The Nobel Prize in Physics 1985

"for the discovery of the quantized Hall effect"

Klaus von Klitzing

Federal Republic of Germany

Max-Planck-Institute for Solid State Research
Stuttgart, Federal Republic of Germany

b.1943

The Nobel Prize in Physics 1998

"for their discovery of a new form of quantum fluid with fractionally charged excitations"

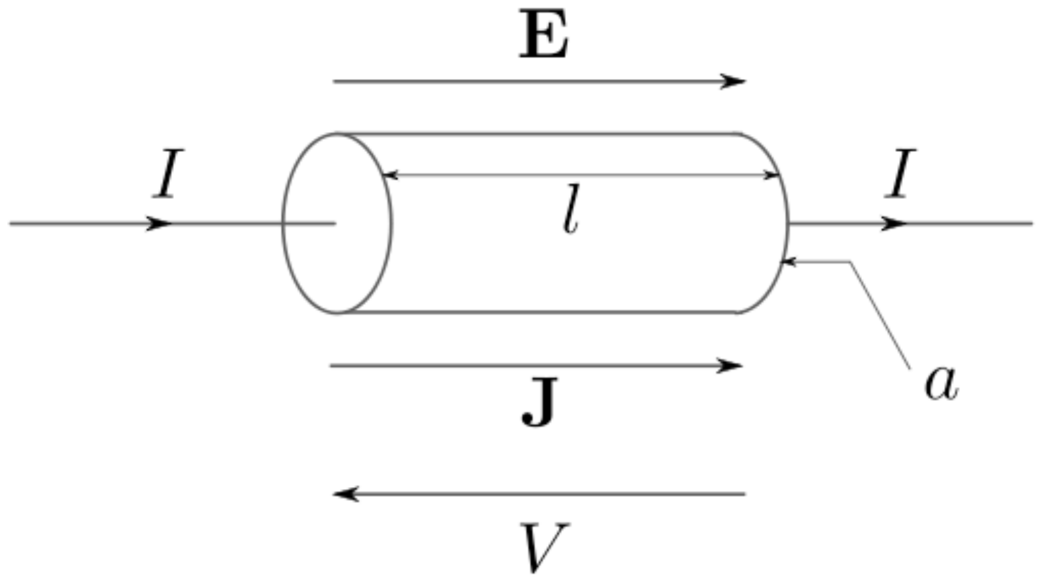


Robert B. Laughlin	**Horst L. Störmer**	**Daniel C. Tsui**
1/3 of the prize	1/3 of the prize	1/3 of the prize
USA	Federal Republic of Germany	USA
Stanford University Stanford, CA, USA	Columbia University New York, NY, USA	Princeton University Princeton, NJ, USA
b.1950	b.1949	b.1939 (in Henan, China)

The Fractional Quantum Hall Effect Mystery

Ohm's law (1827)

