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Towards a *DEPHASING DIODE*: asymmetric and geometric dephasing

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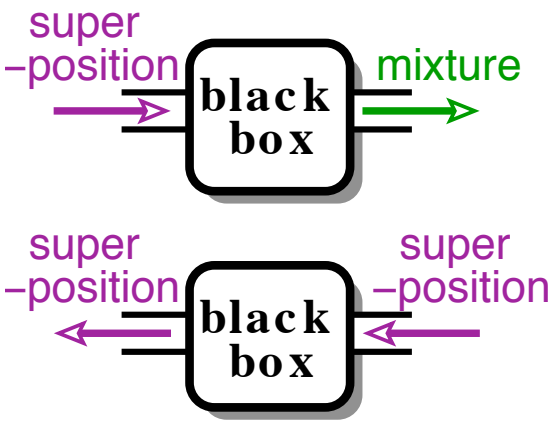
Outline

[1] *DEPHASING DIODE*: asymmetric dephasing of spin



Ingredients:

- ♣ Rashba spin-orbit coupling
- ♣ applied B-field
- ♣ environment ⇒ noise

Satisfy: Onsager relation

[2] *GEOMETRIC DEPHASING*

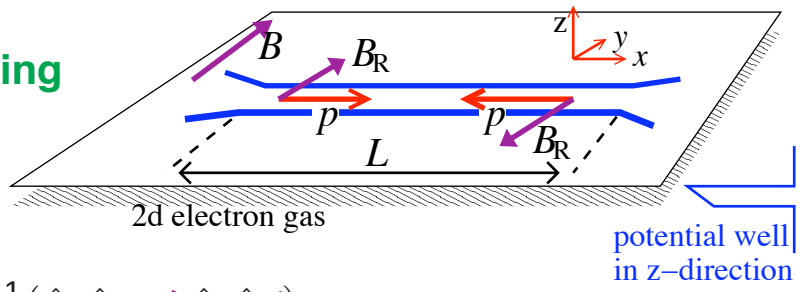
Berry phase ⇒ geometric dephasing or *anti*-dephasing

[3] *CHARGE-TRANSPORT:* Noise-induced asymmetry

Quantum wire with Rashba coupling

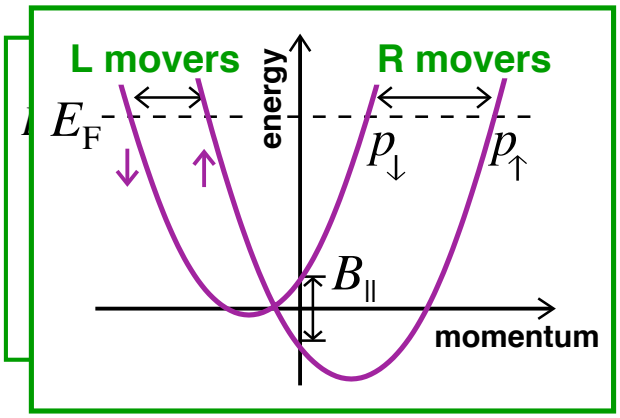
Wire with *Rashba spin-orbit* coupling

i.e. gated Ga/InAs 2DEG



$$\mathcal{H}_{\text{Rashba}} = -(ml_R)^{-1}(\hat{p}_x\hat{\sigma}_y - \hat{p}_y\hat{\sigma}_x)$$

oscillates too fast for spin



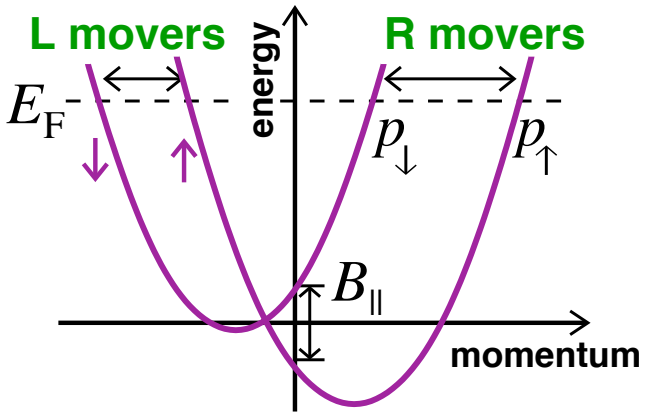
Rashba + applied field
$\Rightarrow$ *asymmetry* in spin-precession rate
$\propto |p_\uparrow - p_\downarrow|$

Environment gives asymmetric dephasing?

