

EEFK1 – Lecture 2

Matthieu Le Tacon

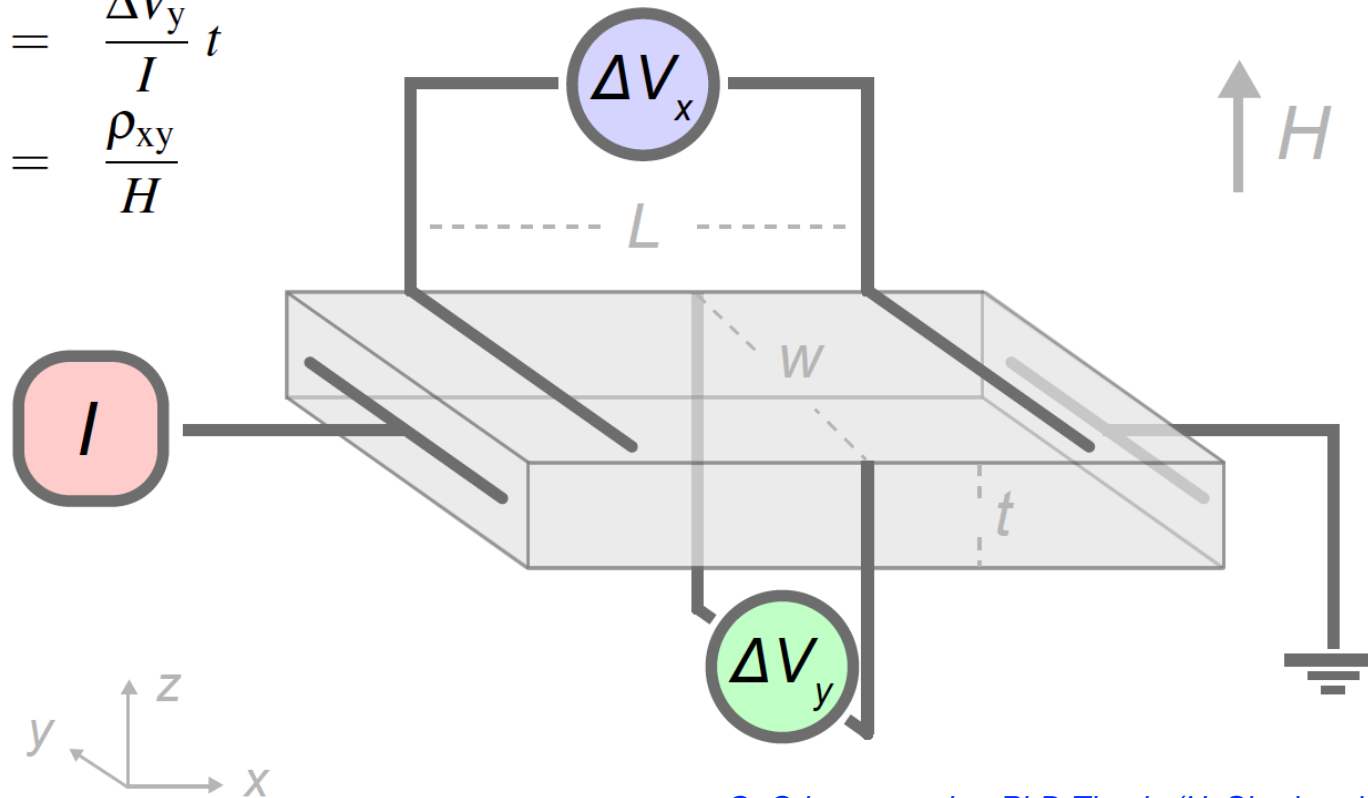


Transport Coefficients

	B = 0, M = 0	
	$\hat{E} = -\nabla\phi_{el}$	$-\nabla T$
J_q	Electrical Conductivity ($\vec{\sigma}$) or resistivity ($\vec{\rho}$)	Seebeck-Effect (S)
J_H	Peltier-Effect (P)	Heat Conductivity ($\vec{\kappa}$)
	B ≠ 0	
	$-\nabla\phi_{el} \times \hat{B}$	$-\nabla T \times \hat{B}$
J_q	Magnetoresistance $\rho_{xx}(B)$ Hall Effect (R_H)	Nernst Effect (N)
J_H	Ettinghausen-Effect	Thermal Hall Effect