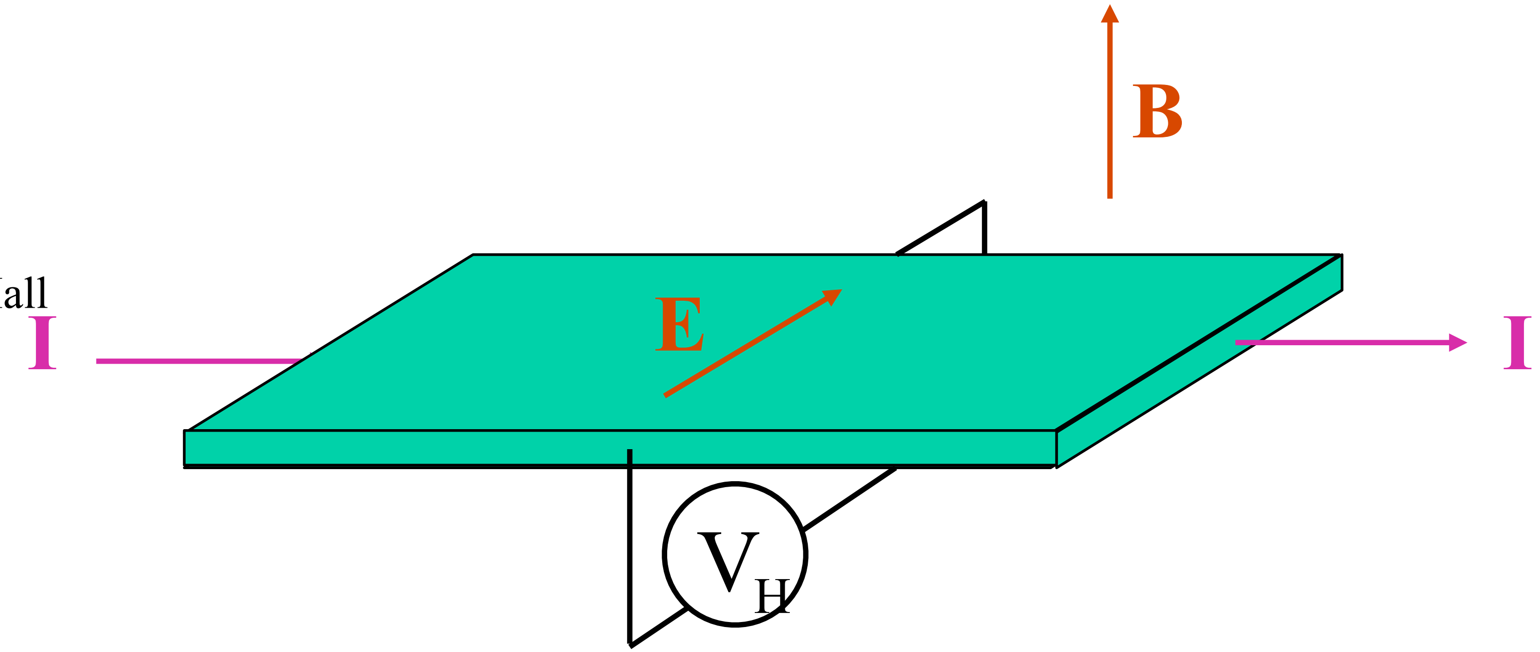
Georg
Simon Ohm
(1787-1854)



$$V = IR \qquad \mathbf{E} = \rho \mathbf{J}$$

Edwin Herbert Hall
(1855 - 1938)

Hall effect (1879)



- In a magnetic field, electrons move perpendicular to the electric field due to the Lorentz force.

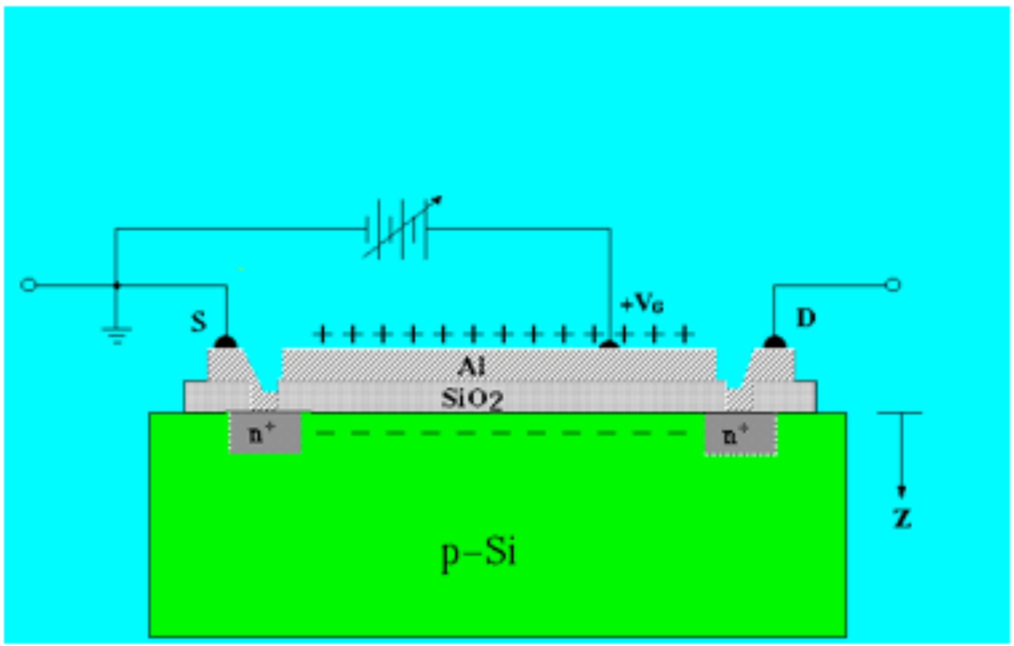
- A new resistance can be defined:

