Fundamental spin interaction in focused laser beams

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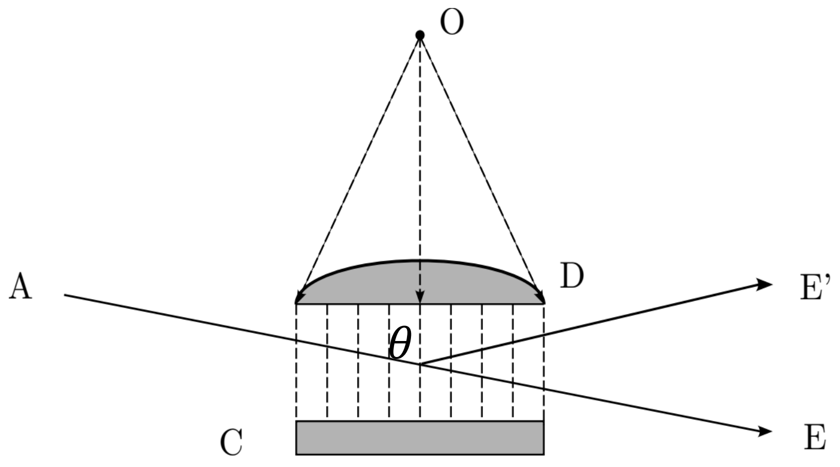
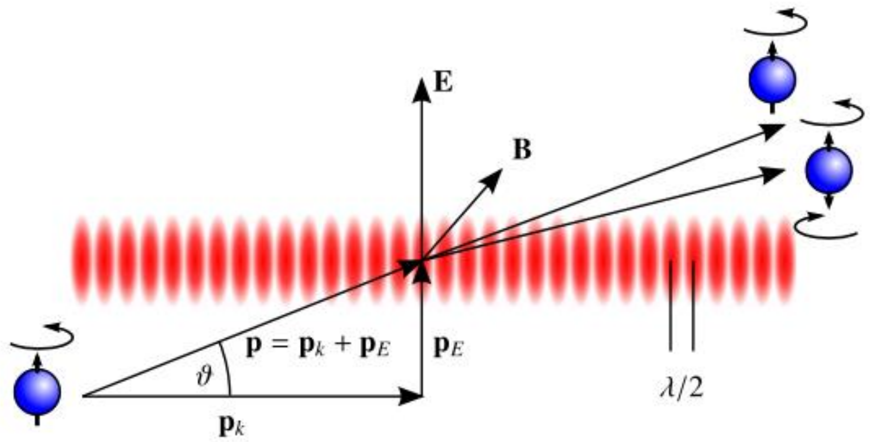
Kapitza-Dirac effect(KDE)

The electrons pass through the standing light wave to interact with photos.



