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Lateral and Axial Magnetisation in the Inverse Faraday Effect for the Interaction of Waves in Plasma

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Abstract

We evaluate the static lateral magnetisation from the inverse Faraday effect, due to a circularly polarised electromagnetic wave and either a high frequency longitudinal dispersive plasma wave (case 1) or an ion acoustic wave (case 2), all propagating in the same direction in an unmagnetised plasma. These two lateral magnetisations are found to be in opposite directions. For the interaction of $1\cdot06\,\mu$m circularly polarised electromagnetic radiation having a power flux $5\times10^{16}\,\mathrm{W\,m^{-2}}$ and pulse width 5 ns in a plasma, in case 2 the induced transverse static magnetic field is about $0\cdot0014\,\mathrm{Wb\,m^{-2}}$. In case 1, this static field is about $0\cdot0234\,\mathrm{Wb\,m^{-2}}$. In a quiescent cesium plasma the magnetisation is found to be insignificant in both cases. These theoretical investigations may help in the understanding of anomalous diffusion of plasmas in some problems, and in the explanation of solar prominences and other such astrophysical effects.

1. Introduction

Magnetisation in the megagauss range, generated by fast electrons in the tail of the distribution, has been detected with high power lasers and discussed by Steiger and Woods (1972), Briand *et al.* (1985) and Chakraborty *et al.* (1986, 1988, 1990). An estimation of the Faraday rotation effect of back scattered radiation for the field has been reported by Briand *et al.* (1985). For strong high frequency electromagnetic (EM) waves the inverse Faraday effect (IFE) has been theoretically formulated and experimentally demonstrated in solids by Pershan (1963), Vander Ziel *et al.* (1965) and in plasmas by Steiger and Woods (1972), Pomeau and Quemada (1967), Deschamps *et al.* (1970) and Chian (1981). None of these earlier investigations, however, took into account the induced magnetisation due to the interaction of a circularly polarised wave with a plasma in the presence of either a high frequency longitudinal dispersive plasma wave (which can also be called an electron acoustic wave) (case 1) or an ion acoustic wave (case 2), all having the same direction of propagation. The induced field is of considerable magnitude in plasmas generated by an Nd–glass laser when incident on a target material.

The well-known IFE is the production of uniform magnetisation from circular motion of charges in different material media, including plasmas, in which a circularly polarised EM wave propagates. In general, this magnetisation is due to the ordered loop motion of charges in the presence of any type of wave field which a plasma can sustain. It occurs exclusively along the direction of wave propagation because it is the line of centres of this ordered

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motion. For EM waves this well-known induced magnetisation may be called the axial magnetisation of the IFE. A modification of this physical process occurs when we consider the additional influence of a longitudinal wave field along the direction of propagation of the EM wave. This longitudinal field is either the high frequency electron acoustic wave or an ion acoustic wave, and may be the coherent part of the local noise field or the field of the pressure wave generated in many types of plasma. In laser irradiated targets, the circularly polarised wave is the strong applied EM field. The ordered motion of charges, in the presence of a longitudinal wave, in addition to this transverse EM wave, is a distortion of the ordered circular motion which occurs if only the circularly polarised wave acts. As the trajectories of these loop motions are three-dimensional curves, the associated magnetic moments have components transverse to the direction of wave propagation. These components and, in particular, their static parts may be called the transverse or lateral magnetisation. These are in addition to the induced axial static magnetisation mentioned earlier. All these fields modify the profile of the ambient magnetic field, if that exists *a priori* in a plasma. In both cases, this axial magnetisation is same in magnitude. The lateral magnetisations in the two cases differ in phase by the angle π at the boundary initially, so these are in opposite directions there at that time. In other words, the resultant transverse field for the high frequency acoustic wave generally differs by the angle π with the resultant transverse field for the ion acoustic wave. Thus, their detection and comparison might be utilised for the diagnosis of plasmas.

We assume that $kT_e = kT_i = 0 \cdot 5$ keV, so that about one part in 10^{-7} of laser energy is converted to pressure wave energy for the electron acoustic wave and about $7 \cdot 34 \times 10^{-6}$ for the ion acoustic wave. The lateral magnetic field due to an ion acoustic wave is then (case 2) $0 \cdot 0014\ \mathrm{Wb\,m^{-2}}$ and to an electron acoustic wave (case 1) $0 \cdot 0234\ \mathrm{Wb\,m^{-2}}$, but in the opposite direction with respect to the former. In contrast the longitudinal induced field, in both cases, is $0 \cdot 00215\ \mathrm{Wb\,m^{-2}}$, for a circularly polarised wave of frequency $1 \cdot 78 \times 10^{15}\ \mathrm{rad\,s^{-1}}$ and power flux $\sim 10^{16}\ \mathrm{W\,m^{-2}}$. These are the parameters of the Nd–glass laser.