$$R_H \equiv \frac{V_H}{I} = \frac{B}{\rho e c}$$

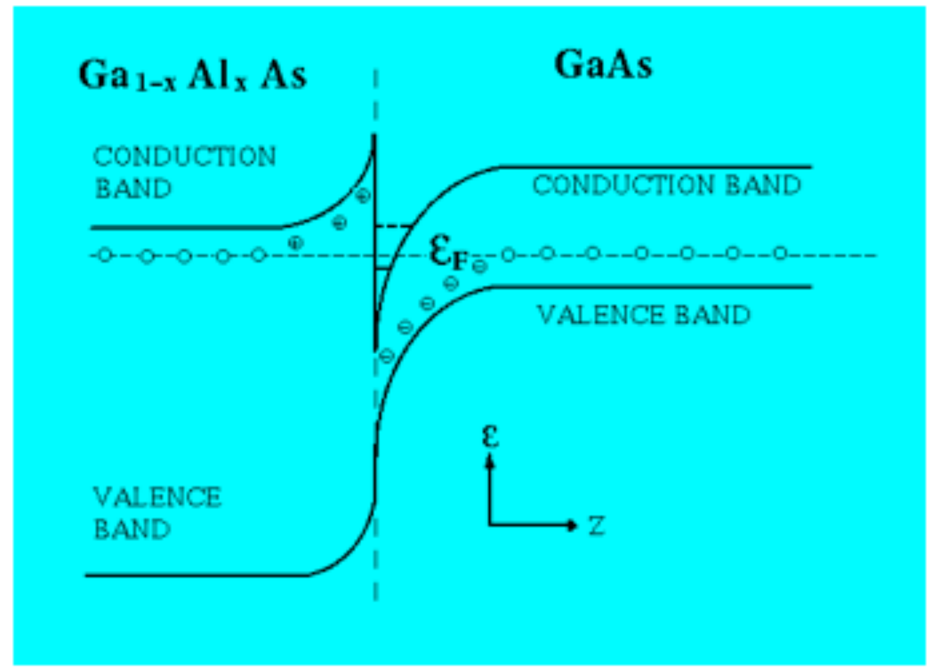
classical result

Two dimensional electron systems

MOSFET
(metal oxide semiconductor field effect transistor)



Semiconductor Heterostructures
(MBE; with modulation doping)



An electric field perpendicular to the interface creates an inversion layer, where, for appropriate parameters, electrons' transverse degrees of freedom are frozen.

http://www.pha.jhu.edu/~qiuym/qhe/node3.html

VOLUME 45, NUMBER 6 PHYSICAL REVIEW LETTERS 11 AUGUST 1980

New Method for High-Accuracy Determination of the Fine-Structure Constant Based on Quantized Hall Resistance

$\alpha = e^2/\hbar c$

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Hochfeld-Magnetlabor des Max-Planck-Instituts für Festkörperforschung, F-38042 Grenoble, France

