Electromagnetic interaction between talcum particle and topological insulator

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Abstract. We identify the electromagnetic interaction between talcum particle and surface of topological insulator which unsatisfied ordinary Maxwell’s equations. For theoretical approach, we use the dyadic green’s function including with the method of an image charge and the topological magneto-electric (TMEP). We describe the electromagnetic response taking into account the property of material in case of the dielectric constant. Our numerical approach demonstrates and discuss the interaction and characteristic of electromagnetic responses between talcum and topological insulator.

1. Introduction
Talcum particle or talcum powder is a particle in nanometer-scale that made from talc consisting of a mineral composed mainly of the element magnesium, silicon, and oxygen: H₂Mg₃O₇Si [1] and has a property of anisotropic crystals. The structure of particle behaves a pole from different of the elements that cause the electrical interaction from itself [2].

Topological insulators (TIs) are a new state of quantum matter that presents quantum-Hall-like properties which are insulator in the bulk but their surface exhibit the conducing states that cause by time-reversal symmetry [3,4]. What makes TIs different from ordinary insulator is that their material has term of the topological magneto-electric polarizability (TMEP). This material has a special property about the interaction when a particle comes closer to the surface inducing the electromagnetic field in the system that occurs the interesting interaction [5].

The electromagnetic interaction between the TIs and a talc particle that exhibit the electric and magnetic field in the system [6,7]. The different types of materials including with dielectric permittivity and magnetic permeability of materials give different and interesting interaction [8,9]. The topological magneto-electric effect (TME) consists of the transmutation of electric and magnetic induction fields that result in term of the modified Maxwell’s equations causing the characteristic property of this materials [10]. When a particle near the surface of TIs in the presence of an electric field, that has the molecular particle–surface interaction with a molecular–image interaction applying the method of images approach in part of the dyadic Green’s function for the system [11,12].

In our work, we indicate the theoretical and numerical calculation in the presence of the dielectric constants which identify the different materials. Describing behavior of the electromagnetic interaction has affect from a property of the materials. We analyze the intensity of the electric and magnetic field in part of contour plot and demonstrate this field in part of quiver plot. Finally, we display results to compare with a property of talc particle.
2. Theoretical approach

A talc particle is brought close to the surface of topological insulator which characterized by dielectric constant \( \epsilon \) and magnetic susceptibility \( \mu \). The lower-half space is occupied by a TI and the upper-half space is occupied by vacuum [8,13]. We determine a charged particle which is located at \((0, 0, d)\) in XYZ-plane as shown in Figure 1.

![Figure 1. A charged particle or talc particle near a TI surface.](image)

That arise the inducing electric polarization by electric field and magnetic polarization by magnetic field in the system. This effect can be written Maxwell’s equations including the topological term as:

\[
\nabla \cdot \mathbf{D} = 4\pi \rho, \quad \nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + 4\pi \mathbf{J},
\]

\[
\nabla \cdot \mathbf{B} = 0, \quad \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t},
\]

but with the modified constitutive equations causing by the TME effect [11,13]:

\[
\mathbf{D} = \epsilon \mathbf{E} + \frac{\alpha}{\pi} \theta \mathbf{B}, \quad \mathbf{H} = \frac{\mathbf{B}}{\mu} - \frac{\alpha}{\pi} \theta \mathbf{E},
\]

where \( \alpha = e^2/\hbar c \) is the fine structure constant and \( \theta \) is TMEP.

We focus on the electromagnetic interaction which is convenient to use the Green’s function method. The dyadic Green’s function distinguishes between the direct and indirect parts including the method of image and that the indirect part must refer to a topological insulator term in the following form [6,14]:

\[
G_{ij}^{(\text{Direct})}(\mathbf{R}, \mathbf{R}') + G_{ij}^{(\text{Indirect})}(\mathbf{R}, \mathbf{R}')
\]

to calculate the electric field and magnetic field, indirect part in Eq. (3) have different coefficient following in refs. [6,13]. That can be expressed in two parts:

