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ENGINEERING THE CHIRAL ANOMALY: VACUUM SPIN WAVES

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ABSTRACT

The chiral anomaly of quantum electrodynamics implies vacuum polarization spin waves with excitation frequencies which are in principle measurable in electrical engineering circuits. The nature of such circuits are discussed.

The chiral anomaly of quantum electrodynamics implies that electromagnetic disturbances in the vacuum produce electronic vacuum polarization chiral currents(1). Electronic chiral currents are equivalent to vacuum polarization densities(2). With $S^{\mu}(x)$ representing the electronic spin density in the vacuum, and $F_{\mu\nu}(x)$ representing the electromagnetic disturbance, the chiral anomaly equation reads ($S^{\mu}=(\hbar/2c)J_5^{\mu}$,

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$$\partial_\mu S^\mu = - (e^2/8\pi^2 \hbar c^2)\, \varepsilon^{\mu\nu\lambda\sigma} F_{\mu\nu} F_{\lambda\sigma} \quad . \tag{1}$$

In previous work[3] the energetics relating Eq. (1) to the quantum Hall effect was discussed in simple physical terms. The quantum electrodynamic circuit engineering considerations concerning the implications of Eq. (1) for capacitors in magnetic fields has also been discussed[4]. The purpose of this work is to show how the vacuum electronic chiral anomaly can in principle be measured by an explicit circuit arrangement. The electrical engineering considerations are quite similar to those conventionally used to detect magneto-electric phenomena[5].

Consider the circuit arrangement shown in Fig. 1. The capacitor plates are

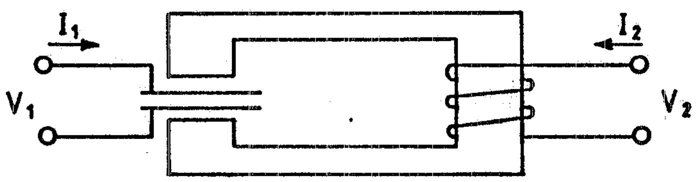

FIG. 1 - A Two-port netweork with a ferromagnet providing the flux through two capacitors plates is shown. The purpose of the network would be to observe the chiral anomaly in the vacuum region between the capacitor plates.

considered to be two thin metal foils exhibiting a surface Hall conductance. The magnetic flux through the capacitor plates is supplied by a ferromagnet as shown, and the flux through the capacitor can be modulated via a coil. For semplicity of presentation, we shall assume ideal conditions in which dissipation is not included, i.e. the energy changes in the two-port network are under ideal conditions assumed to be adiabatic.

Let $\mathcal{U}$ represent the energy of the system as a function of the voltage V_1 across the capacitor and the magnetic flux Φ_2 through the coil. The thermodynamic law for the two-port network then reads

$$d\mathcal{U} = T\, d\, S - Q_1\, dV_1 - \frac{1}{c}\, I_2\, d\Phi_2 \ , \tag{2}$$

where Q_1 is the capacitor charge, and I_2 is the current through the coil.

The adiabatic capacitance is defined as

$$C = (\partial Q_1 / \partial V_1)_{S,\Phi_2} , \tag{3}$$

while the adiabatic coil inductance is defined as

$$L = c(\partial \Phi_2 / \partial I_2)_{S,V_1} . \tag{4}$$

The crucial parameter whose measurement would provide unambiguous evidence for vacuum (chiral) polarization[4] between the capacitor plates is defined by the (chiral) conductance

$$G = (\partial I_2 / \partial V_1)_{S,\Phi_2} , \tag{5}$$

or equivalently (via thermodynamic Maxwell relations)

$$G = c\,(\partial Q_1 / \partial \Phi_2)_{S,V_1} . \tag{6}$$

In virtue of Eqs. (3) and (6), the adiabatic current through the capacitor reads as

$$I_1 = C\,\dot{V}_1 - G\,V_2 , \tag{7}$$

where Faraday's law for the coil

$$V_2 = - d\Phi_2 / c\,dt \tag{8}$$

has been invoked. Similarly, Eqs. (4), (6) and (8) yield

$$\frac{dI_2}{dt} = \frac{dV_1}{dt} - \frac{c^2}{L} V_2 . \tag{9}$$

Eqs. (7) and (9) completely determine the two-port circuit voltage-current characteristics from which the chiral conductance G may be measured.

In actual circuits dissipation must be included. Also, mutual induction in the circuit must be dealt with, for which the engineering considerations are direct[5] so that we shall be content to merely suggest the situation shown in Fig. 2. The D.C. voltage source controls the value of the vacuum chiral

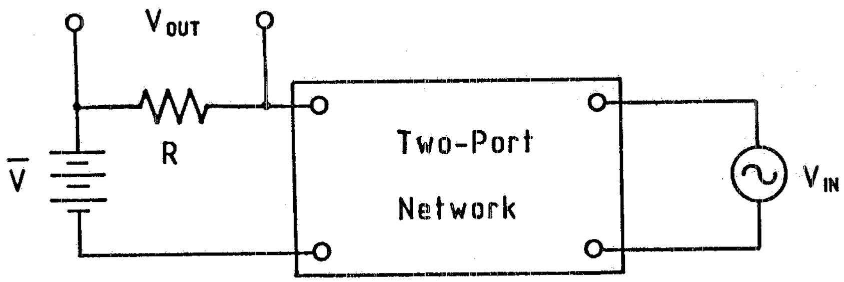

FIG. 2 - With a D.C. voltage V used to control the chiral conductance G, the simple A.C. output response V_{out} to an A.C. input V_{in} in the linear regime would provide direct evidence for chiral vacuum polarization.

conductance G via the Hall effect on the capacitor plates. The A.C. response voltage V_{out} to the A.C. input voltage V_{in} should then yield an experimental measure of chiral vacuum polarization. It is quite likely that such signals have already been observed.

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