and

G. Dorda
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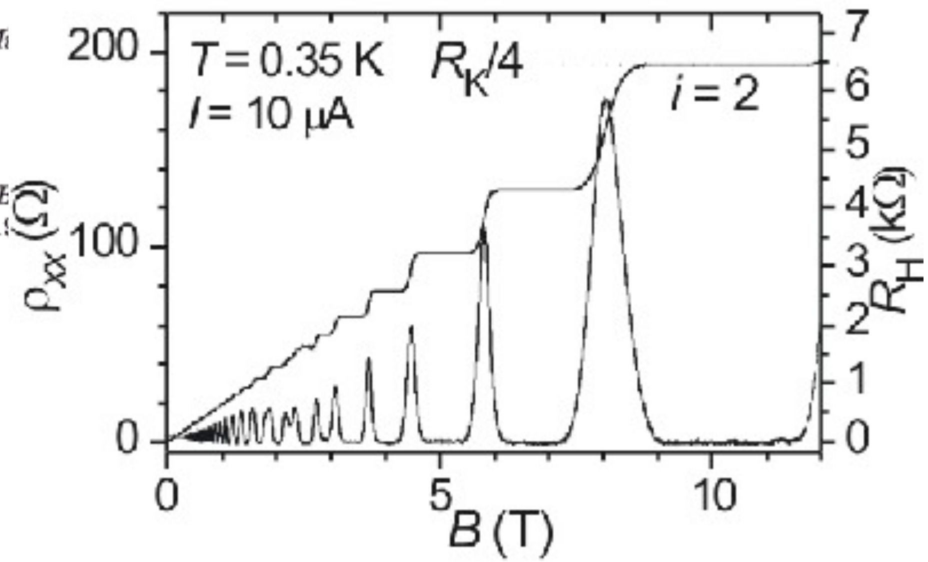
and

M. Pepper
Cavendish Laboratory, Cambridge CE
(Received 30 May 1



Integral quantum Hall effect

$$\boxed{R_H = \frac{h}{ie^2}}$$

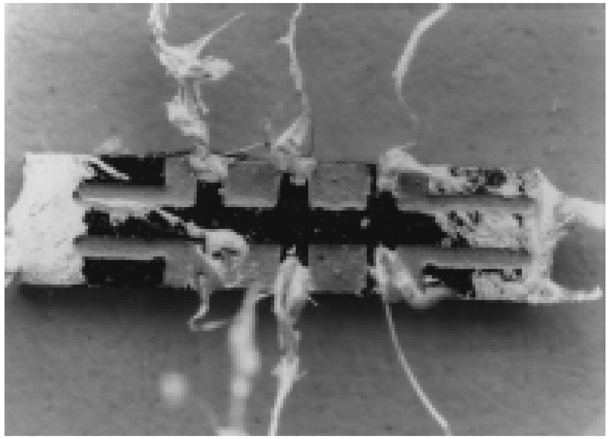
- **Relative accuracy of quantization: 3 parts in 10 billion. (One of the most accurate measurements of the fine structure constant.)**
- **Universal effect, independent of sample type, geometry, or disorder.**
- **Quantum effect.**

$$\alpha^{-1} = \frac{\hbar c}{e^2} = 137.03600300(270)$$

Metrology
Klitzing: New unit of resistance

$$R_K = \frac{h}{e^2} = 25812.807449(86)\Omega$$

$$\alpha^{-1} = \frac{\hbar c}{e^2} = 137.03600300(270)$$



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Two-Dimensional Magnetotransport in the Extreme Quantum Limit

D. C. Tsui,[a],[b] H. L. Stormer,[a] and A. C. Gossard
Bell Laboratories, Murray Hill, New Jersey 07974
(Received 5 March 1982)

FQHE: The discovery

$$R_H = \frac{h}{\frac{1}{3}e^2}$$

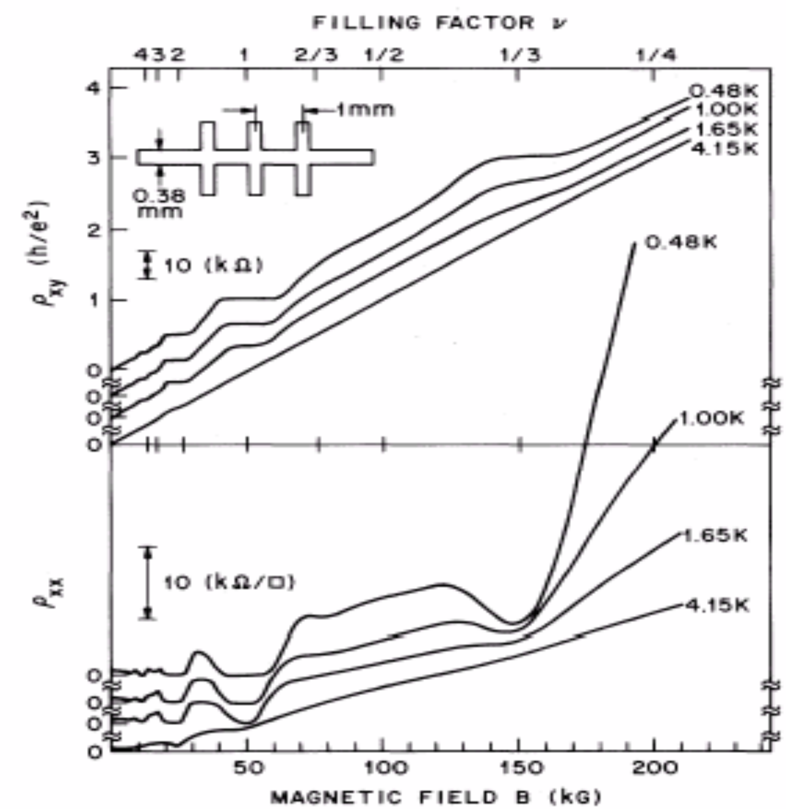
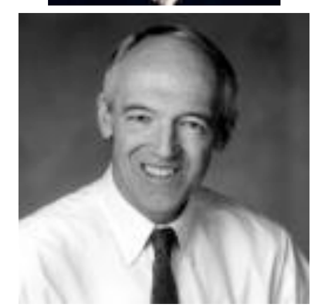