ENVIRONMENT $\Rightarrow$ *Noise*

slow $\equiv$ NMR inhomogeneous broadening

- **Noisy B-field**
- **Noisy backgate voltage $\Rightarrow$ noise in *Rashba***



$\Rightarrow$ Noise in *asymmetric* spin-precession rates
$\Rightarrow$ *asymmetric dephasing*

Perfect dephasing diode

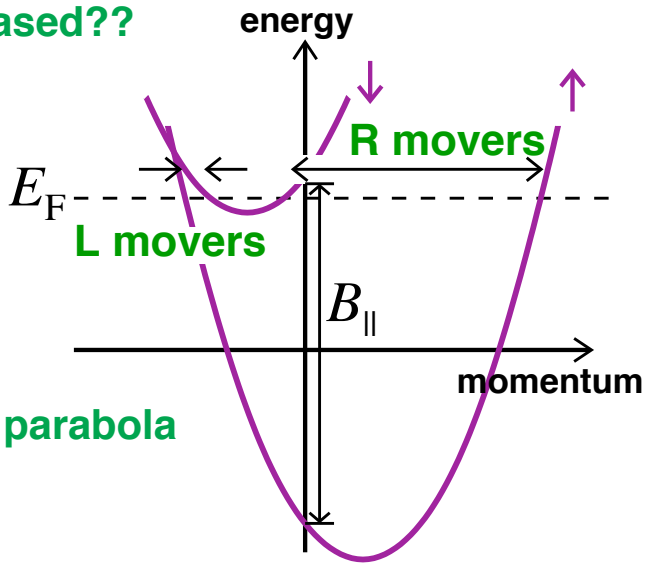
L-movers *not* dephased

R-movers *completely* dephased??

Perfect dephasing diode

L-movers *not* dephased

R-movers *completely* dephased??

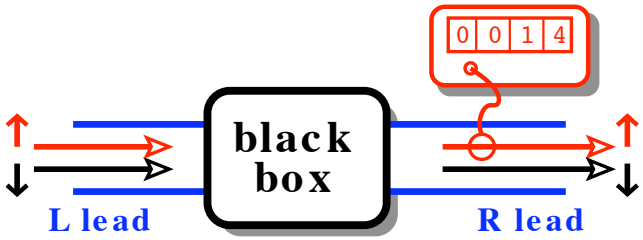


Require BIG $B_{||}$-field

$\Rightarrow$ E_F near *bottom* of one parabola

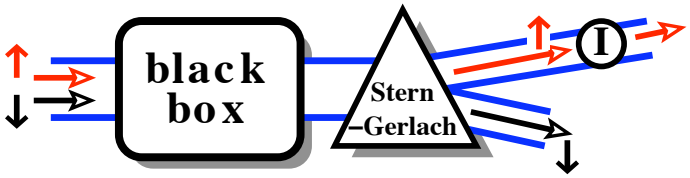
What about Onsager relation?

Charge-transport in 2-terminal device $\Rightarrow \quad G_{\mathrm{L}\to\mathrm{R}} = G_{\mathrm{R}\to\mathrm{L}}$



$\Rightarrow$ *NO* sum over *spin* in lead

...equivalent to



Spin-transport in 2-terminal device $\Rightarrow \quad G^{\sigma\to\sigma'}_{\mathrm{L}\to\mathrm{R}} \neq G^{\sigma'\to\sigma}_{\mathrm{R}\to\mathrm{L}}$

Outline

[1] *DEPHASING DIODE*:
L/R asymmetry in dephasing of spin ☑

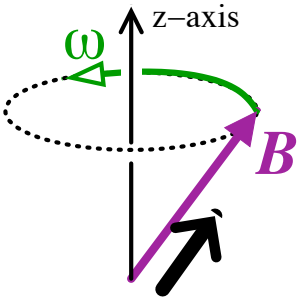
[2] *GEOMETRIC DEPHASING*
Berry phase
$\Rightarrow$ geometric dephasing/*anti*-dephasing ☐

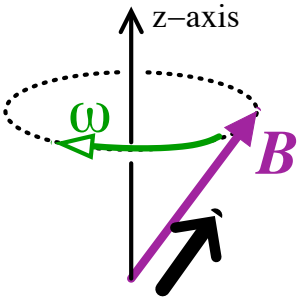
[3] *CHARGE-TRANSPORT:*
Noise-induced asymmetry ☐