Electrical Transport

$$\rho_{xx} = \frac{\Delta V_x}{I} \alpha \quad \text{Geometrical factor: } \alpha = \frac{wt}{L}$$
$$\rho_{xy} = \frac{\Delta V_y}{I} t$$
$$R_H = \frac{\rho_{xy}}{H}$$

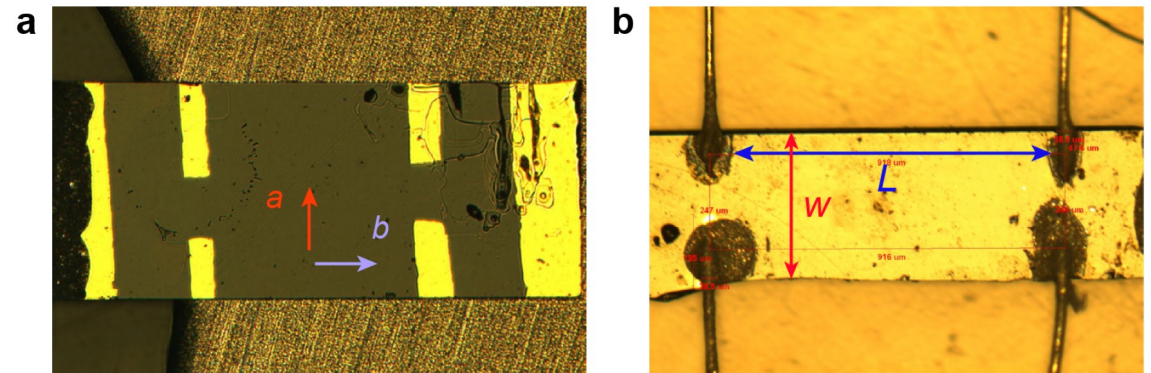


G. Grissonnanche, PhD Thesis (U. Sherbrooke)

Electrical Transport

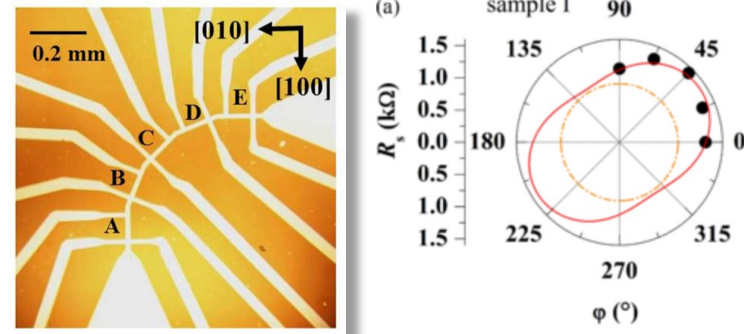
Contacts for resistivity and Hall measurements on a high-temperature superconductor single crystal

