MOTION OF STATIONARY ION-SOUND WAVES

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Abstract: This work describes ion-acoustic waves and their types. In particular, the motion of stationary ion-sound waves, the equation of state and operations performed on them are studied.

Key words: ion-acoustic wave, plasma, electron emission.

Lengmyur to'lqinlaridan farqli o'laroq, ion-akustik to'lqinlar ionlarning sekin harakatlari bilan bog'liq. Bu holda xarakterli chastotalar ion plazma chastotasi ω_i $(\omega_i \ll \omega_e)$ dan oshmaydi. Bunday holda, elektron inersiyani e'tiborsiz qoldirish mumkin, ya'ni potensial o'zgarganda, ularning konsentratsiyasi bir zumda o'zgarishini hisobga olish kerak. U holda Boltsman taqsimoti

$$\rho_e = \rho_0 exp\left(\frac{e\varphi}{k_B T_e}\right)$$

elektron zaryad zichligi uchun amal qiladi, bunda k_B Boltsman doimiysi, T_e elektronning harorati. Shunday qilib, ion-akustik to'lqinlarni tavsiflovchi tenglamalar tizimi harakat tenglamasi

$$v_t + v v_x = -\frac{e}{M}\varphi_x, \qquad (1)$$

uzluksizlik tenglamasi

$$\rho_t + (\rho v)_x = 0 \qquad (2)$$

va Puasson tenglamasidan iborat bo'lib, endi u

$$\varphi_{xx} = \frac{1}{\varepsilon_0}\left(\rho_0 exp\left(\frac{e\varphi}{k_B T_e}\right) - \rho\right) \qquad (3)$$

ko'rinishni oladi. Bu yerda v, ρ va M mos ravishda ionlarning tezligini, zaryad zichligini va massasini bildiradi.

Ion-akustik to'lqinlar elektronlar konsentratsiyasi taxminan ionlar konsentratsiyasiga teng deb taxmin qilingan, bu bizga

$$(\omega - k v_0)^2 = \frac{\omega_e^2 k^2}{k^2 + k_\perp^2}$$

tenglamaning chap tomoni nolga teng deb taxmin qilish imkonini berdi; ikkinchisi dispersiyani e'tiborsiz qoldirishga teng. Shuning uchun oddiy to'lqinlar ko'rinishidagi yechimlarga ega bo'lgan giperbolik tenglamalar tizimi olindi. Endi dispersiyani hisobga olgan holda ion-akustik to'lqinlarni o'rganamiz va yakka to'lqinlarning mavjudligi mumkinligini ko'rsatamiz.

Statsionar to‘lqinlarga o‘tib va (1), (2) tenglamalarni integrallab,

$$\frac{(v-U)^2}{2}+\frac{e\varphi}{M}=\frac{U^2}{2},$$

$$\rho=\frac{\rho_0 U}{U-v}.$$

tenglamani topamiz. Bu ifodalarni (3) Puasson tenglamasiga qo‘yib, chiziqli bo‘lmagan osilator

$$\varphi''=\frac{\rho_0}{\varepsilon_0}\left(exp\left(\frac{e\varphi}{k_B T_e}\right)-\frac{U}{\sqrt{U^2-2e\varphi/M}}\rho\right)$$

tenglamasini olamiz. Bu yerda $\bar{v}=\frac{v}{U}, \bar{\rho}=\frac{\rho}{\rho_0}, \bar{\varphi}=\frac{e\varphi}{MU^2}, \bar{\xi}=\omega_i\xi/U$ ni o’lchamsiz o’zgaruvchilar bilan belgilab, biz quyidagiga erishamiz (o’lchamsiz o’zgaruvchilarni ustki chiziq bilan belgilaymiz):

$$\varphi''=exp(M^2\varphi)-\frac{1}{\sqrt{1-2\varphi}}. \qquad (4)$$

Bu holda Mah soni quyidagicha kiritiladi:

$$M=\frac{U}{c_s},$$

Bu yerda $c_s=\sqrt{k_B T_e/M}$-ion tovush tezligi. Ossilyator (4) ning potensial energiyasi quyidagiga teng

$$W=1-\sqrt{1-2\varphi}-\frac{\exp(M^2\varphi)-1}{M^2}. \qquad (5)$$

Integrallash konstantasi $W(0)=0$ bo'lishi uchun tanlanadi. (4) va (5) tenglamalar