Geometric dephasing Whitney-Shnirman-Makhlin Gefen (2005)

$$\left\langle \exp[i(\Phi_{\mathsf{dyn}} + \Phi_{\mathsf{Berry}})] \right\rangle \longrightarrow \exp\left[-\Gamma \times \boldsymbol{t} - \alpha \times \boldsymbol{n} \right]$$

USUAL DEPHASE — GEOMETRIC DEPHASE





n* windings round path in time *t

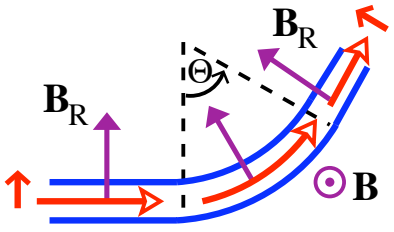
***Environment:* quantum or classical**

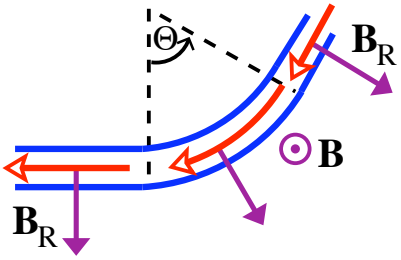
♣ **Geometric dephasing ($n > 0$)**
or *anti*-dephasing ($n < 0$)

♣ **meaningful for open-paths**
GAUGE-INVARIENT

Geometric dephasing in nanowires?

***Adiabatic curve:* spin follows $\mathsf{B} + \mathsf{B}_{\mathsf{R}}$**





$$\left\langle \exp[i(\Phi_{\mathsf{dyn}} \pm \Phi_{\mathsf{Berry}})] \right\rangle$$

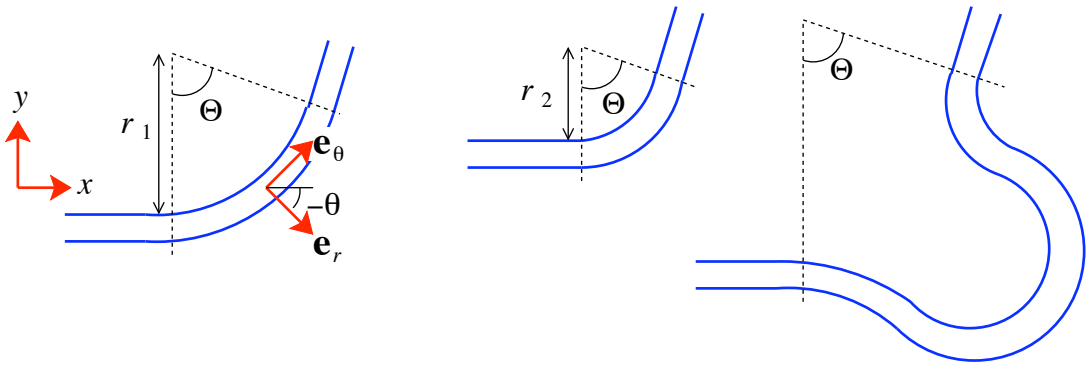
$$\longrightarrow \exp\left[-\left\langle \delta\Phi_{\mathsf{dyn}}^2 \right\rangle \pm 2\left\langle \delta\Phi_{\mathsf{dyn}} \delta\Phi_{\mathsf{Berry}} \right\rangle - \left\langle \delta\Phi_{\mathsf{Berry}}^2 \right\rangle \right]$$

Curve breaks symmetry for L/R movers ($\pm$-sign)

$$\Phi_{\mathsf{dyn}} \propto L \qquad \Phi_{\mathsf{Berry}} \propto \Theta$$

What is geometric in this dephasing?

All these (adiabatically-curved) wires
give *same* geometry-induced dephasing



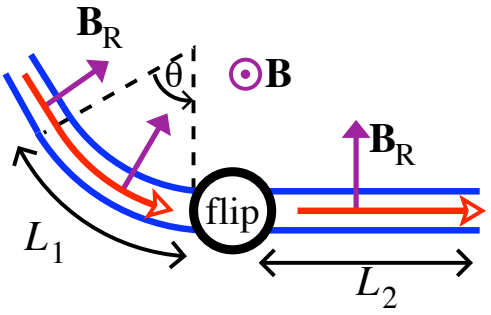
$\Phi_{\text{Berry}} = \Theta \cos\kappa$ κ is angle to $(0, 2(p_0^2 + l_R^{-2})^{1/2}, B_z)$