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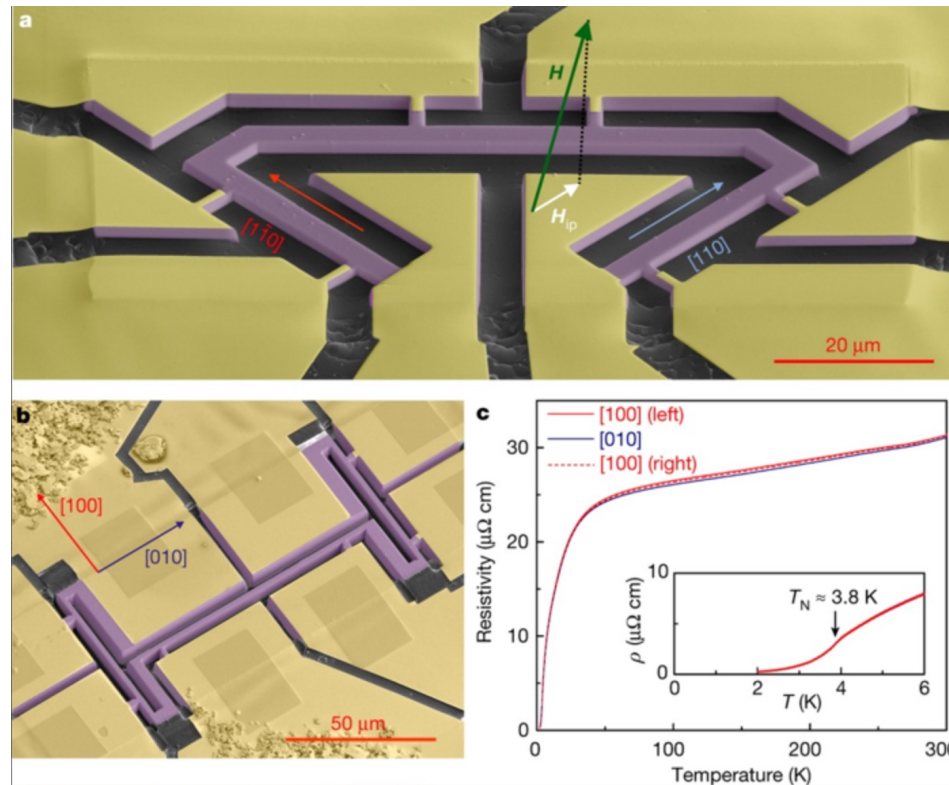


Contacts for angle-resolved resistivity measurements on 2D electron-system $\text{SrTiO}_3/\text{LaAlO}_3$

Wolff et al. Phys. Rev. B 95, 245132 (2017)

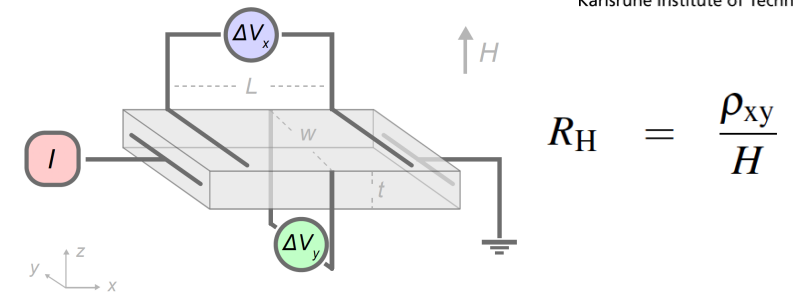
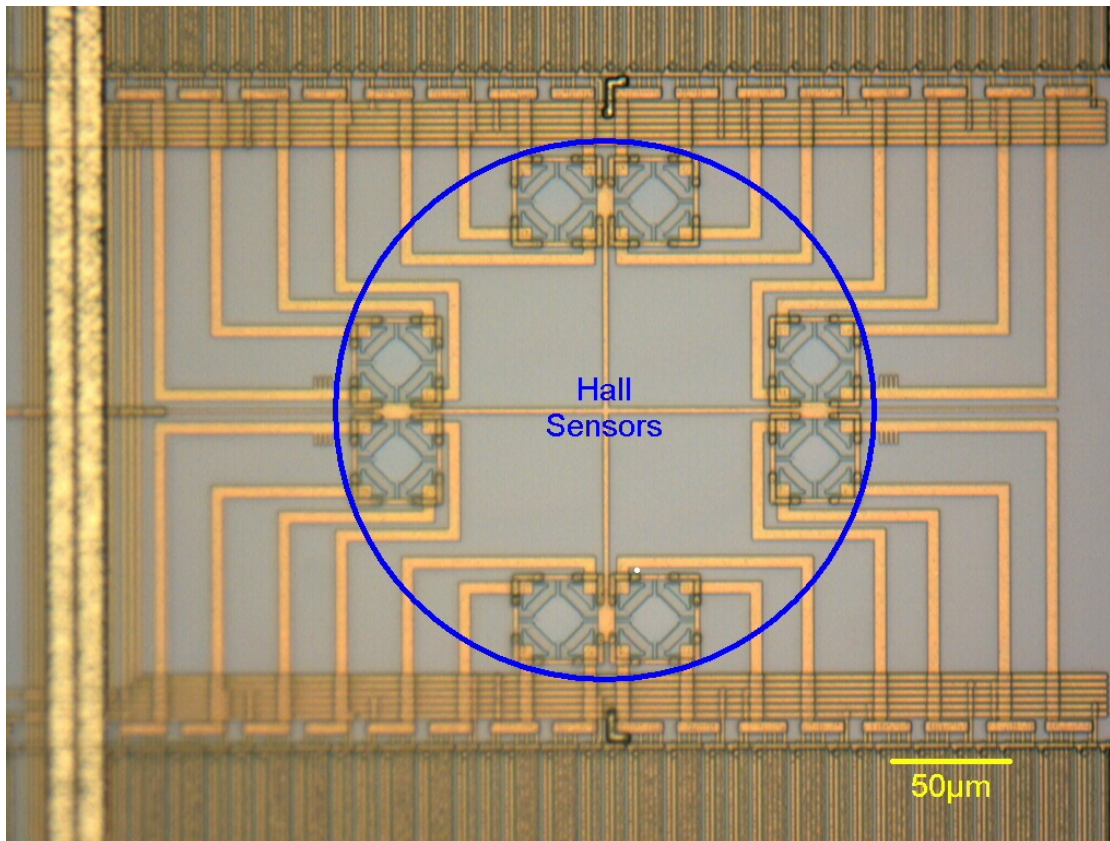


