RESEARCH HUB – International Multidisciplinary Research Journal (RHIMRJ)
Research Paper

The Investigation of Integer Quantum Hall Effect in Electronic Bands

Masud Karim Sarkar

Department of Physics , Bidhan Chandra College, Rishra, Hooghly, West Bengal, India (Affiliated to Calcutta University)

Abstract: ***The integer quantum Hall effect applies to the transport qualities associated with a 2 dimensional electron process in the presence of a magnetic field. The interplay between the magnetic field as well as randomness is a vital problem for the phenomenon of Integer Quantum Hall Effect. Lately, the quantum Hall effect (QHE) has been noticed in graphene and studied thoroughly. With this experiment, the Hall Effect will be utilized to learn several of the physics of electric bands.***

Keywords: Electron, Particle, Quantum, Effect, Electronic.

INTRODUCTION

Over thirty years after the original finding of its of 2 dimensional electron gases (2DEG), the Integer Quantum Hall Effect (IQHE) remains probably the most interesting phenomena in condensed material physics. The latest finding of graphene boosted this exploration discipline by offering a brand new 2D structure where Dirac like electric excitations with Berry's stage leads to an alternative type of IQHE, with plateaus at $\sigma_{xy} = \left(n + \frac{1}{2}\right) ge^2/h$, in which g is actually the Landau amount degeneracy because of to spin and valley amounts of independence. A third IQHE type was then described in bilayer graphene, the place that the 2π Berry's stage of cost carriers leads to a standard quantization sequence, except that the final Hall plateau is actually absent. As the characteristics of charged carriers' change each time an additional graphene layer in added, it was theoretically anticipated that the Landau Level (LL) spectrum of N layer graphene systems will lead to distinct IQHE functions arising out of an N π Berry's stage. Inside trilayer graphene, the zero energy LL is actually anticipated to be 12 fold degenerate so that the Hall resistance plateau sequence follows the identical ladder as in graphene, however the plateau at v=±2 must be lacking. And so much, nearly all almost all of the experiments devoted to IQHE in trilayer graphene have been restricted to theoretical calculations while experimental details are actually limited, after the expertise of the actual amount of levels and their relative stacking order are actually difficult to build unambiguously.

The discovery of quantum Hall effect in two dimensional (2D) electron systems subjected to arbitrary opportunity and powerful perpendicular magnetic field was a triumph of experimental physics. With this particular find experts from different disciplines had been launched right into a frenzy of exercise to make this effect helpful in developing various electronic devices. This kind of efforts have led to the endowment associated with a brand new metrological standard, the resistance quantum, h/e2, containing 2 basic constants, the electric cost e and Planck's continuous h. The scaling principle of localization implies that in absence of magnetic field all of the states corresponding to a method of non interacting electrons are actually localized in 2D as a result of disorder potential which obeys time reversal symmetry. So long as the magnetic field is used on the axis perpendicular to the plane of the device time reversal symmetry is actually damaged along with a series of Landau bands seem. Many scientific studies such as percolation concept as well as calculation of Thouless number were done investigating the dynamics of localizations of Landau quantities. Within each Landau band the localized states are actually separated from the main lengthy region. The states within the lengthy region have drawn a lot of interest to many physicists since these states play a major role in the quantization of Hall conductance.

THE SIMPLE THEORY OF THE HALL EFFECT

Think about a conducting slab as shown in Fig. one with length L in the x direction, width w in the y guidance as well as thickness t in the z direction.

  ISSN: 2349-7637 (Online)

