Fracton Phases of Matter

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Mehdi Ahmadi-Jahmani
Ferdowsi University of Mashhad

18 Sharivar, 1404

Overview

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- Recently, a novel class of emergent quasiparticles has been identified, distinguished from all previously characterized particles by unique and unconventional properties.

These quasiparticles are referred to as "fractons."

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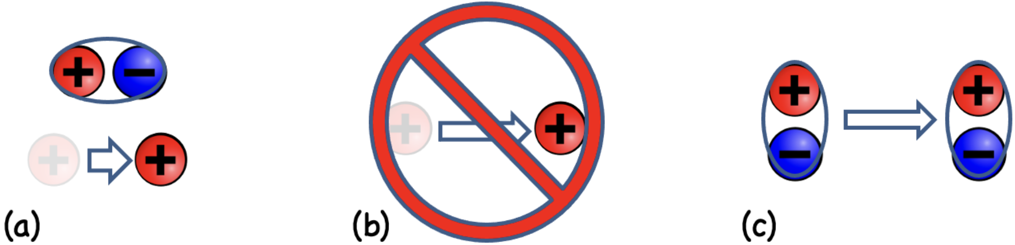
- Fractons can occasionally move by forming specific bound states, such as dipoles. These mobile bound states typically exhibit mobility only in certain directions, giving rise to terms such as lineon and planon.[Pretko et al., 2020]

Introduction



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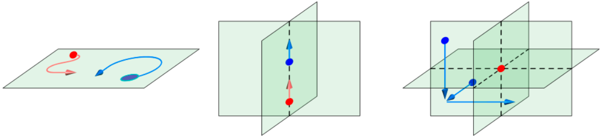

(a) (b) (c)

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Fractons in gauge field

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- Fractons exhibit not only charge conservation, but also dipole moment conservation.[Pretko, 2017a, Pretko, 2017b]

Fracton conservation laws

$$\int \rho = \text{constant}, \quad \int \rho \vec{x} = \text{constant}, \tag{1}$$

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- From a mathematical perspective, fractons emerge as intriguing phenomena that can be described by tensor gauge theories.[Pretko, 2017a, Pretko, 2017b]

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Scalar charge theory:

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Scalar charge theory:

$$\begin{aligned}
&\{\hat{Q}, \hat{Q}_i\} = \{\hat{Q}, \hat{P}_i\} = 0, \quad \{\hat{P}_i, \hat{Q}_j\} = \delta_{ij}\hat{Q}, \\
&\{\hat{P}_i, \hat{J}_{jk}\} = \delta_{ik}\hat{P}_j - \delta_{ij}\hat{P}_k, \quad \{\hat{Q}_i, \hat{J}_{jk}\} = \delta_{ik}\hat{Q}_j - \delta_{ij}\hat{Q}_k, \\
&\{\hat{J}_{ij}, \hat{J}_{kl}\} = \delta_{il}\hat{J}_{jk} - \delta_{ik}\hat{J}_{jl} + \delta_{jk}\hat{J}_{il} - \delta_{jl}\hat{J}_{ik},
\end{aligned} \tag{2}$$

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$$

Dipole Transformations

$$
\delta_\beta x_i = 0, \quad \delta_\beta p_i = q\beta_i, \quad \delta_\beta E = 0, \quad \delta_\beta t = 0 \tag{3}
$$

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- Isolated Fractons:

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Isolated fractons

$$S_{\text{Fracton}} = \int d\tau[-E\dot{t} + (\vec{p} - q\vec{\chi}) \cdot \dot{\vec{x}} - \frac{e}{2}(E^2 - \theta^2)], \tag{4}$$

The equations of motion for this type of particles are

$$\dot{t} = -eE, \quad \dot{\vec{x}} = 0, \quad \dot{E} = 0, \quad \dot{\vec{p}} = q\dot{\vec{\chi}} \tag{5}$$

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$$S_{\text{Dipole}} = \int d\tau[-E\dot{t} + \vec{p}\cdot\dot{\vec{x}} - \frac{e}{2}(E^2 - \theta^2) + d^i\dot{t}\partial_i A_0(\vec{x},t) - \dot{x}^i d^j A_{ij}(\vec{x},t)]. \qquad (6)$$

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Consequently, we can express the equations of motion as follows:

$$\begin{aligned}
\dot{t} &= -eE, \quad \dot{\vec{x}} = 0, \\
\dot{E} &= -d^i\partial_i\dot{A}_0 + d^i\dot{t}\partial_t\partial_i A_0 - \dot{x}^j d^i\partial_t A_{ij} = 0, \\
\dot{p}_m &= d^j\dot{A}_{mj} + d^i\dot{t}\partial_i\partial_m A_0(\vec{x},t) - \dot{x}^i d^j\partial_m A_{ij} \\
&= d^j\partial_t A_{mj} + d^j\partial_j\partial_m A_0 = d^j E_{mj}.
\end{aligned} \tag{7}$$

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- Mobile Dipole:

1- The first mobile dipole:

The first mobile dipole

$$S_{\text{Dipole}} = \int d\tau \Big[- E\dot{t} + \vec{p} \cdot \dot{\vec{x}} - \frac{e}{2}(p^2 - \epsilon^2) + \vec{\chi} \cdot (\vec{d} - \vec{\psi}) + d^i \dot{t} \partial_i A_0(\vec{x}, t) - \dot{x}^i d^j A_{ij}(\vec{x}, t) \Big]. \tag{8}$$

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The resulting equations of motion are:

$$\begin{aligned} &\dot{t} = 0, \quad \dot{\vec{x}} = e\vec{p}, \\ &\dot{E} = -2d^i\dot{x}^j E_{ij}, \quad \dot{p}_m = d^j\dot{x}^i(\partial_i A_{mj} - \partial_m A_{ij}) = d^j(\epsilon_{ijl}\dot{x}^i B^l_m). \end{aligned} \tag{9}$$

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The resulting equations of motion are:

$$\begin{aligned} &\dot{t} = -\widetilde{e}E, \quad \dot{\vec{x}} = e\vec{p}, \quad \dot{E} = -2d^i\dot{x}^j E_{ij}, \\ &\dot{p}_m = d^j[(\dot{t}\partial_t A_{mj} + \dot{x}^i\partial_i A_{mj}) + \dot{t}\partial_i\partial_m A_0(\vec{x}, t) - \dot{x}^i d^j\partial_m A_{ij}] = d^j(E_{mj} + \epsilon_{ijl}\dot{x}^i B^l_m). \end{aligned} \quad (11)$$

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3. Connections between Fracton Geometry and Non-Lorentzian geometry
4. Anisotropic in Fracton Gravity

Thank You

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