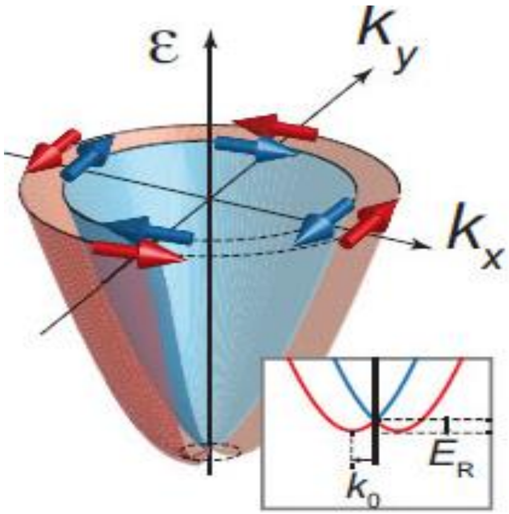
Rashba effect (requires inversion symmetry breaking)

The **Rashba effect**, or **Rashba-Dresselhaus effect**, is a momentum-dependent splitting of spin bands in two-dimensional condensed matter systems (heterostructures and surface states)

The Rashba spin-orbit interaction Hamiltonian is $H_R = \alpha(\boldsymbol{\sigma} \times \mathbf{p}) \cdot \hat{z}$,

where $\boldsymbol{\alpha}$ is the Rashba coupling, $\boldsymbol{p}$ is the momentum and $\boldsymbol{\sigma}$ is the Pauli matrix vector.



Applications

Spintronics - Electronic devices are based on the ability to manipulate the electrons position by means of electric fields. Similarly, devices can be based on the manipulation of the spin degree of freedom. The Rashba effect allows to manipulate the spin without the aid of a magnetic field.

Topological quantum computation - Rashba effect can help to realize a p-wave superconductor. Such a superconductor has very special edge-states known as Majorana bound states. The non-locality immunizes them to local scattering and henceforth they are predicted to have long coherence times. Decoherence is one of the largest barriers on the way to realize a full scale quantum computer and these immune states are therefore considered good candidates for a quantum bit.

Discovery of **giant Rashba effect** in bulk crystals such as BiTe and ferroelectric GeTe.

Naive derivation of the Rashba Hamiltonian

The Rashba effect is a direct result of inversion symmetry breaking in the direction perpendicular to the two-dimensional plane. Therefore, let us add to the Hamiltonian a term that breaks this symmetry in the form of an electric field

$$H_E = -E_0 z,$$

Due to relativistic corrections an electron moving with velocity v in the electric field will experience an effective magnetic field B

$$\mathbf{B} = -(\mathbf{v} \times \mathbf{E})/c^2,$$

where c is the speed of light. This magnetic field couples to the electron spin

$$H_{SO} = \frac{g\mu_B}{2c^2}(\mathbf{v} \times \mathbf{E}) \cdot \boldsymbol{\sigma},$$

where $-g\mu_B\boldsymbol{\sigma}/2$ is the magnetic moment of the electron.

Within this toy model, the Rashba Hamiltonian is given by

$$H_R = \alpha(\boldsymbol{\sigma} \times \mathbf{p}) \cdot \hat{z},$$

where $\alpha = \frac{g\mu_B E_0}{2mc^2}$. However, while this "toy model" is superficially convincing, the Ehrenfest theorem seems to suggest that since the electronic motion in the $\hat{z}$ direction is that of a bound state that confines it to the 2D surface, the time-averaged electric field (i.e., including that of the potential that binds it to the 2D surface) that the electron experiences must be zero! When applied to the toy model, this argument seems to rule out the Rashba effect (and caused much controversy prior to its experimental confirmation), but turns out to be subtly-incorrect when applied to a more realistic model.[9]

