Spin filters: writing quantum information on flying qubits

Amnon Aharony

אוניברסיטת בן-גוריון בנגב
Ben-Gurion University of the Negev

TEL AVIV UNIVERSITY אוניברסיטת תל-אביב

Ora Entin-Wohlman (BGU+TAU), Shlomi Mattiyahu (BGU), Guy Cohen (BGU)
Yasuhiro Tokura (Tsukuba) , Seigo Tarucha (U Tokyo) , Shingo Katsumoto (ISSP)
Yasuhiro Utsumi (Mie), Robert Shekhter & Mats Jonson (Göteborg)
Wei-Min Zhang (Tainan), Carlos Balseiro (CNEA)

ICTP Summer School

Advances in Condensed Matter Physics:

New trends and Materials in Quantum Technologies

Samarkand, May 2019

Outline

- Quantum computers: qubits
- Spin-orbit interaction (SOI) and spin filters
- Time reversal symmetry – no filtering with 2 leads
- Interferometers with Aharonov-Bohm flux or with leakage
- Interferometers with 3 leads
- Datta-Das Spin Field Effect Transistor
- **Helical molecular junctions**

Quantum computers

Conventional computers: information in **bits**,

0 or 1, +1 or -1, ⬆ or ⬇

Quantum computers: information in **Qubits**,

Electron described by **spinor**:

$$\psi = \cos\alpha \begin{pmatrix} 1 \\ 0 \end{pmatrix} + e^{i\gamma} \sin\alpha \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

Complex numbers

Spinor is an eigenvector of $\mathbf{n} \cdot \boldsymbol{\sigma}$, the spin component along $\mathbf{n}$

$\alpha, \gamma \Leftrightarrow \mathbf{n}$

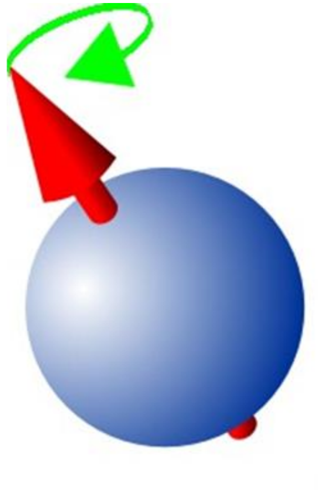
superposition

$$\psi = a$$  $$+\, b$$ 

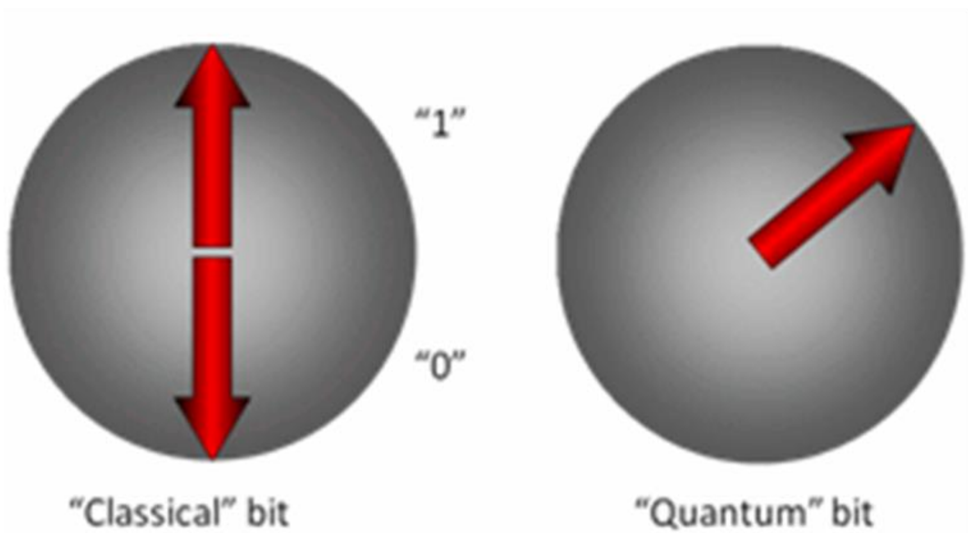
cat lives with probability $|a|^2$ and dies with probability $|b|^2$

