# Introduction to spintronics - spin transistor

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## Introduction

One of characteristic properties of particles described in formalism of quantum mechanics is spin. Spin is important when we consider a behaviour of a particle in magnetic field. Manipulation of spin allow to build devices which in principle use a spin as a information carrier. This laboratory serves as a introduction to spintronic devices such as spin transistor.

## Spin precession in magnetic field

The first analysed system is a simple nano-wire with two contacts. Firstly a dispersion relation $E(k)$ without external magnetic field was calculated and can be seen below:

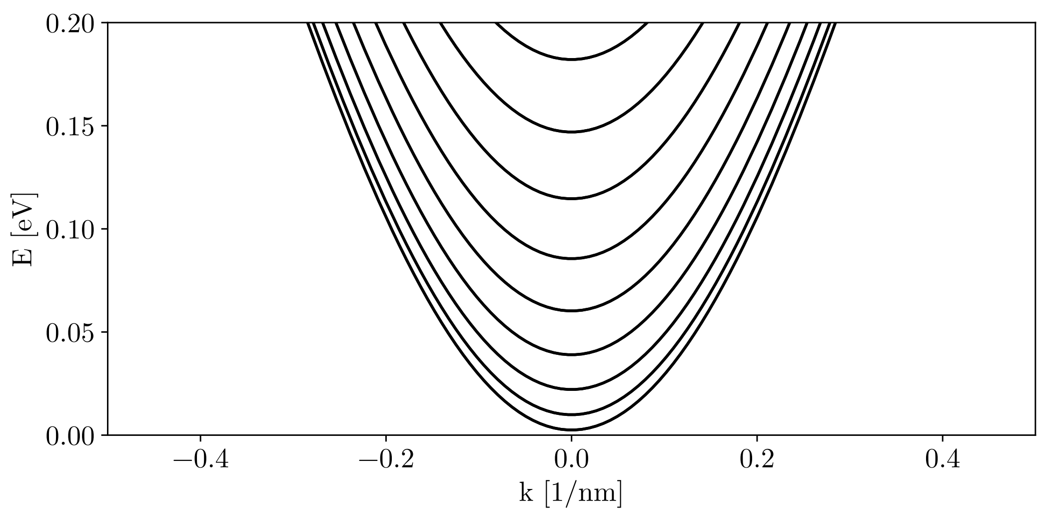
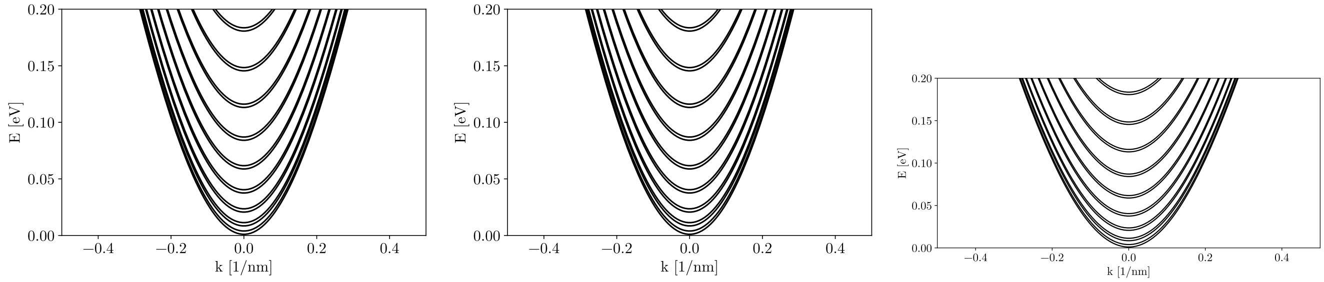



Figure 1: Dispersion relation without external magnetic field.

Now that it's been confirmed, that a system is defined properly, a direction dependence of Zeeman splitting can be analysed. Below are presented dispersion relations for a nanowire with magnetic field defined for three spacial directions.




(a) $\mathbf{B} = [1, 0, 0]$ T (b) $\mathbf{B} = [0, 1, 0]$ T (c) $\mathbf{B} = [0, 0, 1]$ T

Figure 2: Dispersion relations for magnetic field applied in the directions $x, y$ or $z$.