Electrical Transport



Electronic in-plane symmetry breaking at field-tuned quantum criticality in CeRhIn₅
F. Ronning et al. *Nature* **548**, 313–317 (2017)

Practical use of Hall effect



Compass

Quantum Hall Effect (v. Klitzing 1980)

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

K. v. Klitzing

*Physikalisches Institut der Universität Würzburg, D-8700 Würzburg, Federal Republic of Germany, and
Hochfeld-Magnetlabor des Max-Planck-Instituts für Festkörperforschung, F-38042 Grenoble, France*

and

G. Dorda

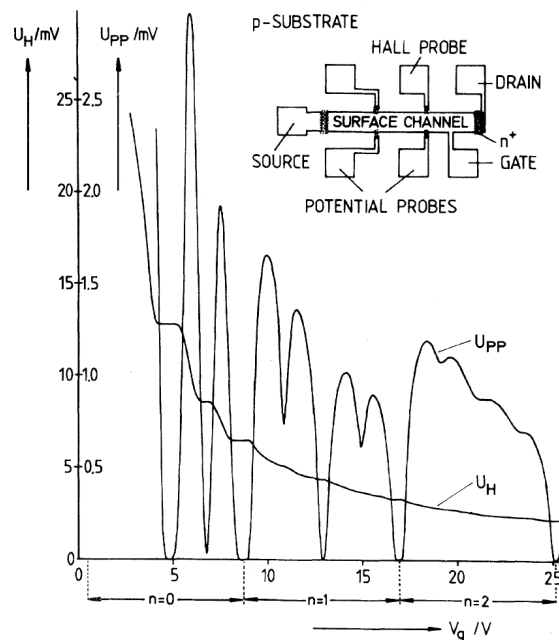
Forschungslaboratorien der Siemens AG, D-8000 München, Federal Republic of Germany

