5	***	***	***	***	***	3.815	1.263	0.534	0.185	7.598
6.6	***	***	***	***	***	4.319	1.732	0.769	0.091	7.793
6.7	***	***	***	***	***	4.848	2.211	1.025	0.046	7.893
6.8	***	***	***	***	***	***	2.657	1.265	0.025	7.941
6.9	***	***	***	***	***	***	3.073	1.485	0.015	7.966
7.0	***	***	***	***	***	***	3.453	1.682	0.009	7.978
7.1	***	***	***	***	***	***	3.809	1.859	0.006	7.986
7.2	***	***	***	***	***	***	4.135	2.017	0.004	7.990
7.3	***	***	***	***	***	***	4.437	2.159	0.003	7.993
7.4	***	***	***	***	***	***	4.716	2.286	0.002	7.995
7.5	***	***	***	***	***	***	4.975	2.400	0.002	7.996
7.6	***	***	***	***	***	***	***	2.505	0.001	7.997
7.7	***	***	***	***	***	***	***	2.600	0.001	7.997
7.8	***	***	***	***	***	***	***	2.687	0.001	7.998
7.9	***	***	***	***	***	***	***	2.766	0.001	7.998
8.0	***	***	***	***	***	***	***	2.840	0.001	7.999

Table A2.3: The charge abundance for O with $\kappa = 5$.

log T	O^{+0}	O^{+1}	O^{+2}	O^{+3}	O^{+4}	O^{+5}	O^{+6}	O^{+7}	O^{+8}	⟨Q⟩
4.0	1.336	0.043	1.318	4.103	***	***	***	***	***	1.002
4.1	1.742	0.070	0.882	3.235	***	***	***	***	***	1.114
4.2	2.154	0.156	0.535	2.464	***	***	***	***	***	1.292
4.3	2.536	0.309	0.309	1.821	4.270	***	***	***	***	1.519
4.4	2.897	0.508	0.195	1.310	3.335	***	***	***	***	1.737
4.5	3.244	0.730	0.162	0.914	2.566	***	***	***	***	1.940
4.6	3.585	0.971	0.192	0.621	1.955	***	***	***	***	2.154
4.7	3.953	1.243	0.277	0.420	1.476	4.148	***	***	***	2.390
4.8	4.382	1.565	0.414	0.295	1.097	3.370	***	***	***	2.641
4.9	4.875	1.937	0.604	0.240	0.789	2.657	4.244	***	***	2.895
5.0	***	2.384	0.852	0.251	0.547	2.010	3.137	***	***	3.156
5.1	***	2.911	1.174	0.335	0.372	1.427	2.107	***	***	3.454
5.2	***	3.542	1.598	0.526	0.297	0.959	1.207	***	***	3.885
5.3	***	4.376	2.224	0.920	0.419	0.698	0.535	4.278	***	4.652
5.4	***	***	3.126	1.595	0.825	0.740	0.192	3.447	***	5.440
5.5	***	***	4.214	2.460	1.422	0.990	0.068	2.843	***	5.813
5.6	***	***	***	3.350	2.053	1.292	0.029	2.336	***	5.934
5.7	***	***	***	4.217	2.664	1.593	0.018	1.863	4.601	5.984
5.8	***	***	***	***	3.235	1.872	0.023	1.426	3.709	6.023
5.9	***	***	***	***	3.770	2.132	0.046	1.035	2.877	6.087
6.0	***	***	***	***	4.268	2.372	0.103	0.699	2.115	6.211
6.1	***	***	***	***	4.743	2.608	0.212	0.455	1.471	6.416
6.2	***	***	***	***	***	2.859	0.387	0.322	0.948	6.700
6.3	***	***	***	***	***	3.161	0.644	0.301	0.564	7.045
6.4	***	***	***	***	***	3.514	0.972	0.390	0.314	7.378
6.5	***	***	***	***	***	3.923	1.357	0.557	0.168	7.635
6.6	***	***	***	***	***	4.364	1.767	0.768	0.090	7.795
6.7	***	***	***	***	***	4.819	2.182	0.994	0.050	7.885
6.8	***	***	***	***	***	***	2.585	1.216	0.028	7.934
6.9	***	***	***	***	***	***	2.964	1.421	0.017	7.960
7.0	***	***	***	***	***	***	3.329	1.614	0.011	7.975
7.1	***	***	***	***	***	***	3.669	1.789	0.007	7.983
7.2	***	***	***	***	***	***	3.987	1.946	0.005	7.988
7.3	***	***	***	***	***	***	4.285	2.091	0.004	7.992
7.4	***	***	***	***	***	***	4.566	2.221	0.003	7.994
7.5	***	***	***	***	***	***	4.825	2.337	0.002	7.995
7.6	***	***	***	***	***	***	***	2.446	0.002	7.996
7.7	***	***	***	***	***	***	***	2.545	0.001	7.997
7.8	***	***	***	***	***	***	***	2.635	0.001	7.998
7.9	***	***	***	***	***	***	***	2.718	0.001	7.998
8.0	***	***	***	***	***	***	***	2.794	0.001	7.998

Table A2.4: The charge abundance for O with $\kappa = 3$.

log T	O^{+0}	O^{+1}	O^{+2}	O^{+3}	O^{+4}	O^{+5}	O^{+6}	O^{+7}	O^{+8}	$\langle Q \rangle$
4.0	2.435	0.405	0.260	1.282	3.174	***	***	***	***	1.653
4.1	2.868	0.612	0.192	0.962	2.551	***	***	***	***	1.868
4.2	3.309	0.861	0.183	0.709	2.006	4.502	***	***	***	2.077
4.3	3.717	1.127	0.227	0.518	1.540	3.842	***	***	***	2.287
4.4	4.103	1.403	0.320	0.387	1.154	3.270	***	***	***	2.513
4.5	4.479	1.691	0.455	0.312	0.855	2.784	4.835	***	***	2.751
4.6	4.838	1.980	0.622	0.287	0.638	2.372	4.100	***	***	2.979
4.7	***	2.284	0.810	0.300	0.484	2.012	3.421	***	***	3.183
4.8	***	2.588	1.010	0.340	0.377	1.684	2.775	***	***	3.364
4.9	***	2.912	1.227	0.407	0.302	1.380	2.152	***	***	3.542
5.0	***	3.274	1.473	0.509	0.263	1.090	1.551	4.860	***	3.759
5.1	***	3.708	1.782	0.671	0.278	0.848	1.000	3.990	***	4.095
5.2	***	4.268	2.208	0.946	0.396	0.704	0.553	3.224	***	4.634
5.3	***	***	2.798	1.384	0.669	0.711	0.263	2.617	***	5.249
5.4	***	***	3.555	1.976	1.080	0.857	0.119	2.158	4.990	5.669
5.5	***	***	4.394	2.647	1.563	1.077	0.060	1.786	4.304	5.871
5.6	***	***	***	3.351	2.074	1.327	0.041	1.461	3.669	5.970
5.7	***	***	***	4.063	2.585	1.583	0.045	1.156	3.057	6.040
5.8	***	***	***	4.771	3.090	1.843	0.070	0.884	2.477	6.121
5.9	***	***	***	***	3.591	2.102	0.122	0.646	1.940	6.241
6.0	***	***	***	***	4.093	2.372	0.211	0.461	1.457	6.411
6.1	***	***	***	***	4.596	2.652	0.350	0.337	1.041	6.640
6.2	***	***	***	***	***	2.953	0.542	0.288	0.708	6.906
6.3	***	***	***	***	***	3.266	0.781	0.313	0.459	7.181
6.4	***	***	***	***	***	3.608	1.073	0.405	0.283	7.436
6.5	***	***	***	***	***	3.960	1.389	0.544	0.172	7.632
6.6	***	***	***	***	***	4.337	1.735	0.723	0.101	7.774
6.7	***	***	***	***	***	4.717	2.083	0.914	0.061	7.861
6.8	***	***	***	***	***	***	2.424	1.106	0.037	7.914
6.9	***	***	***	***	***	***	2.766	1.298	0.023	7.946
7.0	***	***	***	***	***	***	3.095	1.481	0.015	7.965
7.1	***	***	***	***	***	***	3.414	1.651	0.010	7.977
7.2	***	***	***	***	***	***	3.719	1.811	0.007	7.984
7.3	***	***	***	***	***	***	4.010	1.957	0.005	7.989
7.4	***	***	***	***	***	***	4.287	2.093	0.004	7.992
7.5	***	***	***	***	***	***	4.550	2.217	0.003	7.994
7.6	***	***	***	***	***	***	4.803	2.332	0.002	7.995
7.7	***	***	***	***	***	***	***	2.436	0.002	7.996
7.8	***	***	***	***	***	***	***	2.534	0.001	7.997
7.9	***	***	***	***	***	***	***	2.623	0.001	7.998
8.0	***	***	***	***	***	***	***	2.706	0.001	7.998

Table A3.1: The charge abundance for Ne with Maxwellian distribution.

log T	Ne^{+0}	Ne^{+1}	Ne^{+2}	Ne^{+3}	Ne^{+4}	Ne^{+5}	Ne^{+6}	Ne^{+7}	Ne^{+8}	Ne^{+9}	Ne^{+10}	$\langle Q \rangle$
4.0	0.000	***	***	***	***	***	***	***	***	***	***	0.000
4.1	0.000	4.517	***	***	***	***	***	***	***	***	***	0.000
4.2	0.001	2.682	***	***	***	***	***	***	***	***	***	0.002
4.3	0.036	1.102	***	***	***	***	***	***	***	***	***	0.079
4.4	0.373	0.239	4.851	***	***	***	***	***	***	***	***	0.577
4.5	1.136	0.034	2.854	***	***	***	***	***	***	***	***	0.928
4.6	1.732	0.023	1.494	***	***	***	***	***	***	***	***	1.013
4.7	2.260	0.118	0.633	4.171	***	***	***	***	***	***	***	1.228
4.8	2.750	0.358	0.254	2.627	***	***	***	***	***	***	***	1.560
4.9	3.271	0.721	0.108	1.535	***	***	***	***	***	***	***	1.838
5.0	3.851	1.136	0.121	0.771	3.735	***	***	***	***	***	***	2.096
5.1	4.602	1.691	0.313	0.312	2.320	***	***	***	***	***	***	2.477
5.2	***	2.410	0.670	0.132	1.345	3.719	***	***	***	***	***	2.824
5.3	***	3.156	1.143	0.143	0.693	2.221	4.955	***	***	***	***	3.141
5.4	***	4.041	1.745	0.351	0.332	1.155	2.983	***	***	***	***	3.590
5.5	***	***	2.549	0.801	0.295	0.515	1.593	3.589	***	***	***	4.194
5.6	***	***	3.566	1.506	0.580	0.292	0.740	1.931	2.912	***	***	4.883
5.7	***	***	4.845	2.502	1.206	0.476	0.389	0.912	1.155	***	***	5.794
5.8	***	***	***	3.975	2.346	1.229	0.687	0.661	0.290	***	***	7.175
5.9	***	***	***	***	3.836	2.378	1.439	0.949	0.072	***	***	7.802
6.0	***	***	***	***	***	3.488	2.207	1.318	0.024	4.924	***	7.939
6.1	***	***	***	***	***	4.476	2.886	1.652	0.011	3.534	***	7.975
6.2	***	***	***	***	***	***	3.425	1.899	0.007	2.429	***	7.990
6.3	***	***	***	***	***	***	3.844	2.056	0.016	1.555	4.154	8.019
6.4	***	***	***	***	***	***	4.185	2.163	0.063	0.898	2.677	8.124
6.5	***	***	***	***	***	***	4.547	2.321	0.192	0.486	1.590	8.373
6.6	***	***	***	***	***	***	4.994	2.585	0.436	0.309	0.855	8.768
6.7	***	***	***	***	***	***	***	2.997	0.808	0.339	0.415	9.227
6.8	***	***	***	***	***	***	***	3.504	1.265	0.505	0.199	9.577
6.9	***	***	***	***	***	***	***	4.051	1.741	0.730	0.099	9.777
7.0	***	***	***	***	***	***	***	4.592	2.198	0.964	0.053	9.879
7.1	***	***	***	***	***	***	***	***	2.521	1.181	0.031	9.928
7.2	***	***	***	***	***	***	***	***	2.908	1.375	0.019	9.955
7.3	***	***	***	***	***	***	***	***	3.262	1.552	0.013	9.971
7.4	***	***	***	***	***	***	***	***	3.585	1.706	0.009	9.980
7.5	***	***	***	***	***	***	***	***	3.876	1.840	0.006	9.985
7.6	***	***	***	***	***	***	***	***	4.154	1.966	0.005	9.989
7.7	***	***	***	***	***	***	***	***	4.408	2.078	0.004	9.992
7.8	***	***	***	***	***	***	***	***	4.636	2.175	0.003	9.993
7.9	***	***	***	***	***	***	***	***	4.849	2.265	0.002	9.995
8.0	***	***	***	***	***	***	***	***	***	2.349	0.002	9.996

Table A3.2: The charge abundance for Ne with $\kappa = 10$.

log T	Ne^{+0}	Ne^{+1}	Ne^{+2}	Ne^{+3}	Ne^{+4}	Ne^{+5}	Ne^{+6}	Ne^{+7}	Ne^{+8}	Ne^{+9}	Ne^{+10}	$\langle Q \rangle$
4.0	0.014	1.497	***	***	***	***	***	***	***	***	***	0.032
4.1	0.086	0.744	4.174	***	***	***	***	***	***	***	***	0.180
4.2	0.350	0.258	2.872	***	***	***	***	***	***	***	***	0.555
4.3	0.839	0.075	1.872	***	***	***	***	***	***	***	***	0.869
4.4	1.408	0.053	1.117	4.040	***	***	***	***	***	***	***	1.037
4.5	1.951	0.141	0.578	2.805	***	***	***	***	***	***	***	1.256
4.6	2.566	0.373	0.251	1.886	***	***	***	***	***	***	***	1.584
4.7	3.088	0.662	0.138	1.272	4.178	***	***	***	***	***	***	1.834
4.8	3.569	0.977	0.131	0.814	3.143	***	***	***	***	***	***	2.049
4.9	4.051	1.336	0.212	0.474	2.298	***	***	***	***	***	***	2.299
5.0	4.648	1.766	0.392	0.258	1.611	3.795	***	***	***	***	***	2.585
5.1	***	2.296	0.670	0.159	1.069	2.764	***	***	***	***	***	2.865
5.2	***	2.901	1.035	0.172	0.658	1.875	4.003	***	***	***	***	3.152
5.3	***	3.617	1.506	0.309	0.391	1.156	2.747	***	***	***	***	3.520
5.4	***	4.451	2.106	0.603	0.305	0.642	1.729	3.566	***	***	***	4.001
5.5	***	***	2.873	1.082	0.429	0.364	0.978	2.246	3.190	***	***	4.577
5.6	***	***	3.839	1.780	0.791	0.348	0.526	1.275	1.662	***	***	5.274
5.7	***	***	***	2.781	1.482	0.690	0.467	0.740	0.624	***	***	6.382
5.8	***	***	***	4.204	2.610	1.491	0.901	0.747	0.180	4.403	***	7.462
5.9	***	***	***	***	3.904	2.487	1.559	1.023	0.059	3.528	***	7.840
6.0	***	***	***	***	***	3.453	2.217	1.338	0.024	2.796	***	7.942
6.1	***	***	***	***	***	4.326	2.804	1.619	0.015	2.129	***	7.980
6.2	***	***	***	***	***	***	3.312	1.850	0.019	1.539	3.921	8.014
6.3	***	***	***	***	***	***	3.743	2.030	0.047	1.036	2.841	8.085
6.4	***	***	***	***	***	***	4.129	2.190	0.119	0.654	1.933	8.239
6.5	***	***	***	***	***	***	4.529	2.385	0.264	0.408	1.220	8.507
6.6	***	***	***	***	***	***	4.991	2.659	0.499	0.316	0.703	8.877
6.7	***	***	***	***	***	***	***	3.024	0.826	0.365	0.378	9.268
6.8	***	***	***	***	***	***	***	3.464	1.218	0.517	0.197	9.574
6.9	***	***	***	***	***	***	***	3.940	1.636	0.717	0.105	9.762
7.0	***	***	***	***	***	***	***	4.429	2.052	0.931	0.059	9.865
7.1	***	***	***	***	***	***	***	4.903	2.443	1.135	0.035	9.919
7.2	***	***	***	***	***	***	***	***	2.805	1.319	0.022	9.949
7.3	***	***	***	***	***	***	***	***	3.149	1.495	0.014	9.967
7.4	***	***	***	***	***	***	***	***	3.467	1.649	0.010	9.977
7.5	***	***	***	***	***	***	***	***	3.759	1.788	0.007	9.983
7.6	***	***	***	***	***	***	***	***	4.031	1.913	0.005	9.988
7.7	***	***	***	***	***	***	***	***	4.285	2.026	0.004	9.990
7.8	***	***	***	***	***	***	***	***	4.521	2.128	0.003	9.993
7.9	***	***	***	***	***	***	***	***	4.740	2.222	0.003	9.994
8.0	***	***	***	***	***	***	***	***	4.946	2.308	0.002	9.995

Table A3.3: The charge abundance for Ne with $\kappa = 5$.

log T	Ne^{+0}	Ne^{+1}	Ne^{+2}	Ne^{+3}	Ne^{+4}	Ne^{+5}	Ne^{+6}	Ne^{+7}	Ne^{+8}	Ne^{+9}	Ne^{+10}	$\langle Q \rangle$
4.0	0.516	0.168	1.799	4.722	***	***	***	***	***	***	***	0.711
4.1	0.903	0.088	1.231	3.662	***	***	***	***	***	***	***	0.934
4.2	1.372	0.104	0.774	2.727	***	***	***	***	***	***	***	1.130
4.3	1.910	0.215	0.436	1.931	4.992	***	***	***	***	***	***	1.378
4.4	2.496	0.435	0.237	1.308	3.925	***	***	***	***	***	***	1.675
4.5	3.100	0.746	0.166	0.863	3.047	***	***	***	***	***	***	1.958
4.6	3.628	1.071	0.193	0.570	2.353	4.972	***	***	***	***	***	2.192
4.7	4.103	1.400	0.277	0.382	1.800	3.968	***	***	***	***	***	2.407
4.8	4.555	1.727	0.409	0.262	1.362	3.140	***	***	***	***	***	2.617
4.9	***	2.095	0.591	0.197	1.013	2.456	4.730	***	***	***	***	2.832
5.0	***	2.497	0.819	0.188	0.738	1.879	3.835	***	***	***	***	3.052
5.1	***	2.957	1.108	0.236	0.526	1.384	3.017	***	***	***	***	3.303
5.2	***	3.501	1.476	0.359	0.383	0.960	2.264	4.305	***	***	***	3.615
5.3	***	4.148	1.935	0.576	0.335	0.629	1.603	3.249	4.568	***	***	3.997
5.4	***	4.907	2.508	0.911	0.402	0.414	1.059	2.309	3.186	***	***	4.448
5.5	***	***	3.219	1.390	0.617	0.341	0.657	1.522	1.977	***	***	4.987
5.6	***	***	4.128	2.069	1.027	0.468	0.463	0.946	1.000	4.730	***	5.759
5.7	***	***	***	3.039	1.740	0.902	0.595	0.715	0.389	3.630	***	6.846
5.8	***	***	***	4.301	2.749	1.644	1.026	0.801	0.141	2.909	***	7.579
5.9	***	***	***	***	3.882	2.513	1.607	1.062	0.055	2.358	***	7.858
6.0	***	***	***	***	4.980	3.359	2.181	1.333	0.030	1.885	4.521	7.952
6.1	***	***	***	***	***	4.149	2.711	1.585	0.028	1.455	3.653	8.005
6.2	***	***	***	***	***	4.886	3.202	1.818	0.047	1.066	2.845	8.072
6.3	***	***	***	***	***	***	3.648	2.026	0.098	0.736	2.105	8.189
6.4	***	***	***	***	***	***	4.079	2.237	0.196	0.490	1.480	8.384
6.5	***	***	***	***	***	***	4.517	2.471	0.359	0.346	0.969	8.663
6.6	***	***	***	***	***	***	4.989	2.756	0.593	0.310	0.596	8.995
6.7	***	***	***	***	***	***	***	3.098	0.894	0.375	0.347	9.320
6.8	***	***	***	***	***	***	***	3.490	1.240	0.511	0.198	9.576
6.9	***	***	***	***	***	***	***	3.912	1.612	0.691	0.113	9.747
7.0	***	***	***	***	***	***	***	4.346	1.984	0.884	0.066	9.849
7.1	***	***	***	***	***	***	***	4.775	2.343	1.073	0.040	9.906
7.2	***	***	***	***	***	***	***	***	2.691	1.257	0.026	9.941
7.3	***	***	***	***	***	***	***	***	3.014	1.423	0.017	9.960
7.4	***	***	***	***	***	***	***	***	3.324	1.579	0.012	9.973
7.5	***	***	***	***	***	***	***	***	3.614	1.720	0.008	9.980
7.6	***	***	***	***	***	***	***	***	3.888	1.849	0.006	9.986
7.7	***	***	***	***	***	***	***	***	4.142	1.965	0.005	9.989
7.8	***	***	***	***	***	***	***	***	4.380	2.071	0.004	9.991
7.9	***	***	***	***	***	***	***	***	4.604	2.167	0.003	9.993
8.0	***	***	***	***	***	***	***	***	4.814	2.258	0.002	9.994

Table A3.4: The charge abundance for Ne with $\kappa = 3$.

log T	Ne^{+0}	Ne^{+1}	Ne^{+2}	Ne^{+3}	Ne^{+4}	Ne^{+5}	Ne^{+6}	Ne^{+7}	Ne^{+8}	Ne^{+9}	Ne^{+10}	⟨Q⟩
4.0	1.789	0.278	0.375	1.456	3.607	***	***	***	***	***	***	1.476
4.1	2.274	0.464	0.254	1.033	2.931	***	***	***	***	***	***	1.741
4.2	2.822	0.722	0.218	0.702	2.349	***	***	***	***	***	***	2.015
4.3	3.379	1.046	0.259	0.463	1.861	4.248	***	***	***	***	***	2.281
4.4	3.984	1.397	0.355	0.315	1.468	3.517	***	***	***	***	***	2.513
4.5	4.552	1.784	0.506	0.224	1.133	2.848	4.845	***	***	***	***	2.732
4.6	***	2.138	0.672	0.194	0.871	2.266	4.033	***	***	***	***	2.918
4.7	***	2.485	0.855	0.205	0.665	1.762	3.324	***	***	***	***	3.106
4.8	***	2.818	1.054	0.253	0.516	1.347	2.724	4.843	***	***	***	3.309
4.9	***	3.153	1.277	0.333	0.420	1.022	2.225	4.148	***	***	***	3.535
5.0	***	3.516	1.528	0.445	0.370	0.772	1.802	3.528	***	***	***	3.782
5.1	***	3.914	1.816	0.592	0.364	0.587	1.441	2.956	4.328	***	***	4.048
5.2	***	4.373	2.159	0.785	0.400	0.454	1.124	2.418	3.472	***	***	4.337
5.3	***	4.896	2.563	1.032	0.487	0.373	0.852	1.913	2.655	***	***	4.652
5.4	***	***	3.051	1.358	0.644	0.354	0.628	1.441	1.875	***	***	5.030
5.5	***	***	3.654	1.793	0.898	0.426	0.487	1.044	1.181	4.003	***	5.545
5.6	***	***	4.435	2.397	1.315	0.651	0.494	0.786	0.622	3.124	***	6.311
5.7	***	***	***	3.222	1.947	1.083	0.706	0.734	0.283	2.471	***	7.129
5.8	***	***	***	4.244	2.771	1.700	1.093	0.854	0.126	2.001	4.571	7.642
5.9	***	***	***	***	3.674	2.395	1.559	1.058	0.067	1.630	3.898	7.868
6.0	***	***	***	***	4.596	3.106	2.042	1.289	0.051	1.309	3.265	7.978
6.1	***	***	***	***	***	3.810	2.521	1.524	0.061	1.021	2.677	8.063
6.2	***	***	***	***	***	4.495	2.987	1.758	0.096	0.765	2.127	8.167
6.3	***	***	***	***	***	***	3.446	1.993	0.162	0.556	1.625	8.314
6.4	***	***	***	***	***	***	3.900	2.236	0.272	0.404	1.189	8.518
6.5	***	***	***	***	***	***	4.360	2.497	0.433	0.318	0.832	8.772
6.6	***	***	***	***	***	***	4.835	2.784	0.646	0.308	0.553	9.050
6.7	***	***	***	***	***	***	***	3.097	0.902	0.364	0.355	9.315
6.8	***	***	***	***	***	***	***	3.441	1.200	0.475	0.221	9.538
6.9	***	***	***	***	***	***	***	3.799	1.513	0.621	0.137	9.699
7.0	***	***	***	***	***	***	***	4.171	1.835	0.786	0.085	9.807
7.1	***	***	***	***	***	***	***	4.548	2.156	0.958	0.054	9.876
7.2	***	***	***	***	***	***	***	4.925	2.470	1.127	0.035	9.919
7.3	***	***	***	***	***	***	***	***	2.777	1.292	0.024	9.946
7.4	***	***	***	***	***	***	***	***	3.070	1.446	0.016	9.962
7.5	***	***	***	***	***	***	***	***	3.353	1.590	0.012	9.973
7.6	***	***	***	***	***	***	***	***	3.621	1.723	0.008	9.981
7.7	***	***	***	***	***	***	***	***	3.876	1.844	0.006	9.985
7.8	***	***	***	***	***	***	***	***	4.118	1.956	0.005	9.989
7.9	***	***	***	***	***	***	***	***	4.353	2.062	0.004	9.991
8.0	***	***	***	***	***	***	***	***	4.571	2.158	0.003	9.993

Table A4.1: The charge abundance for Mg with Maxwellian distribution.

log T	Mg^{+0}	Mg^{+1}	Mg^{+2}	Mg^{+3}	Mg^{+4}	Mg^{+5}	Mg^{+6}	⟨Q⟩
4.0	0.868	0.063	3.589	***	***	***	***	0.865
4.1	1.357	0.026	1.873	***	***	***	***	0.969
4.2	1.915	0.128	0.615	***	***	***	***	1.230
4.3	2.881	0.702	0.097	***	***	***	***	1.799
4.4	4.038	1.514	0.014	***	***	***	***	1.969
4.5	***	2.234	0.003	***	***	***	***	1.994
4.6	***	2.833	0.001	***	***	***	***	1.999
4.7	***	3.327	0.000	4.759	***	***	***	2.000
4.8	***	3.720	0.000	3.019	***	***	***	2.001
4.9	***	3.957	0.008	1.737	***	***	***	2.018
5.0	***	4.057	0.062	0.875	3.691	***	***	2.134
5.1	***	4.145	0.241	0.378	2.169	***	***	2.432
5.2	***	4.411	0.601	0.172	1.121	3.643	***	2.825
5.3	***	4.871	1.129	0.235	0.474	2.064	***	3.279
5.4	***	***	1.869	0.553	0.214	1.018	3.455	3.790
5.5	***	***	2.788	1.111	0.273	0.422	2.056	4.316
5.6	***	***	3.881	1.870	0.590	0.183	1.154	4.791
5.7	***	***	***	2.723	1.085	0.202	0.606	5.244
5.8	***	***	***	3.725	1.764	0.475	0.408	5.920
5.9	***	***	***	4.987	2.735	1.095	0.611	6.915
6.0	***	***	***	***	4.108	2.166	1.327	8.377
6.1	***	***	***	***	***	3.732	2.577	9.531
6.2	***	***	***	***	***	***	3.910	9.857

log T	Mg^{+6}	Mg^{+7}	Mg^{+8}	Mg^{+9}	Mg^{+10}	Mg^{+11}	Mg^{+12}	⟨Q⟩
5.5	2.056	4.330	***	***	***	***	***	4.316
5.6	1.154	2.614	4.954	***	***	***	***	4.791
5.7	0.606	1.403	2.929	***	***	***	***	5.244
5.8	0.408	0.651	1.497	2.932	4.174	***	***	5.920
5.9	0.611	0.389	0.667	1.421	1.941	***	***	6.915
6.0	1.327	0.713	0.511	0.694	0.616	***	***	8.377
6.1	2.577	1.616	0.999	0.734	0.162	***	***	9.531
6.2	3.910	2.649	1.671	1.029	0.054	4.823	***	9.857
6.3	***	3.571	2.284	1.327	0.024	3.505	***	9.942
6.4	***	4.350	2.787	1.560	0.014	2.463	***	9.972
6.5	***	4.980	3.167	1.706	0.019	1.642	4.197	10.002
6.6	***	***	3.499	1.827	0.052	1.014	2.806	10.084
6.7	***	***	3.832	1.967	0.149	0.581	1.751	10.287
6.8	***	***	4.247	2.200	0.341	0.356	1.010	10.629
6.9	***	***	4.791	2.573	0.657	0.315	0.534	11.067
7.0	***	***	***	3.046	1.057	0.413	0.279	11.436
7.1	***	***	***	3.564	1.501	0.589	0.148	11.678
7.2	***	***	***	4.097	1.938	0.788	0.083	11.814
7.3	***	***	***	4.487	2.229	0.979	0.051	11.883
7.4	***	***	***	4.959	2.596	1.152	0.033	11.924
7.5	***	***	***	***	2.967	1.345	0.021	11.953
7.6	***	***	***	***	3.237	1.456	0.016	11.964
7.7	***	***	***	***	3.527	1.584	0.012	11.973
7.8	***	***	***	***	3.778	1.701	0.009	11.980
7.9	***	***	***	***	4.017	1.808	0.007	11.984
8.0	***	***	***	***	4.233	1.903	0.005	11.987

Table A4.2: The charge abundance for Mg with $\kappa = 10$.

log T	Mg^{+0}	Mg^{+1}	Mg^{+2}	Mg^{+3}	Mg^{+4}	Mg^{+5}	Mg^{+6}	⟨Q⟩
4.0	1.866	0.139	0.583	***	***	***	***	1.247
4.1	2.429	0.454	0.191	***	***	***	***	1.641
4.2	3.190	0.970	0.050	***	***	***	***	1.892
4.3	3.998	1.538	0.013	4.517	***	***	***	1.971
4.4	4.773	2.077	0.004	3.636	***	***	***	1.992
4.5	***	2.572	0.002	2.795	***	***	***	1.999
4.6	***	3.014	0.005	2.005	***	***	***	2.009
4.7	***	3.405	0.023	1.298	3.868	***	***	2.050
4.8	***	3.761	0.094	0.717	2.651	***	***	2.196
4.9	***	4.091	0.260	0.364	1.763	4.458	***	2.467
5.0	***	4.388	0.514	0.209	1.125	3.277	***	2.770
5.1	***	4.700	0.852	0.193	0.670	2.307	***	3.083
5.2	***	***	1.281	0.309	0.371	1.513	3.850	3.436
5.3	***	***	1.838	0.566	0.232	0.898	2.759	3.829
5.4	***	***	2.519	0.968	0.265	0.477	1.882	4.246
5.5	***	***	3.336	1.518	0.464	0.250	1.219	4.660
5.6	***	***	4.275	2.189	0.808	0.196	0.752	5.057
5.7	***	***	***	2.977	1.295	0.314	0.481	5.555
5.8	***	***	***	3.931	1.970	0.652	0.458	6.284
5.9	***	***	***	***	2.908	1.285	0.761	7.315
6.0	***	***	***	***	4.246	2.344	1.513	8.732
6.1	***	***	***	***	***	3.756	2.641	9.597
6.2	***	***	***	***	***	***	3.825	9.859

log T	Mg^{+6}	Mg^{+7}	Mg^{+8}	Mg^{+9}	Mg^{+10}	Mg^{+11}	Mg^{+12}	⟨Q⟩
5.5	1.219	2.575	4.660	***	***	***	***	4.660
5.6	0.752	1.629	3.163	***	***	***	***	5.057
5.7	0.481	0.917	1.945	3.483	4.717	***	***	5.555
5.8	0.458	0.496	1.054	2.058	2.744	***	***	6.284
5.9	0.761	0.436	0.566	1.084	1.275	***	***	7.315
6.0	1.513	0.860	0.601	0.683	0.433	4.752	***	8.732
6.1	2.641	1.691	1.081	0.779	0.138	3.722	***	9.597
6.2	3.825	2.604	1.674	1.036	0.054	2.943	***	9.859
6.3	4.912	3.442	2.222	1.295	0.028	2.282	***	9.941
6.4	***	4.176	2.693	1.512	0.024	1.700	4.145	9.985
6.5	***	4.811	3.088	1.684	0.039	1.202	3.096	10.042
6.6	***	***	3.438	1.827	0.087	0.799	2.193	10.156
6.7	***	***	3.800	2.000	0.188	0.514	1.454	10.366
6.8	***	***	4.208	2.233	0.368	0.358	0.897	10.687
6.9	***	***	4.698	2.555	0.635	0.336	0.517	11.067
7.0	***	***	***	2.956	0.981	0.421	0.288	11.409
7.1	***	***	***	3.416	1.363	0.572	0.162	11.644
7.2	***	***	***	3.887	1.752	0.750	0.095	11.786
7.3	***	***	***	4.356	2.131	0.930	0.058	11.868
7.4	***	***	***	4.808	2.486	1.100	0.037	11.914
7.5	***	***	***	***	2.817	1.260	0.025	11.942
7.6	***	***	***	***	3.118	1.401	0.018	11.959
7.7	***	***	***	***	3.402	1.533	0.013	11.970
7.8	***	***	***	***	3.662	1.651	0.010	11.977
7.9	***	***	***	***	3.901	1.759	0.008	11.982
8.0	***	***	***	***	4.124	1.857	0.006	11.986

Table A4.3: The charge abundance for Mg with $\kappa = 5$.

log T	Mg^{+0}	Mg^{+1}	Mg^{+2}	Mg^{+3}	Mg^{+4}	Mg^{+5}	Mg^{+6}	⟨Q⟩
4.0	2.994	0.758	0.084	3.432	***	***	***	1.824
4.1	3.536	1.161	0.032	2.873	***	***	***	1.932
4.2	4.103	1.581	0.014	2.352	***	***	***	1.978
4.3	4.670	1.993	0.011	1.855	4.614	***	***	2.004
4.4	***	2.406	0.020	1.378	3.647	***	***	2.038
4.5	***	2.809	0.056	0.931	2.729	***	***	2.119
4.6	***	3.235	0.146	0.563	1.916	4.230	***	2.297
4.7	***	3.706	0.328	0.322	1.275	3.196	***	2.584
4.8	***	4.201	0.599	0.225	0.828	2.404	4.882	2.904
4.9	***	4.662	0.922	0.240	0.539	1.810	3.969	3.200
5.0	***	***	1.267	0.332	0.363	1.343	3.219	3.472
5.1	***	***	1.645	0.487	0.267	0.964	2.574	3.743
5.2	***	***	2.077	0.718	0.245	0.656	2.006	4.033
5.3	***	***	2.586	1.025	0.303	0.428	1.513	4.338
5.4	***	***	3.187	1.429	0.454	0.280	1.097	4.663
5.5	***	***	3.876	1.922	0.697	0.228	0.770	4.997
5.6	***	***	4.680	2.519	1.045	0.280	0.543	5.390
5.7	***	***	***	3.233	1.516	0.464	0.450	5.915
5.8	***	***	***	4.120	2.165	0.834	0.543	6.644
5.9	***	***	***	***	3.053	1.457	0.900	7.688
6.0	***	***	***	***	4.293	2.445	1.627	8.936
6.1	***	***	***	***	***	3.686	2.618	9.616
6.2	***	***	***	***	***	4.970	3.668	9.856

log T	Mg^{+6}	Mg^{+7}	Mg^{+8}	Mg^{+9}	Mg^{+10}	Mg^{+11}	Mg^{+12}	⟨Q⟩
5.5	0.770	1.606	3.060	***	***	***	***	4.997
5.6	0.543	1.054	2.137	3.683	4.875	***	***	5.390
5.7	0.450	0.648	1.371	2.515	3.288	***	***	5.915
5.8	0.543	0.437	0.809	1.564	1.937	***	***	6.644
5.9	0.900	0.506	0.544	0.921	0.920	4.351	***	7.688
6.0	1.627	0.959	0.675	0.699	0.346	3.304	***	8.936
6.1	2.618	1.692	1.106	0.801	0.132	2.630	***	9.616
6.2	3.668	2.498	1.628	1.026	0.060	2.116	4.881	9.856
6.3	4.672	3.272	2.134	1.260	0.038	1.668	4.001	9.950
6.4	***	3.976	2.590	1.473	0.041	1.268	3.184	10.016
6.5	***	4.615	2.998	1.664	0.068	0.923	2.442	10.103
6.6	***	***	3.378	1.843	0.131	0.639	1.788	10.247
6.7	***	***	3.763	2.044	0.245	0.440	1.233	10.471
6.8	***	***	4.174	2.283	0.419	0.338	0.811	10.763
6.9	***	***	4.642	2.587	0.667	0.334	0.497	11.098
7.0	***	***	***	2.948	0.971	0.411	0.298	11.395
7.1	***	***	***	3.351	1.312	0.545	0.177	11.616
7.2	***	***	***	3.778	1.667	0.704	0.108	11.759
7.3	***	***	***	4.205	2.019	0.872	0.067	11.846
7.4	***	***	***	4.634	2.357	1.037	0.044	11.899
7.5	***	***	***	***	2.677	1.192	0.030	11.932
7.6	***	***	***	***	2.976	1.335	0.021	11.952
7.7	***	***	***	***	3.257	1.468	0.015	11.965
7.8	***	***	***	***	3.520	1.590	0.011	11.974
7.9	***	***	***	***	3.764	1.700	0.009	11.980
8.0	***	***	***	***	3.990	1.800	0.007	11.984

Table A4.4:The charge abundance for Mg with $\kappa = 3$.

log T	Mg^{+0}	Mg^{+1}	Mg^{+2}	Mg^{+3}	Mg^{+4}	Mg^{+5}	Mg^{+6}	⟨Q⟩
4.0	4.073	1.411	0.040	1.321	3.333	***	***	2.010
4.1	4.474	1.738	0.054	1.015	2.711	***	***	2.082
4.2	4.901	2.086	0.096	0.738	2.119	4.254	***	2.190
4.3	***	2.471	0.180	0.510	1.579	3.401	***	2.359
4.4	***	2.909	0.328	0.347	1.113	2.631	4.886	2.609
4.5	***	3.411	0.555	0.274	0.748	1.978	3.944	2.921
4.6	***	3.972	0.863	0.296	0.494	1.455	3.152	3.256
4.7	***	4.562	1.229	0.397	0.346	1.065	2.519	3.573
4.8	***	***	1.624	0.553	0.281	0.786	2.028	3.855
4.9	***	***	2.001	0.742	0.276	0.591	1.647	4.102
5.0	***	***	2.395	0.946	0.312	0.457	1.353	4.321
5.1	***	***	2.764	1.169	0.382	0.363	1.116	4.530
5.2	***	***	3.136	1.415	0.483	0.303	0.912	4.739
5.3	***	***	3.560	1.706	0.621	0.275	0.743	4.960
5.4	***	***	4.024	2.046	0.808	0.285	0.601	5.211
5.5	***	***	4.562	2.452	1.052	0.341	0.501	5.507
5.6	***	***	***	2.937	1.367	0.466	0.456	5.880
5.7	***	***	***	3.537	1.792	0.682	0.492	6.363
5.8	***	***	***	4.270	2.345	1.028	0.651	7.013
5.9	***	***	***	***	3.104	1.574	1.000	7.944
6.0	***	***	***	***	4.116	2.376	1.601	8.951
6.1	***	***	***	***	***	3.384	2.407	9.569
6.2	***	***	***	***	***	4.469	3.291	9.835

log T	Mg^{+6}	Mg^{+7}	Mg^{+8}	Mg^{+9}	Mg^{+10}	Mg^{+11}	Mg^{+12}	⟨Q⟩
5.5	0.501	0.908	1.901	3.289	4.366	***	***	5.507
5.6	0.456	0.656	1.399	2.527	3.292	***	***	5.880
5.7	0.492	0.484	0.975	1.834	2.299	***	***	6.363
5.8	0.651	0.430	0.671	1.254	1.426	4.172	***	7.013
5.9	1.000	0.563	0.553	0.859	0.744	3.175	***	7.944
6.0	1.601	0.951	0.693	0.723	0.334	2.451	***	8.951
6.1	2.407	1.546	1.041	0.802	0.150	1.958	4.405	9.569
6.2	3.291	2.223	1.478	0.979	0.081	1.585	3.729	9.835
6.3	4.179	2.912	1.930	1.185	0.062	1.269	3.119	9.963
6.4	***	3.578	2.371	1.395	0.071	0.985	2.534	10.060
6.5	***	4.214	2.787	1.599	0.106	0.743	2.009	10.172
6.6	***	4.829	3.194	1.809	0.174	0.546	1.530	10.326
6.7	***	***	3.593	2.028	0.284	0.405	1.116	10.537
6.8	***	***	4.008	2.271	0.441	0.330	0.781	10.793
6.9	***	***	4.442	2.544	0.647	0.324	0.526	11.066
7.0	***	***	4.909	2.856	0.902	0.379	0.341	11.328
7.1	***	***	***	3.200	1.187	0.482	0.219	11.538
7.2	***	***	***	3.562	1.492	0.612	0.141	11.691
7.3	***	***	***	3.942	1.806	0.762	0.091	11.795
7.4	***	***	***	4.326	2.118	0.915	0.060	11.863
7.5	***	***	***	4.705	2.419	1.064	0.041	11.906
7.6	***	***	***	***	2.710	1.206	0.029	11.934
7.7	***	***	***	***	2.989	1.342	0.021	11.952
7.8	***	***	***	***	3.254	1.468	0.015	11.965
7.9	***	***	***	***	3.503	1.584	0.012	11.973
8.0	***	***	***	***	3.739	1.692	0.009	11.979

Table A5.1: The charge abundance for Si with Maxwellian distribution.

log T	Si^{+0}	Si^{+1}	Si^{+2}	Si^{+3}	Si^{+4}	Si^{+5}	Si^{+6}	Si^{+7}	⟨Q⟩
4.0	1.053	0.040	4.149	***	***	***	***	***	0.912
4.1	1.853	0.007	2.518	***	***	***	***	***	0.989
4.2	2.479	0.020	1.371	***	***	***	***	***	1.039
4.3	2.973	0.105	0.670	***	***	***	***	***	1.213
4.4	3.444	0.315	0.288	4.693	***	***	***	***	1.515
4.5	3.909	0.598	0.127	3.285	***	***	***	***	1.748
4.6	4.360	0.926	0.058	2.189	4.825	***	***	***	1.888
4.7	4.835	1.263	0.047	1.333	2.683	***	***	***	1.996
4.8	***	1.678	0.155	0.735	1.023	***	***	***	2.353
4.9	***	2.580	0.769	0.751	0.187	***	***	***	3.474
5.0	***	3.866	1.817	1.289	0.030	***	***	***	3.918
5.1	***	***	2.796	1.831	0.007	3.511	***	***	3.982
5.2	***	***	3.598	2.245	0.007	2.043	***	***	4.003
5.3	***	***	4.232	2.532	0.053	0.948	4.125	***	4.110
5.4	***	***	4.865	2.853	0.283	0.324	2.451	***	4.480
5.5	***	***	***	3.317	0.714	0.116	1.385	3.786	4.847
5.6	***	***	***	3.866	1.227	0.134	0.699	2.216	5.152
5.7	***	***	***	4.545	1.851	0.349	0.335	1.127	5.600
5.8	***	***	***	***	2.659	0.807	0.304	0.489	6.205
5.9	***	***	***	***	3.643	1.487	0.571	0.256	6.821
6.0	***	***	***	***	4.791	2.362	1.091	0.344	7.497
6.1	***	***	***	***	***	3.424	1.847	0.751	8.434
6.2	***	***	***	***	***	4.859	3.008	1.604	9.965
6.3	***	***	***	***	***	***	4.662	2.991	11.345
6.4	***	***	***	***	***	***	***	4.483	11.784

log T	Si^{+7}	Si^{+8}	Si^{+9}	Si^{+10}	Si^{+11}	Si^{+12}	Si^{+13}	Si^{+14}	⟨Q⟩
5.5	3.786	***	***	***	***	***	***	***	4.847
5.6	2.216	***	***	***	***	***	***	***	5.152
5.7	1.127	3.068	***	***	***	***	***	***	5.600
5.8	0.489	1.704	3.472	***	***	***	***	***	6.205
5.9	0.256	0.875	1.973	3.559	***	***	***	***	6.821
6.0	0.344	0.456	1.000	1.934	3.251	4.461	***	***	7.497
6.1	0.751	0.446	0.528	0.911	1.622	2.168	***	***	8.434
6.2	1.604	0.939	0.625	0.552	0.766	0.771	***	***	9.965
6.3	2.991	2.006	1.346	0.883	0.672	0.222	***	***	11.345
6.4	4.483	3.219	2.254	1.453	0.900	0.080	4.329	***	11.784
6.5	***	4.339	3.102	2.002	1.149	0.037	3.154	***	11.907
6.6	***	***	3.811	2.452	1.340	0.025	2.229	***	11.953
6.7	***	***	4.420	2.823	1.477	0.030	1.507	3.799	11.995
6.8	***	***	4.964	3.149	1.597	0.066	0.952	2.579	12.090
6.9	***	***	***	3.497	1.751	0.158	0.576	1.656	12.291
7.0	***	***	***	3.921	1.995	0.338	0.367	0.995	12.622
7.1	***	***	***	4.442	2.346	0.613	0.317	0.569	13.016
7.2	***	***	***	***	2.789	0.973	0.393	0.312	13.378
7.3	***	***	***	***	3.267	1.358	0.533	0.179	13.617
7.4	***	***	***	***	3.640	1.630	0.697	0.110	13.752
7.5	***	***	***	***	4.110	1.993	0.862	0.069	13.842
7.6	***	***	***	***	4.566	2.337	1.019	0.046	13.895
7.7	***	***	***	***	4.978	2.639	1.160	0.032	13.926
7.8	***	***	***	***	***	2.917	1.289	0.023	13.946
7.9	***	***	***	***	***	3.178	1.405	0.018	13.959
8.0	***	***	***	***	***	3.423	1.516	0.014	13.969

