Spin Hall effect for polaritons in a TMDC monolayer embedded in a microcavity

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OUTLINE

- EXCITONS AND MICROCAVITY POLARITONS

- SPIN HALL EFFECT

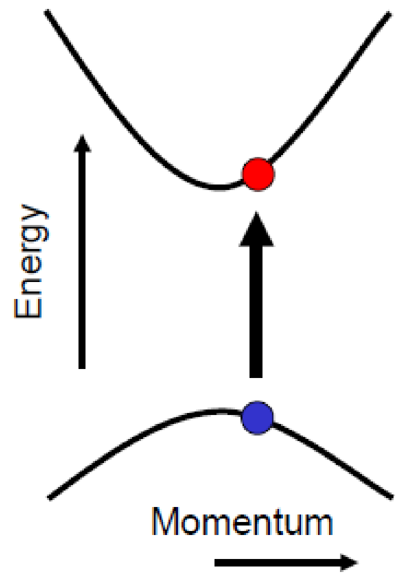
- EXCITONS IN TMDCs MONOLAYERS

- SPIN HALL EFFECT FOR POLARITONS IN A TMDC MONOLAYER EMBEDDED IN A MICROCAVITY

- CONCLUSIONS

Making light atoms inside a solid

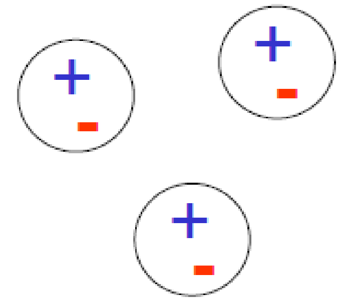
Excite electron-hole pair across a
semiconductor band gap



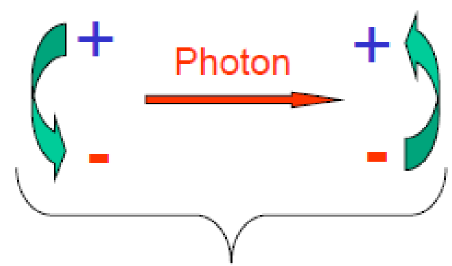
Bound by the screened
Coulomb interaction to
make an exciton

$$Ry^* = \frac{m^*/m}{\epsilon^2} \times \text{Rydberg}$$

$$a_0^* = \frac{\epsilon}{m^*/m} \times a_{Bohr}$$



Excitons are the solid state
analogue of positronium
In GaAs
Binding energy ~ 5 meV
Bohr Radius ~ 7 nm

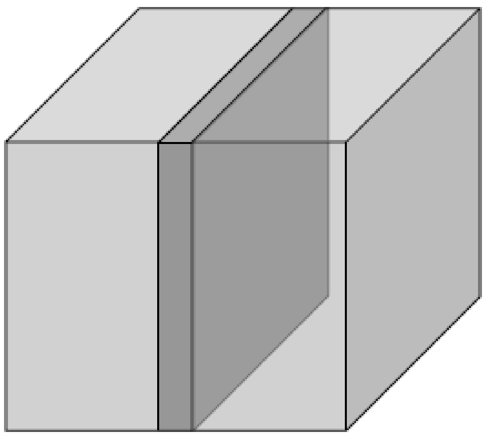


Combined coherent
excitation is called a
polariton

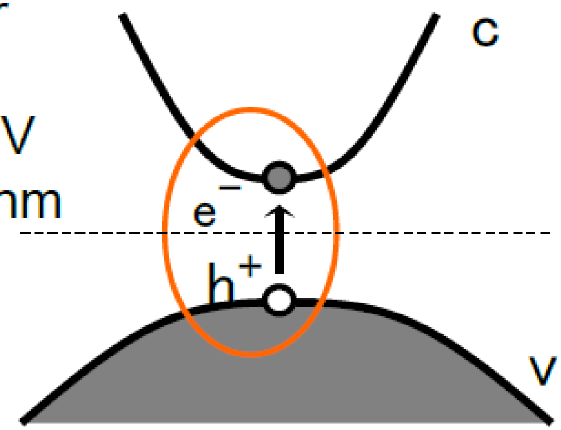
Polariton Effective Mass $m^* \sim 10^{-4}\, m_e$
$T_{BEC} \sim 1/m^*$