Schematic of KDE



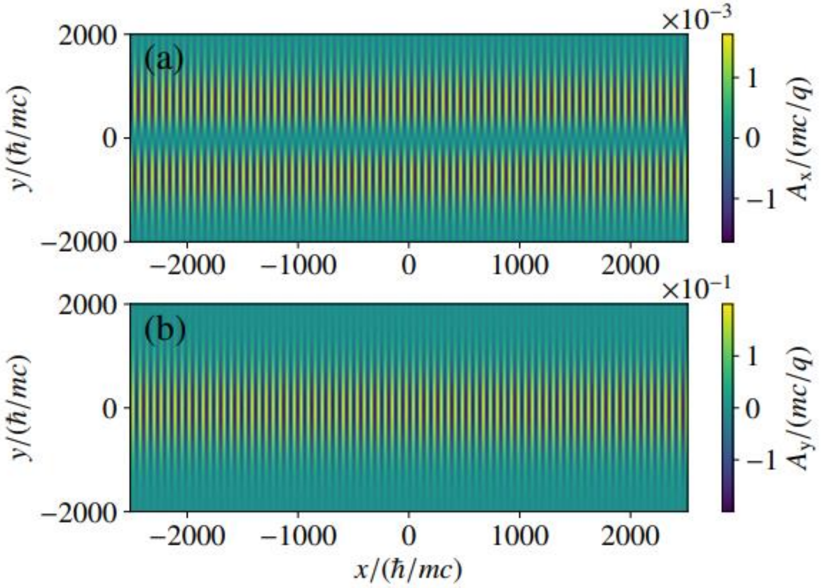
Schematic setup of spin effect

[1]L. Kapitza and P. A. M. Dirac, The reflection of electrons from standing light waves, Math. Proc. Cambridge Philos. Soc. 29, 297 (1933).

[2]S. Ahrens, H. Bauke, C. H. Keitel, and C. Muller, Spin Dynamics in the Kapitza-Dirac Effect, Phys. Rev. Lett. 109, 043601 (2012).

Two-dimensional simulation of the spin-flip in KDE within Bragg regime

Vector potential of Gaussian beam



$$A_{x,d} = -2dA_0 \frac{w_0}{w} \epsilon \frac{y}{w} \exp\left(-\frac{r^2}{w^2}\right) \cos(\phi_{G,d}^{(1)})$$

$$A_{y,d} = -A_0 \frac{w_0}{w} \exp\left(-\frac{y^2}{w^2}\right) \sin(\phi_{G,d}))$$

Description of simulation

$$H = c\left(\boldsymbol{p} - \frac{q}{c}\boldsymbol{A}\right) \cdot \boldsymbol{\alpha} + q\phi + \beta mc^2$$

$$H\psi_z^s(\boldsymbol{p}) = E_p \psi_z^s(\boldsymbol{p})$$

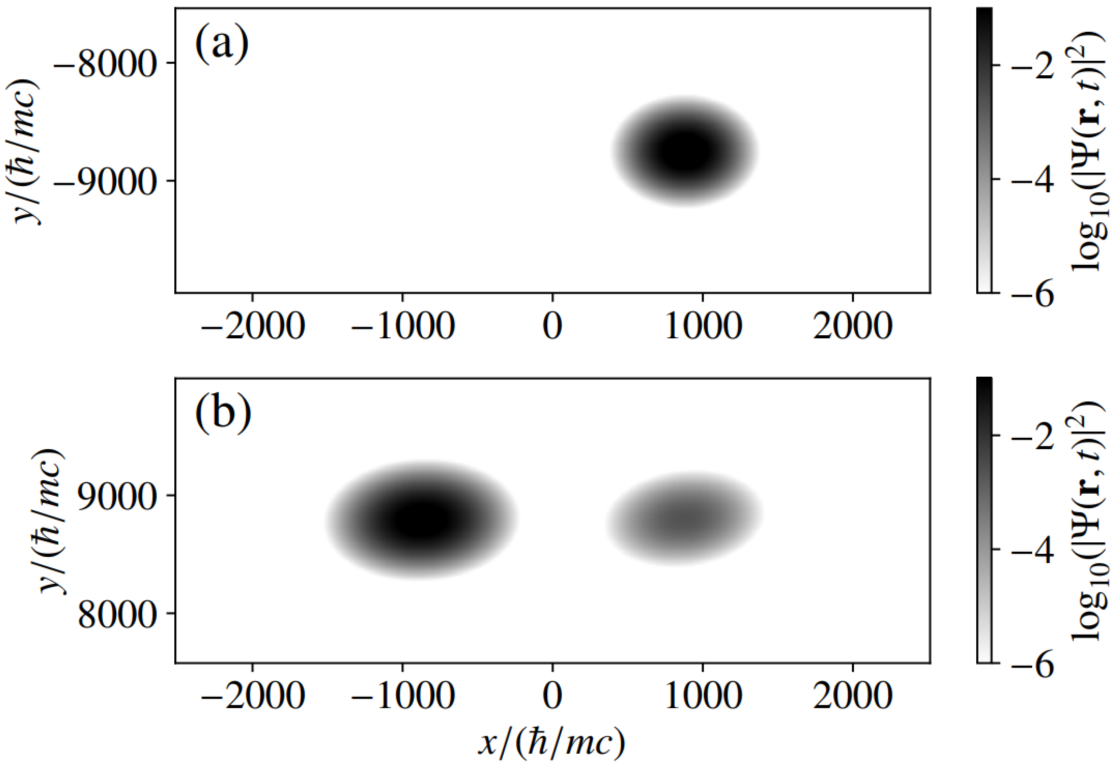
$$\rho(\boldsymbol{p}) = \frac{1}{\sqrt{2\pi}\sigma_p} \exp\left[-\left(\frac{\boldsymbol{p} - \boldsymbol{p}_0}{2\sigma_p}\right)^2 - i\frac{\boldsymbol{r}_0 \cdot \boldsymbol{p}}{\hbar}\right]$$