$$\varphi<\frac{1}{2}$$

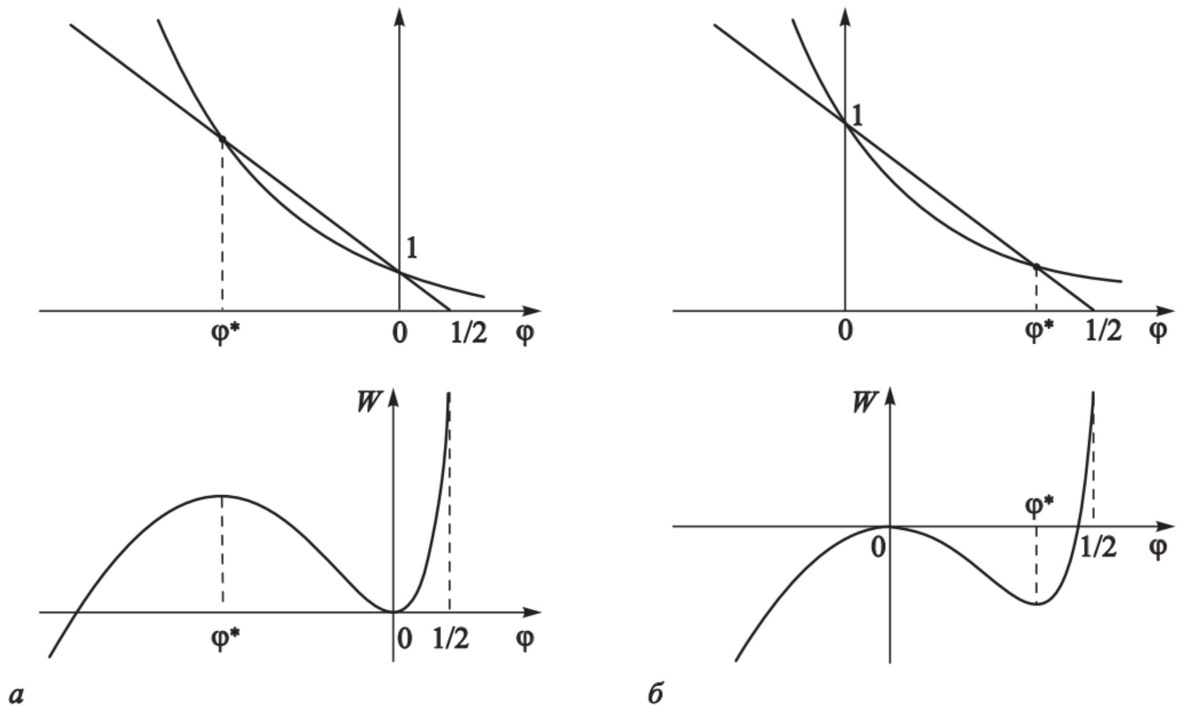
tengsizlikni qanoatlantirishi kerakligini bildiradi.

Keling, potensial energiya (5) ifodaning tuzilishini batafsil qaraymiz. Muvozanat holatlari $W(\varphi)$ funksiyaning ekstremum shartidan aniqlanadi va

$$1-2\varphi=\exp(-2M^2\varphi) \qquad (6)$$

tenglamadan topiladi.

Olingan tenglamaning yechimlaridan biri aniq: $\varphi=0$. $\varphi=0$ nuqtada (6) tenglamaning chap va o‘ng tomonidagi funksiyalarning hosilalari mos ravishda −2 va $-2M^2$ ga teng. Binobarin, M<1 uchun bu funksiyalarning grafiklari qandaydir $\varphi^*<0$ nuqtada, M>1 uchun esa $\varphi^*>0$ nuqtada kesishadi. (6) tenglamaning grafik yechimlari va potensial quduqning mos shakllari 1-rasmda ko'rsatilgan.



1-rasm. M<1(a) va M>1(b) uchun (6) tenglama yechimi grafigi (yuqori) va potensial energiyaga mos keladigan (pastki) chizmalarining grafigi.

Bu yerda kosmik zaryad to'lqinlari ko'rib chiqiladi. Ikkala holatda ham fazali portret egarning ajratilishini o'z ichiga oladi, shuning uchun yolg'iz to'lqinlar ko'rinishidagi yechimlar mavjud bo’lishi mumkin. Biroq, M > 1 bo'lgan holatdagina bu yechimlar chegara shartlarini qanoatlantiradi, ya'ni o'zgaruvchilarning qiymatlari $\xi\to\pm\infty$ kabi buzilmagan holatga moyil bo'ladi.

Shunday qilib, yana bir xulosaga kelish mumkin: yakka to'lqinlar chiziqli to'lqinlarga qaraganda tezroq tarqaladi (chiziqli nazariyadan quyidagicha, $v_{ph} \leq c_s$). M<1 holati davriy statsionar to'lqinlarga mos keladi, bunda osilator muvozanat holati $\varphi = 0$ atrofida tebranadi.

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