

PLASMA TRANSPORT ACROSS A MAGNETIC FIELD BY DRIFT VORTICES

M.V. Nezhlin, A.Yu. Rylov, K.B. Titishov and G.P. Chernikov

*Institute of Nuclear Fusion, Russian Research Center "Kurchatov Institute"
Russia, 123182 Moscow, Kurchatov Square, 1*

The work is devoted to a hydrodynamic modeling of anomalous plasma transport caused by the radial motion of drift vortices carrying the trapped plasma. The modeling is based on the physical analogy between drift vortices in a magnetized plasma and the Rossby vortices on rotating shallow water [1-3]. In the experiments carried out, the velocity have been measured of the meridional and azimuthal drifts of the Rossby vortices on a rotating shallow water in a parabolic vessel (Figs. 1, 2.), in the presence and absence of a meridional gradient in the shallow water depth. The value and sign of the gradient are regulated by the regulation of the paraboloid rotation rate. In particular, at a relatively slow rotation, the shallow water depth, H_0 , has a negative meridional gradient analogous to the negative radial gradient in the magnetized plasma density. In that case, the Rossby vortices drift "eastwards", along the vessel rotation (Fig.1). At fast rotation or at $H_0=const.$, the vortices drift "westwards". In any

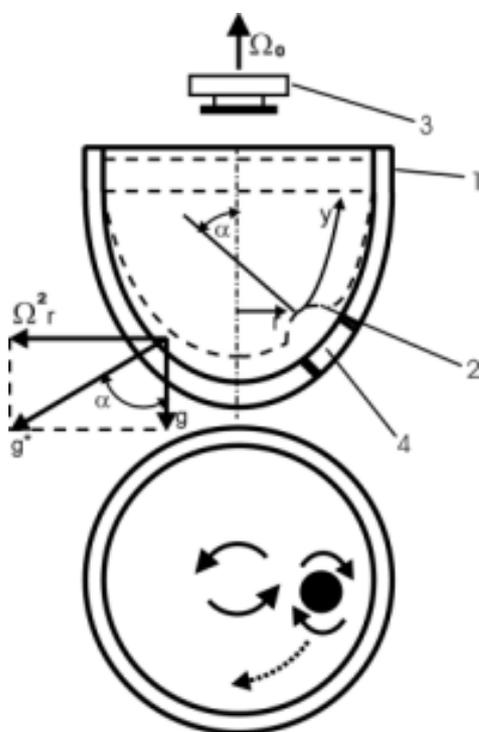


Fig. 1. The equilibrium of a layer of fluid in a rotating paraboloid; also illustrating diagrammatically how anticyclonic Rossby vortices can be generated experimentally in shallow water that is in solid-body rotation. In the upper part of the diagram, (1) indicates a vessel with an approximately paraboloidal bottom; (2) is the surface of the water, which is uniformly spread over the bottom of the paraboloid when it is in rotation; (3) is a camera co-rotating with the vessel; (4) is a vortex source. In the lower view, the solid arrows indicate the direction with which the vessel itself rotates and the anticyclonic direction with which the vortex rotates; the dashed arrow shows the direction in which the vortex drifts in the absence of a gradient in the fluid depth (or at positive sign of the radial gradient); the vortex lags behind the global rotation of the system; α is the angle between the vessel rotation axis and the normal to the fluid surface.

case, the vortices under study have a sufficiently large amplitude, so that they trap the medium and carry it along (Fig. 3). The trapping condition is:

$$h > a / R, \quad (e\varphi / T) > (a / R). \quad (1)$$

Here, h is the dimensionless amplitude, i.e. the ratio of the shallow water elevation (for anticyclones) or depression (for cyclones) over H_0 ; a is the vortex radius, R is the characteristic system size, φ is the vortex potential with respect to the surrounding plasma (negative for a cyclone and positive for an anticyclone), T is the electron temperature.

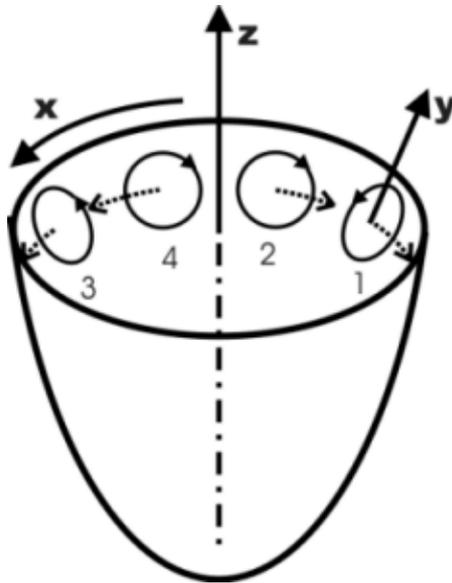


Fig. 2. Diagram of azimuthal drift of the Rossby vortices on shallow water along the back wall of the paraboloid rotating counter-clockwise around the vertical Z-axis. The vortices drift along the inner surface of the vessel, parallel or antiparallel to the X-axis directed "eastwards". The Y-axis is directed along the meridian, upwards. Vector of the local Coriolis parameter is directed along a normal to the shallow water free surface, inside the vessel. The vortex radius is equal to a . (1) - a cyclone drifting westwards, (2) - an anticyclone drifting westwards, (3) - a cyclone drifting eastwards, (4) - an anticyclone drifting eastwards. The Coriolis parameter (and, if pointed out, the shallow water depth) is increased towards the vessel pole. The arrows directed along a parallel show directions of azimuthal drift of the vortices; the arrows directed along the small circles show directions of the vortex own rotation.