Numerical propagation

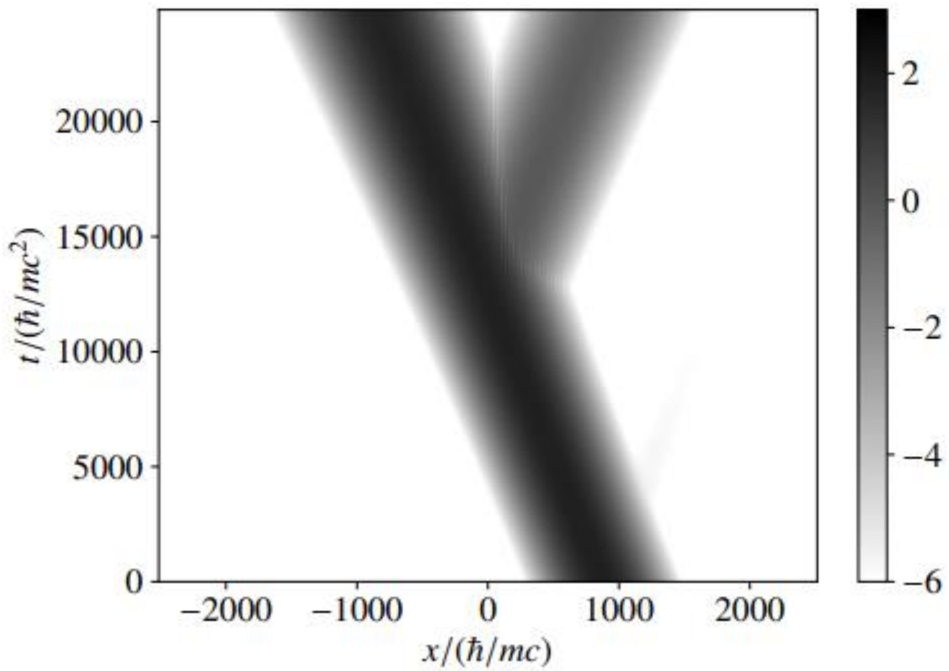
$$\Psi(\boldsymbol{r}, t + \Delta t) = \boldsymbol{U}(t + \Delta t, t)\Psi(\boldsymbol{r}, t)$$

arXiv:2307.01571

Motion of the electron probability density



The y-integrated probability density Φ(x, t)



$$\left|\Psi_z^+(\boldsymbol{r},t)\right|^2 = \left[\Psi_z^+(\boldsymbol{r},t)\right]^\dagger \Psi_z^+(\boldsymbol{r},t) \quad \Longrightarrow \quad \Phi(x,t) = \int_{y_{\min}(t)}^{y_{\max}(t)} \left|\Psi(x,y,t)\right|^2 dy$$

Spin projection along the x direction

X-polarized wavefunction and bi-spinors

$$\varphi_x^s(\boldsymbol{p},t) = \frac{1}{\sqrt{2}}\left[\varphi_z^+(\boldsymbol{p},t) + s\varphi_z^-(\boldsymbol{p},t)\right]$$