Table A5.2: The charge abundance for Si with $\kappa = 10$.

log T	Si^{+0}	Si^{+1}	Si^{+2}	Si^{+3}	Si^{+4}	Si^{+5}	Si^{+6}	Si^{+7}	$\langle Q \rangle$
4.0	2.144	0.084	0.771	4.639	***	***	***	***	1.162
4.1	2.689	0.204	0.429	3.669	***	***	***	***	1.371
4.2	3.201	0.385	0.232	2.945	***	***	***	***	1.588
4.3	3.634	0.580	0.135	2.374	***	***	***	***	1.741
4.4	4.038	0.797	0.083	1.867	4.001	***	***	***	1.854
4.5	4.400	1.023	0.064	1.399	2.788	***	***	***	1.948
4.6	4.767	1.281	0.085	0.980	1.676	***	***	***	2.095
4.7	***	1.650	0.227	0.693	0.739	4.817	***	***	2.545
4.8	***	2.341	0.696	0.754	0.209	3.446	***	***	3.408
4.9	***	3.329	1.471	1.135	0.051	2.480	***	***	3.861
5.0	***	4.358	2.289	1.585	0.023	1.691	4.756	***	3.984
5.1	***	***	3.063	2.012	0.050	1.012	3.493	***	4.086
5.2	***	***	3.817	2.444	0.175	0.489	2.429	***	4.328
5.3	***	***	4.592	2.913	0.451	0.206	1.639	4.040	4.667
5.4	***	***	***	3.396	0.827	0.117	1.068	2.919	4.938
5.5	***	***	***	3.876	1.247	0.151	0.647	1.971	5.190
5.6	***	***	***	4.407	1.725	0.302	0.378	1.207	5.527
5.7	***	***	***	***	2.314	0.605	0.289	0.654	5.987
5.8	***	***	***	***	3.049	1.076	0.406	0.346	6.513
5.9	***	***	***	***	3.932	1.714	0.718	0.273	7.068
6.0	***	***	***	***	4.957	2.511	1.220	0.431	7.740
6.1	***	***	***	***	***	3.525	1.963	0.866	8.734
6.2	***	***	***	***	***	4.894	3.084	1.712	10.263
6.3	***	***	***	***	***	***	4.589	2.965	11.390
6.4	***	***	***	***	***	***	***	4.305	11.774

log T	Si^{+7}	Si^{+8}	Si^{+9}	Si^{+10}	Si^{+11}	Si^{+12}	Si^{+13}	Si^{+14}	$\langle Q \rangle$
5.3	4.040	***	***	***	***	***	***	***	4.667
5.4	2.919	***	***	***	***	***	***	***	4.938
5.5	1.971	4.348	***	***	***	***	***	***	5.190
5.6	1.207	3.024	***	***	***	***	***	***	5.527
5.7	0.654	1.952	3.679	***	***	***	***	***	5.987
5.8	0.346	1.169	2.392	4.050	***	***	***	***	6.513
5.9	0.273	0.665	1.433	2.582	4.038	***	***	***	7.068
6.0	0.431	0.434	0.794	1.478	2.434	3.204	***	***	7.740
6.1	0.866	0.520	0.511	0.774	1.303	1.605	***	***	8.734
6.2	1.712	1.052	0.711	0.598	0.716	0.598	4.747	***	10.263
6.3	2.965	2.021	1.379	0.925	0.692	0.204	3.652	***	11.390
6.4	4.305	3.105	2.188	1.430	0.887	0.084	2.863	***	11.774
6.5	***	4.130	2.960	1.926	1.110	0.044	2.222	***	11.901
6.6	***	***	3.648	2.364	1.302	0.034	1.669	4.007	11.962
6.7	***	***	4.253	2.740	1.458	0.046	1.199	3.017	12.027
6.8	***	***	4.810	3.086	1.601	0.088	0.820	2.170	12.138
6.9	***	***	***	3.439	1.766	0.176	0.548	1.479	12.332
7.0	***	***	***	3.837	1.987	0.329	0.389	0.948	12.623
7.1	***	***	***	4.304	2.285	0.558	0.343	0.578	12.977
7.2	***	***	***	4.847	2.664	0.862	0.397	0.338	13.317
7.3	***	***	***	***	3.085	1.199	0.513	0.201	13.564
7.4	***	***	***	***	3.529	1.551	0.662	0.123	13.725
7.5	***	***	***	***	3.966	1.893	0.816	0.079	13.821
7.6	***	***	***	***	4.392	2.213	0.964	0.053	13.879
7.7	***	***	***	***	4.807	2.521	1.107	0.037	13.916
7.8	***	***	***	***	***	2.802	1.236	0.027	13.939
7.9	***	***	***	***	***	3.060	1.353	0.020	13.954
8.0	***	***	***	***	***	3.303	1.464	0.015	13.965

Table A5.3: The charge abundance for Si with $\kappa = 5$.

log T	Si^{+0}	Si^{+1}	Si^{+2}	Si^{+3}	Si^{+4}	Si^{+5}	Si^{+6}	Si^{+7}	⟨Q⟩
4.0	3.166	0.587	0.140	1.822	4.552	***	***	***	1.755
4.1	3.599	0.767	0.099	1.487	3.714	***	***	***	1.862
4.2	3.971	0.922	0.086	1.235	2.967	***	***	***	1.940
4.3	4.304	1.086	0.089	1.007	2.252	***	***	***	2.028
4.4	4.611	1.260	0.117	0.810	1.576	4.875	***	***	2.153
4.5	4.944	1.486	0.197	0.656	0.956	3.749	***	***	2.410
4.6	***	1.835	0.402	0.616	0.463	2.762	***	***	2.922
4.7	***	2.405	0.809	0.769	0.180	1.986	4.674	***	3.518
4.8	***	3.128	1.383	1.078	0.079	1.400	3.646	***	3.872
4.9	***	3.968	2.048	1.471	0.077	0.925	2.776	***	4.070
5.0	***	4.848	2.758	1.907	0.159	0.549	2.041	4.343	4.285
5.1	***	***	3.524	2.400	0.343	0.295	1.469	3.459	4.572
5.2	***	***	4.320	2.928	0.627	0.173	1.052	2.732	4.854
5.3	***	***	***	3.442	0.967	0.149	0.758	2.129	5.081
5.4	***	***	***	3.933	1.348	0.206	0.515	1.569	5.315
5.5	***	***	***	4.415	1.750	0.334	0.361	1.093	5.585
5.6	***	***	***	4.918	2.209	0.551	0.297	0.706	5.926
5.7	***	***	***	***	2.750	0.877	0.347	0.434	6.330
5.8	***	***	***	***	3.400	1.324	0.527	0.299	6.778
5.9	***	***	***	***	4.174	1.902	0.845	0.317	7.292
6.0	***	***	***	***	***	2.631	1.326	0.512	7.968
6.1	***	***	***	***	***	3.574	2.034	0.950	9.000
6.2	***	***	***	***	***	4.838	3.076	1.744	10.422
6.3	***	***	***	***	***	***	4.407	2.844	11.378
6.4	***	***	***	***	***	***	***	4.061	11.758

log T	Si^{+7}	Si^{+8}	Si^{+9}	Si^{+10}	Si^{+11}	Si^{+12}	Si^{+13}	Si^{+14}	⟨Q⟩
5.2	2.732	***	***	***	***	***	***	***	4.854
5.3	2.129	4.436	***	***	***	***	***	***	5.081
5.4	1.569	3.534	***	***	***	***	***	***	5.315
5.5	1.093	2.707	4.740	***	***	***	***	***	5.585
5.6	0.706	1.969	3.607	***	***	***	***	***	5.926
5.7	0.434	1.347	2.607	4.235	***	***	***	***	6.330
5.8	0.299	0.871	1.770	3.020	4.550	***	***	***	6.778
5.9	0.317	0.560	1.120	2.002	3.127	4.031	***	***	7.292
6.0	0.512	0.445	0.683	1.211	1.956	2.471	***	***	7.968
6.1	0.950	0.590	0.526	0.719	1.110	1.262	4.681	***	9.000
6.2	1.744	1.109	0.764	0.640	0.705	0.516	3.477	***	10.422
6.3	2.844	1.953	1.345	0.924	0.703	0.206	2.714	***	11.378
6.4	4.061	2.930	2.075	1.380	0.869	0.093	2.166	4.905	11.758
6.5	***	3.878	2.788	1.834	1.071	0.056	1.720	4.038	11.900
6.6	***	4.759	3.449	2.258	1.264	0.050	1.326	3.240	11.982
6.7	***	***	4.053	2.641	1.435	0.069	0.979	2.512	12.069
6.8	***	***	4.625	3.007	1.604	0.119	0.700	1.872	12.200
6.9	***	***	***	3.373	1.786	0.211	0.493	1.333	12.397
7.0	***	***	***	3.767	2.006	0.358	0.372	0.899	12.667
7.1	***	***	***	4.211	2.284	0.566	0.338	0.578	12.982
7.2	***	***	***	4.704	2.617	0.829	0.382	0.362	13.282
7.3	***	***	***	***	2.990	1.128	0.482	0.226	13.518
7.4	***	***	***	***	3.393	1.449	0.614	0.142	13.684
7.5	***	***	***	***	3.805	1.774	0.759	0.092	13.792
7.6	***	***	***	***	4.213	2.086	0.904	0.062	13.859
7.7	***	***	***	***	4.608	2.382	1.043	0.043	13.901
7.8	***	***	***	***	4.991	2.661	1.173	0.031	13.928
7.9	***	***	***	***	***	2.915	1.285	0.024	13.946
8.0	***	***	***	***	***	3.167	1.405	0.018	13.959

Table A5.4: The charge abundance for Si with $\kappa = 3$.

log T	Si^{+0}	Si^{+1}	Si^{+2}	Si^{+3}	Si^{+4}	Si^{+5}	Si^{+6}	Si^{+7}	⟨Q⟩
4.0	4.292	1.340	0.173	0.577	1.749	4.494	***	***	2.255
4.1	4.629	1.512	0.233	0.474	1.321	3.744	***	***	2.401
4.2	4.930	1.680	0.315	0.421	0.942	3.043	***	***	2.590
4.3	***	1.885	0.435	0.423	0.623	2.404	4.873	***	2.853
4.4	***	2.143	0.622	0.496	0.376	1.840	3.985	***	3.197
4.5	***	2.506	0.898	0.654	0.219	1.363	3.198	***	3.560
4.6	***	2.959	1.267	0.894	0.150	0.976	2.509	4.612	3.873
4.7	***	3.505	1.720	1.210	0.159	0.671	1.912	3.739	4.137
4.8	***	4.132	2.253	1.590	0.244	0.445	1.412	2.986	4.403
4.9	***	4.861	2.866	2.037	0.409	0.301	1.021	2.365	4.691
5.0	***	***	3.549	2.542	0.648	0.241	0.735	1.875	4.980
5.1	***	***	4.275	3.078	0.946	0.246	0.543	1.498	5.237
5.2	***	***	***	3.607	1.273	0.300	0.418	1.208	5.457
5.3	***	***	***	4.119	1.625	0.392	0.343	0.951	5.667
5.4	***	***	***	4.603	1.988	0.522	0.306	0.736	5.885
5.5	***	***	***	***	2.367	0.694	0.311	0.556	6.121
5.6	***	***	***	***	2.775	0.921	0.366	0.414	6.391
5.7	***	***	***	***	3.236	1.215	0.482	0.324	6.698
5.8	***	***	***	***	3.765	1.590	0.672	0.303	7.058
5.9	***	***	***	***	4.388	2.066	0.961	0.372	7.513
6.0	***	***	***	***	***	2.670	1.378	0.569	8.143
6.1	***	***	***	***	***	3.457	1.975	0.950	9.087
6.2	***	***	***	***	***	4.501	2.831	1.595	10.319
6.3	***	***	***	***	***	***	3.946	2.503	11.256
6.4	***	***	***	***	***	***	***	3.532	11.689

log T	Si^{+7}	Si^{+8}	Si^{+9}	Si^{+10}	Si^{+11}	Si^{+12}	Si^{+13}	Si^{+14}	⟨Q⟩
4.8	2.986	***	***	***	***	***	***	***	4.403
4.9	2.365	4.458	***	***	***	***	***	***	4.691
5.0	1.875	3.795	***	***	***	***	***	***	4.980
5.1	1.498	3.253	***	***	***	***	***	***	5.237
5.2	1.208	2.794	***	***	***	***	***	***	5.457
5.3	0.951	2.363	4.345	***	***	***	***	***	5.667
5.4	0.736	1.964	3.672	***	***	***	***	***	5.885
5.5	0.556	1.590	3.029	4.727	***	***	***	***	6.121
5.6	0.414	1.233	2.410	3.861	***	***	***	***	6.391
5.7	0.324	0.923	1.838	3.038	4.509	***	***	***	6.698
5.8	0.303	0.673	1.334	2.279	3.469	4.414	***	***	7.058
5.9	0.372	0.510	0.920	1.607	2.510	3.173	***	***	7.513
6.0	0.569	0.470	0.635	1.064	1.685	2.044	4.872	***	8.143
6.1	0.950	0.619	0.546	0.718	1.061	1.137	3.652	***	9.087
6.2	1.595	1.038	0.735	0.655	0.732	0.539	2.742	***	10.319
6.3	2.503	1.724	1.200	0.872	0.696	0.243	2.139	4.648	11.256
6.4	3.532	2.540	1.802	1.234	0.816	0.125	1.723	3.930	11.689
6.5	4.580	3.381	2.434	1.635	0.990	0.081	1.387	3.299	11.881
6.6	***	4.203	3.056	2.038	1.179	0.075	1.094	2.717	11.997
6.7	***	4.997	3.654	2.425	1.366	0.096	0.842	2.185	12.106
6.8	***	***	4.228	2.800	1.552	0.144	0.632	1.698	12.242
6.9	***	***	4.793	3.174	1.747	0.228	0.472	1.274	12.424
7.0	***	***	***	3.559	1.962	0.353	0.371	0.920	12.654
7.1	***	***	***	3.968	2.208	0.524	0.333	0.639	12.918
7.2	***	***	***	4.407	2.492	0.740	0.354	0.430	13.183
7.3	***	***	***	4.880	2.811	0.992	0.424	0.284	13.414
7.4	***	***	***	***	3.153	1.267	0.527	0.188	13.593
7.5	***	***	***	***	3.519	1.555	0.654	0.125	13.722
7.6	***	***	***	***	3.887	1.843	0.787	0.085	13.808
7.7	***	***	***	***	4.257	2.128	0.921	0.059	13.865
7.8	***	***	***	***	4.622	2.401	1.051	0.042	13.903
7.9	***	***	***	***	4.981	2.663	1.174	0.031	13.929
8.0	***	***	***	***	***	2.911	1.288	0.024	13.946

Table A6.1: The charge abundance for S with Maxwellian distribution.

log T	S^{+0}	S^{+1}	S^{+2}	S^{+3}	S^{+4}	S^{+5}	S^{+6}	S^{+7}	S^{+8}	⟨Q⟩
4.0	0.152	0.530	***	***	***	***	***	***	***	0.295
4.1	0.870	0.063	***	***	***	***	***	***	***	0.865
4.2	1.749	0.008	3.167	***	***	***	***	***	***	0.983
4.3	2.419	0.011	1.678	***	***	***	***	***	***	1.017
4.4	2.832	0.098	0.698	4.584	***	***	***	***	***	1.199
4.5	3.248	0.382	0.234	2.830	***	***	***	***	***	1.585
4.6	3.720	0.755	0.094	1.746	***	***	***	***	***	1.842
4.7	4.190	1.140	0.079	1.030	3.942	***	***	***	***	2.021
4.8	4.706	1.541	0.169	0.536	2.547	***	***	***	***	2.268
4.9	***	2.036	0.385	0.261	1.521	4.852	***	***	***	2.600
5.0	***	2.637	0.735	0.186	0.793	3.148	4.996	***	***	2.974
5.1	***	3.354	1.219	0.302	0.371	1.912	2.725	***	***	3.395
5.2	***	4.199	1.856	0.626	0.236	1.092	1.058	***	***	3.991
5.3	***	***	2.973	1.443	0.646	0.927	0.209	***	***	5.317
5.4	***	***	4.421	2.625	1.484	1.260	0.041	3.537	***	5.872
5.5	***	***	***	3.692	2.220	1.551	0.017	2.362	***	5.964
5.6	***	***	***	4.496	2.759	1.702	0.026	1.438	3.993	6.013
5.7	***	***	***	***	3.265	1.854	0.100	0.730	2.365	6.180
5.8	***	***	***	***	3.904	2.164	0.338	0.328	1.202	6.593
5.9	***	***	***	***	4.793	2.758	0.837	0.287	0.525	7.226
6.0	***	***	***	***	***	3.648	1.631	0.625	0.319	7.988
6.1	***	***	***	***	***	4.776	2.640	1.255	0.510	8.686
6.2	***	***	***	***	***	***	3.814	2.088	0.962	9.347
6.3	***	***	***	***	***	***	***	3.114	1.660	10.304
6.4	***	***	***	***	***	***	***	4.486	2.744	11.977
6.5	***	***	***	***	***	***	***	***	4.262	13.320

log T	S^{+8}	S^{+9}	S^{+10}	S^{+11}	S^{+12}	S^{+13}	S^{+14}	S^{+15}	S^{+16}	⟨Q⟩
5.6	3.993	***	***	***	***	***	***	***	***	6.013
5.7	2.365	4.890	***	***	***	***	***	***	***	6.180
5.8	1.202	2.844	***	***	***	***	***	***	***	6.593
5.9	0.525	1.425	3.419	***	***	***	***	***	***	7.226
6.0	0.319	0.607	1.925	3.529	***	***	***	***	***	7.988
6.1	0.510	0.276	1.026	2.046	3.452	***	***	***	***	8.686
6.2	0.962	0.287	0.562	1.101	1.919	3.024	4.019	***	***	9.347
6.3	1.660	0.606	0.472	0.620	0.953	1.522	1.940	***	***	10.304
6.4	2.744	1.369	0.883	0.688	0.617	0.756	0.694	***	***	11.977
6.5	4.262	2.601	1.805	1.322	0.896	0.682	0.222	4.975	***	13.320
6.6	***	3.946	2.878	2.118	1.385	0.874	0.088	3.660	***	13.756
6.7	***	***	3.843	2.841	1.836	1.069	0.048	2.661	***	13.883
6.8	***	***	4.692	3.470	2.224	1.228	0.036	1.874	4.514	13.941
6.9	***	***	***	4.016	2.551	1.349	0.047	1.264	3.226	14.005
7.0	***	***	***	4.541	2.874	1.479	0.094	0.811	2.205	14.131
7.1	***	***	***	***	3.239	1.663	0.204	0.501	1.429	14.367
7.2	***	***	***	***	3.684	1.937	0.392	0.347	0.879	14.703
7.3	***	***	***	***	4.205	2.296	0.666	0.323	0.518	15.077
7.4	***	***	***	***	4.790	2.719	0.992	0.388	0.313	15.381
7.5	***	***	***	***	***	3.058	1.230	0.515	0.197	15.574
7.6	***	***	***	***	***	3.512	1.574	0.655	0.124	15.724
7.7	***	***	***	***	***	3.945	1.896	0.791	0.083	15.813
7.8	***	***	***	***	***	4.366	2.203	0.930	0.057	15.870
7.9	***	***	***	***	***	4.758	2.483	1.055	0.042	15.905
8.0	***	***	***	***	***	***	2.743	1.170	0.031	15.929

Table A6.2: The charge abundance for S with $\kappa = 10$.

log T	S^{+0}	S^{+1}	S^{+2}	S^{+3}	S^{+4}	S^{+5}	S^{+6}	S^{+7}	S^{+8}	⟨Q⟩
4.0	1.363	0.030	1.619	***	***	***	***	***	***	0.981
4.1	1.974	0.060	0.925	4.019	***	***	***	***	***	1.108
4.2	2.589	0.204	0.430	2.846	***	***	***	***	***	1.371
4.3	3.159	0.466	0.190	1.959	***	***	***	***	***	1.668
4.4	3.643	0.769	0.106	1.338	3.968	***	***	***	***	1.876
4.5	4.040	1.057	0.105	0.900	3.103	***	***	***	***	2.040
4.6	4.408	1.357	0.159	0.588	2.369	***	***	***	***	2.223
4.7	4.834	1.680	0.271	0.371	1.735	4.680	***	***	***	2.441
4.8	***	2.063	0.444	0.245	1.202	3.620	***	***	***	2.686
4.9	***	2.500	0.699	0.205	0.766	2.673	3.895	***	***	2.970
5.0	***	3.031	1.044	0.272	0.449	1.856	2.429	***	***	3.303
5.1	***	3.690	1.513	0.477	0.290	1.225	1.203	4.523	***	3.789
5.2	***	4.622	2.268	0.976	0.453	0.935	0.377	3.028	***	4.841
5.3	***	***	3.415	1.890	1.047	1.106	0.091	2.140	***	5.709
5.4	***	***	4.630	2.883	1.740	1.404	0.040	1.538	3.993	5.949
5.5	***	***	***	3.769	2.352	1.647	0.055	1.042	2.941	6.061
5.6	***	***	***	4.581	2.904	1.856	0.129	0.635	2.000	6.236
5.7	***	***	***	***	3.492	2.120	0.306	0.361	1.223	6.553
5.8	***	***	***	***	4.202	2.528	0.639	0.276	0.666	7.024
5.9	***	***	***	***	***	3.141	1.172	0.422	0.377	7.623
6.0	***	***	***	***	***	3.971	1.914	0.812	0.368	8.270
6.1	***	***	***	***	***	4.989	2.831	1.408	0.601	8.872
6.2	***	***	***	***	***	***	3.887	2.173	1.040	9.530
6.3	***	***	***	***	***	***	***	3.131	1.705	10.541
6.4	***	***	***	***	***	***	***	4.427	2.736	12.148
6.5	***	***	***	***	***	***	***	***	4.126	13.318

log T	S^{+8}	S^{+9}	S^{+10}	S^{+11}	S^{+12}	S^{+13}	S^{+14}	S^{+15}	S^{+16}	⟨Q⟩
5.4	3.993	***	***	***	***	***	***	***	***	5.949
5.5	2.941	***	***	***	***	***	***	***	***	6.061
5.6	2.000	4.067	***	***	***	***	***	***	***	6.236
5.7	1.223	2.739	***	***	***	***	***	***	***	6.553
5.8	0.666	1.663	3.577	***	***	***	***	***	***	7.024
5.9	0.377	0.892	2.320	3.932	***	***	***	***	***	7.623
6.0	0.368	0.439	1.418	2.570	4.132	***	***	***	***	8.270
6.1	0.601	0.272	0.837	1.582	2.663	4.015	***	***	***	8.872
6.2	1.040	0.341	0.531	0.919	1.566	2.439	3.137	***	***	9.530
6.3	1.705	0.676	0.526	0.596	0.851	1.304	1.565	***	***	10.541
6.4	2.736	1.410	0.950	0.733	0.642	0.732	0.605	4.435	***	12.148
6.5	4.126	2.531	1.788	1.308	0.906	0.684	0.222	3.373	***	13.318
6.6	***	3.737	2.738	2.018	1.336	0.846	0.098	2.632	***	13.731
6.7	***	4.880	3.642	2.699	1.762	1.032	0.056	2.031	4.688	13.875
6.8	***	***	4.466	3.313	2.143	1.195	0.047	1.520	3.649	13.951
6.9	***	***	***	3.867	2.484	1.337	0.061	1.097	2.751	14.031
7.0	***	***	***	4.392	2.811	1.480	0.107	0.762	1.992	14.157
7.1	***	***	***	4.924	3.159	1.653	0.198	0.522	1.370	14.363
7.2	***	***	***	***	3.557	1.886	0.352	0.382	0.896	14.656
7.3	***	***	***	***	4.018	2.187	0.573	0.344	0.564	14.992
7.4	***	***	***	***	4.539	2.554	0.851	0.390	0.347	15.303
7.5	***	***	***	***	***	2.955	1.158	0.489	0.218	15.533
7.6	***	***	***	***	***	3.379	1.482	0.615	0.140	15.690
7.7	***	***	***	***	***	3.795	1.794	0.749	0.094	15.789
7.8	***	***	***	***	***	4.195	2.089	0.880	0.066	15.852
7.9	***	***	***	***	***	4.586	2.370	1.005	0.047	15.893
8.0	***	***	***	***	***	4.951	2.625	1.118	0.036	15.919

Table A6.3: The charge abundance for S with $\kappa = 5$.

log T	S^{+0}	S^{+1}	S^{+2}	S^{+3}	S^{+4}	S^{+5}	S^{+6}	S^{+7}	S^{+8}	⟨Q⟩
4.0	2.454	0.347	0.277	1.745	4.158	***	***	***	***	1.561
4.1	3.073	0.621	0.152	1.262	3.271	***	***	***	***	1.815
4.2	3.629	0.913	0.124	0.907	2.589	***	***	***	***	2.006
4.3	4.103	1.206	0.155	0.638	2.068	4.833	***	***	***	2.185
4.4	4.500	1.473	0.229	0.451	1.663	4.155	***	***	***	2.364
4.5	4.852	1.740	0.334	0.326	1.337	3.573	***	***	***	2.547
4.6	***	2.002	0.460	0.254	1.069	3.050	4.806	***	***	2.720
4.7	***	2.296	0.616	0.224	0.814	2.534	3.806	***	***	2.908
4.8	***	2.620	0.813	0.236	0.598	2.033	2.832	***	***	3.117
4.9	***	3.003	1.061	0.299	0.431	1.575	1.917	4.436	***	3.372
5.0	***	3.479	1.412	0.460	0.335	1.171	1.075	3.141	***	3.813
5.1	***	4.187	1.964	0.816	0.440	0.960	0.449	2.096	4.487	4.670
5.2	***	***	2.821	1.477	0.845	1.048	0.158	1.424	3.458	5.557
5.3	***	***	3.851	2.311	1.425	1.312	0.092	1.008	2.708	5.963
5.4	***	***	4.881	3.159	2.025	1.597	0.117	0.715	2.089	6.163
5.5	***	***	***	3.973	2.601	1.866	0.202	0.486	1.538	6.367
5.6	***	***	***	4.770	3.178	2.146	0.355	0.337	1.064	6.637
5.7	***	***	***	***	3.798	2.480	0.602	0.285	0.688	6.994
5.8	***	***	***	***	4.511	2.920	0.969	0.360	0.441	7.441
5.9	***	***	***	***	***	3.508	1.487	0.589	0.350	7.963
6.0	***	***	***	***	***	4.252	2.155	0.980	0.433	8.499
6.1	***	***	***	***	***	***	2.962	1.524	0.682	9.041
6.2	***	***	***	***	***	***	3.901	2.210	1.091	9.692
6.3	***	***	***	***	***	***	***	3.092	1.711	10.704
6.4	***	***	***	***	***	***	***	4.273	2.647	12.178
6.5	***	***	***	***	***	***	***	***	3.885	13.260

log T	S^{+8}	S^{+9}	S^{+10}	S^{+11}	S^{+12}	S^{+13}	S^{+14}	S^{+15}	S^{+16}	⟨Q⟩
5.3	2.708	***	***	***	***	***	***	***	***	5.963
5.4	2.089	4.084	***	***	***	***	***	***	***	6.163
5.5	1.538	3.194	***	***	***	***	***	***	***	6.367
5.6	1.064	2.374	4.434	***	***	***	***	***	***	6.637
5.7	0.688	1.649	3.381	***	***	***	***	***	***	6.994
5.8	0.441	1.054	2.456	4.003	***	***	***	***	***	7.441
5.9	0.350	0.617	1.691	2.890	4.511	***	***	***	***	7.963
6.0	0.433	0.365	1.116	1.987	3.229	4.744	***	***	***	8.499
6.1	0.682	0.289	0.726	1.291	2.170	3.285	4.180	***	***	9.041
6.2	1.091	0.392	0.528	0.810	1.348	2.091	2.612	***	***	9.692
6.3	1.711	0.721	0.571	0.589	0.804	1.196	1.366	4.666	***	10.704
6.4	2.647	1.388	0.966	0.739	0.657	0.735	0.583	3.422	***	12.178
6.5	3.885	2.375	1.699	1.243	0.885	0.681	0.239	2.640	***	13.260
6.6	***	3.473	2.557	1.886	1.269	0.815	0.114	2.097	4.716	13.695
6.7	***	4.544	3.403	2.525	1.671	0.990	0.070	1.657	3.868	13.867
6.8	***	***	4.196	3.123	2.045	1.159	0.062	1.277	3.103	13.965
6.9	***	***	4.935	3.676	2.392	1.318	0.080	0.950	2.445	14.062
7.0	***	***	***	4.210	2.731	1.477	0.128	0.687	1.811	14.199
7.1	***	***	***	4.740	3.078	1.655	0.218	0.493	1.302	14.397
7.2	***	***	***	***	3.460	1.875	0.356	0.378	0.895	14.659
7.3	***	***	***	***	3.888	2.146	0.551	0.340	0.595	14.958
7.4	***	***	***	***	4.364	2.471	0.797	0.373	0.384	15.246
7.5	***	***	***	***	4.875	2.837	1.077	0.456	0.248	15.478
7.6	***	***	***	***	***	3.219	1.369	0.567	0.164	15.642
7.7	***	***	***	***	***	3.614	1.666	0.692	0.111	15.753
7.8	***	***	***	***	***	4.004	1.956	0.821	0.077	15.826
7.9	***	***	***	***	***	4.379	2.228	0.940	0.056	15.873
8.0	***	***	***	***	***	4.748	2.491	1.060	0.041	15.906

Table A6.4: The charge abundance for S with $\kappa = 3$.

log T	S^{+0}	S^{+1}	S^{+2}	S^{+3}	S^{+4}	S^{+5}	S^{+6}	S^{+7}	S^{+8}	⟨Q⟩
4.0	3.939	1.305	0.282	0.418	1.337	3.306	***	***	***	2.425
4.1	4.459	1.617	0.381	0.332	1.033	2.755	***	***	***	2.632
4.2	4.932	1.930	0.501	0.288	0.815	2.324	4.302	***	***	2.824
4.3	***	2.198	0.624	0.277	0.664	1.995	3.643	***	***	2.987
4.4	***	2.449	0.765	0.279	0.555	1.736	3.057	***	***	3.139
4.5	***	2.673	0.899	0.299	0.474	1.521	2.513	4.935	***	3.275
4.6	***	2.903	1.044	0.334	0.411	1.330	1.998	4.101	***	3.419
4.7	***	3.144	1.211	0.397	0.363	1.150	1.495	3.285	***	3.610
4.8	***	3.440	1.426	0.502	0.350	0.993	1.020	2.503	4.527	3.911
4.9	***	3.816	1.721	0.689	0.410	0.897	0.613	1.795	3.535	4.420
5.0	***	4.351	2.165	1.020	0.601	0.919	0.332	1.226	2.699	5.128
5.1	***	***	2.805	1.530	0.956	1.086	0.208	0.831	2.057	5.768
5.2	***	***	3.575	2.167	1.425	1.355	0.207	0.579	1.581	6.178
5.3	***	***	4.395	2.848	1.934	1.665	0.279	0.425	1.221	6.455
5.4	***	***	***	3.602	2.496	1.989	0.400	0.335	0.934	6.705
5.5	***	***	***	4.340	3.045	2.308	0.562	0.301	0.709	6.957
5.6	***	***	***	***	3.606	2.634	0.770	0.320	0.535	7.234
5.7	***	***	***	***	4.201	2.992	1.038	0.400	0.416	7.549
5.8	***	***	***	***	4.853	3.409	1.385	0.553	0.363	7.908
5.9	***	***	***	***	***	3.906	1.822	0.792	0.389	8.299
6.0	***	***	***	***	***	4.505	2.359	1.131	0.510	8.720
6.1	***	***	***	***	***	***	3.009	1.578	0.735	9.191
6.2	***	***	***	***	***	***	3.779	2.146	1.080	9.784
6.3	***	***	***	***	***	***	4.704	2.872	1.587	10.655
6.4	***	***	***	***	***	***	***	3.833	2.334	11.901
6.5	***	***	***	***	***	***	***	***	3.345	13.009

log T	S^{+8}	S^{+9}	S^{+10}	S^{+11}	S^{+12}	S^{+13}	S^{+14}	S^{+15}	S^{+16}	⟨Q⟩
4.9	3.535	***	***	***	***	***	***	***	***	4.420
5.0	2.699	4.660	***	***	***	***	***	***	***	5.128
5.1	2.057	3.785	***	***	***	***	***	***	***	5.768
5.2	1.581	3.097	***	***	***	***	***	***	***	6.178
5.3	1.221	2.538	4.452	***	***	***	***	***	***	6.455
5.4	0.934	2.055	3.785	***	***	***	***	***	***	6.705
5.5	0.709	1.635	3.186	4.955	***	***	***	***	***	6.957
5.6	0.535	1.260	2.628	4.177	***	***	***	***	***	7.234
5.7	0.416	0.930	2.110	3.436	***	***	***	***	***	7.549
5.8	0.363	0.657	1.638	2.741	4.272	***	***	***	***	7.908
5.9	0.389	0.458	1.233	2.108	3.380	4.940	***	***	***	8.299
6.0	0.510	0.341	0.902	1.551	2.559	3.827	4.832	***	***	8.720
6.1	0.735	0.324	0.664	1.090	1.836	2.810	3.519	***	***	9.191
6.2	1.080	0.428	0.544	0.753	1.239	1.925	2.347	***	***	9.784
6.3	1.587	0.695	0.588	0.588	0.820	1.223	1.368	3.886	***	10.655
6.4	2.334	1.207	0.876	0.676	0.660	0.796	0.678	2.881	***	11.901
6.5	3.345	1.993	1.442	1.050	0.794	0.678	0.312	2.213	4.702	13.009
6.6	4.502	2.932	2.167	1.588	1.104	0.755	0.158	1.762	3.956	13.574
6.7	***	3.899	2.929	2.170	1.468	0.905	0.100	1.414	3.317	13.821
6.8	***	4.846	3.675	2.741	1.833	1.074	0.085	1.122	2.740	13.959
6.9	***	***	4.398	3.291	2.184	1.243	0.100	0.871	2.216	14.075
7.0	***	***	***	3.825	2.530	1.417	0.142	0.658	1.734	14.212
7.1	***	***	***	4.346	2.874	1.598	0.217	0.497	1.317	14.387
7.2	***	***	***	4.877	3.230	1.799	0.328	0.391	0.969	14.604
7.3	***	***	***	***	3.618	2.035	0.485	0.340	0.686	14.859
7.4	***	***	***	***	4.038	2.308	0.682	0.346	0.474	15.118
7.5	***	***	***	***	4.490	2.615	0.914	0.399	0.322	15.350
7.6	***	***	***	***	4.964	2.949	1.169	0.484	0.219	15.533
7.7	***	***	***	***	***	3.300	1.438	0.594	0.150	15.671
7.8	***	***	***	***	***	3.660	1.709	0.710	0.105	15.765
7.9	***	***	***	***	***	4.016	1.972	0.830	0.075	15.830
8.0	***	***	***	***	***	4.373	2.234	0.946	0.055	15.875

Table A7.1: The charge abundance for Ar with Maxwellian distribution.

log T	Ar^{+0}	Ar^{+1}	Ar^{+2}	Ar^{+3}	Ar^{+4}	Ar^{+5}	Ar^{+6}	Ar^{+7}	Ar^{+8}	Ar^{+9}	$\langle Q \rangle$
4.0	0.000	3.339	***	***	***	***	***	***	***	***	0.000
4.1	0.012	1.557	***	***	***	***	***	***	***	***	0.028
4.2	0.221	0.399	4.746	***	***	***	***	***	***	***	0.399
4.3	1.009	0.046	2.488	***	***	***	***	***	***	***	0.905
4.4	2.047	0.055	0.959	***	***	***	***	***	***	***	1.101
4.5	3.181	0.468	0.183	2.584	***	***	***	***	***	***	1.661
4.6	4.477	1.136	0.056	1.321	***	***	***	***	***	***	1.975
4.7	***	1.640	0.117	0.671	4.384	***	***	***	***	***	2.190
4.8	***	2.113	0.279	0.333	3.031	***	***	***	***	***	2.459
4.9	***	2.573	0.529	0.160	2.026	***	***	***	***	***	2.708
5.0	***	3.063	0.819	0.100	1.281	3.672	***	***	***	***	2.899
5.1	***	3.599	1.162	0.132	0.724	2.377	4.959	***	***	***	3.128
5.2	***	4.197	1.586	0.273	0.395	1.423	3.212	***	***	***	3.454
5.3	***	4.908	2.128	0.554	0.273	0.775	1.904	4.164	***	***	3.899
5.4	***	***	2.847	1.024	0.377	0.421	0.997	2.503	2.889	***	4.498
5.5	***	***	3.742	1.718	0.754	0.428	0.519	1.393	1.053	***	5.434
5.6	***	***	***	3.000	1.751	1.072	0.746	1.092	0.197	3.513	7.230
5.7	***	***	***	4.609	3.108	2.111	1.432	1.279	0.047	2.318	7.852
5.8	***	***	***	***	4.304	3.042	2.034	1.451	0.034	1.538	7.973
5.9	***	***	***	***	***	3.874	2.574	1.614	0.063	0.985	8.082
6.0	***	***	***	***	***	4.701	3.134	1.836	0.154	0.613	8.308
6.1	***	***	***	***	***	***	3.781	2.178	0.364	0.430	8.760
6.2	***	***	***	***	***	***	4.580	2.703	0.753	0.485	9.445
6.3	***	***	***	***	***	***	***	3.450	1.361	0.796	10.248
6.4	***	***	***	***	***	***	***	4.409	2.181	1.348	11.164
6.5	***	***	***	***	***	***	***	***	3.280	2.200	12.526

log T	Ar^{+9}	Ar^{+10}	Ar^{+11}	Ar^{+12}	Ar^{+13}	Ar^{+14}	Ar^{+15}	Ar^{+16}	Ar^{+17}	Ar^{+18}	$\langle Q \rangle$
5.7	2.318	***	***	***	***	***	***	***	***	***	7.852
5.8	1.538	3.679	***	***	***	***	***	***	***	***	7.973
5.9	0.985	2.368	4.738	***	***	***	***	***	***	***	8.082
6.0	0.613	1.415	3.020	***	***	***	***	***	***	***	8.308
6.1	0.430	0.766	1.770	3.445	***	***	***	***	***	***	8.760
6.2	0.485	0.430	0.949	2.044	3.394	***	***	***	***	***	9.445
6.3	0.796	0.399	0.509	1.123	1.968	3.094	4.489	***	***	***	10.248
6.4	1.348	0.659	0.417	0.636	1.051	1.650	2.510	3.121	***	***	11.164
6.5	2.200	1.243	0.699	0.585	0.638	0.829	1.257	1.376	***	***	12.526
6.6	3.560	2.358	1.543	1.131	0.875	0.702	0.725	0.429	***	***	14.547
6.7	***	3.794	2.728	2.058	1.531	1.040	0.779	0.154	3.956	***	15.518
6.8	***	***	3.939	3.029	2.255	1.486	0.948	0.072	2.901	***	15.802
6.9	***	***	***	3.898	2.899	1.881	1.099	0.047	2.083	4.952	15.898
7.0	***	***	***	4.668	3.469	2.226	1.217	0.047	1.444	3.631	15.963
7.1	***	***	***	***	4.003	2.557	1.341	0.076	0.961	2.576	16.063
7.2	***	***	***	***	4.538	2.901	1.491	0.152	0.613	1.760	16.244
7.3	***	***	***	***	***	3.315	1.722	0.293	0.398	1.147	16.522
7.4	***	***	***	***	***	3.790	2.023	0.509	0.309	0.723	16.860
7.5	***	***	***	***	***	4.326	2.397	0.785	0.320	0.452	17.181
7.6	***	***	***	***	***	4.911	2.822	1.105	0.392	0.288	17.433
7.7	***	***	***	***	***	***	3.125	1.299	0.511	0.194	17.589
7.8	***	***	***	***	***	***	3.544	1.608	0.630	0.131	17.715
7.9	***	***	***	***	***	***	3.962	1.908	0.757	0.090	17.800
8.0	***	***	***	***	***	***	4.350	2.179	0.869	0.066	17.851

Table A7.2: The charge abundance for Ar with $\kappa = 10$.

