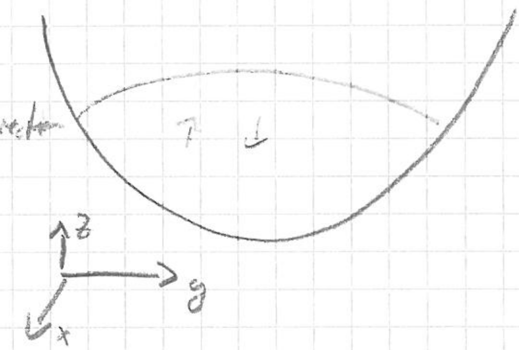
transport like experiments

slide

here only experiment by T. Esslinger's group (design N. Moritz)

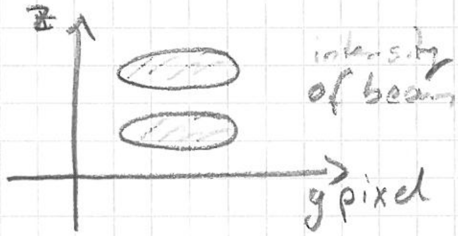
<u>setup</u>: ^{6}Li atoms mixture of lowest 2 third hyperfine state

dipole trap:
elongated in y-direction



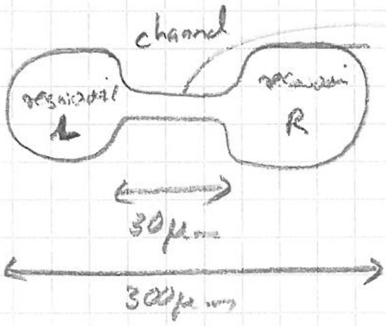
$N \sim 10^5$ atoms
$T \sim 0{,}29\, T_F$

blue detuned laser beam with TEM_{01} mode profile
transversal electromagnetic

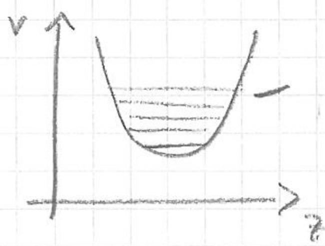


slide 1 ✓ 2013/boulder/transport 2013

↳



very squeezed in z-direction
approx harmonic trapping ω_z



50-200 modes occupied

basic setup
in particular good optical resolution for channel

what can one do ?

channel : different potentials possible

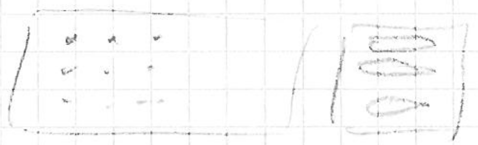
- ballistic channel, ~3D, 2D, 1D, quantum dot or several quantum dots, lattice

- disorder potential
  projection of speckle pattern onto the channel (line disorder)
  for characterisation of such disorder see ref A. Aspect

ref

slide 2
example Fig 4.1 / 4.6 Markete

transport



initial preparation :

- application of gradient (magnetic field) to create particle imbalance in preparation step

- temperature imbalance

stir one cloud with additional laser beam

interaction

tune scattering length by applicational magnetic field
globally applied
effective scatting by different geometries (confinement induced resonances)

possible probes:

- N_L, N_R by absorption images (block → harmonic trap)
- T_L, T_R " "
- locally resolved line density in channel, resolution 1,2 µm/pixel (fluctuations, ...)

difference to solids:

- no 'real' steady state, transient behaviour ← copy picture of next page
- no thermal bath, 'high' temperature
- reservoirs also interacting ⇔ B
- thermodynamic effects of reservoirs play important role

experiments

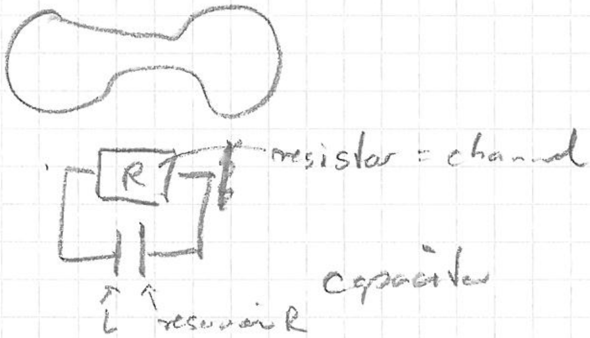
1) slide 3 mass transport Science 337, 1069

2) superfluid Nature 491, 736

fountain effect (?)

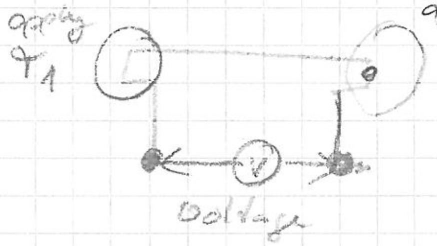
3) thermoelectric effects

theoretical description:



transport corresponds to discharge of capacitor

Seebeck effect



apply a thermal gradient at the ends of an open circuit

↳ induces a finite voltage difference

$$\Delta V = - \alpha \, \Delta T$$

α: Seebeck coefficient

qualitative picture:

