MAGNESIUM ISOTOPE COMPOSITION IN THE SOLAR WIND AS OBSERVED WITH THE MTOF SENSOR ON THE CELIAS EXPERIMENT ON BOARD THE SOHO SPACECRAFT

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ABSTRACT

In this paper we present first results of the abundance ratio of magnesium isotopes measured in the solar wind by using the data from the high resolution Mass Time-of-Flight spectrometer MTOF on board the Solar and Heliospheric Observatory SOHO. MTOF is part of the Charge Element and Isotope Analysis System CELIAS and is with its very high time- and mass resolution an excellent tool for isotope abundance measurements. From the analysis of the data, we have found that the isotopic composition of magnesium in the solar wind agrees within the relative experimental error of less than ten percent with the terrestrial composition. We have obtained isotopic ratios for $^{24}Mg/^{25}Mg = 7.4 \pm 0.6$ and for $^{24}Mg/^{26}Mg = 7.1 \pm 0.6$. These values are consistent with the terrestrial values of $^{24}Mg/^{25}Mg = 7.90$ and $^{24}Mg/^{26}Mg = 7.17$.

Key words: MTOF; magnesium isotope abundance.

1. INTRODUCTION

The knowledge of isotopic composition of solar system material is essential to study the origin of the elements in stars and the formation of the solar system. The analysis of solar particle isotopic abundances provides the only tool to obtain information on the isotopic composition of the outer convective zone of the Sun. The vast majority of solar particles is carried into the interplanetary medium by the solar wind whereas a minor fraction, the so-called solar energetic particles (SEP), undergoes a complicated sequence of acceleration processes. From a theoretical point of view, different physical processes could produce isotope and element fractionation in the different solar environments.

Solar wind particles, for example, are ionized in the chromosphere transition region. Neutrals diffuse from the photosphere into the chromosphere where they get ionized depending on their element specific first ionization time and will then be separated from the ions (see Marsch et al. 1995) which are uplifted due to Coulomb-drag by the proton gas. Further up in the corona minor solar wind ions are accelerated by Coulomb friction with hydrogen and helium ions (Bodmer and Bochsler 1996) which causes slight isotope fractionation and may influence the long term variation of the isotopic abundances in the steady solar wind.

Much stronger fractionation mechanisms are known for the SEP's. In the solar atmosphere element or isotope fractionation may occur by resonant wave particle interaction (Mason et al. 1994). In the interplanetary medium fractionation may occur where shock acceleration processes can enrich or deplete particle abundances according to their mass to charge ratio (Mewaldt and Stone 1989). The fractionations of the latter process, however, may cancel out in long term averages of isotopic abundances in the SEP's.

2. MAGNESIUM ISOTOPES IN THE SOLAR WIND AND ISOTOPE FRACTIONATION

Magnesium is a non-volatile element which has three stable isotopes with a high abundance of more than 10%. The abundances of this element cannot be mod-

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ified in the Sun or during its lifetime by conventional hydrogen burning. Therefore this element with its isotopes can be regarded as a "standard" to investigate fractionation effects on solar wind particles on their way from the source region to the interplanetary medium. As far as magnesium isotopes are concerned, fractionation effects which are related to the separation of ions and neutrals in the chromosphere transition region may have a minor influence on the final abundances in the solar wind (Marsch et al. 1995). However, effects related to inefficient Coulomb coupling in the inner corona could have the strongest effect on fractionation of magnesium isotopes. These effects can occur in streamer type solar wind with strong superradial expansion in the inner corona (Bodmer and Bochsler 1996). The theory predicts a maximum isotopic fractionation factor of 1.03 for the case of $^{24}Mg/^{26}Mg$. Therefore, a precise measurement of element and isotope abundances - and in this case magnesium isotope abundance - provides a unique opportunity to derive constraints on fractionation effects of solar wind particles on their way from the source region in the photosphere to the interplanetary medium. In addition, recent theoretical models of solar wind acceleration and fractionation effects on solar wind ions can be tested.

3. MTOF SENSOR

The MTOF sensor of CELIAS (Charge, Element and Isotope Analysis System) (Hovestadt et al., 1995) on board the SOHO spacecraft is an isochronous time-of-flight mass spectrometer with a mass resolution $M/\Delta M$ better than 100 which provides the possibility to resolve almost all isotopes of the solar wind elements from 3 to 60 atomic mass units. In Figure 1 we show a schematic representation of the MTOF sensor. Highly charged solar wind ions enter the WAVE (Wide Angle Variable Energy) entrance system which is designed to suppress the solar wind proton flux and the UV radiation. After the ions leave the WAVE they can be accelerated or decelerated into the V-shaped VMASS isochronous time of flight spectrometer. At the entrance to VMASS the ions pass through a thin carbon foil where secondary electrons are created which produce a start signal at the electron Micro-Channel plate. After passing through the carbon foil particles are mostly neutral or singly ionized. In VMASS a hyperbola deflection electrode generates an electrostatic harmonic potential so that the time of flight in the detector is proportional to $(M/Q)^{1/2}$ where M is the mass and Q the charge of the ions after passing the thin carbon foil. At the Ion Micro-Channel Plate detector (IMCP) these ions generate a stop signal. For a more detailed description of the sensor as well as for a detailed analysis of the sensor efficiency for the different elements and isotopes, we would like to reference to a more detailed paper by Kallenbach et al., 1997.