$$\psi = a\,|0\rangle + b\,|1\rangle$$

$$\psi = a\begin{pmatrix}1\\0\end{pmatrix} + b\begin{pmatrix}0\\1\end{pmatrix}$$

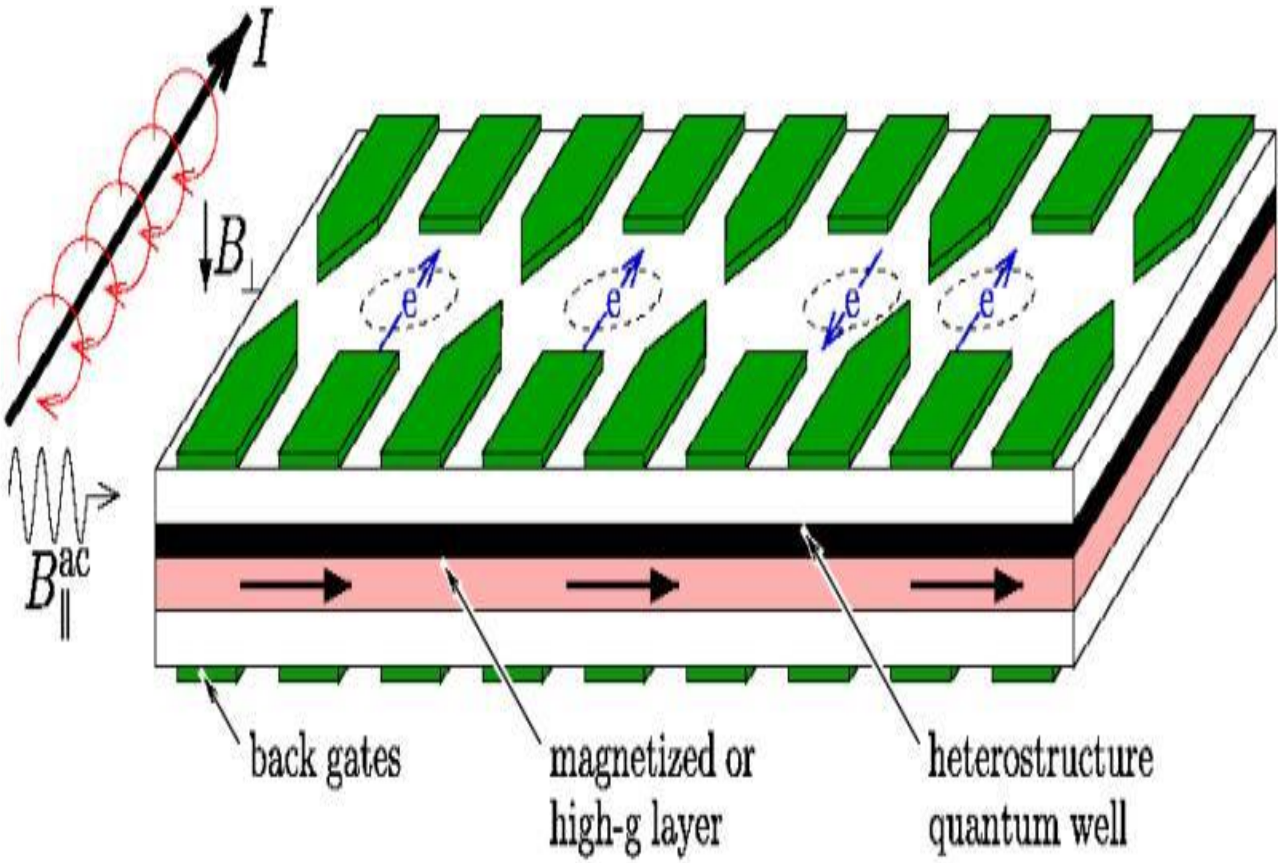


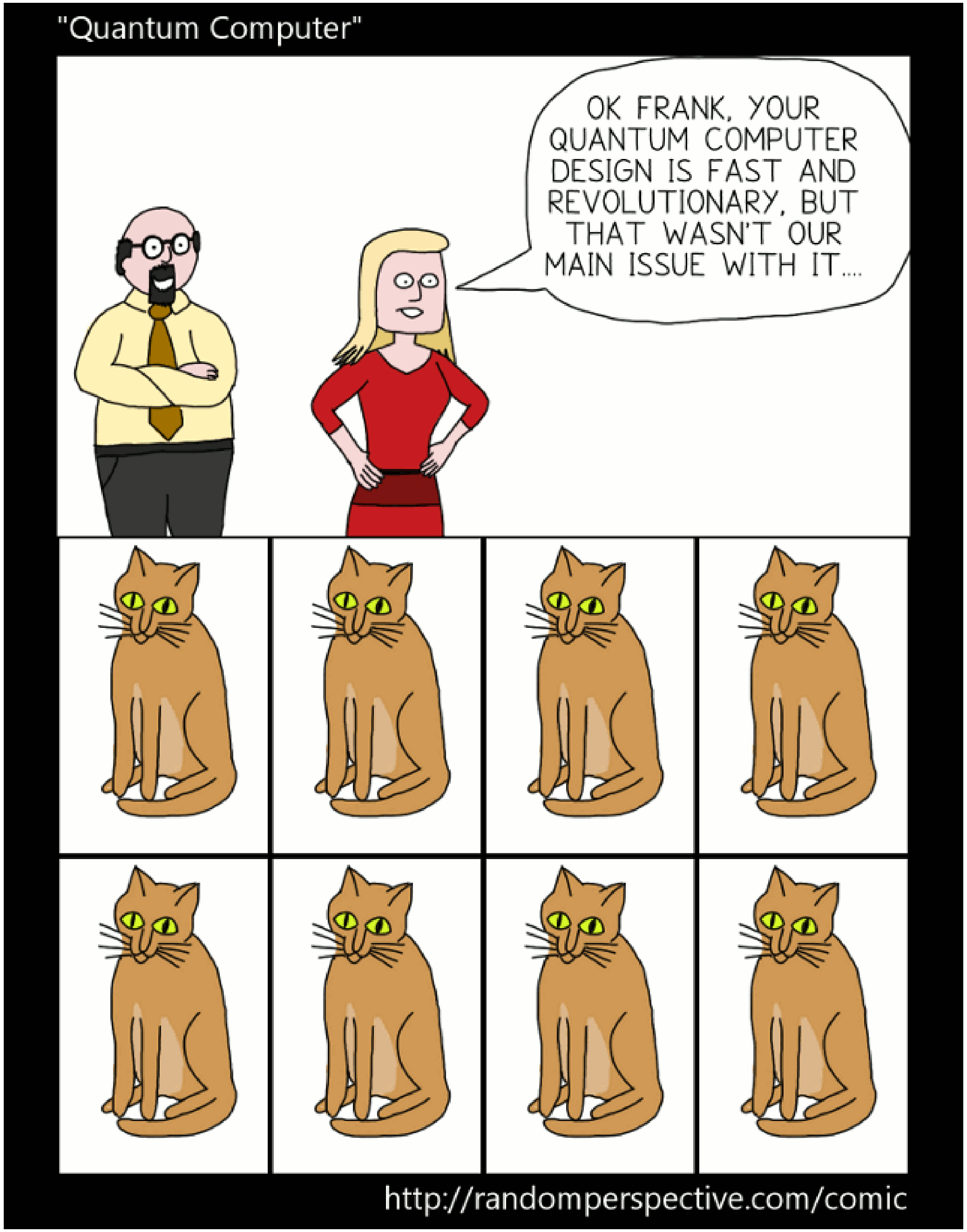
Electronic spin



$$|\psi\rangle = \alpha|\uparrow\rangle + \beta|\downarrow\rangle$$

Static qubits:




"Quantum Computer"
OK FRANK, YOUR QUANTUM COMPUTER DESIGN IS FAST AND REVOLUTIONARY, BUT THAT WASN'T OUR MAIN ISSUE WITH IT....
http://randomperspective.com/comic

Here we discuss **mobile (**or **flying)** qubits, in **mesoscopic semiconductor** devices

Flying qubits

‘Writing’ on flying spinor (=Qubit):
Spin filtering

Work with **mobile** electrons,

Generate **fully spin-polarized** current out of an unpolarized source

The Aharonov-Bohm (AB) Effect

- Classical Physics, e.g. Lorentz force

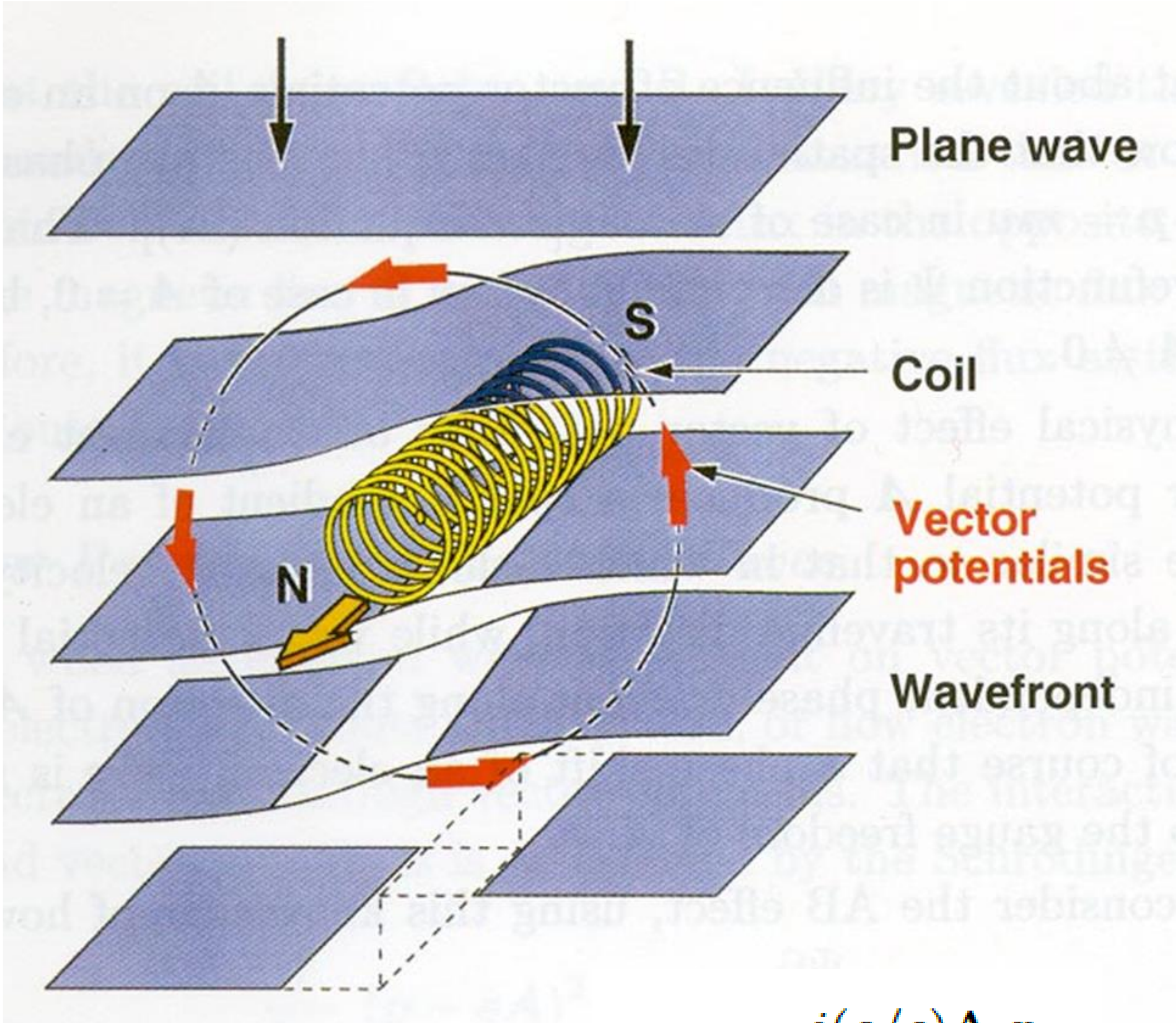
$$m\left(\frac{d^2\vec{r}}{dt^2}\right) = -e\left[\vec{E} + \frac{\vec{v}}{c} \times \vec{B}\right]$$

- Quantum Physics, Schrödinger equation

$$(H_o + V)\Psi = \frac{i\hbar\partial\Psi}{\partial t}$$

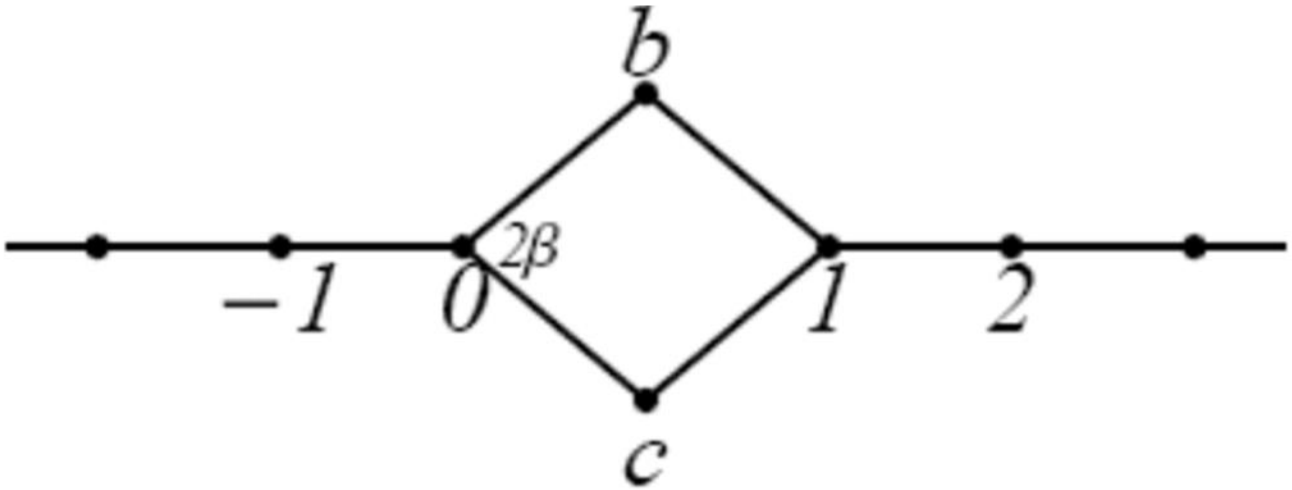
  - $V = -eED$ and $H_o = \frac{p^2}{2m}$, where $\vec{p} = m\vec{v} + \frac{e\vec{A}}{c}$
  - with E electric field, D electrode's separation