Estimation of Rashba coupling in a realistic system

The necessary ingredients to get Rashba splitting are atomic spin-orbit coupling

$$H_{SO} = \Delta_{SO} \mathbf{L} \otimes \boldsymbol{\sigma},$$

and an asymmetric potential in the direction perpendicular to the 2D surface

$$H_E = E_0\, z,$$

The main effect of the symmetry breaking potential is to open a band gap Δ_{BG} between the isotropic p_z and the p_x, p_y bands. The secondary effect of this potential is that it hybridizes the p_z with the p_x and p_y bands. This hybridization can be understood within a tight-binding approximation. The hopping element from a p_z state at

The Rashba effect can be understood as a second order perturbation theory in which a spin-up hole, for example, jumps from a $|p_z, i; \uparrow\rangle$ state to a $|p_{x,y}, i + 1_{x,y}; \uparrow\rangle$ with amplitude t_0 then uses the spin-orbit coupling to flip spin and go back down to the $|p_z, i + 1_{x,y}; \downarrow\rangle$ with amplitude Δ_{SO}. Note that overall the hole hopped one site and flipped spin. The energy denominator in this perturbative picture is of course Δ_{BG} such that all

$\alpha \approx \dfrac{a\, t_0\, \Delta_{SO}}{\Delta_{BG}},$ where a is the interionic distance.

Spin-orbit interaction in atoms $\widehat{V}_{sl} = \sum \alpha_a \widehat{\mathbf{l}}_a \widehat{\mathbf{s}}_a$ **where** $\alpha_a = \dfrac{\hbar^2}{2m^2c^2 r_a} \dfrac{dU(r_a)}{dr_a}$

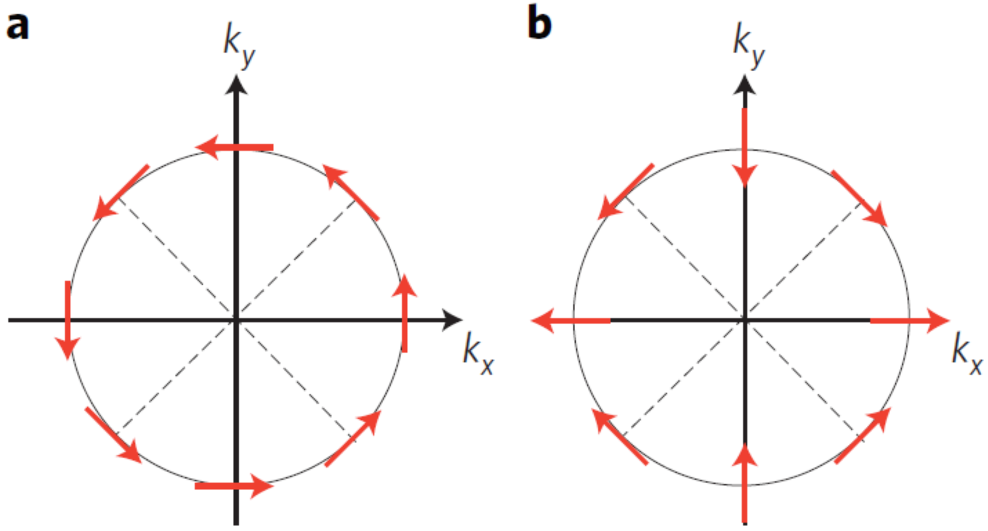
Dresselhaus spin-orbit coupling

Dresselhaus was the first to notice that in zinc-blende III–V semiconductor compounds lacking a centre of inversion, such as GaAs or InSb, the spin-orbit (SO) coupling close to the Γ point adopts the form

$$\hat{H}_{D3} = (\gamma/\hbar)\ ((p_y^2 - p_z^2)p_x\sigma_x + c.p.)\ , \qquad (1)$$

where c.p. denotes circular permutations of indices. Of course, additional symmetry considerations in the band structure result in additional odd-in-p SO coupling terms. In the presence of strain along the (001) direction, the cubic Dresselhaus SO coupling given in equation 1 reduces to the linear Dresselhaus SO coupling

$$\hat{H}_{D1} = (\beta/\hbar)\ (p_x\sigma_x - p_y\sigma_y)\ , \qquad (2)$$ where $\beta = \gamma p_z^2$.



Spin texture due to Rashba (**a**) and linear (**b**) Dresselhaus SO coupling when strain is applied along [001].