Solar prominences might be due to this type of evolving lateral magnetic field from the interaction of EM waves guided along the lines of force of surface magnetic fields with local longitudinal wave fields. Also, anomalous diffusion of plasmas in the presence of fields in plasma devices might be due to the evolution of such lateral magnetisation. Much further theoretical work is necessary to decide the plausibility of these preliminary claims.

In Section 2 we consider case 1: the induced magnetisation due to the interaction of a circularly polarised wave and an electron acoustic wave with plasma. In Section 3 we consider case 2: the induced magnetisation for the interaction of a circularly polarised wave and an ion acoustic wave with plasma. Our findings are summarised in Section 4.

2. Interaction of a Circularly Polarised EM Wave and an Electron Acoustic Wave with Plasma

We consider the plasma to be in a fluid state, fully ionised, unmagnetised, and having thermal motion providing a pressure perturbation. The ion motion may be neglected compared with that of electrons. The electrons of charge $-e$, mass m and number density N are assumed to move with velocity $\boldsymbol{u}$.

The appropriate set of linearised basic equations in SI units is

$$\dot{N}+N_0(\nabla.\boldsymbol{u}) = 0, \tag{1}$$

$$\dot{\boldsymbol{u}}+\frac{e}{m}\boldsymbol{E}+\frac{\nabla p}{mN_0} = 0, \tag{2}$$

$$\nabla\times\boldsymbol{E} = \mu_0\frac{\partial \boldsymbol{H}}{\partial t}, \tag{3}$$

$$\nabla\times\boldsymbol{H} = \epsilon_0\frac{\partial \boldsymbol{E}}{\partial t}+\boldsymbol{j}, \tag{4}$$

$$\nabla.\boldsymbol{E} = \frac{\rho}{\epsilon_0}, \tag{5}$$

$$\nabla.\boldsymbol{H} = 0, \tag{6}$$

where

$$\boldsymbol{j} = -N_0 e\boldsymbol{u}, \qquad \rho = -(N-N_0)e, \tag{7}$$

ϵ_0 and μ_0 are respectively the electrical permittivity and magnetic permeability of the vacuum, N_0 is the electron number density in the equilibrium state, while $\boldsymbol{E}$ and $\boldsymbol{H}$ are the electric and magnetic field vectors respectively.

For a circularly polarised wave, together with an electron acoustic wave, both propagating in the z-direction, the electric field vector is expressed in the form

$$\boldsymbol{E}=(a_\perp\cos\theta_\perp,\ a_\perp\sin\theta_\perp,\ a_\parallel\cos\theta_\parallel+b_\parallel\sin\theta_\parallel), \tag{8}$$

where

$$\theta_\perp=k_\perp z-\omega_\perp t, \qquad \theta_\parallel=k_\parallel z-\omega_{\parallel_{\mathrm{ea}}}t. \tag{9}$$

Here $a_\perp$ and $(a_\parallel, b_\parallel)$ represent the amplitudes of the electromagnetic wave and the electron acoustic wave respectively, while $k_\perp, k_\parallel$ and $\omega_\perp, \omega_{\parallel_{\mathrm{ea}}}$ represent the respective wave numbers and wave frequencies. These equations give the first order dispersive magnetic field:

$$\boldsymbol{H}=n_\perp\left(\frac{\epsilon_0}{\mu_0}\right)^{\frac{1}{2}}(-a_\perp\sin\theta_\perp,\ a_\perp\cos\theta_\perp,\ 0), \tag{10}$$

where $n_\perp = k_\perp/\omega_\perp(\epsilon_0\mu_0)^{\frac{1}{2}}$. The ordered motion of electrons, under the influence of the wave field (8), is given by

$$\boldsymbol{u}=\frac{1}{(\epsilon_0\mu_0)^{\frac{1}{2}}}\left(\alpha_{\perp_e}\sin\theta_\perp,\ -\alpha_{\perp_e}\cos\theta_\perp,\ \frac{1}{\chi_{\parallel_{\mathrm{ea}}}}(\alpha_{\parallel_{\mathrm{ea}}}\sin\theta_\parallel-\beta_{\parallel_{\mathrm{ea}}}\cos\theta_\parallel)\right). \tag{11}$$