2.1. Electric field calculation

The indirect part of Green’s function can be written in form:

\[
G_{ij}^{(\text{Indirect})}(\mathbf{R}, \mathbf{R}') = G_{il}^{(\text{Direct})}(\mathbf{R}, \mathbf{R}_M) M_{lj} = G_{il}^{(\text{Direct})}(\mathbf{R}, \mathbf{R}_M) \begin{pmatrix}
(\epsilon_r - 1)(1 + 1) + \tilde{\theta}^2 & -1 & 0 & 0 \\
0 & -1 & 0 & 0 \\
(\epsilon_r + 1)(1 + 1) + \tilde{\theta}^2 & 0 & 0 & 1
\end{pmatrix},
\]

to obtain the electric field, using the Lippmann-Schwinger equation in the following equation [7]:

\[
\mathbf{E}_i(\mathbf{R}) = \mathbf{E}_i^{(0)}(\mathbf{R}) + \frac{k_0^2}{\epsilon_0} \int_{V_p} d\mathbf{R}_p G_{ij}(\mathbf{R}, \mathbf{R}_{ip}) \cdot \mathbf{P}_j(\mathbf{R}_{ip})
\]

where \( \tilde{\theta} = \alpha \theta / \pi \), \( k_0 = \omega / c \), \( \mathbf{R}_M = (x', y', -z') \), \( \mathbf{P}_j \) is particle polarization and \( c \) is the speed of light.
2.2. Magnetic field calculation

The indirect part of Green’s function can be written in form:

\[ G_{ij}^{(\text{indirect})}(\mathbf{R}, \mathbf{R}') = G_{ij}^{(\text{direct})}(\mathbf{R}, \mathbf{R}') M_{ij} = G_{ij}^{(\text{direct})}(\mathbf{R}, \mathbf{R}') \frac{2\theta^2}{(\varepsilon_x + 1)(\frac{1}{\mu} + 1) + \theta^2} \begin{pmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix} , \]

To obtain the magnetic field, using the Lippmann-Schwinger equation with magnetic polarization $\mu_j$ in the following equation [7]:

\[ B_j(\mathbf{R}) = B_j^{(0)}(\mathbf{R}) + \frac{k^2}{\varepsilon_0 \gamma_p} \int d\mathbf{R}_p G_{ij}(\mathbf{R}, \mathbf{R}_p') \cdot \mu_j(\mathbf{R}_p') \]

3. Numerical approach

Let us consider the distribution of electromagnetic field applying electric field in this system. We describe by setting same size of the square particle in this situation. For the system, it is convenient to explain the interaction that can be considerably simplified in YZ-plane as shown in Figure 2.

![Figure 2](image2.png)

**Figure 2.** A square talc particle focuses on YZ-plane.

We illustrate and show calculation of the distribution with different dielectric constant.

3.1. Electric field distribution

We obtain the distribution and intensity of the field (insert) as shown in Figure 3 and Figure 4.

![Figure 3](image3.png)  
**Figure 3.** Illustration of electric field caused by TI with dielectric constant = 10.

![Figure 4](image4.png)  
**Figure 4.** Illustration of electric field caused by TI with dielectric constant = 130.
3.2. Magnetic field distribution

We obtain the field distribution as shown in Figure 5 and Figure 6.

**Figure 5.** Illustration of magnetic field caused by TI with dielectric constant = 10.

**Figure 6.** Illustration of magnetic field caused by TI with dielectric constant = 130.

4. Conclusion

In this work, we have shown the theoretical and numerical framework to estimate the electromagnetic response due to talc particle and different topological insulator. In electric distribution, As the results are shown that the density of field direction in high dielectric constant has more than low dielectric constant which corresponds to insert that $\varepsilon_r = 130$ has more intensity of image particle than $\varepsilon_r = 10$ since the higher dielectric constant is the great of the material’s ability to store the energy, see ref. [8,14]. When we discuss on the magnetic distribution that give the similar results of field density to electric field but no variation of field above TI because the talc particle has a very weak magnetization that affect the magnetic field in vacuum about the intensity. That is an interesting property of TI, although the talc particle has weak magnetic property, but this material can induce magnetic field in the system.

5. References

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