Hanle Effect in Magnetotransport

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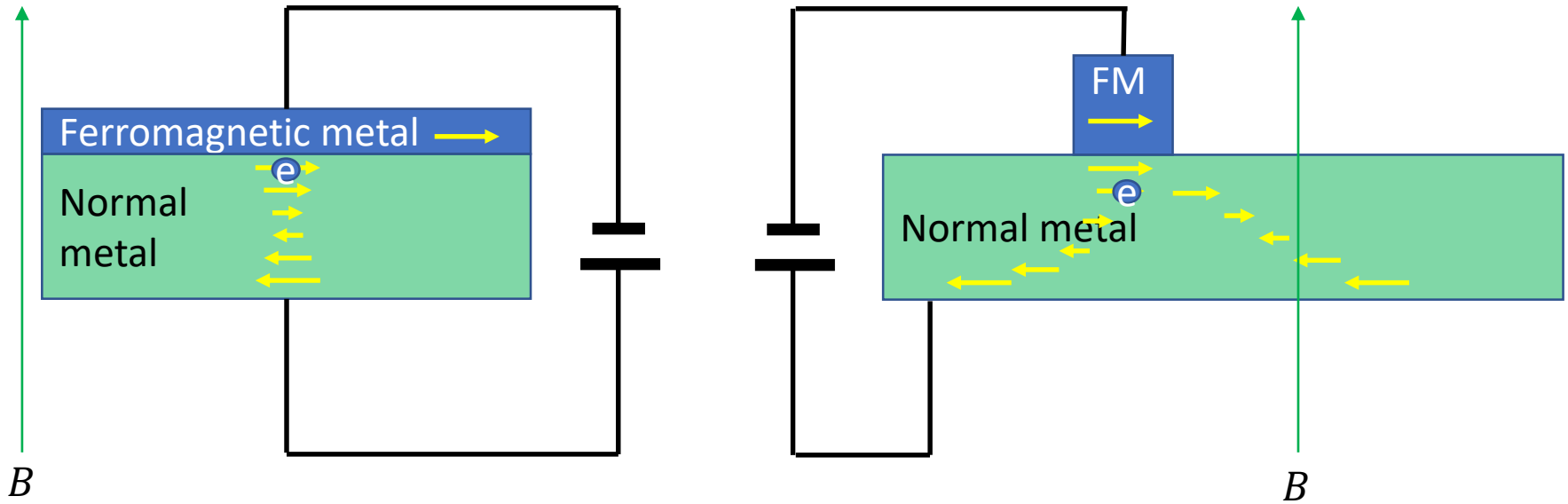
What is Hanle effect?

- Hanle effect describes the precession of magnetic moment (spin) of electrons in a perpendicular magnetic field during the spin current
- Manifest itself slightly differently in two cases
  - Spin current due to charge current
  - Spin current due to diffusion
- Hanle effect is believe to be the most direct evidence of spin current.