FIG. 1. ρ_{xy} and ρ_{xx} vs B, taken from a GaAs-$Al_{0.3}$-$Ga_{0.7}As$ sample with $n = 1.23\times10^{11}/cm^2$, $\mu = 90\,000\ cm^2/V\ sec$, using $I = 1\ \mu A$. The Landau level filling factor is defined by $\nu = nh/eB$.



Theory of 1/3 FQHE

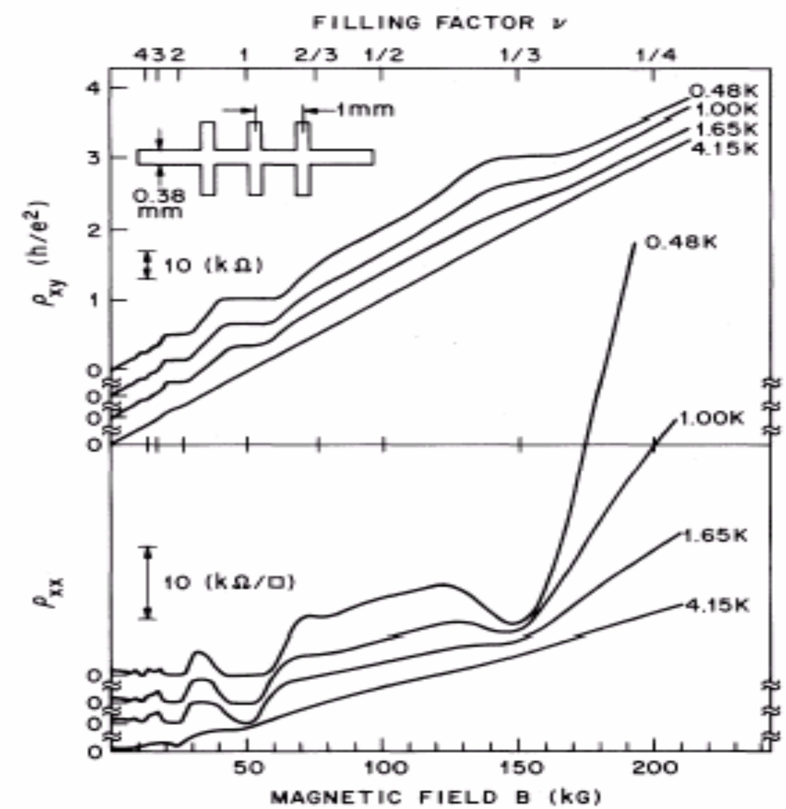
Laughlin, 1983

wave function at 1/m (m odd integer)