As one can see the Zeeman splitting seems to be direction independent.

For a magnetic field defined as $\mathbf{B} = [0, 0, 1]$ T a conductance as a function of incident electron energy was calculated. Result are presented below:

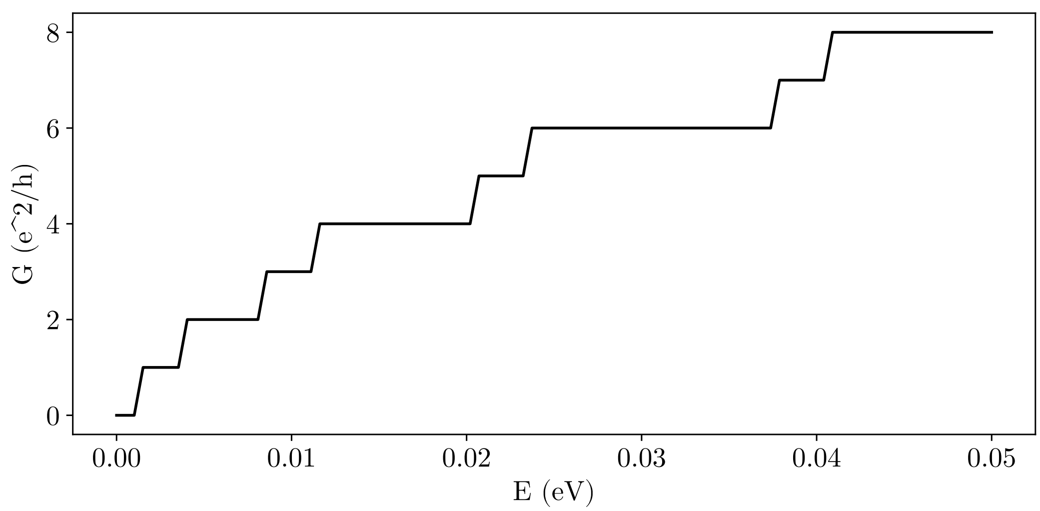



Figure 3: Conductance of a nanowire as a function of energy.

On a conductance function plot we can see a characteristic step-like behaviour on discreet quantized conductance values.

As a next step a spatially variant magnetic field was applied. Said magnetic field is defined so that for a whole nanowire applied magnetic field is $\mathbf{B} = [0, 0, 0.1]$ T. Additionally a $B_y$ component is added for region $x/L \in [0.2, 0.8]$, so effectively the magnetic field in this region is defined as $\mathbf{B} = [0, B_y, 0.1]$. For $B_y \in [0, 1]$ T spin dependent transmission coefficients were calculated. The results are presented in a figure below:

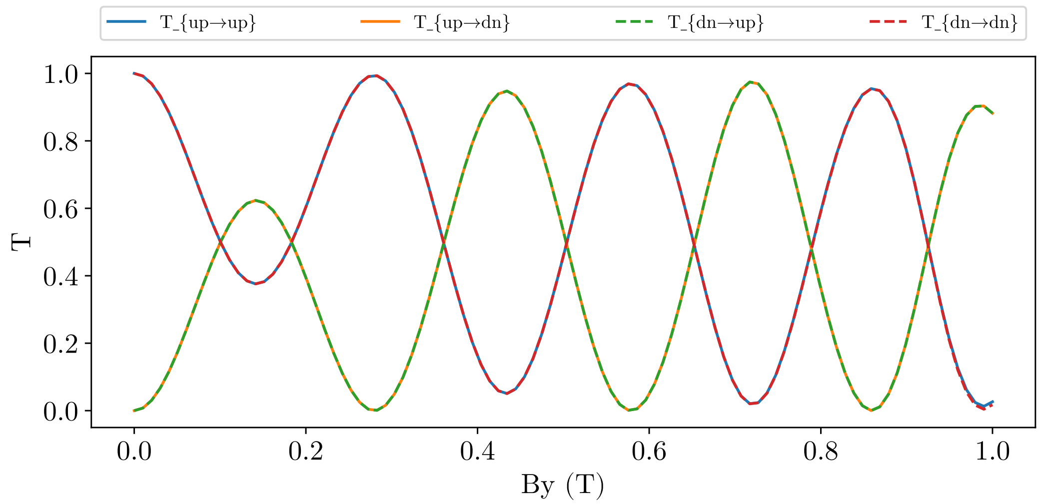



Figure 4: Spin dependent transmission coefficients as a $B_y$ function.