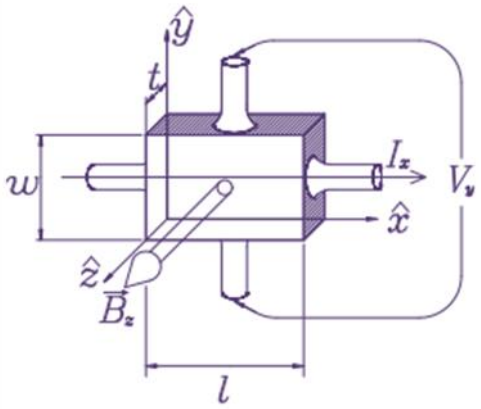

Figure 1: Geometry of fields and sample in Hall Effect experiment

Believe the conductor to possess cost carrier of cost q (can be sometimes negative or positive or perhaps both, though we get it to be of only one sign here), charge carrier number density n (i.e., selection of carriers a device volume), as well as charge carrier drift velocity v_x when a current I_x moves in the positive x direction. The drift velocity is actually an average velocity of the fee carriers with the volume of the conductor; each fee carrier might go in a seemingly arbitrary means to the conductor, but under the influence of applied areas there'll be a net transportation of carriers on the length of the conductor. The present I_x is actually the current density J_x times the cross sectional location of the conductor Assume the conductor to possess cost carrier of charge q (can be sometimes negative or positive or perhaps both, though we get it to be of only one sign here), charge carrier number density n (i.e., selection of carriers a device volume), as well as charge carrier drift velocity v_x when a current Ix moves in the positive x direction. The drift velocity is actually an average velocity of the fee carriers with the volume of the conductor; each fee carrier might go in a seemingly arbitrary means to the conductor, but under the influence of applied areas there'll be a net transportation of carriers on the length of the conductor. The present Ix is actually the current density J_x times the cross sectional location of the conductor

$$I_x = J_x wt = nqv_x wt \quad (1)$$

The present I_x is actually brought on by the application of an electrical field on the length of the conductor E_x. In the situation where the current is directly proportional to the area, we say that the content obeys Ohm's law, which might be written

$$J_x = \sigma E_x, \quad (2)$$

where σ is the conductivity of the material in the conductor.

Now think that the conductor is actually positioned in a magnetic field perpendicular to the plane of the slab. The cost carriers are going to experience a Lorentz force which will deflect them to one side of the slab. The result of this deflection is to cause an accumulation of charges along one side of the slab which creates a transverse electric field E_y that counteracts the force of the magnetic field. (Recall that the force of an electric field on a charge q is q($E^{\rightarrow}$)

When constant state is actually reached, there is going to be no net flow of cost in the y direction, after the magnetic and electrical forces on the fee carriers in this direction should be balanced. Assuming these circumstances, it's simple to show that

$$E_y = v_x B_z \quad (3)$$

where E_y is actually the electrical area, considered the Hall field, in the y guidance as well as B_z the magnetic field in the z direction.

In an experiment, we determine the prospective difference across the sample - the Hall voltage VH - which is actually connected to the Hall field by

$$V_H = -\int_0^w E_y dy = -E_y w \,. \quad (4)$$

Thus, from equations (1), (3) and (4) we obtain

$$V_H = -\left(\frac{1}{nq}\right)\frac{I_x B_z}{t} \quad (5)$$

The term in parenthesis is known as the Hall coefficient:

$$R_H = \frac{1}{nq} \quad (6)$$

It's positive in case the charge carriers are actually positive and negative in case the charge carriers are actually negative. In training, the polarity of VH determines the sign of the charge carriers. Note that the SI units of the Hall coefficient are [m^3/C] or more commonly stated [m^3/A-s].

ELECTRONIC BAND STRUCTURE

To recognize the fundamental electric properties, we begin with the band structure of its. As shown in Fig. below, the honeycomb lattice of graphene may be represented as a Bravais lattice with a 2 carbon atom foundation on triangular lattice.

Within small binding calculations, the band system of graphene close to Fermi power is actually linear ($E = \pm c\hbar|k|$, in which $c \approx 10^6$ ms^{-1} is actually the Fermi velocity). Fig. 2(b) shows the band system of graphene close to Fermi level. Conduction band as well as valence band meet at 2 distinct points (Fermi points, too K as well as K' point) in reciprocal room forming 2 unique cones in close proximity to Fermi amount, generally called Dirac cones. For cost basic graphene the Fermi amount lies precisely at the conference points of conduction and valence bands. It's 0 band gap with vanishing density of states at the Fermi point. Consequently it's feasible to tune the Fermi amount (or maybe carrier density) of graphene continually from valence band to conduction band by chemical or electrical doping. The power doping is attained by making graphene devices within FET geometry, in which by using a gate voltage fees may be caused on the graphene sheet.

