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CALCULATIONS OF HEAVY ION CHARGE STATE DISTRIBUTIONS FOR NONEQUILIBRIUM CONDITIONS

A. Luhn, D. Hovestadt
Max-Planck-Institut fur extraterrestrische Physik
8046 Garching, F R G

ABSTRACT

Numerical calculations of the charge state distributions of test ions in a hot plasma under nonequilibrium conditions are presented In particular, we derive the mean ionic charges of heavy ions for finite residence times in an instantaneously heated plasma and for a non-Maxwellian electron distribution function. Comparing the results with measurements of the charge states of solar energetic particles, we find that neither of the two simple cases considered can explain the observations.

1 Introduction Recent measurements of the charge states of heavy ions in solar energetic particle events[1] indicate that nonequilibrium conditions at the source of the solar energetic particles (presumably an active region in the lower corona) are likeley to play a key role in establishing the charge state distribution observed at earth. In particular, the temperature as derived from the equilibrium tables of charge state distributions [2,3,4] differed significantly for different ion species. Calculations of equilibration times for impurity ions in a fusion plasma [5] indicate that, as a function of plasma temperature, the time for initially neutral atoms to reach their equilibrium charge state distribution can vary by approximately two orders of magnitude We have therefore calculated the mean ionic charges for elements of relevance to solar flare studies which are expected a) for a finite residence time of the ions after an instantaneous heating of the plasma, and b) for a non-Maxwellian distribution function for the electrons in the plasma.

2 Methods The rate of change of the abundances n_i of the ionization states i of an ion with nuclear charge Z is given by the following system of equations

$$
\begin{aligned}
\dot{n}_1 &= n_e(-n_1S_1 + n_2\alpha_2),\\
\dot{n}_i &= n_e(n_{i-1}S_{i-1} + n_{i+1}\alpha_{i+1} - n_i(S_i + \alpha_i)), \quad (i=2\ \ .Z),\\
\dot{n}_{Z+1} &= n_e(n_ZS_Z - n_{Z+1}\alpha_{Z+1}).
\end{aligned}
\tag{1}
$$

For vanishing time dependence this becomes

$$n_i S_i = n_{i+1}\alpha_{i+1}, \quad (i = 1 \quad Z) \tag{2}$$

S_i denotes the total ionization rate coefficient from ionization state i to i+1, α_i the total recombination rate coefficient from i to i-1, and n_e is the electron density The rate coefficients are obtained by multiplication of the relevant cross sections with the electron velocity, averaged over the electron distribution function For the time dependent calculations with a Maxwellian electron distribution we use the fit parameters for the rate coefficients given in [2] and [3] These are calculated using the corona aproximation, i e. neglecting any density dependent terms in the cross sections and photoionization by the radiation field, which is valid for the parameter range considered here The processes included are collisional ionization and radiative and dielectronic recombination together with corrections taking into account autoionization after collisional excitation and dielectronic recombination. For the calculation of the charge states produced by a non-Maxwellian distribution, however, we need the cross sections σ as a function of electron impact velocity To obtain these, we use the analytical forms of the rate coefficients for a Maxwellian distribution given by [6] and solve numerically for the parameters of the cross sections by comparing them with the rate coefficients given by [2,3] We then can find the rate coefficients for an arbitrary electron distribution f_e by calculating $\int v\sigma(v)f_e(v)dv$, were v denotes the electron velocity

The equations (1) are solved by numerical integration with an algorithm suited for the widely differing time scales of the abundance changes for the different ionization states The initial charge distributions and the equilibrium distributions for a non-Maxwellian electron distribution function are calculated using the equilibrium equations (2). In view of the accuracy of the parameters given by [2] for the interpolation formulæ for the rate coefficients, conclusions based on the values of specific ionization ratios have to be made with caution However, the mean values of the charge distributions, which are used for this work, are much less affected

3 Results and Discussion We first discuss the time development of the mean ionic charge of different ions after an instantaneous heating of the plasma. This is motivated by the observation that in the initial phase of a solar flare the temperature rises by a factor of approx. 10 over the ambient coronal temperature of about 10^6 K within a time of the order of 1 second (see for instance [7] and [8]) The subsequent acceleration of protons, alpha particles, and heavier ions may remove the ions in a timescale comparable to the equilibration time for the ionic charge In Fig.1 we plot the mean charge as a function of $n_e t$ for the case of a temperature rise from 10^6K to 10^7K Note that the time for Neon and Magnesium to reach their new equilibrium charge state distribution is a factor of ten larger than that for e g Oxygen if one assumes a typical electron density of 10^9 cm^{-3}, it is of the order of 100 s