The perturbed electron number density is

$$N_1=\frac{N_0}{\chi_{\parallel_{\mathrm{ea}}}}\frac{n_{\parallel_{\mathrm{ea}}}}{c_e(\epsilon_0\mu_0)^{\frac{1}{2}}}(\alpha_{\parallel_{\mathrm{ea}}}\sin\theta_\parallel-\beta_{\parallel_{\mathrm{ea}}}\cos\theta_\parallel), \tag{12}$$

where

$$(\alpha_{\|\mathrm{ea}}, \beta_{\|\mathrm{ea}}) = \frac{e(a_{\|}, b_{\|})}{m\omega_{\|\mathrm{ea}}(\epsilon_0 \mu_0)^{\frac{1}{2}}}, \qquad x_{\|\mathrm{ea}} = \frac{\omega_{\mathrm{pe}}^2}{\omega_{\|\mathrm{ea}}^2},$$
$$\alpha_{\perp_\mathrm{e}} = \frac{ea_\perp}{m\omega_\perp(\epsilon_0 \mu_0)^{\frac{1}{2}}}, \qquad n_{\|\mathrm{ea}} = \frac{k_\| c_\mathrm{e}}{\omega_{\|\mathrm{ea}}}, \qquad c_\mathrm{e}^2 = \frac{kT_\mathrm{e}}{m},$$
$$\omega_{\mathrm{pe}}^2 = \frac{N_0 e^2}{m\epsilon_0}, \qquad N = N_0 + N_1, \qquad x_\perp = \frac{\omega_{\mathrm{pe}}^2}{\omega_\perp^2}. \tag{13}$$

The linearised dispersion relations for the two waves are

$$n_\perp^2 = 1 - x_\perp, \tag{14}$$

$$n_{\|\mathrm{ea}}^2 = 1 - x_{\|\mathrm{ea}}. \tag{15}$$

The velocity profile of (11) approximately shows a spiralling motion with variable pitch, which is a three-dimensional oscillating curve. So, each electron, gyrating with this velocity, contributes a magnetic dipole moment $\boldsymbol{\mu}$ given by

$$\boldsymbol{\mu} = \tfrac{1}{2}(\boldsymbol{r} \times \boldsymbol{j}). \tag{16}$$

It has a nonzero static part in both longitudinal and transverse directions. Here $\boldsymbol{r}$ is the position vector of the electric charge q $(=-e)$ and $\boldsymbol{j}$ $(=q\boldsymbol{u})$ is its current. The evolved magnetic induction field, due to the orbital motion of electrons, is then

$$\boldsymbol{B}_\mathrm{i} = \frac{N\mu_0}{2}(\boldsymbol{r} \times \boldsymbol{j}). \tag{17}$$

The lateral component with respect to the direction of wave propagation has the static part

$$B_{\mathrm{ie}_\perp} = -\frac{Ne\delta_{\|\mathrm{ea}}\, \alpha_{\perp_\mathrm{e}}}{4\epsilon_0\, x_{\|\mathrm{ea}}\, \omega_\perp\, \omega_{\|\mathrm{ea}}}(\omega_\perp + \omega_{\|\mathrm{ea}}). \tag{18}$$

The corresponding static part of the axially evolved complementary magnetisation is

$$B_{\mathrm{ie}_\|} = \frac{Ne}{2\epsilon_0\, \omega_\perp}\alpha_{\perp_\mathrm{e}}^2. \tag{19}$$

where

$$\delta_{\|\mathrm{ea}} = (\alpha_{\|\mathrm{ea}}^2 + \beta_{\|\mathrm{ea}}^2)^{\frac{1}{2}}. \tag{20}$$

This field has been evaluated with the help of the relation

$$P_\| = p_\mathrm{e}\, u_z,$$

where $p_\mathrm{e} = mc_\mathrm{e}^2 N_1$, so that it can be reduced to

$$P_\| = \frac{mN_0\, c_\mathrm{e}\, n_{\|\mathrm{ea}}}{2x_{\|\mathrm{ea}}^2\, \epsilon_0\, \mu_0}\delta_{\|\mathrm{ea}}^2,$$

where $P_{\|}$ $(= W_p V/A\tau)$ is the longitudinal energy flux, $W_P = \frac{5}{2}(2+1/z)N_0 kT_e$ is the potential energy density, ze is the effective ion charge of the target, A and V are the area and volume of the pellet respectively and τ is the pulse width of the incident laser beam.