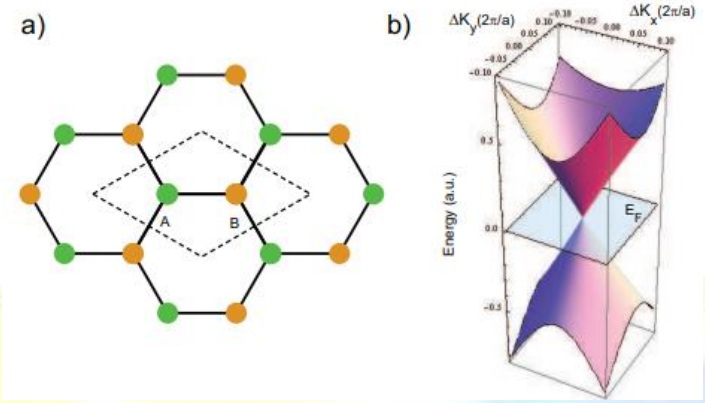

Figure 2: a) Lattice structure of graphene showing the unit cell with two carbon atom basis. b) Band structure of graphene near the Fermi level showing linearly dispersing conduction and valance band meeting at a point (also known as Dirac point) at Fermi level.

Probably the most common method to generate graphene is actually the physical exfoliation, which in essence is pulling single layer graphene sheets from bulk graphite using scotch tape. It's then transferred to a degenerately doped Si substrate coated with 300 nm of SiO_2, giving the very best contrast to see monolayer graphene in the noticeable wavelength range and it gets to be feasible to see atomically slim sheets using very simple resources like optical microscope.

QUANTUM HALL EFFECT IN ELECTRONIC BANDS

The classical theory of the Hall Effect presented above assumes that the electrically charged current is actually the outcome of countless cost carriers moving independently of one another and responding to applied fields as classical particles. Though we are aware that electrons are actually quantum particles, particularly fermions, and they've wavelike properties. Strangely enough, the action of changing the product out of classical impartial particles shifting freely to quantum impartial particles moving freely modifications very little in the results thus far provided. The free electron quantum gasoline version still predicts a hall coefficient of 1/nq along with 0 magneto resistance.

The advantage of utilizing a quantum strategy becomes obvious when it's in addition to a far more reasonable type of reliable material, particularly, crystalline. In a crystal, the atoms are actually set up in a regular lattice. Electrons of the lattice feel the effect of a regular potential on the motion of theirs. Probably the strongest effect takes place for those electrons in the external atomic orbitals - the valence electrons, and particularly those valence electrons whose deBroglie wavelength is actually close to the spacing of the potential's periodicity.

Within the regular potential the allowed energies of the valence electrons are actually broken into a number of electrical power bands with electricity spaces in between them. When the selection of valence electrons a device cell of the crystal is precisely adequate to fill up a band, the strong will be a bad conductor, since by symmetry at electricity there'll be filled momentum states aimed in reverse directions. Conduction is able to happen just when an electron could jump a gap into an unoccupied express. In case the spaces are big, the essential power might be too much, as well as the good is an insulator. When the gap is small, subsequently winter power could be adequate to trigger adequate electrons to go the gap, as well as the good is known as a semiconductor. On the other hand, if the selection of valence electrons a device cell isn't adequate to fill up a band, then numerous unfilled momentum states lie within easy power reach, as well as the good is actually a great conductor - a metal.

Nevertheless, the form of the energy surfaces - the band system - has a good impact on the kind of conduction which can happen. Electron states with energies near the bottom part of a band - probably the lowest allowed electricity in the band - behave like free electrons, except that the reaction of theirs to an applied area could be that of a lighter or heavier particle. It like the electron mass m has been transformed to a good mass $m*$ While this statement appears to be weird, stranger still are the responses of electrons with energies near the top part of a band; these electrons act like the mass of theirs is actually negative! In other words, they accelerate oppositely a free electron when acted upon by an applied area. In fact, it's a lot easier to imagine particle states of this particular kind as acting like positive costs. This kind of states are labeled as “hole” states.

An additional way to think of the consequences would be that the electron states with wave numbers lying close to the band extremes are actually diffracted by the regular lattice in the exact same way that light is actually diffracted by a grating: the activity of an electron wave is significantly changed, actually reversed, analogous to the manner in which that a grating is able to reflect light of a certain color at certain angles.