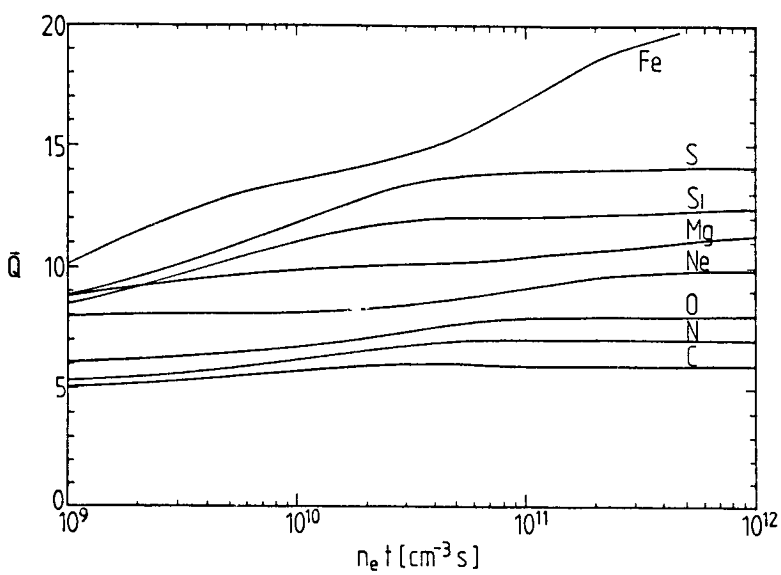

Fig 1 *Time development of mean charges after an instantaneous heating of the plasma from 10^6 K to 10^7 K at time t=0*

This is a consequence of the high ionization potential for the K shell electrons of these elements, which in this temperature range cannot be removed for ions with a higher atomic number Z The differences in the equilibration times contrast with the observation of rather high charge states for Ne and Mg [1], which on the basis of the notion sketched above would be expected for elements with short equilibration times. For different initial and final temperatures the equilibration times change However, their ratios for the different ions remain approximately the same We can therefore conclude, that the simple model of the freezing in of nonequilibrium charge states due to the escape of the particles from the heated coronal material cannot explain the ionic charges of solar energetic particles.

The second case considered is the calculation of equilibrium charge distributions for a non-Maxwellian electron distribution function of the coronal plasma The existence of a non-thermal tail of electrons in the transition zone and the lower corona is supported both by theoretical calculations for the quiet sun (e.g [9,10]) and observations in flaring regions (e g [11,12]) Owocki and Scudder ([6]) have considered this case and derived the ionization ratios O^{+6}/O^{+7} and Fe^{+11}/Fe^{+12} They find that an estimation of the temperature based on these ratios overestimates or underestimates the true temperature of the plasma depending on the ratio $k_B T_m / I$, were k_B is the Boltzmann constant, T_m the temperature inferred with a Maxwellian distribution, and I the ionization potential of the state considered We follow [6] in employing the "kappa" (generalized Lorentzian) distribution as a convenient one parameter representation of a Maxwellian with a power law tail Our result is that the mean charge changes in general by considerably less than the ionization state ratios, especially if states are compared which constitute the flanks of the charge distribution

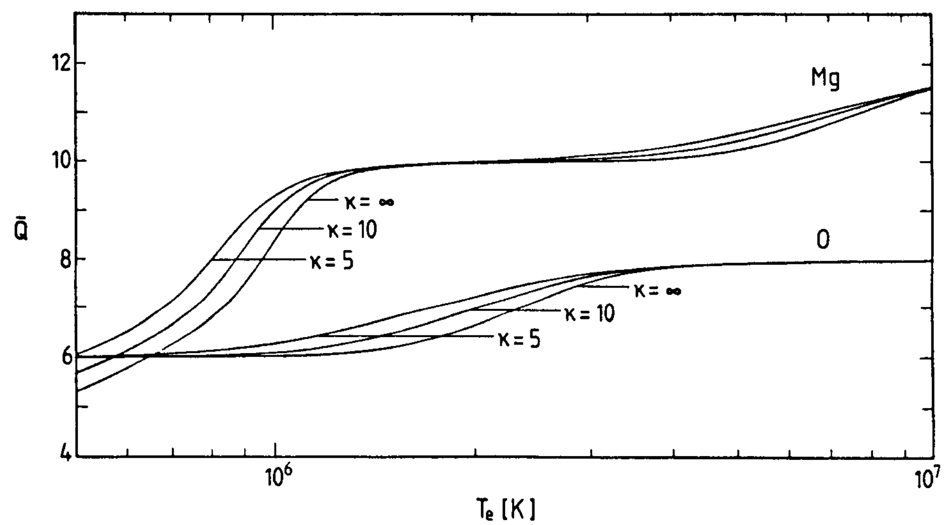

Fig 2 *Mean equilibrium charges of O and Mg for a κ electron distribution function with κ=5 and 10 and a Maxwellian (κ=∞)*