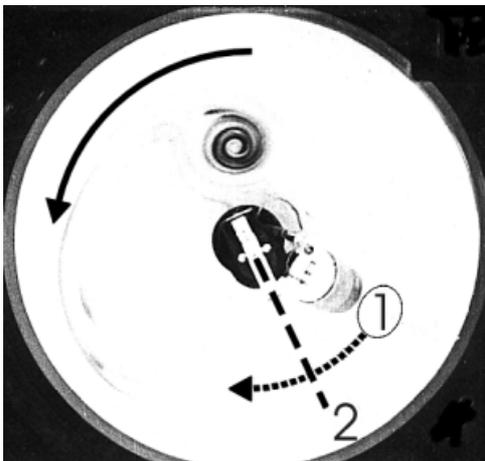


Fig. 3. "Westward" (clockwise) drift of a Rossby anticyclone in a parabolic shallow water layer rotating counter-clockwise ("eastwards"). $H_0 = 0.5 \text{ cm} = \text{const}$. The vortex is produced in position 1, in position 2 it captures a dye introduced from above and involves it in the (azimuthal) drift. The meridional drift velocity is near to zero. The vortex amplitude $h \approx 0.5$.

It is not difficult to write a simple criterion which will give one a possibility to predict the plasma transport rate by drift vortices, on the basis of measurement of the meridional drift of the large-scale Rossby vortices (which are larger than the known Rossby-Obukhov radius and its plasma counterpart, the ion Larmor radius at the electron temperature). Indeed, as it can easily be seen, the ratio of the sought for plasma equivalent plasma diffusion coefficient, D , to the Bohm diffusion coefficient, $D_B = cT/eB$, is:

$$D/D_B = V_r/V^*, \quad (2)$$

where V_r is the velocity of the radial plasma flow and $V^* = cT/eBR$ - the known drift plasma velocity. The right relationship in (2) is analogous to the ratio of the meridional drift velocity of the Rossby vortices, V_y , to the Rossby velocity, $V_R = g \frac{d}{dy} (H_0 / f)$, which is the counterpart of V^* . Here g is the gravity acceleration, y is the meridional coordinate, f is the Coriolis parameter. According to (2), in order to find the ratio D/D_B , it is sufficient to measure the ratio V_y/V_R .

Therewith, as known [3], the value V_R is practically equal to the azimuthal (along a parallel) drift velocity of a large-scale Rossby vortex. So, the problem turns out to be reduced to the measurements of the Rossby vortex drift velocities.

The main results of the experiments under consideration (in detail, see [4]) are the following.

- (i) Meridional drift of the vortices of opposite polarities, at small and moderate amplitudes, is directed in the opposite directions. At a "small" period of the vessel rotation, the cyclones drift to the vessel pole and the anticyclones, to the periphery. At a "large" vessel rotation period, i.e. under the presence of a significant negative meridional gradient in the shallow water thickness (what corresponds to a negative radial gradient in the plasma density), the cyclones drift to the periphery and the anticyclones, to the vessel pole.
- (ii) At some intermediate vessel rotation period, when the Rossby velocity, V_R , is near to zero, the meridional drift of the Rossby vortices of a small (or moderate) amplitude is absent.
- (iii) The ratio of the meridional drift velocity to the azimuthal drift velocity of the Rossby large-scale vortices is near to 0.1 - 0.15. The factor a/R , under the conditions of the experiments considered, is nearly equal to 0.1.
- (iv) It follows from (iii) and (2) that the equivalent plasma diffusion coefficient

$$D \approx \frac{a}{R} D_B ; \quad (3)$$

therewith, in a plasma, $a \approx r_L$. The relationship means that the rate of plasma transverse transport is equivalent to the gyro-Bohm diffusion coefficient.

The next question is what part of the plasma is captured by the drift vortices. An answer to this question has been in the experiments [5] where the microwave scattering on the drift turbulence in the stellarator plasma has been investigated. The authors of [5] come to a conclusion that the plasma under study is an ensemble of large amplitude vortices satisfying to the condition (1) for plasma capture by drift vortices.

Acknowledgements

The work has been implemented under financial support by the Russian Foundation of Basic Research (RFBR, grant 96-05-64061), the joint foundation RFBR-INTAS (grant 95-0988) and the Russian Ministry of Science and Technology.

References

- [1] M. Nezlin and E. Snezhkin: *Rossby Vortices, Spiral Structures, Solitons*. Springer-Verlag, Berlin, 1993.
- [2] M.V. Nezlin and G.P. Chernikov: *Plasma Physics Reports* **21**, 922 (1995).
- [3] M.V. Nezlin, A.Yu. Rylov, K.B. Titishov and G.P. Chernikov: *Chaos* **6**, 309 (1996).
- [4] M.V. Nezlin, A.Yu. Rylov, K.B. Titishov and G.P. Chernikov: *Plasma Physics Reports*, 1998, *submitted*.
- [5] G.M. Batanov, K.M. Likin, K.A. Sarksyanyan and M.G. Shats: *Fizika Plazmy* **19**, 1199 (1993).