log T	Ar^{+0}	Ar^{+1}	Ar^{+2}	Ar^{+3}	Ar^{+4}	Ar^{+5}	Ar^{+6}	Ar^{+7}	Ar^{+8}	Ar^{+9}	⟨Q⟩
4.0	0.391	0.230	2.316	***	***	***	***	***	***	***	0.599
4.1	0.947	0.075	1.343	4.436	***	***	***	***	***	***	0.932
4.2	1.654	0.130	0.630	2.878	***	***	***	***	***	***	1.215
4.3	2.573	0.429	0.219	1.690	***	***	***	***	***	***	1.643
4.4	3.649	0.962	0.118	0.891	3.713	***	***	***	***	***	2.019
4.5	4.739	1.552	0.210	0.451	2.827	***	***	***	***	***	2.329
4.6	***	2.056	0.370	0.253	2.229	***	***	***	***	***	2.561
4.7	***	2.447	0.537	0.162	1.772	4.340	***	***	***	***	2.719
4.8	***	2.788	0.717	0.118	1.351	3.520	***	***	***	***	2.850
4.9	***	3.148	0.923	0.111	0.984	2.749	***	***	***	***	2.987
5.0	***	3.540	1.169	0.147	0.678	2.048	4.130	***	***	***	3.159
5.1	***	3.986	1.476	0.248	0.441	1.426	3.049	***	***	***	3.407
5.2	***	4.521	1.862	0.433	0.308	0.931	2.109	4.167	***	***	3.736
5.3	***	***	2.362	0.734	0.308	0.569	1.328	2.871	3.175	***	4.177
5.4	***	***	2.998	1.180	0.473	0.410	0.780	1.834	1.569	4.279	4.805
5.5	***	***	3.968	1.965	0.999	0.615	0.620	1.216	0.465	2.552	6.278
5.6	***	***	***	3.293	2.080	1.404	1.063	1.231	0.105	1.662	7.636
5.7	***	***	***	4.720	3.267	2.318	1.663	1.434	0.063	1.162	7.975
5.8	***	***	***	***	4.368	3.170	2.222	1.626	0.094	0.815	8.137
5.9	***	***	***	***	***	3.988	2.764	1.829	0.177	0.573	8.351
6.0	***	***	***	***	***	4.823	3.341	2.093	0.333	0.442	8.696
6.1	***	***	***	***	***	***	3.998	2.466	0.598	0.443	9.196
6.2	***	***	***	***	***	***	4.778	2.982	1.002	0.601	9.808
6.3	***	***	***	***	***	***	***	3.662	1.566	0.931	10.502
6.4	***	***	***	***	***	***	***	4.526	2.309	1.453	11.362
6.5	***	***	***	***	***	***	***	***	3.311	2.242	12.709
6.6	***	***	***	***	***	***	***	***	4.724	3.452	14.496
6.7	***	***	***	***	***	***	***	***	***	4.960	15.463

log T	Ar^{+9}	Ar^{+10}	Ar^{+11}	Ar^{+12}	Ar^{+13}	Ar^{+14}	Ar^{+15}	Ar^{+16}	Ar^{+17}	Ar^{+18}	⟨Q⟩
5.5	2.552	***	***	***	***	***	***	***	***	***	6.278
5.6	1.662	3.876	***	***	***	***	***	***	***	***	7.636
5.7	1.162	2.807	***	***	***	***	***	***	***	***	7.975
5.8	0.815	1.967	4.074	***	***	***	***	***	***	***	8.137
5.9	0.573	1.306	2.877	***	***	***	***	***	***	***	8.351
6.0	0.442	0.815	1.916	3.665	***	***	***	***	***	***	8.696
6.1	0.443	0.502	1.189	2.464	3.945	***	***	***	***	***	9.196
6.2	0.601	0.377	0.703	1.557	2.604	3.969	***	***	***	***	9.808
6.3	0.931	0.446	0.452	0.937	1.593	2.511	3.632	4.526	***	***	10.502
6.4	1.453	0.726	0.445	0.605	0.924	1.443	2.152	2.599	***	***	11.362
6.5	2.242	1.289	0.746	0.618	0.639	0.800	1.151	1.201	***	***	12.709
6.6	3.452	2.283	1.497	1.108	0.858	0.700	0.736	0.441	3.798	***	14.496
6.7	4.960	3.586	2.573	1.945	1.450	1.004	0.761	0.170	2.903	***	15.463
6.8	***	4.909	3.684	2.836	2.114	1.410	0.913	0.084	2.250	***	15.775
6.9	***	***	4.723	3.670	2.736	1.794	1.067	0.057	1.721	4.073	15.895
7.0	***	***	***	4.433	3.302	2.142	1.201	0.058	1.271	3.144	15.976
7.1	***	***	***	***	3.835	2.475	1.332	0.085	0.907	2.353	16.079
7.2	***	***	***	***	4.358	2.811	1.480	0.148	0.631	1.701	16.237
7.3	***	***	***	***	4.905	3.184	1.674	0.260	0.443	1.173	16.473
7.4	***	***	***	***	***	3.606	1.925	0.427	0.348	0.782	16.767
7.5	***	***	***	***	***	4.086	2.242	0.655	0.335	0.508	17.077
7.6	***	***	***	***	***	4.605	2.606	0.923	0.386	0.331	17.342
7.7	***	***	***	***	***	***	2.999	1.214	0.479	0.218	17.543
7.8	***	***	***	***	***	***	3.399	1.508	0.590	0.148	17.679
7.9	***	***	***	***	***	***	3.790	1.790	0.706	0.104	17.770
8.0	***	***	***	***	***	***	4.171	2.060	0.819	0.076	17.831

Table A7.3: The charge abundance for Ar with $\kappa = 5$.

log T	Ar^{+0}	Ar^{+1}	Ar^{+2}	Ar^{+3}	Ar^{+4}	Ar^{+5}	Ar^{+6}	Ar^{+7}	Ar^{+8}	Ar^{+9}	$\langle Q \rangle$
4.0	1.729	0.242	0.404	1.838	4.541	***	***	***	***	***	1.404
4.1	2.460	0.515	0.209	1.141	3.376	***	***	***	***	***	1.760
4.2	3.320	0.946	0.183	0.645	2.467	***	***	***	***	***	2.119
4.3	4.238	1.462	0.301	0.346	1.844	4.111	***	***	***	***	2.445
4.4	***	2.031	0.495	0.198	1.439	3.434	***	***	***	***	2.698
4.5	***	2.507	0.687	0.139	1.192	2.970	***	***	***	***	2.855
4.6	***	2.869	0.850	0.123	0.991	2.581	4.872	***	***	***	2.964
4.7	***	3.152	0.993	0.131	0.820	2.233	4.306	***	***	***	3.060
4.8	***	3.429	1.151	0.156	0.663	1.880	3.724	***	***	***	3.173
4.9	***	3.711	1.328	0.207	0.521	1.534	3.131	***	***	***	3.315
5.0	***	4.024	1.542	0.292	0.404	1.195	2.534	4.599	***	***	3.502
5.1	***	4.411	1.815	0.429	0.326	0.889	1.959	3.703	4.299	***	3.749
5.2	***	4.862	2.164	0.631	0.312	0.636	1.421	2.833	2.975	***	4.068
5.3	***	***	2.614	0.930	0.390	0.470	0.971	2.039	1.749	3.577	4.530
5.4	***	***	3.260	1.422	0.664	0.490	0.704	1.429	0.746	2.168	5.544
5.5	***	***	4.332	2.339	1.363	0.939	0.870	1.253	0.226	1.293	7.186
5.6	***	***	***	3.579	2.390	1.726	1.371	1.419	0.121	0.876	7.950
5.7	***	***	***	4.841	3.447	2.547	1.924	1.644	0.151	0.639	8.227
5.8	***	***	***	***	4.485	3.349	2.460	1.866	0.236	0.493	8.462
5.9	***	***	***	***	***	4.147	3.004	2.111	0.373	0.421	8.759
6.0	***	***	***	***	***	4.958	3.581	2.405	0.576	0.429	9.139
6.1	***	***	***	***	***	***	4.220	2.776	0.860	0.526	9.587
6.2	***	***	***	***	***	***	4.946	3.253	1.246	0.731	10.104
6.3	***	***	***	***	***	***	***	3.853	1.749	1.052	10.708
6.4	***	***	***	***	***	***	***	4.620	2.414	1.536	11.513
6.5	***	***	***	***	***	***	***	***	3.307	2.248	12.778
6.6	***	***	***	***	***	***	***	***	4.545	3.309	14.401
6.7	***	***	***	***	***	***	***	***	***	4.641	15.372

log T	Ar^{+9}	Ar^{+10}	Ar^{+11}	Ar^{+12}	Ar^{+13}	Ar^{+14}	Ar^{+15}	Ar^{+16}	Ar^{+17}	Ar^{+18}	$\langle Q \rangle$
5.3	3.577	***	***	***	***	***	***	***	***	***	4.530
5.4	2.168	4.208	***	***	***	***	***	***	***	***	5.544
5.5	1.293	2.941	***	***	***	***	***	***	***	***	7.186
5.6	0.876	2.151	4.377	***	***	***	***	***	***	***	7.950
5.7	0.639	1.574	3.424	***	***	***	***	***	***	***	8.227
5.8	0.493	1.109	2.589	4.681	***	***	***	***	***	***	8.462
5.9	0.421	0.758	1.884	3.609	***	***	***	***	***	***	8.759
6.0	0.429	0.514	1.301	2.665	4.197	***	***	***	***	***	9.139
6.1	0.526	0.385	0.863	1.885	3.061	4.579	***	***	***	***	9.587
6.2	0.731	0.373	0.567	1.266	2.111	3.255	4.577	***	***	***	10.104
6.3	1.052	0.495	0.427	0.827	1.367	2.160	3.117	3.825	***	***	10.708
6.4	1.536	0.777	0.468	0.594	0.855	1.318	1.940	2.290	***	***	11.513
6.5	2.248	1.296	0.760	0.636	0.640	0.798	1.114	1.135	4.176	***	12.778
6.6	3.309	2.170	1.420	1.062	0.829	0.706	0.745	0.466	3.063	***	14.401
6.7	4.641	3.320	2.366	1.791	1.338	0.953	0.740	0.197	2.369	***	15.372
6.8	***	4.539	3.388	2.609	1.947	1.319	0.873	0.102	1.875	4.303	15.738
6.9	***	***	4.373	3.400	2.541	1.689	1.028	0.072	1.466	3.509	15.890
7.0	***	***	***	4.152	3.105	2.042	1.178	0.073	1.117	2.796	15.992
7.1	***	***	***	4.863	3.637	2.377	1.321	0.101	0.830	2.168	16.105
7.2	***	***	***	***	4.157	2.714	1.475	0.162	0.599	1.623	16.262
7.3	***	***	***	***	4.691	3.073	1.659	0.262	0.439	1.175	16.474
7.4	***	***	***	***	***	3.471	1.889	0.412	0.350	0.817	16.738
7.5	***	***	***	***	***	3.913	2.169	0.609	0.329	0.555	17.019
7.6	***	***	***	***	***	4.392	2.493	0.846	0.366	0.373	17.274
7.7	***	***	***	***	***	4.901	2.852	1.112	0.443	0.251	17.481
7.8	***	***	***	***	***	***	3.223	1.386	0.542	0.173	17.629
7.9	***	***	***	***	***	***	3.601	1.662	0.653	0.122	17.733
8.0	***	***	***	***	***	***	3.971	1.929	0.764	0.088	17.804

Table A7.4: The charge abundance for Ar with $\kappa = 3$.

log T	Ar^{+0}	Ar^{+1}	Ar^{+2}	Ar^{+3}	Ar^{+4}	Ar^{+5}	Ar^{+6}	Ar^{+7}	Ar^{+8}	Ar^{+9}	⟨Q⟩
4.0	3.619	1.242	0.314	0.377	1.432	3.125	***	***	***	***	2.438
4.1	4.389	1.716	0.489	0.249	1.051	2.476	4.534	***	***	***	2.732
4.2	***	2.228	0.721	0.202	0.782	1.975	3.791	***	***	***	2.985
4.3	***	2.719	0.955	0.204	0.621	1.637	3.241	***	***	***	3.172
4.4	***	3.158	1.177	0.232	0.517	1.388	2.825	4.937	***	***	3.323
4.5	***	3.509	1.356	0.269	0.452	1.216	2.520	4.458	***	***	3.440
4.6	***	3.797	1.502	0.310	0.407	1.085	2.278	4.065	***	***	3.540
4.7	***	4.026	1.633	0.361	0.374	0.960	2.044	3.689	4.902	***	3.646
4.8	***	4.233	1.758	0.425	0.349	0.845	1.820	3.326	4.207	***	3.764
4.9	***	4.466	1.917	0.506	0.335	0.730	1.587	2.949	3.501	***	3.906
5.0	***	4.713	2.097	0.612	0.337	0.622	1.354	2.558	2.783	4.552	4.082
5.1	***	***	2.328	0.759	0.364	0.531	1.111	2.140	2.047	3.504	4.325
5.2	***	***	2.621	0.966	0.447	0.473	0.896	1.737	1.330	2.490	4.737
5.3	***	***	3.076	1.319	0.654	0.529	0.771	1.408	0.704	1.580	5.631
5.4	***	***	3.805	1.941	1.126	0.837	0.892	1.311	0.330	0.945	7.032
5.5	***	***	4.819	2.840	1.875	1.417	1.272	1.462	0.233	0.619	7.993
5.6	***	***	***	3.895	2.758	2.114	1.763	1.716	0.279	0.464	8.431
5.7	***	***	***	4.975	3.669	2.840	2.277	1.982	0.382	0.398	8.718
5.8	***	***	***	***	4.585	3.565	2.789	2.246	0.522	0.389	8.992
5.9	***	***	***	***	***	4.308	3.313	2.520	0.699	0.432	9.286
6.0	***	***	***	***	***	***	3.850	2.815	0.917	0.523	9.603
6.1	***	***	***	***	***	***	4.426	3.153	1.184	0.667	9.951
6.2	***	***	***	***	***	***	***	3.551	1.513	0.873	10.351
6.3	***	***	***	***	***	***	***	4.037	1.927	1.160	10.846
6.4	***	***	***	***	***	***	***	4.642	2.454	1.556	11.520
6.5	***	***	***	***	***	***	***	***	3.150	2.116	12.543
6.6	***	***	***	***	***	***	***	***	4.111	2.938	13.959
6.7	***	***	***	***	***	***	***	***	***	4.016	15.076

log T	Ar^{+9}	Ar^{+10}	Ar^{+11}	Ar^{+12}	Ar^{+13}	Ar^{+14}	Ar^{+15}	Ar^{+16}	Ar^{+17}	Ar^{+18}	⟨Q⟩
5.1	3.504	***	***	***	***	***	***	***	***	***	4.325
5.2	2.490	4.117	***	***	***	***	***	***	***	***	4.737
5.3	1.580	2.935	***	***	***	***	***	***	***	***	5.631
5.4	0.945	2.044	3.918	***	***	***	***	***	***	***	7.032
5.5	0.619	1.474	3.140	***	***	***	***	***	***	***	7.993
5.6	0.464	1.089	2.542	4.488	***	***	***	***	***	***	8.431
5.7	0.398	0.801	2.035	3.777	***	***	***	***	***	***	8.718
5.8	0.389	0.589	1.596	3.119	4.778	***	***	***	***	***	8.992
5.9	0.432	0.441	1.214	2.512	3.937	***	***	***	***	***	9.286
6.0	0.523	0.357	0.899	1.962	3.148	4.701	***	***	***	***	9.603
6.1	0.667	0.337	0.654	1.482	2.428	3.704	***	***	***	***	9.951
6.2	0.873	0.388	0.489	1.079	1.785	2.787	3.948	4.848	***	***	10.351
6.3	1.160	0.524	0.416	0.776	1.246	1.980	2.856	3.467	***	***	10.846
6.4	1.556	0.772	0.466	0.602	0.847	1.318	1.920	2.245	4.958	***	11.520
6.5	2.116	1.183	0.689	0.615	0.647	0.864	1.208	1.263	3.666	***	12.543
6.6	2.938	1.854	1.178	0.900	0.728	0.702	0.804	0.605	2.707	***	13.959
6.7	4.016	2.781	1.928	1.459	1.095	0.838	0.717	0.279	2.073	4.483	15.076
6.8	***	3.839	2.814	2.160	1.610	1.134	0.799	0.148	1.647	3.768	15.607
6.9	***	4.913	3.718	2.887	2.162	1.475	0.942	0.100	1.319	3.155	15.841
7.0	***	***	4.609	3.606	2.707	1.819	1.098	0.092	1.037	2.595	15.980
7.1	***	***	***	4.301	3.234	2.156	1.255	0.113	0.801	2.092	16.103
7.2	***	***	***	4.979	3.749	2.490	1.414	0.162	0.608	1.644	16.247
7.3	***	***	***	***	4.264	2.832	1.588	0.242	0.462	1.256	16.427
7.4	***	***	***	***	4.791	3.194	1.788	0.359	0.368	0.931	16.645
7.5	***	***	***	***	***	3.588	2.023	0.515	0.328	0.669	16.889
7.6	***	***	***	***	***	4.012	2.292	0.708	0.336	0.472	17.131
7.7	***	***	***	***	***	4.462	2.593	0.928	0.384	0.331	17.344
7.8	***	***	***	***	***	4.939	2.923	1.174	0.462	0.232	17.517
7.9	***	***	***	***	***	***	3.267	1.426	0.557	0.164	17.646
8.0	***	***	***	***	***	***	3.616	1.681	0.661	0.119	17.739

Table A8.1: The charge abundance for Ca with Maxwellian distribution.

log T	Ca^{+0}	Ca^{+1}	Ca^{+2}	Ca^{+3}	Ca^{+4}	Ca^{+5}	Ca^{+6}	Ca^{+7}	Ca^{+8}	Ca^{+9}	Ca^{+10}	⟨Q⟩
4.0	1.120	0.040	1.934	***	***	***	***	***	***	***	***	0.936
4.1	1.719	0.121	0.651	***	***	***	***	***	***	***	***	1.204
4.2	2.709	0.675	0.104	***	***	***	***	***	***	***	***	1.785
4.3	3.902	1.478	0.015	***	***	***	***	***	***	***	***	1.966
4.4	4.983	2.211	0.003	***	***	***	***	***	***	***	***	1.994
4.5	***	2.822	0.001	4.541	***	***	***	***	***	***	***	1.999
4.6	***	3.187	0.001	2.841	***	***	***	***	***	***	***	2.001
4.7	***	3.204	0.008	1.730	***	***	***	***	***	***	***	2.018
4.8	***	3.074	0.037	1.090	3.833	***	***	***	***	***	***	2.081
4.9	***	3.002	0.107	0.668	2.630	***	***	***	***	***	***	2.218
5.0	***	3.074	0.242	0.391	1.707	3.923	***	***	***	***	***	2.445
5.1	***	3.298	0.469	0.252	1.017	2.512	***	***	***	***	***	2.762
5.2	***	3.668	0.815	0.271	0.562	1.445	3.831	***	***	***	***	3.193
5.3	***	4.248	1.330	0.488	0.364	0.719	2.371	4.840	***	***	***	3.781
5.4	***	***	2.043	0.924	0.433	0.337	1.380	3.133	***	***	***	4.408
5.5	***	***	2.916	1.544	0.722	0.231	0.747	1.883	3.607	***	***	4.956
5.6	***	***	3.923	2.316	1.201	0.351	0.415	1.027	2.130	3.719	4.135	5.523
5.7	***	***	***	3.276	1.883	0.716	0.390	0.545	1.115	2.070	1.783	6.310
5.8	***	***	***	4.694	3.052	1.601	0.926	0.678	0.782	1.190	0.381	8.371
5.9	***	***	***	***	4.867	3.157	2.167	1.564	1.256	1.174	0.077	9.714
6.0	***	***	***	***	***	4.677	3.394	2.467	1.786	1.280	0.045	9.928
6.1	***	***	***	***	***	***	4.510	3.288	2.272	1.396	0.061	10.036
6.2	***	***	***	***	***	***	***	4.088	2.765	1.555	0.126	10.219
6.3	***	***	***	***	***	***	***	4.918	3.321	1.816	0.285	10.630
6.4	***	***	***	***	***	***	***	***	4.065	2.295	0.652	11.532
6.5	***	***	***	***	***	***	***	***	***	3.160	1.398	12.805
6.6	***	***	***	***	***	***	***	***	***	4.311	2.425	13.964
6.7	***	***	***	***	***	***	***	***	***	***	3.789	15.458

log T	Ca^{+10}	Ca^{+11}	Ca^{+12}	Ca^{+13}	Ca^{+14}	Ca^{+15}	Ca^{+16}	Ca^{+17}	Ca^{+18}	Ca^{+19}	Ca^{+20}	⟨Q⟩
5.7	1.783	***	***	***	***	***	***	***	***	***	***	6.310
5.8	0.381	3.479	***	***	***	***	***	***	***	***	***	8.371
5.9	0.077	2.294	***	***	***	***	***	***	***	***	***	9.714
6.0	0.045	1.601	3.677	***	***	***	***	***	***	***	***	9.928
6.1	0.061	1.087	2.494	4.378	***	***	***	***	***	***	***	10.036
6.2	0.126	0.713	1.589	2.751	4.715	***	***	***	***	***	***	10.219
6.3	0.285	0.498	0.938	1.515	2.830	4.393	***	***	***	***	***	10.630
6.4	0.652	0.542	0.611	0.694	1.469	2.501	3.840	***	***	***	***	11.532
6.5	1.398	0.988	0.722	0.386	0.708	1.293	2.127	3.158	4.101	***	***	12.805
6.6	2.425	1.755	1.224	0.542	0.479	0.709	1.114	1.698	2.142	***	***	13.964
6.7	3.789	2.879	2.086	1.101	0.706	0.614	0.661	0.879	0.919	***	***	15.458
6.8	***	4.345	3.321	2.065	1.376	1.012	0.744	0.648	0.350	4.234	***	16.908
6.9	***	***	4.694	3.199	2.253	1.634	1.090	0.719	0.157	3.064	***	17.552
7.0	***	***	***	4.269	3.091	2.251	1.459	0.852	0.090	2.230	***	17.776
7.1	***	***	***	***	3.885	2.838	1.820	0.982	0.070	1.567	3.878	17.888
7.2	***	***	***	***	4.617	3.373	2.156	1.114	0.081	1.077	2.825	17.995
7.3	***	***	***	***	***	3.906	2.502	1.269	0.135	0.700	1.984	18.160
7.4	***	***	***	***	***	4.467	2.891	1.480	0.244	0.456	1.343	18.405
7.5	***	***	***	***	***	***	3.333	1.755	0.419	0.324	0.898	18.709
7.6	***	***	***	***	***	***	3.833	2.097	0.657	0.292	0.583	19.024
7.7	***	***	***	***	***	***	4.270	2.382	0.831	0.348	0.398	19.244
7.8	***	***	***	***	***	***	4.801	2.772	1.113	0.421	0.266	19.461
7.9	***	***	***	***	***	***	***	3.175	1.403	0.519	0.182	19.616
8.0	***	***	***	***	***	***	***	3.567	1.683	0.628	0.129	19.722

Table A8.2: The charge abundance for Ca with $\kappa = 10$.

log T	Ca^{+0}	Ca^{+1}	Ca^{+2}	Ca^{+3}	Ca^{+4}	Ca^{+5}	Ca^{+6}	Ca^{+7}	Ca^{+8}	Ca^{+9}	Ca^{+10}	⟨Q⟩
4.0	2.245	0.451	0.193	***	***	***	***	***	***	***	***	1.635
4.1	3.050	0.974	0.049	4.310	***	***	***	***	***	***	***	1.892
4.2	3.896	1.544	0.013	3.412	***	***	***	***	***	***	***	1.972
4.3	4.709	2.087	0.005	2.570	***	***	***	***	***	***	***	1.994
4.4	***	2.558	0.008	1.802	4.878	***	***	***	***	***	***	2.013
4.5	***	2.900	0.031	1.166	3.522	***	***	***	***	***	***	2.068
4.6	***	3.076	0.089	0.741	2.531	***	***	***	***	***	***	2.187
4.7	***	3.146	0.172	0.503	1.896	3.997	***	***	***	***	***	2.339
4.8	***	3.202	0.279	0.362	1.419	3.096	***	***	***	***	***	2.512
4.9	***	3.292	0.417	0.282	1.046	2.355	***	***	***	***	***	2.715
5.0	***	3.470	0.608	0.261	0.733	1.700	4.060	***	***	***	***	2.978
5.1	***	3.745	0.880	0.316	0.507	1.137	3.053	***	***	***	***	3.327
5.2	***	4.155	1.258	0.482	0.392	0.692	2.178	4.297	***	***	***	3.776
5.3	***	4.724	1.776	0.785	0.416	0.397	1.470	3.139	***	***	***	4.273
5.4	***	***	2.423	1.222	0.584	0.257	0.937	2.170	3.937	***	***	4.738
5.5	***	***	3.185	1.777	0.884	0.264	0.576	1.398	2.692	4.361	4.738	5.186
5.6	***	***	4.077	2.470	1.332	0.428	0.393	0.829	1.679	2.844	2.668	5.726
5.7	***	***	***	3.383	2.008	0.836	0.471	0.543	0.980	1.670	1.032	6.768
5.8	***	***	***	4.846	3.248	1.825	1.158	0.893	0.946	1.200	0.223	8.983
5.9	***	***	***	***	4.915	3.252	2.302	1.721	1.412	1.265	0.078	9.835
6.0	***	***	***	***	***	4.635	3.422	2.545	1.904	1.392	0.078	10.037
6.1	***	***	***	***	***	***	4.480	3.329	2.379	1.530	0.124	10.201
6.2	***	***	***	***	***	***	***	4.104	2.870	1.714	0.225	10.467
6.3	***	***	***	***	***	***	***	4.937	3.438	2.003	0.427	10.978
6.4	***	***	***	***	***	***	***	***	4.179	2.492	0.823	11.866
6.5	***	***	***	***	***	***	***	***	***	3.261	1.489	12.938
6.6	***	***	***	***	***	***	***	***	***	4.305	2.427	14.039
6.7	***	***	***	***	***	***	***	***	***	***	3.650	15.443

log T	Ca^{+10}	Ca^{+11}	Ca^{+12}	Ca^{+13}	Ca^{+14}	Ca^{+15}	Ca^{+16}	Ca^{+17}	Ca^{+18}	Ca^{+19}	Ca^{+20}	⟨Q⟩
5.6	2.668	***	***	***	***	***	***	***	***	***	***	5.726
5.7	1.032	3.191	***	***	***	***	***	***	***	***	***	6.768
5.8	0.223	1.897	4.213	***	***	***	***	***	***	***	***	8.983
5.9	0.078	1.345	3.124	***	***	***	***	***	***	***	***	9.835
6.0	0.078	0.990	2.303	4.145	***	***	***	***	***	***	***	10.037
6.1	0.124	0.721	1.631	2.944	4.972	***	***	***	***	***	***	10.201
6.2	0.225	0.537	1.093	1.917	3.438	***	***	***	***	***	***	10.467
6.3	0.427	0.472	0.716	1.102	2.163	3.395	4.954	***	***	***	***	10.978
6.4	0.823	0.616	0.576	0.571	1.218	2.056	3.170	4.458	***	***	***	11.866
6.5	1.489	1.048	0.746	0.395	0.673	1.167	1.884	2.760	3.527	***	***	12.938
6.6	2.427	1.760	1.219	0.559	0.503	0.692	1.059	1.574	1.947	***	***	14.039
6.7	3.650	2.772	2.004	1.064	0.708	0.623	0.676	0.877	0.906	4.369	***	15.443
6.8	***	4.092	3.114	1.921	1.295	0.960	0.730	0.650	0.381	3.220	***	16.808
6.9	***	***	4.370	2.947	2.080	1.515	1.028	0.697	0.179	2.457	***	17.484
7.0	***	***	***	3.980	2.883	2.105	1.385	0.824	0.104	1.876	4.364	17.752
7.1	***	***	***	4.951	3.647	2.669	1.733	0.959	0.081	1.408	3.420	17.886
7.2	***	***	***	***	4.367	3.202	2.067	1.096	0.089	1.028	2.618	17.999
7.3	***	***	***	***	***	3.723	2.404	1.247	0.131	0.726	1.938	18.146
7.4	***	***	***	***	***	4.255	2.763	1.430	0.215	0.508	1.389	18.351
7.5	***	***	***	***	***	4.812	3.159	1.661	0.349	0.375	0.965	18.615
7.6	***	***	***	***	***	***	3.606	1.950	0.538	0.322	0.652	18.910
7.7	***	***	***	***	***	***	4.090	2.284	0.772	0.337	0.437	19.186
7.8	***	***	***	***	***	***	4.597	2.647	1.031	0.397	0.298	19.406
7.9	***	***	***	***	***	***	***	3.025	1.302	0.484	0.207	19.569
8.0	***	***	***	***	***	***	***	3.400	1.570	0.582	0.148	19.683

Table A8.3: The charge abundance for Ca with $\kappa = 5$.

log T	Ca^{+0}	Ca^{+1}	Ca^{+2}	Ca^{+3}	Ca^{+4}	Ca^{+5}	Ca^{+6}	Ca^{+7}	Ca^{+8}	Ca^{+9}	Ca^{+10}	⟨Q⟩
4.0	3.508	1.255	0.028	2.147	***	***	***	***	***	***	***	1.951
4.1	4.107	1.682	0.019	1.651	4.233	***	***	***	***	***	***	2.001
4.2	4.700	2.094	0.033	1.193	3.282	***	***	***	***	***	***	2.057
4.3	***	2.494	0.079	0.799	2.425	4.794	***	***	***	***	***	2.163
4.4	***	2.854	0.173	0.512	1.722	3.620	***	***	***	***	***	2.345
4.5	***	3.143	0.310	0.349	1.223	2.703	***	***	***	***	***	2.572
4.6	***	3.357	0.456	0.286	0.908	2.046	4.341	***	***	***	***	2.791
4.7	***	3.516	0.601	0.278	0.709	1.580	3.660	***	***	***	***	2.997
4.8	***	3.664	0.754	0.303	0.574	1.233	3.102	***	***	***	***	3.210
4.9	***	3.834	0.933	0.360	0.478	0.951	2.607	4.783	***	***	***	3.447
5.0	***	4.058	1.154	0.458	0.420	0.711	2.142	4.084	***	***	***	3.721
5.1	***	4.362	1.444	0.614	0.408	0.509	1.701	3.395	***	***	***	4.036
5.2	***	4.758	1.814	0.840	0.454	0.360	1.301	2.733	4.696	***	***	4.367
5.3	***	***	2.267	1.145	0.574	0.271	0.949	2.108	3.752	***	***	4.702
5.4	***	***	2.817	1.535	0.772	0.256	0.668	1.542	2.860	4.442	4.709	5.045
5.5	***	***	3.467	2.023	1.064	0.328	0.473	1.058	2.045	3.264	3.112	5.438
5.6	***	***	4.255	2.643	1.484	0.529	0.402	0.697	1.355	2.208	1.672	6.027
5.7	***	***	***	3.538	2.184	1.008	0.616	0.623	0.957	1.452	0.594	7.541
5.8	***	***	***	4.985	3.431	2.038	1.389	1.115	1.131	1.278	0.172	9.433
5.9	***	***	***	***	4.913	3.308	2.412	1.867	1.577	1.391	0.117	10.008
6.0	***	***	***	***	***	4.577	3.439	2.629	2.044	1.540	0.150	10.229
6.1	***	***	***	***	***	***	4.428	3.365	2.501	1.699	0.227	10.451
6.2	***	***	***	***	***	***	***	4.118	2.987	1.906	0.360	10.783
6.3	***	***	***	***	***	***	***	4.933	3.551	2.207	0.589	11.322
6.4	***	***	***	***	***	***	***	***	4.254	2.668	0.974	12.107
6.5	***	***	***	***	***	***	***	***	***	3.346	1.568	13.027
6.6	***	***	***	***	***	***	***	***	***	4.256	2.387	14.043
6.7	***	***	***	***	***	***	***	***	***	***	3.459	15.338

log T	Ca^{+10}	Ca^{+11}	Ca^{+12}	Ca^{+13}	Ca^{+14}	Ca^{+15}	Ca^{+16}	Ca^{+17}	Ca^{+18}	Ca^{+19}	Ca^{+20}	⟨Q⟩
5.5	3.112	***	***	***	***	***	***	***	***	***	***	5.438
5.6	1.672	3.268	***	***	***	***	***	***	***	***	***	6.027
5.7	0.594	1.859	3.763	***	***	***	***	***	***	***	***	7.541
5.8	0.172	1.148	2.674	4.781	***	***	***	***	***	***	***	9.433
5.9	0.117	0.851	2.035	3.765	***	***	***	***	***	***	***	10.008
6.0	0.150	0.656	1.526	2.873	4.864	***	***	***	***	***	***	10.229
6.1	0.227	0.526	1.111	2.084	3.701	***	***	***	***	***	***	10.451
6.2	0.360	0.460	0.791	1.405	2.658	4.023	***	***	***	***	***	10.783
6.3	0.589	0.494	0.587	0.861	1.763	2.789	4.117	***	***	***	***	11.322
6.4	0.974	0.687	0.560	0.509	1.080	1.792	2.771	3.901	4.921	***	***	12.107
6.5	1.568	1.092	0.753	0.403	0.663	1.091	1.745	2.533	3.199	***	***	13.027
6.6	2.387	1.724	1.180	0.557	0.526	0.694	1.047	1.526	1.865	***	***	14.043
6.7	3.459	2.612	1.873	0.994	0.693	0.621	0.699	0.899	0.943	3.665	***	15.338
6.8	4.806	3.778	2.849	1.734	1.183	0.888	0.710	0.659	0.433	2.721	***	16.640
6.9	***	***	3.995	2.660	1.876	1.371	0.956	0.675	0.213	2.098	4.671	17.383
7.0	***	***	***	3.626	2.626	1.921	1.285	0.788	0.126	1.636	3.824	17.710
7.1	***	***	***	4.559	3.356	2.462	1.620	0.925	0.098	1.261	3.086	17.877
7.2	***	***	***	***	4.067	2.994	1.957	1.071	0.104	0.949	2.438	18.009
7.3	***	***	***	***	4.758	3.512	2.293	1.225	0.142	0.697	1.873	18.157
7.4	***	***	***	***	***	4.033	2.641	1.402	0.217	0.508	1.397	18.346
7.5	***	***	***	***	***	4.567	3.014	1.613	0.333	0.386	1.008	18.581
7.6	***	***	***	***	***	***	3.430	1.870	0.495	0.327	0.710	18.847
7.7	***	***	***	***	***	***	3.879	2.168	0.699	0.326	0.493	19.108
7.8	***	***	***	***	***	***	4.357	2.502	0.936	0.371	0.342	19.333
7.9	***	***	***	***	***	***	4.849	2.856	1.189	0.446	0.240	19.508
8.0	***	***	***	***	***	***	***	3.213	1.445	0.538	0.171	19.637

Table A8.4: The charge abundance for Ca with $\kappa = 3$.

log T	Ca^{+0}	Ca^{+1}	Ca^{+2}	Ca^{+3}	Ca^{+4}	Ca^{+5}	Ca^{+6}	Ca^{+7}	Ca^{+8}	Ca^{+9}	Ca^{+10}	⟨Q⟩
4.0	4.726	2.043	0.134	0.615	1.849	3.700	***	***	***	***	***	2.262
4.1	***	2.421	0.236	0.431	1.361	2.890	***	***	***	***	***	2.458
4.2	***	2.820	0.395	0.319	0.963	2.176	4.098	***	***	***	***	2.717
4.3	***	3.222	0.601	0.292	0.674	1.587	3.250	***	***	***	***	3.014
4.4	***	3.600	0.838	0.336	0.498	1.137	2.580	4.483	***	***	***	3.326
4.5	***	3.925	1.072	0.432	0.416	0.815	2.082	3.790	***	***	***	3.630
4.6	***	4.204	1.299	0.548	0.399	0.604	1.733	3.287	***	***	***	3.903
4.7	***	4.432	1.500	0.670	0.419	0.469	1.486	2.914	4.887	***	***	4.131
4.8	***	4.640	1.693	0.790	0.454	0.383	1.300	2.619	4.466	***	***	4.319
4.9	***	4.839	1.882	0.913	0.501	0.327	1.138	2.350	4.073	***	***	4.482
5.0	***	***	2.084	1.052	0.558	0.288	0.991	2.090	3.677	***	***	4.640
5.1	***	***	2.323	1.215	0.633	0.265	0.847	1.825	3.267	4.912	***	4.804
5.2	***	***	2.598	1.412	0.732	0.260	0.711	1.554	2.834	4.297	4.696	4.985
5.3	***	***	2.938	1.660	0.873	0.279	0.585	1.277	2.380	3.646	3.728	5.199
5.4	***	***	3.346	1.968	1.062	0.337	0.482	1.009	1.919	2.973	2.747	5.465
5.5	***	***	3.840	2.348	1.316	0.457	0.427	0.775	1.479	2.304	1.788	5.861
5.6	***	***	4.502	2.891	1.714	0.700	0.488	0.645	1.128	1.716	0.931	6.745
5.7	***	***	***	3.752	2.433	1.259	0.854	0.807	1.060	1.397	0.380	8.567
5.8	***	***	***	***	3.532	2.190	1.587	1.330	1.346	1.428	0.219	9.854
5.9	***	***	***	***	4.772	3.257	2.454	1.983	1.760	1.585	0.231	10.307
6.0	***	***	***	***	***	4.355	3.349	2.659	2.192	1.760	0.299	10.562
6.1	***	***	***	***	***	***	4.245	3.338	2.630	1.945	0.404	10.827
6.2	***	***	***	***	***	***	***	4.036	3.093	2.162	0.556	11.169
6.3	***	***	***	***	***	***	***	4.787	3.613	2.444	0.778	11.626
6.4	***	***	***	***	***	***	***	***	4.227	2.830	1.107	12.239
6.5	***	***	***	***	***	***	***	***	4.967	3.355	1.570	12.959
6.6	***	***	***	***	***	***	***	***	***	4.053	2.199	13.811
6.7	***	***	***	***	***	***	***	***	***	4.967	3.038	14.902
6.8	***	***	***	***	***	***	***	***	***	***	4.110	16.151

log T	Ca^{+10}	Ca^{+11}	Ca^{+12}	Ca^{+13}	Ca^{+14}	Ca^{+15}	Ca^{+16}	Ca^{+17}	Ca^{+18}	Ca^{+19}	Ca^{+20}	⟨Q⟩
5.3	3.728	***	***	***	***	***	***	***	***	***	***	5.199
5.4	2.747	4.104	***	***	***	***	***	***	***	***	***	5.465
5.5	1.788	2.879	4.596	***	***	***	***	***	***	***	***	5.861
5.6	0.931	1.782	3.239	***	***	***	***	***	***	***	***	6.745
5.7	0.380	1.021	2.227	3.893	***	***	***	***	***	***	***	8.567
5.8	0.219	0.676	1.643	3.082	***	***	***	***	***	***	***	9.854
5.9	0.231	0.528	1.264	2.470	4.251	***	***	***	***	***	***	10.307
6.0	0.299	0.452	0.975	1.942	3.486	***	***	***	***	***	***	10.562
6.1	0.404	0.425	0.747	1.464	2.767	4.150	***	***	***	***	***	10.827
6.2	0.556	0.447	0.586	1.050	2.101	3.234	4.687	***	***	***	***	11.169
6.3	0.778	0.538	0.499	0.725	1.524	2.407	3.587	4.924	***	***	***	11.626
6.4	1.107	0.735	0.530	0.488	1.035	1.676	2.586	3.633	4.543	***	***	12.239
6.5	1.570	1.063	0.696	0.408	0.706	1.116	1.767	2.539	3.172	***	***	12.959
6.6	2.199	1.551	1.027	0.503	0.558	0.750	1.150	1.657	2.023	4.551	***	13.811
6.7	3.038	2.245	1.559	0.806	0.626	0.612	0.777	1.041	1.154	3.373	***	14.902
6.8	4.110	3.168	2.325	1.357	0.951	0.743	0.681	0.718	0.594	2.513	***	16.151
6.9	***	4.278	3.278	2.104	1.493	1.100	0.824	0.649	0.306	1.930	4.201	17.078
7.0	***	***	4.340	2.970	2.145	1.572	1.090	0.720	0.179	1.518	3.510	17.563
7.1	***	***	***	3.845	2.826	2.079	1.403	0.845	0.129	1.198	2.911	17.812
7.2	***	***	***	4.710	3.504	2.588	1.726	0.989	0.122	0.932	2.379	17.976
7.3	***	***	***	***	4.172	3.092	2.053	1.144	0.146	0.718	1.909	18.124
7.4	***	***	***	***	4.835	3.596	2.386	1.312	0.202	0.543	1.493	18.293
7.5	***	***	***	***	***	4.110	2.737	1.502	0.291	0.418	1.136	18.492
7.6	***	***	***	***	***	4.636	3.108	1.719	0.415	0.344	0.844	18.718
7.7	***	***	***	***	***	***	3.508	1.970	0.576	0.318	0.615	18.955
7.8	***	***	***	***	***	***	3.937	2.253	0.770	0.334	0.442	19.180
7.9	***	***	***	***	***	***	4.386	2.561	0.988	0.384	0.317	19.373
8.0	***	***	***	***	***	***	4.850	2.889	1.223	0.457	0.229	19.527

Table A9.1: The charge abundance for Fe with Maxwellian distribution.

log T	Fe^{+0}	Fe^{+1}	Fe^{+2}	Fe^{+3}	Fe^{+4}	Fe^{+5}	Fe^{+6}	Fe^{+7}	Fe^{+8}	Fe^{+9}	Fe^{+10}	Fe^{+11}	Fe^{+12}	Fe^{+13}	⟨Q⟩
4.0	0.916	0.056	4.000	***	***	***	***	***	***	***	***	***	***	***	0.879
4.1	1.454	0.019	2.166	***	***	***	***	***	***	***	***	***	***	***	0.972
4.2	1.978	0.085	0.778	***	***	***	***	***	***	***	***	***	***	***	1.156
4.3	2.883	0.588	0.131	***	***	***	***	***	***	***	***	***	***	***	1.739
4.4	3.921	1.292	0.023	3.058	***	***	***	***	***	***	***	***	***	***	1.950
4.5	4.718	1.750	0.022	1.506	***	***	***	***	***	***	***	***	***	***	2.013
4.6	***	2.149	0.157	0.528	3.813	***	***	***	***	***	***	***	***	***	2.289
4.7	***	2.691	0.507	0.170	1.968	***	***	***	***	***	***	***	***	***	2.696
4.8	***	3.250	0.901	0.126	0.901	3.638	***	***	***	***	***	***	***	***	2.999
4.9	***	3.876	1.370	0.281	0.378	1.839	***	***	***	***	***	***	***	***	3.405
5.0	***	4.633	1.981	0.613	0.224	0.832	3.043	***	***	***	***	***	***	***	3.884
5.1	***	***	2.709	1.099	0.322	0.370	1.807	4.077	***	***	***	***	***	***	4.374
5.2	***	***	3.539	1.699	0.583	0.208	1.021	2.487	4.930	***	***	***	***	***	4.800
5.3	***	***	4.438	2.384	0.972	0.251	0.541	1.401	3.052	***	***	***	***	***	5.255
5.4	***	***	***	3.194	1.524	0.505	0.350	0.718	1.740	***	***	***	***	***	5.853
5.5	***	***	***	4.178	2.273	0.986	0.442	0.394	0.899	3.999	***	***	***	***	6.542
5.6	***	***	***	***	3.186	1.659	0.768	0.361	0.433	2.657	***	***	***	***	7.156
5.7	***	***	***	***	4.179	2.433	1.233	0.511	0.215	1.712	3.472	***	***	***	7.583
5.8	***	***	***	***	***	3.253	1.769	0.762	0.147	1.047	2.162	3.579	***	***	7.896
5.9	***	***	***	***	***	4.123	2.382	1.117	0.219	0.615	1.202	2.051	3.212	***	8.313
6.0	***	***	***	***	***	***	3.167	1.663	0.512	0.494	0.640	1.010	1.671	2.956	9.140
6.1	***	***	***	***	***	***	4.286	2.562	1.179	0.803	0.567	0.528	0.760	1.536	10.446
6.2	***	***	***	***	***	***	***	3.803	2.209	1.516	0.963	0.572	0.437	0.781	11.683
6.3	***	***	***	***	***	***	***	***	3.515	2.546	1.705	1.015	0.559	0.534	12.898
6.4	***	***	***	***	***	***	***	***	***	3.849	2.747	1.793	1.053	0.701	14.084
6.5	***	***	***	***	***	***	***	***	***	***	3.949	2.760	1.761	1.125	14.881
6.6	***	***	***	***	***	***	***	***	***	***	***	3.785	2.555	1.654	15.391
6.7	***	***	***	***	***	***	***	***	***	***	***	4.842	3.398	2.270	15.862
6.8	***	***	***	***	***	***	***	***	***	***	***	***	4.330	2.987	16.574
6.9	***	***	***	***	***	***	***	***	***	***	***	***	***	3.943	17.863

log T	Fe^{+13}	Fe^{+14}	Fe^{+15}	Fe^{+16}	Fe^{+17}	Fe^{+18}	Fe^{+29}	Fe^{+20}	Fe^{+21}	Fe^{+22}	Fe^{+23}	Fe^{+24}	Fe^{+25}	Fe^{+26}	⟨Q⟩
6.0	2.956	4.506	***	***	***	***	***	***	***	***	***	***	***	***	9.140
6.1	1.536	2.538	3.884	4.862	***	***	***	***	***	***	***	***	***	***	10.446
6.2	0.781	1.325	2.180	2.845	***	***	***	***	***	***	***	***	***	***	11.683
6.3	0.534	0.674	1.136	1.570	4.006	***	***	***	***	***	***	***	***	***	12.898
6.4	0.701	0.496	0.626	0.864	2.676	4.914	***	***	***	***	***	***	***	***	14.084
6.5	1.125	0.613	0.464	0.518	1.826	3.444	***	***	***	***	***	***	***	***	14.881
6.6	1.654	0.874	0.480	0.349	1.237	2.348	3.465	***	***	***	***	***	***	***	15.391
6.7	2.270	1.240	0.617	0.296	0.821	1.507	2.144	3.256	4.556	***	***	***	***	***	15.862
6.8	2.987	1.738	0.902	0.390	0.602	0.918	1.201	1.909	2.780	3.849	***	***	***	***	16.574
6.9	3.943	2.488	1.451	0.748	0.679	0.683	0.641	1.005	1.512	2.178	3.101	4.200	***	***	17.863
7.0	***	3.620	2.387	1.494	1.168	0.888	0.560	0.619	0.810	1.137	1.710	2.450	***	***	19.485
7.1	***	***	3.658	2.584	2.027	1.496	0.915	0.703	0.617	0.642	0.913	1.355	***	***	21.016
7.2	***	***	***	3.933	3.162	2.398	1.585	1.130	0.793	0.554	0.557	0.751	3.828	***	22.225
7.3	***	***	***	***	4.399	3.421	2.396	1.722	1.162	0.688	0.460	0.450	2.840	***	22.940
7.4	***	***	***	***	***	4.477	3.253	2.374	1.608	0.916	0.477	0.294	2.136	4.489	23.337
7.5	***	***	***	***	***	***	4.083	3.014	2.056	1.171	0.551	0.211	1.593	3.462	23.579
7.6	***	***	***	***	***	***	4.884	3.636	2.508	1.444	0.649	0.176	1.170	2.628	23.766
7.7	***	***	***	***	***	***	***	4.251	2.953	1.720	0.775	0.181	0.848	1.962	23.954
7.8	***	***	***	***	***	***	***	4.856	3.402	2.019	0.934	0.224	0.618	1.442	24.177
7.9	***	***	***	***	***	***	***	***	3.868	2.342	1.126	0.310	0.469	1.040	24.438
8.0	***	***	***	***	***	***	***	***	4.354	2.696	1.366	0.442	0.386	0.740	24.728
8.1	***	***	***	***	***	***	***	***	4.840	3.056	1.618	0.603	0.364	0.533	24.993
8.2	***	***	***	***	***	***	***	***	***	3.455	1.898	0.793	0.383	0.385	25.224
8.3	***	***	***	***	***	***	***	***	***	3.799	2.170	0.980	0.430	0.286	25.398
8.4	***	***	***	***	***	***	***	***	***	4.157	2.442	1.172	0.487	0.219	25.529
8.5	***	***	***	***	***	***	***	***	***	4.491	2.700	1.358	0.554	0.171	25.627
8.6	***	***	***	***	***	***	***	***	***	4.809	2.945	1.535	0.625	0.135	25.701
8.7	***	***	***	***	***	***	***	***	***	***	3.177	1.703	0.694	0.109	25.756
8.8	***	***	***	***	***	***	***	***	***	***	3.394	1.856	0.759	0.091	25.797
8.9	***	***	***	***	***	***	***	***	***	***	3.590	1.999	0.822	0.076	25.829
9.0	***	***	***	***	***	***	***	***	***	***	3.780	2.137	0.883	0.065	25.854