In Fig 2 we compare the mean equilibrium charges of O and Mg as a function of temperature (defined for the κ distribution as corresponding to the mean electron energy) for values of the parameter κ of 5, 10, and ∞ (corresponding to a strong and moderately pronounced electron tail and a purely Maxwellian distribution). Fig 3 shows the mean charges for various heavy ions for a κ distribution with κ=5. Although the effect of the energetic tail of the electron distribution is to raise the mean charge above that of a Maxwellian with the same temperature, the variation of this effect for the different ions is not pronounced enough to explain the variation of the temperature inferred for the different ions from a Maxwellian

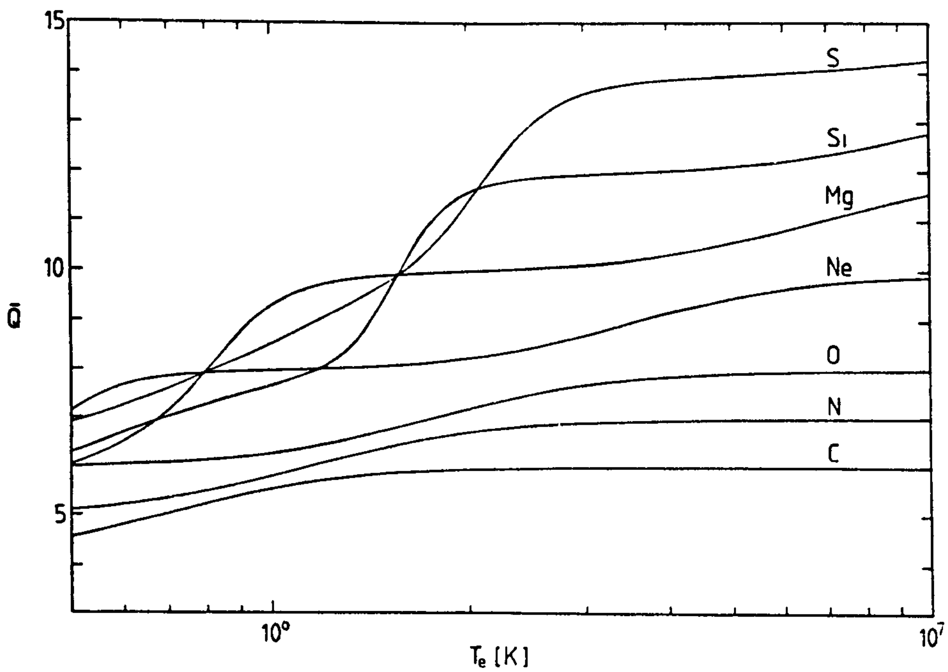

Fig 3 *Mean equilibrium charges as a function of electron temperature for a κ distribution with κ=5*

In closing we conclude that neither of the above two simple models is able to explain the observed discrepancy in the temperatures derived from the mean ionic charge states for the heavy constituents of flare generated solar energetic particles.

References

1 A.Luhn et al paper SH 2 1-11, this conference
2 M. J. Shull, M v Steenberg. Ap J. Suppl **48**, p 95 (1982)
3 M J Shull, M. v Steenberg· Ap J. Suppl **49**, p 351 (1982)
4 C Jordan M N R A S **142**, p 501 (1969)
5 P. G. Carolan, V A Piotrowicz Plasma Phys **25**, p 1086 (1983)
6 S P. Owocki, J D Scudder· Ap J **270**, p 758 (1983)
7 R P Lin, H S Hudson· Solar Phys **50**, p 153 (1976)
8 D. M Rust et al. Ap. J. **288**, p 401 (1985)
9 R Roussel-Dupré So' Phys **68**, p. 243 and p. 265 (1980)
10 E C. Shoub. Ap J **266**, p.339 (1983)
11 S F Smerd, in AAS-NASA Symposion on Solar Flares, NASA SP-50 (1964)
12 P L Dufton, A E Kingston, F P Keenan· Ap. J. **280**, L35 (1984)