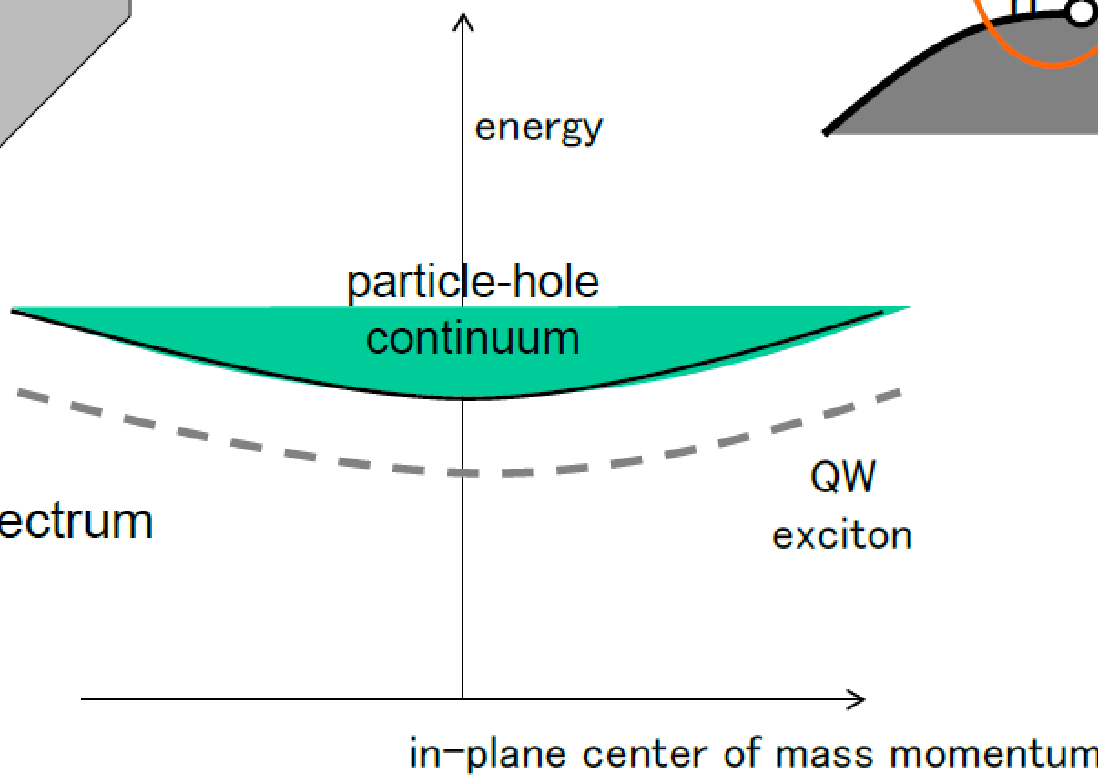
Quantum Well Excitons

Weakly bound
electron-hole pair
EXCITON
Rydberg – few meV
Bohr Radius – few nm



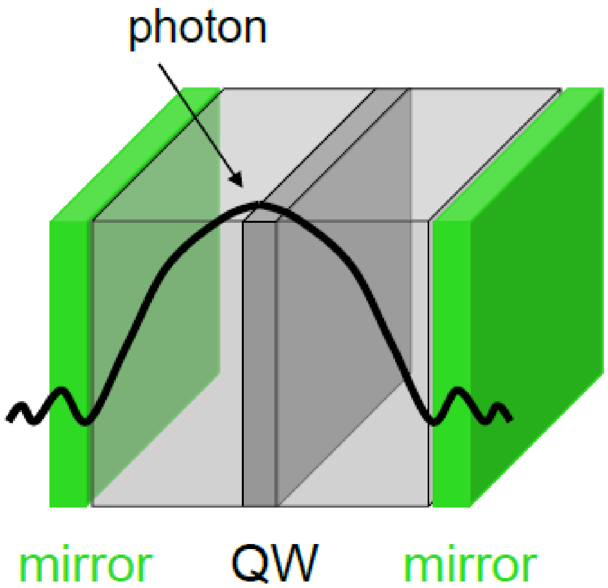
QW

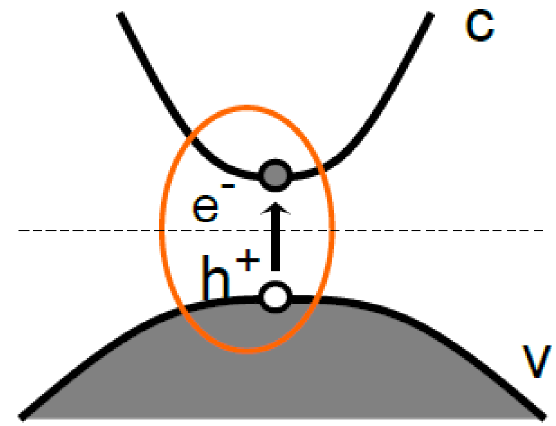


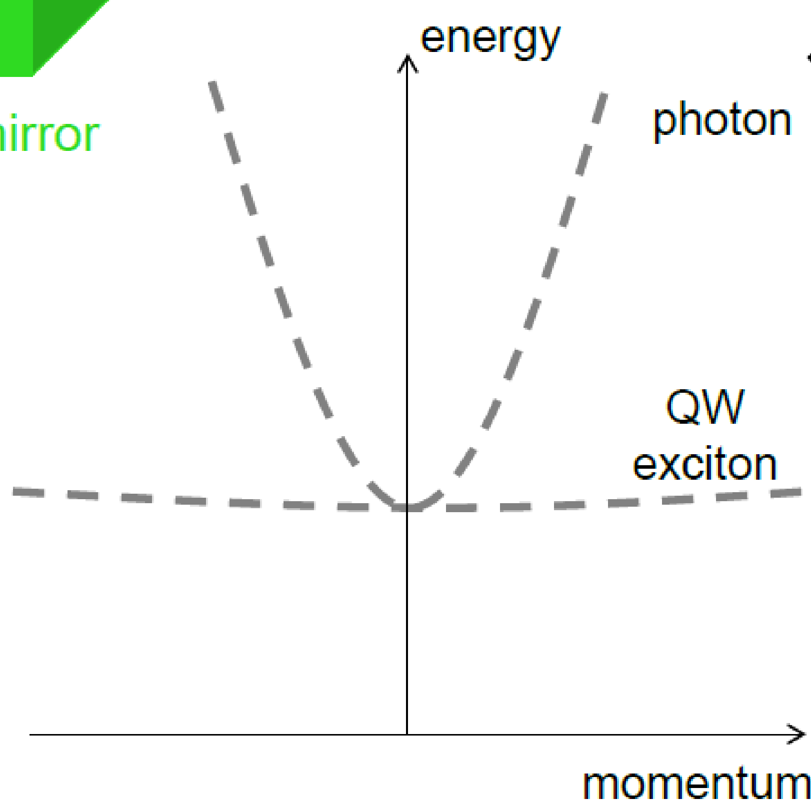


Excitation spectrum

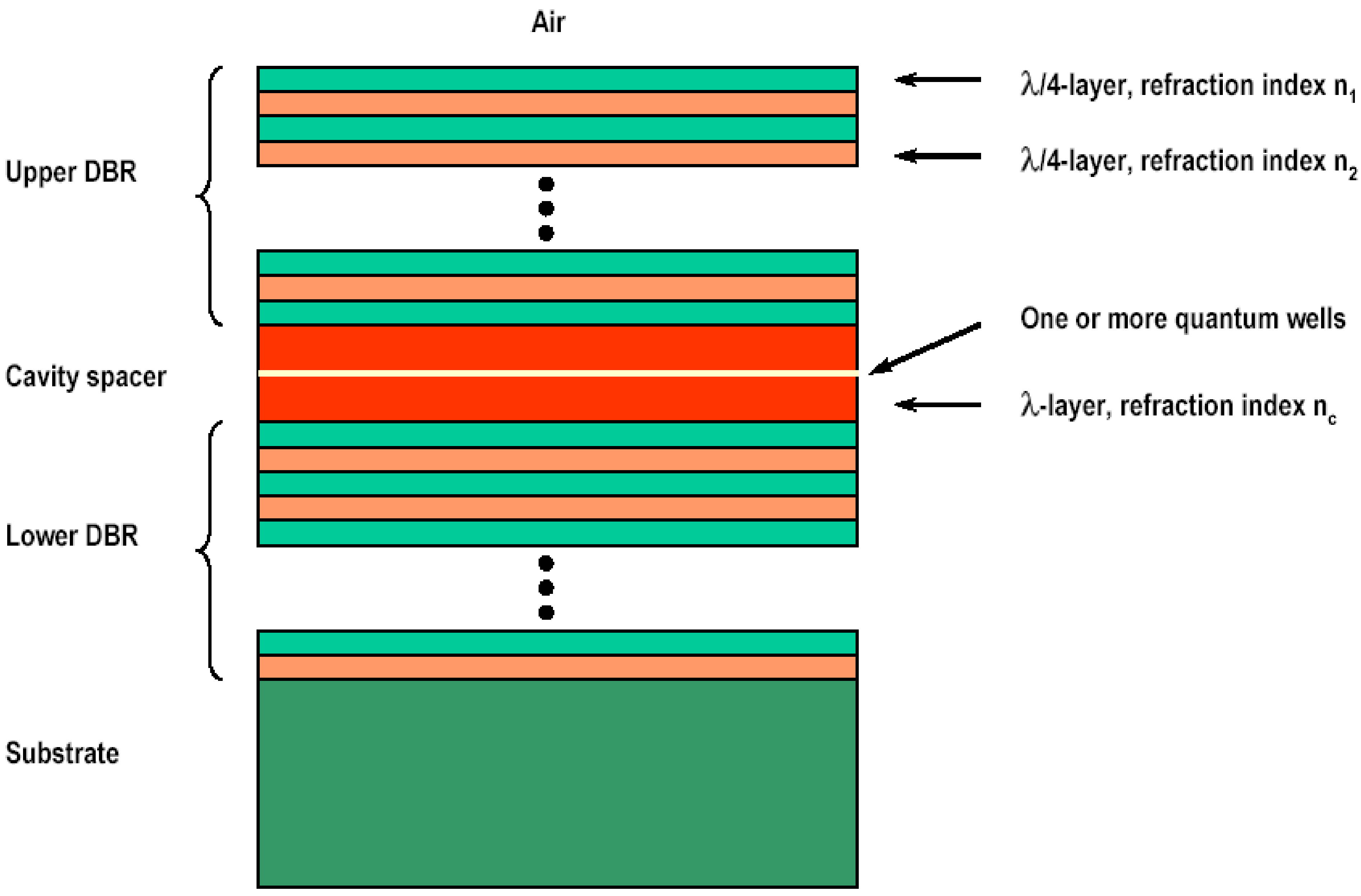
Excitons + Cavity Photons





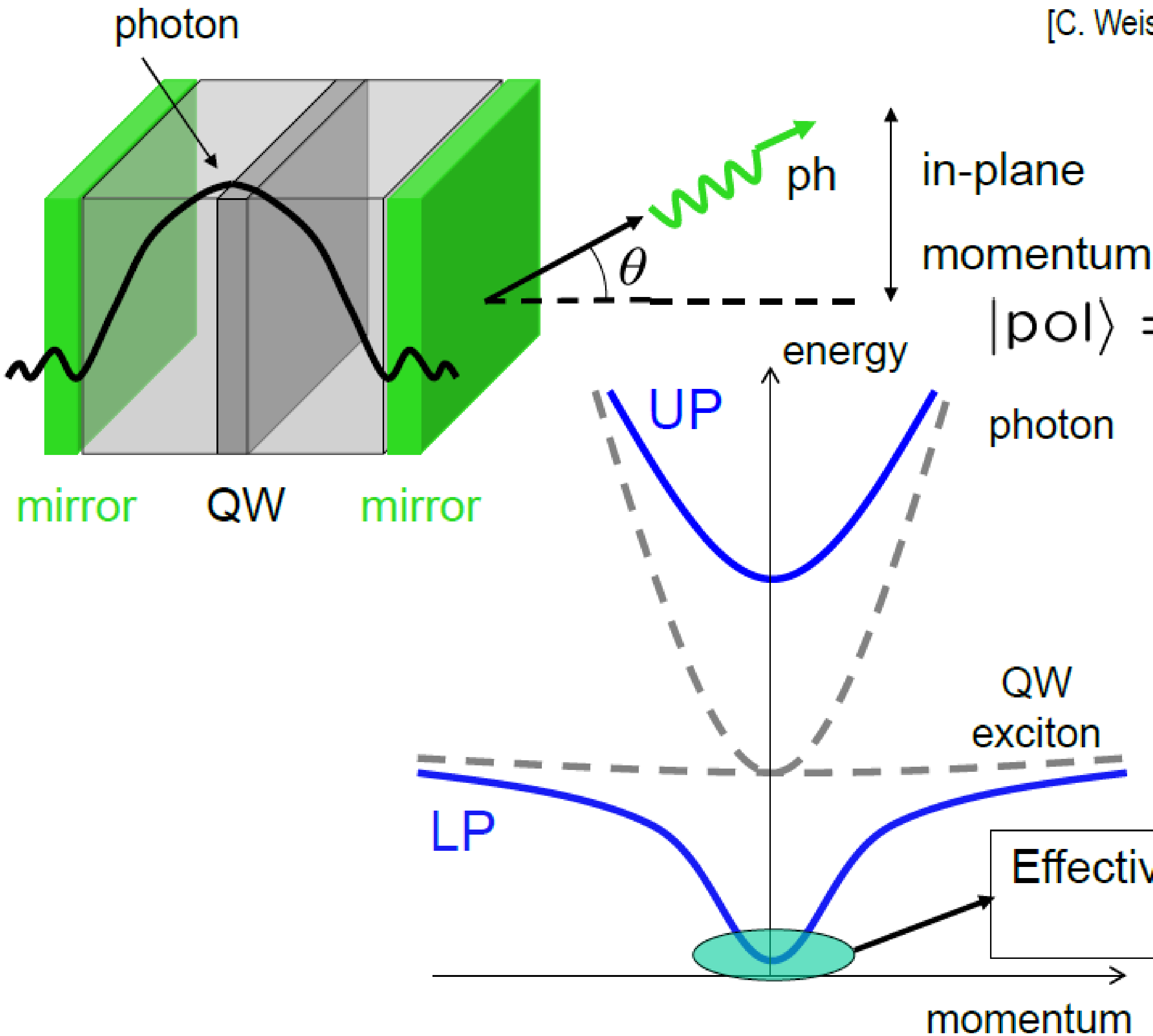


Semiconductor microcavity structure



Polaritons: Matter-Light Composite Bosons

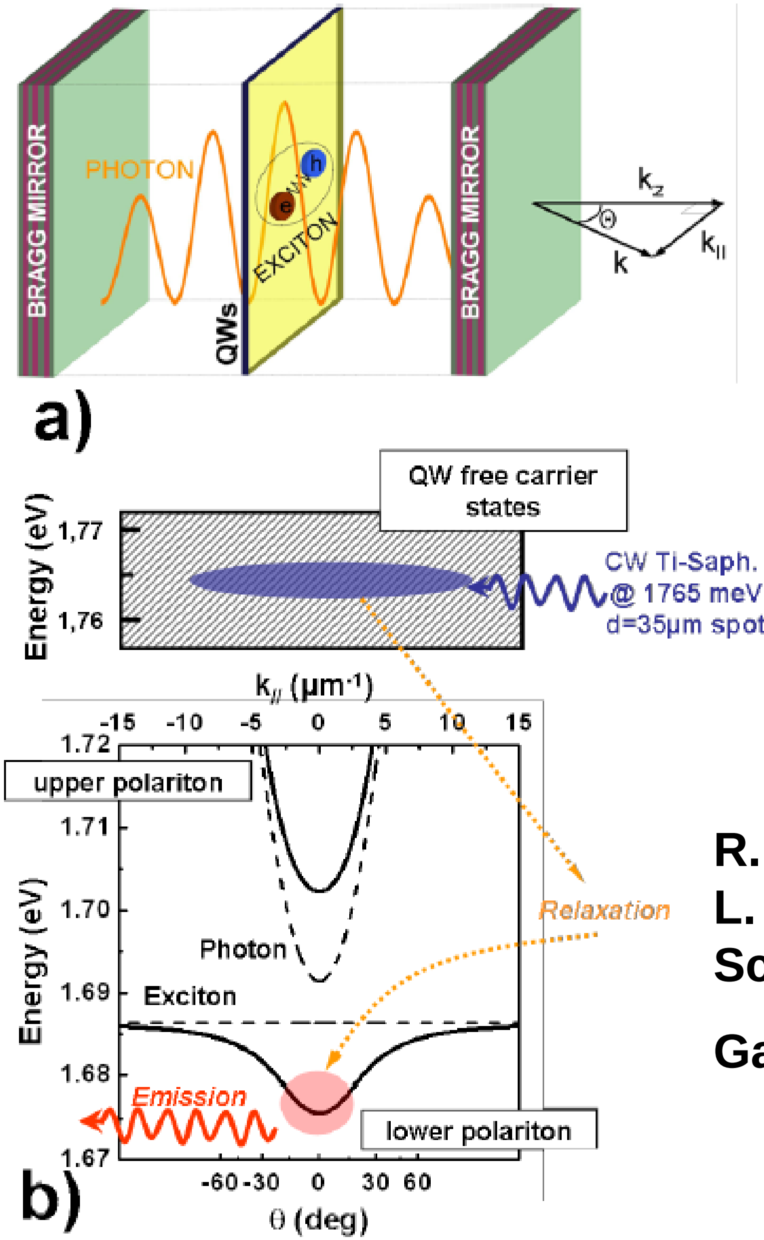
[C. Weisbuch *et al.*, *PRL* **69** 3314 (1992)]