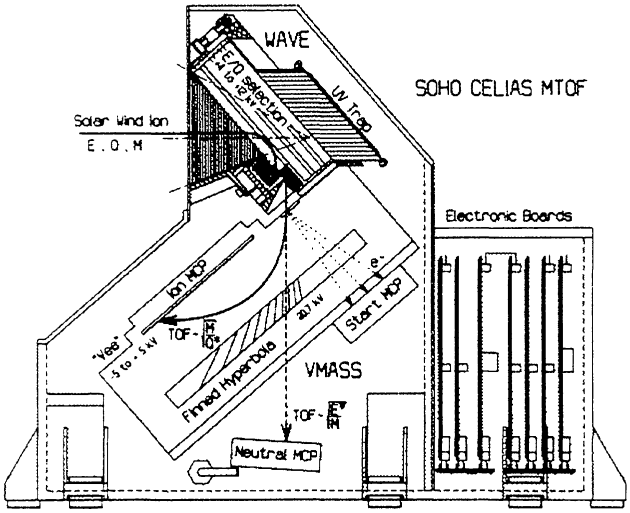

Figure 1. Schematic representation of the MTOF sensor with the entrance system WAVE

4. DATA ANALYSIS

For the analysis of the TOF spectra Puls Height Analysis words (PHA) have been used and selected according to instrument parameters v_f, U_w and solar wind parameters v_{bulk} and v_{therm}. The instrument settings such as the instrument voltage V_f and U_w have been taken from the housekeeping data. The data from the Proton Monitor (for details see Ipavich et al. 1997) have been used to extract the velocity of the solar wind v_{bulk} and its kinetic temperature v_{therm}. These data are available with a time resolution of about five minutes. The time series of PHA words for the magnesium isotopes have then been selected into groups of these parameters. These groups of TOF spectra have been selected according to their detection efficiency ratio for $^{25}Mg/^{24}Mg$ and $^{26}Mg/^{24}Mg$. Figure 2 shows a spectrum of PHA words which is a superposition of data of the first 200 days (20-220) from the year 1996 selected according to the detection efficiency ratio of 0.85 to 1.15. The squares show the data points whereas the red line represents a fitted function which is described below. For this spectrum 4 TOF channels have been binned and the data have then been smoothed with a filter width that corresponds to half of the TOF resolution so that the reduction of the peak resolution is minor, only 12%. In order to improve the signal to noise ratio we have used a filter for the outer stop position with a low He background. All three isotopes of magnesium are clearly visible and also the neighboring elements at the low and the high end of the TOF spectra. All three peaks of ^{24}Mg,^{25}Mg and ^{26}Mg are described by the same lorentzian like function with an identical width. The position and the height of the peak have been fitted. The magnesium spectrum model function is a sum of Lorentzian shape functions which can be divided into the following parts:

$$
\begin{aligned}
f &= \sum \frac{A_x}{(1+\frac{1}{2}(\frac{x_i-x0_i}{b_i})^2 * \lambda_i)^{\lambda_i}} && (1)\\
&+ \sum \frac{An_x}{(1+\frac{1}{2}(\frac{x_i-xn0_i}{bn_i})^2 * \lambda n_i)^{\lambda n_i}} && (2)\\
&+ \sum \frac{Ar_x}{(1+\frac{1}{2}(\frac{x_i-xr0_i}{br_i})^2 * \lambda r_i)^{\lambda r_i}} && (3)\\
&+ Cx_i && (4)\\
&+ D && (5)
\end{aligned}
$$

The first sum in this equation describes the peaks of the magnesium isotopes. Here the amplitudes are denoted by $A_{24,25,26}$ whereas the peak position in the spectrum is given by $x0_{24,25,26}$ for the isotopes $^{24,25,26}Mg$. The half widths b_i of the functions have been fitted to the spectra but are the same for all the isotopes. The parameter λ which describes the deviation from a Lorentzian function has also been fitted to the time-of-flight spectrum. This parameter is the same for all peaks. In addition we have fitted the neighboring elements Na and Al (second sum) as well as the peaks which originate from the electronic ringing effect (third sum). This is a systematic instrumental effect and the peaks are observable at about 25 to 35 channels to the left of any well resolved time-of-flight peak. Therefore, at every magnesium peak a hump on the slope to lower TOF channels has been identified. The magnesium peaks are resolved with very good statistics. Therefore these error bars are not shown in Figure 2. In contrast to other isotopes like Neon (Kallenbach et al., 1997), the TOF spectrum is not disturbed by possible double charged heavier isotopes. The background is described by a linear function and a constant described by the last two terms.