and

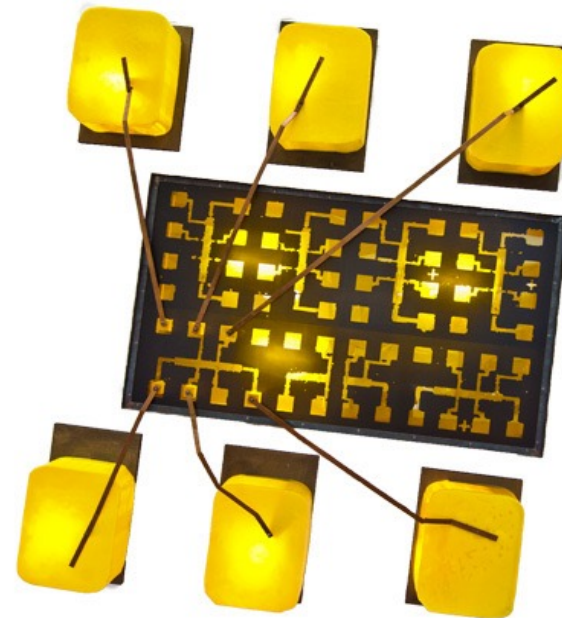
M. Pepper

Cavendish Laboratory, Cambridge CB3 0HE, United Kingdom

(Received 30 May 1980)



Nobel Prize contacts



$$\sigma = \frac{I_{\text{channel}}}{V_{\text{Hall}}} = \nu \frac{e^2}{h}$$

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New definition of units in Physics

THE NEW DEFINITIONS OF UNITS IN PHYSICS

THE KILOGRAM (kg) INSTRUCTION MANUAL

PREREQUISITES

- Classical mechanics theory x1
- Quantum physics theory x1

WHAT YOU NEED

- Big trash x1
- second meter Unit x2
- Material to build a Watt balance
- Quantum effect with steps x2

$h = 6.626\,070\,15 \times 10^{-34} \text{ J}\cdot\text{s}$
Planck's constant

1 DISCARD OLD METHODS

Between 500 and 600,000 BC
Shape stones to create weights (animal shapes authorized)

1795 Measure the mass of a kilogram of distilled water at 4°C

With this value, build a kilogram prototype in platinum and iridium and protect it.

2 BUILD FROM 2018

A Build a Watt balance
On one side of a scale, put the weight you want to measure. On the other side put an electrical coil and a magnetic field.

Cause a current to flow through the coil, this creates a force which counterbalances the weight. Measure the current using the quantum phenomena Hall effect and Josephson effect (see "The Ampere Manual instruction" for details).

Move the coil vertically at constant speed v . Measure the induced voltage with Josephson effect.

B The mass is just a function of these two measures and the Planck constant (h). Force the constant value (h). Then deduce the mass: you obtain your new prototype.

$h = 6.626\,070\,15 \times 10^{-34} \text{ J}\cdot\text{s}$

3 SHARE

Duplicate the kilogram you built for the entire world.

Sort your waste for recycling!

THE NEW DEFINITIONS OF UNITS IN PHYSICS

THE AMPERE (A) INSTRUCTION MANUAL

PREREQUISITES

- Quantum Hall effect / Nobel Prize x2
- Ohm's law x1

WHAT YOU NEED

- Big trash x1
- second Unit x1
- Material to build a superconducting Josephson junction
- Electromagnetic waves x1
- Magnetic field x1

$e = 1.602\,176\,634 \times 10^{-19} \text{ C}$
electric charge of the electron

$R_H = \frac{h}{e^2}$
Physics formula x2

1 DISCARD OLD METHODS

1906 Measure the force acting between two wires 1 m apart and carrying a constant electrical current. When this force equals 2×10^{-7} Newton per meter, the current is worth 1 ampere.

$I = \frac{F}{\mu_0} = \frac{F}{2 \times 10^{-7} \text{ N}\cdot\text{m}^{-1}}$

2 BUILD FROM 2018

A Measure the Quantum Hall effect
Cause an electrical current to flow through a thin metallic layer, and place this layer in a magnetic field.

