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spontaneous rotation in plasmas

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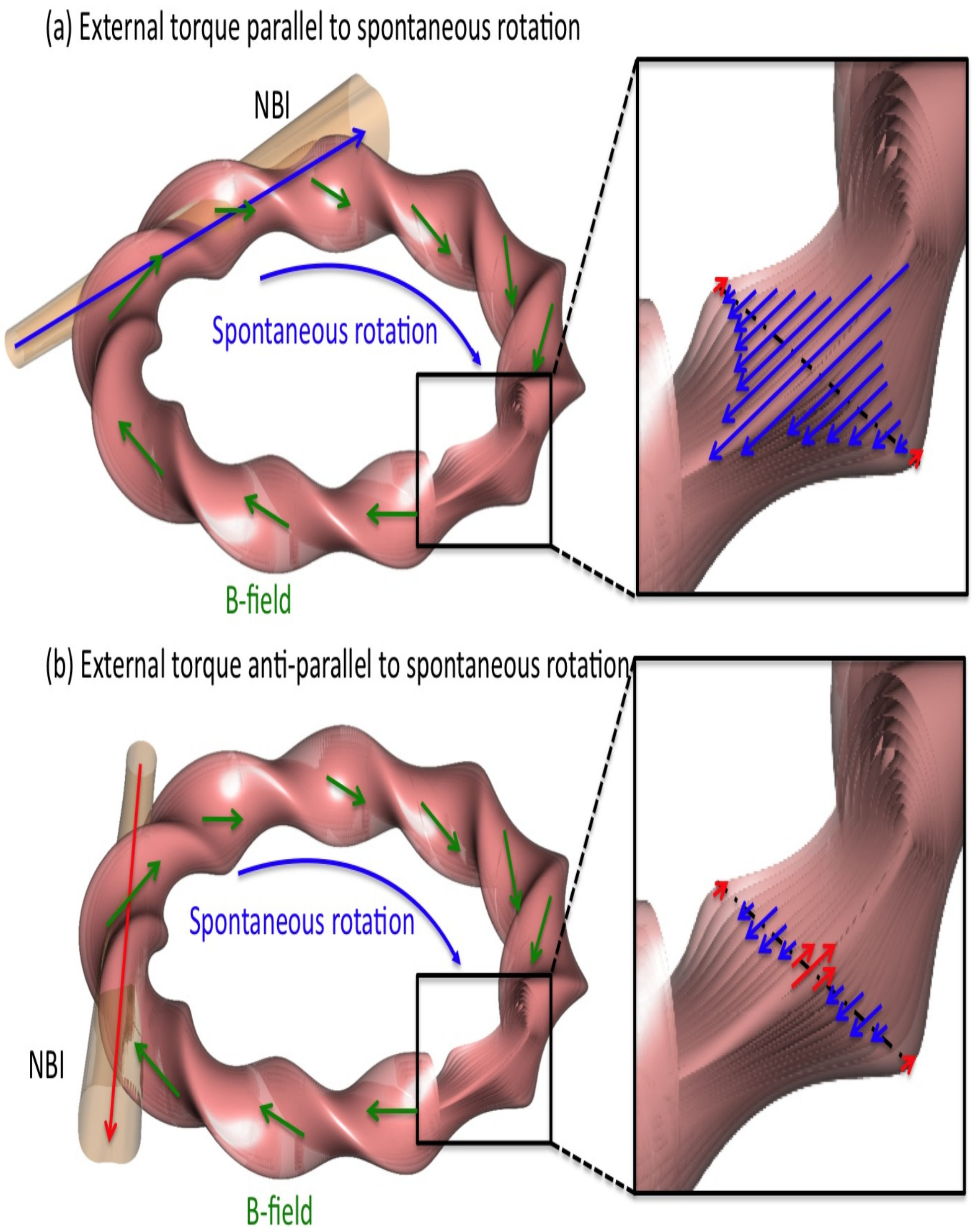

A spontaneous rotation in toroidal plasmas is an interesting phenomenon because it looks break the conservation of the angular momentum in the plasma confined with toroidal magnetic field. One of the clear evidences for the spontaneous rotation is a fact that plasma rotates toroidally even without external torque or rotates in the direction opposite to the direction of torque input. The mechanism driving this spontaneous rotation is a radial flux of toroidal momentum associated with a symmetry breaking of turbulence in the plasma. Historically the spontaneous rotation has been observed as a preference of direction of toroidal rotation in the plasma: plasma rotates faster (or slower) in the CW direction than in the direction of CCW for the given torque in the experiment in 1995[1,2]. The differences in the magnitude of toroidal rotation between CW and CCW are not due to the differences in viscosity but due to the effect of spontaneous rotation. The spontaneous rotation was found to be more significant in the plasma with larger temperature gradients. The spontaneous rotation larger than the rotation driven by external torque was observed in the plasma with electron internal transport barrier, where the temperature gradient is significantly large in 2001[3]. Recently spontaneous rotation has been reported in various experiments and various theoretical models have been proposed[4]. The symmetry breaking of turbulence with the existence of radial electric field shear can produce the Reynolds stress as an internal toroidal torque and results in the spontaneous rotation.

Since the spontaneous rotation due to the Reynolds stress has the sign preference, either co- or counter-direction to the plasma current (equivalent toroidal current in helical plasmas), this spontaneous rotation appears as a disparity of co- and counter- driven toroidal rotation profiles in the discharges with co- and counter- neutral beam injection (NBI) with similar injection power. Figure 1 shows the shape of toroidal plasma confined by torodail magnetic field (B-field) and the direction of NBI as a source of external torque and radial profiles of toroidal rotation velocity observed in Large Helical Device (LHD). The direction and magnitude of the toroidal rotation velocity are indicated by arrows. When the direction of the external torque is parallel to the direction of spontaneous rotation (Fig1(a)), the toroidal rotation velocity is parallel to the direction of external torque and is peaked at the center of plasma. However, the toroidal rotation velocity driven by NBI is almost canceled by the spontaneous rotation when the direction of the external torque is anti-parallel to the direction of spontaneous rotation (Fig1(b)). The plasma rotates in the direction opposite to the external torque except for the plasma center and periphery. This is because the Reynolds stress in the plasma exceeds the torque externally driven by the NBI. Here the Reynolds stress does not produce a net angular momentum but transfer the angular momentum from interior to periphery of plasmas (produce the toroidal momentum flux in radial direction). In both cases, the angular momentum externally injected to the plasma by NBI are transferred towards the plasma periphery and finally exhausted in a steady-state.

The spontaneous rotation in the plasma is considered to be the rotation due to radial diffusion of particle and energy through Reynolds stress and this issue would be interesting topics in other field in physics, especially in astrophysics where magneto hydrodynamics is important as well as Newton dynamics. For instance, the rotating disk observed in a black hole near the center of the galaxy[5] is a similar problem.

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