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QUANTUM HALL EFFECT: PROPOSED MULTI-ELECTRON TUNNELING EXPERIMENT *

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ABSTRACT

Here we propose a tunneling experiment for the fractional and Integral Quantum Hall Effect. It may demonstrate multi-electron tunneling and may provide information about the nature of the macroscopic quantum states of 2D electronic liquid or solid.

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The tunneling experiment described here is proposed in order to clarify the nature of the elementary excitations which play a role in the Quantum Hall Effect (QHE) [1]-[3]. The Fractional Quantum Hall Effect (FQHE) theories [4]-[11] operate with new quantum states of the 2-D electronic system (liquid or crystalline). The elementary excitations are considered to be either fractionally charged solitons [4]-[8] or multi-electron aggregates [9]-[11]. In the first case the fractional Hall conductivity is realized by fractional charge transport (solitons, ring exchange excitations [12]). In the second case the system is undergoing a phase transition into a quantum state with triplicated (for $\nu = 1/3$) carriers and the magnetic flux quantum is a fractional one [9]-[11]. No suggestions were made about the tunneling of fractionally charged solitons but for electron triples ($\nu = 1/3$) the quantum interference was predicted [9] to be of the type

$$J = J_1 \sin \phi \quad . \tag{1}$$

For the case of external potential $V(t)$ applied to the barrier of the type

$$V(t) = V_0 + V_1 \cos \omega t \tag{2}$$

the phase ϕ time dependence is

$$\phi(t) = \frac{3eV_0 t}{\hbar} + \frac{3eV_1}{\hbar\omega} \sin \omega t \quad , \tag{3}$$

The following schematical experiment can be considered as a possible realization of the multi-electron tunneling (Fig. 1). In this experiment the inversion layer is in the form of two parallel (with high precision!) Hall geometry samples as shown in Fig. 1. The barrier between the two strips should be as thin as possible in order to make the simultaneous tunneling of 3, 5, etc. electrons possible at all. For simplicity the applied potential is considered to be static $V(t) = V_0$. In strong magnetic field in $\nu = 1/3$ quantization conditions the Hall current between the two Hall probes, isolated from each other, will be periodical if a tunneling current J_H is passing through the barrier. The frequency of the oscillations of J_H will be

$$\omega_{3e} = \frac{3e\, V_0}{h}$$

in the case of $\nu = 1/3$ quantization or

$$J_H = J_1 \sin\left(\frac{3e\,V_0 t}{\hbar}\right) \quad (4)$$

The independent sets of Hall probes on each sample may be used for monitoring the Hall quantization conditions in the two samples simultaneously. By control of the constant potential V_0 the effect can be established at available frequencies.

Another possible realization is the Corbino geometry shown in Fig. 2 with two (or more) "scratches", but in that case the potential V_0 is possibly more difficult to control.

Recently [13] the critical current in the Integral QHE (IQHE) was explained by electrons pairing and BCS type ground state. Therefore in the multi-electron theory the IQHE is due to boson quantum 2-D liquid while the FQHE is due to fermion macroscopic quantum states. In a tunneling experiment of the type suggested here the Hall current J_H through the barrier for the integer filling numbers $\nu = 1, 2, \ldots$ will be

$$J_H = J_1 \sin\left(\frac{2eV_0}{\hbar}\, t\right) \quad \text{(IQHE)} \quad (5)$$

This type of experiment is worthwhile since in the case it does not confirm either theory it will undoubtedly shed some light on the nature of the macroscopic quantum states of the 2-D electronic system.

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REFERENCES

[1] K. von Klitzing, G. Dorda and I. Pepper, Phys. Rev. Lett. 45, 494(1980).

[2] D.C. Tsui, H.L Störmer and A.C. Gossard, Phys. Rev. Lett. 43, 1559(1982).

