FORBIDDEN LINES OF IONIZED NICKEL IN THE SPECTRA OF BRIGHT-LINE STARS

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The ultraviolet spectra of the bright-line stars HD 45677 (MWC 142), HD 60415 (Boss 1985), and HD 42474 (WY Geminorum) reveal,[1] in addition to bright lines of [*Fe* II], *Fe* II, and *Cr* II, several relatively strong bright lines not previously identified. Of these lines the three most intense, measured at λλ 3439.1 (int. 5), 3559.6 (int. 4), and 3223.6 (int. 2), are forbidden transitions of *Ni* II as will appear from the following discussion.

The spectrum of *Ni* II has been thoroughly analyzed by A. G. Shenstone[2] and A. C. Menzies.[3] The metastable levels are schematized in Figure 1, and the computed wave lengths of the forbidden a^2D–a^2P and a^2D–a^2G multiplets are given in Table I; the adopted term values are those listed by Bacher and Goudsmit.

The estimated relative intensities of the four a^2D–a^2P lines, with reasonable assumption as to the effect of blending, are those to be expected for a ^2D–^2P forbidden transition: in accordance with theoretical expectations λ 3439 and λ 3560 are the strongest lines, λ 3439 being slightly stronger than λ 3560. Since no other satisfactory identification suggests itself for λλ 3439, 3560, and 3223, the attribution of these three lines to [*Ni* II] is probably correct.

Predicted wave lengths of other forbidden multiplets are collected in Table II. Most of the [*Ni* II] lines, especially the a^2D–a^2F multiplet which is most likely the strongest, fall in spectral regions which are still unsatisfactorily investigated in the peculiar bright-line stars. Complete discussion of the [*Ni* II] spectrum in stars will thus have to await additional observations. Some of the [*Ni* II] lines would be expected in the spectra of most stars which show strong [*Fe* II] lines; for example, novae in the η Carinae stage.

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[1] Swings and Struve, *Ap. J.*, **91**, 600, 1940; **93**, 457, 1941; **98**, 94, 1943.

[2] *Phys. Rev.*, **30**, 255, 1927.

[3] *Proc. R. Soc.*, A, **122**, 134, 1929.

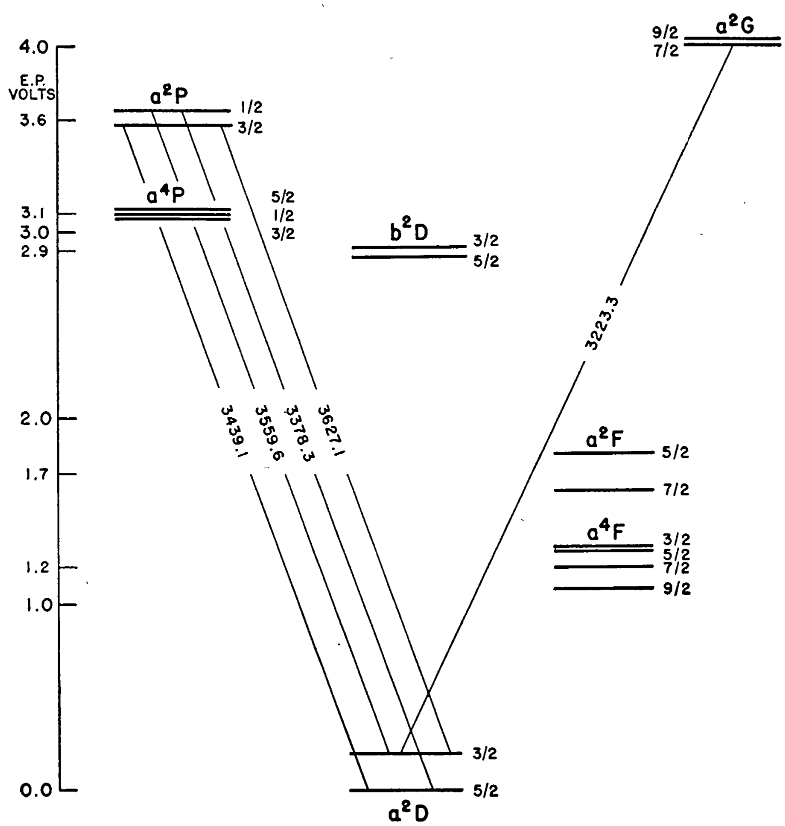

FIG. 1.—Metastable levels of *Ni* II and the observed forbidden transitions.

TABLE I

FORBIDDEN a^2D–a^2P AND a^2D–a^2G MULTIPLETS OF *Ni* II

Transition	Predicted λ	Observed λ	Stellar Intensity	Notes
a^2D -a^2P				
5/2 3/2	3439.1	3439.1	5	
3/2 1/2	3559.6	3559.6	4	
5/2 1/2	3378.3	3376.6	2–3	Blend*
3/2 3/2	3627.1	3626.5	4	Blend†
a^2D -a^2G				
3/2 7/2	3223.3	3223.6	2	
5/2 9/2	3076.2	......	..	....‡
5/2 7/2	3073.9	......	..	....‡

* Blended with [*Fe* II] line of predicted wave length λ 3376.2.
† Blended with [*Fe* II] line of predicted wave length λ 3625.8.
‡ Region not covered by stellar spectroscopic observations.