$$\Psi_{1/m} = \prod_{j<k} (z_j - z_k)^m \exp[-\frac{1}{4}\sum_l |z_l|^2]$$

$$z_j = x_j + iy_j$$

This was just the beginning…



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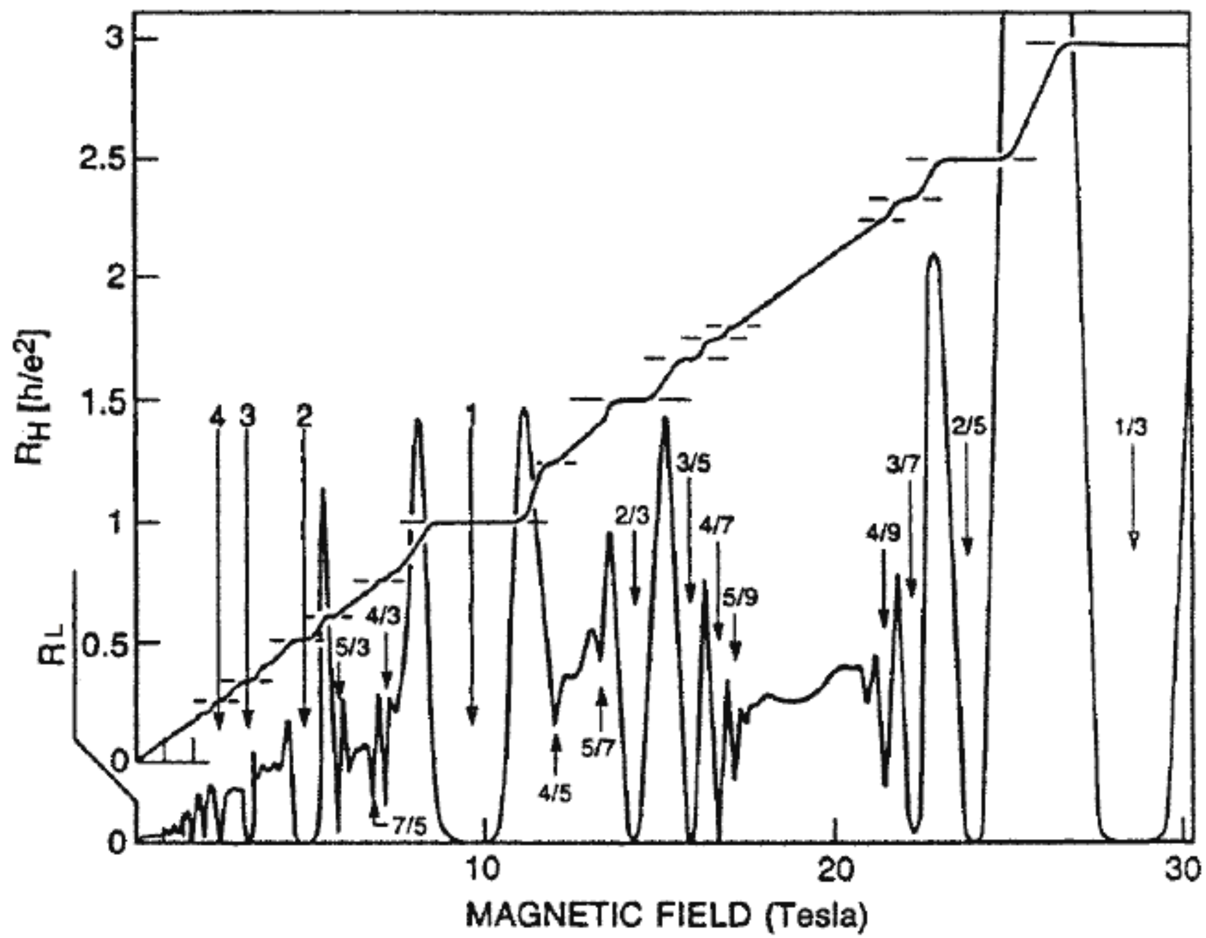
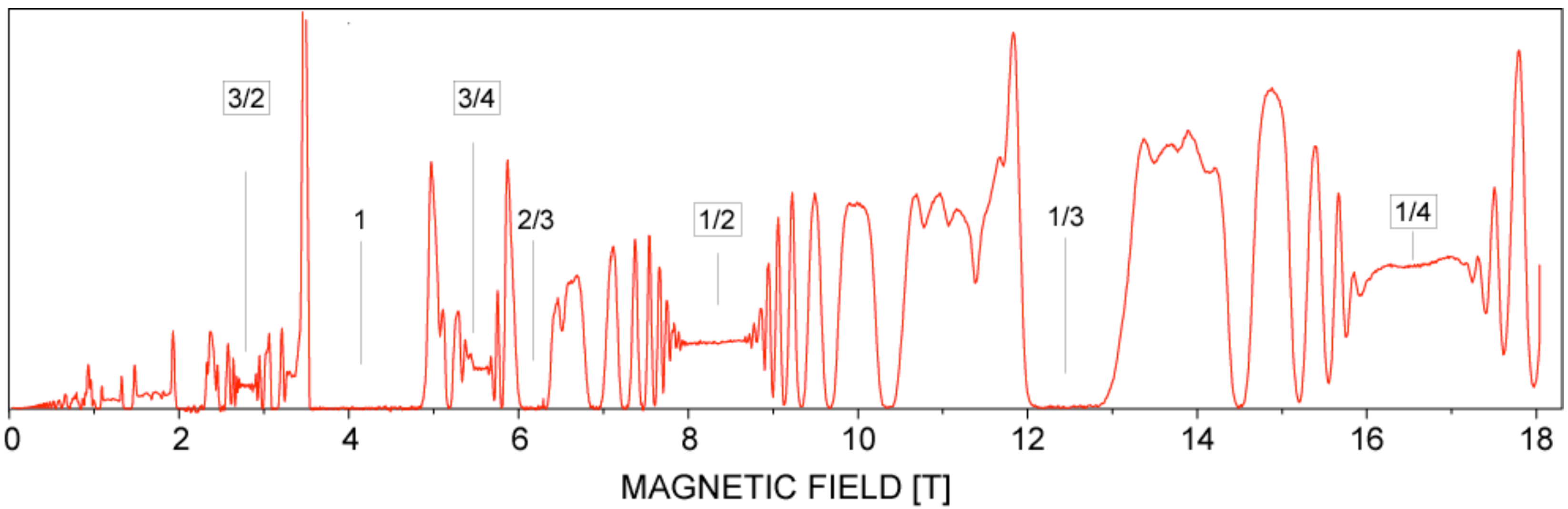
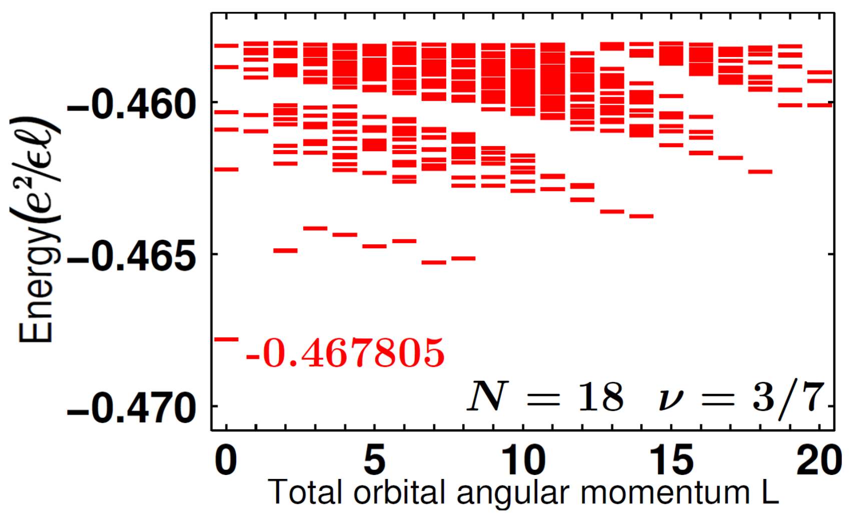