$$|\mathrm{pol}\rangle = c_1|\mathrm{exc}\rangle + c_2|\mathrm{ph}\rangle$$

Effective Mass $m^* \sim 10^{-4}\, m_e$

$T_{BEC} \sim 1/m^*$



Microcavity polaritons

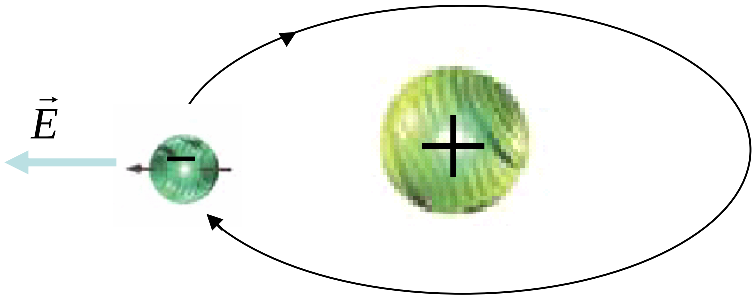
Experiments:
Kasprzak et al 2006
CdTe microcavities
Nature 443, 409 (2006).

R. B. Balili, V. Hartwell, D. W. Snoke, L. Pfeiffer and K. West, Science 316, 1007 (2007).

GaAs microcavities

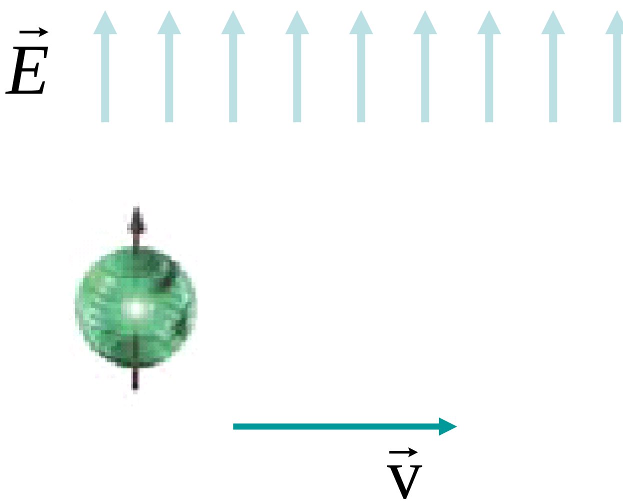
The spin Hall effect

Relativistic Spin-Orbit Coupling



- Relativistic effect: a particle in an electric field experiences an internal effective magnetic field in its moving frame

$$\vec{B}_{eff} \sim \vec{v} \times \vec{E}$$



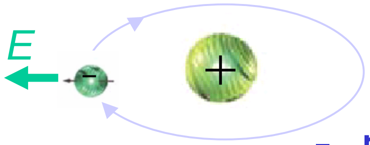
- Spin-Orbit coupling is the coupling of spin with the internal effective magnetic field

$$H \sim -\vec{S} \cdot \vec{B}_{eff}$$

Spin-orbit coupling (relativistic effect)

Ingredients: - potential V(r) → Produces an electric field

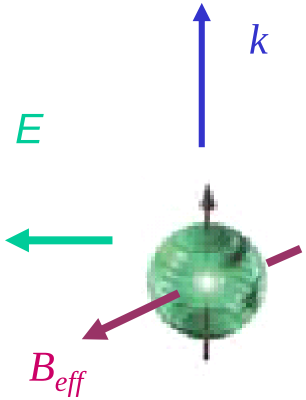
$$\vec{E} = -\left(\frac{1}{e}\right)\nabla V(r)$$



- motion of an electron → In the rest frame of an electron the electric field generates and effective magnetic field

$$\vec{B}_{eff} = -\left(\frac{\hbar\vec{k}}{cm}\right)\times\vec{E}$$

- gives an effective interaction with the electron's magnetic moment



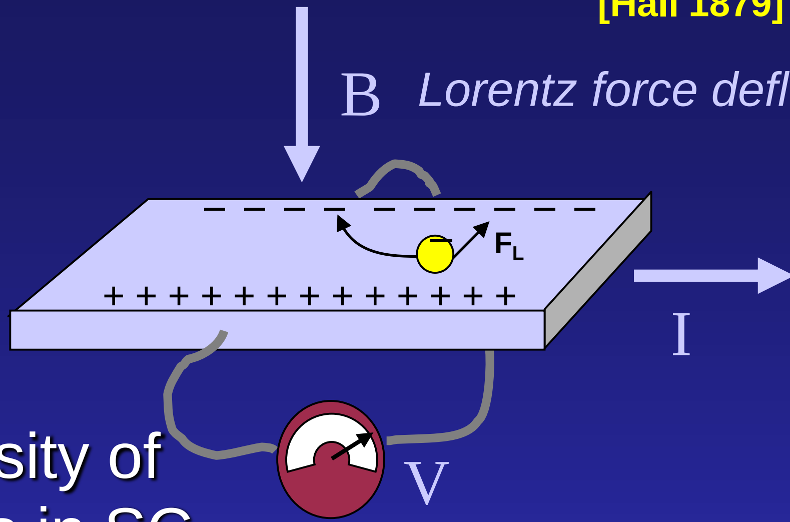
$$H_{SO} = -\vec{\mu}\cdot\vec{B}_{eff}$$

Ordinary Hall effect

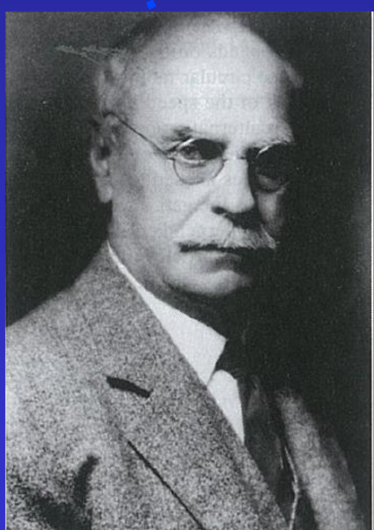
[Hall 1879]

*Lorentz force deflect **like-charge** particles*

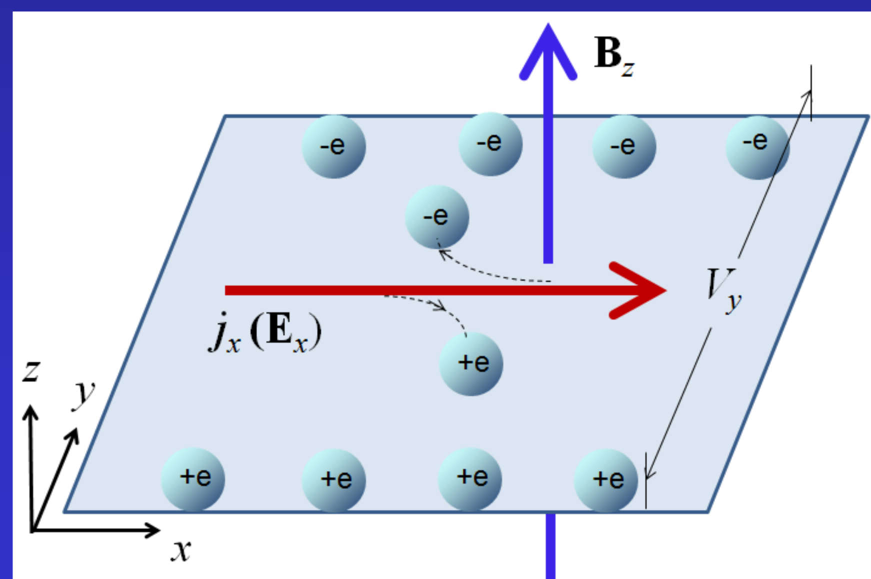
Ordinary:



Sign and density of carriers; holes in SC



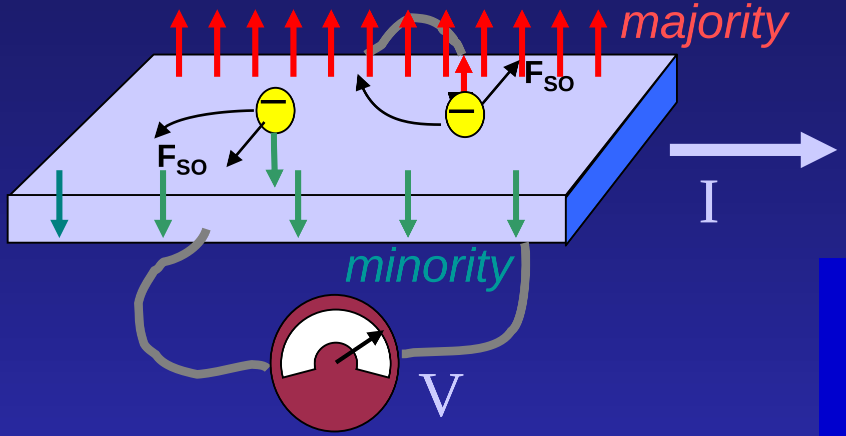
Edwin H. Hall (1855-1938)



Anomalous Hall effect [Hall, 1880 & 1881]

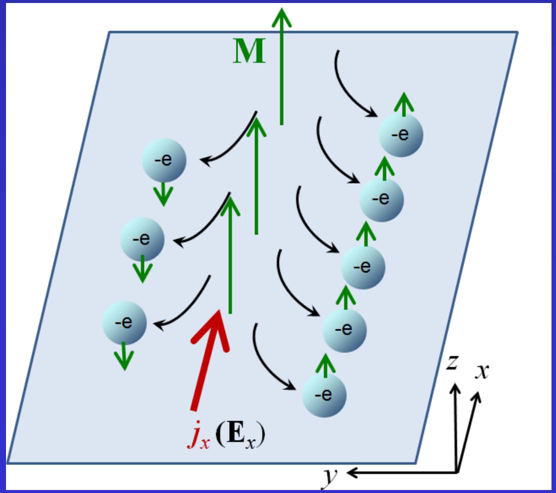
In ferromagnetic materials (and paramagnetic materials in a magnetic field)

