LITHIUM OBSERVATIONS IN THE SUN

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The determination of the lithium abundance in the solar atmosphere is essentially based on the Li I resonance doublet at λ 6707·761 and 6707·912 Å. These two lines form a very faint absorption feature, the central depth of the stronger component being of the order of 1% of the continuum. The violet component, which is also the stronger of the two, occurs near the red wing of a faint solar line of unknown origin, and the lines appear to be blended with other faint lines including possibly the doublet of the Li^6 isotope (the isotopic shift being 0·160 Å). No other line of Li I has been detected in the Fraunhofer spectum of the undisturbed solar disk. This is nothing surprising, because practically all lithium is expected to be ionized in the photosphere on account of its low ionization potential (Xion = 5·37 e.v.). In sunspot spectra the lower temperature reduces the degree of ionization of lithium and causes a strengthening of the Li I lines. In fact, the Li I resonance lines which appear as a very faint absorption feature on disk spectra are about 50 times stronger in spot spectra. Furthermore, the very weak feature at λ 6103·6 Å was identified by Dubov (1964) and by Schmahl and Schröter (1965) as due to the 2s ^{2}S–3d ^{2}D transition of Li I. Both the resonance doublet and the faint feature at 6103·6 Å have been used by the above-mentioned authors to derive the lithium abundance in spots.

Since in the following paper we shall hear more about the lithium abundance in sunspots, I shall restrict myself to present the results obtained from disk spectra. In

Table 1

Determinations of the solar lithium abundance

Authors	Total W_λ (mÅ)	Solar Model	$\log \varepsilon_{\mathrm{Li}}$[a]
Greenstein and Richardson (1951)	3·5	Milne-Eddington	1·26
Claas (1951)	2·9	Claas	1·08
Dubov (1955)	1·74	…	0·93
Goldberg *et al.* (1960)	2·6	Aller-Pierce-Elste	0·96
Utrecht (1960)	2·0	–	–
Mutschlecner (1963)	7·4	Mutschlecner	1·54
Lynds (1965)	$<1·6$	–	–
Peach (1967)	$<0·61$	$T = 5300°$, $\xi = 1·4$ km/sec	$<0·38$

[a] On the basis of $\log \varepsilon_{\mathrm{H}} = 12·00$ for the hydrogen abundance.

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particular, I wish to stress the following two main difficulties that are encountered when determining the lithium abundance in the undisturbed photosphere:

(1) The identification of the Li I resonance lines which is hampered by the fact that the absorption feature is faint and composite, and consequently introduces great uncertainties in the equivalent width measurements of the lithium feature.

(2) The choice of the photospheric model which by its temperature distribution in the line-forming region influences the abundance results, inasmuch as the Doppler-broadened lithium lines are quite sensitive to the temperature.

In order to illustrate these two points the Table 1 collects the results of the equivalent width measurements, the photospheric models used, and the lithium abundance derived by different authors. The equivalent widths are given for the whole lithium feature which includes both the Li^7 doublet and the corresponding isotopic Li^6 doublet. The large disagreement in the equivalent widths is mainly due to identification differences, i.e. to how much of the observed absorption feature each author attributes to lithium. Apparently, as time goes on, that is with increasing spectral resolution, one finds less and less lithium in the Sun.

A high resolution spectrum of the Li I absorption feature observed at the centre of the solar disk with the Kitt Peak solar spectrograph was published by Lynds (1965). On this spectrum, two distinct small absorptions occur in the wavelength region of the Li^7 and Li^6 resonance doublets. However, Lynds points out that the wavelengths of the lithium lines do not coincide with the observed features and questions the presence of the lithium-absorption lines. This poor wavelength agreement was already noted by Greenstein and Richardson (1951), who interpreted it as due to pressure effects. Lynds suggests that 1·6 mÅ is the maximum value of the total equivalent width which may be attributed to lithium on the solar disk. Recently, Peach (1967) re-investigated the lithium feature on high-resolution low-noise spectra. He found no direct evidence of the lithium lines in the observed absorption feature. Consequently, he gives an even smaller upper limit for the equivalent width which may be due to lithium.

