BREMSSTRAHLUNG MODEL OF POLARIZED RADIATION FROM MAGNETIC WHITE DWARFS

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Motivated by the desire to provide a model for the polarized radiation observed from some white dwarfs, we calculate the intensities of right and left circularly polarized bremsstrahlung radiation emitted by electrons in the atmospheres of magnetic white dwarfs.

A new and very fruitful method of detecting stellar magnetic fields was initiated by Kemp [1]. He predicted that the *continuous* spectrum of light from magnetic white dwarfs should exhibit a fractional circular polarization q, given by

$$q \equiv [P_+(\omega) - P_-(\omega)]/[P_+(\omega) + P_-(\omega)] \approx -(\Omega/\omega). \tag{1}$$

Hence $P_\pm(\omega)$ are the intensities of right and left circularly polarized light of angular frequency ω, and $\Omega = (eB/2\mu c)$ is the Larmor frequency, where B is the magnetic field. This has led to the discovery of magnetic fields $\approx (10^6 - 10^7)$G in at least four white dwarfs [2]. Nevertheless, Kemp's prediction [1] that $q \sim \lambda$ (wavelength) is at variance with observations and it soon became apparent [2] that a more physical model than Kemp's oscillator model [1] is required.

Bremsstrahlung in a magnetic field has been considered by many authors [3–7] but, unfortunately, with no obvious agreement in the final results. Thus, we have carried out the calculation ab initio. For white-dwarf atmospheres, the electrons are nonrelativistic and the effects of the medium are negligible. As with [7], we disagree with [5], but we also differ from [7] due to the fact that they used a free particle Green function whereas we used an exact function. Our results are consistent with those of [6]. In units $\hbar = c = \mu = 1$, the initial electron energy is

$$E = (p^2/2) + n\omega_c, \qquad n = 0, 1, 2, \ldots \tag{2}$$

where n denotes the Landau level, p the momentum along the magnetic field, and $\omega_c = 2\Omega$ is the cyclotron frequency. Corresponding quantities in the final state will be denoted by a prime. With $\beta \equiv (n, n', p)$ we obtain, for photon emission along B,

$$P_\pm(\omega,\beta) = \frac{\alpha^3 Z^2 n_i}{2^{5/2}\pi^2} \frac{Q_\pm(\omega,\beta)}{(E-\omega-n'\omega_c)^{1/2}}, \tag{3}$$

where α is the fine-structure constant, n_i is the number of ions per unit volume, Z is the atomic number,

$$Q_+(\omega,\beta) = \int_0^\infty \frac{dt}{(t+\lambda)^2} J_{n'n}, \tag{4}$$

$$Q_-(\omega,\beta) = \int_0^\infty \frac{dt}{(t+\lambda)^2} J_{nn'}, \tag{5}$$

$$\lambda = (2\omega_c)^{-1}\{p-[p^2+2\{(n-n')\omega_c-\omega\}]^{1/2}-\omega\}^2, \tag{6}$$

$$J_{n'n} = \{(n+1)^{1/2}\, I(n'n+1,t) + (n')^{1/2}\, I(n'-1,n,t)\} \tag{7}$$

and, as given in [6],

$$I(n,n',t) = (n!n'!)^{-1/2}\, e^{-t/2} \times t^{(n+n')/2}\, {}_2F_0(-n',-n;-t^{-1}) = I(n',n,t) \tag{8}$$

Except for a trivial factor of $(2/\pi)$, our results agree with those of [6], but are much different than the non-relativistic limits of the results of [7]. We now use these results as the basis of a model of the polarized radiation from magnetic white dwarfs. It follows that the fractional polarization is given by

$$q(\omega,\beta) = \{(Q_+ - Q)/(Q_+ + Q_-)\}. \tag{9}$$

We see that $q = 0$ when $n = n'$. If $\omega_c \approx kT$ ($T \approx 10^4$ K and $B \approx 10^8$ G), then only a small number of the lowest

Landau levels are occupied. For $\lambda \gg 1$, we get $q \approx 0$ for $n(n') = 0$ and $n'(n) = 1$. For $\lambda \ll 1$, we get $q \approx -1$ for $n(n') = 0$ and $n'(n) = 1$ i.e. only one type of circularly polarized radiation is emitted. If $kT \gg \omega_c$, we may use Boltzmann statistics, then integrate over p and sum over n, n' to get a $Q_{\pm}(\omega, T)$ and hence a $q(\omega, T)$. These operations will have to be performed numerically. Details will appear elsewhere.

References

[1] J.C. Kemp, Astrophys., J. 162 (1970) 169.
[2] R.F. O'Connell, Polarized radiation from magnetic white dwarfs, in Proc. Intern. Astronomical Union Symposium no. 53, Physics of dense matter, Boulder, Colorado, August 1972, eds. W. Brittin and C. Hansen (Reidel Publishers, 1973) gives a summary of observations and theoretical speculations.
[3] R. Goldman and L. Oster, Phys. Rev. 129 (1963) 1469; R. Goldman, Phys. Rev. 133 (1964) A647.
[4] R. Goldman and L. Oster, Phys. Rev. 136 (1964) A602, A606.
[5] V. Canuto, H.Y. Chiu and L. Fassio-Canuto, Phys. Rev. 185 (1969) 1607.
[6] V. Canuto and H.Y. Chiu, Phys. Rev. A2 (1970) 518.
[7] A. El-Gowhari and J. Arponen, Nuovo Cim. 11B (1972) 201.