A transversal resistance (R_H) will appear in the shape of steps. Measure the highest one which equals to:

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

B Measure the Josephson effect
Take a superconducting-insulating-superconducting sandwich. Add some electromagnetic waves at the frequency (ν) and cause an electric current to flow.

A voltage (V_J) will appear in the shape of steps. Measure any of them which equals to:

$V_J = \frac{h \nu}{2e}$

C Deduce the ampere from your measures. Find a current (i) thanks to Ohm's Law.

$i = \frac{V_J}{R_H} = \frac{e \nu}{2}$

3 SHARE

Duplicate the ampere you built for the entire world.

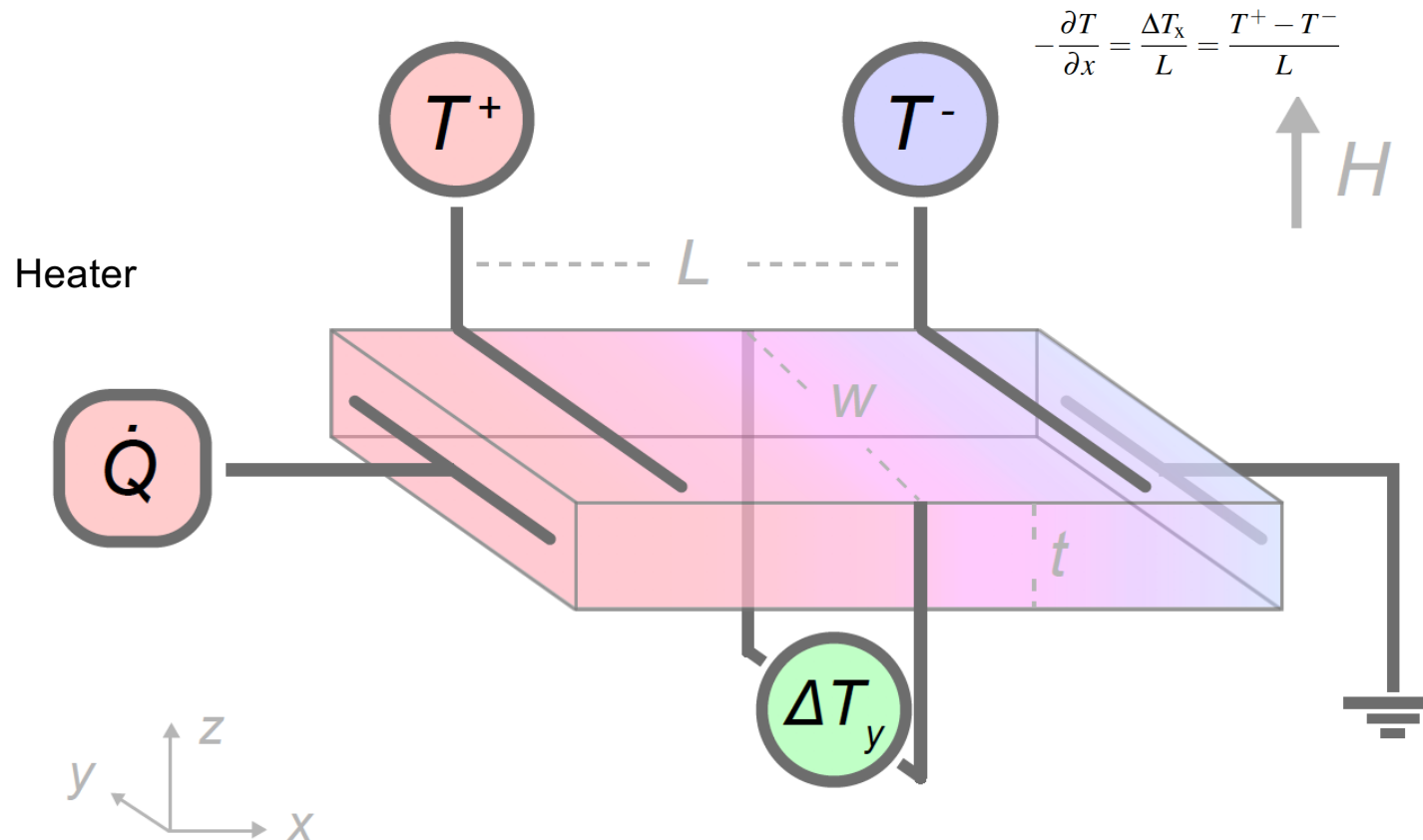
Sort your waste for recycling!