Table A9.2: The charge abundance for Fe with $\kappa = 10$.

log T	Fe^{+0}	Fe^{+1}	Fe^{+2}	Fe^{+3}	Fe^{+4}	Fe^{+5}	Fe^{+6}	Fe^{+7}	Fe^{+8}	Fe^{+9}	Fe^{+10}	Fe^{+11}	Fe^{+12}	Fe^{+13}	⟨Q⟩
4.0	2.031	0.134	0.590	4.071	***	***	***	***	***	***	***	***	***	***	1.248
4.1	2.611	0.453	0.191	2.828	***	***	***	***	***	***	***	***	***	***	1.644
4.2	3.362	0.962	0.057	1.883	***	***	***	***	***	***	***	***	***	***	1.903
4.3	4.126	1.490	0.051	1.102	3.879	***	***	***	***	***	***	***	***	***	2.047
4.4	4.840	1.980	0.165	0.519	2.490	***	***	***	***	***	***	***	***	***	2.299
4.5	***	2.511	0.460	0.212	1.430	4.127	***	***	***	***	***	***	***	***	2.685
4.6	***	3.078	0.865	0.173	0.725	2.637	***	***	***	***	***	***	***	***	3.055
4.7	***	3.675	1.330	0.330	0.341	1.529	3.843	***	***	***	***	***	***	***	3.468
4.8	***	4.310	1.847	0.616	0.236	0.797	2.478	***	***	***	***	***	***	***	3.896
4.9	***	***	2.419	1.006	0.329	0.396	1.579	3.428	***	***	***	***	***	***	4.350
5.0	***	***	3.044	1.453	0.531	0.243	1.032	2.308	4.265	***	***	***	***	***	4.735
5.1	***	***	3.693	1.937	0.793	0.231	0.681	1.517	2.976	***	***	***	***	***	5.088
5.2	***	***	4.423	2.481	1.125	0.333	0.472	0.959	2.020	***	***	***	***	***	5.504
5.3	***	***	***	3.120	1.562	0.562	0.404	0.594	1.312	4.610	***	***	***	***	6.021
5.4	***	***	***	3.890	2.133	0.932	0.487	0.405	0.808	3.507	***	***	***	***	6.574
5.5	***	***	***	4.772	2.823	1.427	0.708	0.368	0.476	2.610	4.940	***	***	***	7.064
5.6	***	***	***	***	3.603	2.019	1.036	0.448	0.277	1.887	3.671	***	***	***	7.443
5.7	***	***	***	***	4.442	2.675	1.438	0.611	0.177	1.307	2.593	4.046	***	***	7.730
5.8	***	***	***	***	***	3.381	1.902	0.847	0.166	0.856	1.692	2.716	3.945	***	8.018
5.9	***	***	***	***	***	4.166	2.460	1.187	0.271	0.570	1.002	1.628	2.463	3.972	8.481
6.0	***	***	***	***	***	***	3.209	1.726	0.589	0.536	0.610	0.866	1.333	2.391	9.378
6.1	***	***	***	***	***	***	4.270	2.585	1.240	0.871	0.622	0.538	0.664	1.308	10.657
6.2	***	***	***	***	***	***	***	3.789	2.246	1.591	1.050	0.657	0.468	0.736	12.022
6.3	***	***	***	***	***	***	***	***	3.669	2.754	1.950	1.275	0.795	0.718	13.849
6.4	***	***	***	***	***	***	***	***	***	4.319	3.270	2.341	1.592	1.201	15.147
6.5	***	***	***	***	***	***	***	***	***	***	4.686	3.527	2.531	1.852	15.653
6.6	***	***	***	***	***	***	***	***	***	***	***	4.691	3.463	2.522	15.940
6.7	***	***	***	***	***	***	***	***	***	***	***	***	4.381	3.199	16.263
6.8	***	***	***	***	***	***	***	***	***	***	***	***	***	3.937	16.846
6.9	***	***	***	***	***	***	***	***	***	***	***	***	***	4.832	17.921

log T	Fe^{+13}	Fe^{+14}	Fe^{+15}	Fe^{+16}	Fe^{+17}	Fe^{+18}	Fe^{+29}	Fe^{+20}	Fe^{+21}	Fe^{+22}	Fe^{+23}	Fe^{+24}	Fe^{+25}	Fe^{+26}	⟨Q⟩
5.9	3.972	***	***	***	***	***	***	***	***	***	***	***	***	***	8.481
6.0	2.391	3.570	***	***	***	***	***	***	***	***	***	***	***	***	9.378
6.1	1.308	2.044	2.992	3.388	***	***	***	***	***	***	***	***	***	***	10.657
6.2	0.736	1.056	1.575	1.692	3.833	***	***	***	***	***	***	***	***	***	12.022
6.3	0.718	0.663	0.800	0.694	2.408	4.626	***	***	***	***	***	***	***	***	13.849
6.4	1.201	0.804	0.611	0.317	1.657	3.391	***	***	***	***	***	***	***	***	15.147
6.5	1.852	1.145	0.666	0.201	1.210	2.519	3.832	***	***	***	***	***	***	***	15.653
6.6	2.522	1.532	0.803	0.179	0.885	1.819	2.731	4.065	***	***	***	***	***	***	15.940
6.7	3.199	1.953	1.004	0.226	0.655	1.251	1.813	2.784	3.924	***	***	***	***	***	16.263
6.8	3.937	2.458	1.306	0.378	0.550	0.844	1.088	1.738	2.533	3.516	4.731	***	***	***	16.846
6.9	4.832	3.140	1.803	0.728	0.663	0.681	0.642	0.995	1.484	2.133	3.009	4.061	***	***	17.921
7.0	***	4.109	2.599	1.378	1.087	0.849	0.555	0.641	0.849	1.197	1.773	2.513	***	***	19.344
7.1	***	***	3.698	2.335	1.830	1.357	0.828	0.667	0.623	0.697	1.001	1.471	4.547	***	20.774
7.2	***	***	***	3.535	2.830	2.140	1.393	1.005	0.729	0.555	0.612	0.848	3.401	***	21.985
7.3	***	***	***	4.866	3.972	3.078	2.131	1.531	1.043	0.642	0.478	0.511	2.593	***	22.781
7.4	***	***	***	***	***	4.073	2.935	2.137	1.448	0.838	0.473	0.334	1.999	4.166	23.241
7.5	***	***	***	***	***	***	3.744	2.760	1.885	1.082	0.531	0.238	1.537	3.312	23.523
7.6	***	***	***	***	***	***	4.528	3.373	2.325	1.344	0.624	0.193	1.165	2.594	23.729
7.7	***	***	***	***	***	***	***	3.979	2.765	1.617	0.742	0.188	0.873	1.997	23.919
7.8	***	***	***	***	***	***	***	4.575	3.207	1.904	0.886	0.220	0.651	1.509	24.128
7.9	***	***	***	***	***	***	***	***	3.664	2.217	1.067	0.292	0.494	1.115	24.375
8.0	***	***	***	***	***	***	***	***	4.131	2.549	1.278	0.401	0.403	0.817	24.641
8.1	***	***	***	***	***	***	***	***	4.610	2.902	1.520	0.548	0.366	0.595	24.907
8.2	***	***	***	***	***	***	***	***	***	3.266	1.781	0.718	0.372	0.435	25.141
8.3	***	***	***	***	***	***	***	***	***	3.627	2.048	0.899	0.407	0.325	25.328
8.4	***	***	***	***	***	***	***	***	***	3.984	2.317	1.088	0.461	0.246	25.475
8.5	***	***	***	***	***	***	***	***	***	4.323	2.576	1.272	0.523	0.191	25.585
8.6	***	***	***	***	***	***	***	***	***	4.646	2.824	1.449	0.590	0.151	25.667
8.7	***	***	***	***	***	***	***	***	***	4.946	3.055	1.614	0.658	0.122	25.729
8.8	***	***	***	***	***	***	***	***	***	***	3.278	1.776	0.724	0.100	25.776
8.9	***	***	***	***	***	***	***	***	***	***	3.485	1.925	0.789	0.083	25.813
9.0	***	***	***	***	***	***	***	***	***	***	3.679	2.064	0.851	0.071	25.841
9.1	***	***	***	***	***	***	***	***	***	***	3.860	2.195	0.909	0.060	25.864
9.2	***	***	***	***	***	***	***	***	***	***	4.032	2.319	0.966	0.052	25.882
9.3	***	***	***	***	***	***	***	***	***	***	4.194	2.435	1.019	0.046	25.897
9.4	***	***	***	***	***	***	***	***	***	***	4.346	2.545	1.070	0.040	25.909
9.5	***	***	***	***	***	***	***	***	***	***	4.491	2.649	1.119	0.035	25.919

Table A9.3: The charge abundance for Fe with $\kappa = 5$.

log T	Fe^{+0}	Fe^{+1}	Fe^{+2}	Fe^{+3}	Fe^{+4}	Fe^{+5}	Fe^{+6}	Fe^{+7}	Fe^{+8}	Fe^{+9}	Fe^{+10}	Fe^{+11}	Fe^{+12}	Fe^{+13}	⟨Q⟩
4.0	3.305	0.862	0.095	1.241	3.484	***	***	***	***	***	***	***	***	***	1.920
4.1	3.910	1.312	0.108	0.772	2.522	***	***	***	***	***	***	***	***	***	2.126
4.2	4.564	1.818	0.230	0.426	1.690	4.051	***	***	***	***	***	***	***	***	2.401
4.3	***	2.378	0.485	0.241	1.032	2.902	***	***	***	***	***	***	***	***	2.760
4.4	***	2.998	0.882	0.232	0.569	1.957	4.206	***	***	***	***	***	***	***	3.159
4.5	***	3.644	1.367	0.390	0.310	1.228	3.003	***	***	***	***	***	***	***	3.568
4.6	***	4.299	1.906	0.682	0.239	0.713	2.039	4.063	***	***	***	***	***	***	3.980
4.7	***	4.957	2.473	1.060	0.335	0.399	1.323	2.880	4.996	***	***	***	***	***	4.404
4.8	***	***	3.016	1.503	0.554	0.270	0.854	1.974	3.639	***	***	***	***	***	4.817
4.9	***	***	3.628	1.950	0.831	0.275	0.586	1.320	2.578	***	***	***	***	***	5.192
5.0	***	***	4.194	2.408	1.139	0.371	0.459	0.873	1.786	***	***	***	***	***	5.584
5.1	***	***	4.811	2.886	1.477	0.543	0.435	0.597	1.232	4.252	***	***	***	***	6.014
5.2	***	***	***	3.413	1.863	0.786	0.491	0.446	0.853	3.528	***	***	***	***	6.448
5.3	***	***	***	4.005	2.311	1.094	0.611	0.385	0.591	2.916	***	***	***	***	6.838
5.4	***	***	***	4.660	2.818	1.463	0.789	0.391	0.408	2.379	4.461	***	***	***	7.164
5.5	***	***	***	***	3.387	1.891	1.022	0.451	0.280	1.889	3.602	***	***	***	7.429
5.6	***	***	***	***	4.016	2.375	1.304	0.559	0.199	1.441	2.791	4.121	***	***	7.651
5.7	***	***	***	***	4.698	2.908	1.637	0.715	0.164	1.056	2.049	3.089	4.236	***	7.866
5.8	***	***	***	***	***	3.506	2.032	0.932	0.190	0.745	1.400	2.150	3.022	4.639	8.148
5.9	***	***	***	***	***	4.207	2.534	1.253	0.321	0.557	0.888	1.347	1.945	3.206	8.658
6.0	***	***	***	***	***	***	3.227	1.765	0.646	0.583	0.616	0.785	1.108	2.024	9.586
6.1	***	***	***	***	***	***	4.196	2.556	1.252	0.910	0.666	0.559	0.613	1.200	10.794
6.2	***	***	***	***	***	***	***	3.652	2.168	1.567	1.063	0.690	0.485	0.747	12.146
6.3	***	***	***	***	***	***	***	***	3.470	2.628	1.881	1.256	0.801	0.762	13.959
6.4	***	***	***	***	***	***	***	***	***	4.050	3.076	2.215	1.522	1.200	15.218
6.5	***	***	***	***	***	***	***	***	***	***	4.383	3.304	2.382	1.795	15.727
6.6	***	***	***	***	***	***	***	***	***	***	***	4.393	3.255	2.420	16.024
6.7	***	***	***	***	***	***	***	***	***	***	***	***	4.129	3.061	16.353
6.9	***	***	***	***	***	***	***	***	***	***	***	***	***	4.579	17.855

log T	Fe^{+13}	Fe^{+14}	Fe^{+15}	Fe^{+16}	Fe^{+17}	Fe^{+18}	Fe^{+29}	Fe^{+20}	Fe^{+21}	Fe^{+22}	Fe^{+23}	Fe^{+24}	Fe^{+25}	Fe^{+26}	⟨Q⟩
5.8	4.639	***	***	***	***	***	***	***	***	***	***	***	***	***	8.148
5.9	3.206	4.530	***	***	***	***	***	***	***	***	***	***	***	***	8.658
6.0	2.024	2.987	4.154	4.593	***	***	***	***	***	***	***	***	***	***	9.586
6.1	1.200	1.814	2.603	2.772	4.652	***	***	***	***	***	***	***	***	***	10.794
6.2	0.747	1.025	1.461	1.412	2.981	***	***	***	***	***	***	***	***	***	12.146
6.3	0.762	0.721	0.833	0.606	1.893	3.685	***	***	***	***	***	***	***	***	13.959
6.4	1.200	0.859	0.678	0.299	1.329	2.763	4.202	***	***	***	***	***	***	***	15.218
6.5	1.795	1.172	0.728	0.209	1.004	2.114	3.210	4.695	***	***	***	***	***	***	15.727
6.6	2.420	1.534	0.855	0.203	0.770	1.584	2.368	3.535	4.882	***	***	***	***	***	16.024
6.7	3.061	1.930	1.040	0.257	0.610	1.148	1.639	2.517	3.554	4.800	***	***	***	***	16.353
6.8	3.754	2.396	1.313	0.400	0.546	0.827	1.051	1.658	2.408	3.343	4.489	***	***	***	16.902
6.9	4.579	3.010	1.748	0.704	0.645	0.686	0.665	1.020	1.506	2.153	3.009	4.038	***	***	17.855
7.0	***	3.843	2.414	1.239	0.985	0.799	0.555	0.676	0.918	1.299	1.891	2.647	***	***	19.111
7.1	***	4.943	3.355	2.049	1.603	1.202	0.736	0.634	0.646	0.784	1.131	1.642	4.271	***	20.446
7.2	***	***	4.533	3.095	2.463	1.858	1.188	0.875	0.672	0.574	0.698	0.986	3.230	***	21.657
7.3	***	***	***	4.302	3.494	2.694	1.831	1.318	0.912	0.600	0.511	0.603	2.490	4.876	22.544
7.4	***	***	***	***	4.600	3.616	2.572	1.869	1.271	0.757	0.473	0.390	1.944	3.984	23.095
7.5	***	***	***	***	***	4.560	3.343	2.459	1.681	0.977	0.511	0.275	1.526	3.246	23.433
7.6	***	***	***	***	***	***	4.111	3.056	2.106	1.226	0.592	0.216	1.186	2.609	23.668
7.7	***	***	***	***	***	***	4.869	3.650	2.537	1.489	0.700	0.199	0.910	2.065	23.866
7.8	***	***	***	***	***	***	***	4.241	2.973	1.769	0.833	0.217	0.693	1.599	24.069
7.9	***	***	***	***	***	***	***	4.834	3.417	2.065	0.994	0.270	0.534	1.219	24.293
8.0	***	***	***	***	***	***	***	***	3.871	2.381	1.185	0.360	0.430	0.912	24.542
8.1	***	***	***	***	***	***	***	***	4.339	2.718	1.407	0.486	0.376	0.676	24.799
8.2	***	***	***	***	***	***	***	***	4.812	3.069	1.651	0.638	0.365	0.501	25.038
8.3	***	***	***	***	***	***	***	***	***	3.426	1.908	0.810	0.388	0.374	25.242
8.4	***	***	***	***	***	***	***	***	***	3.778	2.169	0.989	0.431	0.284	25.403
8.5	***	***	***	***	***	***	***	***	***	4.118	2.425	1.169	0.488	0.219	25.528
8.6	***	***	***	***	***	***	***	***	***	4.449	2.677	1.347	0.552	0.172	25.623
8.7	***	***	***	***	***	***	***	***	***	4.761	2.917	1.518	0.618	0.138	25.695
8.8	***	***	***	***	***	***	***	***	***	***	3.142	1.679	0.684	0.113	25.749
8.9	***	***	***	***	***	***	***	***	***	***	3.355	1.833	0.749	0.093	25.791
9.0	***	***	***	***	***	***	***	***	***	***	3.555	1.977	0.812	0.078	25.824

Table A9.4: The charge abundance for Fe with $\kappa = 3$.

log T	Fe^{+0}	Fe^{+1}	Fe^{+2}	Fe^{+3}	Fe^{+4}	Fe^{+5}	Fe^{+6}	Fe^{+7}	Fe^{+8}	Fe^{+9}	Fe^{+10}	Fe^{+11}	Fe^{+12}	Fe^{+13}	⟨Q⟩
4.0	4.898	2.003	0.484	0.290	0.844	2.259	4.375	***	***	***	***	***	***	***	2.806
4.1	***	2.581	0.787	0.286	0.533	1.636	3.433	***	***	***	***	***	***	***	3.172
4.2	***	3.218	1.182	0.395	0.343	1.132	2.615	4.687	***	***	***	***	***	***	3.542
4.3	***	3.905	1.675	0.611	0.266	0.747	1.918	3.669	***	***	***	***	***	***	3.916
4.4	***	4.607	2.221	0.921	0.302	0.483	1.351	2.786	4.701	***	***	***	***	***	4.291
4.5	***	***	2.805	1.314	0.447	0.337	0.913	2.035	3.632	***	***	***	***	***	4.682
4.6	***	***	3.423	1.769	0.690	0.306	0.610	1.429	2.715	***	***	***	***	***	5.086
4.7	***	***	4.031	2.262	1.011	0.381	0.441	0.969	1.956	4.508	***	***	***	***	5.502
4.8	***	***	4.636	2.769	1.382	0.542	0.394	0.652	1.359	3.765	***	***	***	***	5.936
4.9	***	***	***	3.278	1.783	0.769	0.451	0.470	0.925	3.189	***	***	***	***	6.374
5.0	***	***	***	3.773	2.185	1.037	0.578	0.395	0.633	2.751	4.942	***	***	***	6.768
5.1	***	***	***	4.248	2.575	1.317	0.738	0.391	0.449	2.409	4.432	***	***	***	7.076
5.2	***	***	***	4.698	2.945	1.594	0.905	0.423	0.334	2.120	3.967	***	***	***	7.300
5.3	***	***	***	***	3.309	1.871	1.070	0.474	0.259	1.856	3.511	4.810	***	***	7.466
5.4	***	***	***	***	3.681	2.156	1.240	0.538	0.208	1.601	3.050	4.199	***	***	7.600
5.5	***	***	***	***	4.081	2.465	1.425	0.617	0.174	1.347	2.582	3.579	4.596	***	7.724
5.6	***	***	***	***	4.519	2.805	1.634	0.717	0.158	1.101	2.099	2.936	3.802	***	7.856
5.7	***	***	***	***	***	3.192	1.881	0.848	0.167	0.873	1.633	2.301	3.006	4.539	8.029
5.8	***	***	***	***	***	3.647	2.187	1.030	0.220	0.682	1.200	1.690	2.229	3.530	8.314
5.9	***	***	***	***	***	4.208	2.593	1.305	0.359	0.576	0.853	1.149	1.516	2.577	8.841
6.0	***	***	***	***	***	4.938	3.164	1.738	0.650	0.626	0.667	0.764	0.949	1.762	9.721
6.1	***	***	***	***	***	***	3.959	2.390	1.155	0.897	0.704	0.595	0.600	1.163	10.804
6.2	***	***	***	***	***	***	***	3.286	1.901	1.417	1.002	0.686	0.489	0.800	12.039
6.3	***	***	***	***	***	***	***	4.496	2.958	2.256	1.627	1.102	0.708	0.770	13.730
6.4	***	***	***	***	***	***	***	***	4.347	3.435	2.601	1.871	1.279	1.098	15.131
6.5	***	***	***	***	***	***	***	***	***	4.771	3.741	2.810	2.024	1.606	15.763
6.6	***	***	***	***	***	***	***	***	***	***	4.918	3.796	2.815	2.169	16.097
6.7	***	***	***	***	***	***	***	***	***	***	***	4.787	3.618	2.753	16.410
6.8	***	***	***	***	***	***	***	***	***	***	***	***	4.451	3.376	16.866
6.9	***	***	***	***	***	***	***	***	***	***	***	***	***	4.084	17.598

log T	Fe^{+13}	Fe^{+14}	Fe^{+15}	Fe^{+16}	Fe^{+17}	Fe^{+18}	Fe^{+29}	Fe^{+20}	Fe^{+21}	Fe^{+22}	Fe^{+23}	Fe^{+24}	Fe^{+25}	Fe^{+26}	⟨Q⟩
5.7	4.539	***	***	***	***	***	***	***	***	***	***	***	***	***	8.029
5.8	3.530	4.827	***	***	***	***	***	***	***	***	***	***	***	***	8.314
5.9	2.577	3.631	4.903	***	***	***	***	***	***	***	***	***	***	***	8.841
6.0	1.762	2.566	3.554	3.759	***	***	***	***	***	***	***	***	***	***	9.721
6.1	1.163	1.712	2.417	2.410	3.749	***	***	***	***	***	***	***	***	***	10.804
6.2	0.800	1.093	1.520	1.336	2.469	4.217	***	***	***	***	***	***	***	***	12.039
6.3	0.770	0.807	0.965	0.632	1.574	3.056	4.529	***	***	***	***	***	***	***	13.730
6.4	1.098	0.883	0.787	0.327	1.092	2.315	3.522	***	***	***	***	***	***	***	15.131
6.5	1.606	1.147	0.811	0.240	0.838	1.813	2.764	4.076	***	***	***	***	***	***	15.763
6.6	2.169	1.471	0.915	0.238	0.675	1.416	2.120	3.183	4.411	***	***	***	***	***	16.097
6.7	2.753	1.826	1.067	0.288	0.570	1.091	1.561	2.391	3.377	4.579	***	***	***	***	16.410
6.8	3.376	2.233	1.287	0.402	0.529	0.839	1.088	1.699	2.452	3.399	4.531	***	***	***	16.866
6.9	4.084	2.734	1.615	0.623	0.592	0.700	0.740	1.140	1.672	2.376	3.266	4.321	***	***	17.598
7.0	4.934	3.388	2.106	1.005	0.816	0.730	0.569	0.771	1.092	1.566	2.228	3.052	***	***	18.619
7.1	***	4.239	2.802	1.588	1.241	0.965	0.615	0.622	0.744	0.999	1.445	2.048	4.365	***	19.781
7.2	***	***	3.713	2.383	1.875	1.415	0.881	0.702	0.630	0.677	0.920	1.319	3.361	***	20.944
7.3	***	***	4.811	3.363	2.696	2.058	1.347	0.986	0.727	0.575	0.624	0.834	2.597	4.847	21.962
7.4	***	***	***	4.475	3.648	2.835	1.954	1.416	0.979	0.637	0.502	0.539	2.041	4.021	22.699
7.5	***	***	***	***	4.671	3.692	2.643	1.933	1.323	0.797	0.488	0.368	1.621	3.342	23.178
7.6	***	***	***	***	***	4.576	3.365	2.489	1.713	1.012	0.535	0.272	1.288	2.765	23.495
7.7	***	***	***	***	***	***	4.095	3.057	2.120	1.252	0.619	0.227	1.017	2.256	23.728
7.8	***	***	***	***	***	***	4.825	3.631	2.539	1.513	0.731	0.218	0.798	1.816	23.933
7.9	***	***	***	***	***	***	***	4.206	2.965	1.787	0.866	0.242	0.625	1.435	24.138
8.0	***	***	***	***	***	***	***	4.785	3.400	2.079	1.026	0.298	0.498	1.118	24.358
8.1	***	***	***	***	***	***	***	***	3.847	2.389	1.212	0.388	0.415	0.853	24.595
8.2	***	***	***	***	***	***	***	***	4.303	2.716	1.425	0.508	0.373	0.646	24.834
8.3	***	***	***	***	***	***	***	***	4.761	3.052	1.655	0.650	0.366	0.491	25.052
8.4	***	***	***	***	***	***	***	***	***	3.398	1.902	0.813	0.389	0.371	25.245
8.5	***	***	***	***	***	***	***	***	***	3.742	2.154	0.984	0.430	0.286	25.399
8.6	***	***	***	***	***	***	***	***	***	4.077	2.403	1.157	0.485	0.223	25.521
8.7	***	***	***	***	***	***	***	***	***	4.400	2.646	1.329	0.546	0.176	25.615
8.8	***	***	***	***	***	***	***	***	***	4.710	2.883	1.497	0.610	0.142	25.687
8.9	***	***	***	***	***	***	***	***	***	***	3.107	1.657	0.676	0.116	25.743
9.0	***	***	***	***	***	***	***	***	***	***	3.318	1.808	0.739	0.096	25.785

Table A10.1: The charge abundance for Ni with Maxwellian distribution.

log T	Ni^{+0}	Ni^{+1}	Ni^{+2}	Ni^{+3}	Ni^{+4}	Ni^{+5}	Ni^{+6}	Ni^{+7}	Ni^{+8}	Ni^{+9}	Ni^{+10}	Ni^{+11}	Ni^{+12}	Ni^{+13}	Ni^{+14}	⟨Q⟩
4.0	0.494	0.168	4.861	***	***	***	***	***	***	***	***	***	***	***	***	0.680
4.1	1.409	0.018	2.714	***	***	***	***	***	***	***	***	***	***	***	***	0.963
4.2	2.260	0.036	1.126	***	***	***	***	***	***	***	***	***	***	***	***	1.069
4.3	3.153	0.421	0.208	4.833	***	***	***	***	***	***	***	***	***	***	***	1.619
4.4	4.154	1.227	0.027	2.720	***	***	***	***	***	***	***	***	***	***	***	1.943
4.5	4.854	1.854	0.036	1.177	***	***	***	***	***	***	***	***	***	***	***	2.053
4.6	***	2.404	0.331	0.277	3.016	***	***	***	***	***	***	***	***	***	***	2.526
4.7	***	3.074	0.865	0.087	1.355	***	***	***	***	***	***	***	***	***	***	2.906
4.8	***	3.643	1.342	0.206	0.481	2.783	***	***	***	***	***	***	***	***	***	3.288
4.9	***	4.269	1.862	0.505	0.195	1.447	***	***	***	***	***	***	***	***	***	3.696
5.0	***	4.953	2.431	0.875	0.162	0.760	3.593	***	***	***	***	***	***	***	***	4.033
5.1	***	***	3.028	1.310	0.270	0.389	2.391	***	***	***	***	***	***	***	***	4.366
5.2	***	***	3.690	1.802	0.476	0.207	1.541	3.821	***	***	***	***	***	***	***	4.663
5.3	***	***	4.411	2.357	0.769	0.153	0.925	2.498	***	***	***	***	***	***	***	4.946
5.4	***	***	***	2.963	1.139	0.225	0.524	1.510	3.313	***	***	***	***	***	***	5.288
5.5	***	***	***	3.689	1.641	0.451	0.336	0.819	2.021	3.569	***	***	***	***	***	5.771
5.6	***	***	***	4.557	2.307	0.868	0.389	0.433	1.126	2.148	4.267	***	***	***	***	6.395
5.7	***	***	***	***	3.177	1.498	0.695	0.356	0.596	1.163	2.654	***	***	***	***	7.131
5.8	***	***	***	***	4.252	2.361	1.261	0.573	0.417	0.584	1.526	3.521	***	***	***	7.931
5.9	***	***	***	***	***	3.422	2.051	1.052	0.538	0.348	0.805	2.188	3.966	***	***	8.675
6.0	***	***	***	***	***	4.651	3.025	1.741	0.899	0.381	0.417	1.283	2.486	3.493	***	9.333
6.1	***	***	***	***	***	***	4.133	2.588	1.457	0.645	0.303	0.720	1.453	1.943	3.177	9.993
6.2	***	***	***	***	***	***	***	3.654	2.255	1.167	0.492	0.526	0.839	0.876	1.605	11.024
6.3	***	***	***	***	***	***	***	***	3.478	2.145	1.171	0.860	0.807	0.453	0.738	12.745
6.4	***	***	***	***	***	***	***	***	***	3.741	2.497	1.882	1.500	0.795	0.690	14.988
6.5	***	***	***	***	***	***	***	***	***	***	4.470	3.581	2.916	1.898	1.445	16.852
6.6	***	***	***	***	***	***	***	***	***	***	***	***	4.511	3.212	2.451	17.471
6.7	***	***	***	***	***	***	***	***	***	***	***	***	***	4.458	3.419	17.759
6.8	***	***	***	***	***	***	***	***	***	***	***	***	***	***	4.346	18.044

log T	Ni^{+14}	Ni^{+15}	Ni^{+16}	Ni^{+17}	Ni^{+18}	Ni^{+19}	Ni^{+20}	Ni^{+21}	Ni^{+22}	Ni^{+23}	Ni^{+24}	Ni^{+25}	Ni^{+26}	Ni^{+27}	Ni^{+28}	⟨Q⟩
6.1	3.177	4.628	***	***	***	***	***	***	***	***	***	***	***	***	***	9.993
6.2	1.605	2.507	3.580	4.734	***	***	***	***	***	***	***	***	***	***	***	11.024
6.3	0.738	1.162	1.698	2.287	2.788	***	***	***	***	***	***	***	***	***	***	12.745
6.4	0.690	0.692	0.762	0.887	1.090	3.619	***	***	***	***	***	***	***	***	***	14.988
6.5	1.445	1.078	0.743	0.489	0.447	2.373	4.447	***	***	***	***	***	***	***	***	16.852
6.6	2.451	1.754	1.068	0.508	0.251	1.677	3.206	4.884	***	***	***	***	***	***	***	17.471
6.7	3.419	2.433	1.440	0.633	0.183	1.186	2.257	3.386	4.895	***	***	***	***	***	***	17.759
6.8	4.346	3.100	1.835	0.817	0.188	0.835	1.518	2.198	3.240	4.484	***	***	***	***	***	18.044
6.9	***	3.808	2.304	1.098	0.300	0.623	0.967	1.270	1.921	2.757	3.806	***	***	***	***	18.582
7.0	***	4.689	2.970	1.596	0.633	0.672	0.723	0.697	1.009	1.498	2.148	3.051	4.120	***	***	19.766
7.1	***	***	3.994	2.462	1.341	1.128	0.909	0.599	0.618	0.797	1.118	1.684	2.415	***	***	21.467
7.2	***	***	***	3.693	2.418	1.968	1.505	0.941	0.699	0.609	0.641	0.915	1.367	***	***	23.014
7.3	***	***	***	***	3.715	3.051	2.371	1.578	1.101	0.771	0.547	0.566	0.785	3.637	***	24.171
7.4	***	***	***	***	***	4.245	3.368	2.365	1.674	1.122	0.667	0.456	0.480	2.693	***	24.886
7.5	***	***	***	***	***	***	4.379	3.185	2.298	1.544	0.880	0.464	0.318	1.999	4.312	25.294
7.6	***	***	***	***	***	***	***	3.978	2.909	1.967	1.114	0.523	0.238	1.482	3.331	25.542
7.7	***	***	***	***	***	***	***	4.775	3.534	2.417	1.388	0.620	0.202	1.076	2.537	25.755
7.8	***	***	***	***	***	***	***	***	4.118	2.842	1.652	0.745	0.211	0.771	1.915	25.965
7.9	***	***	***	***	***	***	***	***	4.712	3.287	1.949	0.908	0.263	0.552	1.415	26.210
8.0	***	***	***	***	***	***	***	***	***	3.690	2.216	1.051	0.302	0.483	1.109	26.382
8.1	***	***	***	***	***	***	***	***	***	4.142	2.536	1.260	0.412	0.394	0.821	26.645
8.2	***	***	***	***	***	***	***	***	***	4.605	2.880	1.500	0.559	0.356	0.601	26.907
8.3	***	***	***	***	***	***	***	***	***	***	3.220	1.746	0.719	0.362	0.448	27.128
8.4	***	***	***	***	***	***	***	***	***	***	3.563	2.002	0.893	0.392	0.341	27.308
8.5	***	***	***	***	***	***	***	***	***	***	3.892	2.252	1.066	0.439	0.264	27.447
8.6	***	***	***	***	***	***	***	***	***	***	4.208	2.493	1.237	0.499	0.207	27.557
8.7	***	***	***	***	***	***	***	***	***	***	4.508	2.721	1.399	0.556	0.167	27.636
8.8	***	***	***	***	***	***	***	***	***	***	4.784	2.937	1.555	0.619	0.137	27.700
8.9	***	***	***	***	***	***	***	***	***	***	***	3.140	1.699	0.676	0.114	27.747
9.0	***	***	***	***	***	***	***	***	***	***	***	3.330	1.836	0.734	0.097	27.785

Table A10.2: The charge abundance for Ni with $\kappa = 10$.

log T	Ni^{+0}	Ni^{+1}	Ni^{+2}	Ni^{+3}	Ni^{+4}	Ni^{+5}	Ni^{+6}	Ni^{+7}	Ni^{+8}	Ni^{+9}	Ni^{+10}	Ni^{+11}	Ni^{+12}	Ni^{+13}	Ni^{+14}	⟨Q⟩
4.0	1.834	0.121	0.640	3.718	***	***	***	***	***	***	***	***	***	***	***	1.215
4.1	2.676	0.422	0.211	2.443	***	***	***	***	***	***	***	***	***	***	***	1.621
4.2	3.600	0.948	0.068	1.492	4.667	***	***	***	***	***	***	***	***	***	***	1.919
4.3	4.433	1.550	0.099	0.757	3.089	***	***	***	***	***	***	***	***	***	***	2.149
4.4	***	2.199	0.334	0.288	1.817	4.949	***	***	***	***	***	***	***	***	***	2.539
4.5	***	2.898	0.787	0.145	0.925	3.237	***	***	***	***	***	***	***	***	***	2.954
4.6	***	3.578	1.337	0.269	0.393	1.941	***	***	***	***	***	***	***	***	***	3.381
4.7	***	4.238	1.907	0.583	0.193	1.074	3.628	***	***	***	***	***	***	***	***	3.798
4.8	***	4.842	2.431	0.947	0.209	0.582	2.527	***	***	***	***	***	***	***	***	4.147
4.9	***	***	2.913	1.300	0.319	0.343	1.828	4.136	***	***	***	***	***	***	***	4.432
5.0	***	***	3.385	1.652	0.469	0.227	1.354	3.186	***	***	***	***	***	***	***	4.660
5.1	***	***	3.871	2.017	0.648	0.181	0.990	2.431	4.546	***	***	***	***	***	***	4.865
5.2	***	***	4.398	2.421	0.869	0.191	0.699	1.791	3.508	***	***	***	***	***	***	5.090
5.3	***	***	4.992	2.883	1.153	0.267	0.484	1.243	2.595	4.200	***	***	***	***	***	5.377
5.4	***	***	***	3.434	1.524	0.435	0.367	0.807	1.810	2.984	***	***	***	***	***	5.762
5.5	***	***	***	4.107	2.020	0.725	0.383	0.508	1.172	1.994	3.759	***	***	***	***	6.268
5.6	***	***	***	4.929	2.667	1.174	0.564	0.388	0.726	1.233	2.599	4.999	***	***	***	6.899
5.7	***	***	***	***	3.500	1.812	0.941	0.474	0.496	0.711	1.695	3.636	***	***	***	7.623
5.8	***	***	***	***	4.507	2.628	1.510	0.768	0.487	0.424	1.041	2.548	4.410	***	***	8.327
5.9	***	***	***	***	***	3.601	2.247	1.240	0.671	0.340	0.610	1.706	3.135	4.304	***	8.941
6.0	***	***	***	***	***	4.698	3.118	1.860	1.018	0.431	0.370	1.082	2.106	2.847	4.328	9.496
6.1	***	***	***	***	***	***	4.118	2.622	1.521	0.688	0.318	0.676	1.324	1.669	2.710	10.106
6.2	***	***	***	***	***	***	***	3.580	2.236	1.167	0.512	0.543	0.848	0.827	1.466	11.108
6.3	***	***	***	***	***	***	***	4.920	3.345	2.052	1.127	0.855	0.836	0.477	0.742	12.785
6.4	***	***	***	***	***	***	***	***	***	3.503	2.324	1.776	1.462	0.791	0.718	15.065
6.5	***	***	***	***	***	***	***	***	***	***	4.139	3.331	2.747	1.790	1.398	16.902
6.6	***	***	***	***	***	***	***	***	***	***	***	***	4.217	2.996	2.317	17.523
6.7	***	***	***	***	***	***	***	***	***	***	***	***	***	4.180	3.236	17.819
6.8	***	***	***	***	***	***	***	***	***	***	***	***	***	***	4.128	18.120

log T	Ni^{+14}	Ni^{+15}	Ni^{+16}	Ni^{+17}	Ni^{+18}	Ni^{+19}	Ni^{+20}	Ni^{+21}	Ni^{+22}	Ni^{+23}	Ni^{+24}	Ni^{+25}	Ni^{+26}	Ni^{+27}	Ni^{+28}	⟨Q⟩
6.0	4.328	***	***	***	***	***	***	***	***	***	***	***	***	***	***	9.496
6.1	2.710	3.915	***	***	***	***	***	***	***	***	***	***	***	***	***	10.106
6.2	1.466	2.241	3.132	4.017	4.578	***	***	***	***	***	***	***	***	***	***	11.108
6.3	0.742	1.120	1.583	2.033	2.316	4.559	***	***	***	***	***	***	***	***	***	12.785
6.4	0.718	0.735	0.808	0.876	0.935	2.772	4.748	***	***	***	***	***	***	***	***	15.065
6.5	1.398	1.083	0.798	0.537	0.402	1.877	3.453	***	***	***	***	***	***	***	***	16.902
6.6	2.317	1.702	1.096	0.555	0.243	1.385	2.599	3.970	***	***	***	***	***	***	***	17.523
6.7	3.236	2.343	1.446	0.670	0.194	1.035	1.919	2.879	4.175	***	***	***	***	***	***	17.819
6.8	4.128	2.982	1.824	0.843	0.212	0.769	1.355	1.955	2.884	3.990	***	***	***	***	***	18.120
6.9	***	3.663	2.266	1.104	0.322	0.618	0.929	1.208	1.813	2.588	3.560	4.772	***	***	***	18.648
7.0	***	4.483	2.868	1.545	0.615	0.669	0.725	0.716	1.030	1.506	2.150	3.032	4.073	***	***	19.715
7.1	***	***	3.769	2.293	1.215	1.041	0.861	0.592	0.645	0.852	1.202	1.784	2.528	***	***	21.253
7.2	***	***	4.983	3.363	2.142	1.750	1.350	0.845	0.657	0.618	0.702	1.018	1.501	4.495	***	22.736
7.3	***	***	***	4.673	3.309	2.717	2.108	1.386	0.976	0.708	0.551	0.626	0.890	3.381	***	23.922
7.4	***	***	***	***	4.605	3.823	3.019	2.094	1.480	1.001	0.622	0.478	0.547	2.583	***	24.713
7.5	***	***	***	***	***	4.962	3.974	2.861	2.054	1.380	0.802	0.460	0.363	2.000	4.160	25.180
7.6	***	***	***	***	***	***	4.932	3.643	2.656	1.799	1.028	0.505	0.263	1.547	3.335	25.471
7.7	***	***	***	***	***	***	***	4.405	3.249	2.218	1.273	0.586	0.213	1.183	2.641	25.683
7.8	***	***	***	***	***	***	***	***	3.830	2.638	1.531	0.694	0.201	0.894	2.058	25.876
7.9	***	***	***	***	***	***	***	***	4.407	3.063	1.805	0.828	0.224	0.674	1.578	26.082
8.0	***	***	***	***	***	***	***	***	4.982	3.494	2.095	0.992	0.284	0.514	1.192	26.316
8.1	***	***	***	***	***	***	***	***	***	3.934	2.404	1.185	0.379	0.414	0.895	26.566
8.2	***	***	***	***	***	***	***	***	***	4.384	2.730	1.405	0.506	0.365	0.667	26.819
8.3	***	***	***	***	***	***	***	***	***	4.834	3.066	1.642	0.655	0.357	0.501	27.046
8.4	***	***	***	***	***	***	***	***	***	***	3.399	1.885	0.816	0.376	0.384	27.233
8.5	***	***	***	***	***	***	***	***	***	***	3.730	2.133	0.986	0.418	0.295	27.389
8.6	***	***	***	***	***	***	***	***	***	***	4.047	2.373	1.154	0.469	0.232	27.507
8.7	***	***	***	***	***	***	***	***	***	***	4.351	2.605	1.318	0.525	0.186	27.598
8.8	***	***	***	***	***	***	***	***	***	***	4.636	2.825	1.475	0.585	0.152	27.669
8.9	***	***	***	***	***	***	***	***	***	***	4.907	3.034	1.624	0.645	0.125	27.723
9.0	***	***	***	***	***	***	***	***	***	***	***	3.230	1.765	0.704	0.105	27.766

Table A10.3: The charge abundance for Ni with $\kappa = 5$.

