GERMANIUM AND LEAD : SIGNIFICANT DIFFERENCES BETWEEN METEORITIC AND PHOTOSPHERIC ABUNDANCES ?

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1. Introduction. A key question at present is whether the Galactic Cosmic Ray Source (GCRS) composition is ordered in terms of First Ionization Potential (FIP) (in which case the GCRS composition resembles that of the Solar Corona and of Solar Energetic Particles (SEP)/11,12,31,33,39/, and GCR's have probably been first injected by flaring F to M stars /33/), or in terms of volatility (in which case GCR's must be largely interstellar grain destruction products and their similarity to SEP's is purely fortuitous /10,15,4/).

The problem is that, for most elements, the degree of volatility is (positively) correlated with the value of the FIP, so that it is not easy to distinguish a correlation of GCRS abundances anomalies with FIP from a correlation with volatility. Only a few volatile, though low-FIP, elements that are exceptions to the general rule permit to distinguish between the two kinds of ordering : if they are depleted relative to refractory metals, volatility must be relevant, if not, FIP is relevant /32/. Among them Cu (semi-volatile ; not depleted) and Zn (very volatile; only slightly depleted in accordance with its intermediate FIP) would seem to favour FIP. But among the best indicators are Ge and Pb.

Surprizingly enough, Ge and Pb have recently been found deficient relative to refractory elements with similar FIP /6,7,23,16,8,28,17,18/. Is this observation compelling, in the sense that volatility must indeed be the key parameter ?

The abundance anomalies in GCRS are defined relative to a standard which, for the heavy elements concerned, is commonly taken as C1 Carbonaceous Chondrites. While for most elements C1's are certainly not far from being an unbiased sample of the protosolar nebula (their morphology makes it plausible ; good agreement with photosphere whenever check possible ; continuity of abundances beyond Fe), we do not know precisely to within which accuracy this is the case, especially for volatile elements /1,29, 30,2,14,20,21/. Photospheric abundances, though often less accurately determined, are certainly more directly representative of the protosolar nebula, and hence of ordinary local galactic (LG) matter. (As regards C2 carbonaceous chondrites, which are a mixture of 50% C1-like material, plausibly unfractionated, and of 50% highly fractionated material, there is no reason whatsoever to believe that their bulk composition might have any relevance as a standard /1,29,30,2,14/.)

Here we shall more closely look into the Ge and Pb reference abundance determinations in the Photosphere and in C1 meteorites, and discuss their relevance to the problem of FIP vs. volatility in GCR's.

2. The meteoritic and photospheric abundances of Germanium. The Ge abundance in C1's is very reproducible /14/, and the value for C1's quoted in /2/, Ge = 118 (1.10), should therefore be reliable (fig. 1; see Table 1 for notations).

On the other hand, photospheric abundance measurements have now reached a high degree of accuracy for those elements for which well measurable lines are present in the solar spectrum and accurate atomic data are available. The systematic, model dependent errors, as well as the errors related to departure from LTE, have indeed been reduced to the few % level. With the Holweger-Müller model atmosphere and a microturbulence parameter ~0.85 km/s, a high degree of consistency is obtained from a very large number of lines sampling wide ranges of wavelengths, optical depths, and excitation temperatures. In particular, various lines of different ionization states of particular elements, as well as molecular lines, yield very closely consistent abundances. These points are discussed in /20/.

As regards Ge in the photosphere, see /25,35/ for previous studies, and revisions by /5,20/. Five GeI lines can be identified in the solar spectrum : λ3039, 3124, 3269, 4226 and 4685 Å. The λ3124 and 4226 lines are too strongly blended to be of any use. We are thus left with three lines.

In Table 1 we give the measured equivalent widths W_λ . The value for the λ 3039 UV line is based on the spectrum of /35/, which is of good quality. But the line is quite perturbed, partly by an unidentified feature. The λ 3269 line is much less perturbed, and the W_λ value can accordingly be determined much more precisely (see fig. in /35/). Values obtained from older Jungfraujoch spectra, from /35/ and from the atlas of /13/ agree within 4%. As for the blue λ 4685 feature, the atlas of /13/ yields an extremely precise value of W_λ = 5.5±0.2 mÅ. But there are two problems. First, the feature is the sum of the Ge I and of a Co I line at about the same wavelength. The Co I contribution to W_λ can be estimated quite reliably to W_λ (Co I) = 1.5±0.4 mÅ based on the accurate transition probabilities of /9/. We are left with W_λ (GeI) = 4.0±0.5 mÅ for the contribution of Ge to the feature. In addition, the λ 4685 feature shows a slight asymmetry on the red side, which implies an unidentified blend. The above value of W_λ is therefore an upper limit to the true W_λ (GeI).