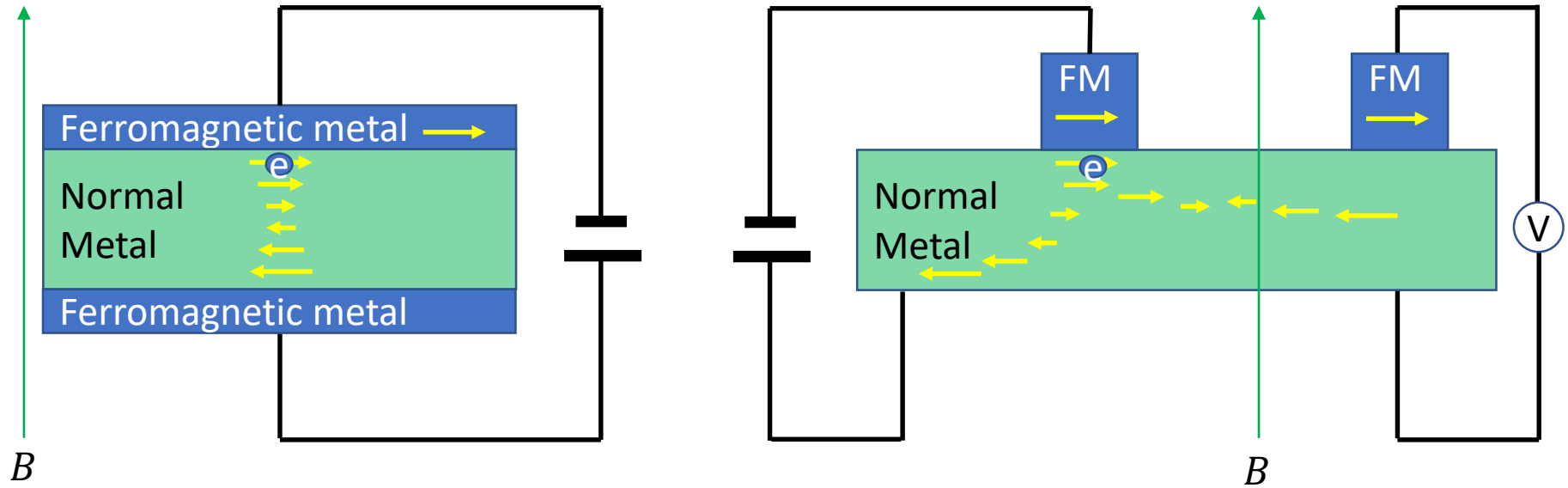
Spin current



Charge current

Spin diffusion

How to measure the spin precession

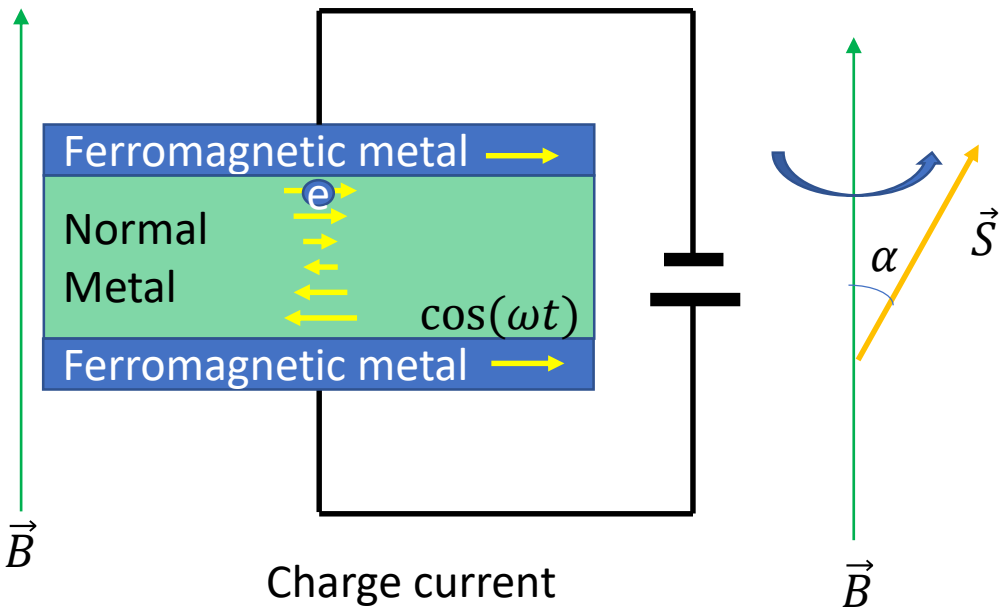


Charge current

Spin diffusion

1. Spin current from charge current

$$\Delta I_{C2} \sim \int \frac{1}{2\sqrt{\pi D t}} e^{-\frac{(x-vt)^2}{4Dt}} \cos(\omega t)\, e^{-t/\tau_{sf}}\, dt$$