[3] D.C. Tsui, IBM Seminar, Davos, Switzerland (1981); A.M. Chang, M.A. Paalanen, D.C. Tsui, H.L. Störmer and J.C. Hwang, Phys. Rev. B23, 6133 (1983); G. Ebert, K. von Klitzing, J.C. Maan, G. Remenyi, C. Probst, G. Weimann and W. Schlapp, J. Phys. C: Solid State Phys. 17L, 775 (1984); J. Wakabayashi, S. Kawaji, J. Joshino and N. Sasaki, 17th International Conference on the Physics of Semiconductors (San Francisco, 1984); C. McFadden, A.P. Long, H.W. Myron, M. Pepper, D.Andrews and C.J. Davies, J. Phys. C: Solid State Phys. 17L, 439 (1984); T.C. Powell, R. Newbury, A.P. Long, C. McFadden, H.W. Myron and M. Pepper, J. Phys. C: Solid State Phys. 18L, 497 (1985); R.B. Laughlin, Phys. Rev. B27, 3383 (1983).

[4] R.B. Laughlin, Phys. Rev. Lett. 50, 1395 (1983); ibid. 52, 2304 (1984); W.P. Su and J.R. Schrieffer, Phys. Rev. Lett. 46, 738 (1981); W.P. Su, Phys. Rev. B30, 1069 (1984).

[5] D. Arovas, J.R. Schrieffer and P. Wilczek, Phys. Rev. Lett. 53, 722 (1984); P.W. Anderson, Phys. Rev. B23, 2264 (1983); R. Tao and D.J. Thouless, B23, 1142 (1983); R. Tao, ibid B29, 636 (1984); D.J. Thouless and Yong-Shi Wu, ibid. B31, 1191 (1985).

[6] B.I. Halperin, Helv. Phys. Acta 56, 75 (1983).

[7] H. Levine, S.B. Libby and A.M.H. Pruisken, Phys. Rev. Lett. 51, 1915(1983); Nucl. Phys. B240 FS12, 30 (1984); D.E. Khmelnitskii, Phys. Lett. 106A, 182, (1984).

[8] R.B. Laughlin, M.L. Cohen, J.M. Kosterlitz, H. Levine, S.B. Libby and A.M.M. Pruisken, Phys. Rev. B32, 1311 (1985).

[9] I.Z. Kostadinov, Solid State Commun. 54, 269 (1985); D.J. Thouless, J. Phys. C: Solid State Phys. 17L, 325 (1984); M.H. Boon and J. Zak, Phys. Rev. B18, 6744 (1978); B.I. Halperin, Phys. Rev. B25, 2185 (1982); D.J. Thouless, M. Kohmoto, M.P. Nightingale and M. den Nijs, Phys. Rev. Lett. 49, 405 (1982); G.C. Aers and A.H. MacDonald, J. Phys. C: Solid State Phys. 17, 5491 (1984); F. Wegner, Z. Phys. B35, 207 (1979); ibid. B36, 209 (1980), also K.B. Efetov, A.I. Larkin and D.E. Khmelnitskii, Sov. Phys. JETP 52, 568 (1980).

[10] I.Z. Kostadinov and V.N. Popov, ICTP Trieste, Internal Report IC/85/97.

[11] I.Z. Kostadinov, ICTP Trieste, preprint IC/85/147.

[12] D. Arovas, C. Kallin, S. Kivelson and J.R. Schrieffer, to be published.

[13] I.Z. Kostadinov, to be published.

FIGURE CAPTIONS

Fig. 1 Two parallel 2-D samples. The Hall current J_H through the barrier is oscillating.

Fig. 2 Corbino geometry with two barriers separating the quantum liquid in two regions. The tunneling circular Hall current J_H is periodical.

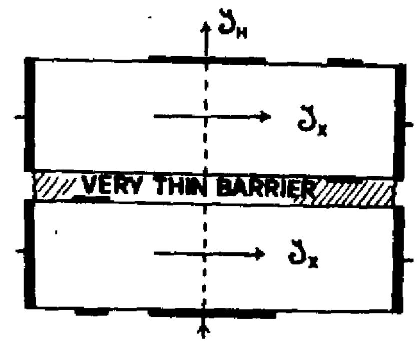

Fig. 1

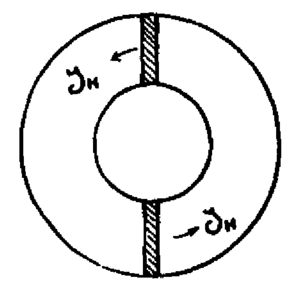

Fig. 2