The transmission character changes periodically from conserved spin transition to spin flip transition.

To further inspect the spin flip transition in a nanowire a spin dependent charge density in system was calculated. Since calculated transmission coefficient $T_{\text{up}\leftarrow\text{up}}$ for $B_y = 0.6$ T is about 0.92, that would mean we expect a transport with either no spin flip or spin flipping occurring so that the spin at both leads is the same. A calculated charge distribution can be seen below:

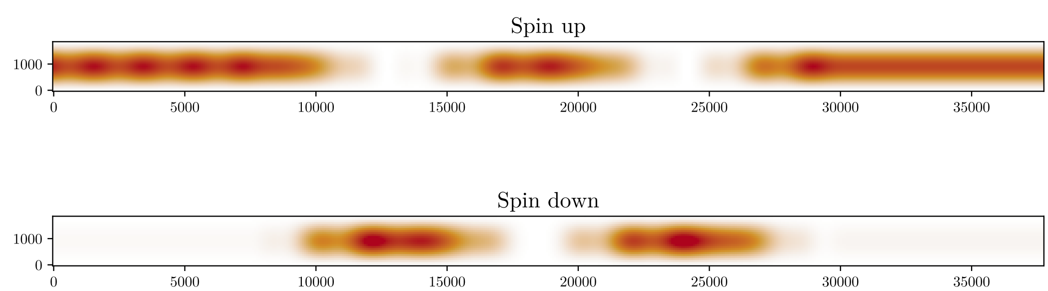



Figure 5: Spin dependent electron density in the nanowire.

The plot implies that during the transport spin "rotates" two times.

For the same system spin $(s_x, s_y, s_z)$ density distribution was calculated and plotted on the picture below:

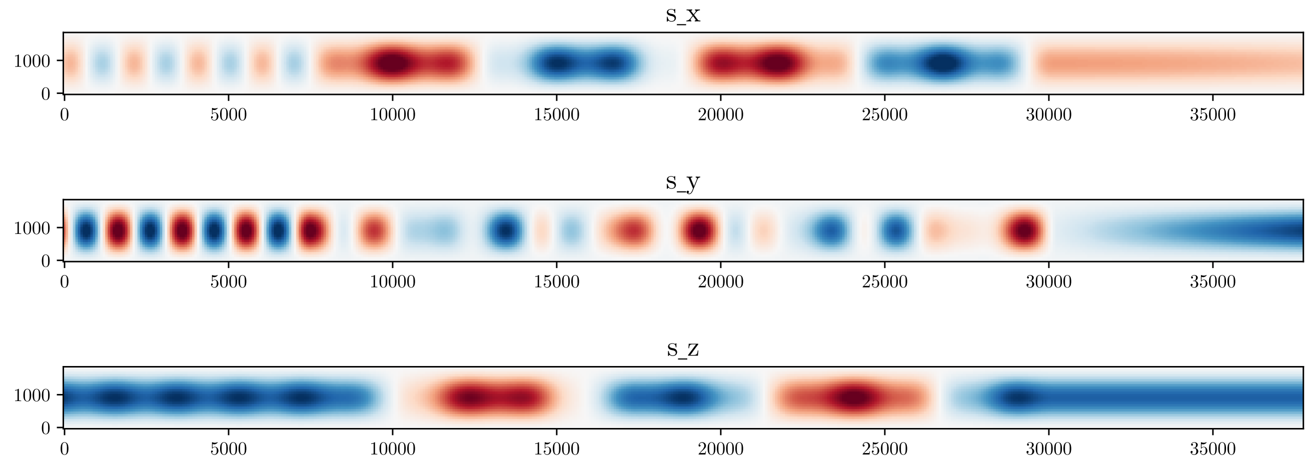



Figure 6: Spin distributions in the nanowire.

