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ON THE MAGNETIC FIELD IN THE WHITE DWARF Grw +70°8247

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ABSTRACT

Greenstein has observed a sharp absorption feature near 1345 Å in the ultraviolet spectrum of the white dwarf Grw +70°8247. He interprets this as a component of hydrogen Lyα in a strong magnetic field, which he estimates to be in the region of 3.5×10^8 gauss. Using a very accurate multiparameter variational approach, we deduce that the maximum Lyα wavelength obtainable is 1342.6 Å (or slightly greater if one includes a gravitational redshift as well as a Stark-induced redshift), at which wavelength the magnetic field is 5.6×10^8 gauss, all other magnetic field values giving rise to smaller wavelengths. In addition, if we assume that the observations are uncertain by, say, ± 8 Å, then we deduce that the Lyα interpretation leads to a white dwarf magnetic field in the range $(4.0\text{–}7.6) \times 10^8$ gauss. Furthermore, we present a (perhaps less likely) alternative interpretation of the 1345 Å line, viz., that it is a component of Hα at 6.2×10^8 gauss or a component of Hβ at 4×10^8 gauss, or a combination of two other components of Hβ at 5×10^8 gauss.

Subject headings: line identification — magnetic fields — stars: white dwarfs

In a recent *Letter*, Greenstein (1984) discussed the ultraviolet spectrum of the white dwarf Grw +70°8247 (EG 129, 1900+70) which he obtained with the *International Ultraviolet Explorer*. In particular, the spectrum contains a sharp absorption feature near 1345 Å, which Greenstein interpreted as the σ_-, $1s0 \rightarrow 2p{-}1$ component of hydrogen Lyα in a strong magnetic field B and which he estimates to be in the region of 3.5×10^8 gauss. A more definitive number was not obtainable because of the lack of closely spaced and accurate theoretical numbers in this region. It is the purpose of this *Letter* to provide such numbers, as a result of which we deduce that the maximum Lyα wavelength obtainable is 1342.6 Å (or slightly greater if one includes a gravitational redshift as well as a Stark-induced redshift). At this wavelength the magnetic field is 5.6×10^8 gauss, all other magnetic field values giving rise to smaller wavelengths. In addition, if we assume that the observations are uncertain by, say, ± 8 Å, then we deduce that the Lyα interpretation leads to a white dwarf magnetic field in the range $(4.0\text{–}7.6) \times 10^8$ gauss. Furthermore, we present alternative interpretations of the 1345 Å line based on a consideration of Hα and Hβ components.

We use a very accurate multiparameter variational approach, as described in our original work along these lines (Smith *et al.* 1972), but now we also take into account the small correction due to the finite proton mass (O'Connell 1979 displays in eq. [7] the basic Hamiltonian which we use). As emphasized by Smith *et al.*, the only good quantum numbers are m (the z-component of the angular momentum) and parity Π, but it is useful to *label* the energy levels with the familiar nlm quantum numbers of the hydrogenic energy levels in the absence of a magnetic field. Even more concisely, we also refer to the energy levels as $E_0, E_1, E_2 \ldots$, in ascending order. Thus the σ_- transition referred to above is from the E_0 level ($m = 0$, $\Pi = 1$) to the E_1 level ($m = -1$, $\Pi = -1$). Since there is no linear Zeeman contribution to E_0, the quadratic Zeeman contribution causes E_0 to increase with increasing B for all B. On the other hand, E_1 decreases initially with increasing B as a result of the linear Zeeman term, but eventually the quadratic Zeeman term begins to dominate and E_1 then starts to increase with increasing B. Since, for a given B, the quadratic Zeeman contribution to E_1 is greater than the corresponding contribution to E_0 (since for E_1 the electron is farther from the nucleus), it is clear that there will be only one minimum in the $\Delta E \equiv E_1 - E_0$ versus B curve. In other words, the corresponding wavelength λ will have one maximum, λ_m say, at some magnetic field which we designate as B_m.

Our goal is to obtain the B value corresponding to Greenstein's (1984) observed Lyα wavelength of 1345 Å. Thus, in Table 1, we present results for E_1, E_0, ΔE, and λ corresponding to B field values ranging from 2.0×10^8 gauss to 8.0×10^8 gauss, with an emphasis on the region around $B = B_m$. We note that λ initially increases with increasing B and then starts to decrease, reaching a maximum $\lambda_m = 1342.6$ Å at a magnetic field value $B_m = 5.6 \times 10^8$ gauss. We emphasize the computational accuracy of these results, obtained by using at least enough variational parameters to assure convergence of the results. By contrast, a single variational parameter calculation, along the lines suggested by Rajagopal *et al.* (1972), which *a priori* might be thought to give reasonable results, only results in a λ_m value of the order of 1319 Å. It is also of interest to note that the finite proton mass effects associated with the presence of the B field result in contributions of approximately -0.5 Å to the λ values appearing in Table 1.