Numerical Estimation

Consider the laser plasma interaction for an Nd–glass laser ($\lambda = 1\cdot06\ \mu$m, $P_\perp = 5{\times}10^{16}$ W m^{-2}, $\omega_\perp = 1\cdot78{\times}10^{15}$ rad s^{-1}, $\tau = 5$ ns and spot radius $R = 30\ \mu$m). An electron acoustic wave of frequency 10^{15} rad s^{-1} interacts with the plasma at the density $N_0 = 25{\times}10^{25}$ m^{-3}, where $x_{\|ea} = 0\cdot795$ and $\delta_{\|ea} = 0\cdot0084$. We assume that $kT_e = kT_i = 0\cdot5$ keV. So, about one part in 10^{-7} of laser energy is converted into pressure wave energy for the electron acoustic wave. Then the static part of the induced lateral field is approximately $0\cdot0234$ Wb m^{-2} and the corresponding longitudinal field is nearly $0\cdot00215$ Wb m^{-2}.

3. Interaction of a Circularly Polarised EM Wave and an Ion Acoustic Wave with Plasma

For the existence of an ion acoustic wave the additional assumptions are (i) electrons and ions are both mobile and their velocities are comparable and (ii) the number densities of electrons and ions are nearly equal. The linearised set of basic equations, in addition to (3)–(6), is

$$\dot{N}_e + N_0(\nabla . \boldsymbol{u}_e) = 0, \tag{21}$$

$$\dot{N}_i + N_0(\nabla . \boldsymbol{u}_i) = 0, \tag{22}$$

$$\dot{\boldsymbol{u}}_e + \frac{e}{m_e}\boldsymbol{E} + \frac{\nabla p_e}{m_e N_0} = 0, \tag{23}$$

$$\dot{\boldsymbol{u}}_i - \frac{e}{m_i}\boldsymbol{E} + \frac{\nabla p_i}{m_i N_0} = 0, \tag{24}$$

where

$$\begin{aligned} N_e &= N_0 + N_{1e}, & N_i &= N_0 + N_{1i}, \\ p_e &= N_e kT_e, & p_i &= N_i kT_i, \\ \boldsymbol{j} &= Ne(\boldsymbol{u}_i - \boldsymbol{u}_e), & \rho &= (N_i - N_e)e. \end{aligned} \tag{25}$$

The electric field is the same as (8), but this time

$$\theta_{\|} = k_{\|} z - \omega_{\|ia} t,$$

where $\omega_{\|ia}$ is the frequency of the ion acoustic wave. Substituting this electric field in (3) we recover the first order excited magnetic field (10). Electrons and ions acquire the velocities $\boldsymbol{u}_e, \boldsymbol{u}_i$ respectively, given by

$$\boldsymbol{u}_{\mathrm{e}} = \frac{1}{(\epsilon_0 \mu_0)^{\frac{1}{2}}}\left(\alpha_{\perp_{\mathrm{e}}} \sin\theta_\perp, -\alpha_{\perp_{\mathrm{e}}} \cos\theta_\perp, \right.$$
$$\left. \frac{c_s^2}{c_s^2 - c_e^2}(\alpha_{\|_{\mathrm{e}}} \sin\theta_\| - \beta_{\|_{\mathrm{e}}} \cos\theta_\|)\right), \tag{26}$$

$$\boldsymbol{u}_{\mathrm{i}} = \frac{1}{(\epsilon_0 \mu_0)^{\frac{1}{2}}}\left(-\alpha_{\perp_{\mathrm{i}}} \sin\theta_\perp, \alpha_{\perp_{\mathrm{i}}} \cos\theta_\perp, \right.$$
$$\left. \frac{c_s^2}{c_i^2 - c_s^2}(\alpha_{\|_{\mathrm{i}}} \sin\theta_\| - \beta_{\|_{\mathrm{i}}} \cos\theta_\|)\right), \tag{27}$$

where

$$\alpha_{\perp_{\mathrm{e}}} = \frac{e a_\perp (\epsilon_0 \mu_0)^{\frac{1}{2}}}{m_e \omega_\perp}, \qquad \alpha_{\perp_{\mathrm{i}}} = \frac{e a_\perp (\epsilon_0 \mu_0)^{\frac{1}{2}}}{m_i \omega_\perp},$$

