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INFLUENCE OF THE RADIAL COMPONENT OF THE DISCHARGE CURRENT ON THE ROTATION OF DUST STRUCTURES IN A GLOW DISCHARGE IN AN AXIAL MAGNETIC FIELD

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Introduction

Two types of **dust particle traps** in a stratified dc discharge:

1) in striation head
2) in dielectric insert narrowing the current channel for discharge stabilization

Two types of dust particle **rotation mechanisms:**

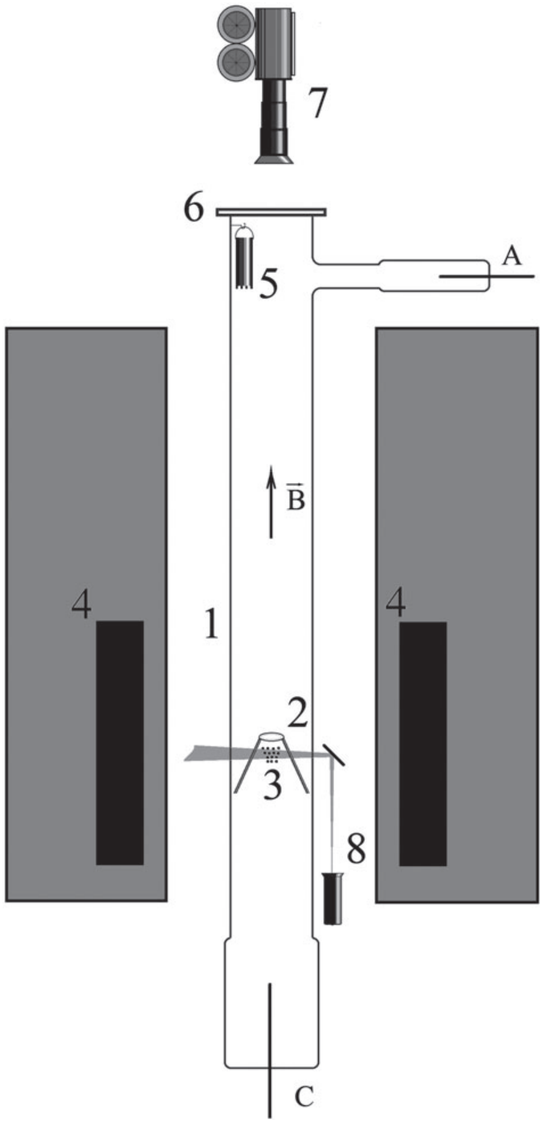
1) ion drag
2) gas drag, if $\mathbf{j}\times\mathbf{B} \neq 0$

We compare **the effect of these mechanisms** in two types of traps:

1) in the area of the current channel narrowing;
2) in a striation.