The oscillator strengths log gf given in Table 1 are based on branching ratio measurements by /26/ normalized to beam foil lifetime measurements. They should be accurate to within 20%.

Our adopted photospheric Ge abundance, Ge = 72 (1.38)(Table 1, Fig.1) is lower than the C1 value by a factor of 0.61 (1.40).

3. The meteoritic and photospheric abundances of Lead.

The abundance of Pb in C1's is rather well defined : Pb = 3.15 (1.08) /2/ (Table 2, fig.2).

As regards the photosphere, see /36, 25, 19/, and especially /22/ for previous studies. Five Pb I lines can be identified in the solar spectrum : λ 3639, 3683, 3739, 4057 and 7229 Å. The latter two are extremely doubtful. The λ 3639 and λ 3739 lines will be considered, but they are seriously blended with much more intense lines. Only the λ 3683 line is a really good abundance indicator (see fig. in /19/).

In Table 2 we give the equivalent widths W_λ obtained on the atlas of /13/. The λ 3683 value is in excellent agreement with earlier determinations /19/. The other two values are very uncertain, and the previous determinations indeed diverge.

The oscillator strengths log gf given in table 2 are based on lifetime measurements for several Pb I states (to within 5%) combined with branching ratio measurements (to within 8%) by /27/. The overall accuracy is 10%. The validity of the data is confirmed by the relative oscillator strengths measurements of /34/ which agree within 0.7% with /27/ for the ratio of the gf values for the λ 3683 and 3639 lines.

Our adopted photospheric Pb abundance, Pb = 1.97 (1.12) (Table 2, fig.2) is lower than the C1 value by a factor of 0.63 (1.15).

4. General discussion of photospheric vs. C1 abundances. We have found that the photospheric abundance determinations of both Ge and Pb are lower than their C1 abundance. How does this fit into a more general comparison between C1 and photospheric abundances ? Ge is a moderately volatile element ($T_{cond} \approx 900$ K), and /2/ consider that elements of this class may be on average ~ 25% lower in the Photosphere than in C1's. But the agreement between Photosphere and C1's is generally improved in the updated assessment of /20/. The smoothness of the abundance curve of odd-A (r+s) isotopes vs. mass in the Ga,Ge,As,Se region, as derived from C1 data, tends to support the C1 value for Ge /1,29,2/. The situation is,