log T	Ni^{+0}	Ni^{+1}	Ni^{+2}	Ni^{+3}	Ni^{+4}	Ni^{+5}	Ni^{+6}	Ni^{+7}	Ni^{+8}	Ni^{+9}	Ni^{+10}	Ni^{+11}	Ni^{+12}	Ni^{+13}	Ni^{+14}	⟨Q⟩
4.0	3.279	0.959	0.124	0.869	2.719	***	***	***	***	***	***	***	***	***	***	2.028
4.1	4.102	1.470	0.209	0.477	1.833	4.369	***	***	***	***	***	***	***	***	***	2.329
4.2	4.944	2.089	0.446	0.253	1.124	3.161	***	***	***	***	***	***	***	***	***	2.703
4.3	***	2.787	0.842	0.218	0.616	2.159	4.955	***	***	***	***	***	***	***	***	3.109
4.4	***	3.525	1.366	0.366	0.315	1.379	3.692	***	***	***	***	***	***	***	***	3.525
4.5	***	4.255	1.960	0.666	0.208	0.820	2.666	***	***	***	***	***	***	***	***	3.918
4.6	***	4.935	2.552	1.056	0.259	0.462	1.879	4.085	***	***	***	***	***	***	***	4.278
4.7	***	***	3.091	1.462	0.410	0.278	1.327	3.104	***	***	***	***	***	***	***	4.588
4.8	***	***	3.554	1.828	0.591	0.211	0.965	2.361	4.421	***	***	***	***	***	***	4.830
4.9	***	***	3.955	2.146	0.770	0.205	0.734	1.822	3.503	***	***	***	***	***	***	5.031
5.0	***	***	4.329	2.440	0.944	0.236	0.581	1.425	2.796	4.786	***	***	***	***	***	5.222
5.1	***	***	4.724	2.750	1.136	0.297	0.473	1.108	2.226	3.786	***	***	***	***	***	5.434
5.2	***	***	***	3.099	1.366	0.397	0.405	0.846	1.744	2.922	4.823	***	***	***	***	5.693
5.3	***	***	***	3.516	1.655	0.552	0.385	0.636	1.329	2.181	3.797	***	***	***	***	6.020
5.4	***	***	***	4.021	2.029	0.784	0.436	0.488	0.978	1.558	2.919	***	***	***	***	6.440
5.5	***	***	***	4.644	2.514	1.121	0.584	0.431	0.709	1.060	2.176	4.200	***	***	***	6.968
5.6	***	***	***	***	3.136	1.588	0.855	0.491	0.552	0.694	1.565	3.316	***	***	***	7.575
5.7	***	***	***	***	3.899	2.194	1.260	0.682	0.520	0.464	1.088	2.555	4.342	***	***	8.178
5.8	***	***	***	***	4.798	2.929	1.796	1.000	0.611	0.359	0.728	1.906	3.394	4.580	***	8.715
5.9	***	***	***	***	***	3.774	2.442	1.433	0.817	0.364	0.483	1.371	2.556	3.421	***	9.186
6.0	***	***	***	***	***	4.737	3.206	1.976	1.133	0.482	0.344	0.943	1.830	2.378	3.619	9.646
6.1	***	***	***	***	***	***	4.083	2.641	1.574	0.723	0.334	0.650	1.240	1.480	2.389	10.207
6.2	***	***	***	***	***	***	***	3.488	2.204	1.153	0.518	0.561	0.865	0.804	1.385	11.152
6.3	***	***	***	***	***	***	***	4.656	3.161	1.914	1.043	0.822	0.848	0.501	0.772	12.715
6.4	***	***	***	***	***	***	***	***	4.621	3.183	2.082	1.608	1.370	0.750	0.721	14.971
6.5	***	***	***	***	***	***	***	***	***	***	3.690	2.977	2.488	1.607	1.295	16.871
6.6	***	***	***	***	***	***	***	***	***	***	***	4.555	3.830	2.705	2.126	17.558
6.7	***	***	***	***	***	***	***	***	***	***	***	***	***	3.818	2.989	17.879
6.8	***	***	***	***	***	***	***	***	***	***	***	***	***	4.908	3.843	18.187
6.9	***	***	***	***	***	***	***	***	***	***	***	***	***	***	4.713	18.686

log T	Ni^{+14}	Ni^{+15}	Ni^{+16}	Ni^{+17}	Ni^{+18}	Ni^{+19}	Ni^{+20}	Ni^{+21}	Ni^{+22}	Ni^{+23}	Ni^{+24}	Ni^{+25}	Ni^{+26}	Ni^{+27}	Ni^{+28}	⟨Q⟩
6.0	3.619	***	***	***	***	***	***	***	***	***	***	***	***	***	***	9.646
6.1	2.389	3.427	4.577	***	***	***	***	***	***	***	***	***	***	***	***	10.207
6.2	1.385	2.080	2.866	3.595	3.931	***	***	***	***	***	***	***	***	***	***	11.152
6.3	0.772	1.138	1.574	1.949	2.075	3.756	***	***	***	***	***	***	***	***	***	12.715
6.4	0.721	0.774	0.880	0.931	0.874	2.290	3.819	***	***	***	***	***	***	***	***	14.971
6.5	1.295	1.051	0.842	0.602	0.389	1.560	2.810	4.351	***	***	***	***	***	***	***	16.871
6.6	2.126	1.606	1.102	0.604	0.248	1.183	2.174	3.360	4.857	***	***	***	***	***	***	17.558
6.7	2.989	2.209	1.431	0.707	0.212	0.920	1.666	2.522	3.687	***	***	***	***	***	***	17.879
6.8	3.843	2.821	1.789	0.866	0.235	0.727	1.238	1.793	2.659	3.671	4.919	***	***	***	***	18.187
6.9	4.713	3.465	2.200	1.100	0.338	0.615	0.901	1.179	1.764	2.501	3.442	4.602	***	***	***	18.686
7.0	***	4.222	2.741	1.481	0.586	0.655	0.726	0.748	1.079	1.561	2.217	3.094	4.127	***	***	19.610
7.1	***	***	3.512	2.104	1.076	0.945	0.807	0.593	0.689	0.931	1.324	1.938	2.706	***	***	20.969
7.2	***	***	4.556	3.006	1.845	1.520	1.183	0.750	0.626	0.645	0.796	1.167	1.699	4.295	***	22.369
7.3	***	***	***	4.153	2.858	2.347	1.816	1.177	0.844	0.653	0.577	0.722	1.040	3.265	***	23.573
7.4	***	***	***	***	4.033	3.338	2.623	1.790	1.262	0.870	0.582	0.520	0.649	2.521	4.919	24.454
7.5	***	***	***	***	***	4.411	3.517	2.502	1.788	1.206	0.721	0.464	0.427	1.978	4.038	25.018
7.6	***	***	***	***	***	***	4.436	3.245	2.357	1.596	0.924	0.488	0.303	1.555	3.308	25.369
7.7	***	***	***	***	***	***	***	3.991	2.935	2.003	1.158	0.556	0.237	1.217	2.680	25.613
7.8	***	***	***	***	***	***	***	4.722	3.507	2.414	1.407	0.653	0.213	0.941	2.143	25.815
7.9	***	***	***	***	***	***	***	***	4.077	2.831	1.669	0.774	0.222	0.723	1.706	26.013
8.0	***	***	***	***	***	***	***	***	4.643	3.252	1.946	0.921	0.265	0.559	1.303	26.231
8.1	***	***	***	***	***	***	***	***	***	3.683	2.242	1.096	0.341	0.447	0.996	26.467
8.2	***	***	***	***	***	***	***	***	***	4.122	2.554	1.296	0.448	0.382	0.756	26.709
8.3	***	***	***	***	***	***	***	***	***	4.564	2.877	1.516	0.581	0.358	0.573	26.940
8.4	***	***	***	***	***	***	***	***	***	***	3.208	1.754	0.733	0.365	0.437	27.144
8.5	***	***	***	***	***	***	***	***	***	***	3.537	1.995	0.896	0.395	0.337	27.312
8.6	***	***	***	***	***	***	***	***	***	***	3.856	2.233	1.059	0.440	0.265	27.444
8.7	***	***	***	***	***	***	***	***	***	***	4.164	2.466	1.223	0.492	0.212	27.547
8.8	***	***	***	***	***	***	***	***	***	***	4.457	2.691	1.381	0.550	0.171	27.629
8.9	***	***	***	***	***	***	***	***	***	***	4.736	2.904	1.533	0.609	0.141	27.691
9.0	***	***	***	***	***	***	***	***	***	***	4.998	3.106	1.677	0.668	0.117	27.741

Table A10.4: The charge abundance for Ni with $\kappa = 3$.

log T	Ni^{+0}	Ni^{+1}	Ni^{+2}	Ni^{+3}	Ni^{+4}	Ni^{+5}	Ni^{+6}	Ni^{+7}	Ni^{+8}	Ni^{+9}	Ni^{+10}	Ni^{+11}	Ni^{+12}	Ni^{+13}	Ni^{+14}	$\langle Q \rangle$
4.0	***	2.463	0.841	0.296	0.493	1.618	3.678	***	***	***	***	***	***	***	***	3.219
4.1	***	3.128	1.257	0.422	0.311	1.120	2.868	***	***	***	***	***	***	***	***	3.587
4.2	***	3.848	1.759	0.653	0.243	0.740	2.179	4.296	***	***	***	***	***	***	***	3.938
4.3	***	4.580	2.322	0.974	0.278	0.472	1.610	3.415	***	***	***	***	***	***	***	4.272
4.4	***	***	2.912	1.362	0.404	0.310	1.159	2.659	4.759	***	***	***	***	***	***	4.589
4.5	***	***	3.492	1.788	0.600	0.243	0.822	2.026	3.817	***	***	***	***	***	***	4.885
4.6	***	***	4.032	2.215	0.838	0.252	0.590	1.516	3.009	***	***	***	***	***	***	5.164
4.7	***	***	4.505	2.608	1.086	0.316	0.452	1.126	2.337	4.287	***	***	***	***	***	5.430
4.8	***	***	4.918	2.960	1.328	0.414	0.390	0.845	1.798	3.436	***	***	***	***	***	5.693
4.9	***	***	***	3.274	1.556	0.535	0.381	0.656	1.384	2.715	4.506	***	***	***	***	5.960
5.0	***	***	***	3.567	1.776	0.668	0.411	0.539	1.080	2.118	3.635	***	***	***	***	6.230
5.1	***	***	***	3.863	2.002	0.819	0.468	0.474	0.864	1.625	2.898	4.809	***	***	***	6.514
5.2	***	***	***	4.185	2.254	0.996	0.555	0.450	0.711	1.222	2.283	4.042	***	***	***	6.833
5.3	***	***	***	4.557	2.552	1.216	0.681	0.470	0.609	0.900	1.778	3.401	***	***	***	7.211
5.4	***	***	***	***	2.914	1.494	0.857	0.535	0.559	0.664	1.386	2.876	4.653	***	***	7.632
5.5	***	***	***	***	3.355	1.842	1.091	0.651	0.556	0.502	1.074	2.427	4.065	***	***	8.065
5.6	***	***	***	***	3.877	2.261	1.388	0.820	0.597	0.405	0.834	2.040	3.528	4.715	***	8.465
5.7	***	***	***	***	4.486	2.758	1.751	1.046	0.685	0.361	0.643	1.691	3.017	4.014	***	8.825
5.8	***	***	***	***	***	3.333	2.184	1.327	0.820	0.369	0.494	1.369	2.521	3.324	4.810	9.150
5.9	***	***	***	***	***	3.990	2.691	1.676	1.011	0.427	0.387	1.080	2.042	2.636	3.906	9.467
6.0	***	***	***	***	***	4.736	3.278	2.098	1.266	0.544	0.332	0.828	1.591	1.973	3.018	9.816
6.1	***	***	***	***	***	***	3.964	2.614	1.609	0.744	0.349	0.641	1.194	1.355	2.162	10.284
6.2	***	***	***	***	***	***	4.794	3.270	2.087	1.070	0.488	0.574	0.910	0.847	1.414	11.045
6.3	***	***	***	***	***	***	***	4.154	2.790	1.617	0.848	0.724	0.840	0.551	0.875	12.305
6.4	***	***	***	***	***	***	***	***	3.876	2.543	1.575	1.238	1.134	0.619	0.699	14.263
6.5	***	***	***	***	***	***	***	***	***	3.969	2.808	2.257	1.935	1.197	1.036	16.460
6.6	***	***	***	***	***	***	***	***	***	***	4.369	3.611	3.072	2.117	1.718	17.500
6.7	***	***	***	***	***	***	***	***	***	***	***	***	4.285	3.118	2.490	17.916
6.8	***	***	***	***	***	***	***	***	***	***	***	***	***	4.139	3.290	18.233
6.9	***	***	***	***	***	***	***	***	***	***	***	***	***	***	4.097	18.646
7.0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	4.965	19.328

log T	Ni^{+14}	Ni^{+15}	Ni^{+16}	Ni^{+17}	Ni^{+18}	Ni^{+19}	Ni^{+20}	Ni^{+21}	Ni^{+22}	Ni^{+23}	Ni^{+24}	Ni^{+25}	Ni^{+26}	Ni^{+27}	Ni^{+28}	$\langle Q \rangle$
5.9	3.906	***	***	***	***	***	***	***	***	***	***	***	***	***	***	9.467
6.0	3.018	4.189	***	***	***	***	***	***	***	***	***	***	***	***	***	9.816
6.1	2.162	3.085	4.097	***	***	***	***	***	***	***	***	***	***	***	***	10.284
6.2	1.414	2.080	2.826	3.473	3.642	***	***	***	***	***	***	***	***	***	***	11.045
6.3	0.875	1.286	1.763	2.136	2.129	3.375	4.766	***	***	***	***	***	***	***	***	12.305
6.4	0.699	0.855	1.064	1.171	1.015	2.082	3.260	4.873	***	***	***	***	***	***	***	14.263
6.5	1.036	0.942	0.885	0.739	0.456	1.356	2.340	3.680	***	***	***	***	***	***	***	16.460
6.6	1.718	1.378	1.063	0.681	0.281	1.023	1.821	2.895	4.251	***	***	***	***	***	***	17.500
6.7	2.490	1.914	1.349	0.750	0.243	0.829	1.450	2.265	3.365	4.586	***	***	***	***	***	17.916
6.8	3.290	2.477	1.676	0.880	0.264	0.692	1.140	1.708	2.559	3.536	4.762	***	***	***	***	18.233
6.9	4.097	3.073	2.043	1.069	0.342	0.613	0.892	1.224	1.842	2.589	3.560	4.725	***	***	***	18.646
7.0	4.965	3.733	2.486	1.351	0.515	0.623	0.731	0.840	1.240	1.771	2.499	3.424	4.499	***	***	19.328
7.1	***	4.520	3.070	1.789	0.840	0.786	0.727	0.626	0.819	1.146	1.646	2.343	3.190	***	***	20.366
7.2	***	***	3.863	2.445	1.380	1.165	0.934	0.634	0.629	0.759	1.040	1.522	2.155	4.477	***	21.619
7.3	***	***	4.875	3.325	2.143	1.761	1.362	0.872	0.680	0.621	0.694	0.972	1.405	3.455	***	22.819
7.4	***	***	***	4.393	3.090	2.545	1.978	1.308	0.934	0.694	0.570	0.654	0.904	2.680	4.966	23.833
7.5	***	***	***	***	4.172	3.466	2.736	1.888	1.340	0.921	0.608	0.509	0.593	2.110	4.132	24.584
7.6	***	***	***	***	***	4.455	3.564	2.549	1.832	1.244	0.751	0.476	0.407	1.677	3.444	25.087
7.7	***	***	***	***	***	***	4.428	3.250	2.369	1.615	0.949	0.508	0.300	1.339	2.865	25.420
7.8	***	***	***	***	***	***	***	3.956	2.919	2.005	1.175	0.578	0.246	1.064	2.361	25.662
7.9	***	***	***	***	***	***	***	4.660	3.470	2.407	1.421	0.677	0.228	0.842	1.921	25.869
8.0	***	***	***	***	***	***	***	***	4.030	2.814	1.680	0.799	0.243	0.662	1.538	26.070
8.1	***	***	***	***	***	***	***	***	4.585	3.228	1.953	0.944	0.287	0.527	1.214	26.282
8.2	***	***	***	***	***	***	***	***	***	3.645	2.237	1.110	0.360	0.435	0.950	26.502
8.3	***	***	***	***	***	***	***	***	***	4.079	2.544	1.307	0.465	0.378	0.731	26.735
8.4	***	***	***	***	***	***	***	***	***	4.511	2.857	1.517	0.589	0.359	0.564	26.950
8.5	***	***	***	***	***	***	***	***	***	4.945	3.178	1.743	0.733	0.366	0.436	27.143
8.6	***	***	***	***	***	***	***	***	***	***	3.500	1.977	0.889	0.394	0.340	27.306
8.7	***	***	***	***	***	***	***	***	***	***	3.813	2.209	1.047	0.437	0.269	27.436
8.8	***	***	***	***	***	***	***	***	***	***	4.118	2.438	1.206	0.488	0.216	27.539
8.9	***	***	***	***	***	***	***	***	***	***	4.409	2.658	1.361	0.543	0.175	27.620
9.0	***	***	***	***	***	***	***	***	***	***	4.686	2.869	1.511	0.601	0.144	27.684

Appendix B

Calculation Program

```
#include<stdio.h>
#include<math.h>
#include<conio.h>
#include<string.h>
void main()
{
   double Di(),Au(),Ra(),Die();
   double direc[30],aut[30],radi[30],diel[30],rate_i[30],rate_r[30];
   double T,kT,n[30],N,frac[30];
   double test,y,start,error,Q,lim1,lim2;
   int Z,i,k,d,num(),type;
   char element = 'F'; //type the name of element

   FILE *RATE,*ino,*table,*check,*chk1,*chk2,*r_com,*table1,*table2;

//****** input *******
//   d=1;  // Maxwellian
   d=2;  // kappa
   Z=num();

   k=3;

   type=2; //choose 1 for 1 table
   //choose 2 for 2 tables
  //choose for divided temperature of two table
   lim1=pow(10.,9.60);
   lim2=pow(10.,4.00);
//***** end input ****
   clrscr();

   RATE=fopen("new_rate.dat","w");
   ino=fopen("rate.dat","w");
   table=fopen("table.dat","w");
   table1=fopen("table1.dat","w");
   table2=fopen("table2.dat","w");
   check=fopen("error.dat","w");
   chk1=fopen("check1.dat","w");
   chk2=fopen("check2.dat","w");
   r_com=fopen("rate_com.dat","w");

   if(d==1){
     /* for the case of small Z*/
     if(type==1)fprintf(table,"For Maxwellian for Z=%d\n",Z);
     /* for the case of large Z*/
     else{fprintf(table1,"For Maxwellian for Z=%d\n",Z);
  fprintf(table2,"For Maxwellian for Z=%d\n",Z);
 }
     /* checking rate fraction */
      fprintf(r_com,"For Maxwellian for Z=%d\n",Z);
   }
```

```
    else{
      /* for the case of small Z*/
       if(type==1)fprintf(table,"For Kappa = %d  for Z=%d\n",k,Z);
      /* for the case of large Z*/
       else{fprintf(table1,"For Kappa = %d  for Z=%d\n",k,Z);
    fprintf(table2,"For Kappa = %d  for Z=%d\n",k,Z);
   }
      /* checking rate fraction */
       fprintf(r_com,"For Kappa = %d  for Z=%d\n",k,Z);
    }

  /* for the case of small Z*/
   if(type==1){
      fprintf(table,"log T&");
      for(i=0;i<=Z;i++)fprintf(table,"%c$^{+%d}$&",element,i);
      fprintf(table,"<Q>\\\\ \n");
   }
  /* for the case of large Z*/
   else{
      fprintf(table1,"log T&");
      for(i=0;i<=Z/2;i++)fprintf(table1,"%c$^{+%d}$&",element,i);
      fprintf(table1,"<Q>\\\\ \n");

      fprintf(table2,"log T&");
      for(i=Z/2;i<=Z;i++)fprintf(table2,"%c$^{+%d}$&",element,i);
      fprintf(table2,"<Q>\\\\ \n");
   }

  /* checking rate fraction */
   fprintf(r_com,"log T&");
   for(i=0;i<=Z-1;i++)fprintf(r_com,"%c$^{+%d}$&",element,i);
   fprintf(r_com,"%c+%d\\\\ \n",element,Z);

 for(T=1e4;T<pow(10.,9.6);T*=pow(10.,0.1)){

   if(type==1)fprintf(table,"%.1lf&",log10(T));
   else{
     if(T<lim1)fprintf(table1,"%.1lf&",log10(T));
     if(T>lim2) fprintf(table2,"%.1lf&",log10(T));
   }

   fprintf(r_com,"%.1lf&",log10(T));

  printf("this is  temperature = %.1le  kelvin\n",T);
    kT=T*8.6171e-5;

    for(i=0;i<=Z;i++){
       direc[i]=aut[i]=radi[i]=diel[i]=0.0;
       if(i<Z){
 direc[i]=Di(d,k,Z,i,kT);
    if(direc[i]<0.0){
       fprintf(check," at Z=%d state %d direct is %.4le\n",Z,
                      i,direc[i]);
       direc[i]=0.0;
    }
 aut[i]=Au(d,k,Z,i,kT);
    if(aut[i]<0.0){
       fprintf(check," at Z=%d state %d aut is %.4le\n",Z,i,
                      aut[i]);
       aut[i]=0.0;
```

```
    }
      }
      if(i>0){
radi[i]=Ra(d,k,Z,i,kT);
if(i<Z)diel[i]=Die(d,k,Z,i,kT);
     }
     rate_i[i]=direc[i]+aut[i];
     rate_r[i]=radi[i]+diel[i];

     fprintf(ino," +%d direct is %.4le  auto is %.4le  ionize
            rate is %.4le\n ",i,direc[i],aut[i],rate_i[i]);
     fprintf(RATE," +%d radiate is %.4le dielec is %.4le recom
            rate is %.4le\n ",i,radi[i],diel[i],rate_r[i]);

     fprintf(r_com,"%.3le  %.3le&",rate_r[i],rate_i[i]);
   }

   //**************  calculate ionization Balance  **************
   //***************  and calculate mean charge   ***************

 n[0]=N=1.0;
 Q=0.0;
 for(i=1;i<=Z;i++){
    n[i]=n[i-1]*(rate_i[i-1]/rate_r[i]);
    Q+=i*n[i];
 fprintf(ino,"tatal Q is %.3le\n ",Q);
    N+=n[i];
 }
 Q=Q/N;
 fprintf(ino,"mean Q is %.3le\n ",Q);

  if(d==1)fprintf(ino,"for maxwell\n");
  else fprintf(ino,"for kappa = %d\n",k);

  for(i=0;i<=Z;i++){
    n[i]=-log10(n[i]/N);
 }
    for(i=0;i<Z;i++){
       frac[i]=pow(10.0,-(n[i]-n[i+1]) );
       fprintf(ino,"\nSi[+%2d]   %7.3lf  where n[%2d]/n[%2d] is
              %.3lf",i,n[i],i,i+1,frac[i]);
    }
    fprintf(ino,"\nSi[+%2d]   %7.3lf\n  ",i,n[i]);

  if(type==1){
    for(i=0;i<=Z;i++){
      if(n[i]<5.)fprintf(table,"%.3lf&",n[i]);
      else fprintf(table,"***&");
    }
    fprintf(table," %.3lf\\\\ \n",Q);
  }

  else{
    if(T<lim1){
      for(i=0;i<=Z/2;i++){
if(n[i]<5.)fprintf(table1,"%.3lf&",n[i]);
else fprintf(table1,"***&");
      }
      fprintf(table1,"%.3lf\\\\ \n",Q);
    }
    if(T>lim2){
```

```
      for(i=Z/2;i<=Z;i++){
if(n[i]<5.)fprintf(table2,"%.3lf&",n[i]);
else fprintf(table2,"***&");
      }
      fprintf(table2,"%.3lf\\\\ \n",Q);
    }
  }


  fprintf(r_com,"\\\\ %.3lf\n",Q);
}

   fclose(RATE);
   fclose(ino);
   fclose(table);
   fclose(check);
   fclose(chk1);
   fclose(chk2);
   fclose(r_com);

}

//************ Decleration of Z number **************
 int num()
{
 return 26;
}

 //**** Calculation of direct ionization rate coefficient ***

 double Di(int d,int k,int Z,int i,double kT)
{
   double  I_energy[30][5],A[30][5][6],rate,IEA,y,sum,F1,F2,F3,
           K,sum1,sum2;
   double  Robust(),Acons();
   double  F4,F5,F6,F7,test,sum3;
   int s,j,n,m,stage[30];
   FILE *cons;

   K=1.*k;


   //***** Input constant **************

   cons=fopen("C60_I_26.DAT","r");
   for(n=0;n<=Z-1;n++){
      fscanf(cons,"%d ",&stage[n]);
      for(j=1;j<=stage[n];j++){
 fscanf(cons,"%lf",&I_energy[n][j]);
 for(m=1;m<=4;m++)fscanf(cons,"%lf",&A[n][j][m]);
      }
   }
   fclose(cons);


   rate=0.0;
   for(s=1;s<=stage[i];s++){ //** for state s **

     IEA=I_energy[i][s];
     y=IEA/kT;
```

```
    if(d==1){

      F4=A[i][s][1]*Robust(4,d,y,K);
printf("f4 = %.4le\n",F4);
      F5=A[i][s][2]*Robust(5,d,y,K);
printf("f5 = %.4le\n",F5);
      F6=A[i][s][3]*Robust(6,d,y,K);
printf("f6 = %.4le\n",F6);
      F7=A[i][s][4]*Robust(7,d,y,K);
printf("f7 = %.4le\n",F7);

    rate+=F4+F5+F6+F7;

    }
    else{
      y/=(K-1.5);

      F3=Robust(3,d,y,K);
      sum1=sum2=sum3=0.0;
      for(m=2;m<=k+1;m++){
 sum1+=1./(m-1.)/pow(1.+y,m-1.);
 sum2+=(K*y-m*y+2.*y+2.)/(m-1.)/pow(1.+y,m-1.);
 if(m<k+1)sum3+=1./(m-1)/pow(1.+y,m-1.);
      }
      rate+=A[i][s][1]*( pow(1.+y,-K)/K/y + log(y/(1.+y)) +sum1 );
      rate+=A[i][s][2]*( pow(1.+y,-K)/K/y + (2.+K*y+y)*log(y/(1.+y))
            +sum2+1.);
      rate+=A[i][s][3]/K/y*( log(1./y+1.) - sum3 );
      rate+= A[i][s][4]*F3;

    }

  }

  printf(" there are direc ionization state +%d \n",i);
  return rate*6.69e-7/kT/sqrt(kT)*Acons(K,d);

}

//********* end Direct ionization ****

//******** Calculation of auto ionization rate coefficience ***

 double Au(int d,int k,int Z,int i,double kT)
{
 double Acons(),Robust(),Au_cons();
 double K,y,rate,sum1,sum2,sum3,sum4,F1,state;
 double A[6],Zeff,a,a0,b,I2s,IEA,alfa,Xai,cons,z,I_ea[30],
        coeff[30][7];
 int n,m;
 FILE *Fe;

  K=1.*k;

 if(Z==26){
     printf(" there are auto ionization for Fe state +%d\n",i);
     Fe=fopen("AUT_I_FE.DAT","r");
   for(n=0;n<=Z-1;n++){
      fscanf(Fe,"%lf",&I_ea[n]);
      for(m=1;m<=5;m++)fscanf(Fe,"%lf",&coeff[n][m]);
```

```
    }
    fclose(Fe);

    if(d==1){
       cons=6.69/1e9/sqrt(kT)/kT*I_ea[i];
       y=I_ea[i]/kT;
       state=i*1.;
       return Robust(16,d,y,state)*cons;
    }
    else {
       cons=6.69/1e9/sqrt(kT)/kT*Acons(K,d)*I_ea[i];
       y=I_ea[i]/kT/(K-1.5);

       sum1=sum2=sum3=sum4=0.0;
       for(n=2;n<=k+1;n++){
if(n<k+1){
  sum1+=pow(1.+y,-n+1.)/(n-1.);
}
sum2+=pow(1.+y,-n+1.)/(n-1.);
sum3+=(K-n+2.)*y/(n-1.)/pow(1.+y,n-1.);
sum4+=(K-n+2.)*(K-n+3.)*0.5*y*y/(n-1.)/pow(1.+y,n-1.);
       }

     rate=coeff[i][1]*pow(1.+y,-K)/y/K;
     rate+=coeff[i][2]*(pow(1.+y,-K)/y/K - log(1.+1./y) + sum2);
     rate+=coeff[i][3]*(pow(1.+y,-K)/y/K -sum3 +
            (K+1.)*y*log(1.+1./y)-1.);
     rate+=coeff[i][4]*(pow(1.+y,-K)/y/K +(K+1.)*y-0.5-0.5*(K+1.)
            *(K+2.)*y*y*log(1.+1./y) + sum4);
     rate+=coeff[i][5]/K/y*( log(1.+1./y) - sum1);

     return rate*cons;
    }
  }

 //***** especially for Ca0 and C+1
 else if(Z==20&&i<2){

    if(i==0){
      a=6.0*pow(10.,-17.);
      b=1.12;
      IEA=25.;
    }
    else{
      a=9.8*pow(10.,-17.);
      b=1.12;
      IEA=29.;
    }

     cons=6.69e7/kT/sqrt(kT)*a*IEA*IEA*Acons(K,d);
     y=IEA/kT;
     if(d==1){// for maxwell
       F1=Robust(17,d,y,b);
       return F1*cons;
     }
     else{ // for kappa
       y/=(K-1.5);

       sum1=0.0;
       for(n=2;n<=k;n++)sum1+=pow(1.+y,-n+1.)/(n-1.);
       rate=pow(1.+y,-K)/K/y + b/K/y*( log((1.+y)/y) - sum1 );
```

```
      return rate*cons;
    }

 }//*** end especially for Ca0 and C+1

 else{  // this routine for other elements and other state of ca

  printf(" there are auto ionization state +%d\n",i);
  //********* Lithium sequent *******
  if(i==(Z-3)){

    I2s=13.6*0.25*(Z-1.679)*(Z-1.679);
    IEA=13.6*( (Z-0.835)*(Z-0.835) - 0.25*(Z-1.620)*(Z-1.620) );
    alfa=1.0/( 1.0 + 2.0*pow(10,-4)*Z*Z*Z );
    Zeff=Z-0.43;
    a0=5.292*1e-9;
    A[1]=2.220;
    A[2]=0.669;
    A[3]=0.488;
    A[4]=1.201;
    Xai=IEA/I2s;

    rate=0.0;
    if(d==1){  //** Maxwell

      cons=6.69e7/sqrt(kT)*M_PI*2.0*a0*a0*alfa/Zeff/Zeff;
      y=IEA/kT;

      F1=exp(y)*Robust(1,d,y,K);

      rate+=A[1]*(log(IEA/I2s)+F1) + A[2]*(1.-I2s/kT*F1);
      rate+=I2s/kT*A[3]*F1 + I2s*I2s/kT/kT*A[4]*(kT/IEA-F1);
      return rate*exp(-y)*cons;
    }
    else    {  //** kappa
      cons=6.69e7/kT/sqrt(kT)*M_PI*2.0*a0*a0*alfa/Zeff/Zeff*
           Acons(K,d)*I2s;
      y=I2s/(K-1.5)/kT;
      sum1=sum2=sum3=0.0;
      for(n=2;n<=k+1;n++){
if(n<k+1)sum1+=pow(1.+y*Xai,-n+1.)/(n-1.);
sum2+=pow(1.+y*Xai,-n+1.)/(n-1.);
sum3+=(K-n+2.)*y/(n-1.)/pow(1.+y*Xai,n-1.);
      }
      rate+=A[1]/K/y*( log(Xai)/pow(1.+y*Xai,K) + log((1.+y*Xai)
            /y/Xai)-sum1 );
      rate+=A[2]*( log(y*Xai/(1.+y*Xai))+pow(1.+y*Xai,-K)/K/y+sum2);
      rate+=A[3]*( log((1.+y*Xai)/y/Xai)-sum2 );
      rate+=A[4]*( 1./Xai - (K+1.)*y*log((1.+y*Xai)/y/Xai) + sum3 );
      return rate*cons;
    }

 } //**end lithium sequence**

 //**** Na sequence *****
 else if(i==(Z-11)){
//******** for Z<=16 ********
   if(Z<=16){
     z=1.*Z;
     IEA=26.0*(z-10.0);
     a=2.8*1e-17*pow(z-11.,-0.7);
```

```
      y=IEA/kT;

      rate=0.0;

      if(d==1){
        F1=Robust(4,d,y,K);
        return 6.69e7/kT/sqrt(kT)*a*IEA*IEA*F1;
      }
      else{
y/=(K-1.5);
cons= 6.69e7/kT/sqrt(kT)*Acons(K,d)*IEA*IEA*a;
F1=Robust(8,d,y,K);
return cons*F1;
      }
    }
//****** for Z > 16 *****
   else{
    z=1.*Z;
    IEA=11.0*pow(z-10.0,1.5);
    a=1.3*1e-14*pow(z-10.,-3.73);
    y=IEA/kT;

    rate=0.0;

    if(d==1){
      F1=Robust(14,d,y,K);
      return 6.69e7/kT/sqrt(kT)*a*IEA*IEA*F1;
    }
    else {
      y/=(K-1.5);
      cons = 6.69e7/kT/sqrt(kT)*a*IEA*IEA*Acons(K,d);
      rate=Robust(15,d,y,K);
      return rate*cons;

    }
   }
 } //** end Na sequence **

 //**** Mg to S sequence ****

  else if (i<=(Z-12)&&i>=(Z-16)){
    if(i==(Z-12)) IEA=10.3*pow(Z-10.,1.52); // Mg sequence
    else if(i==(Z-13)) IEA=18.0*pow(Z-11.,1.33); // Al sequence
    else if(i==(Z-14)) IEA=18.4*pow(Z-12.,1.36); // Si sequence
    else if(i==(Z-15)) IEA=23.7*pow(Z-13.,1.29); // P  sequence
    else  IEA=40.1*pow(Z-14.,1.10); // S  sequence

    y=IEA/kT;
    z=1.*Z;
    a=4.0e-13/z/z/IEA;

    rate=0.0;

    if(d==1){
      F1=Robust(14,d,y,K);
      return 6.69e7/kT/sqrt(kT)*a*IEA*IEA*F1;
    }
    else {
      y/=(K-1.5);
      cons = 6.69e7/kT/sqrt(kT)*a*IEA*IEA*Acons(K,d);
      rate=Robust(15,d,y,K);
```

```
      return rate*cons;

    }
  }//** end Mg to S sequenec ***

 else return 0.0;
} // end other elements


}//**end auto ionization ******


//** Radiative recombination rate coefficient *****

 double Ra(int d,int K,int Z,int i,double kT)
{

   double LnGamma(),Acons();
   double Arad[30],Xrad[30],k,rate,t;
   int j;

   FILE *cons;
   k=K*1.;
   t=kT/8.6171e-5;

   printf(" there are radiative recombinative state +%d\n",i);

   cons=fopen("C60_RE26.DAT","r");
   for(j=1;j<=Z;j++)fscanf(cons,"%lf   %lf ",&Arad[j],&Xrad[j]);
   fclose(cons);


      if(d==1)rate=Arad[i]*pow(t/(1e4),-Xrad[i]) ;
      else rate=Acons(k,d)*Arad[i]*pow((t/1e4),-Xrad[i])*pow(k-1.5,
          -Xrad[i]+1.5)*exp(LnGamma(k+Xrad[i]-0.5)-LnGamma(k+1.0));

   return rate ;

}//** end radiave recombination

 //***** dielectronic recombination rate coefficient ****

 double Die(int d,int K,int Z,int i,double kT)
{
   double rate,c[30][4],E[30][4],k,LnGamma(),Acons(),sum;
   int n,j;

   FILE *cons;

   k=K*1.;

   printf(" there are dielectronic recombination state +%d\n",i);

   cons=fopen("C60_DI26.DAT","r");
   for(n=1;n<=Z-1;n++){
      for(j=1;j<=4;j++)fscanf(cons,"%le ",&c[n][j]);
      for(j=1;j<=4;j++)fscanf(cons,"%lf ",&E[n][j]);
   }
   fclose(cons);


      if(d==1){
```

```
 sum=0.0;
 for(j=1;j<=4;j++)sum+=c[i][j]*exp(-E[i][j]/kT);
 rate=pow(kT,-1.5)*sum;
      }
      else{
 sum=0.0;
 for(j=1;j<=4;j++)sum+=c[i][j]/pow(1.0+E[i][j]/(k-1.5)
                          /kT,k+1.0);
 rate=Acons(k,d)*pow(kT,-1.5)*sum;
      }

   return rate;

}//** end dielectronic recombination

 double Robust(int i,int d,double y,double K)
{
   double a,b,T_IEA,u0,error,U[30],total_int,integral[30],
          total_old,INTEGRAL;
   double IEA,Z,I2s;
   double bisec_f0(),In(),bisec_Fi();
   int N,j,n,m,best_n,num();
   FILE *chk;

   chk=fopen("error.dat","a");

    Z=1.*num();
    I2s=13.6*0.25*(Z-1.679)*(Z-1.679);
    IEA=13.6*( (Z-0.835)*(Z-0.835) - 0.25*(Z-1.620)*(Z-1.620) );

   if(i==13){
      if(d==2) T_IEA=1./y/(K-1.5)*IEA/I2s;
      else T_IEA=1./y;

   }
   else{
      if(d==1)T_IEA=1./y;
      else T_IEA=1./y/(K-1.5);
   }

//*****  find u0 that F(u0) is peak *********
printf("robust %d  state 1\n",i);

   if(i==1||i==12||i==13)u0=1.;
   else{
     if(i==16)a=1.+T_IEA*1e-50;
       else a=1.+T_IEA*1e-6;
     if(d==2) b=1.+T_IEA*1e5/K;
       else b=1.+T_IEA*100.;
     u0=bisec_f0(i,K,y,a,b);

   }//***** end finding u0 ********

//*****  find best N **************

  error=1.0;
  for(N=2;error>=1e-4;N++){

 //**** finding the satisfy U1,U2,...Uj,...,UN **
     for(j=1;j<=N;j++){
 if(d==1){
```

```
    a=u0+T_IEA*1e-16;
    if(i==16) b=u0+1000.*T_IEA*log(pow(2.,j)*500.);
    else b=u0+100.*T_IEA*log(pow(2.,j)*500.);
 }
 else {
   a=u0+1e-21;
   b=u0+5e6/(K*K)*T_IEA*log(pow(2.,j)*500.);
 }
 U[j]=bisec_Fi(i,j,K,y,a,b,u0);
      }
      U[0]=1.;

//*** check error by integral [N-1]/intrgral[N] > 10^-4 ***

      total_int=0.0;
      for(m=1;m<=N-1;m++){
 n=2;
 integral[m]=In(i,n,K,y,U[m],U[m-1]);
 total_int+=integral[m];

//**** checking for very low integral ****
 if(total_int<1e-50){
   fprintf(chk," 0 check! for robust state %d  the
                 int is %.4le\n",i,total_int);
   fclose(chk);
   return 0.0;
 }
       }
      integral[N]=In(i,n,K,y,U[N],U[N-1]);
      total_int+=integral[N];
      error=integral[N]/total_int;
  }

//*** real N is added by 1 from the last loop ***
  N-=1;

 //***  the real integrate is begin to fine the best du (choose by n)

   total_old=error=10.;
   for(n=2;error>1e-4;n+=10){
      INTEGRAL=0.;
      for(m=1;m<=N;m++)INTEGRAL+=In(i,n,K,y,U[m],U[m-1]);

      error=fabs(INTEGRAL/total_old-1.);
      total_old=INTEGRAL;
   } //*** end choosing n ***

   fclose(chk);
   return INTEGRAL;

}

//**** sunroutine for bisection method *******

 double bisec_f0(int i,double K,double y,double a,double b)
{
  double check,u_old,u,mid,f0();
  FILE *chk;

  u=b;
  check=10.;
```

```
  chk=fopen("check1.dat","a");
  for(;check>1e-11;){
      mid=(a+b)/2.;
      u_old=a;
if(f0(i,K,y,a)*f0(i,K,y,b)>0.){
   printf("\n BAD a and b where a= %le b = %le \n",a,b);
   fprintf(chk,"BAD a and b where a=%le f(a)=%.3le b= %le
                    f(b)=%.3le \n",a,f0(i,K,y,a),b,f0(i,K,y,b));
 //    getch();
   break;
   }
      if(f0(i,K,y,a)*f0(i,K,y,mid)<0.)b=u=mid;
      else a=mid;
      check=fabs((u-1.)/(u_old-1.)-1.);
   }
  fclose(chk);

  return u;

}

//******** Function to calculate u0 **********

 double f0(int i,double K,double y,double u)
{
    double k,I_ea[30],coeff[30][6],check,F;
    int n,m,j,num(),Z;

    FILE *Fe;

    k=K*1.;
    Z=num();

      if(i==2)return 1.-log(u)-y*u*log(u);
      else if(i==3) return 1.+y*u-log(u)*(1.+y*u) -(K+1.)
                          *y*u*log(u);

      else if(i==4)return 1.-y*u*u+y*u;
      else if(i==5)return 2.-y*u*u+y*u;
      else if(i==6)return 1./u-y*log(u);
      else if(i==7)return 1.-log(u)-y*u*log(u);

      else if(i==8)return 1.+(k+2.)*y*u-(k+1.)*y*u*u;
      else if(i==9)return 2.*(u+y*u*u-1.-y*u)-(k+1.)*y*(u*
                         u*u-2.*u*u+u);
      else if(i==10)return 1.+y*u-(k+1.)*y*u*log(u);
      else if(i==11)return 1.+y*u-(1.+y*u)*log(u)-(k+1.)*y*
                          u*log(u);

      else if(i==14)return 3.+y*u-y*u*u*u*u;
      else if(i==15)return 3.*(1.+y*u)-(k+1.)*(u*u*u*u-u)*y;

      else if(i==16){

      Fe=fopen("AUT_I_FE.DAT","r");
for(n=0;n<=Z-1;n++){
  fscanf(Fe,"%lf",&I_ea[n]);
  for(m=1;m<=5;m++)fscanf(Fe,"%lf",&coeff[n][m]);
}
      fclose(Fe);
```

```
      check=0.5;
      for(j=0;j<=Z-1;j++){
 if(k<check){
    n=j;
    break;
 }
 check+=1.0;
      }

      F= -y*coeff[n][1]+coeff[n][2]*(1./u/u-y+y/u)+coeff[n][3]
             *(2./u/u/u-y+y/u/u);
      return F+coeff[n][4]*(3./u/u/u/u-y+y/u/u/u)+coeff[n][5]*
             (1./u-y*log(u));
     }
    else return k/u-(1.+k*log(u));
}

 //**** bisection method to find ui *******

 double bisec_Fi(int i,int j,double K,double y,double a,double
        b,double u0)
{
double check,u_old,u,mid,F(),up,low,between;
  FILE *error;

  error=fopen("check2.dat","a");
  u=b;
  check=1.0;
  for(;check>1e-11;){
      mid=(a+b)/2.;
      u_old=a;

      up=F(i,K,y,a)-F(i,K,y,u0)/pow(2.,j);
      low=F(i,K,y,b)-F(i,K,y,u0)/pow(2.,j);
      between=F(i,K,y,mid)-F(i,K,y,u0)/pow(2.,j);
      if( up*low >0.){
 printf("\n !!!!!!! worse a=%.3le and b=%.3le where f(a)= %.4le
               f(b) = %.4le \n",a,b,up,low);
 fprintf(error,"!! worse a=%.3le and b=%.3le where f(a) = %.4le
               f(b) = %.4le \n",a,b,up,low);
//  getch();
 break;
      }
      if( up*between<0.)b=u=mid;
      else a=mid;
      check=fabs((u-1.)/(u_old-1.)-1.);
  }
   fclose(error);
   return u;
}

 //****** function for calculate ui *****

 double F(int i,double k,double y,double u)
{
   double A[6],I2s,IEA,Xi,Z,I_ea[30],coeff[30][6],check,F;
   int num(),n,m,j,ze;

    FILE *Fe;
```

```
    ze=num();

    Z=1.*num();
    A[1]=2.220;
    A[2]=0.669;
    A[3]=0.488;
    A[4]=1.201;
    I2s=13.6*0.25*(Z-1.679)*(Z-1.679);
    IEA=13.6*( (Z-0.835)*(Z-0.835) - 0.25*(Z-1.620)*(Z-1.620) );
    Xi=IEA/I2s;

   if(i==1)return exp(-u*y)/u;
   else if(i==2)return log(u)/u*exp(-u*y);
   else if(i==3)return log(u)/u/pow(1.+y*u,k+1.);

   else if(i==4)return (1.-1./u)*exp(-u*y);
   else if(i==5)return (1.-1./u)*(1.-1./u)*exp(-u*y);
   else if(i==6)return log(u)*exp(-u*y);
   else if(i==7)return log(u)/u*exp(-u*y);

   else if(i==8)return (1.-1./u)/pow((1.+y*u),(k+1.));
   else if(i==9)return (1.-1./u)*(1.-1./u)/pow((1.+y*u),(k+1.));
   else if(i==10)return log(u)/pow((1.+y*u),(k+1.));
   else if(i==11) return log(u)/u/pow((1.+y*u),(k+1.));

   else if(i==12)return ( A[1]*log(u*Xi)+A[2]*(1.-1./u/Xi)+A[3]
        /u/Xi+A[4]/(Xi*Xi*u*u) )*exp(-y*u);
   else if(i==13)return ( A[1]*log(u*Xi)+A[2]*(1.-1./u/Xi)+A[3]
        /u/Xi+A[4]/(Xi*Xi*u*u) )/pow(1.+y*Xi*u,k+1);
   else if(i==14)return (1.-1./u/u/u)*exp(-y*u);
   else if(i==15)return (1.-1./u/u/u)/pow((1.+y*u),(k+1.));

   else if(i==16){

      Fe=fopen("AUT_I_FE.DAT","r");
for(n=0;n<=ze-1;n++){
  fscanf(Fe,"%lf",&I_ea[n]);
  for(m=1;m<=5;m++)fscanf(Fe,"%lf",&coeff[n][m]);
}
      fclose(Fe);

      check=0.5;
      for(j=0;j<=ze-1;j++){
 if(k<check){
    n=j;
    break;
 }
 check+=1.0;
      }

      F= (coeff[n][1] + coeff[n][2]*(1.-1./u) + coeff[n][3]*
         (1.-1./u/u))*exp(-u*y);
      return F+(coeff[n][4]*(1.-1./u/u/u)+coeff[n][5]*log(u))
         *exp(-u*y);
     }

  else return (1.+k*log(u))*exp(-u*y);

}

//**** Subroutime for integration ******
```

```
 double In(int i,int n,double k,double y,double upper,double low)
{
  double u,F(),sum,du;
  int p;

      u=low;

      du=(upper-u)/n;

      sum=(1.0/3.0)*F(i,k,y,u);
      for(p=1;u<upper;p++){
  u+=du;
  if(p%2)sum+=(4.0/3.0)*F(i,k,y,u);
  if(!(p%2))sum+=(2.0/3.0)*F(i,k,y,u);
      }
      u=upper;
      sum+=(1.0/3.0)*F(i,k,y,u);
      sum*=du;
      return sum;
 }

double Acons(double k,int d)
{
 double LnGamma();
 if(d==2)return( exp(LnGamma(k+1.0)-LnGamma(k-0.5))
         /pow((k-1.5),1.5) );
 else return(1.0);
}

/*****************  file for gamma function  ***********/
double LnGamma(double xx)
{
   double x,y,tmp,ser;
   static double cof[6]={76.18009172947146,
      -86.50532032941677,24.01409824083091,-1.231739572450155,
      0.1208650973866179e-2,-0.5395239384953e-5};
   int j;

   y=x=xx;
   tmp=x+5.5;
   tmp-=(x+0.5)*log(tmp);
   ser=1.000000000190015;
   for(j=0;j<=5;j++)ser+=cof[j]/++y;
   return -tmp+log(2.5066282746310005*ser/x);
}
```

