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Chiral Vortical Effect in Terms of Defects

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We show that in rotating superfluid chiral liquid vortices carry axial current corresponding to chiral vortical effect. We argue that axial current carried by fermionic zero modes propagating along defects. The current evaluated by zero modes counting differs by a factor of two from the answer of standard consideration. It corresponds to two component nature of the system where zero modes propagate with speed of light and thus the liquid cannot be described by a single (local) velocity. The picture with defects is the first step to understand non-dissipativity of chiral currents similar to edge currents in topological insulators.

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1. Introduction

Hydrodynamics of chiral liquids has been widely discussed. In [1] it was shown that there exists chiral current j^5_μ proportional to the vorticity $\omega^\mu = \frac{1}{2}\varepsilon^{\mu\nu\alpha\beta}u_\nu\partial_\alpha u_\beta$. This current is closely tied with phenomenon of axial anomaly in the corresponding microscopic theory and called chiral vortical effect (CVE). In literature there is a great number of different approaches to chiral effects (see [2], [3], [4], etc.). Moreover recently (see [5]) assumptions for chiral kinetic coefficients derivation were reduced to general Ward identities.

All macroscopic considerations (despite of their wide variety) consider the liquid as a slowly-varying in its properties medium. Such assumption should be justified by giving an answer on the question how to introduce classical approximation for fermions. However CVE can be considered within another approach which starts with a microscopical picture. It is known (see [6, 7])that defects in field theory are closely tied with the realization of chiral anomaly and that chiral current is carried by fermionic zero modes living on the defects. Therefore we expect that microscopically the anomaly is realized on vortex-like strings and that continuum-medium limit arises upon averaging over defects. For the chiral magnetic effect (CME) such consideration was done in particular in [8], [9] and resulted in the same answer as on the macroscopic level.

In case of superfluidity the vortices could be understood dynamically. As it is known the velocity field of the superfluid is potential. However angular momentum is still transferred to the liquid through vortices. The vorticity is vanishing everywhere but vortices which make the whole liquid globally possessing angular momentum and the entire chiral current flows along them. So upon averaging over defects there is recovering of the continuum limit. Interest to such picture is additionally motivated by recent suggestion that chiral currents are dissipationless. Non-dissipative phenomena for example take place on boundaries of topologically non-trivial systems like topological insulators. Zero modes on low-dimensional defects could propagate without any resistance (similar to superconductivity of cosmological strings [10]) and such consideration could give us a model of dissipationless currents.

Finally we will show that answer obtained microscopically differs from the macroscopic one and that this difference signalizes about crucial role of one velocity assumption. The system of superfluid with vortices is crucially two component. The second component corresponding to zero modes on defects which could be treat as additional superfluid constituent.

2. Evaluation of chiral current

As it mentioned above there are two ways to obtain kinetic coefficient for CVE. Firstly lets consider macroscopic method closely tied with evaluation of axial anomaly in field theory. In superfluid at zero temperature one can identify NG boson gradient with velocity of medium which is potential $v_i \sim \partial_i\phi$. Nearby any given vortex (with unit wind) the NG field is given by $\phi = \mu t + \varphi$ where φ is the polar angle in the plane orthogonal to the vortex.

Following method suggested in [2] one can introduce effective Lagrangian $L = \overline{\psi}i(\partial_\mu + i\partial_\mu\phi)\gamma^\mu\psi$ where we assume non-relativistic limit $\partial_0\phi \to \mu$, $\partial_i\phi \to \mu v^s_i$. Using standard methods of evaluating the anomalous triangle diagrams one obtains for the axial current $j^5_\mu = \frac{1}{4\pi^2}\varepsilon_{\mu\nu\alpha\beta}\partial^\nu\phi\partial^\alpha\partial^\beta\phi$.

This current seems to vanish identically. However for the vortex field $\phi = \mu t + \varphi$ and hence $j_3^5 = \frac{\mu}{2\pi}\delta(x,y)$ since $[\partial_x, \partial_y]\phi = 2\pi\delta(x,y)$ the total current (the sum over the vortices) equals to

$$J_3^5 = \int d^2x\, j_3^5 = \frac{\mu}{2\pi} n. \tag{2.1}$$

Now lets proceed to microscopic calculation which reduces to counting zero chiral modes. Following [11] after some algebra one gets:

$$J_5^3 = (N_+ - N_-)\frac{1}{L}\sum_{p_3}(\theta(\mu - |p_3|) = \frac{\mu}{\pi} n, \tag{2.2}$$

The result for CVE obtained through counting zero modes can be compared to the evaluation of the same currents within effective field theory. This result differs from the one obtained macroscopically (from triangle graphs) unlike the case of CME when two answers coincide [11]. In both cases it is the triangle graphs which control the effect: CME is linear both in the interaction qA_μ and μu_μ while CVE is quadratic in μu_μ.

3. Conclusion

We showed that CVE evaluated in terms of the zero modes differs from the result of macroscopic calculation by a factor of two. The difference corresponds to the fact that the fermionic zero modes propagate with speed of light and are not equilibrated to the local velocity of the liquid. This appearance of the additional component does not reduce to the standard introduction of the normal component in the theory of superfluidity and results in some kind of double superfluidity.

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