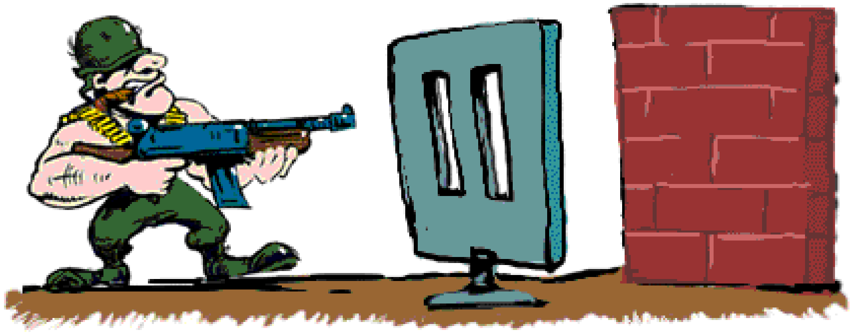
- Aharonov and Bohm (AB), *Phys.Rev.* **115**, 485 (1959)
- Phase Shift $\Delta\phi = \frac{1}{\hbar}\int L dt = \frac{1}{\hbar}\int\left(m\vec{v} + \frac{e\vec{A}}{c}\right).d\vec{s} - \frac{1}{\hbar}\int eED dt$



$$\psi \to e^{i(e/c)\mathbf{A}\cdot\mathbf{r}}\psi$$

Aharonov-Bohm interferometer





Rashba Spin-orbit interactions

Dirac:

$$\hat{H}_{SO} = \frac{\hbar}{(2M_0c)^2} \nabla V(\mathbf{r})(\hat{\boldsymbol{\sigma}} \times \hat{\mathbf{p}}).$$

Rashba: 2DEG, confined to a plane by an asymmetric potential along z:

$$\mathcal{H}_\mathrm{R} = \frac{\hbar k_R}{m}(p_y\sigma_x - p_x\sigma_y)$$

Strength of Rashba term can be tuned by gate voltage!

On a straight wire of length **R**,

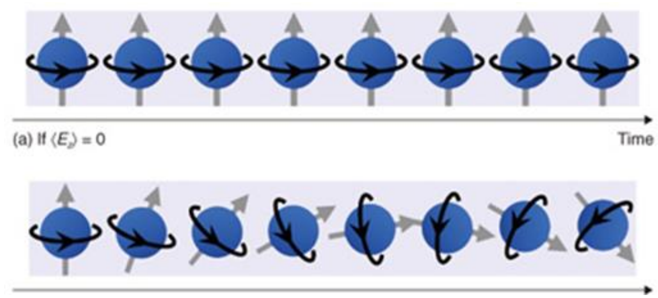
$$\mathcal{H}_\mathrm{link} = -\frac{1}{2m^*}\boldsymbol{\nabla}^2 - i\frac{\widetilde{k}_\mathrm{so}}{m^*}\hat{\mathrm{n}} \cdot [\boldsymbol{\sigma} \times \boldsymbol{\nabla}]$$

$$\mathbf{E} = E\hat{\mathbf{n}}$$

$$\mathcal{H}_\mathrm{link} = \frac{\mathrm{k}^2}{2m^*} - \frac{\widetilde{k}_\mathrm{so}}{m^*}[\hat{\mathrm{n}} \times \mathrm{k}] \cdot \boldsymbol{\sigma} = \frac{\mathrm{k}^2}{2m^*} - \mathrm{H}_\mathrm{so} \cdot \boldsymbol{\sigma}$$

$$\mathcal{H}_\mathrm{link} = \frac{\mathrm{k}^2}{2m^*} - \frac{\widetilde{k}_\mathrm{so}}{m^*}[\boldsymbol{\sigma} \times \mathrm{n}] \cdot \hat{\mathrm{k}} = \frac{\left(\mathrm{k} - \widetilde{k}_\mathrm{so}\boldsymbol{\sigma} \times \mathrm{n}\right)^2}{2m^*} + const.$$

Entin-Wohlman, Gefen, Meir, Oreg (1989, 1992):
Spinor moving on wire "gains" a "phase factor" $e^{-ik_{so}[\mathbf{R}\times\hat{\mathbf{n}}]\cdot\boldsymbol{\sigma}}$

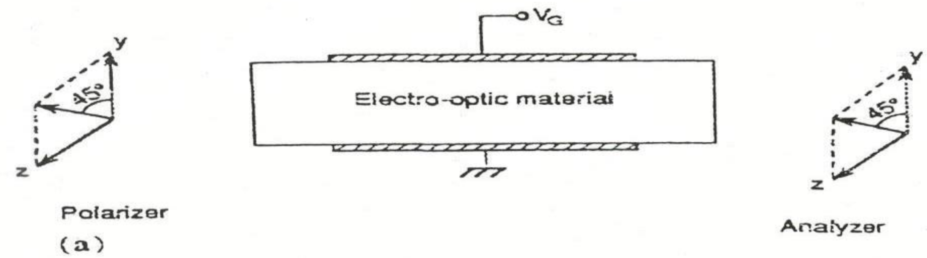


Spin field effect transistor

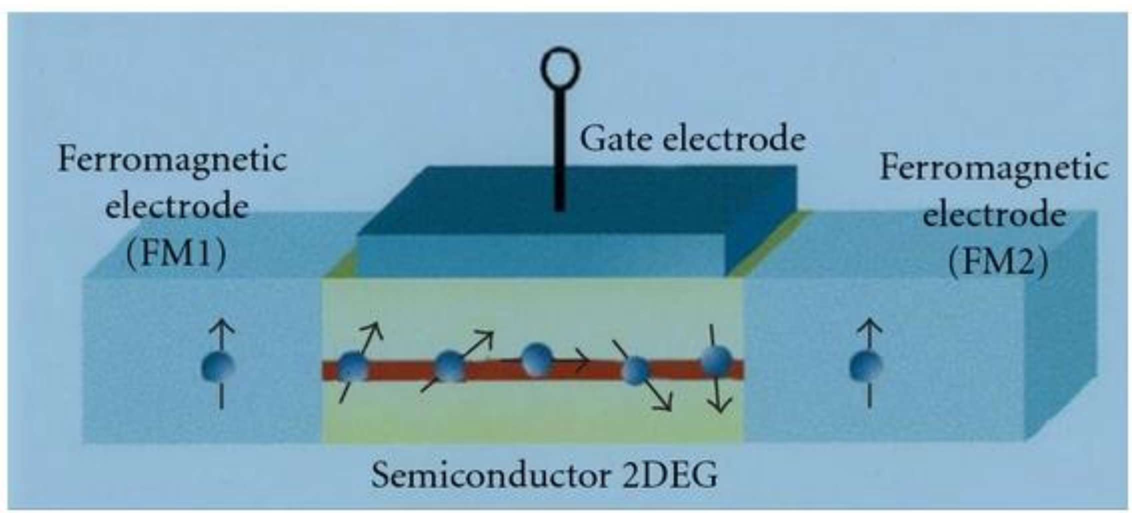
Electronic analog of the electro-optic modulator

Supriyo Datta and Biswajit Das
School of Electrical Engineering, Purdue University, West Lafayette, Indiana 47907

Appl. Phys. Lett. 56 (7), 665   12 February 1990



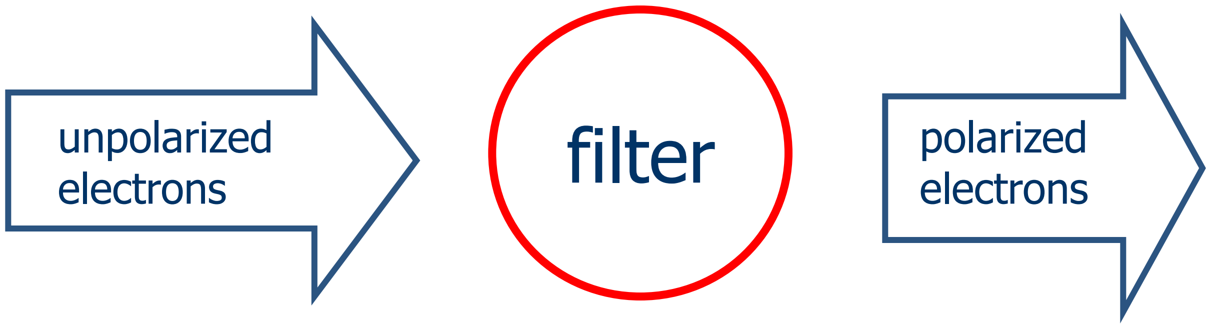
$$\underset{(45^\circ\ \text{pol.})}{\begin{pmatrix}1\\1\end{pmatrix}} = \underset{(z\ \text{pol.})}{\begin{pmatrix}1\\0\end{pmatrix}} + \underset{(y\ \text{pol.})}{\begin{pmatrix}0\\1\end{pmatrix}} .\qquad P_0 \propto \left| (1\ 1)\begin{pmatrix}e^{ik_1L}\\e^{ik_2L}\end{pmatrix}\right|^2 = 4\cos^2\frac{(k_1-k_2)L}{2} .$$



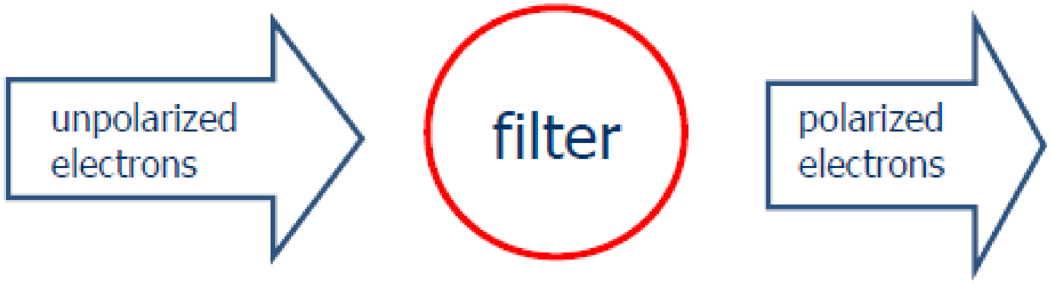
‘Writing’ on spinor (=Qubit): Spin filtering

