Institut Laue Langevin
Grenoble, France

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Thermoelectricity in mesoscopic devices due to Aharonov-Bohm interference

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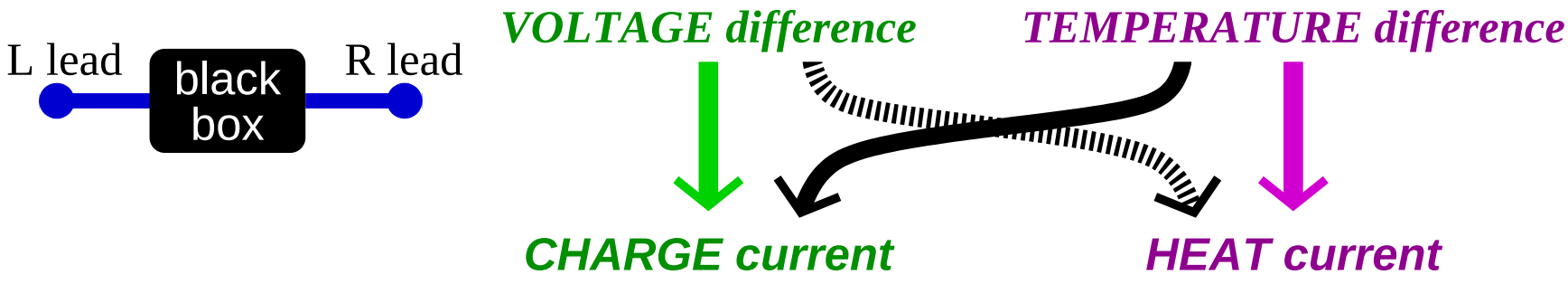
[1] Thermoelectricity ♣ density-of-states
♣ **interference** e.g. Aharonov-Bohm

[2] Nanostructures with SC loops — explain puzzling expts :
Chandrasekhar's group (1998,2009), Petrashov's group (2003)

Ph. Jacquod & R.W. arXiv:0910.2943
see also R.W. & Ph. Jacquod, PRL **103**, 247002 (2009)

THERMOELECTRICITY — Peltier or Seebeck effect



APPLICATIONS at nanoscale (sub-Kelvin):

♣ Refrigeration $\Longrightarrow$ colder than cryostat ?

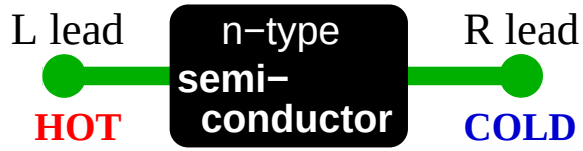
Expts: Courtois-Pannetier Group

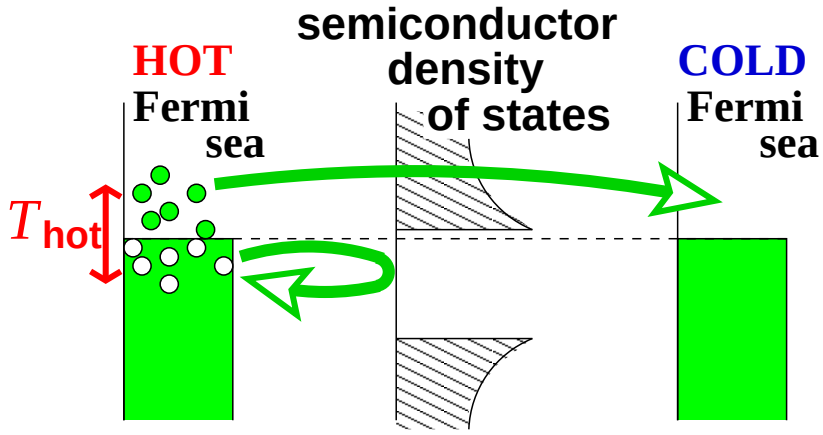
♣ Novel transport probe of nanostructures

$\Longrightarrow$ **difference** between physics at $(E_{\rm F} + k_{\rm B}T)$
and at $(E_{\rm F} - k_{\rm B}T)$

ORIGINS OF THERMOELECTRICITY

DENSITY OF STATES

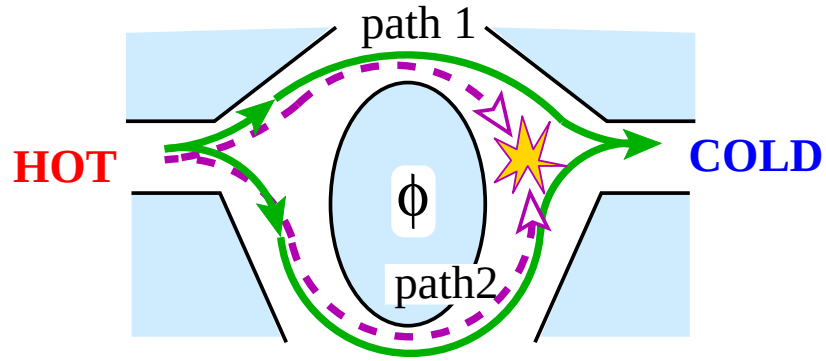




SUB-KELVIN: semicond→*SUPERCOND*

Expt: Courtois-Pannetier Group

INTERFERENCE: coherence ⇒ only sub-Kelvin



PHASE-DIFFERENCE:

$$\Phi = \mathrm{p}(l_2 - l_1) + \phi$$

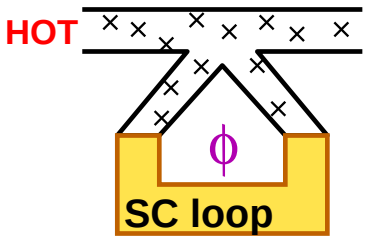
with $\mathrm{p} \propto \sqrt{\text{ENERGY}}$

Electrons – ***contructive***

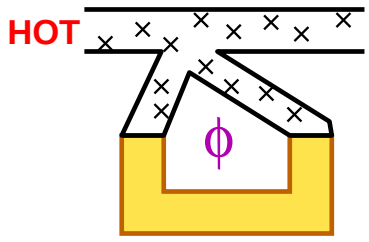
Holes – ***destructive***

PUZZLING EXPTS on THERMOPOWER

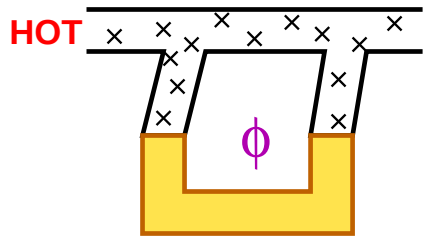
house (1998)
Chadrasekhar's group



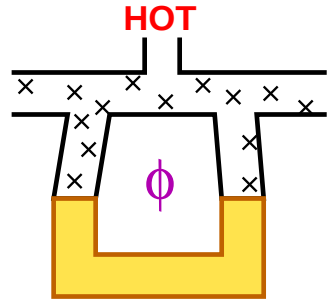
asym. house (2003)
Petrashov's group



parallelogram (1998)
Chadrasekhar's group



hot−middle (2009)
Chadrasekhar's group



EVEN in ϕ

ODD in ϕ

PREVIOUS THEORY: quasiclassical *"Usadel equations"*

Virtanen-Heikilla (2004-07), Titov (2008)

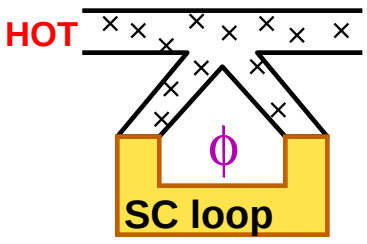
Thermopower **ALWAYS** odd in ϕ

& will **VANISHES** in symmetric case; i.e. house

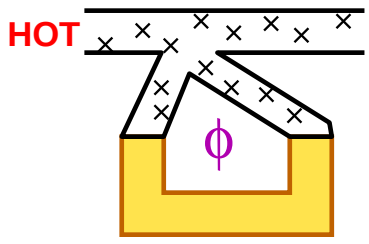
... BUT theory misses mesoscopic fluctuations