Appendix C
Verner's FORTRAN Program

This does not represent work of this thesis, but rather is a FORTRAN program used to check our results. This program was obtained from the website of Dima Verner (http://www.pa.uky.edu/∼verner/fortran.html), as cited by Mazzotta et al. (1998).

```
      subroutine colfit(iz,in,is,t,c)
* Version 4.
* January 8, 1997. Minor modification (exp are calculated with
* double precision) which improves accuracy of very low rates
* (less than 10**(-20)) to avoid negative Na+ rates at logT < 4.2
* November 12, 1996. Improved presentation for the first exponential integral
******************************************************************************
*** This subroutine calculates partial or total rates of direct collisional
*** ionization, including excitation-autoionization contribution, for all
*** ionization stages of all elements from H to Zn (Z=30)
*** in the range 10^4 - 10^9 K by use of the fits from
*** M. Arnaud and J. Raymond, 1992, ApJ 398, 394 for Fe, from
*** M. Arnaud and R. Rothenflug, 1985, A&AS 60, 425 for H, He, C, N, O, Ne,
*** Na, Mg, Al, Si, S, Ar, Ca, Ni (with some corrections described in
*** Verner & Yakovlev, 1990, ApSS, 165, 27), and from
*** interpolation/extrapolation for other elements.
*** Input parameters:  iz - atomic number
***                    in - number of electrons from 1 to iz
***                    is - shell number
***                    t  - temperature, K
*** Output parameter:  c  - rate coefficient, cm^3 s^(-1)
*** If the input parameter is=0, the subroutine calculates total rate,
*** otherwise the subroutine calculates partial rate for the corresponding
*** shell: 1 - 1s, 2 - 2s, 3 - 2p, 4 - 3s, 5 - 3p, 6 - 3d, 7 - 4s.
*** Autoionization contribution is added to the rate for the outermost shell.
*** Fits are available for 3 (or less) outer shells. In other cases,
*** the subroutine returns c=0.
******************************************************************************
      common/clion/clion(5,30,30,7)
      common/eafe/eafe(6,26)
      real*8 x,y,fcl1,fcl2
      c=0.0
      if(iz.lt.1.or.iz.gt.30)return
      if(in.lt.1.or.in.gt.iz)return
      if(in.lt.5)ismin=1
      if(in.gt.4.and.in.lt.13)ismin=2
      if(in.gt.12.and.in.lt.29)ismin=4
      if(in.gt.28.or.(iz.eq.in.and.iz.gt.20).or.((iz-in).eq.1.and.
     &(iz.eq.22.or.iz.eq.25.or.iz.eq.26)))ismin=5
      ismax=ismin+2
      if(in.lt.3)ismax=1
      if((in.gt.2.and.in.lt.11).or.(in.gt.12.and.in.lt.19))
     &ismax=ismin+1
      if((in.eq.19.and.iz.gt.18.and.iz.lt.21).or.(in.eq.20.
     &and.iz.eq.20))ismax=ismin+3
      imin=ismin
```

```
      imax=ismax
      if(is.ne.0) then
         if(is.lt.imin.or.is.gt.imax) then
            return
         else
            imin=is
            imax=is
         endif
      endif
      tk=8.6171e-05*t
      do i=imin,imax
         x=clion(1,iz,in,i)/tk
         if(x.le.30.0)c=c+((dexp(-x)/x)*((((clion(2,iz,in,i)*
     &(1.0-(x*fcl1(x))))+(clion(3,iz,in,i)*((1.0+x)-((x*(x+2.0))
     &*fcl1(x)))))+(clion(4,iz,in,i)*fcl1(x)))+((clion(5,iz,in,i)
     &*x)*fcl2(x))))
      enddo
      c=6.69e-07*c/tk/sqrt(tk)
      if(is.ne.0.and.is.lt.ismax)return
*** autoionization rates
      ct=6.69e+07/sqrt(tk)
      if(iz.eq.26)then
         if((in.gt.10.and.in.lt.25).or.in.eq.3)then
            y=eafe(1,in)/tk
            if(y.lt.50.0)c=c+ct*dexp(-y)*(eafe(2,in)+eafe(3,in)*
     &(1.0-y*fcl1(y))+eafe(4,in)*(1.0-y*(1.0-y*fcl1(y)))+eafe(5,in)*
     &(1.0-0.5*(y-y*y+y**3*fcl1(y)))+eafe(6,in)*fcl1(y))*1.0e-16
         endif
      else
      if(in.eq.3)then
         ea=13.6*((iz-0.835)**2-0.25*(iz-1.62)**2)
         y=ea/tk
         if(y.lt.50.0)then
            b=1.0/(1.0+2.0e-04*iz**3)
            g=2.22*fcl1(y)+0.67*(1.0-y*fcl1(y))+0.49*y*fcl1(y)+
     &1.2*y*(1.0-y*fcl1(y))
            ca=1.92e-07*b/(iz-0.43)**2/sqrt(tk)*dexp(-y)*g
            if(iz.eq.6)ca=ca*0.6
            if(iz.eq.7)ca=ca*0.8
            if(iz.eq.8)ca=ca*1.25
            c=c+ca
         endif
      endif
      if(in.eq.11)then
         if(iz.lt.17) then
            ea=26.0*(iz-10)
            y=ea/tk
            dz=(iz-11)**0.7
            if(iz.eq.11)dz=1.0
            if(y.lt.50.0)c=c+2.8e-17/dz*ct*ea*dexp(-y)*(1.0-y*fcl1(y))
         else
            ea=11*(iz-10)*sqrt(iz-10.0)
            y=ea/tk
            if(y.lt.50.0)c=c+1.3e-14/(iz-10)**3.73*ct*ea*dexp(-y)
     &*(1.0-0.5*(y-y*y+y**3*fcl1(y)))
         endif
      endif
      if(in.gt.11.and.in.lt.17) then
         if(in.eq.12)ea=10.3*(iz-10)**1.52
         if(in.eq.13)ea=18.0*(iz-11)**1.33
         if(in.eq.14)ea=18.4*(iz-12)**1.36
         if(in.eq.15)ea=23.7*(iz-13)**1.29
         if(in.eq.16)ea=40.1*(iz-14)**1.10
         y=ea/tk
```

```
         if(y.lt.50.0)c=c+4.0e-13/(iz*iz)*ct*dexp(-y)*(1.0-0.5*
     &(y-y*y+y**3*fcl1(y)))
      endif
      if(iz.eq.20.and.in.eq.20)then
         ea=25.0
         ab=6.0e-17
         ba=1.12
         y=ea/tk
         if(y.lt.50.0)c=c+ct*ab*ea*dexp(-y)*(1.0+ba*fcl1(y))
      endif
      if(iz.eq.20.and.in.eq.19)then
         ea=29.0
         ab=9.8e-17
         ba=1.12
         y=ea/tk
         if(y.lt.50.0)c=c+ct*ab*ea*dexp(-y)*(1.0+ba*fcl1(y))
      endif
      endif
      return
      end
      double precision function fcl1(x)
      real*8 x
      dimension a(6),b(8)
      data a/-0.57721566,0.99999193,-0.24991055,
     &0.05519968,-0.00976004,0.00107857/
      data b/8.5733287401,18.0590169730,8.6347608925,0.2677737343,
     &9.5733223454,25.6329561486,21.0996530827,3.9584969228/
      if(x.lt.1.0)then
         aa=(a(1)+a(2)*x+a(3)*x*x+a(4)*x**3+a(5)*x**4+a(6)*x**5-
     &dlog(x))*dexp(x)
      else
         if(x.lt.1.0e9)then
            aa=(x**4+b(1)*x**3+b(2)*x**2+b(3)*x+b(4))/(x**4+b(5)*x**3+
     &b(6)*x**2+b(7)*x+b(8))/x
         else
            aa=1.0/x
         endif
      endif
      fcl1=aa
      return
      end
      double precision function fcl2(x)
      real*8 x
      dimension pa(15),qa(15)
      data pa/1.0000e+00,2.1658e+02,2.0336e+04,1.0911e+06,3.7114e+07,
     &8.3963e+08,1.2889e+10,1.3449e+11,9.4002e+11,4.2571e+12,1.1743e+13,
     &1.7549e+13,1.0806e+13,4.9776e+11,0.0000e+00 /
      data qa/1.0000e+00,2.1958e+02,2.0984e+04,1.1517e+06,4.0349e+07,
     &9.4900e+08,1.5345e+10,1.7182e+11,1.3249e+12,6.9071e+12,2.3531e+13,
     &4.9432e+13,5.7760e+13,3.0225e+13,3.3641e+12 /
      if(x.gt.0.27)then
        p=0.0
        q=0.0
        do i=1,15
          p=p+(pa(i)/(x**(i-1)))
          q=q+(qa(i)/(x**(i-1)))
          fcl2=((p/q)/x)/x
        enddo
      else
        fcl2=(((dlog(x)**2)/2.0)+(0.57722*dlog(x)))+1.0
      endif
      return
      end
*********************************************
      block data exaife
      common/eafe/eafe(6,26)
```

```
      data(eafe(i, 3),i=1,6)/6592.0,0.0164,0.00176,-0.0117,0.00,0.0216/
      data(eafe(i,11),i=1,6)/ 704.0,0.0000,0.00000, 0.0000,2.95,0.0000/
      data(eafe(i,12),i=1,6)/ 700.0,0.0000,0.00000, 0.0000,4.81,0.0000/
      data(eafe(i,13),i=1,6)/ 671.0,0.0000,0.00000, 0.0000,5.92,0.0000/
      data(eafe(i,14),i=1,6)/ 670.0,0.0000,0.00000, 0.0000,4.10,0.0000/
      data(eafe(i,15),i=1,6)/ 650.0,0.0000,0.00000, 0.0000,3.89,0.0000/
      data(eafe(i,16),i=1,6)/ 650.0,0.0000,0.00000, 0.0000,3.21,0.0000/
      data(eafe(i,17),i=1,6)/ 650.0,0.0000,0.00000, 0.0000,1.96,0.0000/
      data(eafe(i,18),i=1,6)/ 650.0,0.0000,0.00000, 0.0000,1.87,0.0000/
      data(eafe(i,19),i=1,6)/ 160.0,5.0000,43.0000,-72.600,42.9,0.0000/
      data(eafe(i,20),i=1,6)/ 125.0,0.0000,0.00000,-48.100,42.5,16.300/
      data(eafe(i,21),i=1,6)/  95.0,0.0000,0.00000,-5.8300,12.3,8.8500/
      data(eafe(i,22),i=1,6)/  81.0,0.0000,0.28000,-16.200,35.5,0.0000/
      data(eafe(i,23),i=1,6)/  60.0,3.0200,67.5000,-59.800,46.0,0.0000/
      data(eafe(i,24),i=1,6)/  57.3,0.8780,0.00000,-115.00,71.2,47.900/
      end
**********************************************
      block data collis
      common/clion/clion(5,30,30,7)
      data(clion(i, 1, 1,1),i=1,5)/   13.60, 22.8,-12.000, 1.90, -22.60/
      data(clion(i, 2, 1,1),i=1,5)/   54.42, 14.4, -5.600, 1.90, -13.30/
      data(clion(i, 3, 1,1),i=1,5)/  122.50, 13.8, -5.175, 1.90, -12.55/
      data(clion(i, 4, 1,1),i=1,5)/  217.70, 13.3, -4.750, 1.90, -11.80/
      data(clion(i, 5, 1,1),i=1,5)/  340.20, 12.8, -4.325, 1.90, -11.05/
      data(clion(i, 6, 1,1),i=1,5)/  490.00, 12.2, -3.900, 1.90, -10.30/
      data(clion(i, 7, 1,1),i=1,5)/  667.10, 12.3, -4.000, 1.90, -10.30/
      data(clion(i, 8, 1,1),i=1,5)/  871.40, 12.3, -4.000, 1.90, -10.30/
      data(clion(i, 9, 1,1),i=1,5)/ 1103.00, 12.4, -4.050, 1.90, -10.35/
      data(clion(i,10, 1,1),i=1,5)/ 1362.00, 12.5, -4.100, 1.90, -10.40/
      data(clion(i,11, 1,1),i=1,5)/ 1649.00, 12.5, -4.100, 1.90, -10.40/
      data(clion(i,12, 1,1),i=1,5)/ 1963.00, 12.6, -4.200, 1.90, -10.40/
      data(clion(i,13, 1,1),i=1,5)/ 2304.00, 12.6, -4.200, 1.90, -10.40/
      data(clion(i,14, 1,1),i=1,5)/ 2673.00, 12.7, -4.300, 1.90, -10.40/
      data(clion(i,15, 1,1),i=1,5)/ 3070.00, 12.8, -4.300, 1.90, -10.45/
      data(clion(i,16, 1,1),i=1,5)/ 3494.00, 12.8, -4.300, 1.90, -10.50/
      data(clion(i,17, 1,1),i=1,5)/ 3946.00, 12.8, -4.350, 1.90, -10.50/
      data(clion(i,18, 1,1),i=1,5)/ 4426.00, 12.8, -4.400, 1.90, -10.50/
      data(clion(i,19, 1,1),i=1,5)/ 4934.00, 12.9, -4.400, 1.90, -10.50/
      data(clion(i,20, 1,1),i=1,5)/ 5470.00, 12.9, -4.400, 1.90, -10.50/
      data(clion(i,21, 1,1),i=1,5)/ 6034.00, 12.9, -4.417, 1.90, -10.52/
      data(clion(i,22, 1,1),i=1,5)/ 6626.00, 12.9, -4.433, 1.90, -10.53/
      data(clion(i,23, 1,1),i=1,5)/ 7246.00, 12.9, -4.450, 1.90, -10.55/
      data(clion(i,24, 1,1),i=1,5)/ 7895.00, 13.0, -4.467, 1.90, -10.57/
      data(clion(i,25, 1,1),i=1,5)/ 8572.00, 13.0, -4.483, 1.90, -10.58/
      data(clion(i,26, 1,1),i=1,5)/ 9278.00, 13.0, -4.500, 1.90, -10.60/
      data(clion(i,27, 1,1),i=1,5)/10010.00, 13.0, -4.500, 1.90, -10.60/
      data(clion(i,28, 1,1),i=1,5)/10780.00, 13.0, -4.500, 1.90, -10.60/
      data(clion(i,29, 1,1),i=1,5)/11570.00, 13.0, -4.500, 1.90, -10.60/
      data(clion(i,30, 1,1),i=1,5)/12390.00, 13.0, -4.500, 1.90, -10.60/
      data(clion(i, 2, 2,1),i=1,5)/   24.59, 17.8,-11.000, 7.00, -23.20/
      data(clion(i, 3, 2,1),i=1,5)/   75.64, 18.4, -9.775, 6.38, -21.90/
      data(clion(i, 4, 2,1),i=1,5)/  153.90, 19.1, -8.550, 5.75, -20.60/
      data(clion(i, 5, 2,1),i=1,5)/  259.40, 19.8, -7.325, 5.12, -19.30/
      data(clion(i, 6, 2,1),i=1,5)/  392.10, 20.4, -6.100, 4.50, -18.00/
      data(clion(i, 7, 2,1),i=1,5)/  552.10, 20.8, -6.300, 4.40, -18.20/
      data(clion(i, 8, 2,1),i=1,5)/  739.30, 21.2, -6.500, 4.30, -18.40/
      data(clion(i, 9, 2,1),i=1,5)/  953.90, 21.5, -6.650, 4.25, -18.55/
      data(clion(i,10, 2,1),i=1,5)/ 1196.00, 21.9, -6.800, 4.20, -18.70/
      data(clion(i,11, 2,1),i=1,5)/ 1465.00, 22.2, -7.000, 4.20, -18.80/
      data(clion(i,12, 2,1),i=1,5)/ 1762.00, 22.4, -7.100, 4.10, -18.90/
      data(clion(i,13, 2,1),i=1,5)/ 2086.00, 22.7, -7.200, 4.10, -19.00/
      data(clion(i,14, 2,1),i=1,5)/ 2438.00, 22.9, -7.300, 4.00, -19.10/
      data(clion(i,15, 2,1),i=1,5)/ 2817.00, 23.1, -7.450, 4.00, -19.20/
      data(clion(i,16, 2,1),i=1,5)/ 3224.00, 23.3, -7.600, 4.00, -19.30/
      data(clion(i,17, 2,1),i=1,5)/ 3659.00, 23.5, -7.700, 3.95, -19.40/
      data(clion(i,18, 2,1),i=1,5)/ 4121.00, 23.7, -7.800, 3.90, -19.50/
      data(clion(i,19, 2,1),i=1,5)/ 4611.00, 23.9, -7.850, 3.90, -19.55/
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data(clion(i,20, 2,1),i=1,5)/ 5129.00, 24.0, -7.900, 3.90, -19.60/
data(clion(i,21, 2,1),i=1,5)/ 5675.00, 24.1, -7.983, 3.88, -19.67/
data(clion(i,22, 2,1),i=1,5)/ 6249.00, 24.3, -8.067, 3.87, -19.73/
data(clion(i,23, 2,1),i=1,5)/ 6852.00, 24.4, -8.150, 3.85, -19.80/
data(clion(i,24, 2,1),i=1,5)/ 7482.00, 24.5, -8.233, 3.83, -19.87/
data(clion(i,25, 2,1),i=1,5)/ 8141.00, 24.7, -8.317, 3.82, -19.93/
data(clion(i,26, 2,1),i=1,5)/ 8829.00, 24.8, -8.400, 3.80, -20.00/
data(clion(i,27, 2,1),i=1,5)/ 9545.00, 24.9, -8.450, 3.75, -20.05/
data(clion(i,28, 2,1),i=1,5)/10290.00, 25.0, -8.500, 3.70, -20.10/
data(clion(i,29, 2,1),i=1,5)/11060.00, 25.0, -8.500, 3.70, -20.10/
data(clion(i,30, 2,1),i=1,5)/11870.00, 25.0, -8.500, 3.70, -20.10/
data(clion(i, 3, 3,2),i=1,5)/    5.39,  8.2, -2.700, 1.40,  -6.60/
data(clion(i, 3, 3,1),i=1,5)/   64.39, 20.0, -5.600, 4.10, -18.00/
data(clion(i, 4, 3,2),i=1,5)/   18.21,  8.2, -2.700, 1.40,  -6.60/
data(clion(i, 4, 3,1),i=1,5)/  129.90, 20.0, -5.600, 4.10, -18.00/
data(clion(i, 5, 3,2),i=1,5)/   37.93,  8.2, -2.700, 1.40,  -6.60/
data(clion(i, 5, 3,1),i=1,5)/  227.40, 20.0, -5.600, 4.10, -18.00/
data(clion(i, 6, 3,2),i=1,5)/   64.49,  8.2, -2.700, 1.40,  -6.60/
data(clion(i, 6, 3,1),i=1,5)/  352.20, 20.0, -5.600, 4.10, -18.00/
data(clion(i, 7, 3,2),i=1,5)/   97.89, 10.5, -3.300, 1.40,  -7.70/
data(clion(i, 7, 3,1),i=1,5)/  504.30, 20.5, -5.800, 4.10, -18.00/
data(clion(i, 8, 3,2),i=1,5)/  138.10, 10.4, -3.300, 1.40,  -7.40/
data(clion(i, 8, 3,1),i=1,5)/  683.70, 20.8, -6.000, 4.10, -18.00/
data(clion(i, 9, 3,2),i=1,5)/  185.20, 10.2, -3.200, 1.40,  -7.25/
data(clion(i, 9, 3,1),i=1,5)/  890.50, 21.1, -6.200, 4.10, -18.00/
data(clion(i,10, 3,2),i=1,5)/  239.10, 10.1, -3.100, 1.40,  -7.10/
data(clion(i,10, 3,1),i=1,5)/ 1125.00, 21.5, -6.400, 4.10, -18.00/
data(clion(i,11, 3,2),i=1,5)/  299.90, 10.0, -3.000, 1.40,  -6.90/
data(clion(i,11, 3,1),i=1,5)/ 1386.00, 21.7, -6.500, 4.10, -18.00/
data(clion(i,12, 3,2),i=1,5)/  367.50, 10.0, -3.000, 1.40,  -6.80/
data(clion(i,12, 3,1),i=1,5)/ 1675.00, 22.0, -6.700, 4.10, -18.00/
data(clion(i,13, 3,2),i=1,5)/  442.10,  9.9, -3.000, 1.40,  -6.70/
data(clion(i,13, 3,1),i=1,5)/ 1992.00, 22.2, -6.800, 4.10, -18.00/
data(clion(i,14, 3,2),i=1,5)/  523.50,  9.8, -2.900, 1.40,  -6.60/
data(clion(i,14, 3,1),i=1,5)/ 2336.00, 22.4, -6.900, 4.10, -18.00/
data(clion(i,15, 3,2),i=1,5)/  611.90,  9.8, -2.850, 1.40,  -6.50/
data(clion(i,15, 3,1),i=1,5)/ 2707.00, 22.6, -7.000, 4.10, -18.00/
data(clion(i,16, 3,2),i=1,5)/  707.20,  9.7, -2.800, 1.40,  -6.40/
data(clion(i,16, 3,1),i=1,5)/ 3107.00, 22.8, -7.100, 4.10, -18.00/
data(clion(i,17, 3,2),i=1,5)/  809.40,  9.6, -2.800, 1.40,  -6.30/
data(clion(i,17, 3,1),i=1,5)/ 3534.00, 23.0, -7.200, 4.10, -18.00/
data(clion(i,18, 3,2),i=1,5)/  918.00,  9.6, -2.800, 1.40,  -6.20/
data(clion(i,18, 3,1),i=1,5)/ 3988.00, 23.1, -7.300, 4.10, -18.00/
data(clion(i,19, 3,2),i=1,5)/ 1035.00,  9.6, -2.750, 1.40,  -6.15/
data(clion(i,19, 3,1),i=1,5)/ 4471.00, 23.2, -7.350, 4.10, -18.00/
data(clion(i,20, 3,2),i=1,5)/ 1157.00,  9.5, -2.700, 1.40,  -6.10/
data(clion(i,20, 3,1),i=1,5)/ 4982.00, 23.4, -7.400, 4.10, -18.00/
data(clion(i,21, 3,2),i=1,5)/ 1288.00,  9.5, -2.683, 1.40,  -6.05/
data(clion(i,21, 3,1),i=1,5)/ 5520.00, 23.5, -7.483, 4.10, -18.00/
data(clion(i,22, 3,2),i=1,5)/ 1425.00,  9.4, -2.667, 1.40,  -6.00/
data(clion(i,22, 3,1),i=1,5)/ 6087.00, 23.6, -7.567, 4.10, -18.00/
data(clion(i,23, 3,2),i=1,5)/ 1570.00,  9.4, -2.650, 1.40,  -5.95/
data(clion(i,23, 3,1),i=1,5)/ 6682.00, 23.8, -7.650, 4.10, -18.00/
data(clion(i,24, 3,2),i=1,5)/ 1721.00,  9.4, -2.633, 1.40,  -5.90/
data(clion(i,24, 3,1),i=1,5)/ 7306.00, 23.9, -7.733, 4.10, -18.00/
data(clion(i,25, 3,2),i=1,5)/ 1880.00,  9.3, -2.617, 1.40,  -5.85/
data(clion(i,25, 3,1),i=1,5)/ 7957.00, 24.0, -7.817, 4.10, -18.00/
data(clion(i,26, 3,2),i=1,5)/ 2046.00,  9.3, -2.600, 1.40,  -5.80/
data(clion(i,26, 3,1),i=1,5)/ 8638.00, 24.1, -7.900, 4.10, -18.00/
data(clion(i,27, 3,2),i=1,5)/ 2219.00,  9.2, -2.600, 1.40,  -5.75/
data(clion(i,27, 3,1),i=1,5)/ 9347.00, 24.2, -7.950, 4.10, -18.00/
data(clion(i,28, 3,2),i=1,5)/ 2399.00,  9.2, -2.600, 1.40,  -5.70/
data(clion(i,28, 3,1),i=1,5)/10080.00, 24.3, -8.000, 4.10, -18.00/
data(clion(i,29, 3,2),i=1,5)/ 2585.00,  9.2, -2.600, 1.40,  -5.70/
data(clion(i,29, 3,1),i=1,5)/10850.00, 24.3, -8.000, 4.10, -18.00/
data(clion(i,30, 3,2),i=1,5)/ 2780.00,  9.2, -2.600, 1.40,  -5.70/
data(clion(i,30, 3,1),i=1,5)/11650.00, 24.3, -8.000, 4.10, -18.00/
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data(clion(i, 4, 4,2),i=1,5)/    9.32, 23.2, -7.400, 2.50, -19.40/
data(clion(i, 4, 4,1),i=1,5)/  119.30, 20.0, -5.600, 4.10, -18.00/
data(clion(i, 5, 4,2),i=1,5)/   25.16, 23.2, -7.400, 2.50, -19.40/
data(clion(i, 5, 4,1),i=1,5)/  209.80, 20.0, -5.600, 4.10, -18.00/
data(clion(i, 6, 4,2),i=1,5)/   47.89, 23.2, -7.400, 2.50, -19.40/
data(clion(i, 6, 4,1),i=1,5)/  328.90, 20.0, -5.600, 4.10, -18.00/
data(clion(i, 7, 4,2),i=1,5)/   77.47, 17.6, -3.800, 2.80, -13.60/
data(clion(i, 7, 4,1),i=1,5)/  475.30, 20.5, -5.800, 4.10, -18.00/
data(clion(i, 8, 4,2),i=1,5)/  113.90, 16.4, -3.000, 2.90, -12.00/
data(clion(i, 8, 4,1),i=1,5)/  649.10, 20.8, -6.000, 4.10, -18.00/
data(clion(i, 9, 4,2),i=1,5)/  157.20, 16.5, -3.050, 2.85, -11.70/
data(clion(i, 9, 4,1),i=1,5)/  850.20, 21.1, -6.200, 4.10, -18.00/
data(clion(i,10, 4,2),i=1,5)/  207.30, 16.5, -3.100, 2.80, -11.40/
data(clion(i,10, 4,1),i=1,5)/ 1078.00, 21.5, -6.400, 4.10, -18.00/
data(clion(i,11, 4,2),i=1,5)/  264.20, 16.8, -3.400, 2.80, -11.40/
data(clion(i,11, 4,1),i=1,5)/ 1335.00, 21.7, -6.500, 4.10, -18.00/
data(clion(i,12, 4,2),i=1,5)/  328.20, 17.1, -3.600, 2.70, -11.50/
data(clion(i,12, 4,1),i=1,5)/ 1618.00, 22.0, -6.700, 4.10, -18.00/
data(clion(i,13, 4,2),i=1,5)/  399.40, 17.4, -3.800, 2.70, -11.60/
data(clion(i,13, 4,1),i=1,5)/ 1929.00, 22.2, -6.800, 4.10, -18.00/
data(clion(i,14, 4,2),i=1,5)/  476.10, 17.7, -4.000, 2.70, -11.70/
data(clion(i,14, 4,1),i=1,5)/ 2268.00, 22.4, -6.900, 4.10, -18.00/
data(clion(i,15, 4,2),i=1,5)/  560.40, 17.9, -4.200, 2.70, -11.75/
data(clion(i,15, 4,1),i=1,5)/ 2633.00, 22.6, -7.000, 4.10, -18.00/
data(clion(i,16, 4,2),i=1,5)/  651.70, 18.1, -4.400, 2.70, -11.80/
data(clion(i,16, 4,1),i=1,5)/ 3029.00, 22.8, -7.100, 4.10, -18.00/
data(clion(i,17, 4,2),i=1,5)/  749.80, 18.2, -4.500, 2.70, -11.90/
data(clion(i,17, 4,1),i=1,5)/ 3448.00, 23.0, -7.200, 4.10, -18.00/
data(clion(i,18, 4,2),i=1,5)/  854.80, 18.4, -4.600, 2.70, -12.00/
data(clion(i,18, 4,1),i=1,5)/ 3898.00, 23.1, -7.300, 4.10, -18.00/
data(clion(i,19, 4,2),i=1,5)/  968.00, 18.5, -4.600, 2.70, -12.05/
data(clion(i,19, 4,1),i=1,5)/ 4375.00, 23.2, -7.350, 4.10, -18.00/
data(clion(i,20, 4,2),i=1,5)/ 1087.00, 18.6, -4.600, 2.70, -12.10/
data(clion(i,20, 4,1),i=1,5)/ 4880.00, 23.4, -7.400, 4.10, -18.00/
data(clion(i,21, 4,2),i=1,5)/ 1213.00, 18.7, -4.717, 2.70, -12.13/
data(clion(i,21, 4,1),i=1,5)/ 5413.00, 23.5, -7.483, 4.10, -18.00/
data(clion(i,22, 4,2),i=1,5)/ 1346.00, 18.8, -4.833, 2.70, -12.17/
data(clion(i,22, 4,1),i=1,5)/ 5974.00, 23.6, -7.567, 4.10, -18.00/
data(clion(i,23, 4,2),i=1,5)/ 1487.00, 18.9, -4.950, 2.70, -12.20/
data(clion(i,23, 4,1),i=1,5)/ 6563.00, 23.8, -7.650, 4.10, -18.00/
data(clion(i,24, 4,2),i=1,5)/ 1634.00, 19.0, -5.067, 2.70, -12.23/
data(clion(i,24, 4,1),i=1,5)/ 7181.00, 23.9, -7.733, 4.10, -18.00/
data(clion(i,25, 4,2),i=1,5)/ 1788.00, 19.1, -5.183, 2.70, -12.27/
data(clion(i,25, 4,1),i=1,5)/ 7827.00, 24.0, -7.817, 4.10, -18.00/
data(clion(i,26, 4,2),i=1,5)/ 1950.00, 19.2, -5.300, 2.70, -12.30/
data(clion(i,26, 4,1),i=1,5)/ 8484.00, 24.1, -7.900, 4.10, -18.00/
data(clion(i,27, 4,2),i=1,5)/ 2119.00, 19.2, -5.350, 2.70, -12.30/
data(clion(i,27, 4,1),i=1,5)/ 9205.00, 24.2, -7.950, 4.10, -18.00/
data(clion(i,28, 4,2),i=1,5)/ 2295.00, 19.3, -5.400, 2.70, -12.30/
data(clion(i,28, 4,1),i=1,5)/ 9937.00, 24.3, -8.000, 4.10, -18.00/
data(clion(i,29, 4,2),i=1,5)/ 2459.00, 19.3, -5.400, 2.70, -12.30/
data(clion(i,29, 4,1),i=1,5)/10700.00, 24.3, -8.000, 4.10, -18.00/
data(clion(i,30, 4,2),i=1,5)/ 2647.00, 19.3, -5.400, 2.70, -12.30/
data(clion(i,30, 4,1),i=1,5)/11490.00, 24.3, -8.000, 4.10, -18.00/
data(clion(i, 5, 5,3),i=1,5)/    8.30, 16.0, -9.000, 2.50, -10.50/
data(clion(i, 5, 5,2),i=1,5)/   14.05, 23.7, -7.600, 2.50, -21.70/
data(clion(i, 6, 5,3),i=1,5)/   24.38, 16.0, -9.000, 2.50, -10.50/
data(clion(i, 6, 5,2),i=1,5)/   30.47, 23.7, -7.600, 2.50, -21.70/
data(clion(i, 7, 5,3),i=1,5)/   47.45, 16.0, -7.500, 2.30, -10.00/
data(clion(i, 7, 5,2),i=1,5)/   55.45, 18.1, -4.000, 2.80, -15.80/
data(clion(i, 8, 5,3),i=1,5)/   77.41, 15.0, -5.000, 2.20, -10.50/
data(clion(i, 8, 5,2),i=1,5)/   87.37, 16.8, -3.300, 2.80, -14.10/
data(clion(i, 9, 5,3),i=1,5)/  114.20, 14.8, -4.800, 2.05,  -9.50/
data(clion(i, 9, 5,2),i=1,5)/  126.20, 16.8, -3.350, 2.80, -13.65/
data(clion(i,10, 5,3),i=1,5)/  157.90, 14.5, -4.600, 1.90,  -8.50/
data(clion(i,10, 5,2),i=1,5)/  171.90, 16.9, -3.400, 2.80, -13.20/
data(clion(i,11, 5,3),i=1,5)/  208.50, 14.5, -4.600, 1.80,  -8.50/
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data(clion(i,11, 5,2),i=1,5)/  224.40, 17.2, -3.700, 2.80, -13.10/
data(clion(i,12, 5,3),i=1,5)/  266.00, 14.5, -4.600, 1.80,  -8.50/
data(clion(i,12, 5,2),i=1,5)/  283.90, 17.5, -4.000, 2.80, -13.00/
data(clion(i,13, 5,3),i=1,5)/  330.10, 14.0, -4.600, 1.70,  -8.50/
data(clion(i,13, 5,2),i=1,5)/  350.20, 17.9, -4.100, 2.80, -13.00/
data(clion(i,14, 5,3),i=1,5)/  401.40, 14.0, -4.600, 1.60,  -8.50/
data(clion(i,14, 5,2),i=1,5)/  423.40, 18.0, -4.300, 2.80, -12.90/
data(clion(i,15, 5,3),i=1,5)/  479.60, 14.0, -4.600, 1.55,  -8.50/
data(clion(i,15, 5,2),i=1,5)/  503.50, 18.1, -4.500, 2.80, -12.85/
data(clion(i,16, 5,3),i=1,5)/  564.70, 14.0, -4.600, 1.50,  -8.50/
data(clion(i,16, 5,2),i=1,5)/  590.60, 18.3, -4.700, 2.80, -12.80/
data(clion(i,17, 5,3),i=1,5)/  656.70, 14.0, -4.600, 1.45,  -8.50/
data(clion(i,17, 5,2),i=1,5)/  684.60, 18.4, -4.850, 2.80, -12.70/
data(clion(i,18, 5,3),i=1,5)/  755.80, 14.0, -4.600, 1.40,  -8.50/
data(clion(i,18, 5,2),i=1,5)/  785.60, 18.5, -5.000, 2.80, -12.60/
data(clion(i,19, 5,3),i=1,5)/  861.10, 14.0, -4.600, 1.35,  -8.50/
data(clion(i,19, 5,2),i=1,5)/  893.50, 18.6, -5.150, 2.80, -12.50/
data(clion(i,20, 5,3),i=1,5)/  974.50, 14.0, -4.600, 1.30,  -8.50/
data(clion(i,20, 5,2),i=1,5)/ 1008.00, 18.7, -5.300, 2.80, -12.40/
data(clion(i,21, 5,3),i=1,5)/ 1094.00, 13.9, -4.567, 1.25,  -8.47/
data(clion(i,21, 5,2),i=1,5)/ 1130.00, 18.8, -5.333, 2.80, -12.38/
data(clion(i,22, 5,3),i=1,5)/ 1221.00, 13.9, -4.533, 1.20,  -8.43/
data(clion(i,22, 5,2),i=1,5)/ 1260.00, 18.9, -5.367, 2.80, -12.37/
data(clion(i,23, 5,3),i=1,5)/ 1355.00, 13.9, -4.500, 1.15,  -8.40/
data(clion(i,23, 5,2),i=1,5)/ 1396.00, 19.0, -5.400, 2.80, -12.35/
data(clion(i,24, 5,3),i=1,5)/ 1497.00, 13.8, -4.467, 1.10,  -8.37/
data(clion(i,24, 5,2),i=1,5)/ 1539.00, 19.0, -5.433, 2.80, -12.33/
data(clion(i,25, 5,3),i=1,5)/ 1644.00, 13.8, -4.433, 1.05,  -8.33/
data(clion(i,25, 5,2),i=1,5)/ 1689.00, 19.1, -5.467, 2.80, -12.32/
data(clion(i,26, 5,3),i=1,5)/ 1799.00, 13.7, -4.400, 1.00,  -8.30/
data(clion(i,26, 5,2),i=1,5)/ 1847.00, 19.2, -5.500, 2.80, -12.30/
data(clion(i,27, 5,3),i=1,5)/ 1961.00, 13.7, -4.400, 1.00,  -8.30/
data(clion(i,27, 5,2),i=1,5)/ 2012.00, 19.3, -5.600, 2.80, -12.30/
data(clion(i,28, 5,3),i=1,5)/ 2131.00, 13.7, -4.400, 1.00,  -8.30/
data(clion(i,28, 5,2),i=1,5)/ 2184.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,29, 5,3),i=1,5)/ 2298.00, 13.7, -4.400, 1.00,  -8.30/
data(clion(i,29, 5,2),i=1,5)/ 2363.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,30, 5,3),i=1,5)/ 2479.00, 13.7, -4.400, 1.00,  -8.30/
data(clion(i,30, 5,2),i=1,5)/ 2550.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i, 6, 6,3),i=1,5)/   11.26,  6.0,-16.000,12.00, -15.10/
data(clion(i, 6, 6,2),i=1,5)/   19.39, 24.3, -7.800, 2.50, -24.00/
data(clion(i, 7, 6,3),i=1,5)/   29.60, 21.0, -9.000, 5.30, -22.50/
data(clion(i, 7, 6,2),i=1,5)/   37.96, 18.5, -4.300, 2.80, -18.00/
data(clion(i, 8, 6,3),i=1,5)/   54.94, 25.0, -7.000, 5.00, -18.00/
data(clion(i, 8, 6,2),i=1,5)/   65.51, 17.3, -3.500, 2.90, -16.10/
data(clion(i, 9, 6,3),i=1,5)/   87.14, 25.2, -7.750, 4.75, -17.40/
data(clion(i, 9, 6,2),i=1,5)/   99.57, 17.3, -3.650, 2.85, -15.50/
data(clion(i,10, 6,3),i=1,5)/  126.20, 25.5, -8.500, 4.50, -16.80/
data(clion(i,10, 6,2),i=1,5)/  141.50, 17.4, -3.800, 2.80, -14.90/
data(clion(i,11, 6,3),i=1,5)/  172.20, 25.5, -8.500, 4.20, -16.80/
data(clion(i,11, 6,2),i=1,5)/  189.90, 17.6, -4.000, 2.80, -14.70/
data(clion(i,12, 6,3),i=1,5)/  224.90, 25.5, -8.500, 4.10, -16.80/
data(clion(i,12, 6,2),i=1,5)/  244.40, 18.0, -4.300, 2.80, -14.50/
data(clion(i,13, 6,3),i=1,5)/  284.60, 27.0, -8.500, 3.90, -16.80/
data(clion(i,13, 6,2),i=1,5)/  306.50, 18.2, -4.500, 2.80, -14.30/
data(clion(i,14, 6,3),i=1,5)/  351.10, 27.0, -8.500, 3.80, -16.80/
data(clion(i,14, 6,2),i=1,5)/  375.60, 18.3, -4.700, 2.80, -14.10/
data(clion(i,15, 6,3),i=1,5)/  424.50, 27.0, -8.500, 3.55, -16.80/
data(clion(i,15, 6,2),i=1,5)/  452.20, 18.5, -4.900, 2.80, -13.90/
data(clion(i,16, 6,3),i=1,5)/  504.80, 27.0, -8.500, 3.30, -16.80/
data(clion(i,16, 6,2),i=1,5)/  534.60, 18.6, -5.100, 2.80, -13.70/
data(clion(i,17, 6,3),i=1,5)/  592.00, 27.0, -8.500, 3.15, -16.80/
data(clion(i,17, 6,2),i=1,5)/  624.90, 18.7, -5.250, 2.80, -13.50/
data(clion(i,18, 6,3),i=1,5)/  686.10, 27.0, -8.500, 3.00, -16.80/
data(clion(i,18, 6,2),i=1,5)/  721.70, 18.7, -5.400, 2.80, -13.30/
data(clion(i,19, 6,3),i=1,5)/  786.70, 27.0, -8.500, 2.85, -16.80/
data(clion(i,19, 6,2),i=1,5)/  825.50, 18.8, -5.600, 2.80, -13.05/
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data(clion(i,20, 6,3),i=1,5)/  894.60, 27.0, -8.500, 2.70, -16.80/
data(clion(i,20, 6,2),i=1,5)/  935.70, 18.9, -5.800, 2.80, -12.80/
data(clion(i,21, 6,3),i=1,5)/ 1009.00, 27.1, -8.550, 2.58, -16.77/
data(clion(i,21, 6,2),i=1,5)/ 1054.00, 19.0, -5.750, 2.80, -12.72/
data(clion(i,22, 6,3),i=1,5)/ 1131.00, 27.1, -8.600, 2.47, -16.73/
data(clion(i,22, 6,2),i=1,5)/ 1179.00, 19.0, -5.700, 2.80, -12.63/
data(clion(i,23, 6,3),i=1,5)/ 1260.00, 27.2, -8.650, 2.35, -16.70/
data(clion(i,23, 6,2),i=1,5)/ 1311.00, 19.0, -5.650, 2.80, -12.55/
data(clion(i,24, 6,3),i=1,5)/ 1396.00, 27.3, -8.700, 2.23, -16.67/
data(clion(i,24, 6,2),i=1,5)/ 1450.00, 19.1, -5.600, 2.80, -12.47/
data(clion(i,25, 6,3),i=1,5)/ 1539.00, 27.3, -8.750, 2.12, -16.63/
data(clion(i,25, 6,2),i=1,5)/ 1596.00, 19.2, -5.550, 2.80, -12.38/
data(clion(i,26, 6,3),i=1,5)/ 1689.00, 27.4, -8.800, 2.00, -16.60/
data(clion(i,26, 6,2),i=1,5)/ 1745.00, 19.2, -5.500, 2.80, -12.30/
data(clion(i,27, 6,3),i=1,5)/ 1846.00, 27.4, -8.800, 2.00, -16.60/
data(clion(i,27, 6,2),i=1,5)/ 1910.00, 19.3, -5.600, 2.80, -12.30/
data(clion(i,28, 6,3),i=1,5)/ 2011.00, 27.4, -8.800, 2.00, -16.60/
data(clion(i,28, 6,2),i=1,5)/ 2077.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,29, 6,3),i=1,5)/ 2173.00, 27.4, -8.800, 2.00, -16.60/
data(clion(i,29, 6,2),i=1,5)/ 2253.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,30, 6,3),i=1,5)/ 2363.00, 27.4, -8.800, 2.00, -16.60/
data(clion(i,30, 6,2),i=1,5)/ 2435.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i, 7, 7,3),i=1,5)/   14.53, 19.5,-30.500,15.00, -29.00/
data(clion(i, 7, 7,2),i=1,5)/   25.41, 19.0, -4.500, 2.80, -20.20/
data(clion(i, 8, 7,3),i=1,5)/   35.12, 25.0, -8.000, 8.40, -29.50/
data(clion(i, 8, 7,2),i=1,5)/   45.99, 17.8, -3.800, 2.90, -18.10/
data(clion(i, 9, 7,3),i=1,5)/   62.71, 29.5, -9.000, 7.95, -27.25/
data(clion(i, 9, 7,2),i=1,5)/   76.10, 17.8, -3.900, 2.85, -17.40/
data(clion(i,10, 7,3),i=1,5)/   97.12, 34.0,-10.000, 7.50, -25.00/
data(clion(i,10, 7,2),i=1,5)/  113.20, 17.8, -4.000, 2.80, -16.70/
data(clion(i,11, 7,3),i=1,5)/  138.40, 35.1,-12.400, 7.20, -25.10/
data(clion(i,11, 7,2),i=1,5)/  156.70, 18.0, -4.300, 2.80, -16.30/
data(clion(i,12, 7,3),i=1,5)/  186.50, 35.1,-12.400, 6.90, -25.10/
data(clion(i,12, 7,2),i=1,5)/  207.60, 18.2, -4.600, 2.80, -16.00/
data(clion(i,13, 7,3),i=1,5)/  241.40, 38.3,-12.400, 6.70, -25.10/
data(clion(i,13, 7,2),i=1,5)/  266.20, 18.4, -4.800, 2.80, -15.70/
data(clion(i,14, 7,3),i=1,5)/  303.20, 38.3,-12.400, 6.40, -25.10/
data(clion(i,14, 7,2),i=1,5)/  331.00, 18.6, -5.100, 2.80, -15.40/
data(clion(i,15, 7,3),i=1,5)/  371.70, 38.3,-12.400, 5.95, -25.10/
data(clion(i,15, 7,2),i=1,5)/  401.80, 18.7, -5.300, 2.80, -15.05/
data(clion(i,16, 7,3),i=1,5)/  447.10, 38.3,-12.400, 5.50, -25.10/
data(clion(i,16, 7,2),i=1,5)/  480.40, 18.8, -5.500, 2.80, -14.70/
data(clion(i,17, 7,3),i=1,5)/  529.30, 38.3,-12.400, 5.15, -25.10/
data(clion(i,17, 7,2),i=1,5)/  566.00, 18.8, -5.700, 2.80, -14.35/
data(clion(i,18, 7,3),i=1,5)/  618.30, 38.3,-12.400, 4.80, -25.10/
data(clion(i,18, 7,2),i=1,5)/  658.40, 18.9, -5.900, 2.80, -14.00/
data(clion(i,19, 7,3),i=1,5)/  714.70, 38.3,-12.400, 4.55, -25.10/
data(clion(i,19, 7,2),i=1,5)/  757.80, 19.0, -6.100, 2.80, -13.60/
data(clion(i,20, 7,3),i=1,5)/  817.70, 38.3,-12.400, 4.30, -25.10/
data(clion(i,20, 7,2),i=1,5)/  864.20, 19.0, -6.300, 2.80, -13.20/
data(clion(i,21, 7,3),i=1,5)/  927.50, 38.8,-12.533, 4.10, -25.07/
data(clion(i,21, 7,2),i=1,5)/  977.50, 19.0, -6.167, 2.80, -13.05/
data(clion(i,22, 7,3),i=1,5)/ 1044.00, 39.2,-12.667, 3.90, -25.03/
data(clion(i,22, 7,2),i=1,5)/ 1098.00, 19.1, -6.033, 2.80, -12.90/
data(clion(i,23, 7,3),i=1,5)/ 1168.00, 39.7,-12.800, 3.70, -25.00/
data(clion(i,23, 7,2),i=1,5)/ 1225.00, 19.1, -5.900, 2.80, -12.75/
data(clion(i,24, 7,3),i=1,5)/ 1299.00, 40.2,-12.933, 3.50, -24.97/
data(clion(i,24, 7,2),i=1,5)/ 1359.00, 19.1, -5.767, 2.80, -12.60/
data(clion(i,25, 7,3),i=1,5)/ 1437.00, 40.6,-13.067, 3.30, -24.93/
data(clion(i,25, 7,2),i=1,5)/ 1500.00, 19.2, -5.633, 2.80, -12.45/
data(clion(i,26, 7,3),i=1,5)/ 1582.00, 41.1,-13.200, 3.10, -24.90/
data(clion(i,26, 7,2),i=1,5)/ 1648.00, 19.2, -5.500, 2.80, -12.30/
data(clion(i,27, 7,3),i=1,5)/ 1735.00, 41.1,-13.200, 3.00, -24.90/
data(clion(i,27, 7,2),i=1,5)/ 1803.00, 19.3, -5.600, 2.80, -12.30/
data(clion(i,28, 7,3),i=1,5)/ 1894.00, 41.1,-13.200, 2.90, -24.90/
data(clion(i,28, 7,2),i=1,5)/ 1965.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,29, 7,3),i=1,5)/ 2045.00, 41.1,-13.200, 2.90, -24.90/
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data(clion(i,29, 7,2),i=1,5)/ 2133.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,30, 7,3),i=1,5)/ 2216.00, 41.1,-13.200, 2.90, -24.90/
data(clion(i,30, 7,2),i=1,5)/ 2309.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i, 8, 8,3),i=1,5)/   13.62,  9.5,-17.500,12.50, -19.50/
data(clion(i, 8, 8,2),i=1,5)/   28.48, 18.2, -4.000, 2.80, -20.20/
data(clion(i, 9, 8,3),i=1,5)/   34.97, 21.2,-17.500,11.85, -26.25/
data(clion(i, 9, 8,2),i=1,5)/   54.59, 18.2, -4.200, 2.80, -19.30/
data(clion(i,10, 8,3),i=1,5)/   63.46, 33.0,-17.500,11.20, -33.00/
data(clion(i,10, 8,2),i=1,5)/   87.21, 18.2, -4.400, 2.80, -18.40/
data(clion(i,11, 8,3),i=1,5)/   98.92, 43.3,-16.300,10.70, -33.40/
data(clion(i,11, 8,2),i=1,5)/  126.90, 18.4, -4.700, 2.80, -18.00/
data(clion(i,12, 8,3),i=1,5)/  141.30, 43.3,-16.300,10.30, -33.40/
data(clion(i,12, 8,2),i=1,5)/  173.50, 18.6, -4.900, 2.80, -17.50/
data(clion(i,13, 8,3),i=1,5)/  190.50, 49.5,-16.300, 9.90, -33.40/
data(clion(i,13, 8,2),i=1,5)/  226.80, 18.9, -5.200, 2.80, -17.10/
data(clion(i,14, 8,3),i=1,5)/  246.50, 49.5,-16.300, 9.60, -33.40/
data(clion(i,14, 8,2),i=1,5)/  287.20, 19.0, -5.400, 2.80, -16.60/
data(clion(i,15, 8,3),i=1,5)/  309.40, 49.5,-16.300, 8.80, -33.40/
data(clion(i,15, 8,2),i=1,5)/  355.20, 19.0, -5.650, 2.80, -16.10/
data(clion(i,16, 8,3),i=1,5)/  379.10, 49.5,-16.300, 8.00, -33.40/
data(clion(i,16, 8,2),i=1,5)/  429.60, 19.1, -5.900, 2.80, -15.60/
data(clion(i,17, 8,3),i=1,5)/  455.60, 49.5,-16.300, 7.45, -33.40/
data(clion(i,17, 8,2),i=1,5)/  510.90, 19.2, -6.150, 2.80, -15.10/
data(clion(i,18, 8,3),i=1,5)/  539.00, 49.5,-16.300, 6.90, -33.40/
data(clion(i,18, 8,2),i=1,5)/  599.20, 19.2, -6.400, 2.80, -14.60/
data(clion(i,19, 8,3),i=1,5)/  629.50, 49.5,-16.300, 6.50, -33.40/
data(clion(i,19, 8,2),i=1,5)/  694.50, 19.2, -6.600, 2.80, -14.15/
data(clion(i,20, 8,3),i=1,5)/  726.70, 49.5,-16.300, 6.10, -33.40/
data(clion(i,20, 8,2),i=1,5)/  796.80, 19.2, -6.800, 2.80, -13.70/
data(clion(i,21, 8,3),i=1,5)/  830.80, 50.4,-16.517, 5.77, -33.37/
data(clion(i,21, 8,2),i=1,5)/  906.20, 19.2, -6.583, 2.80, -13.47/
data(clion(i,22, 8,3),i=1,5)/  941.90, 51.3,-16.733, 5.43, -33.33/
data(clion(i,22, 8,2),i=1,5)/ 1022.00, 19.2, -6.367, 2.80, -13.23/
data(clion(i,23, 8,3),i=1,5)/ 1060.00, 52.2,-16.950, 5.10, -33.30/
data(clion(i,23, 8,2),i=1,5)/ 1146.00, 19.2, -6.150, 2.80, -13.00/
data(clion(i,24, 8,3),i=1,5)/ 1185.00, 53.0,-17.167, 4.77, -33.27/
data(clion(i,24, 8,2),i=1,5)/ 1276.00, 19.2, -5.933, 2.80, -12.77/
data(clion(i,25, 8,3),i=1,5)/ 1317.00, 53.9,-17.383, 4.43, -33.23/
data(clion(i,25, 8,2),i=1,5)/ 1414.00, 19.2, -5.717, 2.80, -12.53/
data(clion(i,26, 8,3),i=1,5)/ 1456.00, 54.8,-17.600, 4.10, -33.20/
data(clion(i,26, 8,2),i=1,5)/ 1559.00, 19.2, -5.500, 2.80, -12.30/
data(clion(i,27, 8,3),i=1,5)/ 1603.00, 54.8,-17.600, 4.00, -33.20/
data(clion(i,27, 8,2),i=1,5)/ 1711.00, 19.3, -5.600, 2.80, -12.30/
data(clion(i,28, 8,3),i=1,5)/ 1756.00, 54.8,-17.600, 3.90, -33.20/
data(clion(i,28, 8,2),i=1,5)/ 1870.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,29, 8,3),i=1,5)/ 1905.00, 54.8,-17.600, 3.90, -33.20/
data(clion(i,29, 8,2),i=1,5)/ 2037.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,30, 8,3),i=1,5)/ 2070.00, 54.8,-17.600, 3.90, -33.20/
data(clion(i,30, 8,2),i=1,5)/ 2210.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i, 9, 9,3),i=1,5)/   17.42, 37.0,-33.000,15.50, -46.00/
data(clion(i, 9, 9,2),i=1,5)/   37.86, 18.6, -4.600, 2.80, -20.20/
data(clion(i,10, 9,3),i=1,5)/   40.96, 37.0,-33.000,15.50, -46.00/
data(clion(i,10, 9,2),i=1,5)/   63.74, 18.6, -4.600, 2.80, -20.20/
data(clion(i,11, 9,3),i=1,5)/   71.62, 50.1,-20.200,14.80, -41.70/
data(clion(i,11, 9,2),i=1,5)/   99.45, 18.8, -5.000, 2.80, -19.60/
data(clion(i,12, 9,3),i=1,5)/  109.30, 50.1,-20.200,14.20, -41.70/
data(clion(i,12, 9,2),i=1,5)/  141.10, 19.0, -5.300, 2.80, -19.00/
data(clion(i,13, 9,3),i=1,5)/  153.80, 60.8,-20.200,13.70, -41.70/
data(clion(i,13, 9,2),i=1,5)/  190.30, 19.1, -5.500, 2.80, -18.40/
data(clion(i,14, 9,3),i=1,5)/  205.10, 60.8,-20.200,13.20, -41.70/
data(clion(i,14, 9,2),i=1,5)/  246.80, 19.3, -5.800, 2.80, -17.80/
data(clion(i,15, 9,3),i=1,5)/  263.20, 60.8,-20.200,12.05, -41.70/
data(clion(i,15, 9,2),i=1,5)/  309.80, 19.3, -6.050, 2.80, -17.20/
data(clion(i,16, 9,3),i=1,5)/  328.20, 60.8,-20.200,10.90, -41.70/
data(clion(i,16, 9,2),i=1,5)/  379.70, 19.3, -6.300, 2.80, -16.60/
data(clion(i,17, 9,3),i=1,5)/  400.10, 60.8,-20.200,10.10, -41.70/
data(clion(i,17, 9,2),i=1,5)/  456.50, 19.3, -6.550, 2.80, -15.95/
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data(clion(i,18, 9,3),i=1,5)/  478.70, 60.8,-20.200, 9.30, -41.70/
data(clion(i,18, 9,2),i=1,5)/  540.30, 19.4, -6.800, 2.80, -15.30/
data(clion(i,19, 9,3),i=1,5)/  564.70, 60.8,-20.200, 8.70, -41.70/
data(clion(i,19, 9,2),i=1,5)/  631.00, 19.4, -7.050, 2.80, -14.70/
data(clion(i,20, 9,3),i=1,5)/  657.20, 60.8,-20.200, 8.10, -41.70/
data(clion(i,20, 9,2),i=1,5)/  728.70, 19.4, -7.300, 2.80, -14.10/
data(clion(i,21, 9,3),i=1,5)/  756.70, 62.1,-20.500, 7.60, -41.67/
data(clion(i,21, 9,2),i=1,5)/  833.30, 19.4, -7.000, 2.80, -13.80/
data(clion(i,22, 9,3),i=1,5)/  863.10, 63.4,-20.800, 7.10, -41.63/
data(clion(i,22, 9,2),i=1,5)/  944.80, 19.3, -6.700, 2.80, -13.50/
data(clion(i,23, 9,3),i=1,5)/  975.80, 64.7,-21.100, 6.60, -41.60/
data(clion(i,23, 9,2),i=1,5)/ 1063.00, 19.3, -6.400, 2.80, -13.20/
data(clion(i,24, 9,3),i=1,5)/ 1097.00, 65.9,-21.400, 6.10, -41.57/
data(clion(i,24, 9,2),i=1,5)/ 1189.00, 19.3, -6.100, 2.80, -12.90/
data(clion(i,25, 9,3),i=1,5)/ 1224.00, 67.2,-21.700, 5.60, -41.53/
data(clion(i,25, 9,2),i=1,5)/ 1321.00, 19.2, -5.800, 2.80, -12.60/
data(clion(i,26, 9,3),i=1,5)/ 1358.00, 68.5,-22.000, 5.10, -41.50/
data(clion(i,26, 9,2),i=1,5)/ 1460.00, 19.2, -5.500, 2.80, -12.30/
data(clion(i,27, 9,3),i=1,5)/ 1505.00, 68.5,-22.000, 5.00, -41.50/
data(clion(i,27, 9,2),i=1,5)/ 1606.00, 19.3, -5.600, 2.80, -12.30/
data(clion(i,28, 9,3),i=1,5)/ 1648.00, 68.5,-22.000, 4.90, -41.50/
data(clion(i,28, 9,2),i=1,5)/ 1760.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,29, 9,3),i=1,5)/ 1793.00, 68.5,-22.000, 4.90, -41.50/
data(clion(i,29, 9,2),i=1,5)/ 1920.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,30, 9,3),i=1,5)/ 1953.00, 68.5,-22.000, 4.90, -41.50/
data(clion(i,30, 9,2),i=1,5)/ 2087.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,10,10,3),i=1,5)/   21.56, 40.0,-42.000,18.00, -56.00/
data(clion(i,10,10,2),i=1,5)/   48.47, 19.0, -4.900, 2.80, -22.00/
data(clion(i,11,10,3),i=1,5)/   47.29, 40.0,-28.000,19.40, -60.00/
data(clion(i,11,10,2),i=1,5)/   73.47, 19.2, -5.300, 2.80, -21.20/
data(clion(i,12,10,3),i=1,5)/   80.14, 55.5,-24.100,18.70, -65.00/
data(clion(i,12,10,2),i=1,5)/  111.10, 19.3, -5.600, 2.80, -20.50/
data(clion(i,13,10,3),i=1,5)/  120.00, 72.0,-24.100,18.00, -50.00/
data(clion(i,13,10,2),i=1,5)/  155.80, 19.5, -5.900, 2.80, -19.80/
data(clion(i,14,10,3),i=1,5)/  166.80, 72.0,-24.100,17.40, -50.00/
data(clion(i,14,10,2),i=1,5)/  207.60, 19.6, -6.200, 2.80, -19.00/
data(clion(i,15,10,3),i=1,5)/  220.40, 72.0,-24.100,15.80, -50.00/
data(clion(i,15,10,2),i=1,5)/  266.30, 19.6, -6.500, 2.80, -18.25/
data(clion(i,16,10,3),i=1,5)/  280.90, 72.0,-24.100,14.20, -50.00/
data(clion(i,16,10,2),i=1,5)/  332.10, 19.6, -6.800, 2.80, -17.50/
data(clion(i,17,10,3),i=1,5)/  348.30, 72.0,-24.100,13.05, -50.00/
data(clion(i,17,10,2),i=1,5)/  404.80, 19.6, -7.050, 2.80, -16.75/
data(clion(i,18,10,3),i=1,5)/  422.50, 72.0,-24.100,11.90, -50.00/
data(clion(i,18,10,2),i=1,5)/  484.50, 19.6, -7.300, 2.80, -16.00/
data(clion(i,19,10,3),i=1,5)/  503.80, 72.0,-24.100,11.10, -50.00/
data(clion(i,19,10,2),i=1,5)/  571.20, 19.5, -7.550, 2.80, -15.25/
data(clion(i,20,10,3),i=1,5)/  591.90, 72.0,-24.100,10.30, -50.00/
data(clion(i,20,10,2),i=1,5)/  664.90, 19.5, -7.800, 2.80, -14.50/
data(clion(i,21,10,3),i=1,5)/  687.40, 73.7,-24.483, 9.60, -49.97/
data(clion(i,21,10,2),i=1,5)/  765.70, 19.5, -7.417, 2.80, -14.13/
data(clion(i,22,10,3),i=1,5)/  787.80, 75.4,-24.867, 8.90, -49.93/