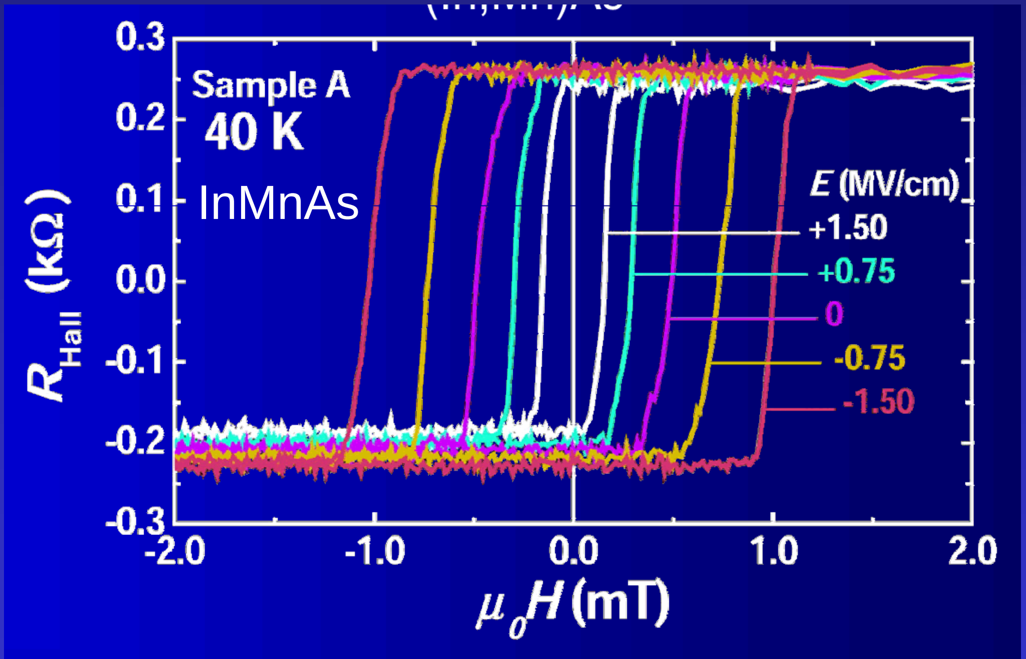
Spin-orbit coupling "force" deflects ***like-spin*** *particles*



$$\rho_H = R_0 B + \boxed{4\pi R_s M}$$

Simple electrical measurement of magnetization





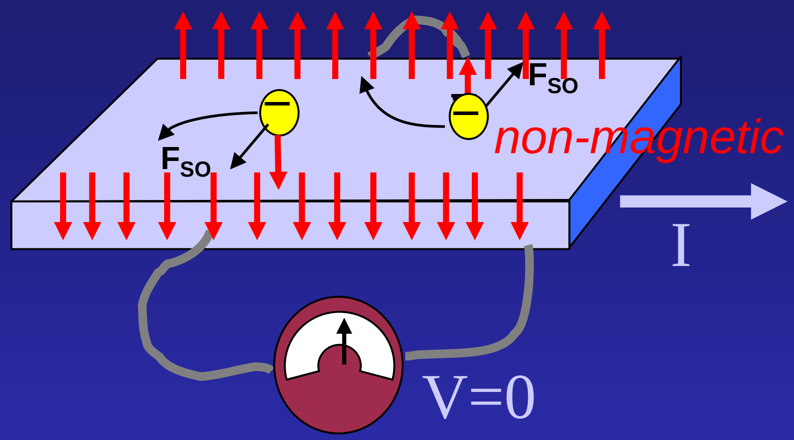
D. Chiba *et al.*, Science **301**, 943 (2003)

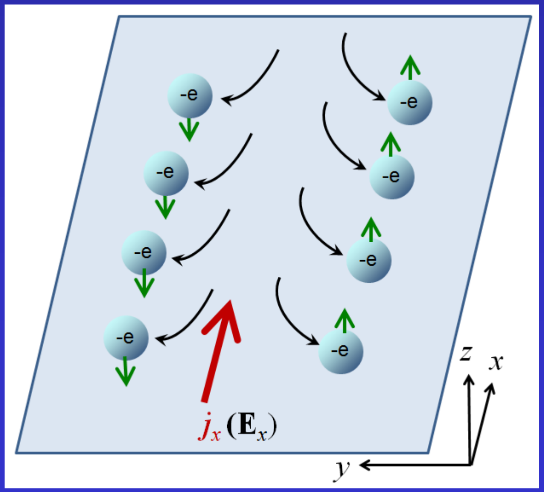
Spin Hall effect

Dyakonov & Perel, JETP Lett. 13, 467 (1971); Hirsch, Phys. Rev. Lett. 83, 1834 (1999); Zhang, Phys. Rev. Lett. 85, 393 (2000).

In the systems with strong SOC due either the properties of the electron band structure or scattering on the impurities

Spin-orbit coupling "force" deflects ***like-spin*** *particles*





Spin-current generation in non-magnetic systems without applying external magnetic fields

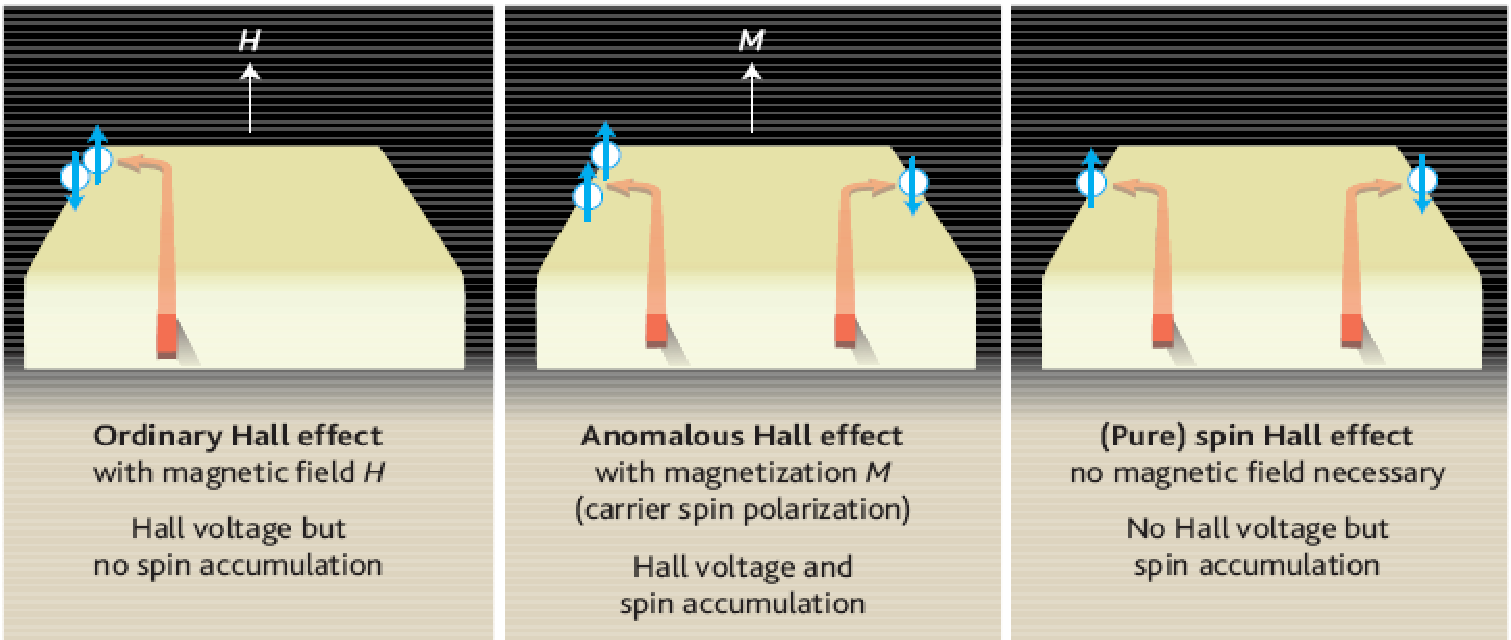
Spin accumulation without charge accumulation excludes simple electrical detection

PERSPECTIVES

PHYSICS

Taking the Hall Effect for a Spin

Junichiro Inoue and Hideo Ohno



Light-induced effective magnetic fields for ultracold atoms in planar geometries

G. Juzeliūnas, J. Ruseckas,P. Öhberg, and M. Fleischhauer, Physical Review A 73, 025602 (2006)

The effective magnetic field is induced for three-level Λ-type atoms by two counterpropagating laser beams with shifted spatial profiles.

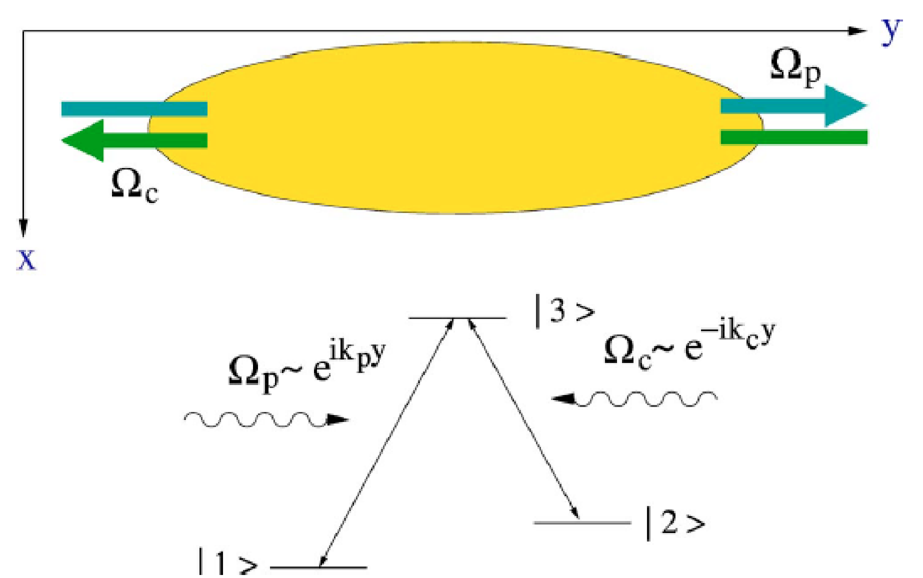


FIG. 1. (Color online) (top) Schematic representation of setup for light-induced effective magnetic fields: Two counterpropagating and overlapping laser beams interact with a cloud of cold atoms. (bottom) The level scheme for the Λ-type atoms interacting with the resonant probe and control beams characterized by Rabi frequencies Ω_p and Ω_c.