# Spin transistor

Including a spin-orbit interaction into calculations changes the outcomes and broadens the possibilities of effects to analyse. On a picture below a calculated dispersion relation with spin-orbit coupling inclusion is presented.

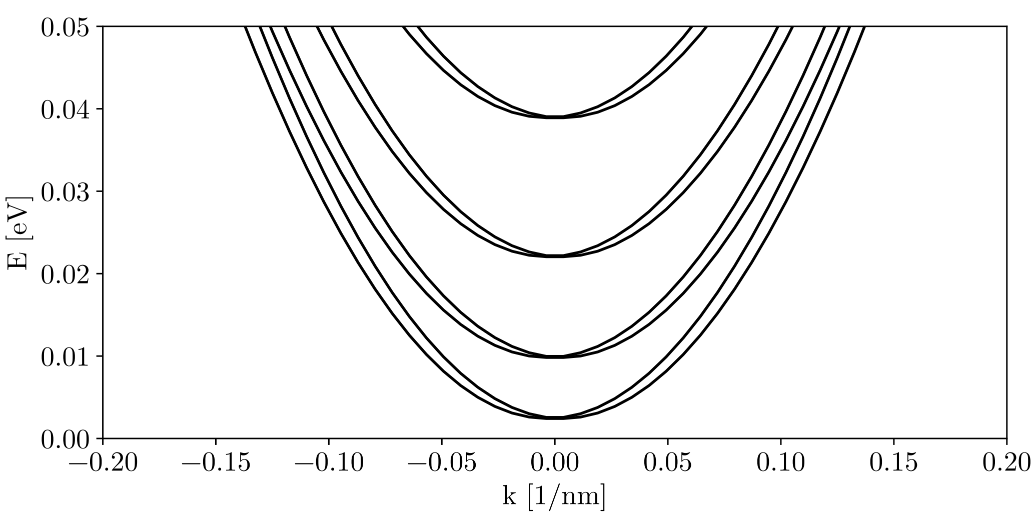



Figure 7: Dispersion relation in the nanowire with SOC ($\alpha = 50$ meVnm).

Including the spin-orbit coupling in calculations changes the shape of the dispersion relation. The bands are now horizontally split.

The changes of conductance as a function of incident electron energy can also be analysed. The calculation results pictured on a figure can be seen below.

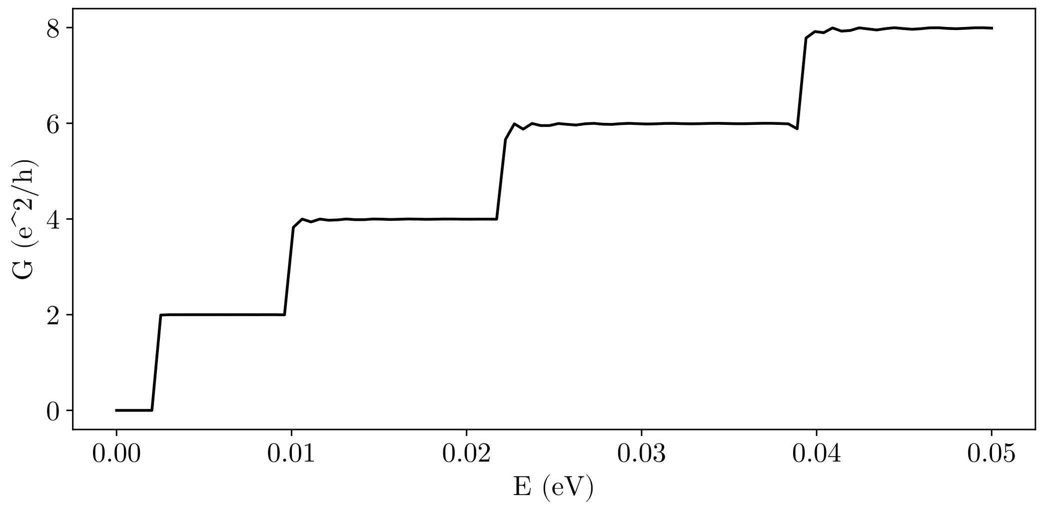



Figure 8: Conductance as a function of electron energy with SOC considered.

