CHARGED UNRUH EFFECT ON GEON SPACETIMES

DAVID E. BRUSCHI and JORMA LOUKO
School of Mathematical Sciences, University of Nottingham,
Nottingham NG7 2RD, United Kingdom

A topological geon black hole with gauge charges may have a gauge bundle that necessarily incorporates charge conjugation as a gauge symmetry. This happens for example for the Reissner-Nordström geon. We show that gauging the charge conjugation leaves an imprint in the Unruh effect: the geon’s exterior region contains non-thermal correlations for particle pairs of the same, rather than opposite, charge. The phenomenon occurs also in topologically similar Rindler spacetimes with a background gauge field.

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1. Introduction

Given a stationary black hole spacetime with a bifurcate Killing horizon, it may be possible to form a time-orientable quotient spacetime in which the two opposing exterior regions have become identified. In the Hawking-Unruh effect on the resulting topological geon black holes, a suitably limited set of observations in the exterior region displays thermality in the usual Hawking temperature, but there are also non-thermal correlations that bear an imprint of the unusual geometry behind the horizons. In a sense, the Hawking-Unruh effect on a geon black hole reveals to an exterior observer features of the geometry that are classically hidden behind the horizons. A recent review can be found in.

When the geon has a gauge field, it may be necessary for the geon’s gauge bundle to be nontrivial in a way that incorporates charge conjugation as a gauge symmetry. This happens for example for the Reissner-Nordström geon, both with electric and magnetic charge. In this contribution we show that the Hawking-Unruh effect on the geon bears an imprint of the gauged charge conjugation: the geon’s exterior region contains non-thermal correlations for particle pairs of the same, rather than opposite, charge.

We focus this contribution on two geon-type Rindler spacetimes with a background magnetic field. The black hole case is qualitatively similar.

2. Magnetic Rindler geons

Given Minkowski space with global coordinates \((t, x, y, z)\), we denote by \(\mathcal{M}_0\) the spacetime in which the \(z\)-coordinate is periodic with period \(L > 0\). We introduce on \(\mathcal{M}_0\) the background Maxwell field with the globally-defined gauge potential

\[
A = -Cy\,dz
\]

where \(C\) is a constant.
\( M_0 \) admits the freely-acting involutive isometries
\[
J_\pm : (t, x, y, z) \mapsto (t, -x, \pm y, z + \frac{1}{2}L),
\]
and we denote the respective quotients of \( M_0 \) by \( M_\pm \). As the gauge potential (1) is invariant under \( J_+ \), the gauge bundle over \( M_+ \) is the trivial \( \text{U}(1) \) bundle. However, as the gauge potential (1) changes sign under \( J_- \), the gauge bundle over \( M_- \) has gauge group \( \text{O}(2) \cong \mathbb{Z}_2 \rtimes \text{U}(1) \), where the nontrivial element of \( \mathbb{Z}_2 \) acts on \( \text{U}(1) \) by complex conjugation.

\[ A \mapsto -A. \]

\( M_0 \) is analogous to magnetic Reissner-Nordström, with the Rindler wedges at \( x > |t| \) and \( x < -|t| \) corresponding to the opposing Reissner-Nordström exteriors. \( M_\pm \) are each analogous to the Reissner-Nordström geon, but it is only in \( M_- \) that the analogue extends to the gauged charge conjugation in the gauge bundle.

3. Charged scalar field on \( M_\pm \)

We consider on \( M_\pm \) a complex scalar field \( \phi \) with the Lagrangian
\[
\mathcal{L} = -(D_\mu \phi^*) D^\mu \phi - m^2 \phi^* \phi
\]
where the gauge-covariant derivative \( D_\mu := \nabla_\mu - ieA_\mu \) contains the coupling to the background gauge field and \( ^* \) denotes complex conjugation. Note that when the gauge group is \( \mathbb{Z}_2 \rtimes \text{U}(1) \), the action of the disconnected component on \( \phi \) includes complex conjugation: in particular, \( (-1_{\mathbb{Z}_2}, 1_{\mathbb{Z}_2}) \) has the action \( (A, \phi) \mapsto (-A, \phi^*) \).

On \( M_- \), positive and negative charges are thus gauge-equivalent.

We quantise \( \phi \) on \( M_\pm \) in the usual fashion and prepare it in the Minkowski-like vacuum \( |0_\pm \rangle \), defined in terms of positive and negative frequencies with respect to the Killing vector \( \partial_t \). Note that \( \partial_t \) is globally defined on \( M_\pm \) and the purely spatial gauge potential does not affect the positive and negative frequencies. On \( M_- \), gauge invariance under the disconnected component of the gauge group can be handled like the restriction of a complex scalar field to a real scalar field.

4. Unruh effect

To analyse the Unruh effect, the task is now to express \( |0_\pm \rangle \) in terms of Rindler excitations on the Rindler vacuum. We suppress here the formulas and just describe the qualitative outcome.

The result has expected similarities to that for the real scalar field. In particular, the Rindler excitations come (for generic quantum numbers) in correlated pairs, and observations that only see one member of each pair are thermal in the usual Unruh temperature.

The new phenomenon is in the charge of the Rindler excitations. Observe first that this notion is well defined not only for \( M_+ \) but also for \( M_- \), despite the gauged charge conjugation on \( M_- \). The reason is that \( J_- \) maps the two Rindler wedges of \( M_0 \) to each other, and the charge gauging on \( M_- \) can thus be fixed within the Rindler wedge.
We find:

- In \(|0_+\rangle\) the two Rindler particles in each correlated pair have the \textit{opposite} charge. This is as expected: the same can be verified to hold also for a complex scalar field in the absence of a background gauge field.
- In \(|0_-\rangle\), the two Rindler particles in each correlated pair have the \textit{same} charge. This is a direct consequence of the gauged charge conjugation in the gauge bundle.

5. Conclusions

On a Rindler version of the magnetic Reissner-Nordström geon, non-thermal correlations in the Unruh effect reveal to a Rindler observer that charge conjugation has become a gauge symmetry, even though the charge gauging only affects the gauge bundle behind the Rindler horizons. The case for the genuine Reissner-Nordström geon is qualitatively similar.\[\text{[15]}\]

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