Spin-echo trick: emphasising geometric effects

Dephasing $\sim \langle \delta\Phi^2_{\text{dyn}} \rangle \pm 2\langle \delta\Phi_{\text{dyn}} \delta\Phi_{\text{Berry}} \rangle - \langle \delta\Phi^2_{\text{Berry}} \rangle$
big *small*

$\Rightarrow$ ***only SMALL asymmetry* in dephasing**

Instead: SPIN-ECHO set-up
$\Rightarrow$ **spin-flip between two wires**



$\Phi_{\text{dyn}} = \Phi^{(1)}_{\text{dyn}} - \Phi^{(2)}_{\text{dyn}}$

Can have $\delta\Phi_{\text{dyn}} \sim \delta\Phi_{\text{Berry}}$
by choosing $L_2 \sim L_1$ $\Rightarrow$ ***strong asymmetry***

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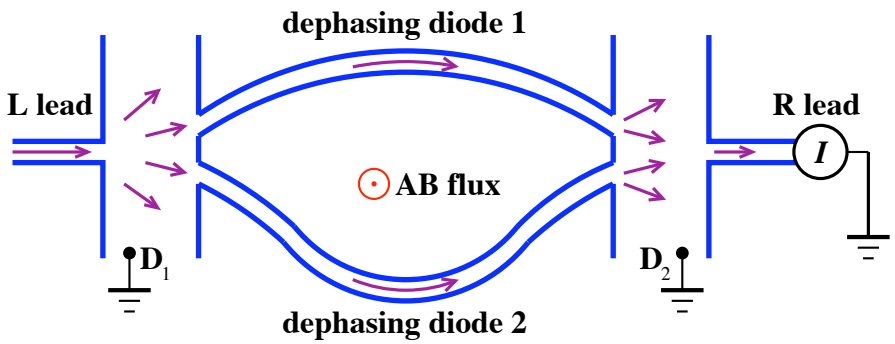
[3] *CHARGE-TRANSPORT:*
Noise-induced asymmetry ☐

Asymmetry in charge-transport (not spin-transport)

spins-polarized



Aharonov-Bohm *dephased differently* for L/R movers

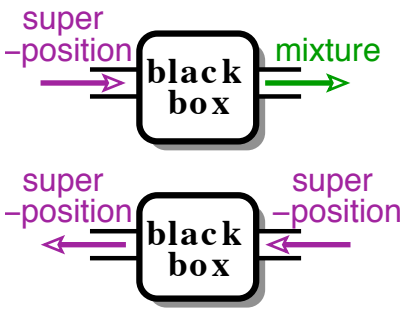
Many **other asymmetries in current**
...but this is *noise-induced* asymmetry

increase noise $\Rightarrow$ increase asymmetry!!

Summary

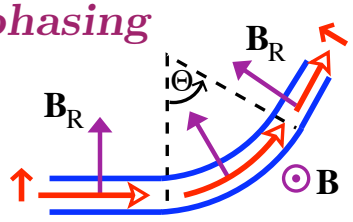
[1] *Dephasing diode*

- Rashba + B-field + environment
- *big* asymmetry



[2] *Geometric dephasing and anti-dephasing*

- spin-echo $\Rightarrow$ *big* asymmetry
- meaningful for open path



[3] *Asymmetric Charge-transport due to noise*

- Aharonov-Bohm with Rashba
- *increase* noise $\Rightarrow$ *increase* asymmetry

APPENDICES

Geometric phase for open-paths?

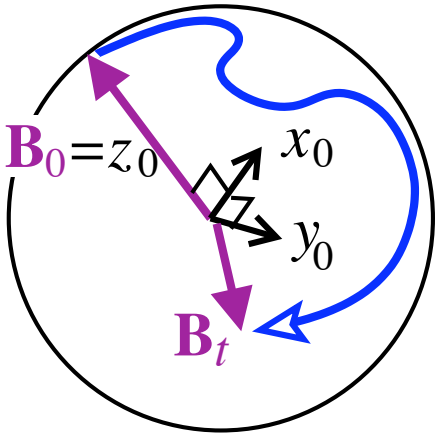
Schiff's textbook (1950s)

"Berry phase meaningless for open-paths"!!

— gauge dependent

Problem for open-loops: B-field defines z-axis

but x-axis/y-axis are *ambiguous*



...but dephasing

$\sim$ oscillation-*amplitude*

in *plane* $\perp$ *to z-axis*

Independent of choice of x/y-axis

for open paths (gauge-independent)