Since Lynds' observation of the lithium feature is the only high-resolution spectrophotometric recording which has been published so far, we used it as a basis to derive the lithium abundance employing different photospheric models. The computations were carried out for the entire blend composed of the two Li^7 and the two Li^6 lines, the composite line having an equivalent width of 1·6 mÅ. The calculations were performed with the fine analysis program of Baschek *et al.* (1966) and its FORTRAN translation by Peytremann. For the Li^7/Li^6 isotopic abundance ratio the following three values were used: 2, 11 (corresponding approximately to the terrestrial ratio), and 20. The four photospheric models employed and the resulting lithium abundances are given in Table 2. It is evident that different abundance results are obtained from different models. The abundance values are upper limits, inasmuch as 1·6 mÅ is an upper limit of the total lithium equivalent width according to Lynds. The theoretical

Table 2

The solar lithium abundance derived for $W_\lambda = 1{\cdot}6$ mÅ with different atmospheric models

Model	$\log \varepsilon_{\mathrm{Li}}$
Holweger (1967)	0·88
Mutschlecner (1963)	0·80
U.R.M. (average column) (1964)	0·62
Heintze (1965)	0·49

profiles best reproduced the expected lithium contribution to the observed absorption feature when setting the Li^7/Li^6 isotopic abundance ratio equal to 20. Any large value of this ratio fits just as well. On the other hand, the small ratio of 2 produces two close lying but distinct absorption lines of almost equal central depths which is not observed. We may conclude that, if the light Li^6 isotope is present, it is at least 20 times less abundant than Li^7. It is interesting to note that a similar conclusion was reached by Schmahl and Schröter from sunspot spectra.

That the question of the solar abundance is by no means solved was made clear a few days ago during a session of Commission 12. L. Delbouille presented a spectrographic recording made at the Jungfraujoch of the region between λ 6705 and 6711 Å, in which he showed that numerous unidentified faint lines may be due to the red bands of CN. Some of these CN lines fall right on the so-called lithium-absorption feature. Consequently, the lithium abundance and the Li^7/Li^6 abundance ratio must be revised, taking into account the CN line blending. It may be that we end up having barely any or no lithium at all present in the undisturbed photosphere.

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DISCUSSION

L. Delbouille: Recently, high-resolution and low-noise spectra have been secured by Miss G. Roland and myself. The identifications by W. S. Benedict of many lines due to CN in the λ 6708 Å region of the solar spectrum seriously complicate the situation. It seems impossible to explain this region by fitting in the Li I lines only or even the Li I and the CN lines.

J.P. Mutschlecner: It should also be noted that an additional observational difficulty is the location of the local continuum. In my work, e.g., it was possible to obtain a considerable greater equivalent width due to my different interpretation of the continuum. The unidentified line at about 6707·5 also contributes to the uncertainty in the lithium lines and it would be good if it could be identified. The work of Mark Daehler (so far unpublished) might also be mentioned. In a careful re-observation and analysis he concluded that no lithium exists in the disk spectrum.

W.A. Fowler: Is there any lithium in the Sun?

L. Delbouille: As experimentalists, we try to obtain the best possible spectral tracings, but we are quite reluctant in attempting to derive an abundance of lithium for the Sun.

Mrs. Ch. Moore–Sitterly: Although there is justifiable criticism of the Li I identifications in the disk spectrum, there is no question that the resonance lines are conspicuous features in the spot spectrum. The low ionization potential of Li I makes it reasonable that Li I should be present only in the spot spectrum. Its absence from the disk spectrum may not be puzzling.

G.H. Herbig: I hardly think there can be any question that lithium exists in the solar surface. It may be marginal in the disk, but λ 6707 becomes very strong in spots ($W_\lambda \approx$ 50–100 mÅ) and I would not question the identification there.

H.E. Mitler: Since there is so much question as to the correct lithium abundance in the Sun, may there not be some question as to the stellar observations, especially in the low-lithium cases?

M.W. Feast: It may be as well to point out that the strength of the lithium line in the lithium lide stars is so much greater than in the Sun that we do not have in this case the kind of problems that the solar observers have.

H. Reeves: The lithium in sunspots may be formed right there by increased activity and may not be just strengthened over the disk spectrum by temperature effects. In this case we should expect $Li^7/Li^6 \simeq 2$ and possibly some Be^7.

Miss E.A. Müller: Due to temperature effects the Li I and the CN lines will be enhanced over sunspots compared to the disk spectrum, but they are expected to be strengthened differently and, hence, one might be able to separate the components. Another way of disentangling the Li I and the CN lines is to study the centre-to-limb variation of the Li I + CN absorption feature and of other CN lines in neighbouring wavelengths pertaining to the same band. The CN lines are expected to have a different centre-to-limb behaviour than the Li I lines. So far, all observations discussed here refer to the centre of the solar disk. It seems to me that it would be extremely important to secure high-resolution low-noise observations of the Li I + CN absorption feature at various positions on the solar disk and as far out to the limb as possible. If lithium is formed in sunspots, as suggested by Dr. Reeves, then one might find abundance differences in different spots depending on their activity. Be^7 is probably extremely difficult to detect because the Be I and Be II lines observed in the solar spectrum occur in a big jungle of strong lines due to various atoms and molecules.