Work with **mobile** electrons,

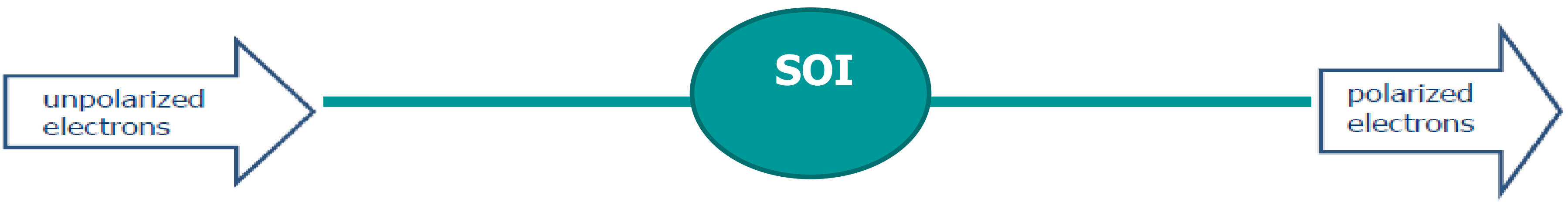
Generate **fully spin-polarized** current out of an unpolarized source



Can we imitate Datta and Das and use spin-orbit interactions to filter spins in mesoscopic wire networks?



Can spin polarization be generated in a **2-terminal** setup with **spin-orbit interaction** (SOI)?



Spin transmission between **2 terminals** with **time reversal symmetry?**

$$|\psi^L\rangle = c^{in,L}\,|n\rangle + c^{out,L}\,|Tn\rangle \qquad |\psi^R\rangle = c^{in,R}\,|m\rangle + c^{out,R}\,|Tm\rangle$$

$$\begin{pmatrix} c^{out,L} \\ c^{out,R} \end{pmatrix} = S \begin{pmatrix} c^{in,L} \\ c^{in,R} \end{pmatrix} = \begin{pmatrix} r & t' \\ t & r' \end{pmatrix} \begin{pmatrix} c^{in,L} \\ c^{out,L} \end{pmatrix}$$

$$T\,|\psi^L\rangle = (c^{in,L})^*\,|Tn\rangle - (c^{out,L})^*\,|n\rangle \qquad T\,|\psi^R\rangle = (c^{in,R})^*\,|Tm\rangle - (c^{out,R})^*\,|m\rangle$$

$$\begin{pmatrix} (c^{in,L})^* \\ (c^{in,R})^* \end{pmatrix} = S \begin{pmatrix} -(c^{out,L})^* \\ -(c^{out,R})^* \end{pmatrix}$$

TT=-1

S unitary

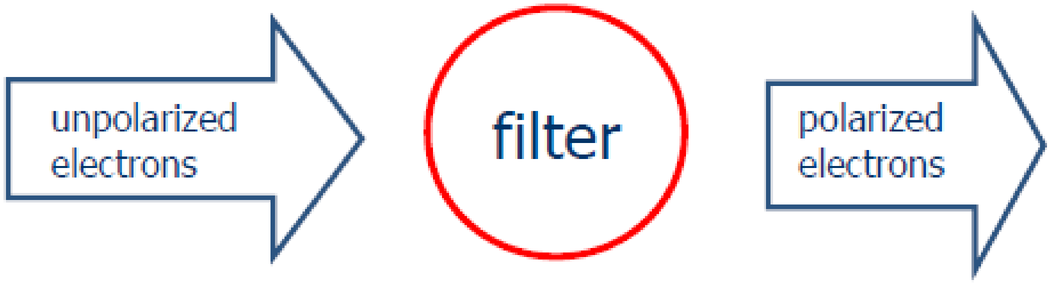
$$S^T \begin{pmatrix} c^{in,L} \\ c^{in,R} \end{pmatrix} = -\begin{pmatrix} c^{out,L} \\ c^{out,R} \end{pmatrix} \qquad S^T = -S \qquad r^T = -r \qquad r = \begin{pmatrix} 0 & \lambda \\ -\lambda & 0 \end{pmatrix}$$

$$\boxed{r^\dagger r = |\lambda|^2 I} \qquad \boxed{t^\dagger t = 1 - r^\dagger r}$$

Same transmissions for both spin polarizations

Beenakker: scattering matrix is **self-dual**

J. H. Bardarson, J. Phys. A: Math. Theor. **41**, 405203 (2008)



Can spin polarization be generated in

a **2-terminal** setup with **spin-orbit interaction**?

NO, since SOI obeys **time reversal symmetry**

--- Kramer's degeneracy

MUST BREAK TIME REVERSAL SYMMETRY OR ADD TERMINALS

5 ways to obtain spin separation (filtering):

1) Break time reversal by Aharonov-Bohm flux

2) Break unitarity by leakage

3) Use 2 drain terminals

4) Use transient time-dependence

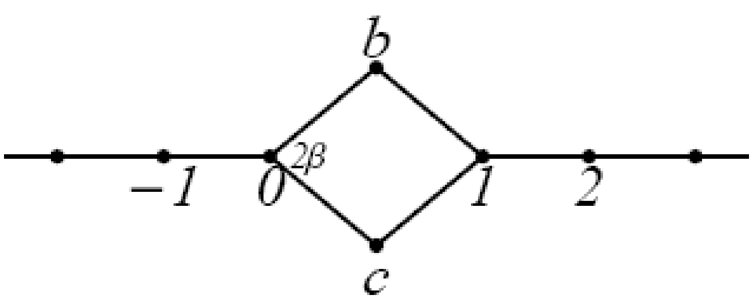
5) Add magnetization on leads

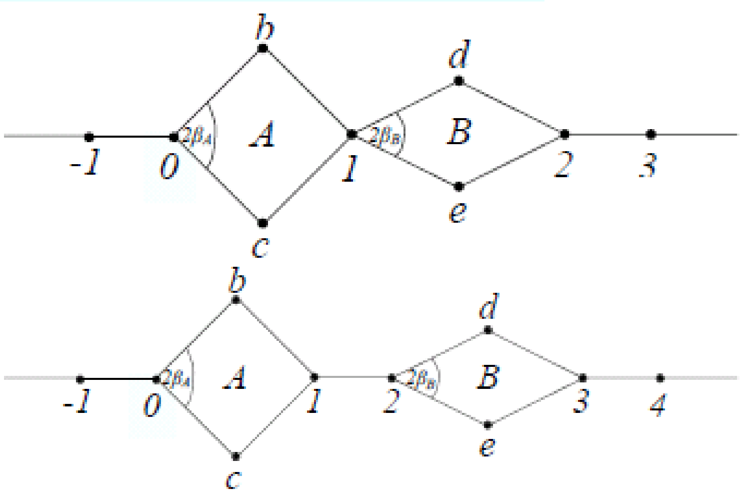
PHYSICAL REVIEW B 84, 035323 (2011)

Filtering and analyzing mobile qubit information via Rashba–Dresselhaus–Aharonov–Bohm interferometers

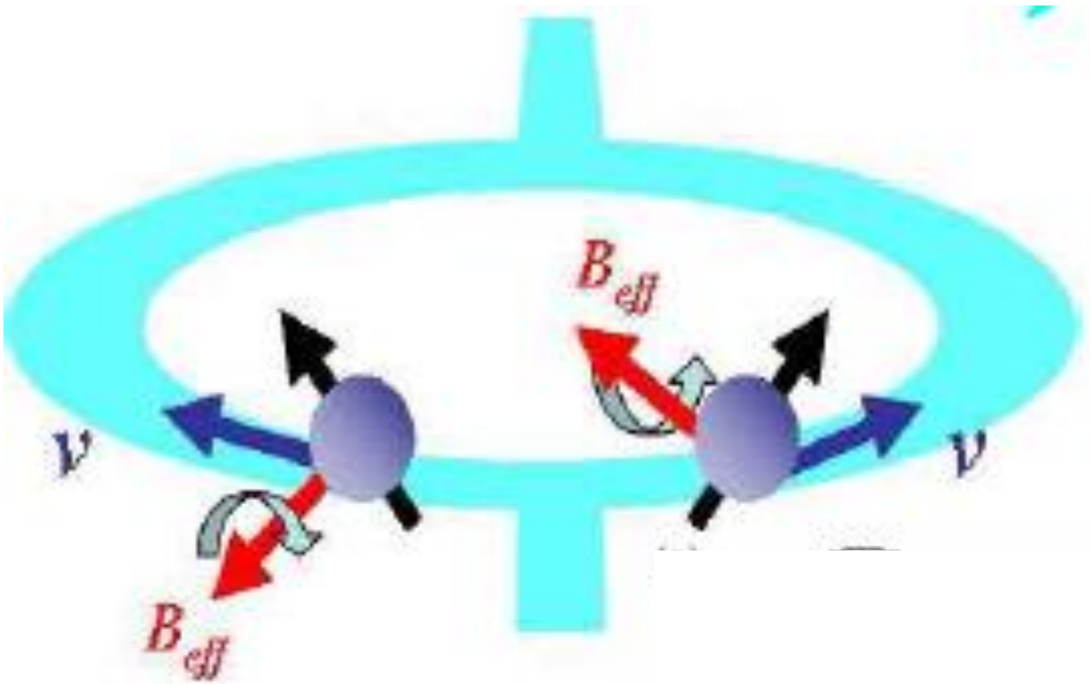
Amnon Aharony,[1,*] Yasuhiro Tokura,[2] Guy Z. Cohen,[3,†] Ora Entin-Wohlman,[1,‡] and Shingo Katsumoto[4]