Outreach project by Julien Bobroff

http://hebergement.u-psud.fr/supraconductivite/projet/unitas_mode_demploi/?lang=en

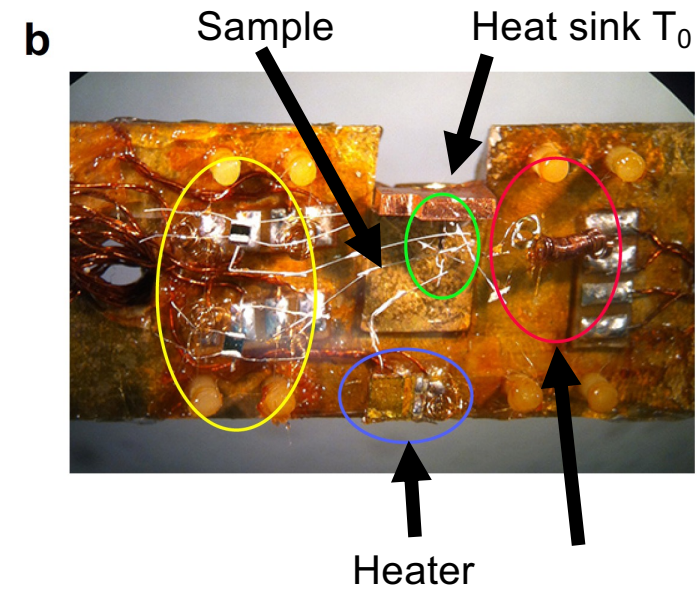
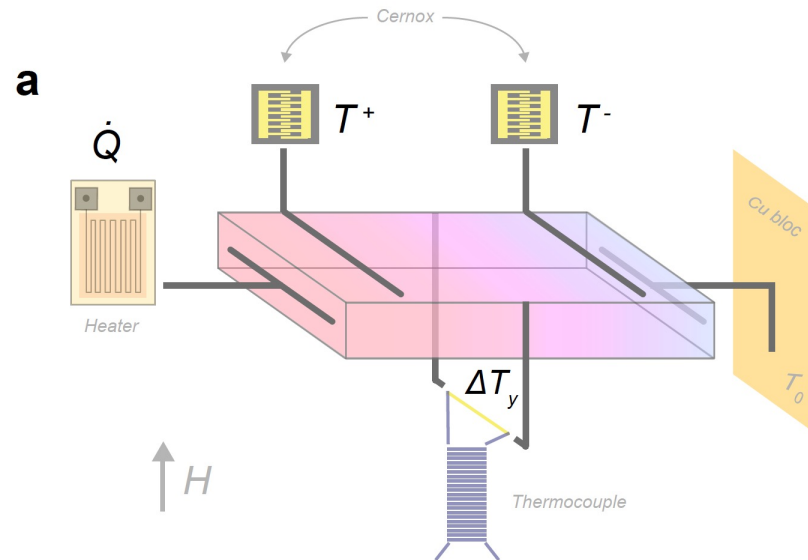
Thermal Transport

$$\begin{pmatrix} j_{Q,x} \\ 0 \end{pmatrix} = - \begin{pmatrix} \kappa_{xx} & \kappa_{xy}(H) \\ -\kappa_{yx}(H) & \kappa_{yy} \end{pmatrix} \begin{pmatrix} \frac{\partial T}{\partial x} \\ \frac{\partial T}{\partial y} \end{pmatrix}$$