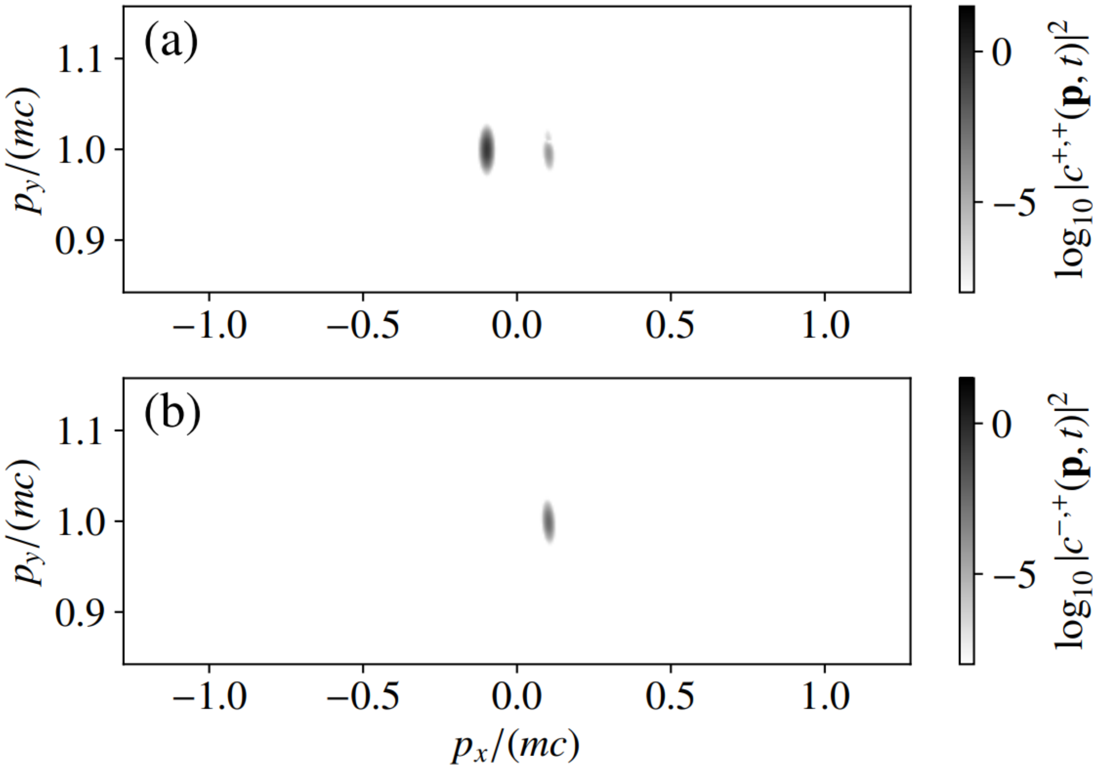
$$s \in \{+,-\}$$

$$u_x^s(\boldsymbol{p}) = \frac{1}{\sqrt{2}}\left[u_z^+(\boldsymbol{p}) + s u_z^-(\boldsymbol{p})\right]$$