We propose a mechanism of fast rotation of dust structures in dielectric insert

Experimental setup

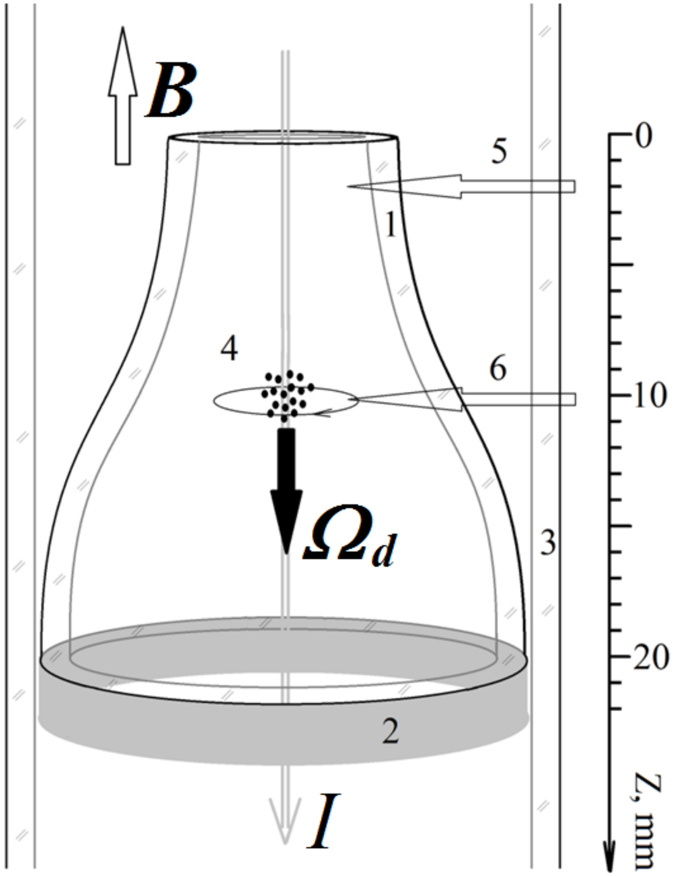


Scheme of the setup

1—discharge tube;
2—dielectric insert;
3—dust structure;
4—superconducting solenoid;
5—container with particles;
6—interference filter;
7—video camera;
8—laser illumination system
A—anode
C—cathode
B—magnetic field

Discharge tube radius $R \cong 1$ cm
Neon, $p = 0.4$ Torr $I \sim 2$ mA
quartz particles with a radius $a \sim 1$ μm
$B \leq 2$ T

Trap in a dielectric insert where the current channel narrows



1 – glass insert (upper inner diameter 5 mm)
2 – PTFE spring holding the insert in the tube
3 – discharge tube (inner diameter 19 mm)
4 – dust cloud
5 – dust cloud position at $B < 0.15$ T
6 – dust cloud position at $B > 0.2$ T

Rotation under action of the ion drag force

The ion rotation is the result of

1) the ion **drift in the crossing magnetic B** and **radial ambipolar electric E** fields and
2) gradient of ion pressure (diamagnetic ion current):

$$\mathbf{u}_i = \frac{\dfrac{e}{|\mathbf{B}|}[\mathbf{E}\times\mathbf{B}] + \dfrac{1}{n_i|\mathbf{B}|}[\mathbf{B}\times\nabla(n_i T_i)]}{m_i\omega_{iB}(1+\nu_{ia}^2/4\omega_{iB}^2)},$$

where $\boldsymbol{\omega}_{\mathbf{iB}}$ is the ion **cyclotron frequency**, ν_{ia} is the ion-atom collision frequency.

The uniform rotation of dust particles is the result of the balance of the ion drag and neutral atom gas forces. As a result we have the dust particle velocity as

$$u_d(r) \cong \frac{1}{4} z_d^2 \tau^2 \frac{n_i}{n_a} u_i(r), \qquad z_d = \frac{|Z_d|e^2}{aT_e} = 2-3, \qquad \tau = \frac{T_e}{T_i} \sim 10^2$$