Transition metal dichalcogenide (TMDC)

MoS_2, $MoSe_2$, $MoTe_2$, WS_2, WSe_2, WTe_2

Review:

A. Kormanyos, G. Burkard, M. Gmitra, J. Fabian, V. Zolyomi, N. D. Drummond, and V. Fal’ko, 2D Mater. 2, 022001 (2015)

Excitons in TMDCs: A. Chernikov, T. C. Berkelbach, H. M. Hill, A. Rigosi, Y. Li, O. B. Aslan, D. R. Reichman, M. S. Hybertsen, and T. F. Heinz, Phys. Rev. Lett. **113**, 076802 (2014).

BEC of dipolar excitons in a TMDC double ilayer:

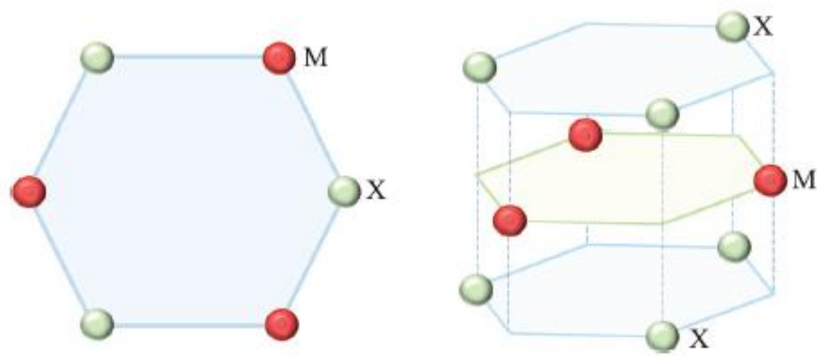
M. M. Fogler, L. V. Butov, and K. S. Novoselov, Nat. Commun. 5, 4555 (2014).

F.-C. Wu, F. Xue, and A. H. MacDonald, Phys. Rev. B 92, 165121 (2015)

BEC and superfluidity of two-component system of A and B dipolar excitons in a TMDC double layer:

O. L. Berman and R. Ya. Kezerashvili, Phys. Rev. B 93, 245410 (2016). O. L. Berman and R. Ya. Kezerashvili, Physical Review B 96, 094502 (2017).

The structure of a TMDC monolayer.



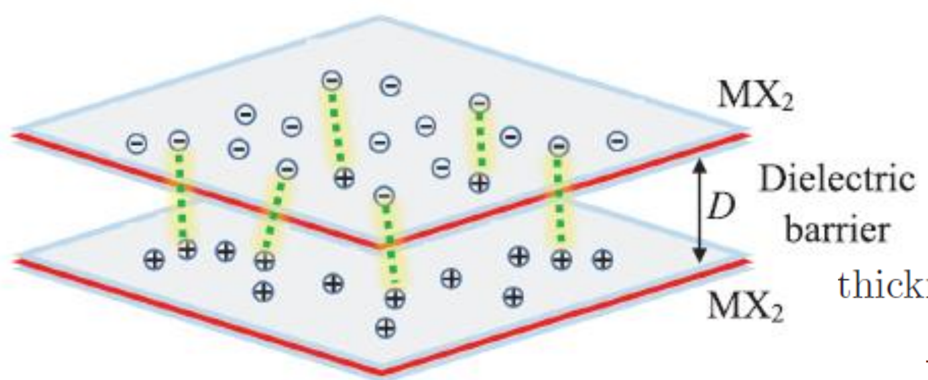
Spatially separated electrons and holes in a TMDC double layer

M is a transition metal

X is a chalcogenide

1. Gap between valence and conduction bands: 1.6 -- 1.8 eV

2. No fluctuations of the width of TMDC layers.



***h*-BN monolayers**

N_L number of monolayers

$$D = N_L D_{hBN}$$

thickness of one h-BN monolayer

$$D_{hBN} = 0.333 \text{ nm}$$

A and B 2D excitons in a TMDC monolayer

The low-energy effective two-band single-electron Hamiltonian in the form of a spinor with a gapped spectrum for TMDCs in the $k \cdot p$ approximation:

D. Xiao, G.-B. Liu, W. Feng, X. Xu, and W. Yao, Phys. Rev. Lett. 108, 196802 (2012).

$$\hat{H}_s = at(\tau k_x \hat{\sigma}_x + k_y \hat{\sigma}_y) + \frac{\Delta}{2}\hat{\sigma}_z - \lambda\tau\frac{\hat{\sigma}_z - 1}{2}\hat{s}_z.$$

$\hat{\sigma}$ denotes the Pauli matrices, a is the lattice constant, t is the effective hopping integral, Δ is the energy gap, $\tau = \pm 1$ is the valley index, 2λ is the spin splitting at the valence band top caused by the spin-orbit coupling (SOC), and $\hat{s}_z$ is the Pauli matrix for spin

Δ = 1.6 -- 1.8 eV

2λ = 0.1 -- 0.5 eV

Strong spin-orbit coupling (SOC) !!!

T. C. Berkelbach, M. S. Hybertsen, and D. R. Reichman, Phys. Rev. B 88, 045318 (2013):

Significant spin-orbit splitting in the valence band leads to the formation of A and B excitons in TMDC layers:

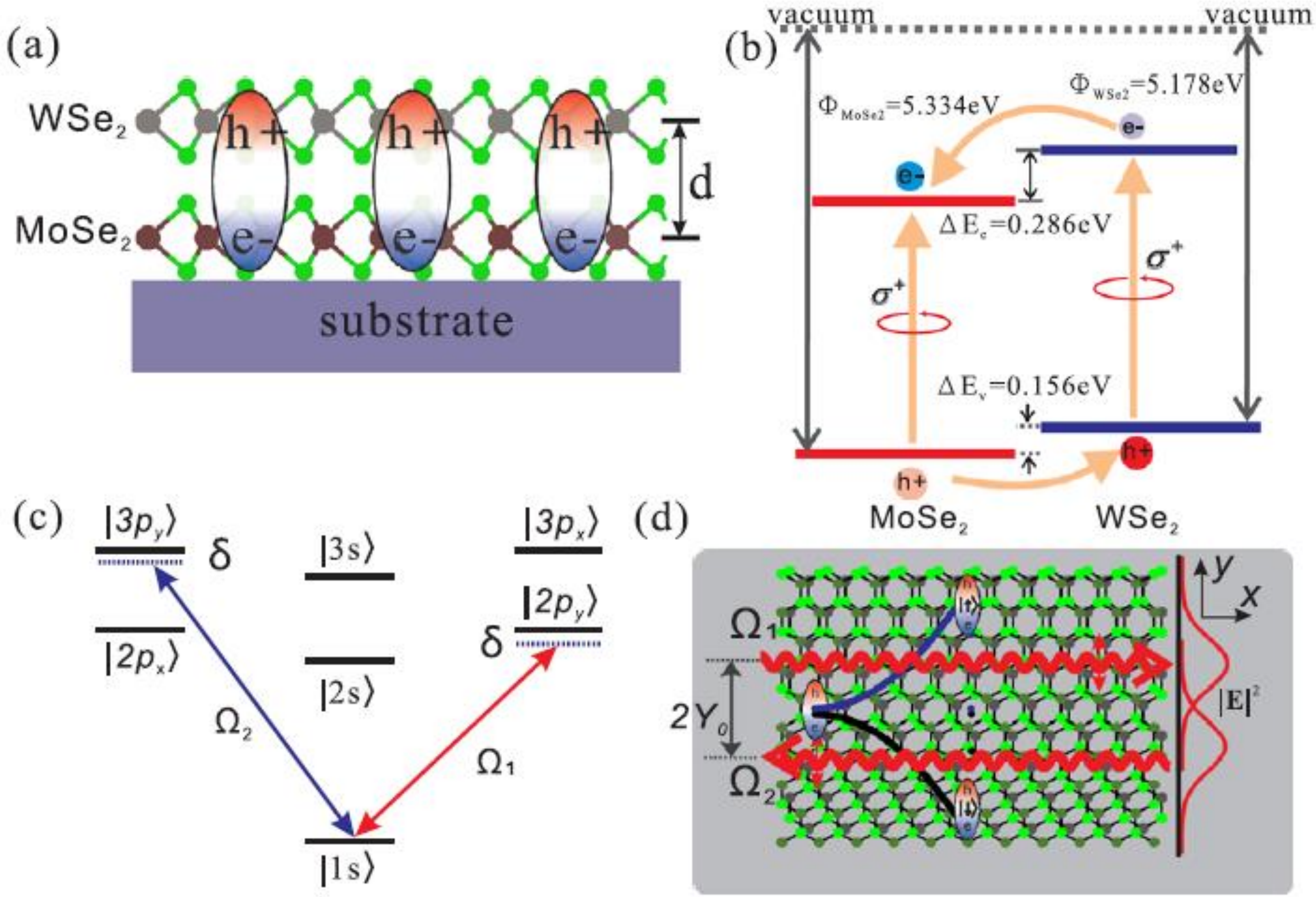
Type A excitons are formed by spin-up electrons from conduction and spin-down holes from valence bands.

Type B excitons are formed by spin-down electrons from conduction and spin-up holes from valence bands.

Light-Induced Exciton Spin Hall Effect in van der Waals Heterostructure

Y.-M. Li, J. Li, L.-K. Shi, D. Zhang, W. Yang, and K. Chang, Phys. Rev. Lett. 115, 166804 (2015).

A light-induced spin Hall effect for interlayer exciton gas in monolayer $MoSe_2$-WSe_2 van der Waals heterostructure. By applying two infrared, spatially varying laser beams coupled to the exciton internal states, a spin-dependent gauge potential on the exciton center-of-mass motion is induced. This gauge potential deflects excitons in different spin states towards opposite directions, leading to a finite spin current.



