# ナノテクとスピントロニクス入門

# End of term report

Select 2 problems and solve them
Deadline:  8 Jan. 2020
Submit by e-mail to
Suzuki-y@mp.es.osaka-u.ac.jp
Subject: REPORT +your name

# Report problem 1: Pauli spin

i) From $\sigma_i \sigma_j = \delta_{ij}\sigma_0 + i\varepsilon_{ijk}\sigma_k$, and $\sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$, $\sigma_0 = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$,

obtain expression of $\sigma_x$ and $\sigma_y$.

ii) Show that $\langle \theta,\phi | \vec{\sigma} | \theta,\phi \rangle = \begin{pmatrix} \sin\theta\cos\phi \\ \sin\theta\sin\phi \\ \cos\theta \end{pmatrix}$.

Here, $|\theta,\phi\rangle \equiv \cos\frac{\theta}{2}|\uparrow\rangle + e^{i\phi}\sin\frac{\theta}{2}|\downarrow\rangle$.

iii) Calculate $e^{-i\frac{\pi}{4}\sigma_x}|\uparrow\rangle$, and $e^{-i\pi\sigma_x}|\uparrow\rangle$.

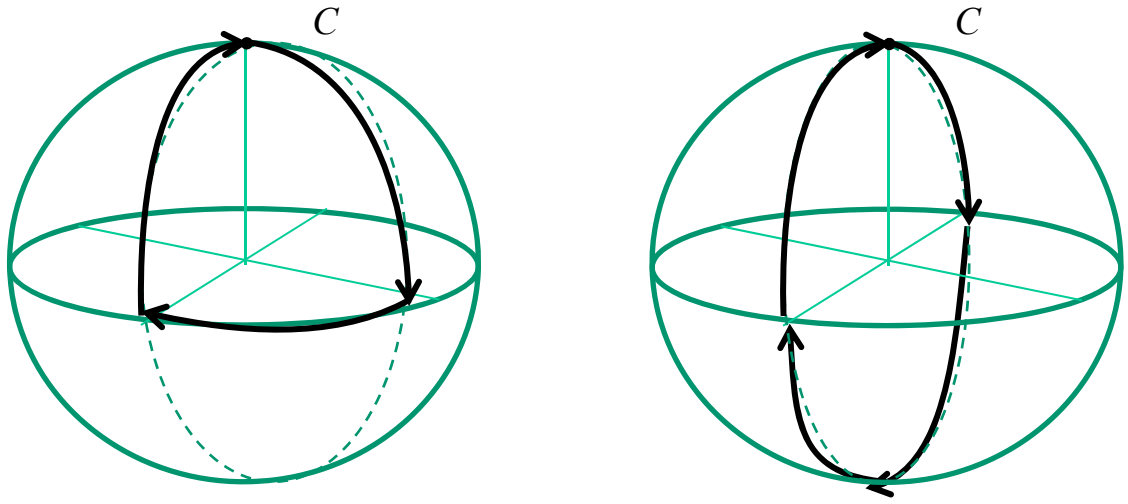
# Report problem 2: Spin-Berry phase

i) We start from $\left|\uparrow\right\rangle$ state and apply sucessive 3 rotations as shown in the right hand side picture. Obtaine additional phase factor that appears after operations.

Hint: $e^{i\gamma}\left|\uparrow\right\rangle = e^{i\frac{\pi}{4}\sigma_y} e^{i\frac{\pi}{4}\sigma_z} e^{i\frac{\pi}{4}\sigma_x}\left|\uparrow\right\rangle$

ii) Similarly, we start from $\left|\uparrow\right\rangle$ and rotate $2\pi$ by y-aixis. Obtain additional phase factor after the operation.

Those phases are known as spin-Berry phase.



# Report problem 3: Quantum conductance and Magnetic tunnel junction

Imagine an MTJ with resistance area product at parallel alignment of $RA \equiv R \times Area = 1000\ [\Omega\,\mu m^2]$.

Assuming area of one conduction channel as $0.2 \times 0.2\ [nm^2]$, estimate tunneling probability in this MTJ. Here, we neglect a conduction through a minority spin channel.

Hint: $\text{Conductance} = \left(2R_Q\right)^{-1} \times \left(\text{Number of channels}\right)$

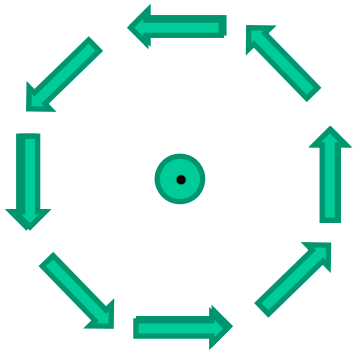
$$R_Q = 12.9\ [k\Omega]$$

# Report problem 4: スピン注入磁化反転

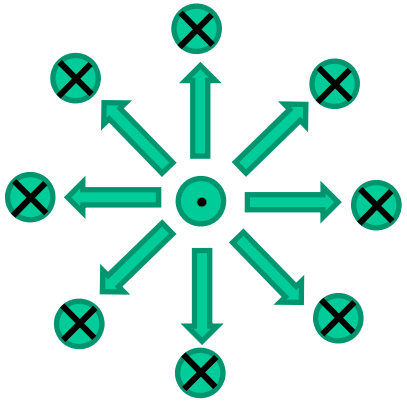
30%スピン偏極した電流を注入してスピン注入磁化反転を行いたい。素子断面を一辺100nmの正方形とし、1.4nmの厚さのbcc-Feにスピン注入を行う。Feのスピンが緩和する時間を10nsecとしてスピン注入磁化反転に必要な電流を見積もれ。

# Report problem 5: Chiral structure

Draw a mirror transfered structure of the magnetic vortex and 2D skyrmion with respect to a vertical mirror and an in - plane mirror.

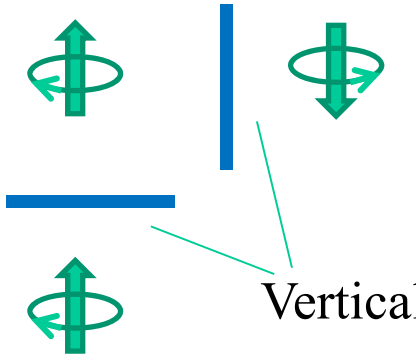


Vortex



Skyrmion

Hint: A spin can be treated as a rotating current.




*The horizontal mirror is parallel to the paper/computer screeen.