Spin transport through single or double diamond, With a magnetic flux – Aharonov-Bohm effect



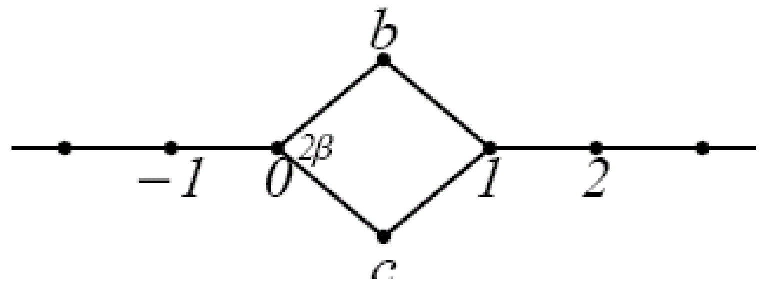


AB interferometer with spin-orbit interactions



$$t|\chi_t\rangle = \mathcal{T}|\chi_{in}\rangle, \quad r|\chi_r\rangle = \mathcal{R}|\chi_{in}\rangle$$

Single diamond



$$(\epsilon - \epsilon_u)\psi(u) = -\sum_v J_{uv} U_{uv} \psi(v)$$

$$U_{0b} = \exp(i\alpha\sigma_1), \quad U_{b1} = \exp(-i\phi/2 - i\alpha\sigma_2),$$
$$U_{0c} = \exp(-i\alpha\sigma_2), \quad U_{c1} = \exp(i\phi/2 + i\alpha\sigma_1),$$

Tight-binding

$$(\epsilon - \epsilon_0)|\psi(0)\rangle = -\big(\widetilde{U}_{0b}|\psi(b)\rangle + \widetilde{U}_{0c}|\psi(c)\rangle\big) - j|\psi(-1)\rangle$$
$$(\epsilon - \epsilon_1)|\psi(1)\rangle = -\big(\widetilde{U}_{b1}^{\dagger}|\psi(b)\rangle + \widetilde{U}_{c1}^{\dagger}|\psi(c)\rangle\big) - j|\psi(2)\rangle,$$
$$(\epsilon - \epsilon_b)|\psi(b)\rangle = -\big(\widetilde{U}_{0b}^{\dagger}|\psi(0)\rangle + \widetilde{U}_{b1}|\psi(1)\rangle\big),$$
$$(\epsilon - \epsilon_c)|\psi(c)\rangle = -\big(\widetilde{U}_{0c}^{\dagger}|\psi(0)\rangle + \widetilde{U}_{c1}|\psi(1)\rangle\big).$$

Eliminate b and c

$$(\epsilon - \epsilon_0 - \gamma_b - \gamma_c)|\psi(0)\rangle = \boxed{\mathbf{W}}|\psi(1)\rangle - j|\psi(-1)\rangle,$$
$$(\epsilon - \epsilon_1 - \gamma_b - \gamma_c)|\psi(1)\rangle = \boxed{\mathbf{W}^{\dagger}}|\psi(0)\rangle - j|\psi(2)\rangle,$$

$$\mathbf{W} \equiv \gamma_{0b1} U_{0b} U_{b1} + \gamma_{0c1} U_{0c} U_{c1}$$

$$\mathbf{W} = \gamma_b U_b + \gamma_c U_c$$

Non unitary: SO cage

Scattering theory

Electron from left:

$$|\psi(n)\rangle = e^{ikna}|\chi_{in}\rangle + re^{-ikna}|\chi_r\rangle, \quad n \leq 0,$$
$$|\psi(n)\rangle = te^{ik(n-1)a}|\chi_t\rangle, \quad n \geq 1,$$

$$t|\chi_t\rangle = \mathcal{T}|\chi_{in}\rangle, \quad r|\chi_r\rangle = \mathcal{R}|\chi_{in}\rangle$$

Transmission:

Reflection:

$$\boxed{\begin{aligned} \mathcal{T} &= 2ij\sin(ka)\mathbf{W}^{\dagger}\left(Y\mathbf{1} - \mathbf{W}\mathbf{W}^{\dagger}\right)^{-1}, \\ \mathcal{R} &= -\mathbf{1} - 2ij\sin(ka)X_1(Y\mathbf{1} - \mathbf{W}\mathbf{W}^{\dagger})^{-1}. \end{aligned}}$$

Basic idea: diagonalize transmission matrix

$$\mathcal{T} = t_+|\mathbf{n}'\rangle\langle\mathbf{n}| + t_-|-\mathbf{n}'\rangle\langle-\mathbf{n}|$$

Incoming spinor: $|\chi_{in}\rangle = c_+|\hat{\mathbf{n}}\rangle + c_-|-\hat{\mathbf{n}}\rangle$

Outgoing spinor: $t|\chi_t\rangle = c_+t_+|\hat{\mathbf{n}}'\rangle + c_-t_-|-\hat{\mathbf{n}}'\rangle$

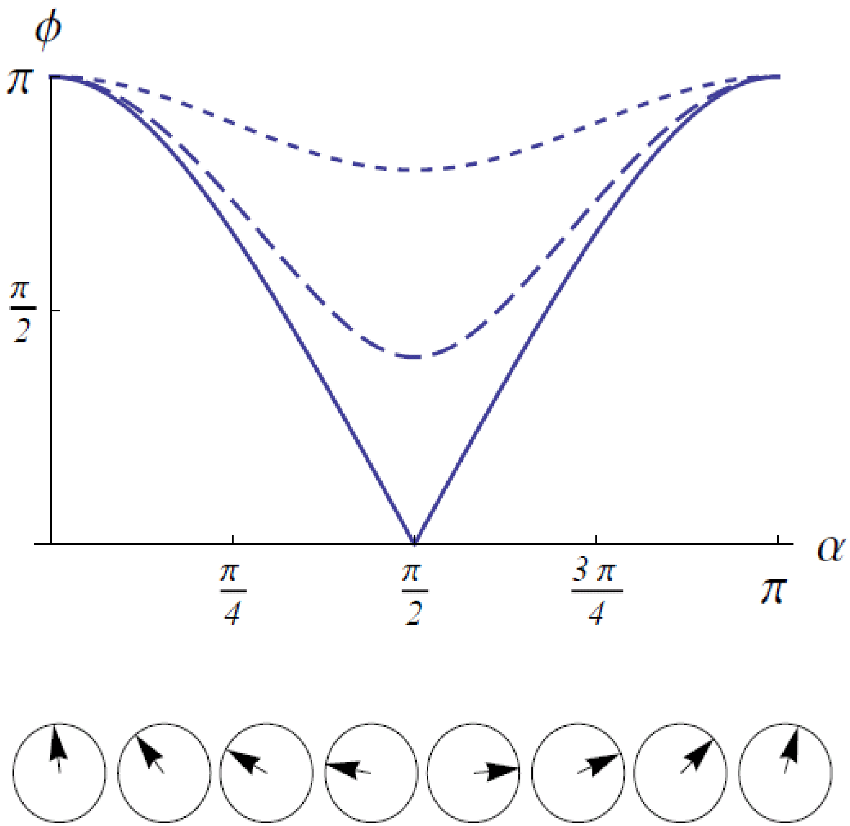
Full filtering if one eigenvalue vanishes!

$$t_- = 0 \Rightarrow t|\chi_t\rangle = c_+t_+|\hat{\mathbf{n}}'\rangle \Rightarrow T = T_+|c_+|^2$$

Rashba spin orbit

$$\cos(\phi/2) = s^2 \sin(2\beta)$$

Independent of energy!



$$\beta/\pi = .25,\ .15,\ .05.$$

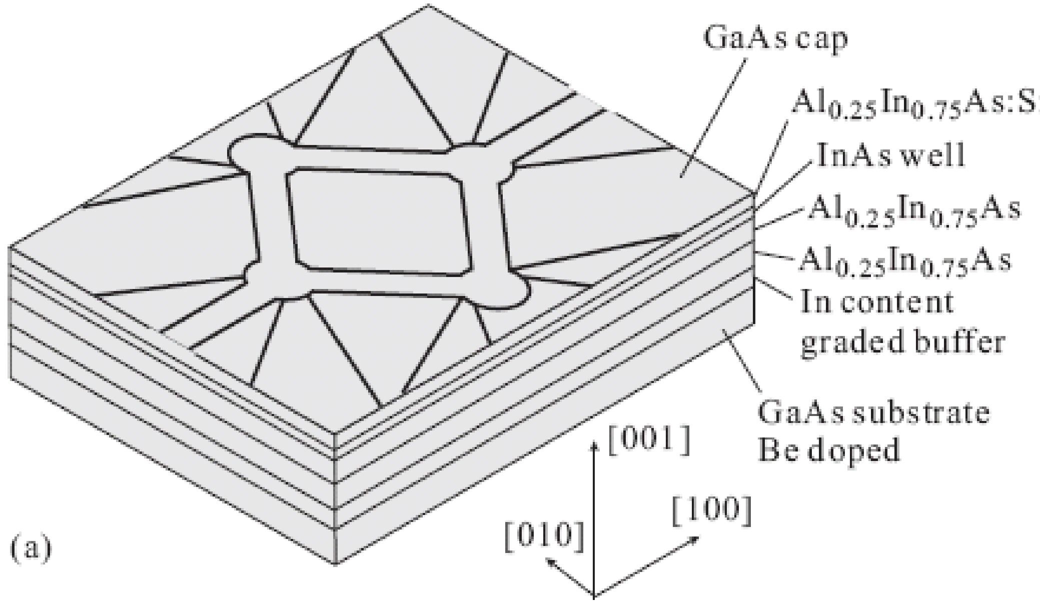
“Reading” spin information

Incoming electrons polarized, $|\chi_{in}\rangle \equiv |\hat{\mathbf{n}}_0\rangle$

$$|c_+|^2 = |\langle\hat{\mathbf{n}}|\hat{\mathbf{n}}_0\rangle|^2 = \frac{1}{2}[1 + \hat{\mathbf{n}}_0 \cdot \hat{\mathbf{n}}]$$

