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Vipin Srivastava
School of Physics, University of Hyderabad
Hyderabad - 500 134, **INDIA**

Abstract. Hall voltage, V_H, is calculated for narrow two-dimensional electron gas ($2DEG$) system at weak magnetic field and $T \simeq 0°K$. Condition has been derived under which the V_H might vanish.

Introduction

The Hall effect (HE) measurements on narrow ($\sim 100nm$) $2DEG$ systems have exhibited quenching of the HE (i.e., $V_H = 0$) for magnetic fields, $0 \leq B < 1$ Tesla, at very low temperature, $T \simeq 0$ [1]. The diameter of the smallest cyclotron orbit at these values of B is larger than the width of the system, so every trajectory starts and finishes on one edge or the other. A tentative proposal is that the V_H does not build up because the electrons are frequently colliding against the edges and, therefore, do not accumulate on one of the edges under the Lorentz force [2]. We investigate this suggestion rigorously by considering all types of trajectories of electrons and also take into account the possibility of their reflecting from the edges specularly. We are able to find a condition under which V_H should vanish — it is a rather stringent condition.

Calculation

For a system with $\beta = w/R \ll 1$ (w=width of the system; R=radius of the cyclotron orbit) the possible trajectories are shown in figure 1. The potential felt at the edges is $\pm V_o - E_x x$ ($2V_o$ =Hall voltage, and E_x =electric field in the x-direction). Note that $\beta = \cos\varphi - \cos\theta$, $x_o = R(\sin\theta - \sin\varphi)$, and $x_1 = 2R\sin\theta$ where x_o and x_1 are explained in Fig.1.

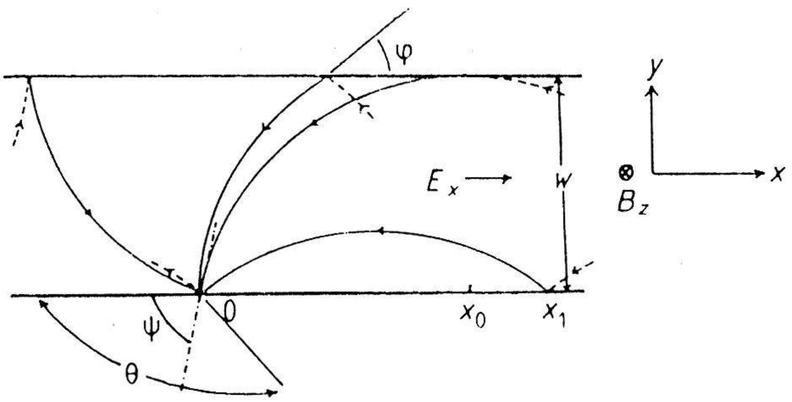

Fig. 1: *The experimental arrangement of the sample and examples of different trajectories running along an edge as well as between the edges. ψ is the angle corresponding to the grazing orbit.*

Electrons leaving the upper (lower) edge have energy $-\varepsilon'$ (ε') where ε' is found by requiring that J_y vanishes. For $0 < \theta < \psi$ electrons leave the lower edge with kinetic energy ε' and come back to it with $\varepsilon' - eE_x x_1$; whereas, for $\psi < \theta < \pi$ they come from the upper edge and arrive at the lower edge with energy $-\varepsilon' - 2eV_o - eE_x x_o$. If p is the probability that an electron after hitting an edge is reflected specularly then it can be seen that x_1 increases by a factor $(1-p)^{-1}$ so that

$$\varepsilon(\theta) = \varepsilon' - 2eE_x R sin\theta/(1-p) \quad for \quad 0 < \theta < \psi \tag{1}$$

and a little more detailed analysis shows that

$$\begin{aligned}\varepsilon(\theta) &= -\varepsilon'(1-p)/(1+p) - 2eV_o/(1+p) \\ &- eE_xR(\sin\theta - \sin\varphi)/(1-p) \qquad for \qquad \psi < \theta < \pi\end{aligned} \tag{2}$$

For the narrow $2DEG, \beta \simeq 0$ so that $\sin\theta \simeq \sin\varphi, \psi \simeq 0$. Thus, as $\sin\theta \to 0, (1-p) \to 0$. Consequently,

$$\varepsilon(\theta) = \begin{cases} \varepsilon' - 2eE_xR & 0 < \theta < \psi \\ -[(1-p)/(1+p)]\varepsilon' - 2eV_o/(1+p) & \psi < \theta < \pi \end{cases} \tag{3}$$

Now, to obtain ε' we require the charge neutrality at the edges:

$$\int_o^\pi \varepsilon \, d\theta = 0 \quad , \tag{4}$$

which, for (3), gives

$$\varepsilon' \simeq -2eV_o/(1-p) \qquad for \psi \simeq 0 \tag{5}$$

Finally we determine total current to obtain resistance. For a displacement of Fermi surface by $\varepsilon(\theta)$ the excess number of carriers is $n\varepsilon\delta\theta/(2\pi E_F)$, n being the electron density. These move with velocity $v_F \sin\theta$ in the y direction. The rate of increase of momentum will be,

$$\dot{P}_y = \int_o^\pi (n\varepsilon \; d\theta/2\pi E_F) m v_F^2 \sin^2\theta = (n/\pi)\int_o^\pi \varepsilon \sin^2\theta \; d\theta \quad . \tag{6}$$

The Hall field increases P_y by $2neV_o$ and the Lorentz force increases it by $B_zI_x(I_x =$ total current). In the steady state.

$$B_zI_x + 2neV_o + (2n/\pi)\int_o^\pi \varepsilon \sin^2\theta \; d\theta = 0 \quad . \tag{7}$$

For $\varepsilon(\theta)$ as in (3),

$$B_zI_x + 2neV_o - n[(1-p)\varepsilon' + 2eV_o]/(1+p) = 0 \quad . \tag{8}$$

or

$$I_x = 2neV_o/B_z \quad , \tag{9}$$

for ε' of (5). Thus we obtain the normal Hall effect in our narrow $2DEG$. However, in the limiting situation of $p = 1$, the V_o will vanish according to (5).

We obtain a very stringent condition: unless $p = 1$, i.e., the reflections of all angles are specular with probability one, we should observed the normal Hall effect in the narrow $2DEG$ in spite of the electrons impinging against the edges frequently. It is, thus, concluded that either the reflections are specular with $p = 1$ under the given experimental conditions or else a new phenomenon, such as the one proposed in [3], is responsible for the compensation of the Lorentz force to cause $V_o = 0$.

References

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