SOLAR ABUNDANCES OF LITHIUM, BERYLLIUM AND BORON*

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Abstract. New solar abundances have been derived for Li, Be and B. They are mainly based on high-resolution spectra obtained at the Jungfraujoch Scientific Station (Switzerland). For Li, the abundance results from a discussion of the photospheric and sunspot spectra. Our results, log \(N_{\text{Li}} = 0.42\), log \(N_{\text{Be}} = 1.17\) and log \(N_{\text{B}} < 2.80\) (in the log \(N_{\text{H}} = 12.00\) scale), are lower than the previously admitted abundances for these elements. The far UV spectrum (\(\lambda < 3000 \text{ Å}\)) has also been considered in each case. The meaning of our results is discussed from the point of view of the destruction of these elements during the evolution of the sun.

1. Introduction

The problem of the abundances of lithium, beryllium and boron in the stars and in the sun has been discussed extensively in the last few years. The origin of these elements has been studied mainly by FOWLER et al. (1962) and by BERNAS et al. (1967a). Fowler et al. believe that the light elements were formed by spallation reactions (protons and neutrons) on light nuclei (C, N, O and Ne) during an intermediate stage of the evolution of the solar system. At that stage, the matter from which planets and meteorites will be formed, is already partially separated from the star. In this theory, the light elements are created at different rates in the star and in the meteorites. Bernas et al. assume that Li, Be and B are formed, in each star, by spallation reactions (protons), at the very beginning of the gravitational contraction, before planetary and meteoritic material becomes separated from the star.

The observations of the abundances of Li, Be and B in the stars and in the sun give rise to a great dispersion in the results for Li and to a very much lower dispersion in the results for Be. Except for a few tentative identifications (SWINGS, 1936; H.D. BABCOCK, 1945; DAVIS, 1947; UNDERHILL, 1960; KOHL, 1964), boron has not yet been detected in stellar spectra. The abundances show two principal correlations:

1) between the age of the star and the Li abundance; the oldest stars have a lower Li abundance than the youngest ones;

2) between the mass of the star and its Li abundance; WALLERSTEIN et al. (1965) have shown that stars, with masses less than 1.1 solar mass, have much lower Li abundances than stars with \(M > 1.1 \, M_{\odot}\).

Different hypotheses (see e.g., HERBIG and WOLFF, 1966) have been suggested to explain the observed abundances of the light elements (principally Li).

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(1) An initial dispersion of the Li content between the different stars must exist.

(2) During the pre-main sequence contraction phase, Li could be partly destroyed, by \((p, \alpha)\) reactions, at the bottom of the convection zone. Be and B are not affected by this phenomenon. Differences exist between the results of Hayashi et al. (1962), Weymann and Moore (1963), Ezer and Cameron (1965) and Bodenheimer (1965, 1966). These differences may be explained as follows:

(a) the destruction of Li is extremely sensitive to the temperature;

(b) the physical conditions at the bottom of the convection zone are themselves very sensitive to the values of the opacities used in building stellar models and to the values of the mixing-length chosen for the treatment of the convection. Bodenheimer (1965, 1966) explained the results obtained by Wallerstein et al. (1965) for stars belonging to the Hyades cluster by means of Li destruction during the gravitational contraction phase.

(3) On the main sequence, Li might again be depleted at the bottom of the convection zone. Nevertheless, Weymann and Sears (1965) showed that the temperature at the bottom of the convection zones is always somewhat too low to destroy Li. We have here to point out that the two remarks (a) and (b) of point (2) are still valuable. Other hypotheses have later been tentatively suggested to interpret the Li observations: loss of mass by stellar wind (Weymann and Sears, 1965; Herbig and Wolff, 1966), 'overshooting' (Böhm, 1963a, b). None of these hypotheses has succeeded in giving a quantitative explanation of the observed abundances for main sequence stars. Recently, Howard et al. (1967) and Goldreich and Schubert (1967) suggested that the Li depletion could be qualitatively explained by the presence of turbulence below the convection zone, thus allowing photospheric matter to be exposed to much higher temperatures than those at the bottom of the convection zone. This turbulence would be a consequence of the rapid rotation of the solar interior suggested by Dickel (1964). A very important observational correlation between the Li content and the rotational velocities of the stars has been found by Conti (1968). He finds that stars that still have appreciable rotation have the greater Li content. This means that they had less Li destruction. Conti's work has to be considered as the first quantitative result in favor of the hercubie mentioned phenomenon.

(4) Among sub-giants and red-giants (Herbig and Wolff, 1966), the lowering of the Li abundance is due to dilution phenomenon (Iben, 1965), during the evolution away from the main sequence. Nevertheless, there exist a few sub-giants of about \(1 \, M_\odot\), having anomalously high Li abundances. Feast (1966) suggested a new Li creation, at the surface of these stars, during their evolution. Alexander (1967) explained these anomalies by the annexion of planets, having Li contents nearly equal to that of the earth, during the evolution to the red-giants phase.

From the foregoing introduction, it may be seen that the explanation of the abundances of the light elements, and principally Li, is not yet satisfactory. In tackling the problem of these elements in the sun, one meets numerous discrepancies between the results of different authors. Our aim is to attempt to reach a clearer situation in this important problem which has already been the object of many efforts.