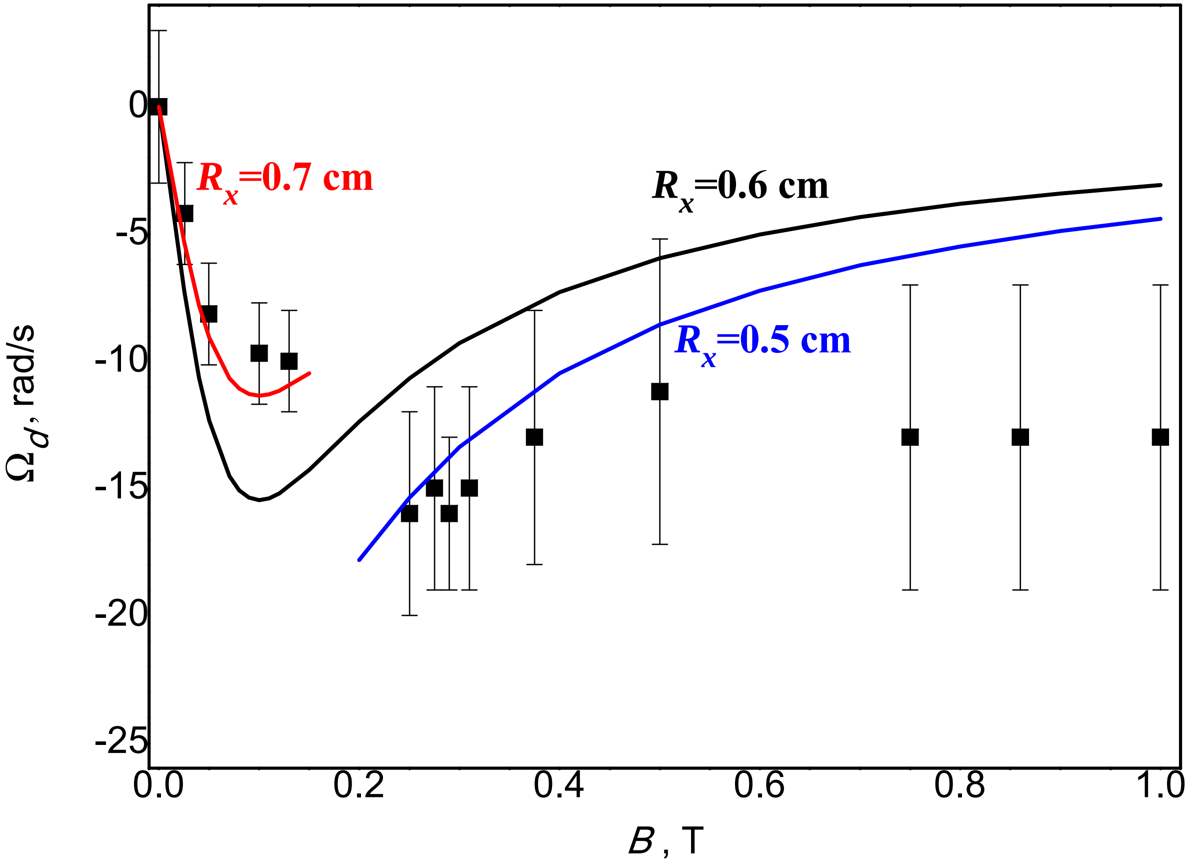
Angular velocity of dust particles

$$\Omega_d^{(1)} = \frac{u_d(r)}{r} \cong -\frac{2.9 n_i(0)}{R_x^2 n_a} \frac{T_e z_d^2 \tau^2 \nu_{ea} \omega_{iB}}{m_i \nu_{ea}(\nu_{ia}^2 + 4\omega_{iB}^2) + 2m_e \nu_{ia}(\nu_{ea}^2 + \omega_{eB}^2)}$$

Formally, R_x is the radius of the current channel.