Are there any other effects which can bring the observational and theoretical values into even closer agreement? We estimate that relativistic effects are only about 10^{-5} times the dominant effect and hence are negligible. On the other hand, because the radius of Grw +70°8247 is abnormally small

TABLE 1

WAVELENGTHS OF THE σ_-; $1s0 \rightarrow 2p-1$ COMPONENT OF HYDROGEN LYMAN-ALPHA IN A STRONG MAGNETIC FIELD B[a]

B	$\|E_0\|$	$\|E_1\|$	ΔE	λ
2.0	0.9958726	0.2983152	0.6975574	1306.37
2.5	0.9938657	0.3024117	0.6914540	1317.90
3.0	0.9914437	0.3044796	0.6869641	1326.51
3.5	0.9886247	0.3049033	0.6837214	1332.80
4.0	0.9853941	0.3039543	0.6814398	1337.27
4.5	0.9817772	0.3018331	0.6799441	1340.21
5.0	0.9778464	0.2987513	0.6790951	1341.88
5.1	0.9769385	0.2979574	0.6789811	1342.11
5.2	0.9760947	0.2971981	0.6788966	1342.28
5.3	0.9752371	0.2964062	0.6788309	1342.41
5.4	0.9743450	0.2955627	0.6787823	1342.50
5.5	0.9734602	0.2947074	0.6787528	1342.56
5.6	0.9725401	0.2938005	0.6787396	1342.59
5.7	0.9716061	0.2928628	0.6787433	1342.58
5.8	0.9706807	0.2919176	0.6787631	1342.54
5.9	0.9697193	0.2909209	0.6787984	1342.47
6.0	0.9687671	0.2899195	0.6788476	1342.37
7.6	0.9515916	0.2703045	0.6812871	1337.57
8.0	0.9467927	0.2645084	0.6822843	1335.61

[a] The lowest and first-excited state energy levels are designated as E_0 and E_1 respectively, $E \equiv E_1 - E_0 = |E_0| - |E_1|$, and λ is the corresponding wavelength. All energies are in rydbergs, λ is in Å, and B is in units of 10^8 gauss.

(Greenstein and Oke 1982), the gravitational redshift is larger than usual and could result in a $\Delta\lambda \approx 0.4$ Å redshift at $\lambda \approx \lambda_m$. There may also be Stark-induced redshifts of a similar magnitude (Wiese and Kelleher 1971) which serve to bring the observational and theoretical numbers into even closer agreement. In the same context, we investigated the effects of screening by replacing the Coulomb potential by a screened Coulomb potential, along the lines carried out by Roussel and O'Connell (1974). Assuming a temperature T of 1.4×10^4 K (Greenstein and Oke 1982), we find that λ_m is increased from the unscreened result of 1342.59 Å to a value of 1342.62 Å at an electron density n of 10^{17} cm^{-3}. Since the Debye screening radius is proportional to $(T/n)^{1/2}$, we find that a decrease of (T/n) by a factor as large as 100 is necessary to bring λ_m to a value of 1345.72 Å.

We conclude that the maximum wavelength λ_m of the σ_-, $1s0 \rightarrow 2p-1$ component of hydrogen Lyα in a magnetic field is 1342.6 Å in the absence of gravitational or Stark-induced redshifts. This is close to the value of 1345 Å observed by Greenstein (1984), and the agreement is especially good since the observed value is subject to downward revision due to the gravitational redshift. Since the magnetic field corresponding to λ_m is 5.6×10^8 gauss, we conclude that this is the order of the magnetic field occurring in the white dwarf Grw + 70°8247. Of course, one should expect some variation of the magnetic field at the surface, but it is clear from Table 1 that the corresponding variation in the wavelength in the vicinity of the maximum wavelength is much less pronounced. In addition, there are observational uncertainties. Thus, if we assume that the observations are uncertain by, say, ±8 Å, then we deduce that the Lyα interpretation leads to a white dwarf magnetic field in the range $(4.0\text{–}7.6) \times 10^8$ gauss. We note that lower field values are favored if one interprets the continuum dip at higher wavelengths as being due to cyclotron absorption (Greenstein 1984); at 4.6×10^8 gauss, the cyclotron frequency is 1.29×10^{15} s^{-1} and thus $\lambda^{-1} = 4.3$ μm^{-1}, corresponding to a continuum dip displayed in the observed results (Greenstein and Oke 1982; Greenstein 1984).

Finally, we present an alternative interpretation of the 1345 Å line (based on an accurate multiparameter calculation for the $n = 3$ and $n = 4$ levels), viz., that it is the $2p1 \rightarrow 3d2$ component of Hα at 6.2×10^8 gauss or the $2p1 \rightarrow 4d1$ component of Hβ at 4×10^8 gauss, or a combination of the $2p0 \rightarrow 4d1$ and $2s0 \rightarrow 4p1$ components of Hβ at 5×10^8 gauss. However, $(\Delta\lambda/\lambda)$ changes rapidly with B for the Hα and Hβ components, making these possible explanations less likely than Lyα.

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