$$(\alpha_{\|_{\mathrm{e}}}, \beta_{\|_{\mathrm{e}}}) = \frac{e(a_\|, b_\|)(\epsilon_0 \mu_0)^{\frac{1}{2}}}{m_e \omega_{\|\mathrm{ia}}}, \qquad (\alpha_{\|_{\mathrm{i}}}, \beta_{\|_{\mathrm{i}}}) = \frac{e(a_\|, b_\|)(\epsilon_0 \mu_0)^{\frac{1}{2}}}{m_i \omega_{\|\mathrm{ia}}},$$

$$c_e^2 = \frac{kT_e}{m_e}, \quad c_i^2 = \frac{kT_i}{m_i}, \quad c_s^2 = \frac{kT_e}{m_i} + \frac{kT_i}{m_i}. \tag{28}$$

The linearised dispersion relation for the ion acoustic wave approximation is

$$k_\|^2 c_s^2 = \omega_{\|\mathrm{ia}}^2. \tag{29}$$

As the magnetic dipole moment for the αth species of charges is

$$\boldsymbol{\mu}_\alpha = \tfrac{1}{2}(\boldsymbol{r}_\alpha \times \boldsymbol{j}_\alpha), \tag{30}$$

where for the two-component plasma $\alpha = (\mathrm{e}, \mathrm{i})$, the expression for the induced magnetic field due to the orbital motion of the electrons and ions is

$$\boldsymbol{B} = \mu_0(N_i \boldsymbol{\mu}_i + N_e \boldsymbol{\mu}_e). \tag{31}$$

Since $N_i \approx N_e \approx N_0$, by using (26)–(31) the expression for the static part of the induced lateral magnetic field is found to be

$$B_{\mathrm{ii}_\perp} = \frac{Ne(\omega_\perp + \omega_{\|\mathrm{ia}})}{2\epsilon_0 \omega_\perp \omega_{\|\mathrm{ia}}}\left(\frac{c_s^2}{c_e^2 - c_s^2}\delta_{\|_{\mathrm{e}}} \alpha_{\perp_{\mathrm{e}}} + \frac{c_s^2}{c_s^2 - c_i^2}\delta_{\|_{\mathrm{i}}} \alpha_{\perp_{\mathrm{i}}}\right). \tag{32}$$

The corresponding axially evolved static magnetic field is

$$B_{\mathrm{ii}_\|} = \frac{N_0 e}{\omega_\perp \epsilon_0}(\alpha_{\perp_{\mathrm{e}}}^2 - \alpha_{\perp_{\mathrm{i}}}^2), \tag{33}$$

where

$$\delta_{\|_{\mathrm{e}}} = (\alpha_{\|_{\mathrm{e}}}^2 + \beta_{\|_{\mathrm{e}}}^2)^{\frac{1}{2}}, \qquad \delta_{\|_{\mathrm{i}}} = (\alpha_{\|_{\mathrm{i}}}^2 + \beta_{\|_{\mathrm{i}}}^2)^{\frac{1}{2}}. \tag{34}$$

Relation (33) shows that the direction of the axial magnetic field for ion motion only is opposite to that of the axial magnetic field generated due to electron motion.

Since $m_i \gg m_e$ we find that $\alpha_{\perp_i} \ll \alpha_{\perp_e}$, and consequently

$$B_{ii_{\|}} = \frac{N_0\, e}{\omega_\perp\, \epsilon_0}\, \alpha_{\perp_e}^2 . \tag{35}$$

Hence the net $B_{ii_{\|}}$, like $B_{ie_{\|}}$ of (19), lies along the common direction of propagation of all the waves. Using the same approximation

$$\frac{c_s^2\, \delta_{\|_e}}{(c_e^2 - c_s^2)\omega_{\|_{ia}}^2} \approx \frac{c_s^2\, \delta_{\|_i}}{(c_s^2 - c_i^2)\omega_{\|_{ia}}^2}, \tag{36}$$

we find that (32) reduces to

$$B_{ii_\perp} = \frac{N e\, \delta_{\|_i}\, \alpha_{\perp_e}}{\epsilon_0\, \omega_\perp\, \omega_{\|_{ia}}}(\omega_\perp + \omega_{\|_{ia}}). \tag{37}$$