Spin precession:

$$\frac{d\vec{S}}{dt} = \vec{\tau} = \frac{g\mu_B}{\hbar}\vec{S} \times \vec{B}$$

$$S\sin(\alpha)\,\omega = \frac{g\mu_B}{\hbar} SB\sin(\alpha)$$

$$\omega = \frac{g\mu_B}{\hbar} B$$

a) Spin precession factor:

$$\cos(\omega t)$$

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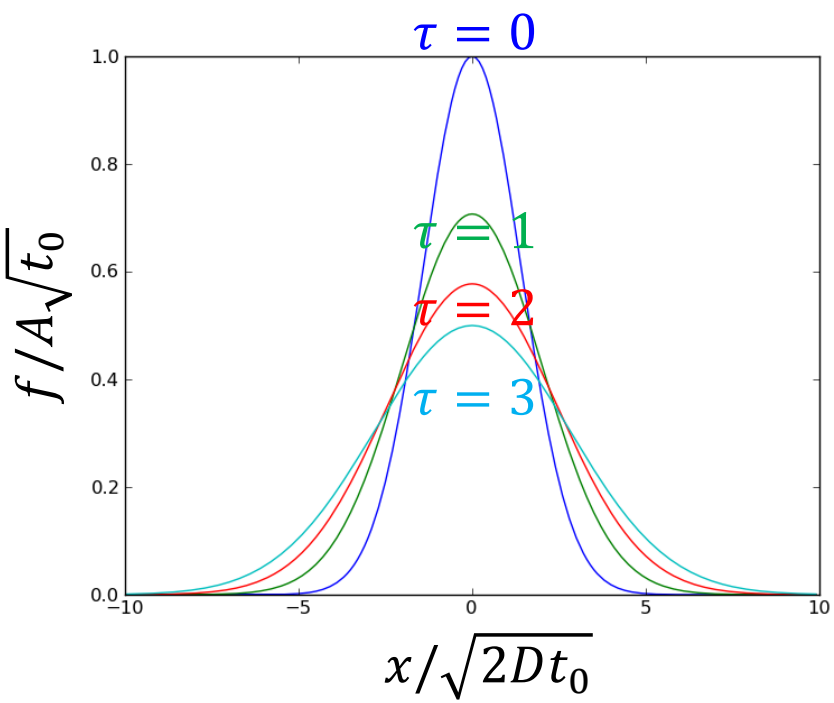
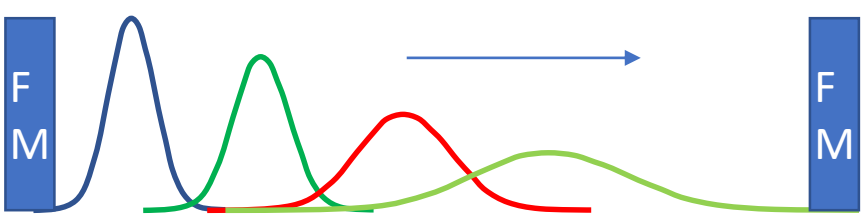
1. Spin current from charge current



$$f(x,t) = \frac{A}{\sqrt{t+t_0}} e^{-\frac{x^2}{4D(t+t_0)}}$$



b) Diffusion factor:

$$\frac{1}{2\sqrt{\pi D t}} e^{-\frac{(x-vt)^2}{4Dt}}$$

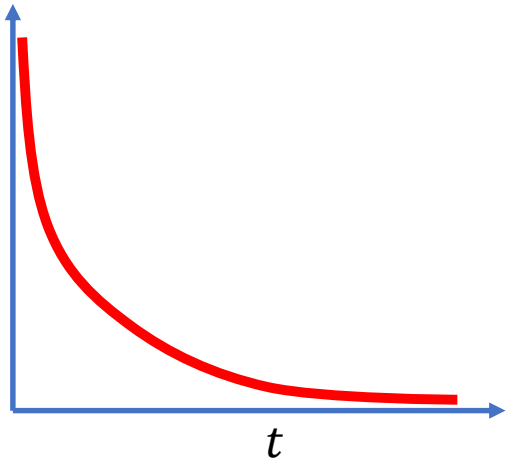
1. Spin current from charge current

Thermal fluctuation cause spin alignment to change or “loss of coherence”.