TABLE II
ADDITIONAL PREDICTED LINES OF [*Ni* II]

Transition	Predicted λ	Transition	Predicted λ	Transition	Predicted λ
$a^2D - a^2F$		7/2 5/2	7256	3/2 3/2	5431.4
5/2 7/2	7378	7/2 3/2	6911.0	3/2 1/2	5281.5
5/2 5/2	6667.3	5/2 5/2	7695		
3/2 7/2	8302	5/2 3/2	7308	$a^4F - a^2G$	
3/2 5/2	7412	3/2 5/2	8034	9/2 9/2	4147.3
		3/2 3/2	7613	9/2 7/2	4143.2
$a^2D - b^2D$				7/2 9/2	4314.9
5/2 5/2	4326.5	$a^4F - a^4P$		7/2 7/2	4310.5
5/2 3/2	4201.4	9/2 5/2	6007.3	5/2 9/2	4466.3
3/2 5/2	4628.3	7/2 3/2	6467.5	5/2 7/2	4461.5
3/2 3/2	4485.4	7/2 5/2	6365.5	3/2 7/2	4573.5
		5/2 3/2	6813.7		
$a^2D - a^4P$		5/2 1/2	6791.6	$a^2F - a^2P$	
5/2 3/2	4033.2	5/2 5/2	6700.6	7/2 3/2	6441.4
5/2 1/2	4025.5	3/2 3/2	7078	5/2 3/2	7103
5/2 5/2	3993.3	3/2 1/2	7054	5/2 1/2	6848.6
3/2 3/2	4294.3	3/2 5/2	6956.3		
3/2 1/2	4285.5			$a^2F - a^2G$	
3/2 5/2	4249.1	$a^4F - a^2P$		7/2 9/2	5275.8
		7/2 3/2	5064.4	7/2 7/2	5269.2
$a^4F - b^2D$		5/2 3/2	5274.3	5/2 9/2	5711.5
9/2 5/2	6794.4	5/2 1/2	5132.8	5/2 7/2	5703.6

NOTES

Multiplet a^2D–b^2D. Faint lines have been observed in η Carinae* near λ 4326.5 and λ 4201.4. The author has also measured very faint emission lines at these wave lengths in B 1985 and WY Gem, but these observations alone would not be conclusive evidence of identification on account of the complexity of the spectra of these two stars, owing to the presence of a late-type companion.

Multiplet a^2D–a^4P. A fairly conspicuous emission line has been observed at λ 3993.1 in WY Gem and B 1985, and has been attributed† to [*Cr* II], $a^6S_{5/2}$–$b^4D_{7/2}$. Since no other transition of the [*Ni* II] multiplet can be definitely found in *Fe* II stars, the tentative identification of λ 3993.1 with [*Cr* II] may be provisionally maintained, pending further observations, but the possibility remains that the line may actually be due to [*Ni* II].

Multiplets a^4F–a^4P, a^4F–a^2G, a^2F–a^2P, a^2F–a^2G. Some coincidences with stellar lines exist, but are not sufficient to establish identification.

* See P. W. Merrill, *Ap. J.*, **67**, 391, 1928.

† Swings and Struve, *Ap. J.*, **91**, 600, 1940; **93**, 457, 1941.

The simultaneous presence of forbidden lines of *Fe* II and of *Ni* II in bright-line stars emphasizes the similar role played by certain lines of the *Fe* II and the *Ni* II ions in spectra of extended stellar atmospheres. Similarities have also been found in the behavior of certain absorption lines of *Fe* II and of *Ni* II in stellar shells. For some time stellar spectroscopists have been aware of the persistence of *Ni* II lines in such shells; this has recently been discussed in detail for HD 45910,[4] Pleione,[5] and 48 Librae.[6] It is known that in certain stars with gaseous shells (Z Canis Majoris, 17 Leporis, CD—27°11944, BD+47°3487, HD 160529, ...) the *Fe* II sextets (a^6S–z^6P^0, z^6F^0) sometimes exhibit strong violet absorption components whereas the quartets (b^4P–z^4D^0, z^4F^0; b^4F–z^4D^0, z^4F^0; a^4G–z^4F^0) appear in pure emission. The metastability of the lower terms of the observed *Ni* II lines resembles the metastability of the *Fe* II sextet a^6S, more closely than that of the *Fe* II quartets. From observations of 48 Librae it appears that *Ni* II may be at the top of its atmosphere; hence the dilution effects should be conspicuous if the *Ni* II atom has the proper distribution of energy levels. In the interpretation suggested here the persistence of the *Ni* II absorption lines in shells would be similar to the presence of absorption lines for the *Fe* II sextets when the *Fe* II atoms are in the proper conditions of dilution. In either case a field of dilute radiation would create abnormal overpopulations in the lower levels of the lines considered, as a result of the type of metastability and of the general distribution of the levels.

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[4] O. Struve, *Ap. J.*, **98**, 212, 1943.
[5] Struve and Swings, *Ap. J.*, **93**, 446, 1941; **97**, 426, 1943.
[6] Struve, *Ap. J.*, **98**, 98, 1943.