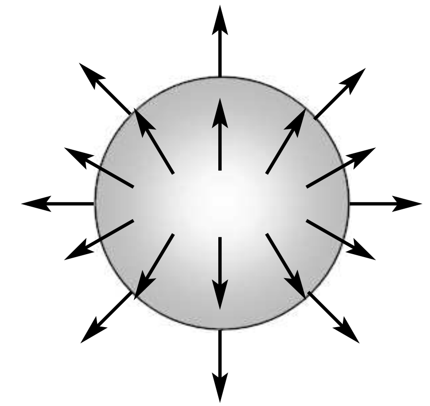
R_H [h/e^2]
R_L
3
2.5
2
1.5
1
0.5
0
0
10
20
30
MAGNETIC FIELD (Tesla)
4
3
2
1
5/3
4/3
7/5
4/5
5/7
2/3
3/5
4/7
5/9
4/9
3/7
2/5
1/3

The FQHE is a data rich field



- There are 80+ fractions. The number of FQHE states is actually much larger, because, in general, many FQHE states with different spin polarizations occur at each fraction.
- Experiments have measured the energy gaps, collective modes, spin polarizations, spin wave excitations, transport coefficients, etc. for many of these FQHE states.
- The 1/2 Fermi sea is a part of a broad range of closely interconnected phenomenology.





In addition, there is a huge amount of exact computer data…

questions for theory

- Should explain the physical mechanism of the FQHE.
- Should explain the essential phenomenology in a qualitative fashion.
- Should enable calculations of various experimentally measured quantities.
- ~~Ideally, we would like to have exact solutions for all eigenstates at arbitrary filling factors in the lowest Landau level. (This is impossible, and not even desirable.)~~
- Should give accurate solutions (eigenfunctions and eigenenergies) for all low-energy eigenstates (defined later) at arbitrary filling factors in the lowest Landau level.
- Should be simple. As few adjustable parameters as possible.
- Elegance is desirable thought not necessary.
- Should suggest brand new questions and make additional new nontrivial predictions.