c) Coherence factor:

$$e^{-t/\tau_{sf}}$$

τ_{sf}: spin diffusion time



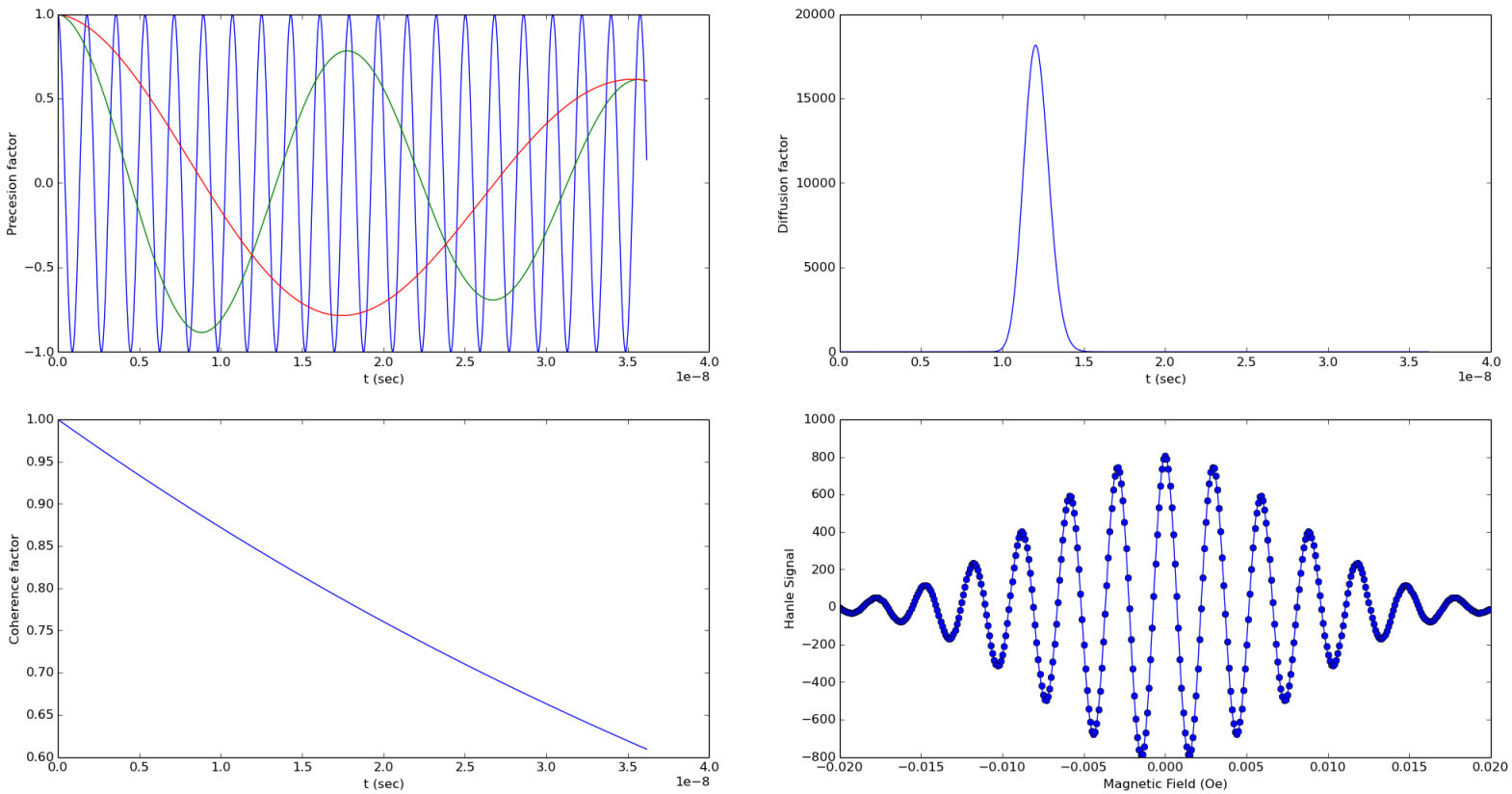
1. Spin current from charge current

a) Spin precession factor: $\cos(\omega t)$

b) Diffusion factor: $\frac{1}{2\sqrt{\pi D t}} e^{-[\frac{(x-vt)^2}{4Dt}]}$

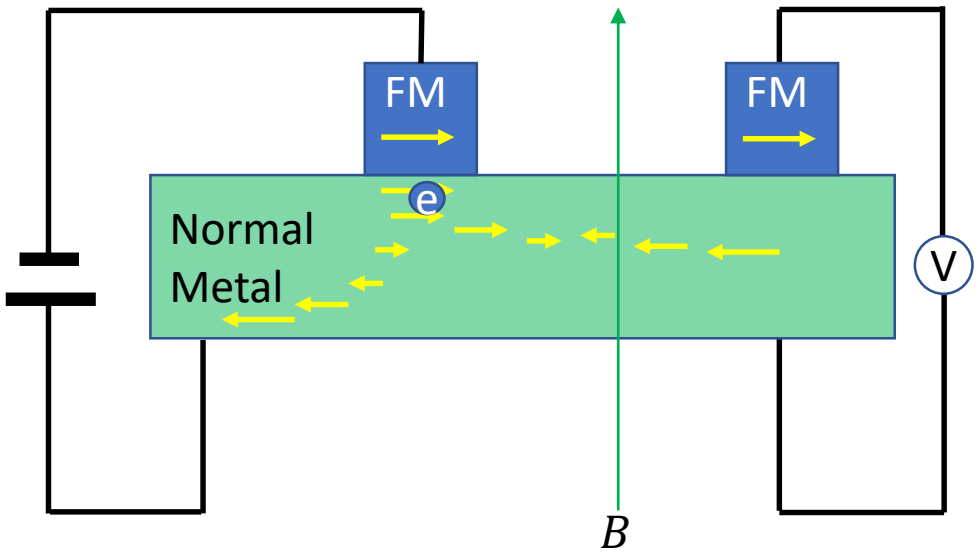
c) Coherence factor: $e^{-t/\tau_{sf}}$

$$\Delta I_{C2} \sim \int \frac{1}{2\sqrt{\pi D t}} e^{-\frac{(x-vt)^2}{4Dt}} \cos(\omega t)\, e^{-t/\tau_{sf}}\, dt$$



2. Spin current from diffusion

$$\Delta I_{C2} \sim \int \frac{1}{2\sqrt{\pi D t}} e^{-\frac{x^2}{4Dt}} \cos(\omega t)\, e^{-t/\tau_{sf}}\, dt$$



Spin diffusion

a) Spin precession factor:

$$\cos(\omega t)$$

b) Diffusion factor:

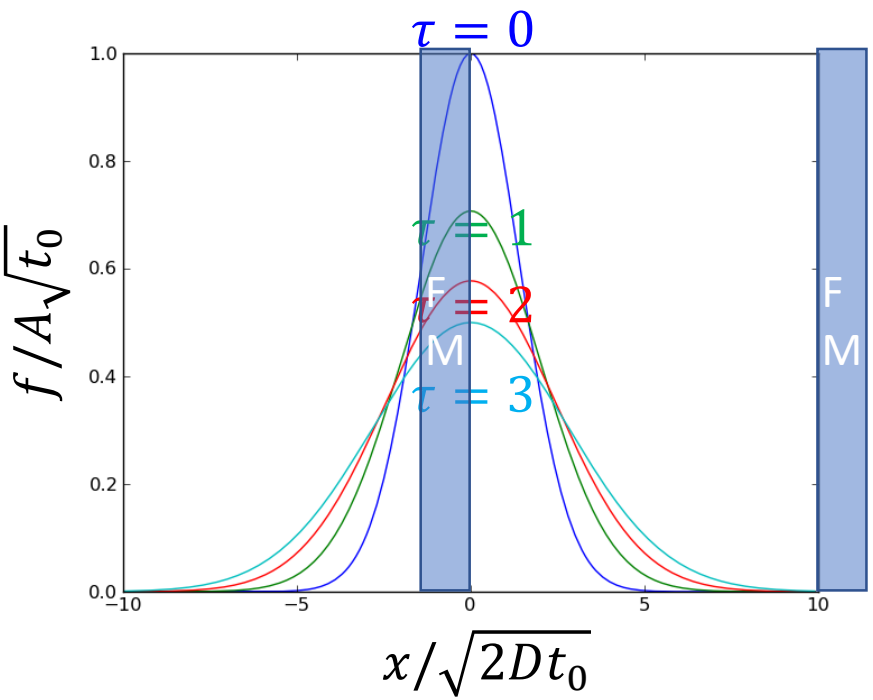
$$\frac{1}{2\sqrt{\pi D t}} e^{-\frac{x^2}{4Dt}}$$

c) Coherence factor:

$$e^{-t/\tau_{sf}}$$

PRL **55,** 1790 (1985), Nature, **416**, 713 (2002).

2. Spin current from diffusion



b) Diffusion factor:

$$\frac{1}{2\sqrt{\pi D t}} e^{-\frac{x^2}{4Dt}}$$

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2. Spin current from diffusion

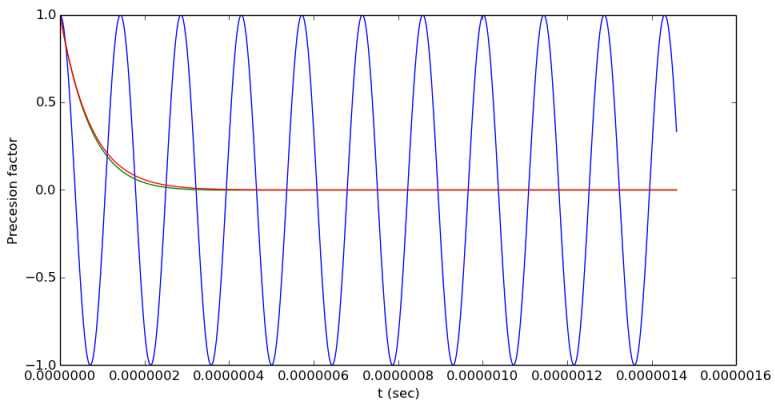
Put it all together

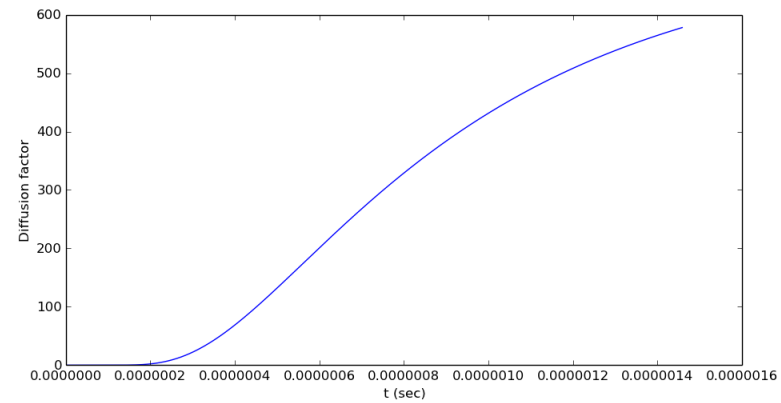
a) Spin precession factor: $\cos(\omega t)$