Fig.1

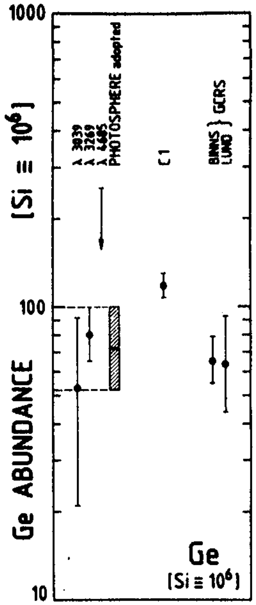

Fig.2

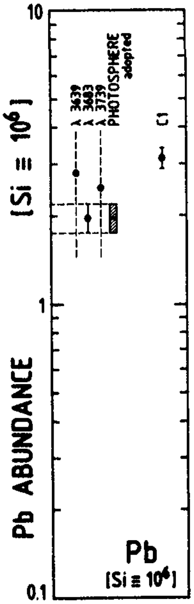

Fig.3

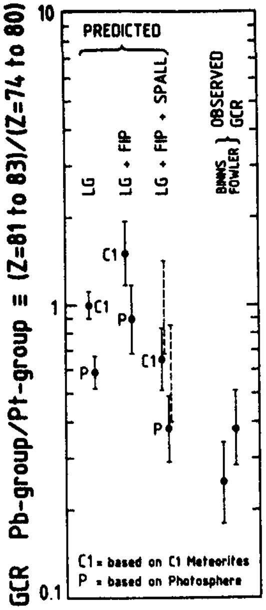

Table 1 - Photospheric and meteoritic abundances of Germanium

Line [Å]	W_λ [mÅ]	log gf	$\log N_{Ge}$ [$\log N_H$=12]	Ge [Si=10^6]
3039	$61.5^{+8.5}_{-11.5}$	0.017 ± 0.080	$3.28^{+0.24}_{-0.40}$	$53.(^{1.74}_{2.51})$
3269	43.3 ± 1.3	-0.921 ± 0.080	3.46±0.09	80.(1.23)
4685	< 4.0 ± 0.5	-2.013 ± 0.080	<3.86±0.10	<202.(1.26)
Adopted Photospheric			3.41±0.14	72.(1.38)
Meteoritic C1			3.63±0.04	118.(1.10)

Notations : In parenthesis : error factors ; "log N_{Ge}": scale log N_H= 12; "Ge" : scale Si = 10^6, based on log N_{Si}=7.555 /20/.

Table 2 - Photospheric and meteoritic abundances of Lead

Line [Å]	W_λ [mÅ]	log gf	$\log N_{Pb}$ [$\log N_H$=12]	Pb [Si=10^6]
3639	[6.4]	-0.700±0.040	[2.00]	[2.8]
3683	7.7±0.4	-0.513±0.040	1.85±0.05	1.97 (1.12)
3739	[0.8]	-0.117±0.040	[1.96]	[2.5]
Adopted Photospheric			1.85±0.05	1.97 (1.12)
Meteoritic C1			2.05±0.03	3.15 (1.08)

Notations : see Table 1 ; [ ]: highly doubtful.

however, not simple as regards r and s nucleosynthesis in this range of mass /24/. As regards Pb, it is a highly volatile element ($T_{cond} \approx 400$ K) for which fractionation could easily take place in C1's. For highly volatile elements, the observed C1/photospheric ratios scatter a lot /2,20/. The scatter may be real, or be due to poor photospheric determinations. To muddle up the situation a little more, note also the totally unexpected but probably reliable overabundances of Fe and Ti by ~ 45% and 25% in the photosphere relative to C1's, while the agreement between photospheric and C1 data is very close for all neighbouring elements, both refractory and siderophile /20,21/.

5. Discussion of the Cosmic-Ray Ge and Pb abundances. GCRS abundances of Ge = 66 (1.19) and 64 (1.45) relative to Si = 10^6 have been obtained by /7/ and /28/. It is obvious from fig. 1 that these values, while low with respect to the C1 abundance of Ge, are prefectly consistent with its photospheric abundance relative to Si and other low FIP metals.

As regards Pb, we shall compare the (Pb-group)/(Pt-group) = (Z=81 to 83)/(Z=74 to 80) ratio observed in GCR's to that predicted near earth, starting from LG abundances based on, either meteoritic, or photospheric data. The LG abundances for the Pt-group and the Pb-group are respectively 3.46 (1.07) and 3.47 (1.08) based on meteorites, and 3.88 (1.08) and 2.29 (1.11) based mainly on the photosphere (Si = 10^6) /2,20,21,this paper,3,38/. So the LG Pb-group/Pt-group ratio is 1.00 (1.11) based on meteorites and 0.59 (1.14) based on the Photosphere (fig.3). Applying a bias related to FIP enhances this ratio by a factor of 1.50 (1.25) /33/ (fig.3). Taking into account spallation in the interstellar medium and instrumental effects on the HEAO-C3 data reduces the predicted observable ratio by a factor of ~0.43 /7/ (fig.3). (Pure interstellar spallation calculations by /37/ yield a reduction by a factor of 0.58 to 0.73, depending on the model, the models with the larger reductions being favoured in view of the high fluxes of nuclei in the range Z=61 to 75 ; dashed on fig. 3). The ratios obtained might be compared with the observed ratios 0.25 (1.35) by /7/ and 0.38 (1.33) by /18/. It is clear from fig. 3 that the data are inconsistent with the FIP hypothesis if C1 meteorites are taken as a standard, but are not inconsistent if photospheric values are adopted instead.

6. Conclusion. There is an apparently significant discrepancy between the photospheric and the C1 abundances of Ge and Pb. The Ge and Pb abundances in GCR's are consistent with the ordering in terms of FIP if referred to the photospheric values.

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