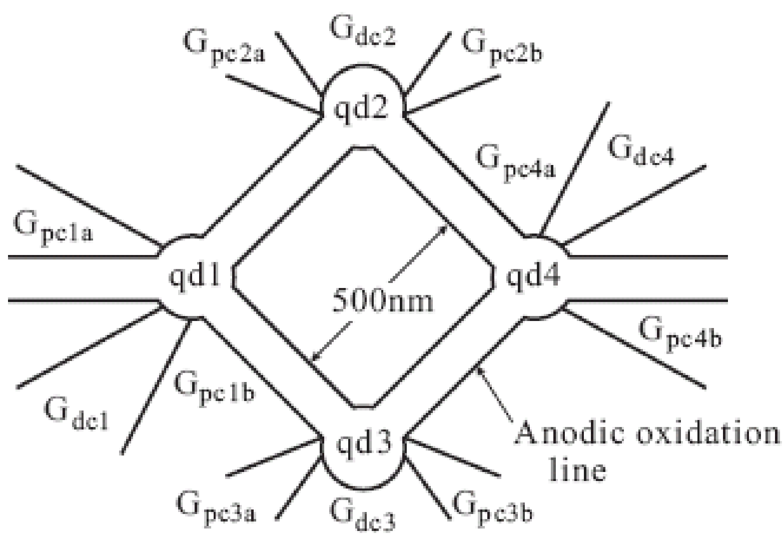
$$T = T_+|c_+|^2$$

Can measure the projection of the incoming polarization on that of the filter



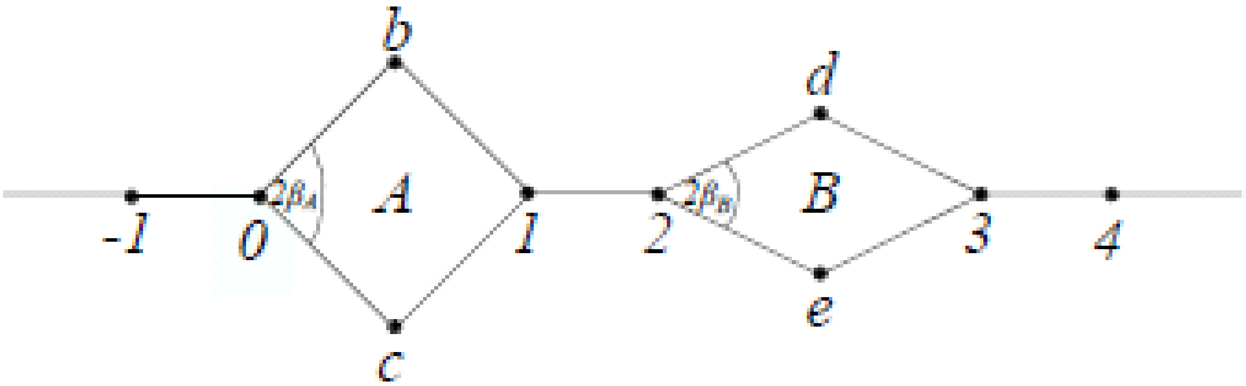
GaAs cap
$Al_{0.25}In_{0.75}As$:Si
InAs well
$Al_{0.25}In_{0.75}As$
$Al_{0.25}In_{0.75}As$
In content graded buffer
GaAs substrate Be doped
[001]
[010]
[100]

(a)



G_{dc2}
G_{pc2a}
G_{pc2b}
qd2
G_{pc4a}
G_{dc4}
G_{pc1a}
qd1
500nm
qd4
G_{pc4b}
G_{pc1b}
G_{dc1}
qd3
Anodic oxidation line
G_{pc3a}
G_{dc3}
G_{pc3b}

(b)



Can rotate the spins between the two diamonds

$\Rightarrow$ **Datta-Das spin FET without ferromagnets!**

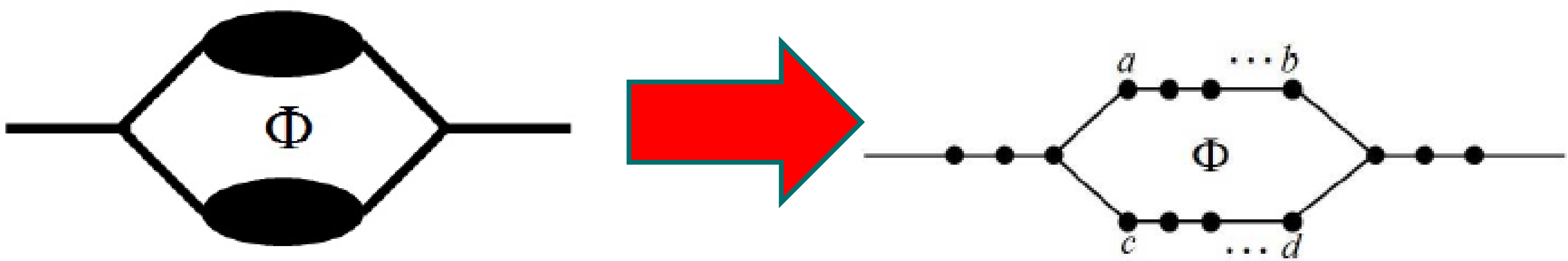
**

New Journal of Physics
The open access journal for physics

New J. Phys. **15** 125017 (2013)

Spin filtering in a Rashba–Dresselhaus–Aharonov–Bohm double-dot interferometer

Shlomi Matityahu[1], Amnon Aharony[1,2,3,6],
Ora Entin-Wohlman[1,2,3] and Seigo Tarucha[4,5]



$$\tilde{\varepsilon}_{uv} = \varepsilon_{uv} - J_{uv}\frac{\sin\left[k_{uv}(M-1)\right]}{\sin(k_{uv}M)} \qquad (uv = ab, cd),$$

$$\tilde{J}_{uv} = J_{uv}\frac{\sin k_{uv}}{\sin(k_{uv}M)} \qquad (uv = ab, cd),$$

$$\tilde{\varepsilon}_{ab}^2 - \tilde{J}_{ab}^2 = \tilde{\varepsilon}_{cd}^2 - \tilde{J}_{cd}^2,$$

$$\omega = \alpha_{cd} - \alpha_{ab} = \phi + \pi.$$

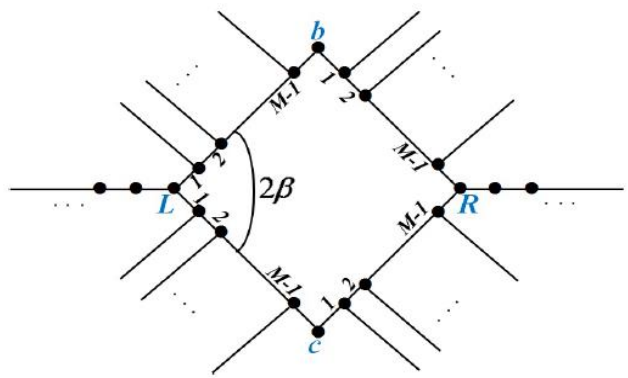
Need to tune only 2 voltages!

Alternative: break unitarity by leakage

PHYSICAL REVIEW B 87, 205438 (2013)

Robustness of spin filtering against current leakage in a Rashba-Dresselhaus-Aharonov-Bohm interferometer

Shlomi Matityahu,[1] Amnon Aharony,[1,2,3,*] Ora Entin-Wohlman,[1,2,3] and Shingo Katsumoto[4]



$$(\epsilon - \widetilde{\epsilon}_{uv})\,|\psi_n^{uv}\rangle = -J_{uv}\left(U_{uv}^{\dagger}|\psi_{n-1}^{uv}\rangle + U_{uv}|\psi_{n+1}^{uv}\rangle\right); \qquad \widetilde{\epsilon}_{uv} = -\frac{|J_{x,uv}|^2 e^{ika}}{j}$$

Complex site energy

Obtain same equations as before, but with shifted magnetic flux,

$$\tilde{\phi} = \phi + \delta_c - \delta_b$$

δ_b δ_c are phases of complex terms on each path

Phases behave like magnetic flux!

Leakage breaks time reversal symmetry!

