Ann. Geophys. Discuss.,
https://doi.org/10.5194/angeo-2019-86-RC1, 2019

Annales Geophysicae
Discussions

Interactive comment on "Mirror mode physics: Amplitude limit" *by* Rudolf A. Treumann and Wolfgang Baumjohann

Anonymous Referee #1

Received and published: 11 August 2019

In the manuscript, the authors construct a theory for the mirror mode as an application of the electron pairing mechanism at a spatial scale of around the Debye screening length in the presence of ion-acoustic waves. The theory predicts that the magnetic field within the mirror mode structure (or magnetic bottle) decreases at most by about 50%, which successfully explains the observations of the mirror mode structures in the Earth magnetosheath region.

This is an interesting manuscript, since the achievement in the manuscript can be summarized or oriented in two ways. The manuscript offers a nonlinear (large-amplitude) treatment of the mirror mode (motivating the plasma instability community and space plasma observation community); the manuscript demonstrates an application of the electron paring around the Debye scale in the spirit of the analogy to the celebrated

BCS theory for superconductivity.

The manuscript follows the earlier works by the authors themselves. The electron paring by over-screening in the presence of waves was studied in more detail by Treumann and Baumjohann (Ann. Geophys., 32, 975, 2014) by revisiting the pioneering works by Neufeld and Ritchie (1955) and Nambu and Akama (1985). Later on, the picture of mirror mode as an analogue to superconductivity is more clearly presented in Treumann and Baumjohann (Ann. Geophys., 36, 1015, 2018). The construction of the theory in the manuscript indeed reminds me of the BCS theory: paring the electrons (wake potential in sec. 3, two-electron potential in sec. 4), macroscopic effect by applying to the mirror mode structure (sec. 5).

The manuscript is worth for publication for various reasons. First, the manuscript deals with the Debye-scale physics, which is one of the frontiers in space plasma physics. Second, the manuscript advances our understanding of the mirror mode physics from the linear regime (small-amplitude) to the nonlinear regime (large-amplitude). Third, the manuscript bridges the gap between space plasma physics with the other branches of physics (in particular, superconductivity and phase transition). I raise some questions and comments in the following, and hope that the questions are solved before the publication.

Major comment

* I agree with most of the parts in the constructed theory. The major question I have is that if the paired electrons develop into a coherent motion in the manner of Bose-Einstein condensation (in the BCS theory) to produce a substantial amount of diamagnetic current and expel the magnetic field out of the magnetic bottle. I am under the impression, after reading section 5.2 and 5.3 many times, that the electron pairs can be incoherent from one pair to another, so not in the gyro-phase bunched fashion. Just a sufficiently large number of electron pairs must exist in the mirror mode structure. Could the authors comment on the coherence among the electron pairs?

Minor comments

* Another question I have is if the proposed theory is really meant for the mirror mode, or if the theory is also applicable to the magnetic holes observed, for example, in the solar wind. Magnetic holes or decreases differ from the mirror mode in that the structures are isolated and can appear in a solitary way in the magnetic holes, while the mirror mode is a plasma instability and is spatially periodic characterized by the wavenumber or wavevector (typically for the maximum growth rate).

* The number of the participating electrons (or electron pairs) to the diamagnetic current is estimated by the parameter alpha in the manuscript as N_pair = alpha N (line after Eq. 58 on page 19). I wonder if one could make use of the London penetration depth, lambda_L, (e.g., Kittel, Charles (2004). Introduction to Solid State Physics. John Wiley & Sons. pp. 273–278) to estimate or double-check the electron-pair number density from the magnetic field profile.

* How was Equation (7) derived? I understand the geometrical condition (equation at line 109), but the concept of temperature (or thermal energy because the Boltzmann constant is set to unity in the manuscript) comes abruptly in Eq. (7). I think some more explanation should be added as how the derivation of Eq. (7).

* Here are some comments about the language editing.

- page 2, line 58, "a combination of a classical plasma ion effect" with what?

- page 3, line 61, I am not a native English speaker, but I think "It are..." should read "It is ..." even though the essential subject is in plural, "electrons".

- page 3, line 78, "Instability..." should read "This instability..."

- page 6, line 170, "wave length" should read "wavelengths".

- page 6, line 173, "independent on" should read "independently of" or "independently from".

- page 7, line 203, "over-screening", I suggest to refer to Fig. 1 in Treumann and Baumjohann (2014) for the concept of over-screening outside the Debye sphere in the presence of acoustic waves.

- page 8, line 231, "at the contrary" should read "on the contrary".

- page 8, line 239, "consist" should read "consists".

- page 9, line 255, the question mark after "Bessel functions" should be resolved.

- page 9, line 264, "nominator", do the authors perhaps mean "numerator"?

- page 10, line 277, "sinus function" should read "sine function".

- page 10, line 282, "sinus function" should read "sine function".

- page 13, line 380, "at the contrary" should read "on the contrary".

- page 15, line 419, "an extended plasma" should read "a spatially extended plasma".

- page 15, line 427, "we need to now" should read "we need to know".

- page 15, line 428, "be tween" should read "between".

- page 18, line 511, "personal" should read "individual".

Interactive comment on Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2019-86, 2019.