Once again step-like behaviour can be observed, although now the steps take up two units of quantized conductance.

The spin dependent transmission coefficients were calculated as a function of $\alpha$ under assumption that the spin-orbit interaction is only present in the region $x/L \in [0.2, 0.8]$. The plotted results are visualized below.

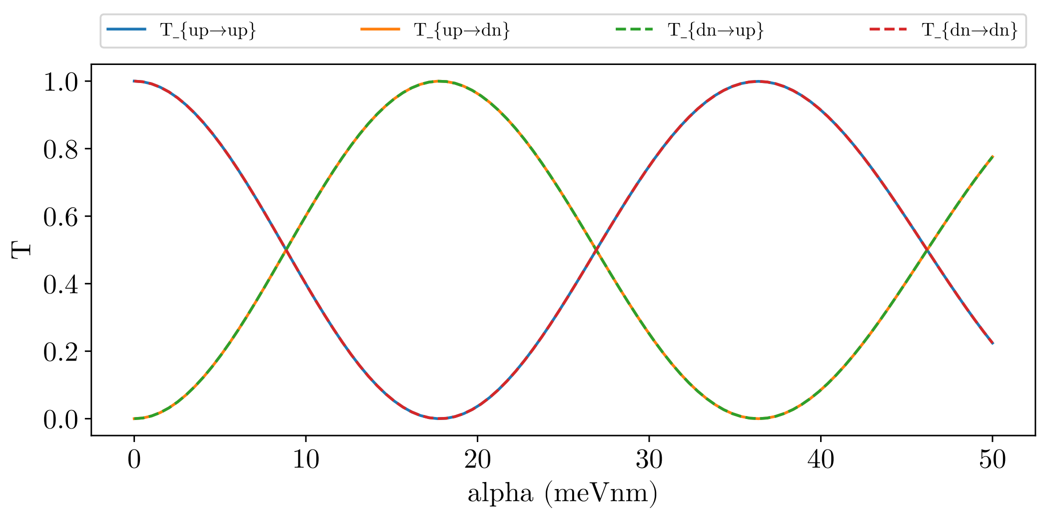



Figure 9: Spin dependent transmission coefficients as a function of $\alpha$.

Analogically the spin dependent conductance can be calculated as a function of $\alpha$, the results are presented in a form of a plot below.

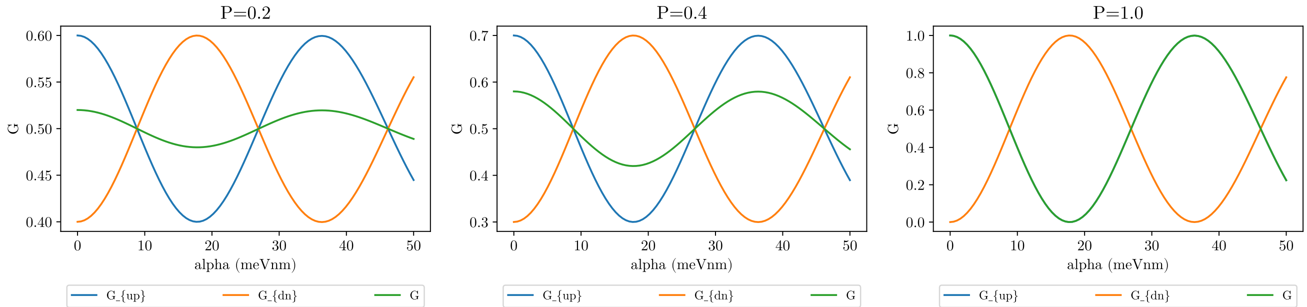



Figure 10: Spin dependent conductance as a function of $\alpha$ for $P \in 0.1, 0.4, 1.0$.

For a full polarization the total current is described by a single factor. For lower spin polarization of flowing current naturally lower total current is observed.

# Summary