electric field is established

if negative carriers ↳ $E \propto -\nabla T$

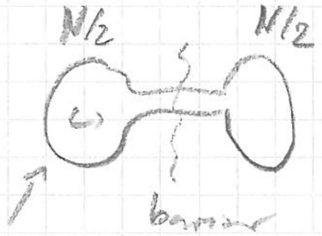
positive $E \propto \nabla T$

useful probe of nature of carriers

slide on jhed instruments

Analogue of Seebeck in cold atoms

no charge ⇝ mass plays the role



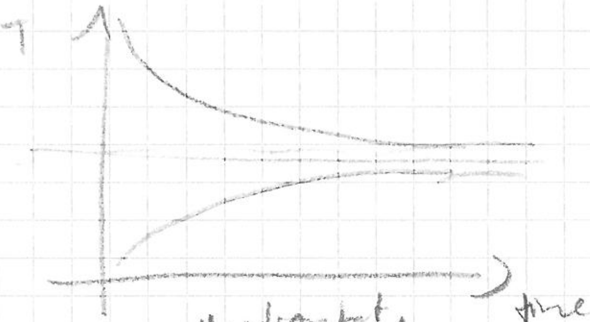
hot cloud expands

⇝ chemical potential

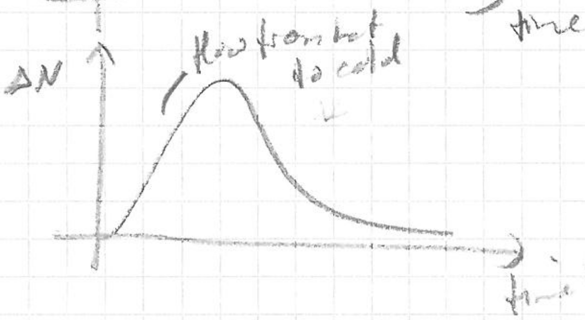
stir additional laser to heat one of the reservoirs

∴ remove barrier

let system evolve



temperature relaxes



particle imbalance arises & relaxes back

~~flow~~

first flow from hot to cold against chemical potential of reservoirs due to thermoelectric power of channel

due to the energy dependent transmission of the channel theoretical description

$$\begin{pmatrix} I_N \\ I_S \end{pmatrix} = -G \begin{pmatrix} 1 & \overset{\text{seebeck coeff}}{\alpha_{ch}} \\ \alpha_{ch} & L + \alpha_{ch}^2 \end{pmatrix} \begin{pmatrix} \overset{\text{chemical potential}}{\mu_c - \mu_h} \\ T_c - T_h \end{pmatrix}$$

$I_N = \frac{\partial \Delta N}{\partial t}$, $\Delta N = N_c - N_h$

$I_S = \frac{\partial \Delta S}{\partial t}$, $\Delta S = S_c - S_h$

$L = \frac{G_T}{T G}$ Lorenz number

need to take care of reservoirs

$$\kappa G^{-1} \frac{d}{dt} \begin{pmatrix} \Delta N \\ \Delta T \end{pmatrix} = - \begin{pmatrix} 1 & -\kappa(\alpha_r - \alpha_{ch}) \\ -\frac{\alpha_r - \alpha_{ch}}{l\kappa} & \frac{L + (\alpha_r - \alpha_{ch})^2}{l} \end{pmatrix} \begin{pmatrix} \Delta N \\ \Delta T \end{pmatrix}$$

κ compressibility $\left(\frac{\partial N}{\partial \mu}\Big|_T \right)$

$\alpha_r = \frac{\partial S}{\partial N}\Big|_T$ dilatation coefficient

$l = \frac{c_V}{\kappa T}$ analogue of Lorenz number

typically in solid α_r small since temperature very low

need to determine parameters

take reservoir free fermions $\Leftrightarrow$ can calculate all params

channel ballistic: all params can be calculated

disorder: ~~effe~~ effective approach

slides for results

channel Landauer Büttiker formalism

$$\text{conductance} \quad G = \frac{1}{h}\int_0^\infty d\varepsilon \; \phi(\varepsilon)\left(-\frac{\partial f}{\partial \varepsilon}\right)$$ — fermi function $f(\varepsilon) = \frac{1}{1+e^{\beta(\varepsilon-\mu)}}$

$$T \alpha_{ch} G = \frac{1}{h}\int_0^\infty d\varepsilon \; \phi(\varepsilon)\,(\varepsilon-\mu)\left(-\frac{\partial f}{\partial \varepsilon}\right)$$ ← measures energy dependent transport

$$\frac{G_T}{T} + G\alpha_{ch}^2 = \frac{1}{h}\int_0^\infty d\varepsilon \; \phi(\varepsilon)\,(\varepsilon-\mu)^2\left(-\frac{\partial f}{\partial \varepsilon}\right)$$

transport function

simple interpretation of ϕ no of channels available for a particle having energy ε $\left(G(T=0K) = \frac{\phi(E_F)}{h} \right)$

here:

$$\phi(\varepsilon) = \sum_{n_z}\sum_{n_x}\int_0^\infty dk_y \; \frac{\hbar k_y}{M}\, T(k_y)\, \delta\!\left(\varepsilon - \hbar\omega_x(n_x+\tfrac{1}{2}) - \hbar\omega_z(n_z+\tfrac{1}{2}) - \frac{\hbar^2 k_y^2}{2M}\right)$$

transmission probability

effects of confinement predicted by Dressel/haus

discard exact description of