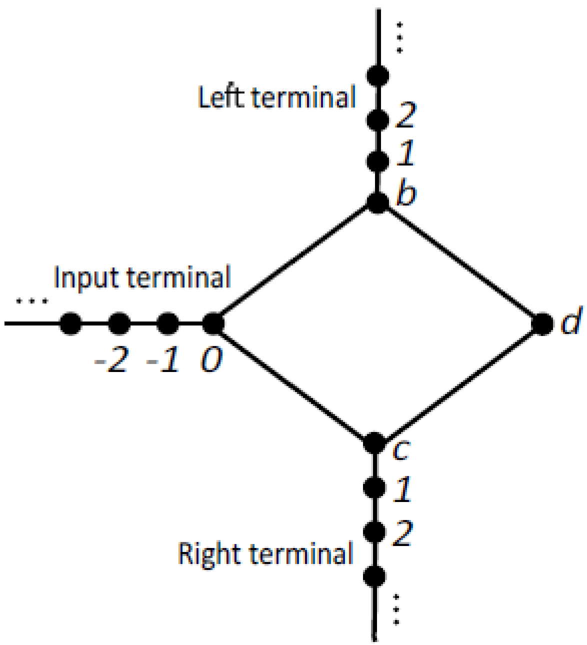
No need for magnetic field

New alternative: use more than 2 terminals

PHYSICAL REVIEW B **95**, 085411 (2017)

Spin filtering in all-electrical three-terminal interferometers

S. Matityahu,[1,2,*] A. Aharony,[1,3] O. Entin-Wohlman,[1,3] and C. A. Balseiro[4,5]



$$I_i^{(C)} = e \int \frac{dE}{2\pi\hbar} \sum_{j\neq i} [f_i(E) - f_j(E)]\, T_{i,j}^{(C)}(E),$$

$$I_i^{(S)} = \int \frac{dE}{4\pi\hbar} \sum_{j\neq i} [f_i(E) - f_j(E)]\, \mathbf{T}_{i,j}^{(S)}(E),$$

Use same chemical potential on drains- Sufficient to solve 1 column in scattering matrix

$$\mathcal{R} = -1 - 2iJ_0 Y \sin k_0 \left[Z - J_{0b}J_{0c}J\left(u + u^\dagger\right)\right]^{-1}$$

$$\mathcal{T}_1 = 2iJ_0 \sin k_0 \left[Z - J_{0b}J_{0c}J\left(u + u^\dagger\right)\right]^{-1} U_{0b} \times \left(JJ_{0c}u - X_c J_{0b}\right),$$

$$\mathcal{T}_2 = 2iJ_0 \sin k_0 \left[Z - J_{0b}J_{0c}J\left(u + u^\dagger\right)\right]^{-1} U_{0c} \times \left(JJ_{0b}u^\dagger - X_b J_{0c}\right),$$

$$r = -1 - \frac{2iJ_0 Y \sin k_0}{Z - 2J_{0b}J_{0c}J\cos\omega}$$

$$t_{\pm}^{(1)}\left|\chi_{t,\pm}^{(1)}\right\rangle = \frac{2iJ_0 \sin k_0 \left(JJ_{0c}e^{\pm i\omega} - X_c J_{0b}\right)}{Z - 2J_{0b}J_{0c}J\cos\omega} U_{0b}\left|\pm\hat{\mathrm{n}}\right\rangle$$

$$t_{\pm}^{(2)}\left|\chi_{t,\pm}^{(2)}\right\rangle = \frac{2iJ_0 \sin k_0 \left(JJ_{0b}e^{\mp i\omega} - X_b J_{0c}\right)}{Z - 2J_{0b}J_{0c}J\cos\omega} U_{0c}\left|\pm\hat{\mathrm{n}}\right\rangle$$

Obtain full polarization along both drains, provided that

$$\frac{JJ_{0c}}{J_{0b}} = |X_c| = \sqrt{y_c^2 + 2y_c J_0 \cos k_0 + J_0^2},$$

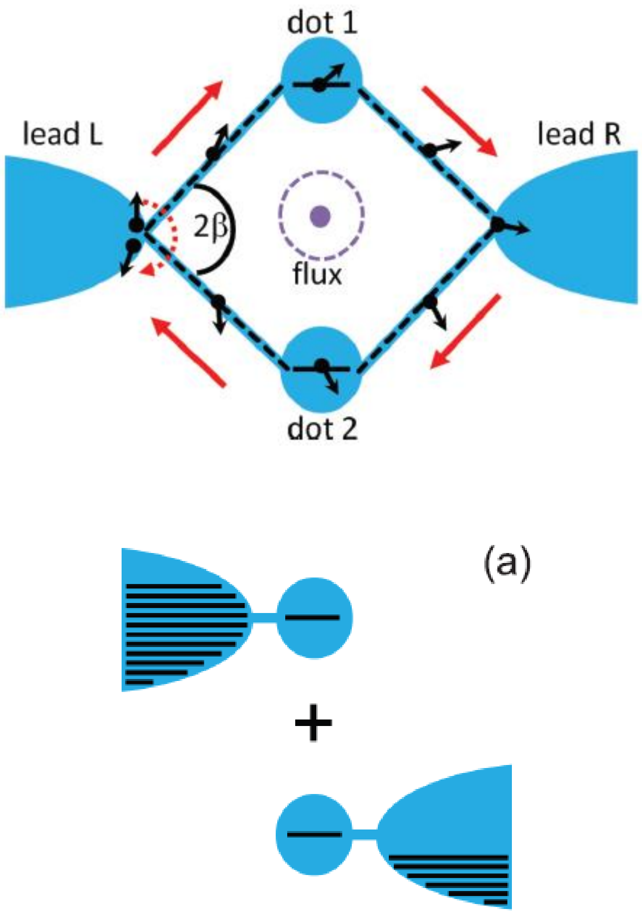
$$\tan\omega = \frac{J_0 \sin k_0}{y_c + J_0 \cos k_0}.$$

Another way: look at transient currents

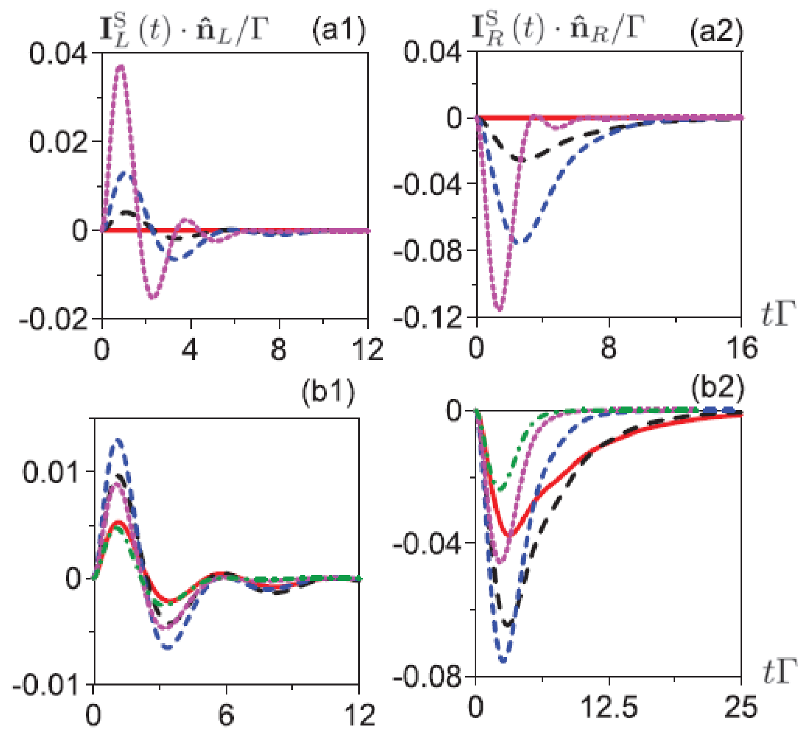
PHYSICAL REVIEW B **90**, 165422 (2014)

Real-time dynamics of spin-dependent transport through a double-quantum-dot Aharonov-Bohm interferometer with spin-orbit interaction

Matisse Wei-Yuan Tu,[1] Amnon Aharony,[2,3,*] Wei-Min Zhang,[1,†] and Ora Entin-Wohlman[2,3]



(a)



Yet another way: return to original Datta-Das SFET

THE JOURNAL OF PHYSICAL CHEMISTRY C

Article

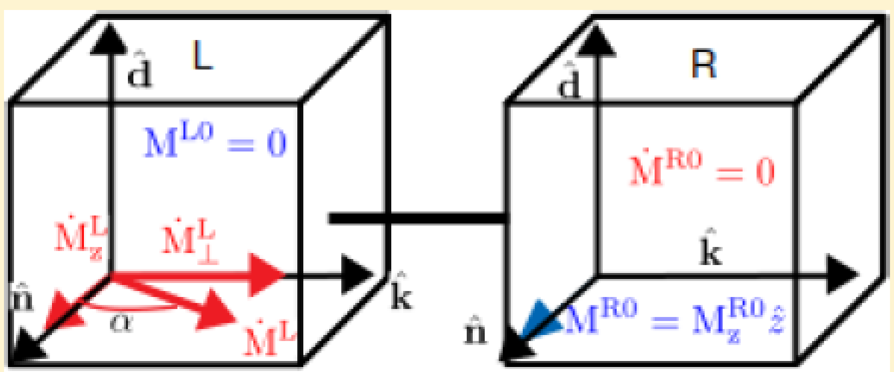
Cite This: *J. Phys. Chem. C* XXXX, XXX, XXX−XXX

pubs.acs.org/JPCC

Effects of Different Lead Magnetizations on the Datta–Das Spin Field-Effect Transistor

Published as part of The Journal of Physical Chemistry virtual special issue "Abraham Nitzan Festschrift".

A. Aharony,[*,†,‡] O. Entin-Wohlman,[†] K. Sarkar,[*,‡] R. I. Shekhter,[§] and M. Jonson[§]



A non-zero bare magnetization (in blue) in the right reservoir generates a rotated magnetization current (in red) in the left reservoir, even when the bare magnetization on the left reservoir is zero.