data(clion(i,22,10,2),i=1,5)/  873.40, 19.4, -7.033, 2.80, -13.77/
data(clion(i,23,10,3),i=1,5)/  896.00, 77.1,-25.250, 8.20, -49.90/
data(clion(i,23,10,2),i=1,5)/  988.30, 19.4, -6.650, 2.80, -13.40/
data(clion(i,24,10,3),i=1,5)/ 1011.00, 78.8,-25.633, 7.50, -49.87/
data(clion(i,24,10,2),i=1,5)/ 1110.00, 19.3, -6.267, 2.80, -13.03/
data(clion(i,25,10,3),i=1,5)/ 1133.00, 80.5,-26.017, 6.80, -49.83/
data(clion(i,25,10,2),i=1,5)/ 1239.00, 19.2, -5.883, 2.80, -12.67/
data(clion(i,26,10,3),i=1,5)/ 1262.00, 82.2,-26.400, 6.10, -49.80/
data(clion(i,26,10,2),i=1,5)/ 1375.00, 19.2, -5.500, 2.80, -12.30/
data(clion(i,27,10,3),i=1,5)/ 1397.00, 82.2,-26.400, 6.00, -49.80/
data(clion(i,27,10,2),i=1,5)/ 1519.00, 19.3, -5.600, 2.80, -12.30/
data(clion(i,28,10,3),i=1,5)/ 1541.00, 82.2,-26.400, 5.90, -49.80/
data(clion(i,28,10,2),i=1,5)/ 1669.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,29,10,3),i=1,5)/ 1690.00, 82.2,-26.400, 5.90, -49.80/
data(clion(i,29,10,2),i=1,5)/ 1827.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,30,10,3),i=1,5)/ 1846.00, 82.2,-26.400, 5.90, -49.80/
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data(clion(i,30,10,2),i=1,5)/ 1992.00, 19.4, -5.700, 2.80, -12.30/
data(clion(i,11,11,4),i=1,5)/    5.14, 16.0, -1.000, 0.20, -13.50/
data(clion(i,11,11,3),i=1,5)/   38.14, 63.9,-27.000,33.00, -80.00/
data(clion(i,11,11,2),i=1,5)/   70.84,  0.0,  0.000, 0.00,   0.00/
data(clion(i,12,11,4),i=1,5)/   15.04,  9.0, -3.600, 0.30,  -5.40/
data(clion(i,12,11,3),i=1,5)/   65.69, 37.7,-30.000,24.80, -62.00/
data(clion(i,12,11,2),i=1,5)/   98.81, 17.6, -5.200, 3.30, -19.00/
data(clion(i,13,11,4),i=1,5)/   28.45,  6.3, -2.400, 0.50,  -4.10/
data(clion(i,13,11,3),i=1,5)/  102.60, 31.3,-22.700,21.00, -44.10/
data(clion(i,13,11,2),i=1,5)/  140.70, 12.1, -3.500, 3.30, -13.10/
data(clion(i,14,11,4),i=1,5)/   45.14,  9.0, -3.000, 0.60,  -5.80/
data(clion(i,14,11,3),i=1,5)/  146.60, 66.7,-24.800,18.70, -65.00/
data(clion(i,14,11,2),i=1,5)/  189.90, 22.0, -7.200, 3.30, -20.90/
data(clion(i,15,11,4),i=1,5)/   65.03,  9.0, -2.900, 0.65,  -5.60/
data(clion(i,15,11,3),i=1,5)/  197.70, 69.9,-25.900,17.25, -63.05/
data(clion(i,15,11,2),i=1,5)/  246.10, 22.5, -7.600, 3.30, -20.20/
data(clion(i,16,11,4),i=1,5)/   88.05,  9.0, -2.800, 0.70,  -5.40/
data(clion(i,16,11,3),i=1,5)/  255.70, 73.2,-27.000,15.80, -61.10/
data(clion(i,16,11,2),i=1,5)/  309.40, 23.1, -8.000, 3.30, -19.50/
data(clion(i,17,11,4),i=1,5)/  114.20,  9.0, -2.750, 0.75,  -5.40/
data(clion(i,17,11,3),i=1,5)/  320.70, 74.0,-27.000,14.95, -59.85/
data(clion(i,17,11,2),i=1,5)/  379.70, 23.2, -8.150, 3.30, -19.00/
data(clion(i,18,11,4),i=1,5)/  143.50,  9.0, -2.700, 0.80,  -5.40/
data(clion(i,18,11,3),i=1,5)/  392.50, 74.8,-27.000,14.10, -58.60/
data(clion(i,18,11,2),i=1,5)/  457.00, 23.4, -8.300, 3.30, -18.50/
data(clion(i,19,11,4),i=1,5)/  175.80,  9.0, -2.650, 0.85,  -5.40/
data(clion(i,19,11,3),i=1,5)/  471.30, 75.4,-27.000,13.45, -57.60/
data(clion(i,19,11,2),i=1,5)/  541.30, 23.5, -8.350, 3.30, -18.15/
data(clion(i,20,11,4),i=1,5)/  211.30,  9.0, -2.600, 0.90,  -5.40/
data(clion(i,20,11,3),i=1,5)/  556.90, 76.1,-27.000,12.80, -56.60/
data(clion(i,20,11,2),i=1,5)/  632.60, 23.5, -8.400, 3.30, -17.80/
data(clion(i,21,11,4),i=1,5)/  249.80,  9.0, -2.600, 0.92,  -5.40/
data(clion(i,21,11,3),i=1,5)/  650.50, 76.6,-27.000,12.43, -55.97/
data(clion(i,21,11,2),i=1,5)/  730.90, 23.5, -8.300, 3.30, -17.58/
data(clion(i,22,11,4),i=1,5)/  291.50,  9.0, -2.600, 0.93,  -5.40/
data(clion(i,22,11,3),i=1,5)/  751.10, 77.0,-27.000,12.07, -55.33/
data(clion(i,22,11,2),i=1,5)/  836.30, 23.5, -8.200, 3.30, -17.37/
data(clion(i,23,11,4),i=1,5)/  336.30,  9.0, -2.600, 0.95,  -5.40/
data(clion(i,23,11,3),i=1,5)/  858.90, 77.5,-27.000,11.70, -54.70/
data(clion(i,23,11,2),i=1,5)/  948.80, 23.5, -8.100, 3.30, -17.15/
data(clion(i,24,11,4),i=1,5)/  384.20,  9.0, -2.600, 0.97,  -5.40/
data(clion(i,24,11,3),i=1,5)/  973.80, 78.0,-27.000,11.33, -54.07/
data(clion(i,24,11,2),i=1,5)/ 1068.00, 23.5, -8.000, 3.30, -16.93/
data(clion(i,25,11,4),i=1,5)/  435.20,  9.0, -2.600, 0.98,  -5.40/
data(clion(i,25,11,3),i=1,5)/ 1096.00, 78.4,-27.000,10.97, -53.43/
data(clion(i,25,11,2),i=1,5)/ 1195.00, 23.5, -7.900, 3.30, -16.72/
data(clion(i,26,11,4),i=1,5)/  489.30,  9.0, -2.600, 1.00,  -5.40/
data(clion(i,26,11,3),i=1,5)/ 1216.00, 78.9,-27.000,10.60, -52.80/
data(clion(i,26,11,2),i=1,5)/ 1329.00, 23.5, -7.800, 3.30, -16.50/
data(clion(i,27,11,4),i=1,5)/  546.60,  9.0, -2.600, 1.00,  -5.40/
data(clion(i,27,11,3),i=1,5)/ 1362.00, 79.2,-27.000,10.35, -52.35/
data(clion(i,27,11,2),i=1,5)/ 1470.00, 23.5, -7.800, 3.30, -16.35/
data(clion(i,28,11,4),i=1,5)/  607.10,  9.0, -2.600, 1.00,  -5.40/
data(clion(i,28,11,3),i=1,5)/ 1506.00, 79.6,-27.000,10.10, -51.90/
data(clion(i,28,11,2),i=1,5)/ 1618.00, 23.5, -7.800, 3.30, -16.20/
data(clion(i,29,11,4),i=1,5)/  670.60,  9.0, -2.600, 1.00,  -5.40/
data(clion(i,29,11,3),i=1,5)/ 1657.00, 79.6,-27.000,10.10, -51.90/
data(clion(i,29,11,2),i=1,5)/ 1773.00, 23.5, -7.800, 3.30, -16.20/
data(clion(i,30,11,4),i=1,5)/  737.40,  9.0, -2.600, 1.00,  -5.40/
data(clion(i,30,11,3),i=1,5)/ 1815.00, 79.6,-27.000,10.10, -51.90/
data(clion(i,30,11,2),i=1,5)/ 1936.00, 23.5, -7.800, 3.30, -16.20/
data(clion(i,12,12,4),i=1,5)/    7.65, 18.0, -1.000, 0.60,  -4.00/
data(clion(i,12,12,3),i=1,5)/   54.90, 37.7,-30.000,24.80, -62.00/
data(clion(i,12,12,2),i=1,5)/   94.00, 17.6, -5.200, 3.30, -19.00/
data(clion(i,13,12,4),i=1,5)/   18.83, 17.0, -6.000, 1.00,  -8.00/
data(clion(i,13,12,3),i=1,5)/   89.97, 31.3,-22.700,21.00, -44.10/
data(clion(i,13,12,2),i=1,5)/  128.10, 12.1, -3.500, 3.30, -13.10/
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data(clion(i,14,12,4),i=1,5)/   33.49, 19.8, -5.700, 1.30, -11.90/
data(clion(i,14,12,3),i=1,5)/  131.10, 66.7,-24.800,18.70, -65.00/
data(clion(i,14,12,2),i=1,5)/  174.40, 22.0, -7.200, 3.30, -20.90/
data(clion(i,15,12,4),i=1,5)/   51.44, 19.8, -5.700, 1.45, -11.90/
data(clion(i,15,12,3),i=1,5)/  179.50, 69.9,-25.900,17.25, -63.05/
data(clion(i,15,12,2),i=1,5)/  228.00, 22.5, -7.600, 3.30, -20.20/
data(clion(i,16,12,4),i=1,5)/   72.68, 19.8, -5.700, 1.60, -11.90/
data(clion(i,16,12,3),i=1,5)/  235.00, 73.2,-27.000,15.80, -61.10/
data(clion(i,16,12,2),i=1,5)/  288.80, 23.1, -8.000, 3.30, -19.50/
data(clion(i,17,12,4),i=1,5)/   97.03, 19.8, -5.700, 1.75, -11.90/
data(clion(i,17,12,3),i=1,5)/  297.40, 74.0,-27.000,14.95, -59.85/
data(clion(i,17,12,2),i=1,5)/  356.60, 23.2, -8.150, 3.30, -19.00/
data(clion(i,18,12,4),i=1,5)/  124.30, 19.8, -5.700, 1.90, -11.90/
data(clion(i,18,12,3),i=1,5)/  366.70, 74.8,-27.000,14.10, -58.60/
data(clion(i,18,12,2),i=1,5)/  431.40, 23.4, -8.300, 3.30, -18.50/
data(clion(i,19,12,4),i=1,5)/  154.70, 19.8, -5.700, 1.85, -11.90/
data(clion(i,19,12,3),i=1,5)/  443.00, 75.4,-27.000,13.45, -57.60/
data(clion(i,19,12,2),i=1,5)/  513.30, 23.5, -8.350, 3.30, -18.15/
data(clion(i,20,12,4),i=1,5)/  188.30, 19.8, -5.700, 1.80, -11.90/
data(clion(i,20,12,3),i=1,5)/  527.00, 76.1,-27.000,12.80, -56.60/
data(clion(i,20,12,2),i=1,5)/  601.80, 23.5, -8.400, 3.30, -17.80/
data(clion(i,21,12,4),i=1,5)/  225.10, 19.8, -5.700, 1.85, -11.90/
data(clion(i,21,12,3),i=1,5)/  617.30, 76.6,-27.000,12.43, -55.97/
data(clion(i,21,12,2),i=1,5)/  698.20, 23.5, -8.300, 3.30, -17.58/
data(clion(i,22,12,4),i=1,5)/  265.00, 19.8, -5.700, 1.90, -11.90/
data(clion(i,22,12,3),i=1,5)/  715.60, 77.0,-27.000,12.07, -55.33/
data(clion(i,22,12,2),i=1,5)/  801.30, 23.5, -8.200, 3.30, -17.37/
data(clion(i,23,12,4),i=1,5)/  308.10, 19.8, -5.700, 1.95, -11.90/
data(clion(i,23,12,3),i=1,5)/  820.90, 77.5,-27.000,11.70, -54.70/
data(clion(i,23,12,2),i=1,5)/  911.40, 23.5, -8.100, 3.30, -17.15/
data(clion(i,24,12,4),i=1,5)/  354.80, 19.8, -5.700, 2.00, -11.90/
data(clion(i,24,12,3),i=1,5)/  933.40, 78.0,-27.000,11.33, -54.07/
data(clion(i,24,12,2),i=1,5)/ 1029.00, 23.5, -8.000, 3.30, -16.93/
data(clion(i,25,12,4),i=1,5)/  403.00, 19.8, -5.700, 2.05, -11.90/
data(clion(i,25,12,3),i=1,5)/ 1053.00, 78.4,-27.000,10.97, -53.43/
data(clion(i,25,12,2),i=1,5)/ 1153.00, 23.5, -7.900, 3.30, -16.72/
data(clion(i,26,12,4),i=1,5)/  457.00, 19.8, -5.700, 2.10, -11.90/
data(clion(i,26,12,3),i=1,5)/ 1181.00, 78.9,-27.000,10.60, -52.80/
data(clion(i,26,12,2),i=1,5)/ 1287.00, 23.5, -7.800, 3.30, -16.50/
data(clion(i,27,12,4),i=1,5)/  512.00, 19.8, -5.700, 2.15, -11.90/
data(clion(i,27,12,3),i=1,5)/ 1314.00, 79.2,-27.000,10.35, -52.35/
data(clion(i,27,12,2),i=1,5)/ 1423.00, 23.5, -7.800, 3.30, -16.35/
data(clion(i,28,12,4),i=1,5)/  571.30, 19.8, -5.700, 2.20, -11.90/
data(clion(i,28,12,3),i=1,5)/ 1456.00, 79.6,-27.000,10.10, -51.90/
data(clion(i,28,12,2),i=1,5)/ 1569.00, 23.5, -7.800, 3.30, -16.20/
data(clion(i,29,12,4),i=1,5)/  633.00, 19.8, -5.700, 2.20, -11.90/
data(clion(i,29,12,3),i=1,5)/ 1604.00, 79.6,-27.000,10.10, -51.90/
data(clion(i,29,12,2),i=1,5)/ 1722.00, 23.5, -7.800, 3.30, -16.20/
data(clion(i,30,12,4),i=1,5)/  698.00, 19.8, -5.700, 2.20, -11.90/
data(clion(i,30,12,3),i=1,5)/ 1760.00, 79.6,-27.000,10.10, -51.90/
data(clion(i,30,12,2),i=1,5)/ 1882.00, 23.5, -7.800, 3.30, -16.20/
data(clion(i,13,13,5),i=1,5)/    5.99, 47.0,-26.000, 0.60, -39.00/
data(clion(i,13,13,4),i=1,5)/   11.33, 55.1,-37.200, 1.40, -41.00/
data(clion(i,14,13,5),i=1,5)/   16.35, 50.4,-33.400, 0.60, -36.90/
data(clion(i,14,13,4),i=1,5)/   22.40, 55.1,-37.200, 1.40, -41.00/
data(clion(i,15,13,5),i=1,5)/   30.20, 50.4,-33.400, 0.60, -36.90/
data(clion(i,15,13,4),i=1,5)/   38.28, 55.1,-37.200, 1.40, -41.00/
data(clion(i,16,13,5),i=1,5)/   47.31, 50.4,-33.400, 0.60, -36.90/
data(clion(i,16,13,4),i=1,5)/   57.50, 55.1,-37.200, 1.40, -41.00/
data(clion(i,17,13,5),i=1,5)/   67.82, 50.4,-33.400, 0.60, -36.90/
data(clion(i,17,13,4),i=1,5)/   79.97, 55.1,-37.200, 1.40, -41.00/
data(clion(i,18,13,5),i=1,5)/   91.01, 50.4,-33.400, 0.60, -36.90/
data(clion(i,18,13,4),i=1,5)/  105.60, 55.1,-37.200, 1.40, -41.00/
data(clion(i,19,13,5),i=1,5)/  117.60, 30.8,-18.400, 0.95, -22.10/
data(clion(i,19,13,4),i=1,5)/  134.40, 38.9,-22.900, 1.65, -28.25/
data(clion(i,20,13,5),i=1,5)/  147.20, 11.1, -3.400, 1.30,  -7.30/
data(clion(i,20,13,4),i=1,5)/  166.40, 22.7, -8.600, 1.90, -15.50/
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data(clion(i,21,13,5),i=1,5)/  180.00, 10.8, -3.267, 1.32,  -7.02/
data(clion(i,21,13,4),i=1,5)/  201.50, 23.6, -9.250, 1.97, -16.15/
data(clion(i,22,13,5),i=1,5)/  215.90, 10.4, -3.133, 1.33,  -6.73/
data(clion(i,22,13,4),i=1,5)/  239.70, 24.5, -9.900, 2.03, -16.80/
data(clion(i,23,13,5),i=1,5)/  255.70, 10.1, -3.000, 1.35,  -6.45/
data(clion(i,23,13,4),i=1,5)/  281.00, 25.5,-10.550, 2.10, -17.45/
data(clion(i,24,13,5),i=1,5)/  298.10,  9.8, -2.867, 1.37,  -6.17/
data(clion(i,24,13,4),i=1,5)/  325.50, 26.4,-11.200, 2.17, -18.10/
data(clion(i,25,13,5),i=1,5)/  343.60,  9.4, -2.733, 1.38,  -5.88/
data(clion(i,25,13,4),i=1,5)/  373.10, 27.3,-11.850, 2.23, -18.75/
data(clion(i,26,13,5),i=1,5)/  392.20,  9.1, -2.600, 1.40,  -5.60/
data(clion(i,26,13,4),i=1,5)/  423.80, 28.2,-12.500, 2.30, -19.40/
data(clion(i,27,13,5),i=1,5)/  444.00,  9.1, -2.600, 1.40,  -5.60/
data(clion(i,27,13,4),i=1,5)/  477.70, 28.2,-12.500, 2.30, -19.40/
data(clion(i,28,13,5),i=1,5)/  498.40,  9.1, -2.600, 1.40,  -5.60/
data(clion(i,28,13,4),i=1,5)/  534.70, 28.2,-12.500, 2.30, -19.40/
data(clion(i,29,13,5),i=1,5)/  557.00,  9.1, -2.600, 1.40,  -5.60/
data(clion(i,29,13,4),i=1,5)/  594.90, 28.2,-12.500, 2.30, -19.40/
data(clion(i,30,13,5),i=1,5)/  619.00,  9.1, -2.600, 1.40,  -5.60/
data(clion(i,30,13,4),i=1,5)/  658.30, 28.2,-12.500, 2.30, -19.40/
data(clion(i,14,14,5),i=1,5)/    8.15, 74.5,-49.400, 1.30, -54.60/
data(clion(i,14,14,4),i=1,5)/   15.17, 53.8,-35.800, 1.40, -40.70/
data(clion(i,15,14,5),i=1,5)/   19.73, 74.5,-49.400, 1.30, -54.60/
data(clion(i,15,14,4),i=1,5)/   27.09, 53.8,-35.800, 1.40, -40.70/
data(clion(i,16,14,5),i=1,5)/   34.83, 74.5,-49.400, 1.30, -54.60/
data(clion(i,16,14,4),i=1,5)/   44.15, 53.8,-35.800, 1.40, -40.70/
data(clion(i,17,14,5),i=1,5)/   53.47, 74.5,-49.400, 1.30, -54.60/
data(clion(i,17,14,4),i=1,5)/   64.70, 53.8,-35.800, 1.40, -40.70/
data(clion(i,18,14,5),i=1,5)/   75.02, 74.5,-49.400, 1.30, -54.60/
data(clion(i,18,14,4),i=1,5)/   88.28, 53.8,-35.800, 1.40, -40.70/
data(clion(i,19,14,5),i=1,5)/   99.44, 48.7,-28.400, 2.05, -35.25/
data(clion(i,19,14,4),i=1,5)/  115.20, 37.8,-21.750, 1.65, -27.80/
data(clion(i,20,14,5),i=1,5)/  127.20, 22.9, -7.400, 2.80, -15.90/
data(clion(i,20,14,4),i=1,5)/  145.20, 21.9, -7.700, 1.90, -14.90/
data(clion(i,21,14,5),i=1,5)/  158.10, 22.6, -7.150, 2.83, -15.35/
data(clion(i,21,14,4),i=1,5)/  178.40, 22.6, -8.283, 1.97, -15.43/
data(clion(i,22,14,5),i=1,5)/  192.10, 22.4, -6.900, 2.87, -14.80/
data(clion(i,22,14,4),i=1,5)/  214.80, 23.4, -8.867, 2.03, -15.97/
data(clion(i,23,14,5),i=1,5)/  230.50, 22.1, -6.650, 2.90, -14.25/
data(clion(i,23,14,4),i=1,5)/  254.30, 24.1, -9.450, 2.10, -16.50/
data(clion(i,24,14,5),i=1,5)/  270.80, 21.8, -6.400, 2.93, -13.70/
data(clion(i,24,14,4),i=1,5)/  296.90, 24.9,-10.033, 2.17, -17.03/
data(clion(i,25,14,5),i=1,5)/  314.40, 21.6, -6.150, 2.97, -13.15/
data(clion(i,25,14,4),i=1,5)/  342.70, 25.6,-10.617, 2.23, -17.57/
data(clion(i,26,14,5),i=1,5)/  361.00, 21.3, -5.900, 3.00, -12.60/
data(clion(i,26,14,4),i=1,5)/  391.60, 26.4,-11.200, 2.30, -18.10/
data(clion(i,27,14,5),i=1,5)/  411.00, 21.3, -5.900, 3.00, -12.60/
data(clion(i,27,14,4),i=1,5)/  443.60, 26.4,-11.200, 2.30, -18.10/
data(clion(i,28,14,5),i=1,5)/  463.70, 21.3, -5.900, 3.00, -12.60/
data(clion(i,28,14,4),i=1,5)/  498.80, 26.4,-11.200, 2.30, -18.10/
data(clion(i,29,14,5),i=1,5)/  520.00, 21.3, -5.900, 3.00, -12.60/
data(clion(i,29,14,4),i=1,5)/  557.20, 26.4,-11.200, 2.30, -18.10/
data(clion(i,30,14,5),i=1,5)/  579.00, 21.3, -5.900, 3.00, -12.60/
data(clion(i,30,14,4),i=1,5)/  618.70, 26.4,-11.200, 2.30, -18.10/
data(clion(i,15,15,5),i=1,5)/   10.49, 98.7,-65.400, 1.90, -72.30/
data(clion(i,15,15,4),i=1,5)/   20.17, 52.5,-34.500, 1.40, -40.50/
data(clion(i,16,15,5),i=1,5)/   23.33, 98.7,-65.400, 1.90, -72.30/
data(clion(i,16,15,4),i=1,5)/   31.90, 52.5,-34.500, 1.40, -40.50/
data(clion(i,17,15,5),i=1,5)/   39.61, 98.7,-65.400, 1.90, -72.30/
data(clion(i,17,15,4),i=1,5)/   50.19, 52.5,-34.500, 1.40, -40.50/
data(clion(i,18,15,5),i=1,5)/   59.81, 98.7,-65.400, 1.90, -72.30/
data(clion(i,18,15,4),i=1,5)/   71.74, 52.5,-34.500, 1.40, -40.50/
data(clion(i,19,15,5),i=1,5)/   82.66, 69.8,-39.500, 2.65, -51.20/
data(clion(i,19,15,4),i=1,5)/   96.57, 36.5,-20.400, 1.75, -27.15/
data(clion(i,20,15,5),i=1,5)/  108.80, 40.9,-13.600, 3.40, -30.10/
data(clion(i,20,15,4),i=1,5)/  124.90, 20.4, -6.300, 2.10, -13.80/
data(clion(i,21,15,5),i=1,5)/  138.00, 40.6,-12.950, 3.57, -28.55/
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data(clion(i,21,15,4),i=1,5)/  155.70, 21.1, -6.883, 2.13, -14.30/
data(clion(i,22,15,5),i=1,5)/  170.40, 40.3,-12.300, 3.73, -27.00/
data(clion(i,22,15,4),i=1,5)/  190.00, 21.8, -7.467, 2.17, -14.80/
data(clion(i,23,15,5),i=1,5)/  205.80, 40.1,-11.650, 3.90, -25.45/
data(clion(i,23,15,4),i=1,5)/  227.40, 22.5, -8.050, 2.20, -15.30/
data(clion(i,24,15,5),i=1,5)/  244.40, 39.8,-11.000, 4.07, -23.90/
data(clion(i,24,15,4),i=1,5)/  268.00, 23.2, -8.633, 2.23, -15.80/
data(clion(i,25,15,5),i=1,5)/  286.00, 39.5,-10.350, 4.23, -22.35/
data(clion(i,25,15,4),i=1,5)/  311.80, 23.9, -9.217, 2.27, -16.30/
data(clion(i,26,15,5),i=1,5)/  330.80, 39.2, -9.700, 4.40, -20.80/
data(clion(i,26,15,4),i=1,5)/  360.00, 24.6, -9.800, 2.30, -16.80/
data(clion(i,27,15,5),i=1,5)/  379.00, 36.3, -9.700, 4.50, -20.80/
data(clion(i,27,15,4),i=1,5)/  408.80, 24.6, -9.800, 2.30, -16.80/
data(clion(i,28,15,5),i=1,5)/  430.20, 33.4, -9.700, 4.60, -20.80/
data(clion(i,28,15,4),i=1,5)/  462.00, 24.6, -9.800, 2.30, -16.80/
data(clion(i,29,15,5),i=1,5)/  484.00, 33.4, -9.700, 4.60, -20.80/
data(clion(i,29,15,4),i=1,5)/  518.40, 24.6, -9.800, 2.30, -16.80/
data(clion(i,30,15,5),i=1,5)/  542.00, 33.4, -9.700, 4.60, -20.80/
data(clion(i,30,15,4),i=1,5)/  578.00, 24.6, -9.800, 2.30, -16.80/
data(clion(i,16,16,5),i=1,5)/   10.36,  6.0,-22.000,20.00, -20.00/
data(clion(i,16,16,4),i=1,5)/   21.30, 51.3,-33.200, 1.40, -40.20/
data(clion(i,17,16,5),i=1,5)/   23.81, 64.4,-51.700,11.30, -55.00/
data(clion(i,17,16,4),i=1,5)/   36.86, 51.3,-33.200, 1.40, -40.20/
data(clion(i,18,16,5),i=1,5)/   40.74,122.8,-81.400, 2.60, -90.00/
data(clion(i,18,16,4),i=1,5)/   56.37, 51.3,-33.200, 1.40, -40.20/
data(clion(i,19,16,5),i=1,5)/   60.91, 84.9,-47.950, 3.70, -62.75/
data(clion(i,19,16,4),i=1,5)/   79.25, 35.1,-19.150, 1.50, -26.70/
data(clion(i,20,16,5),i=1,5)/   84.51, 47.1,-14.500, 4.80, -35.50/
data(clion(i,20,16,4),i=1,5)/  105.40, 18.9, -5.100, 1.60, -13.20/
data(clion(i,21,16,5),i=1,5)/  110.70, 46.8,-14.400, 5.03, -34.58/
data(clion(i,21,16,4),i=1,5)/  134.80, 19.5, -5.650, 1.72, -13.57/
data(clion(i,22,16,5),i=1,5)/  140.80, 46.6,-14.300, 5.27, -33.67/
data(clion(i,22,16,4),i=1,5)/  167.30, 20.2, -6.200, 1.83, -13.93/
data(clion(i,23,16,5),i=1,5)/  173.50, 46.3,-14.200, 5.50, -32.75/
data(clion(i,23,16,4),i=1,5)/  203.10, 20.8, -6.750, 1.95, -14.30/
data(clion(i,24,16,5),i=1,5)/  209.30, 46.1,-14.100, 5.73, -31.83/
data(clion(i,24,16,4),i=1,5)/  241.90, 21.5, -7.300, 2.07, -14.67/
data(clion(i,25,16,5),i=1,5)/  248.30, 45.8,-14.000, 5.97, -30.92/
data(clion(i,25,16,4),i=1,5)/  284.00, 22.1, -7.850, 2.18, -15.03/
data(clion(i,26,16,5),i=1,5)/  290.20, 45.6,-13.900, 6.20, -30.00/
data(clion(i,26,16,4),i=1,5)/  329.20, 22.8, -8.400, 2.30, -15.40/
data(clion(i,27,16,5),i=1,5)/  336.00, 45.6,-13.900, 6.20, -30.00/
data(clion(i,27,16,4),i=1,5)/  377.50, 22.8, -8.400, 2.30, -15.40/
data(clion(i,28,16,5),i=1,5)/  384.00, 45.6,-13.900, 6.20, -30.00/
data(clion(i,28,16,4),i=1,5)/  429.10, 22.8, -8.400, 2.30, -15.40/
data(clion(i,29,16,5),i=1,5)/  435.00, 45.6,-13.900, 6.20, -30.00/
data(clion(i,29,16,4),i=1,5)/  483.80, 22.8, -8.400, 2.30, -15.40/
data(clion(i,30,16,5),i=1,5)/  490.00, 45.6,-13.900, 6.20, -30.00/
data(clion(i,30,16,4),i=1,5)/  541.60, 22.8, -8.400, 2.30, -15.40/
data(clion(i,17,17,5),i=1,5)/   12.97,147.0,-97.400, 3.20,-107.70/
data(clion(i,17,17,4),i=1,5)/   25.31, 50.0,-31.800, 1.40, -40.00/
data(clion(i,18,17,5),i=1,5)/   27.63,147.0,-97.400, 3.20,-107.70/
data(clion(i,18,17,4),i=1,5)/   41.98, 50.0,-31.800, 1.40, -40.00/
data(clion(i,19,17,5),i=1,5)/   45.81,101.4,-56.600, 4.80, -76.10/
data(clion(i,19,17,4),i=1,5)/   62.69, 33.1,-17.500, 1.60, -25.80/
data(clion(i,20,17,5),i=1,5)/   67.27, 55.8,-15.800, 6.40, -44.50/
data(clion(i,20,17,4),i=1,5)/   86.80, 16.2, -3.200, 1.80, -11.60/
data(clion(i,21,17,5),i=1,5)/   91.87, 56.1,-16.267, 6.63, -43.80/
data(clion(i,21,17,4),i=1,5)/  114.10, 17.0, -3.850, 1.88, -12.02/
data(clion(i,22,17,5),i=1,5)/  119.50, 56.4,-16.733, 6.87, -43.10/
data(clion(i,22,17,4),i=1,5)/  144.50, 17.8, -4.500, 1.97, -12.43/
data(clion(i,23,17,5),i=1,5)/  150.60, 56.8,-17.200, 7.10, -42.40/
data(clion(i,23,17,4),i=1,5)/  178.10, 18.6, -5.150, 2.05, -12.85/
data(clion(i,24,17,5),i=1,5)/  184.70, 57.1,-17.667, 7.33, -41.70/
data(clion(i,24,17,4),i=1,5)/  214.80, 19.4, -5.800, 2.13, -13.27/
data(clion(i,25,17,5),i=1,5)/  221.80, 57.4,-18.133, 7.57, -41.00/
data(clion(i,25,17,4),i=1,5)/  254.70, 20.2, -6.450, 2.22, -13.68/
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data(clion(i,26,17,5),i=1,5)/  262.10, 57.7,-18.600, 7.80, -40.30/
data(clion(i,26,17,4),i=1,5)/  299.00, 21.0, -7.100, 2.30, -14.10/
data(clion(i,27,17,5),i=1,5)/  305.30, 57.7,-18.600, 7.80, -40.30/
data(clion(i,27,17,4),i=1,5)/  343.90, 21.0, -7.100, 2.30, -14.10/
data(clion(i,28,17,5),i=1,5)/  352.10, 57.7,-18.600, 7.80, -40.30/
data(clion(i,28,17,4),i=1,5)/  393.30, 21.0, -7.100, 2.30, -14.10/
data(clion(i,29,17,5),i=1,5)/  401.00, 57.7,-18.600, 7.80, -40.30/
data(clion(i,29,17,4),i=1,5)/  445.80, 21.0, -7.100, 2.30, -14.10/
data(clion(i,30,17,5),i=1,5)/  454.00, 57.7,-18.600, 7.80, -40.30/
data(clion(i,30,17,4),i=1,5)/  501.50, 21.0, -7.100, 2.30, -14.10/
data(clion(i,18,18,5),i=1,5)/   15.76,171.1,-78.000, 3.80,-169.00/
data(clion(i,18,18,4),i=1,5)/   28.92, 48.7,-30.500, 1.40, -39.70/
data(clion(i,19,18,5),i=1,5)/   31.63,122.7,-51.100, 5.40,-116.00/
data(clion(i,19,18,4),i=1,5)/   47.28, 33.2,-17.150, 1.65, -26.75/
data(clion(i,20,18,5),i=1,5)/   50.91, 74.3,-24.200, 7.00, -63.00/
data(clion(i,20,18,4),i=1,5)/   69.20, 17.6, -3.800, 1.90, -13.80/
data(clion(i,21,18,5),i=1,5)/   73.49, 73.6,-24.117, 7.42, -61.12/
data(clion(i,21,18,4),i=1,5)/   94.51, 17.9, -4.117, 1.97, -13.62/
data(clion(i,22,18,5),i=1,5)/   99.30, 72.8,-24.033, 7.83, -59.23/
data(clion(i,22,18,4),i=1,5)/  123.10, 18.1, -4.433, 2.03, -13.43/
data(clion(i,23,18,5),i=1,5)/  128.10, 72.1,-23.950, 8.25, -57.35/
data(clion(i,23,18,4),i=1,5)/  154.90, 18.4, -4.750, 2.10, -13.25/
data(clion(i,24,18,5),i=1,5)/  160.20, 71.4,-23.867, 8.67, -55.47/
data(clion(i,24,18,4),i=1,5)/  190.00, 18.7, -5.067, 2.17, -13.07/
data(clion(i,25,18,5),i=1,5)/  194.50, 70.6,-23.783, 9.08, -53.58/
data(clion(i,25,18,4),i=1,5)/  228.20, 18.9, -5.383, 2.23, -12.88/
data(clion(i,26,18,5),i=1,5)/  233.60, 69.9,-23.700, 9.50, -51.70/
data(clion(i,26,18,4),i=1,5)/  269.60, 19.2, -5.700, 2.30, -12.70/
data(clion(i,27,18,5),i=1,5)/  275.40, 69.9,-23.700, 9.50, -51.70/
data(clion(i,27,18,4),i=1,5)/  314.20, 19.2, -5.700, 2.30, -12.70/
data(clion(i,28,18,5),i=1,5)/  321.00, 69.9,-23.700, 9.50, -51.70/
data(clion(i,28,18,4),i=1,5)/  362.00, 19.2, -5.700, 2.30, -12.70/
data(clion(i,29,18,5),i=1,5)/  368.80, 69.9,-23.700, 9.50, -51.70/
data(clion(i,29,18,4),i=1,5)/  412.90, 19.2, -5.700, 2.30, -12.70/
data(clion(i,30,18,5),i=1,5)/  419.70, 69.9,-23.700, 9.50, -51.70/
data(clion(i,30,18,4),i=1,5)/  467.10, 19.2, -5.700, 2.30, -12.70/
data(clion(i,19,19,7),i=1,5)/    4.34,  7.9, -2.000, 0.20,  -6.00/
data(clion(i,19,19,6),i=1,5)/    1.00,  0.0,  0.000, 0.00,   0.00/
data(clion(i,19,19,5),i=1,5)/   24.66, 74.3,-24.200, 7.00, -68.00/
data(clion(i,19,19,4),i=1,5)/   40.80, 17.6, -3.800, 1.90, -13.80/
data(clion(i,20,19,7),i=1,5)/   11.87,  7.9, -2.000, 0.20,  -6.00/
data(clion(i,20,19,6),i=1,5)/    1.00,  0.0,  0.000, 0.00,   0.00/
data(clion(i,20,19,5),i=1,5)/   40.90, 74.3,-24.200, 7.00, -68.00/
data(clion(i,20,19,4),i=1,5)/   60.37, 17.6, -3.800, 1.90, -13.80/
data(clion(i,21,19,6),i=1,5)/   24.76,  9.0, -2.407, 0.57,  -6.59/
data(clion(i,21,19,5),i=1,5)/   55.91, 73.6,-24.117, 7.42, -65.28/
data(clion(i,21,19,4),i=1,5)/   77.62, 17.9, -4.117, 1.97, -13.62/
data(clion(i,22,19,6),i=1,5)/   43.27, 10.0, -2.813, 0.95,  -7.18/
data(clion(i,22,19,5),i=1,5)/   79.17, 72.8,-24.033, 7.83, -62.57/
data(clion(i,22,19,4),i=1,5)/  103.50, 18.1, -4.433, 2.03, -13.43/
data(clion(i,23,19,6),i=1,5)/   65.28, 11.1, -3.220, 1.33,  -7.76/
data(clion(i,23,19,5),i=1,5)/  105.90, 72.1,-23.950, 8.25, -59.85/
data(clion(i,23,19,4),i=1,5)/  132.90, 18.4, -4.750, 2.10, -13.25/
data(clion(i,24,19,6),i=1,5)/   90.64, 12.2, -3.627, 1.70,  -8.35/
data(clion(i,24,19,5),i=1,5)/  135.90, 71.4,-23.867, 8.67, -57.13/
data(clion(i,24,19,4),i=1,5)/  165.60, 18.7, -5.067, 2.17, -13.07/
data(clion(i,25,19,6),i=1,5)/  119.30, 13.2, -4.033, 2.08,  -8.94/
data(clion(i,25,19,5),i=1,5)/  169.10, 70.6,-23.783, 9.08, -54.42/
data(clion(i,25,19,4),i=1,5)/  201.60, 18.9, -5.383, 2.23, -12.88/
data(clion(i,26,19,6),i=1,5)/  151.10, 14.3, -4.440, 2.45,  -9.53/
data(clion(i,26,19,5),i=1,5)/  205.50, 69.9,-23.700, 9.50, -51.70/
data(clion(i,26,19,4),i=1,5)/  240.90, 19.2, -5.700, 2.30, -12.70/
data(clion(i,27,19,6),i=1,5)/  186.10, 13.4, -4.220, 1.43,  -7.76/
data(clion(i,27,19,5),i=1,5)/  245.00, 69.9,-23.700, 9.50, -51.70/
data(clion(i,27,19,4),i=1,5)/  283.30, 19.2, -5.700, 2.30, -12.70/
data(clion(i,28,19,6),i=1,5)/  224.60, 12.5, -4.000, 0.40,  -6.00/
data(clion(i,28,19,5),i=1,5)/  287.70, 69.9,-23.700, 9.50, -51.70/
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data(clion(i,28,19,4),i=1,5)/  329.00, 19.2, -5.700, 2.30, -12.70/
data(clion(i,29,19,6),i=1,5)/  266.10, 12.5, -4.000, 0.40,  -6.00/
data(clion(i,29,19,5),i=1,5)/  333.50, 69.9,-23.700, 9.50, -51.70/
data(clion(i,29,19,4),i=1,5)/  377.80, 19.2, -5.700, 2.30, -12.70/
data(clion(i,30,19,6),i=1,5)/  310.80, 12.5, -4.000, 0.40,  -6.00/
data(clion(i,30,19,5),i=1,5)/  382.80, 69.9,-23.700, 9.50, -51.70/
data(clion(i,30,19,4),i=1,5)/  429.90, 19.2, -5.700, 2.30, -12.70/
data(clion(i,20,20,7),i=1,5)/    6.11,  2.5, -2.500, 8.00,  -5.50/
data(clion(i,20,20,6),i=1,5)/    1.00,  0.0,  0.000, 0.00,   0.00/
data(clion(i,20,20,5),i=1,5)/   34.43, 74.3,-24.200, 7.00, -63.00/
data(clion(i,20,20,4),i=1,5)/   48.30, 17.6, -3.800, 1.90, -13.80/
data(clion(i,21,20,6),i=1,5)/   14.44,  4.5, -2.810, 7.66,  -6.33/
data(clion(i,21,20,5),i=1,5)/   46.78, 73.2,-23.600, 7.47, -61.45/
data(clion(i,21,20,4),i=1,5)/   68.48, 17.3, -3.548, 1.97, -13.27/
data(clion(i,22,20,6),i=1,5)/   27.49,  6.5, -3.120, 7.33,  -7.17/
data(clion(i,22,20,5),i=1,5)/   62.01, 72.2,-23.000, 7.94, -59.90/
data(clion(i,22,20,4),i=1,5)/   86.03, 16.9, -3.297, 2.03, -12.73/
data(clion(i,23,20,6),i=1,5)/   46.71,  8.6, -3.430, 6.99,  -8.00/
data(clion(i,23,20,5),i=1,5)/   85.55, 71.1,-22.400, 8.41, -58.35/
data(clion(i,23,20,4),i=1,5)/  111.80, 16.6, -3.045, 2.10, -12.20/
data(clion(i,24,20,6),i=1,5)/   69.46, 10.6, -3.740, 6.65,  -8.83/
data(clion(i,24,20,5),i=1,5)/  113.40, 70.0,-21.800, 8.88, -56.80/
data(clion(i,24,20,4),i=1,5)/  142.70, 16.3, -2.793, 2.17, -11.67/
data(clion(i,25,20,6),i=1,5)/   95.75, 12.6, -4.050, 6.32,  -9.67/
data(clion(i,25,20,5),i=1,5)/  144.40, 69.0,-21.200, 9.35, -55.25/
data(clion(i,25,20,4),i=1,5)/  176.80, 15.9, -2.542, 2.23, -11.13/
data(clion(i,26,20,6),i=1,5)/  125.00, 14.6, -4.360, 5.98, -10.50/
data(clion(i,26,20,5),i=1,5)/  178.30, 67.9,-20.600, 9.82, -53.70/
data(clion(i,26,20,4),i=1,5)/  213.50, 15.6, -2.290, 2.30, -10.60/
data(clion(i,27,20,6),i=1,5)/  157.80, 19.4, -6.030, 3.34, -11.10/
data(clion(i,27,20,5),i=1,5)/  215.80, 68.9,-22.150, 9.66, -52.70/
data(clion(i,27,20,4),i=1,5)/  254.40, 17.4, -3.995, 2.30, -11.65/
data(clion(i,28,20,6),i=1,5)/  193.00, 24.1, -7.700, 0.70, -11.70/
data(clion(i,28,20,5),i=1,5)/  256.10, 69.9,-23.700, 9.50, -51.70/
data(clion(i,28,20,4),i=1,5)/  297.20, 19.2, -5.700, 2.30, -12.70/
data(clion(i,29,20,6),i=1,5)/  232.00, 24.1, -7.700, 0.70, -11.70/
data(clion(i,29,20,5),i=1,5)/  299.90, 69.9,-23.700, 9.50, -51.70/
data(clion(i,29,20,4),i=1,5)/  344.70, 19.2, -5.700, 2.30, -12.70/
data(clion(i,30,20,6),i=1,5)/  274.00, 24.1, -7.700, 0.70, -11.70/
data(clion(i,30,20,5),i=1,5)/  346.70, 69.9,-23.700, 9.50, -51.70/
data(clion(i,30,20,4),i=1,5)/  393.90, 19.2, -5.700, 2.30, -12.70/
data(clion(i,21,21,7),i=1,5)/    6.56,  2.5, -2.500, 8.00,  -5.50/
data(clion(i,21,21,6),i=1,5)/    8.01, 36.9,-11.800,10.30, -31.50/
data(clion(i,21,21,5),i=1,5)/   33.60, 67.0,-18.600, 9.43, -56.50/
data(clion(i,22,21,7),i=1,5)/   13.58,  2.5, -2.500, 8.00,  -5.50/
data(clion(i,22,21,6),i=1,5)/   16.13, 36.9,-11.800,10.30, -31.50/
data(clion(i,22,21,5),i=1,5)/   52.53, 67.0,-18.600, 9.43, -56.50/
data(clion(i,23,21,6),i=1,5)/   23.91, 36.9,-11.800,10.30, -31.50/
data(clion(i,23,21,5),i=1,5)/   68.13, 67.0,-18.600, 9.43, -56.50/
data(clion(i,23,21,4),i=1,5)/   94.52, 12.7, -0.086, 2.42,  -8.97/
data(clion(i,24,21,6),i=1,5)/   49.16, 36.9,-11.800,10.30, -31.50/
data(clion(i,24,21,5),i=1,5)/   92.75, 67.0,-18.600, 9.43, -56.50/
data(clion(i,24,21,4),i=1,5)/  121.90, 12.7, -0.086, 2.42,  -8.97/
data(clion(i,25,21,6),i=1,5)/   72.40, 36.9,-11.800,10.30, -31.50/
data(clion(i,25,21,5),i=1,5)/  121.00, 67.0,-18.600, 9.43, -56.50/
data(clion(i,25,21,4),i=1,5)/  153.00, 12.7, -0.086, 2.42,  -8.97/
data(clion(i,26,21,6),i=1,5)/   99.06, 36.9,-11.800,10.30, -31.50/
data(clion(i,26,21,5),i=1,5)/  152.70, 67.0,-18.600, 9.43, -56.50/
data(clion(i,26,21,4),i=1,5)/  187.60, 12.7, -0.086, 2.42,  -8.97/
data(clion(i,27,21,6),i=1,5)/  129.00, 35.7,-11.350, 5.70, -24.10/
data(clion(i,27,21,5),i=1,5)/  187.60, 68.4,-21.150, 9.47, -54.10/
data(clion(i,27,21,4),i=1,5)/  225.50, 16.0, -2.893, 2.36, -10.84/
data(clion(i,28,21,6),i=1,5)/  162.00, 34.5,-10.900, 1.10, -16.70/
data(clion(i,28,21,5),i=1,5)/  226.60, 69.9,-23.700, 9.50, -51.70/
data(clion(i,28,21,4),i=1,5)/  268.20, 19.2, -5.700, 2.30, -12.70/
data(clion(i,29,21,6),i=1,5)/  199.00, 34.5,-10.900, 1.10, -16.70/
data(clion(i,29,21,5),i=1,5)/  267.20, 69.9,-23.700, 9.50, -51.70/
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data(clion(i,29,21,4),i=1,5)/  311.30, 19.2, -5.700, 2.30, -12.70/
data(clion(i,30,21,6),i=1,5)/  238.00, 34.5,-10.900, 1.10, -16.70/
data(clion(i,30,21,5),i=1,5)/  312.80, 69.9,-23.700, 9.50, -51.70/
data(clion(i,30,21,4),i=1,5)/  360.90, 19.2, -5.700, 2.30, -12.70/
data(clion(i,22,22,7),i=1,5)/    6.82,  2.5, -2.500, 8.00,  -5.50/
data(clion(i,22,22,6),i=1,5)/    9.94, 48.1,-20.400,16.20, -48.40/
data(clion(i,22,22,5),i=1,5)/   40.00, 66.8,-18.900, 9.29, -60.50/
data(clion(i,23,22,6),i=1,5)/   14.66, 48.1,-20.400,16.20, -48.40/
data(clion(i,23,22,5),i=1,5)/   53.23, 66.8,-18.900, 9.29, -60.50/
data(clion(i,23,22,4),i=1,5)/   79.42, 13.4, -0.410, 2.33, -10.90/
data(clion(i,24,22,6),i=1,5)/   30.96, 48.1,-20.400,16.20, -48.40/
data(clion(i,24,22,5),i=1,5)/   74.36, 66.8,-18.900, 9.29, -60.50/
data(clion(i,24,22,4),i=1,5)/  103.20, 13.4, -0.410, 2.33, -10.90/
data(clion(i,25,22,6),i=1,5)/   51.20, 48.1,-20.400,16.20, -48.40/
data(clion(i,25,22,5),i=1,5)/   98.79, 66.8,-18.900, 9.29, -60.50/
data(clion(i,25,22,4),i=1,5)/  130.00, 13.4, -0.410, 2.33, -10.90/
data(clion(i,26,22,6),i=1,5)/   75.01, 48.1,-20.400,16.20, -48.40/
data(clion(i,26,22,5),i=1,5)/  128.80, 66.8,-18.900, 9.29, -60.50/
data(clion(i,26,22,4),i=1,5)/  163.30, 13.4, -0.410, 2.33, -10.90/
data(clion(i,27,22,6),i=1,5)/  102.00, 45.7,-17.050, 8.75, -34.65/
data(clion(i,27,22,5),i=1,5)/  161.90, 68.4,-21.300, 9.40, -56.10/
data(clion(i,27,22,4),i=1,5)/  199.90, 16.3, -3.055, 2.32, -11.80/
data(clion(i,28,22,6),i=1,5)/  133.00, 43.2,-13.700, 1.30, -20.90/
data(clion(i,28,22,5),i=1,5)/  197.10, 69.9,-23.700, 9.50, -51.70/
data(clion(i,28,22,4),i=1,5)/  237.80, 19.2, -5.700, 2.30, -12.70/
data(clion(i,29,22,6),i=1,5)/  167.00, 43.2,-13.700, 1.30, -20.90/
data(clion(i,29,22,5),i=1,5)/  237.50, 69.9,-23.700, 9.50, -51.70/
data(clion(i,29,22,4),i=1,5)/  282.40, 19.2, -5.700, 2.30, -12.70/
data(clion(i,30,22,6),i=1,5)/  203.00, 43.2,-13.700, 1.30, -20.90/
data(clion(i,30,22,5),i=1,5)/  278.50, 69.9,-23.700, 9.50, -51.70/
data(clion(i,30,22,4),i=1,5)/  325.70, 19.2, -5.700, 2.30, -12.70/
data(clion(i,23,23,7),i=1,5)/    6.74,  2.5, -2.500, 8.00,  -5.50/
data(clion(i,23,23,6),i=1,5)/   12.00, 77.4,-43.900,19.60, -81.90/
data(clion(i,23,23,5),i=1,5)/   47.00, 79.1,-30.000, 8.38, -74.60/
data(clion(i,24,23,6),i=1,5)/   16.50, 77.4,-43.900,19.60, -81.90/
data(clion(i,24,23,5),i=1,5)/   58.79, 79.1,-30.000, 8.38, -74.60/
data(clion(i,24,23,4),i=1,5)/   87.45, 16.7, -3.440, 2.32, -15.10/
data(clion(i,25,23,6),i=1,5)/   33.67, 77.4,-43.900,19.60, -81.90/
data(clion(i,25,23,5),i=1,5)/   80.62, 79.1,-30.000, 8.38, -74.60/
data(clion(i,25,23,4),i=1,5)/  112.00, 16.7, -3.440, 2.32, -15.10/
data(clion(i,26,23,6),i=1,5)/   54.80, 77.4,-43.900,19.60, -81.90/
data(clion(i,26,23,5),i=1,5)/  106.70, 79.1,-30.000, 8.38, -74.60/
data(clion(i,26,23,4),i=1,5)/  141.10, 16.7, -3.440, 2.32, -15.10/
data(clion(i,27,23,6),i=1,5)/   79.50, 64.1,-30.000,10.60, -53.25/
data(clion(i,27,23,5),i=1,5)/  136.60, 74.5,-26.850, 8.94, -63.15/
data(clion(i,27,23,4),i=1,5)/  174.00, 18.0, -4.570, 2.31, -13.90/
data(clion(i,28,23,6),i=1,5)/  108.00, 50.8,-16.100, 1.60, -24.60/
data(clion(i,28,23,5),i=1,5)/  170.90, 69.9,-23.700, 9.50, -51.70/
data(clion(i,28,23,4),i=1,5)/  211.90, 19.2, -5.700, 2.30, -12.70/
data(clion(i,29,23,6),i=1,5)/  139.00, 50.8,-16.100, 1.60, -24.60/
data(clion(i,29,23,5),i=1,5)/  206.70, 69.9,-23.700, 9.50, -51.70/
data(clion(i,29,23,4),i=1,5)/  250.40, 19.2, -5.700, 2.30, -12.70/
data(clion(i,30,23,6),i=1,5)/  175.00, 50.8,-16.100, 1.60, -24.60/
data(clion(i,30,23,5),i=1,5)/  248.70, 69.9,-23.700, 9.50, -51.70/
data(clion(i,30,23,4),i=1,5)/  296.90, 19.2, -5.700, 2.30, -12.70/
data(clion(i,24,24,7),i=1,5)/    6.77,  2.5, -2.500, 8.00,  -5.50/
data(clion(i,24,24,6),i=1,5)/    8.66, 84.8,-67.600,21.00, -84.10/
data(clion(i,24,24,5),i=1,5)/   49.00, 87.7,-49.600,16.40, -84.80/
data(clion(i,25,24,7),i=1,5)/   15.64,  2.5, -2.500, 8.00,  -5.50/
data(clion(i,25,24,6),i=1,5)/   20.58, 84.8,-67.600,21.00, -84.10/
data(clion(i,25,24,5),i=1,5)/   70.09, 87.7,-49.600,16.40, -84.80/
data(clion(i,26,24,6),i=1,5)/   30.65, 84.8,-67.600,21.00, -84.10/
data(clion(i,26,24,5),i=1,5)/   87.05, 87.7,-49.600,16.40, -84.80/
data(clion(i,26,24,4),i=1,5)/  121.10, 25.9,-11.700, 2.32, -23.90/
data(clion(i,27,24,6),i=1,5)/   51.27, 67.4,-41.750,11.30, -54.10/
data(clion(i,27,24,5),i=1,5)/  112.80, 78.8,-36.650,12.95, -68.25/
data(clion(i,27,24,4),i=1,5)/  149.50, 22.5, -8.700, 2.31, -18.30/
```

```
data(clion(i,28,24,6),i=1,5)/   76.10, 49.9,-15.900, 1.60, -24.10/
data(clion(i,28,24,5),i=1,5)/  144.70, 69.9,-23.700, 9.50, -51.70/
data(clion(i,28,24,4),i=1,5)/  184.90, 19.2, -5.700, 2.30, -12.70/
data(clion(i,29,24,6),i=1,5)/  103.00, 49.9,-15.900, 1.60, -24.10/
data(clion(i,29,24,5),i=1,5)/  180.10, 69.9,-23.700, 9.50, -51.70/
data(clion(i,29,24,4),i=1,5)/  224.30, 19.2, -5.700, 2.30, -12.70/
data(clion(i,30,24,6),i=1,5)/  136.00, 49.9,-15.900, 1.60, -24.10/
data(clion(i,30,24,5),i=1,5)/  216.50, 69.9,-23.700, 9.50, -51.70/
data(clion(i,30,24,4),i=1,5)/  263.30, 19.2, -5.700, 2.30, -12.70/
data(clion(i,25,25,7),i=1,5)/    7.43, 17.4, -3.270, 0.16, -10.20/
data(clion(i,25,25,6),i=1,5)/   14.30, 30.1,-38.800,18.60, -45.70/
data(clion(i,25,25,5),i=1,5)/   59.40,115.0,-72.400, 9.57,-107.00/
data(clion(i,26,25,7),i=1,5)/   16.19, 17.4, -3.270, 0.16, -10.20/
data(clion(i,26,25,6),i=1,5)/   21.93, 30.1,-38.800,18.60, -45.70/
data(clion(i,26,25,5),i=1,5)/   76.17,115.0,-72.400, 9.57,-107.00/
data(clion(i,27,25,6),i=1,5)/   33.50, 40.2,-27.400,10.10, -35.00/
data(clion(i,27,25,5),i=1,5)/   93.62, 92.4,-48.050, 9.53, -79.35/
data(clion(i,27,25,4),i=1,5)/  130.50, 19.2, -5.700, 2.30, -12.70/
data(clion(i,28,25,6),i=1,5)/   54.90, 50.3,-16.000, 1.60, -24.30/
data(clion(i,28,25,5),i=1,5)/  120.10, 69.9,-23.700, 9.50, -51.70/
data(clion(i,28,25,4),i=1,5)/  159.70, 19.2, -5.700, 2.30, -12.70/
data(clion(i,29,25,6),i=1,5)/   79.90, 50.3,-16.000, 1.60, -24.30/
data(clion(i,29,25,5),i=1,5)/  152.80, 69.9,-23.700, 9.50, -51.70/
data(clion(i,29,25,4),i=1,5)/  196.00, 19.2, -5.700, 2.30, -12.70/
data(clion(i,30,25,6),i=1,5)/  108.00, 50.3,-16.000, 1.60, -24.30/
data(clion(i,30,25,5),i=1,5)/  189.60, 69.9,-23.700, 9.50, -51.70/
data(clion(i,30,25,4),i=1,5)/  236.90, 19.2, -5.700, 2.30, -12.70/
data(clion(i,26,26,7),i=1,5)/    7.90, 31.9, -15.00, 0.32, -28.10/
data(clion(i,26,26,6),i=1,5)/   14.70, 15.0,-16.700, 7.00, -12.70/
data(clion(i,26,26,5),i=1,5)/   66.00,115.0,-72.400, 9.57,-107.00/
data(clion(i,27,26,6),i=1,5)/   17.08, 29.7,-15.400, 4.20, -17.10/
data(clion(i,27,26,5),i=1,5)/   76.21, 92.4,-48.050, 9.53, -79.35/
data(clion(i,27,26,4),i=1,5)/  112.90, 19.2, -5.700, 2.30, -12.70/
data(clion(i,28,26,6),i=1,5)/   35.32, 44.4,-14.100, 1.40, -21.50/
data(clion(i,28,26,5),i=1,5)/  100.30, 69.9,-23.700, 9.50, -51.70/
data(clion(i,28,26,4),i=1,5)/  140.10, 19.2, -5.700, 2.30, -12.70/
data(clion(i,29,26,6),i=1,5)/   57.38, 44.4,-14.100, 1.40, -21.50/
data(clion(i,29,26,5),i=1,5)/  127.70, 69.9,-23.700, 9.50, -51.70/
data(clion(i,29,26,4),i=1,5)/  170.30, 19.2, -5.700, 2.30, -12.70/
data(clion(i,30,26,6),i=1,5)/   82.60, 44.4,-14.100, 1.40, -21.50/
data(clion(i,30,26,5),i=1,5)/  161.20, 69.9,-23.700, 9.50, -51.70/
data(clion(i,30,26,4),i=1,5)/  207.50, 19.2, -5.700, 2.30, -12.70/
data(clion(i,27,27,7),i=1,5)/    7.86,  3.2,  -1.05, 0.30,  -1.55/
data(clion(i,27,27,6),i=1,5)/   15.80, 32.0, -10.00, 1.00, -15.40/
data(clion(i,27,27,5),i=1,5)/   73.00, 69.9, -23.70, 9.50, -51.70/
data(clion(i,28,27,6),i=1,5)/   18.17, 32.0, -10.00, 1.00, -15.40/
data(clion(i,28,27,5),i=1,5)/   82.32, 69.9, -23.70, 9.50, -51.70/
data(clion(i,28,27,4),i=1,5)/  121.90, 19.2,  -5.70, 2.30, -12.70/
data(clion(i,29,27,6),i=1,5)/   36.84, 32.0, -10.00, 1.00, -15.40/
data(clion(i,29,27,5),i=1,5)/  107.20, 69.9, -23.70, 9.50, -51.70/
data(clion(i,29,27,4),i=1,5)/  149.90, 19.2,  -5.70, 2.30, -12.70/
data(clion(i,30,27,6),i=1,5)/   59.40, 32.0, -10.00, 1.00, -15.40/
data(clion(i,30,27,5),i=1,5)/  136.50, 69.9, -23.70, 9.50, -51.70/
data(clion(i,30,27,4),i=1,5)/  182.60, 19.2,  -5.70, 2.30, -12.70/
data(clion(i,28,28,7),i=1,5)/    7.64,  2.5,  -0.80, 0.20,  -1.20/
data(clion(i,28,28,6),i=1,5)/   17.00, 12.6,  -4.00, 0.40,  -6.10/
data(clion(i,28,28,5),i=1,5)/   82.00, 69.9, -23.70, 9.50, -51.70/
data(clion(i,29,28,6),i=1,5)/   20.29, 12.6,  -4.00, 0.40,  -6.10/
data(clion(i,29,28,5),i=1,5)/   88.61, 69.9, -23.70, 9.50, -51.70/
data(clion(i,29,28,4),i=1,5)/  131.20, 19.2,  -5.70, 2.30, -12.70/
data(clion(i,30,28,6),i=1,5)/   39.72, 12.6,  -4.00, 0.40,  -6.10/
data(clion(i,30,28,5),i=1,5)/  114.30, 69.9, -23.70, 9.50, -51.70/
data(clion(i,30,28,4),i=1,5)/  160.10, 19.2,  -5.70, 2.30, -12.70/
data(clion(i,29,29,7),i=1,5)/    7.73,  2.5,  -0.80, 0.20,  -1.20/
data(clion(i,29,29,6),i=1,5)/   10.64, 12.6,  -4.00, 0.40,  -6.10/
data(clion(i,29,29,5),i=1,5)/   83.00, 69.9, -23.70, 9.50, -51.70/
data(clion(i,30,29,7),i=1,5)/   17.96,  2.5,  -0.80, 0.20,  -1.20/
```

```
data(clion(i,30,29,6),i=1,5)/   26.94, 12.6,  -4.00, 0.40,  -6.10/
data(clion(i,30,29,5),i=1,5)/  102.10, 69.9, -23.70, 9.50, -51.70/
data(clion(i,30,30,7),i=1,5)/    9.34,  2.5,  -0.80, 0.20,  -1.20/
data(clion(i,30,30,6),i=1,5)/   17.30, 12.6,  -4.00, 0.40,  -6.10/
data(clion(i,30,30,5),i=1,5)/   97.00, 69.9, -23.70, 9.50, -51.70/
end
```