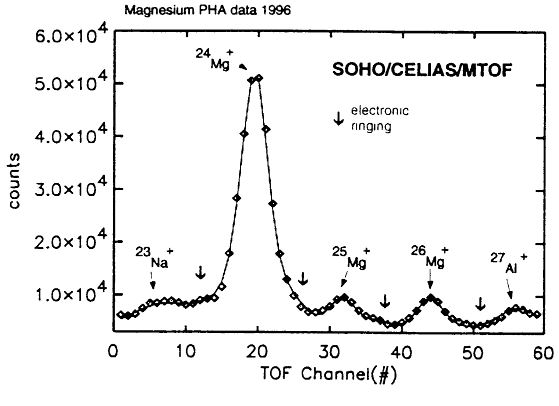

Figure 2. Spectrum for the magnesium isotopes derived from the PHA words accumulated over 200 days (DOY 20 - 220) of the year 1996. For this figure we have binned 4 channels and we have used an instrument fractionation of $< 15\%$.

5. RESULTS

The magnesium peaks are resolved with very good statistics. For the data analysis we have assumed the peak shape of the ringing peak and the isotope peaks are the same. Due to the high statistics the error bars for the statistical errors are rather small. The data points have been fitted by using non linear least square fit. After integration we have obtained the following isotopic abundances: $^{24}Mg = 78.4 \pm 1.0\%$, $^{25}Mg = 10.3 \pm 1.0\%$ and $^{26}Mg = 10.7 \pm 1.0\%$. For a detailed discussion of the calibration and instrument fractionation see (Kucharek et al., 1997). In Table 1 we show a comparison of abundances of the magnesium isotopes measured with MTOF as well as measurements for the terrestrial, and the solar isotopic composition determined in solar energetic particles (SEP) from the flare of September 23, 1978 (Selesnick et al., 1993). In addition we have performed a first and preliminary investigation of the dependence of magnesium isotope abundance on the solar wind velocity. These results are also shown in Table 1.

Table 1. Comparison of different results of the terrestrial and solar wind magnesium isotopic composition.

^{24}Mg	^{25}Mg	^{26}Mg	Source
78.99%	10.00%	11.01%	Terrestrial[1]
$75.5^{+2.3}_{-3.9}\%$	$11.9^{+3.3}_{-1.8}\%$	$12.6^{+3.1}_{-2.0}\%$	SEP[3]
78.6±0.6%	10.3±0.5%	11.1±0.5%	all speeds[2]
77.8±1.0%	10.3±1.0%	11.9±1.0%	(v<400km/s)[2]
79.0±1.0%	10.1±1.0%	10.9±1.0%	(v>400km/s)[2]
78.4±1.0%	10.6±0.6%	11.2±0.6%	all speeds[4]
77.4±1.0%	10.9±1.0%	11.6±1.0%	(v<400km/s)[4]
78.4±1.0%	10.6±1.0%	11.1±1.0%	(v>400km/s)[4]

[1] Anderson & Grevesse (1989)
[2] Bochsler et al. (1996)
[3] Selesnick et al. (1993)
[4] This work

From the comparison in Table 1 it is evident that within the limits of uncertainty the isotopic composition of Mg in the solar wind agrees with the terrestrial abundance. In addition, no significant difference between low and high speed solar wind was found.

6. SUMMARY AND DISCUSSION

The isotopic abundance of magnesium in the solar wind has been investigated by in situ measurement with the Mass-Time-Of-Flight sensor MTOF on board SOHO. For the data evaluation we have used 200 days of the year 1996. The raw data have been corrected with the instrument efficiencies. The obtained values for the magnesium isotope abundances agree well with the terrestrial values and with other measurements (Bochsler et al. 1995, Bochsler et al. 1996). These preliminary results also show no significant difference between low and high speed solar wind. Very good counting statistics could be achieved compared with other missions like WIND.

This is due to the non-spinning spacecraft that provides the possibility to continuously detect the solar wind as well as due to the wide-band energy-per-charge filter WAVE. For future investigations the high temporal and mass resolution makes it feasible to study the abundances of magnesium isotopes of selected solar wind events.

REFERENCES

Bodmer R. and P. Bochsler, 1996, EGS The Hague, NL. 1996.

Bochsler P. et al., 1996, EGS The Hague, NL. 1996.

Bochsler P. et al., 1995, Solar Wind 8 Proc, Dana Point, 1995.

Hovestadt D. et al., 1995, Solar Physics 162, 441.

Marsch E., et al. 1995, Astron. Astrophys., 301, 261

Mason G.M. et al. 1994, Astrophys. J., 425, 843

Mewaldt R. A., and E. C. Stone 1989, Astrophys. J., 337, 959

Ipavich F. M., et al. 1997, submitted to JGR.

Kallenbach R. et al., 1997, submitted to JGR.

Kallenbach R. et al., 1995, Nucl. Instrum. and Methods, B 103, 111.

Kucharek H. et al., 1997, in preparation.

Selesnick R.S. et al., 1993, Astrophys. J. 418, L45-L48.