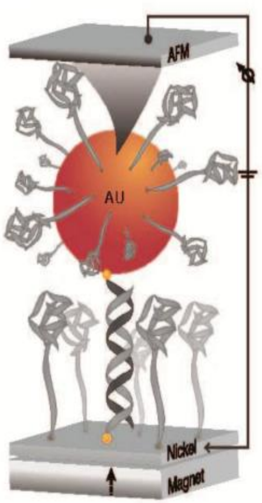
$$\dot{M}^L = \dot{M}_z^{L0}\hat{\mathbf{z}} + \dot{M}_\perp^{L1}[(d_z\hat{\mathbf{d}} - \hat{\mathbf{z}}) - \sin(2\alpha)[\hat{\mathbf{d}} \times \hat{\mathbf{z}}] - \cos(2\alpha)(d_z\hat{\mathbf{d}} - \hat{\mathbf{z}})]$$

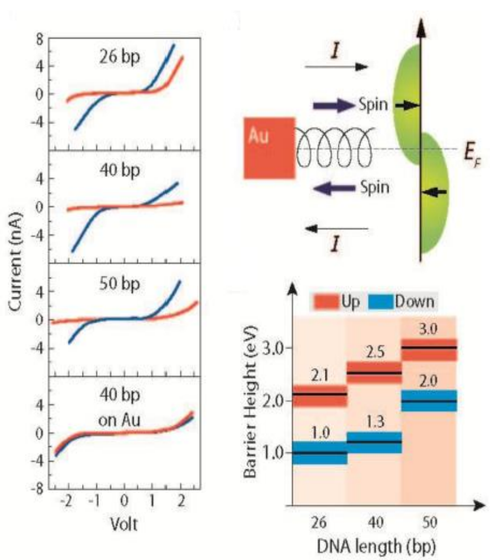
$$\dot{M}_\perp^{L1} = 2\pi J^2[(\mathcal{N}_{R\uparrow} - \mathcal{N}_{R\downarrow})N_0^L - (\mathcal{N}_{L\uparrow} + \mathcal{N}_{L\downarrow})M_{0,z}^R]$$

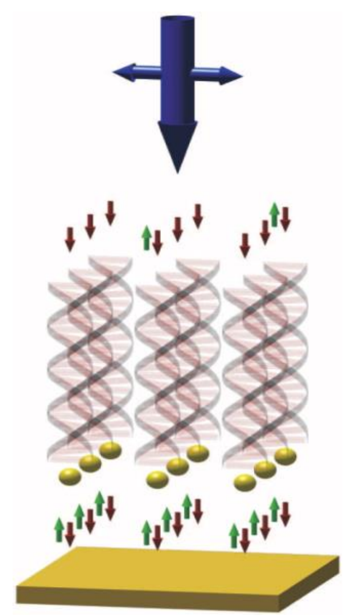
Related study: **Chiral-induced spin selectivity (CISS)**

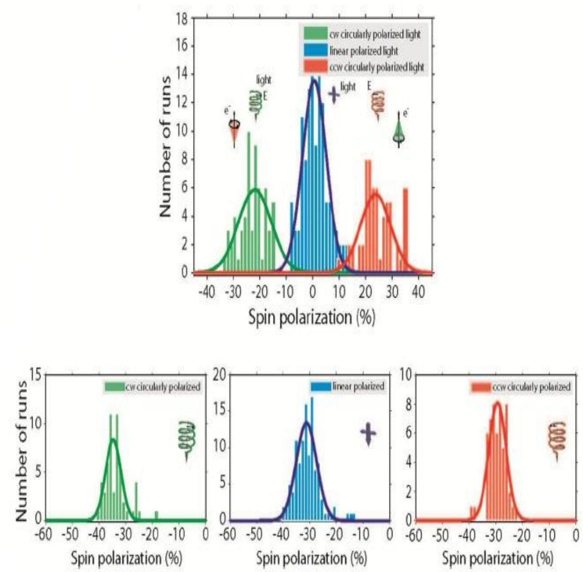
Ron Naaman *et al*:

Chiral molecules can generate spin selectivity









PHYSICAL REVIEW B 93, 075407 (2016)

Spin-dependent transport through a chiral molecule in the presence of spin-orbit interaction and nonunitary effects

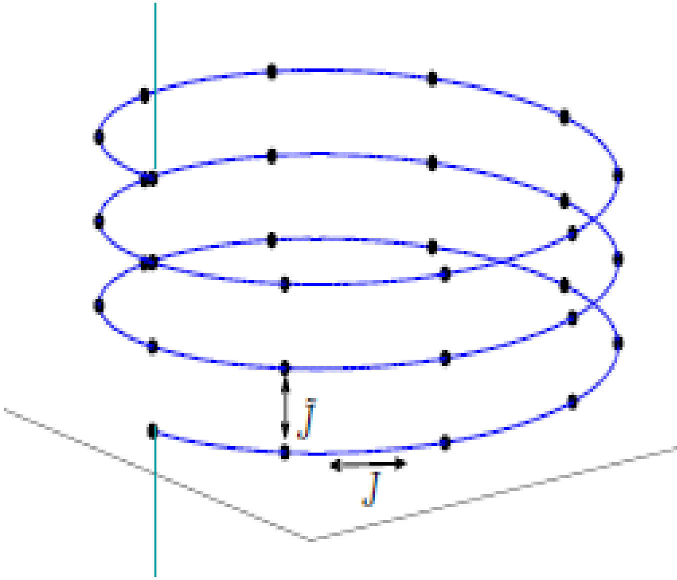
Shlomi Matityahu,[1,*] Yasuhiro Utsumi,[2] Amnon Aharony,[1,3,4] Ora Entin-Wohlman,[1,3,4] and Carlos A. Balseiro[5,6]

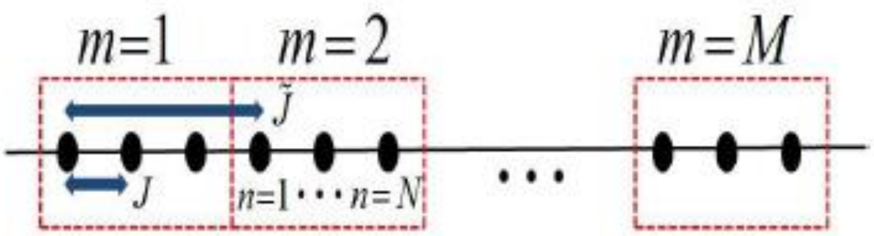
Our approach: scattering with helix between 2 leads

Tight binding hopping on helix

Interference: hopping between helix steps

Spin-orbit interaction

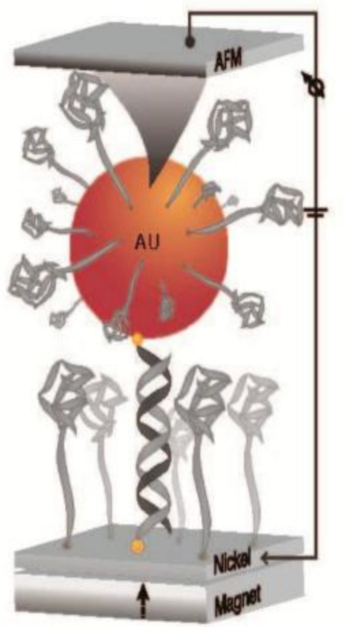




NO POLARIZATION WITH TIME REVERSAL SYMMETRY AND 2 TERMINALS!

THEREFORE WE APPLY LEAKAGE.

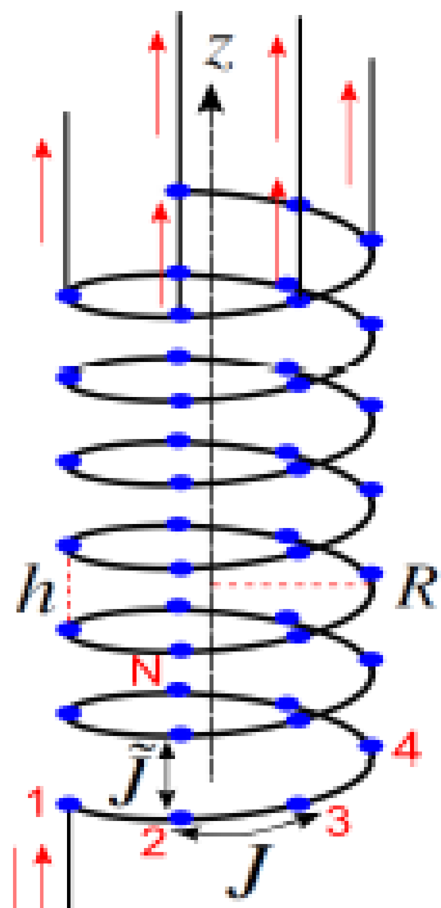
Alternative: collect electrons at the end from the **2** last sites on the helix

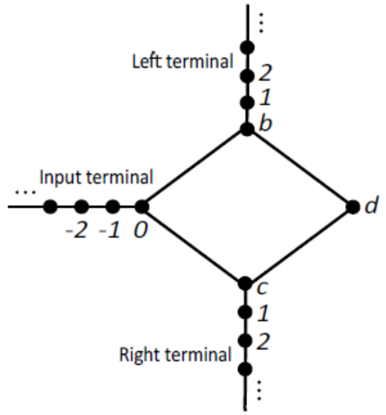


PHYSICAL REVIEW B 95, 085411 (2017)

Spin filtering in all-electrical three-terminal interferometers

S. Matityahu,[1,2,*] A. Aharony,[1,3] O. Entin-Wohlman,[1,3] and C. A. Balseiro[4,5]





Conclusions:

No spin splitting for 2 terminals plus spin orbit

Magnetic flux+Rashba → spin filter, writing on mobile qubits

Double diamond = **Datta-Das** spin FET.

Can replace magnetic flux by **leakage.**

Can obtain spin splitting from **transient currents**.

Alternative: obtain full polarizations without magnetic field with 2 drains

Also: polarize one lead and get rotated spins in the other


Thank you