ISSN: 2349-7637 (Online)

In a semiconductor the band gap is fairly small, and electrons might be excited by winter power to jump the gap. This particular procedure enables an electron like state close to the bottom part of an upper band and a hole like state near the top part of a lower band to come into existence. Both states carry current; with the gap declare acting as a good charge. The amount of the current carrying states is dependent on the heat at a just about exponential way: the number is actually proportional to the Boltzmann element $e^{-Eg/kT}$ in which E_g is actually the power of the gap.

The concept of simultaneous electron hole states has yielded a helpful type of the Hall Effect known as the two band version. The mathematics functions through the same as in Exercise three, except that the entire current is the amount of contributions by the electrons and also the gaps. If we allow each carrier type have a Hall coefficient: R_e (for electrons) and R_h(for holes), as provided by the Eq. and we believe the conductivity σ=σ_e+σ_h, in which σ_e and σ_h are provided by Eq., then we are able to derive an expression for the entire Hall coefficient as

$$R_H = \frac{\sigma_h^2 R_h + \sigma_e^2 R_e}{(\sigma_h + \sigma_e)^2} \quad (7)$$

In the above, the real effective m∗ is actually substituted for m as well as the charge q taken as positive for holes and negative for electrons. This equation follows in the limit that $\omega_c\tau \ll 1$: the low-field limit

In the situation of semiconductors, it's become customary to separate out the carrier density n from the complete conductivity method for, and determine a brand new amount known as the mobility μ:

$$\mu = \left| \frac{q\tau}{m^*} \right| \quad (8)$$

Thus, in our two-band model, the conductivity would look like

$$\sigma = \mu_e |q_e| n_e + \mu_h |q_h| n_h,$$

and the low-field Hall coefficient would look like

$$R_H = \frac{1}{|q|} \frac{n_h \mu_h^2 - n_e \mu_e^2}{(n_h \mu_h + n_e \mu_e)^2} \quad (9)$$

where we have assumed that the charge is the same magnitude for both types of carriers.

CONCLUSION

Hall Effect measurements continue to be a useful technique for characterizing the electrical transport properties of metals and semiconductors. Indeed, the failure of the simple model of metallic conductivity, which we discuss below, to account for many experimental measurements of the Hall effect has been one of the principal motivators leading to a better understanding of electronic properties of materials.

REFERENCES

[1] Liu, & Yun, Luo & Xu, & Tian, Zhihong & Ren, Jun. (2017). Integer quantum Hall effect and topological phase transitions in silicene. Condensed Matter Physics. 20. 43701. 10.5488/CMP.20.43701.

[2] Zhang, Song-Bo & Lu, Hai-Zhou & Shen, Shun-Qing. (2015). Edge states and integer quantum Hall effect in topological insulator thin films. Scientific reports. 5. 10.1038/srep13277.

[3] Jellal, Ahmed. (2015). Integer Quantum Hall Effect in Graphene. Physics Letters A. 380. 10.1016/j.physleta.2016.02.038.

[4] Kumar, A. & Escoffier, Walter & Poumirol, jean-marie & Faugeras, Clément & Arovas, Daniel & Fogler, Michael & Guinea, Francisco & Roche, Stephan & Goiran, M. & Raquet, B.. (2011). Integer Quantum Hall Effect in Trilayer Graphene. Physical Review Letters. 107. 10.1103/PhysRevLett.107.126806.

[5] Falko, Vladimir. (2008). Electronic properties and the quantum Hall effect in bilayer graphene. Philosophical transactions. Series A, Mathematical, physical, and engineering sciences. 366. 205-19; discussion 219. 10.1098/rsta.2007.2156.

[6] Koo, Je Huan & Cho, Guangsup. (2007). The Connection Between Integer Quantum Hall Effect and Fractional Quantum Hall Effect. Modern Physics Letters B - MOD PHYS LETT B. 21. 109-113. 10.1142/S0217984907012530.

[7] Kempa, H. & Esquinazi, P. & Kopelevich, Y.. (2006). Integer Quantum Hall Effect in Graphite. Solid State Communications. 138. 118-122. 10.1016/j.ssc.2006.02.020.

ISSN: 2349-7637 (Online)