Trapping Cavity Polaritons

D. W. Snoke, Science 298, 1368 (2002).

P. Littlewood, Science 316, 989 (2007).

D. W. Snoke and J. Keeling, Phys. Today 70, 54 (2017).

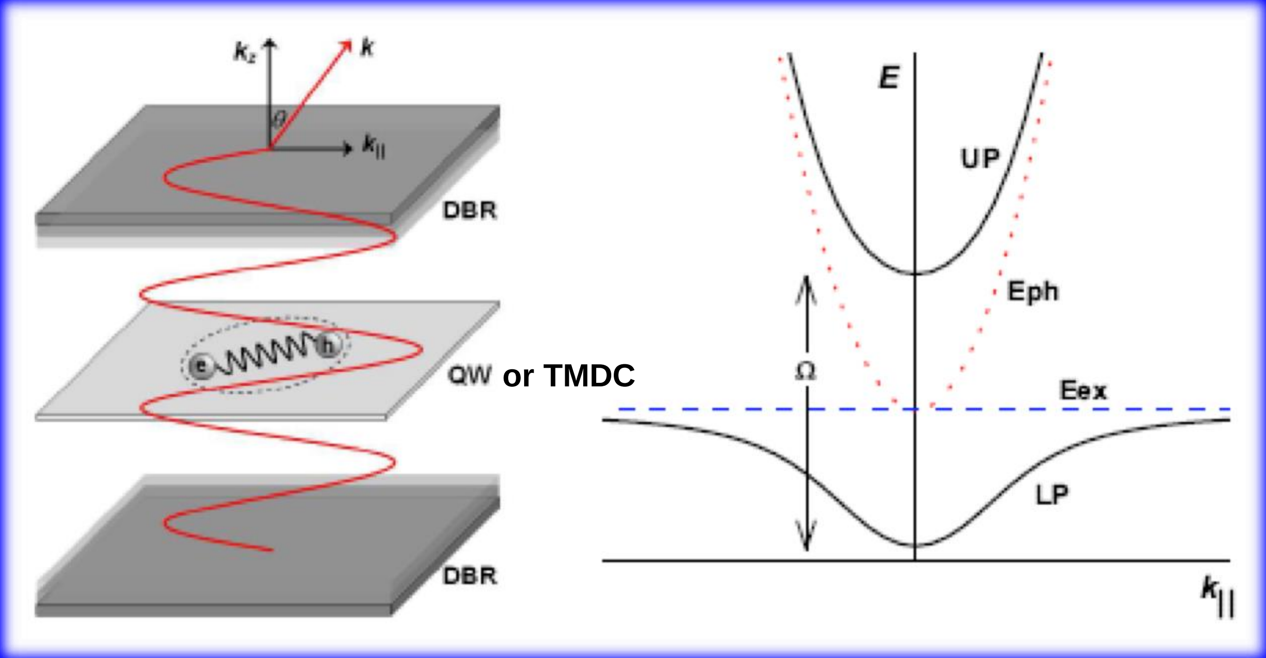
Cavity polaritons in *TMDC*:

Experiments:

X. Liu, et al., Nat. Photonics 9, 30 (2015).

L. C. Flatten, et al., Sci. Rep. 6, 33134 (2016).

S. Dufferwiel, et al., Nature Commun. 6, 8579 (2015).



cavity photon:

$$E = \hbar c\sqrt{k_z^2 + k_{\|}^2} = \hbar c\sqrt{(\pi / L)^2 + k_{\|}^2}$$

quantum well exciton:

$$E = E_{gap} - \Delta_{bind} + \frac{h^2 N^2}{2m_r (2L)^2} + \frac{\hbar^2 k_{\|}^2}{2m}$$

Elementary model of polariton modes

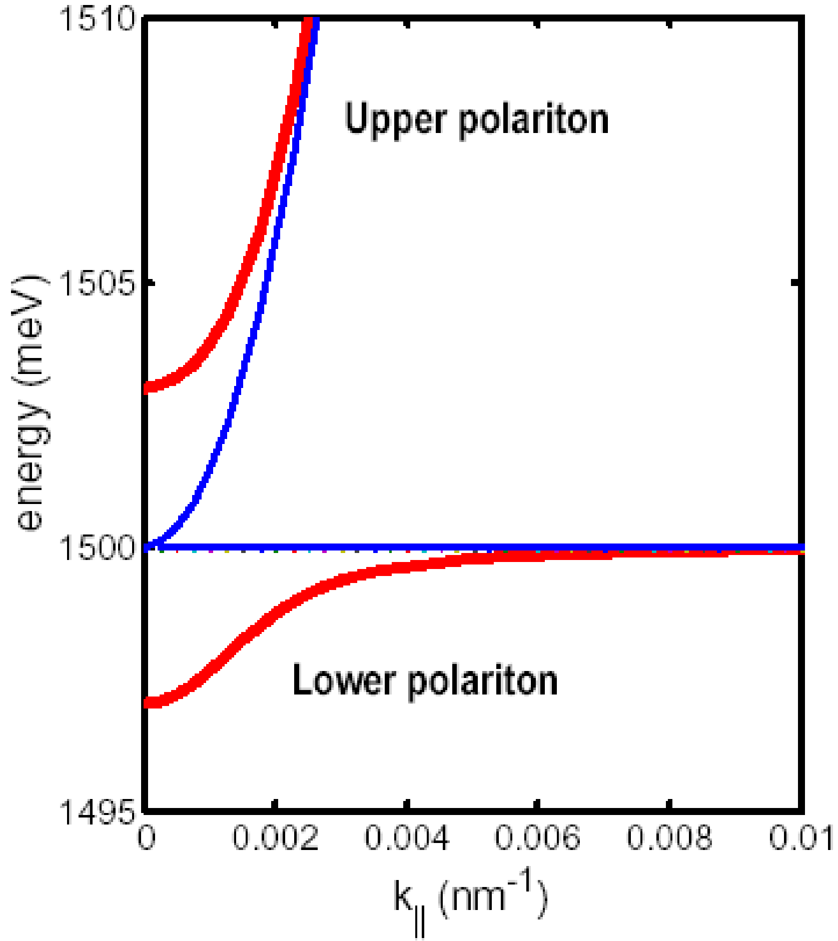
exciton

polariton

photon

$$H_k = \begin{pmatrix} E_k^{(cav)} & \hbar\Omega_R \\ \hbar\Omega_R^* & E_k^{(exc)} \end{pmatrix}$$

$$E_k^{(\pm)} = \frac{E_k^{(cav)} + E_k^{(exc)}}{2} \pm \frac{1}{2}\sqrt{\left(E_k^{(cav)} - E_k^{(exc)}\right)^2 + 4\left|\hbar\Omega_R\right|^2}$$



Realistic model includes finite polariton lifetime, leaky modes in the mirrors, etc.

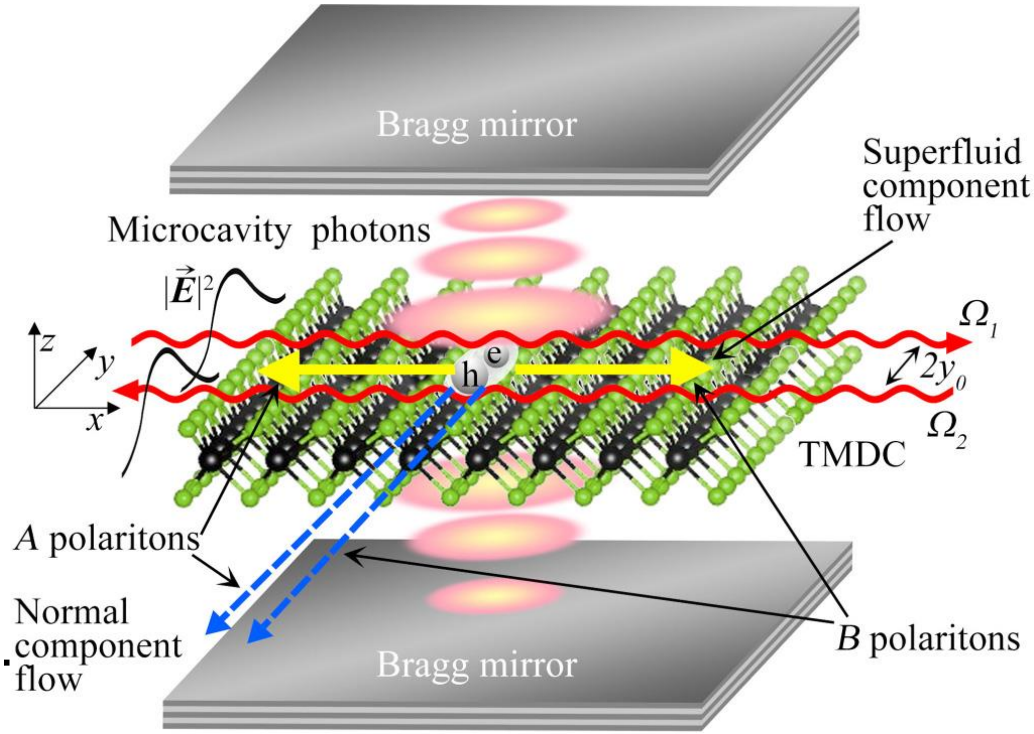
P. B. Littlewood, P. R. Eastham, J. M. J. Keeling, F. M. Marchetti, B. D. Simons, and M. H. Szymanska, J. Phys.: Condens. Matter 16, S3597–S3620 (2004) .

We predict the Spin Hall effect (SHE) for microcavity polaritons in TMDC

O. L. Berman, R. Ya. Kezerashvili, and Yu. E. Lozovik, Physical Review B 99, 085438 (2019).

1. The polaritons cloud is formed due to the coupling of excitons created in a TMDC layer and microcavity photons.
2. Two coordinate-dependent, counterpropagating and overlapping laser beams in the plane of the TMDC layer interact with a cloud of polaritons.
3. The counterpropagating and overlapping laser beams, characterized by Rabi frequencies Ω_1 and Ω_2 produce the spin-dependent gauge magnetic and electric fields due to strong SOC for electron and holes in TMDC.

Y.-M. Li, et al., Phys. Rev. Lett. 115, 166804 (2015).



4. The gauge magnetic field deflects the exciton component of polaritons consisting from the excitons with different spin states of charge carriers, namely *A* and *B* excitons, towards opposite directions.

5. For the laser pumping frequencies, corresponding to the resonant excitations of one type of excitons (*A* or *B*), the corresponding excitons together with coupled to them photons form polaritons, which deflect to opposite transverse directions.

Using circular polarized pumping, one can excite both *A* and *B* excitons in one valley simultaneously.

G. Wang, et al., Rev. Mod. Phys. 90, 021001 (2018).

6. The normal components of the *A* and *B* polariton flows slightly deflect in opposite directions and propagate almost perpendicularly to the counterpropagating beams.

7. In contrast, the superfluid components of the *A* and *B* polariton flows propagate in opposite directions along the counterpropagating beams.