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Thermal Transport

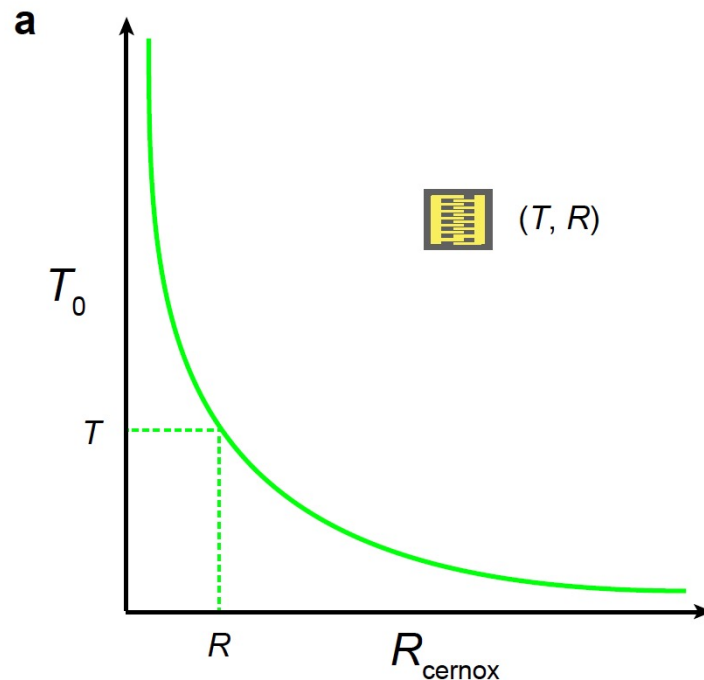


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Application: Thermometry

Cernox

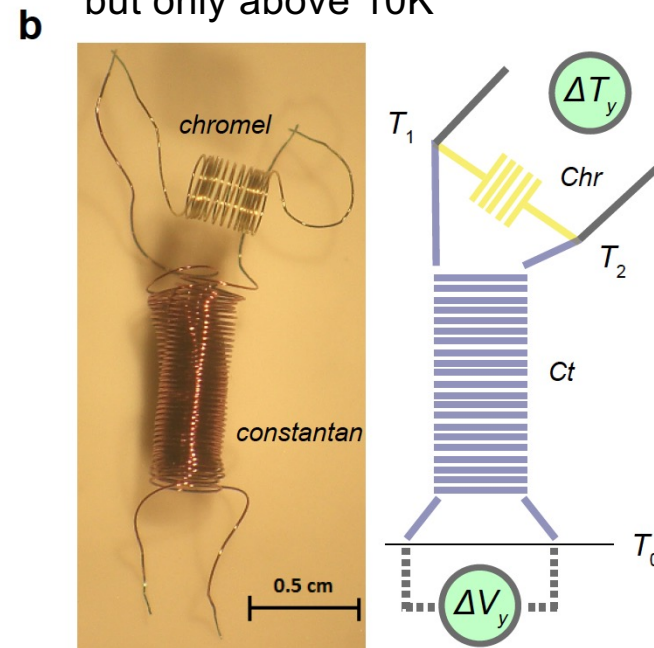
1-100K very sensitive (calibration!)
But strong magnetoresistance



Thermocouples

$$\Delta T_y = - \frac{\Delta V_y}{S_{\text{ther}}(T)}$$

Very sensitive ($\Delta T \sim \text{mK}$)
but only above 10K



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Hall Effect

Metal	Observed R_H	Calculated R_H	j
Li	-17.0	-13.1	1
Na	-25.0	-24.4	1
Cu	-5.5	-7.4	1
Ag	-8.4	-10.4	1
Zn	+4.1	-4.6	2
Cd	+6.0	-6.5	2

Table 1.1: Observed and calculated values of the Hall coefficient R_H in units of $10^{-11} \text{m}^3 \text{C}^{-1}$ for several metals. The calculated values assume j free electrons per atom.

Hall Resistivity of Al