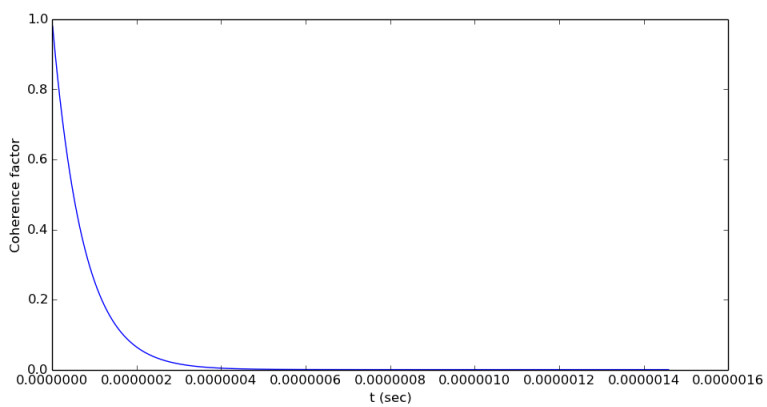
b) Diffusion factor: $\frac{1}{2\sqrt{\pi D t}} e^{-\frac{x^2}{4Dt}}$

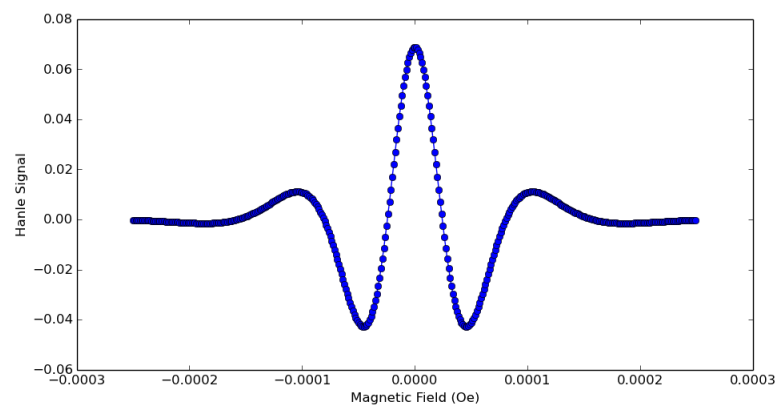
c) Coherence factor: $e^{-t/\tau_{sf}}$

$$\Delta I_{C2} \sim \int \frac{1}{2\sqrt{\pi D t}} e^{-\frac{x^2}{4Dt}} \cos(\omega t)\, e^{-t/\tau_{sf}}\, dt$$



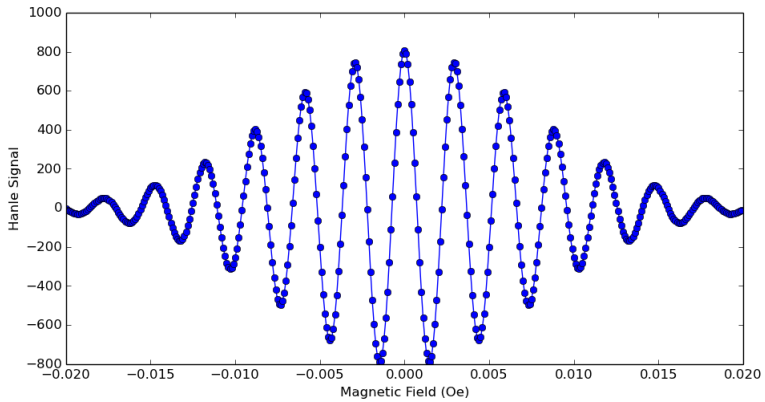






Conclusion

- Spin current due to charge current (local)



- Spin current due to diffusion (non-local)