Here the expression for $\delta_{\|_i}$ is obtained from

$$P_\| = p_e\, u_{ez} + p_i\, u_{iz}, \tag{38}$$

with

$$p_e = m_e\, c_e^2\, N_e, \qquad p_i = m_i\, c_i^2\, N_i,$$

$$N_i \approx N_e \approx \frac{N_0\, \omega_{\|_{ia}}}{k_\| (c_s^2 - c_e^2)(\epsilon_0\, \mu_0)^{\frac{1}{2}}}(\alpha_{\|_e} \sin\theta_\| - \beta_{\|_e} \cos\theta_\|). \tag{39}$$

Hence we have

$$P_\| = \frac{2e^2 N_0\, d_\|^2}{m_i\, k_\|\, \omega_{\|_{ia}}}, \tag{40}$$

where $d_\|^2 = a_\|^2 + b_\|^2$ and $\delta_{\|_i} = e d_\| (\epsilon_0\, \mu_0)^{\frac{1}{2}} / m_i\, \omega_{\|_{ia}}$, while $P_\|$ $(= W_p\, V/A\tau)$ is the longitudinal energy flux; the other quantities are the same as in Section 2.

Numerical Estimation

With the laser parameters of Section 2 the numerical value of the induced lateral magnetic field is found to be approximately $0 \cdot 0014\ \mathrm{Wb\,m^{-2}}$ when an ion acoustic wave, with frequency $10^{13}\ \mathrm{rad\,s^{-1}}$ and $\delta_{\|_i} = 3 \cdot 06 \times 10^{-4}$, interacts with a plasma of density $N = 25 \times 10^{25}$ particles per m^3 and the Nd laser field. The induced magnetic field has also been calculated numerically in a quiescent cesium plasma having an electron concentration $N = 5 \times 10^{15}$ particles per m^3. Due to the interaction of a circularly polarised EM wave ($a_\perp = 10\ \mathrm{V\,m^{-1}}$, $\omega_\perp = 0 \cdot 8 \times 10^{10}\ \mathrm{rad\,s^{-1}}$) and an ion acoustic wave ($a_\| = 5\ \mathrm{V\,m^{-1}}$, $\omega_{\|_{ia}} = 0 \cdot 6 \times 10^5\ \mathrm{rad\,s^{-1}}$), this field is approximately $0 \cdot 165 \times 10^{-12}\ \mathrm{Wb\,m^{-2}}$. Hence, for electron acoustic waves, the field is $0 \cdot 02$ times that for ion acoustic waves. The induced longitudinal field in both cases is therefore negligible.

4. Conclusions

Axial and transverse magnetic fields, both static, are generated in the presence of a circularly polarised EM wave and either an electron acoustic wave or an ion acoustic wave in plasma. These effects might be helpful in the explanation of the magnetic field generated in a laser produced plasma and of the anomalous diffusion of plasma in the presence of wave fields. The resultant induced lateral field makes an angle $\theta_{\perp}-\theta_{\parallel}+\tan^{-1}(b_{\parallel}/a_{\parallel})$ for the electron acoustic wave and $\pi+\theta_{\perp}-\theta_{\parallel}+\tan^{-1}(b_{\parallel}/a_{\parallel})$ for the ion acoustic wave. Thus, phases of the magnetisations in the two cases differ by the angle π. For the Nd–glass laser field this lateral magnetisation is $0\cdot0014\ \mathrm{Wb\,m^{-2}}$ in the case of an ion acoustic wave and $0\cdot0234\ \mathrm{Wb\,m^{-2}}$ in the case of an electron acoustic wave, but in the opposite direction to that of the former. In a quiescent cesium plasma the magnetisation is negligible.

Since the relevant factors involving the plasma and wave parameters for $B_{\mathrm{ie}_{\perp}}$ and $B_{\mathrm{ii}_{\perp}}$ are $N\alpha_{\perp_e}\,\delta_{\parallel_{ea}}/\omega_{\parallel_{ea}}\,x_{\parallel_{ea}}$ and $N\alpha_{\perp_e}\,\delta_{\parallel_{ia}}/\omega_{\parallel_{ia}}$ respectively, the magnetisation for electron acoustic waves is independent of the electron number density and varies directly with the wave field amplitudes, but inversely to the transverse wave frequency. On the other hand, for ion acoustic waves the magnetisation is found to be directly proportional to both the electron number density and the field amplitudes, and inversely proportional to the frequencies of both transverse and longitudinal wave fields. Also, it increases towards the denser regions.

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