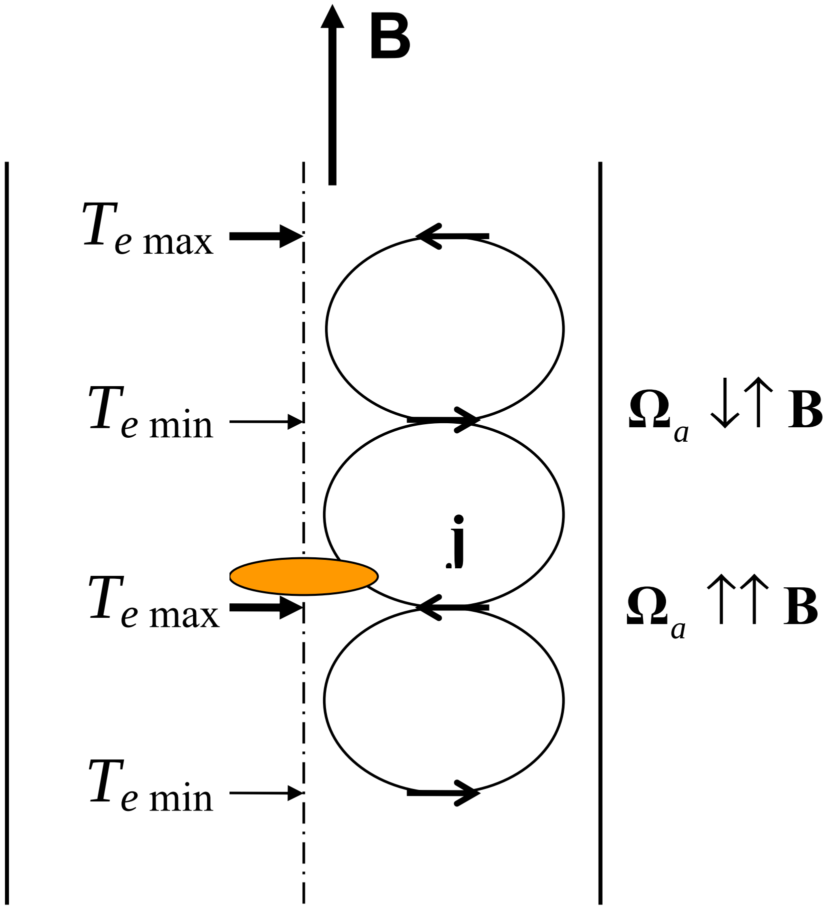
E S Dzlieva, L G D'yachkov, L A Novikov, S I Pavlov and V Yu Karasev.
Fast rotation of dust particle structures in dc glow discharge in a strong magnetic field.
Plasma Sources Sci. Technol. 2019. V. 28. 085020

Ne p = 0.4 Torr, I = 1.5 mA



Trap in a striation

In relatively strong magnetic fields $\boldsymbol{B} \gtrsim 0.1$ T, the main mechanism of dust particles rotation is the neutral gas drag. The gas rotates under the action of eddy currents arising in the stratum due to the crossing of the temperature and electron density gradients.



$$b_e \nabla n_e \times \nabla T_e = -\mathrm{rot}\,\mathbf{j}$$

$b_{ez} = e / m_e \nu_{ea}$ is the electron mobility

$$\eta \frac{\partial^2 \mathbf{u}_\varphi}{\partial r^2} + \mathbf{j} \times \mathbf{B} = 0$$

η is the gas-dynamic viscosity

Nedospasov A V 2013 *Europhys. Lett.* **103** 25001
Tsendin L D 1971 *Sov. Phys.—Tech. Phys.* **15** 1245

Expanding Current Channel

$$\eta \frac{\partial^2 \mathbf{u}_\varphi}{\partial r^2} + \mathbf{j} \times \mathbf{B} = 0$$