Hamiltonian of microcavity polaritons in gauge fields

O. L. Berman, R. Ya. Kezerashvili, and Yu. E. Lozovik, Physical Review B 99, 085438 (2019).

The Hamiltonian of TMDC polaritons in the presence of counterpropagating and overlapping laser beams:

$$\hat{\mathcal{H}} = \hat{H}_{\text{exc}} + \hat{H}_{\text{ph}} + \hat{H}_{\text{exc-ph}} + \hat{H}_{\text{exc-exc}}$$

The Hamiltonian of TMDC excitons: $\hat{H}_{\text{exc}} = \sum_{\mathbf{P}} \varepsilon_{\text{ex}}(\mathbf{P}) \hat{b}^{\dagger}_{\mathbf{P}} \hat{b}_{\mathbf{P}}$

$$\varepsilon_{\text{ex}}(\mathbf{P}) = E_{\text{bg}} - E_b + \varepsilon_0(\mathbf{P})$$

E_{bg} is the band gap energy

$$\varepsilon_0(\mathbf{P}) = \frac{(\mathbf{P} - \mathbf{A}_{\sigma})^2}{2M}$$

E_b is the binding energy of an exciton

where M is the mass of an exciton and $\mathbf{A}_{\sigma}$ is the gauge vector potential acting on the exciton component of polaritons, associated with different spin states of the conduction band electron, forming an exciton, $\sigma = \uparrow$ and $\downarrow$.

Hamiltonian of microcavity photons:

$$\hat{H}_{\text{ph}} = \sum_{\mathbf{P}} \varepsilon_{\text{ph}}(P) \hat{a}^{\dagger}_{\mathbf{P}} \hat{a}_{\mathbf{P}}$$

$$\varepsilon_{\text{ph}}(P) = (c/\tilde{n})\sqrt{P^2 + \hbar^2\pi^2 q^2 L_C^{-2}}$$

L_C is the length of the cavity, $\tilde{n} = \sqrt{\epsilon}$ is index of refraction of the microcavity, q is the longitudinal mode number.

Effective mass of microcavity photons:

$$m_{\text{ph}} = \hbar\pi q/((c/\tilde{n})L_C)$$

Hamiltonian of exciton-photon coupling:

$$\hat{H}_{\text{exc-ph}} = \hbar\Omega_R \sum_{\mathbf{P}} \hat{a}^{\dagger}_{\mathbf{P}} \hat{b}_{\mathbf{P}} + \text{H.c.}$$

Ω_R is the Rabi splitting constant

After applying the unitary transformations of the Hamiltonian at *$H_{exc\text{-}exc} = 0$* →

The Hamiltonian of lower polaritons:

$$\hat{\mathcal{H}}_0 = \sum_{\mathbf{P}} \varepsilon_{LP}(\mathbf{P}) \hat{p}^{\dagger}_{\mathbf{P}} \hat{p}_{\mathbf{P}}$$

$$\varepsilon_{LP}(\mathbf{P}) = \hbar\pi q L_C^{-1} - |\hbar\Omega_R| + \varepsilon(\mathbf{P})$$

$$\alpha \equiv 1/2(M^{-1} + (c/\tilde{n})L_C/\hbar\pi q)P^2/|\hbar\Omega_R| \ll 1$$

$$\varepsilon(\mathbf{P}) = \frac{\left(\mathbf{P} - \mathbf{A}_{\sigma}^{(\text{eff})}\right)^2}{2M_p} + V^{(\text{eff})}$$

effective vector and scalar potentials, respectively, acting on polaritons, $\mathbf{A}_{\sigma}^{(eff)}$ and $V^{(eff)}$

$$\mathbf{A}_{\sigma}^{(\text{eff})} = \frac{m_{\text{ph}}\mathbf{A}_{\sigma}}{M + m_{\text{ph}}}, \quad V^{(\text{eff})} = \frac{A_{\sigma}^2}{4(M + m_{\text{ph}})}$$

$$M_p = 2\mu, \mu = M m_{\text{ph}}/(M + m_{\text{ph}})$$

The dependence of the effective gauge magnetic $B^{(eff)}$ and electric $E^{(eff)}$ fields on the parameter l.

$$\mathbf{B}_{\sigma}^{(eff)} = \nabla_{\mathbf{R}} \times \mathbf{A}_{\sigma}^{(eff)} = \frac{-\eta_{\sigma}\hbar m_{ph}\left(|k_1| + |k_2|\right)}{4l\left(M + m_{ph}\right)}\mathbf{e}_z, \quad \mathbf{E}^{(eff)} = -\nabla_{\mathbf{R}} V^{(eff)} = -\frac{\hbar^2\left(|k_1| + |k_2|\right)^2}{16l\left(M + m_{ph}\right)}\mathbf{e}_y.$$

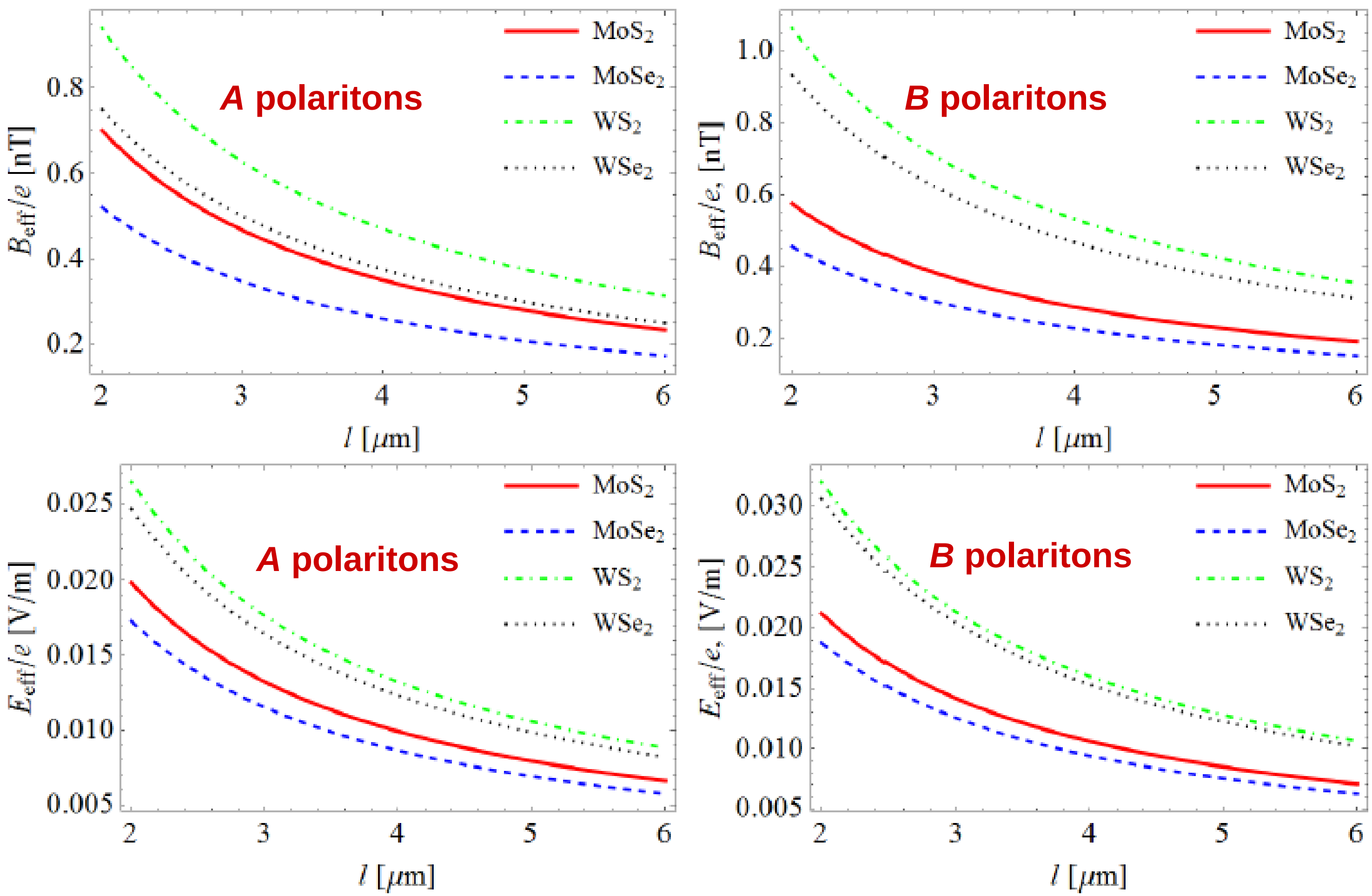
$\eta_{\uparrow} = 1$ for an A exciton and $\eta_{\downarrow} = -1$ for a B exciton.

Calculations performed for $|k_1| + |k_2| = 3\ \mu\mathrm{m}^{-1}$

$l = a^2/8y_0$, $a = 10\ \mu\mathrm{m}$ is the beam width.

M **is an exciton mass;** m_{ph} **is a microcavity photon mass**

y_0 is the spatial shift of two laser beams



Conductivity tensor for non-interacting polaritons

Drude model:

$$\frac{d\mathbf{P}}{dt} = \mathbf{E}^{(\mathrm{eff})} + \mathbf{v} \times \mathbf{B}_{\sigma}^{(\mathrm{eff})} - \frac{\mathbf{P}}{\tau}$$

For a steady state, setting $d\mathbf{P}/dt = 0$,

$$\mathrm{P} = M_p \mathbf{v}$$

$\mathbf{v}$ is the velocity and τ is a scattering time of microcavity polaritons.

linear polariton flow density is defined as $\mathbf{j} = n\mathbf{v}$

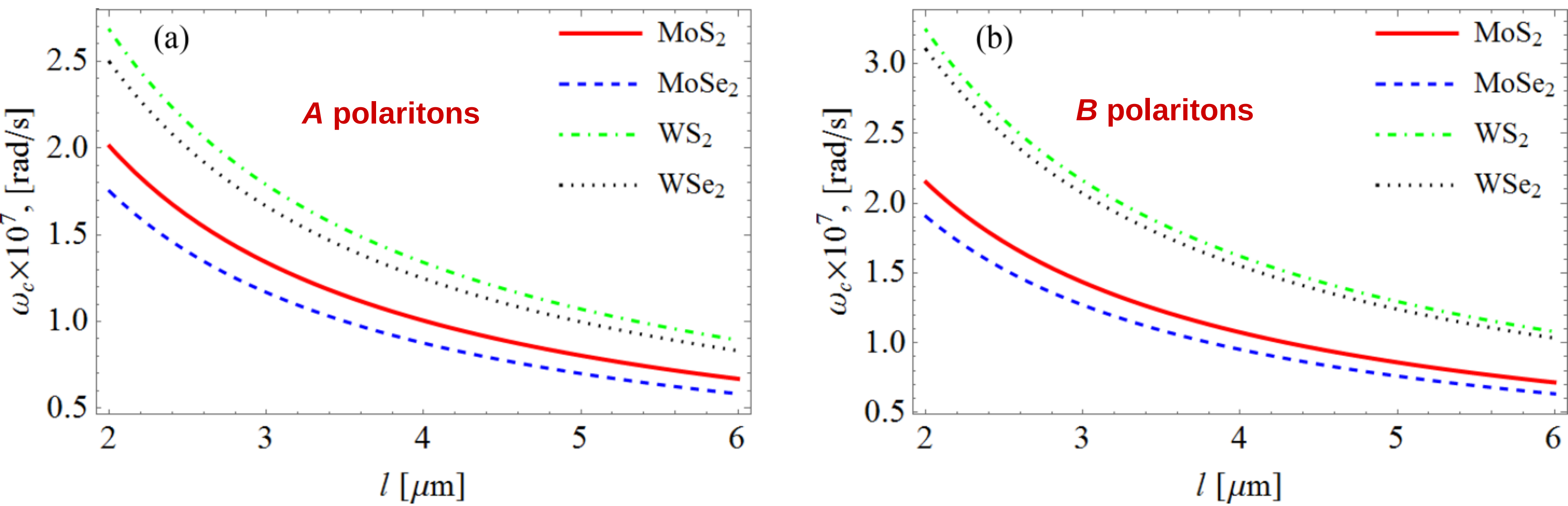
$$\mathbf{E}^{(\mathrm{eff})} = \frac{M_p}{n\tau}\mathbf{j} - \frac{\mathbf{j} \times \mathbf{B}_{\sigma}^{(\mathrm{eff})}}{n}$$