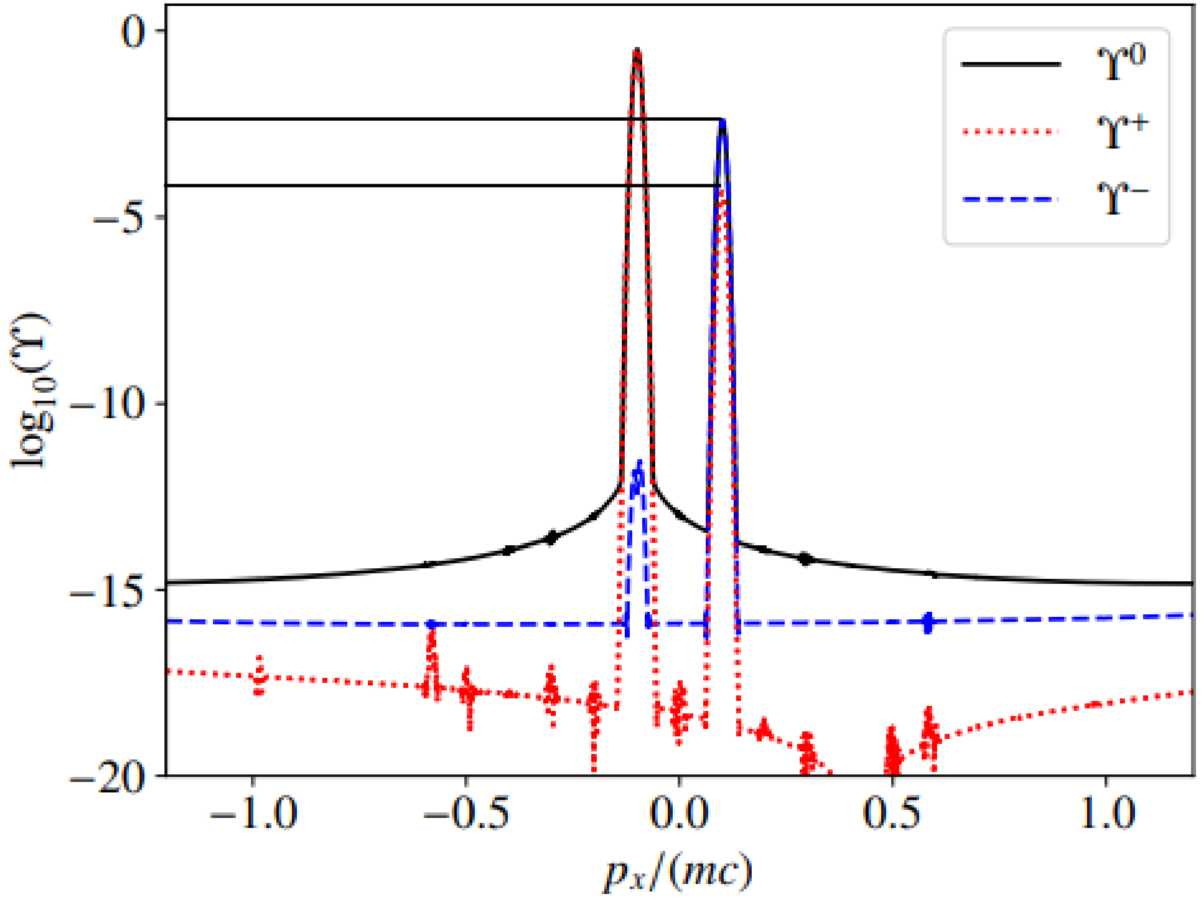
Transition amplitude from final spin s_f to initial spin s_i

$$c^{s_f,s_i}(\boldsymbol{p},t) = \langle u_x^{s_f}(\boldsymbol{p})|\varphi_x^{s_i}(\boldsymbol{p},t)\rangle$$

Electron spin projection



Spin resolved momentum space density of the electron along the p_x-axis



Function's probability density in momentum space

$$\Upsilon^0(p_x) = |\varphi_z^+(p_x, mc, T)|^2$$
$$= [\varphi_z^+(p_x, mc, T)]^\dagger \varphi_z^+(p_x, mc, T)$$

Spin projection amplitude

$$\Upsilon^{s_f}(p_x) = |c^{s_f,+}(p_x, mc, T)|^2$$

$s_f \in \{-, +\}$

CONCLUSION AND OUTLOOK

1. We have demonstrated a spin-flip along the x-polarization, implying that formerly discussed spin effects are theoretically possible in Kapita-Dirac effect.

2. It will be interesting to consider how the spin effects are changing with parameters especially the vector potential with relativistic effect and QED effect.

That’s all, thank you