η is the gas-dynamic viscosity

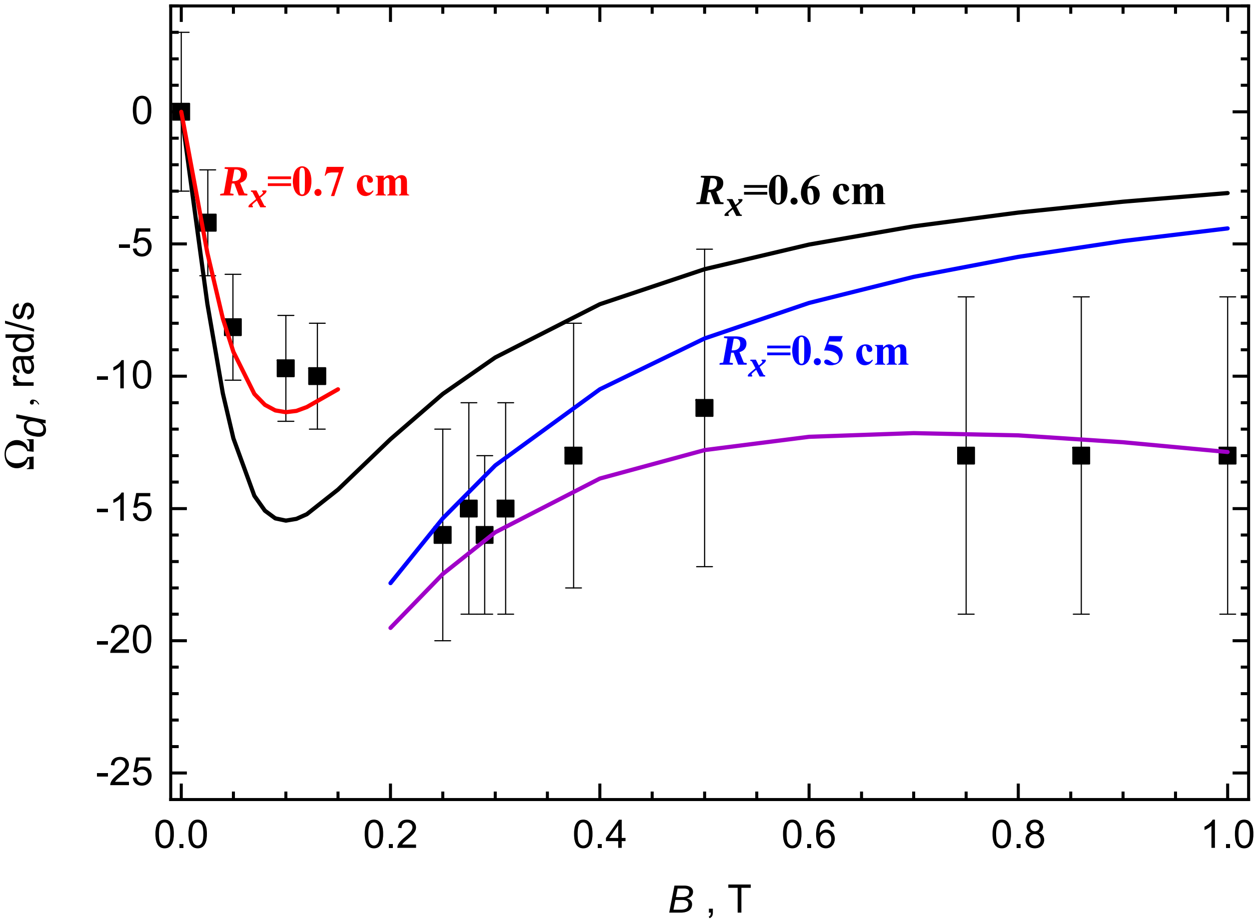
$$\Omega_d^{(2)} = \frac{u_\varphi}{r} = -\frac{BI(R_1 - R_0)(R_1^2 - r^2)}{6\pi\eta R_1^3 l}$$

$R_0 = 0.25$ cm is the minimum current channel radius
R_1 is the current channel radius near the dust particle structure
l is the distance of the dust particle structure from the channel throat

The total angular velocity of dust particle structure

$$\Omega_d = \Omega_d^{(1)} + \Omega_d^{(2)}$$

Ne, $p = 0.4$ Torr, $I = 1.5$ mA



Ultra-fast rotation of the dust structure

Ne, $p = 0.45$ Torr, $I = 2.5$ mA

$$\Omega_d^{(2)} = \frac{u_\varphi}{r} = -\frac{BI}{6\pi\eta}\frac{R(l)}{\left(R_0 + R(l)\right)^3}\left[\left(R_0 + R(l)\right)^2 + r^2\right]$$