2×2 resistivity matrix ϱ_σ can be defined as $\mathbf{E}^{(\mathrm{eff})} = \varrho_\sigma \mathbf{j}$,

The conductivity tensor $\tilde{\sigma}_\sigma$ is defined as the inverse matrix to the resistivity matrix ϱ_σ.

$$\sigma_{\sigma xx} = \sigma_{\sigma yy} = \frac{\sigma_0}{1 + \omega_c^2\tau^2}, \quad \sigma_{\sigma xy} = -\sigma_{\sigma yx} = -\frac{\eta_\sigma \sigma_0 \omega_c \tau}{1 + \omega_c^2\tau^2},$$

$\sigma_0 = \tau n/M_p$ and $\omega_c = B^{(eff)}/M_p$ is the cyclotron frequency.



$l = a^2/8y_0$, $a = 10\ \mu$m is the beam width.

Calculations performed for $|k_1| + |k_2| = 3\ \mu\mathrm{m}^{-1}$

Conductivity tensor for superfluid polaritons

Weakly interacting Bose gas of polaritons in dilute regime below T_c is superfluid

n_n is the concentration of the normal component

$$n_s(T) = n - n_n(T)$$

n_s is the concentration of the superfluid component

$$n_n(T) = \frac{3\zeta(3)}{2\pi\hbar^2}\frac{k_B^3 T^3}{c_S^4 M_p}$$

n is the total concentration

The polaritons in the superfluid component do not collide, $\tau \to +\infty$.

Drude model: $M_p \frac{dv_x}{dt} = -\eta_\sigma B^{(\mathrm{eff})} v_y, \quad M_p \frac{dv_y}{dt} = E^{(\mathrm{eff})} + \eta_\sigma B^{(\mathrm{eff})} v_x$

steady state, which corresponds to $dv_x/dt = dv_y/dt = 0$ $\qquad v_y = 0$

the linear superfluid polariton flow density $\mathbf{j}^{(s)} = n_s \mathbf{v}$. $\qquad v_x = -E^{(eff)}/\eta_\sigma B^{(eff)}$

conductivity tensor $\tilde{\sigma}_\sigma^{(s)}(T)$ for the superfluid

$$\sigma_{\sigma xx}^{(s)} = \sigma_{\sigma yy}^{(s)} = 0, \quad \sigma_{\sigma xy}^{(s)}(T) = -\sigma_{\sigma yx}^{(s)}(T) = -\frac{n_s(T)}{\eta_\sigma B^{(\mathrm{eff})}}$$

For the conductivity tensor $\tilde{\sigma}_\sigma^{(n)}(T)$ for the normal component

$$\sigma_0(T) = \tau n_n(T)/M_p$$

The sound spectrum of collective excitations: $\epsilon(P) = c_s P$

with the sound velocity c_s

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Linear polariton flow density

1. Our calculations show that the contribution to the Hall linear polariton flow density from the superfluid component essentially exceeds the one from the normal component.
2. The contribution to the Hall linear polariton flow density from the superfluid component does not depend on the distance *l* between the counterpropagating laser beams.
3. The contribution to the linear polariton flow density from the superfluid component in the direction of the effective gauge electric field (*y* direction) is zero.

At the temperature $T = 300$ K for A polaritons we have obtained the total Hall linear polariton flow density in the presence of superfluidity $j_x^{(tot)} = 8.51887 \times 10^{13}$ nm^{-1}s^{-1} for MoS_2; $j_x^{(tot)} = 9.54342 \times 10^{13}$ nm^{-1}s^{-1} for $MoSe_2$, $j_x^{(tot)} = 9.76334 \times 10^{13}$ nm^{-1}s^{-1} for WS_2, $j_x^{(tot)} = 1.1415 \times 10^{14}$ nm^{-1}s^{-1} for WSe_2.

Proposed experiment

O. L. Berman, R. Ya. Kezerashvili, and Yu. E. Lozovik, Physical Review B 99, 085438 (2019).

1. The proposed experiment for observation of the spin Hall effect for microcavity polaritons is related to the measurement of the angular distribution of the photons escaping the optical microcavity.
2. In the absence of the effective gauge magnetic and electric fields, the angular distribution of the photons escaping the microcavity is central-symmetric with respect to the perpendicular to the Bragg mirrors.
3. We obtain the average tangent of the angles *α* of deflection for the polariton flow in the (x, y) plane of the microcavity:

$$\overline{\tan\ \alpha} = \left|\frac{j_x}{j_y}\right| = \left|\frac{\sigma_{\sigma xy}}{\sigma_{\sigma yy}}\right|$$

Without superfluidity:

$$\overline{\tan\ \alpha} = \omega_c \tau$$

Proposed experiment for observation of the SHE for microcavity polaritons in the presence of superfluidity

For the normal component:

$$\overline{\tan\ \alpha^{(n)}} = \left|\frac{j_x^{(n)}}{j_y^{(n)}}\right| = \left|\frac{\sigma_{\sigma xy}^{(n)}}{\sigma_{\sigma yy}^{(n)}}\right| = \omega_c \tau$$

For the superfluid component:

$$\overline{\tan\ \alpha^{(s)}} = \left|\frac{j_x^{(s)}}{j_y^{(s)}}\right| = \left|\frac{\sigma_{\sigma xy}^{(s)}}{\sigma_{\sigma yy}^{(s)}}\right| \to +\infty$$

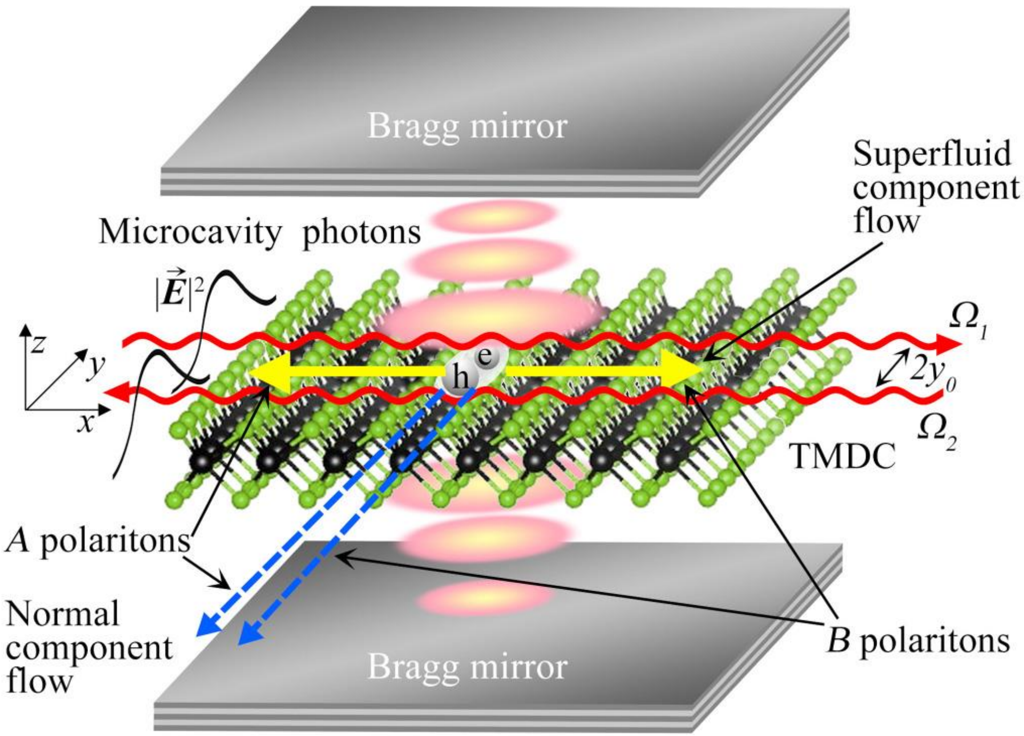
$$\sigma_{\sigma yy}^{(s)} = 0$$

$$\overline{\alpha^{(s)}} = 90^0$$

Calculations performed for $|k_1| + |k_2| = 3\ \mu\mathrm{m}^{-1}$

$l = a^2/8y_0$, $a = 10\ \mu$m is the beam width,

$\overline{\tan\ \alpha^{(n)}} \approx 10^{-5}$, and $\overline{\alpha^{(n)}} \approx 10^{-3\ 0}$



O. L. Berman, R. Ya. Kezerashvili, and Yu. E. Lozovik, Phys. Rev. B, 99, 085438 (2019).

SHE for microcavity polaritons allows to separate the superfluid component from the normal components of the polariton flow!

Conclusions

O. L. Berman, R. Ya. Kezerashvili, and Yu. E. Lozovik, Physical Review B, 99, 085438 (2019).

- **We have predicted the spin Hall effect for microcavity polaritons, formed by excitons in a TMDC and microcavity photons.**

- **We demonstrated that the polariton flow can be achieved by generation the effective gauge vector and scalar potentials, acting on polaritons.**

- **We have obtained the components of polariton conductivity tensor for both non-interacting polaritons without BEC and for weakly-interacting Bose gas of polaritons in the presence of BEC and superfluidity.**

- **We demonstrated that due to the SHE the polariton flows in the same valley are splitting: the normal components of the *A* and *B* polariton flows slightly deflect in opposite directions and propagate almost perpendicularly to the counterpropagating beams, while the superfluid components of the *A* and *B* polariton flows propagate in opposite directions along the counterpropagating beams.**

- **We predicted the method to separate the superfluid component from the normal component of the polariton flow due to the SHE.**

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