FULLY QUANTUM THEORY — random matrix theory or semiclassics

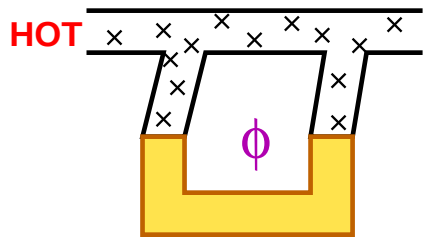
house (1998)
Chadrasekhar's group



asym. house (2003)
Petrashov's group



parallelogram (1998)
Chadrasekhar's group



hot−middle (2009)
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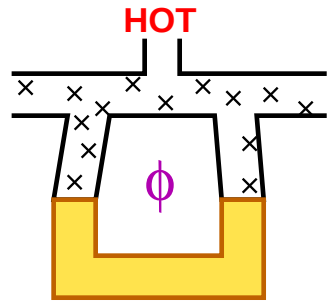
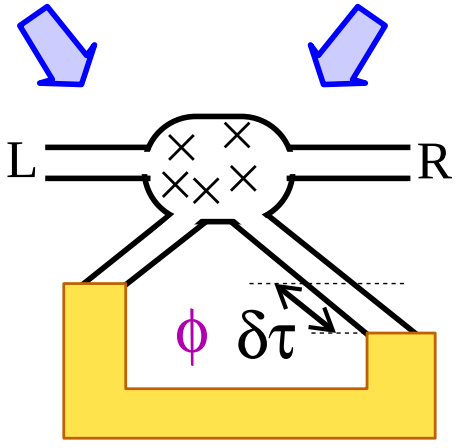
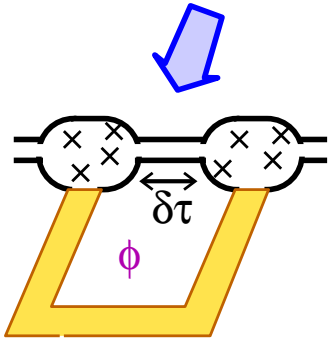
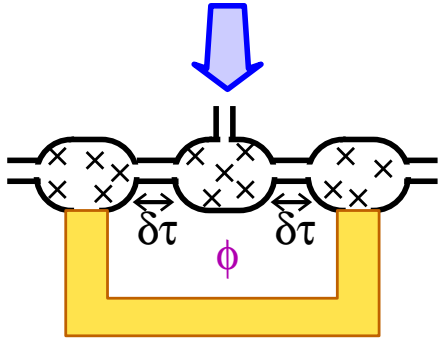
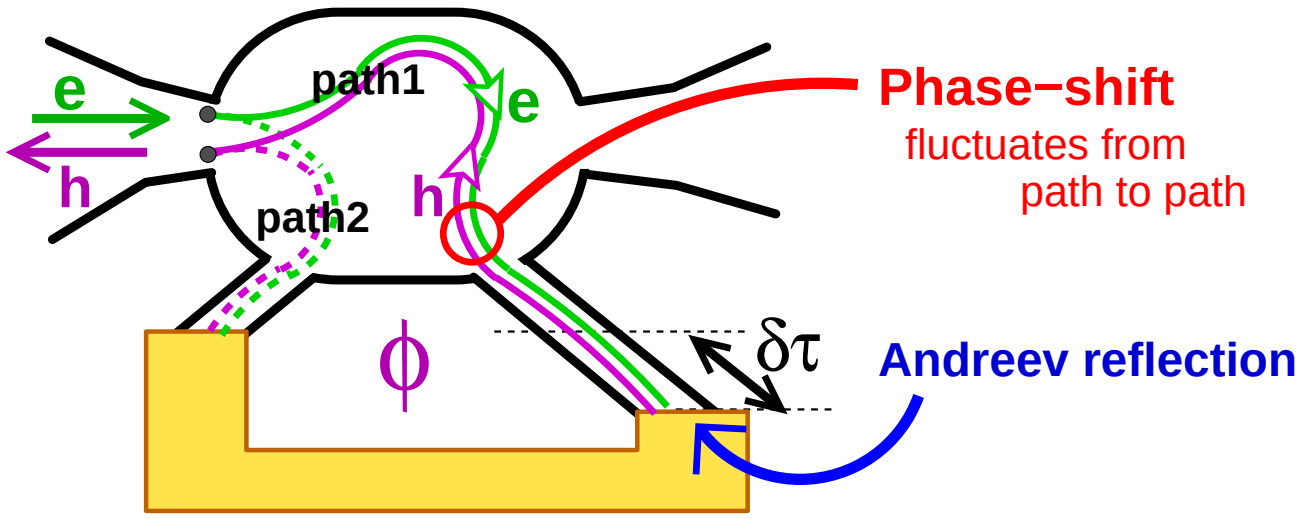








THEORY $\Longrightarrow$ HAND-WAVING PICTURE



AVERAGE: **e $\Rightarrow$ h** **h $\Rightarrow$ e**

$$\cos\left[2\epsilon\,\delta\tau + \phi\right] - \cos\left[2\epsilon\,\delta\tau - \phi\right] \Longrightarrow \cancel{\text{ODD}}\ \text{in}\ \phi$$

SAMPLE-TO-SAMPLE FLUCTUATIONS:

$$\cos\left[(2\epsilon\,\delta\tau + \Delta_{\mathrm{e+h}}) + (\phi + \Delta_{\mathrm{e-h}})\right] - \cos\left[(2\epsilon\,\delta\tau + \Delta_{\mathrm{e+h}}) - (\phi + \Delta_{\mathrm{e-h}})\right]$$

$\Longrightarrow$ $\cancel{\text{ODD}}$ & EVEN but small

For sym. house: **symmetry kills ODD terms**

OVERVIEW : NANO-THERMOELECTRICITY

PHYSICAL ORIGINS:

- ♣ Density of states
- ♣ Interference (need v. low temp)

... anything else??

APPLICATIONS:

- ♣ Refrigeration

NEEDS *BIG* EFFECT

- ♣ Probe of **difference** in physics at $(E_{\rm F} + k_{\rm B}T)$ and $(E_{\rm F} - k_{\rm B}T)$

WORKS WITH *SMALL* EFFECT