$${}_{l}R(l) = (R_1 - R_0)\frac{l}{L}$$

l is the distance of the dust particle structure from the channel throat

$L = \max(l) = 1.1$ cm

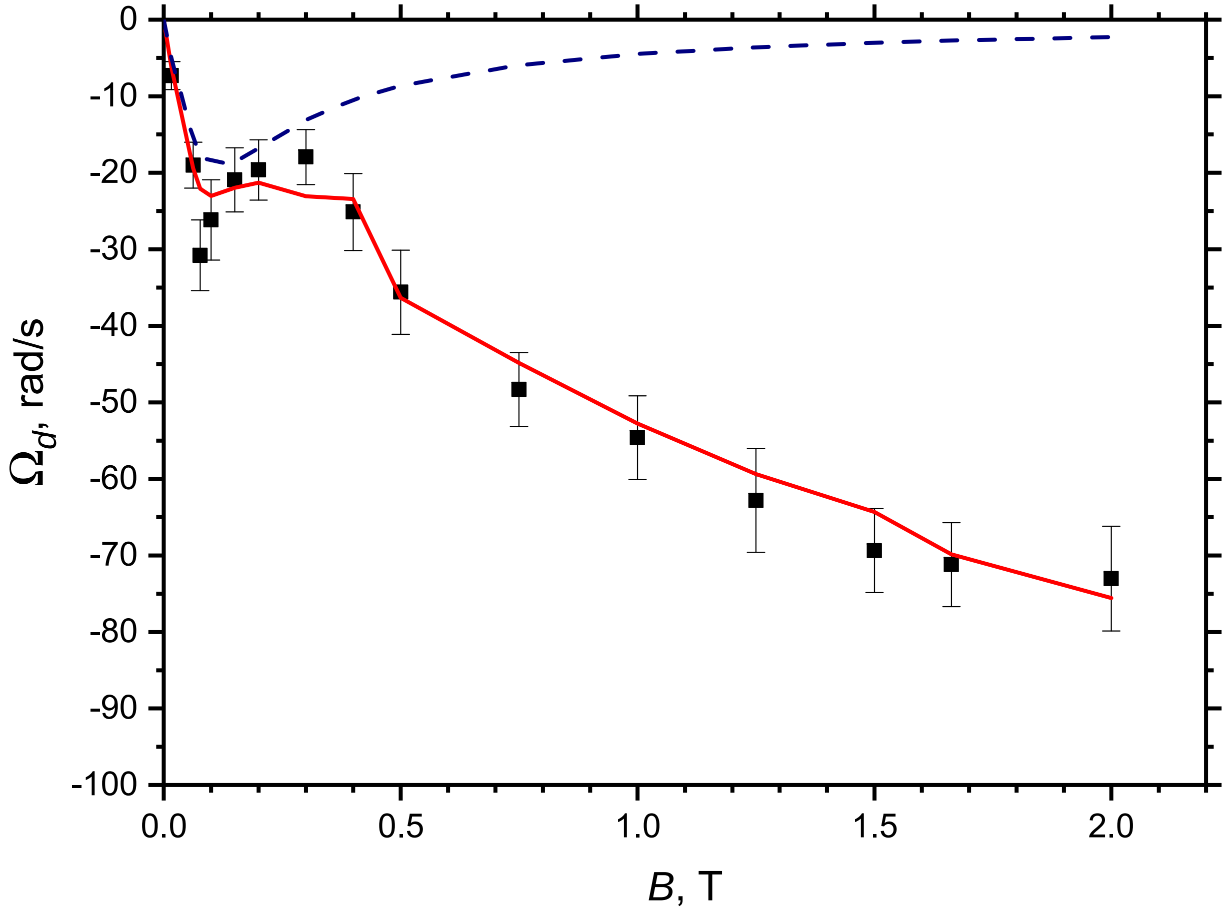
$R_0 = 0.25$ cm is the minimum current channel radius (in the channel throat)

$r \cong 0.1$ cm is the dust structure radius

R_1 is the current channel radius at $l = L$, $R_1 = \begin{cases} 0.31 - 0.015B, & B \le 0.1T,\ B \ge 0.5T, \\ 0.28, & 0.1 < B < 0.5 \end{cases}$

$$\Omega_d = \Omega_d^{(1)} + \Omega_d^{(2)}$$

Ne, $p = 0.45$ Torr, $I = 2.5$ mA



Thank you for listening