Appendix D

Sample Mathematica Calculation

For this integration

$$C\ (T) = \frac{2\verb|^|(3/2)}{T\verb|^|(3/2)} * \frac{4*10\verb|^|-8}{\sqrt{\pi*9.1*10\verb|^|-31}} * (IEA\verb|^|2)*A*\int_1^\infty \frac{u*\sigma\ (u)}{\left(1+\frac{u*IEA}{T*(k-1.5)}\right)\verb|^|(k+1)}\,du$$

that is

$$C\ (T) = \frac{6.69*\verb|^|7}{T^{3/2}} * (IEA\verb|^|2)*A*\int_1^\infty \frac{u*\sigma\ (u)}{\left(1+\frac{u*I}{T*(k-1.5)}\right)\verb|^|(k+1)}\,du$$

We check the integration for direct ionization which

$$\sigma_{DI}\ (u) = \sum_j \frac{1}{uI_j^{\,2}} \left\{ A_j \left(1-\frac{1}{u}\right) + B_j \left(1-\frac{1}{u}\right)^2 + C_j \ln\ (u) + D_j \frac{\ln\ (u)}{u} \right\} \quad \text{and}$$

for the case that $\kappa = 10$

k = 10

10

$$A = \frac{Gamma[k+1]}{Gamma[k-1/2]*(k-1.5)\verb|^|1.5}$$

1.2275

in the case of Si + 0 (from Arnaud and Rothenflug, 1987, we find that j = 2)

Then, we input the ionization threshold energy, Ij.

i1 = 8.1

8.1

i2 = 13.5

13.5

where a unit of T is eV (for temperature of 10 ^ 6 K)

T = T = 10 ^ 6 * 8.6171 * 10 ^ -5

86.171

rate ' s constant for the case of Si + 0

a1 = 74.5

74.5

a2 = 53.8

53.8

b1 = -49.4

-49.4

b2 = -35.8

-35.8

c1 = 1.3

1.3

c2 = 1.4

1.4

d1 = -54.6

-54.6

d2 = -40.7

-40.7

Input variables x,
the fractions between ionization threshold energy and termal energy.

In the case of kappa distributions α **is x devided by k - 3 / 2.**

x1 = i1 / T

0.0939991

$$\alpha 1 = \frac{x1}{(k - 1.5)}$$

0.0110587

x2 = i2 / T

0.156665

$$\alpha 2 = \frac{x2}{(k - 1.5)}$$

0.0184312

In the case of analytical calculation.

First term of integration

$$W1 = \frac{6.69 * 10 \wedge (-7)}{T \wedge (1.5)} * A * \int_1^{10000.} \left(a1 * \left(1 - \frac{1}{u}\right) \Big/ \left(1 + \frac{x1 * u}{(k - 1.5)}\right) \wedge (k + 1)\right) du$$

4.90066×10^{-7}

2 nd term of integration

$$W2 = \frac{6.69 * 10 \wedge (-7)}{T \wedge (1.5)} * A * \int_1^{1000.} \left(a2 * \left(1 - \frac{1}{u}\right) \Big/ \left(1 + \frac{x2 * u}{(k - 1.5)}\right) \wedge (k + 1)\right) du$$

1.80224×10^{-7}

3 rd term of integration

$$F1 = \frac{6.69 * 10 \wedge (-7)}{T \wedge (1.5)} * A * \int_1^{10000.} \left(b1 * \left(\left(1 - \frac{1}{u}\right) \wedge 2\right) \Big/ \left(1 + \frac{x1 * u}{(k - 1.5)}\right) \wedge (k + 1)\right) du$$

-2.74068×10^{-7}

$$F2 = \frac{6.69 * 10 \wedge (-7)}{T \wedge (1.5)} * A * \int_1^{10000.} \left(b2 * \left(\left(1 - \frac{1}{u}\right) \wedge 2\right) \Big/ \left(1 + \frac{x2 * u}{(k - 1.5)}\right) \wedge (k + 1)\right) du$$

-9.49863×10^{-8}

$$G1 = \frac{6.69 * 10 \wedge (-7)}{T \wedge (1.5)} * A * \int_1^{10000.} \left(c1 * Log[u] \Big/ \left(1 + \frac{x1 * u}{(k - 1.5)}\right) \wedge (k + 1)\right) du$$

2.15163×10^{-8}

$$G2 = \frac{6.69 * 10 \wedge (-7)}{T \wedge (1.5)} * A * \int_1^{10000.} \left(c2 * Log[u] \Big/ \left(1 + \frac{x2 * u}{(k - 1.5)}\right) \wedge (k + 1)\right) du$$

1.04504×10^{-8}

4 th term of integration

$$H1 = \int_1^{10000.} \left(\frac{Log[u]}{u} \Big/ (1 + (\alpha 1 * u)) \wedge (k + 1)\right) du$$

1.99159

$$H2 = \int_{1}^{10000.} \left(\frac{Log[u]}{u} \Big/ (1 + (\alpha 2 * u))\,^{\wedge}\,(k+1) \right) du$$

1.23956

$$Q1 = \frac{6.69 * 10\,^{\wedge}\,(-7)}{T\,^{\wedge}\,(1.5)} * A * d1 * H1$$

-1.11634×10^{-7}

$$Q2 = \frac{6.69 * 10\,^{\wedge}\,(-7)}{T\,^{\wedge}\,(1.5)} * A * d2 * H2$$

-5.17925×10^{-8}

direct ionization rate coefficient for Si + 0 at 10 ^ 6 K

$$J = W1 + F1 + G1 + Q1 + W2 + F2 + G2 + Q2$$

1.69776×10^{-7}

In the case of numerical culculation.

first term of integration

$$W1 = \frac{6.69 * 10\,^{\wedge}\,(-7)}{T\,^{\wedge}\,(1.5)} * A * a1 * \left(\frac{(1+\alpha 1)\,^{\wedge}\,(-k)}{\alpha 1 * k} + Log\left[\frac{\alpha 1}{1+\alpha 1}\right] + \sum_{n=2}^{k+1} \frac{(1+\alpha 1)\,^{\wedge}\,(-n+1)}{n-1} \right)$$

4.90066×10^{-7}

$$W2 = \frac{6.69 * 10\,^{\wedge}\,(-7)}{T\,^{\wedge}\,(1.5)} * A * a2 * \left(\frac{(1+\alpha 2)\,^{\wedge}\,(-k)}{\alpha 2 * k} + Log\left[\frac{\alpha 2}{1+\alpha 2}\right] + \sum_{n=2}^{k+1} \frac{(1+\alpha 2)\,^{\wedge}\,(-n+1)}{n-1} \right)$$

1.80224×10^{-7}

2 nd term of integration

$$F1 = \frac{6.69 * 10\,^{\wedge}\,(-7)}{T\,^{\wedge}\,(1.5)} * A * b1 * \left(1 + \frac{(1+\alpha 1)\,^{\wedge}\,(-k)}{\alpha 1 * k} + (2 + (k * \alpha 1) + \alpha 1) * Log\left[\frac{\alpha 1}{1+\alpha 1}\right] + \sum_{n=2}^{k+1} \frac{(2 + \alpha 1 * (k - n + 2)) * (1+\alpha 1)\,^{\wedge}\,(-n+1)}{n-1} \right)$$

-2.74068×10^{-7}

$$F2 = \frac{6.69*10^{(-7)}}{T^{(1.5)}} * A * b2 * \left(1 + \frac{(1+\alpha 2)^{(-k)}}{\alpha 2 * k} + (2 + (k*\alpha 2) + \alpha 2) * Log\left[\frac{\alpha 2}{1+\alpha 2}\right] + \sum_{n=2}^{k+1} \frac{(2 + \alpha 2 * (k - n + 2)) * (1+\alpha 2)^{(-n+1)}}{n-1}\right)$$

-9.49863×10^{-8}

3 rd term of integration

$$G1 = \frac{6.69*10^{(-7)}}{T^{(1.5)}} * A * \frac{c1}{k*\alpha 1} * \left(-Log\left[\frac{\alpha 1}{1+\alpha 1}\right] - \sum_{n=2}^{k} \frac{(1+\alpha 1)^{(-n+1)}}{n-1}\right)$$

2.15163×10^{-8}

$$G2 = \frac{6.69*10^{(-7)}}{T^{(1.5)}} * A * \frac{c2}{k*\alpha 2} * \left(-Log\left[\frac{\alpha 2}{1+\alpha 2}\right] - \sum_{n=2}^{k} \frac{(1+\alpha 2)^{(-n+1)}}{n-1}\right)$$

1.04504×10^{-8}

4 th term of integration

$$H1 = \int_1^{1000.} \left(\frac{Log[u]}{u} \Big/ (1 + (\alpha 1 * u))^{(k+1)}\right) du$$

1.99159

$$H2 = \int_1^{10000.} \left(\frac{Log[u]}{u} \Big/ (1 + (\alpha 2 * u))^{(k+1)}\right) du$$

1.23956

$$Q1 = \frac{6.69*10^{(-7)}}{T^{(1.5)}} * A * d1 * H1$$

-1.11634×10^{-7}

$$Q2 = \frac{6.69*10^{(-7)}}{T^{(1.5)}} * A * d2 * H2$$

-5.17925×10^{-8}

direct ionization rate coefficient for Si + 0 at 10 ^ 6 K

J = W1 + F1 + G1 + Q1 + W2 + F2 + G2 + Q2

1.69776×10^{-7}

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