Dynamical Stark shift in solids

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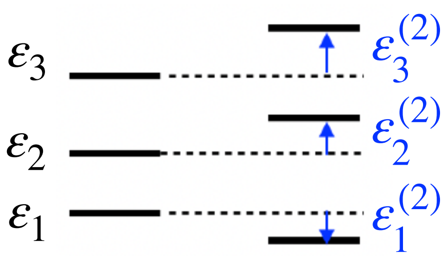
Background: Stark shift in atoms

AC electric field $\mathbf{E}(t) = \frac{1}{2}\left[\mathbf{E}(\omega)\, e^{-i\omega t} + \mathbf{E}^*(\omega)\, e^{i\omega t}\right]$

induces shift of atomic energy levels:



2nd-order energy shift:

$$\varepsilon_n^{(2)} = -\frac{1}{4}\chi_n^{\alpha\beta}(\omega)\, E_\alpha^*(\omega)\, E_\beta(\omega)$$

polarizability

Stark shift in solids

Pershoguba & Yakovenko, PRB **108**, E059904 (2023)

Shift of n-th energy band with quasimomentum $\mathbf{k}$:

$$\varepsilon_n^{(2)}(\mathbf{k}) = \frac{e^2}{4(\hbar\omega)^2}\frac{\partial^2 \varepsilon_n(\mathbf{k})}{\partial k_\alpha \partial k_\beta}\,\mathrm{Re}\left[E_\alpha^*(\omega)E_\beta(\omega)\right]$$

symmetric

$$-\frac{e^2\Omega_{n,\gamma}(\mathbf{k})}{4\,\hbar\omega}\epsilon^{\alpha\beta\gamma}\,\mathrm{Im}\left[E_\alpha^*(\omega)E_\beta(\omega)\right]$$

antisymmetric

intraband terms often overlooked

$$-\frac{e^2}{4}\mathrm{Re}\sum_{m\neq n}\frac{r_{nm}^\alpha(\mathbf{k})r_{mn}^\beta(\mathbf{k})}{\varepsilon_{mn}(\mathbf{k})-\hbar\omega}E_\alpha^*(\omega)E_\beta(\omega)$$

$$-\frac{e^2}{4}\mathrm{Re}\sum_{m\neq n}\frac{\left[r_{nm}^\alpha(\mathbf{k})r_{mn}^\beta(\mathbf{k})\right]^*}{\varepsilon_{mn}(\mathbf{k})+\hbar\omega}E_\alpha^*(\omega)E_\beta(\omega)$$

interband terms

Berry connection $\mathbf{r}_{nm}(\mathbf{k}) = \langle u_{n,\mathbf{k}}|\, i\frac{\partial}{\partial \mathbf{k}}\,|u_{n,\mathbf{k}}\rangle$

Berry curvature $\boldsymbol{\Omega}_n(\mathbf{k}) = \frac{\partial}{\partial \mathbf{k}}\times \mathbf{r}_{nn}(\mathbf{k})$

Antisymmetric term due to circular polarization

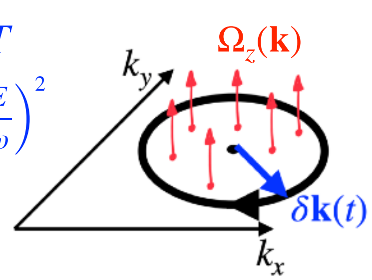
Berry phase accumulation

over one loop per time period T

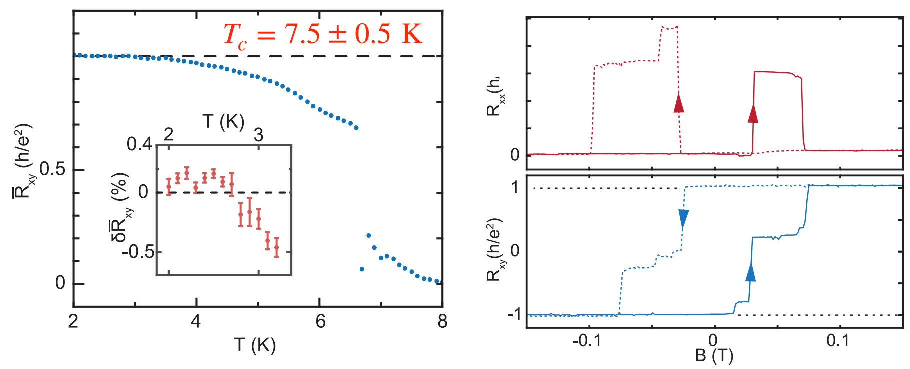
$$\phi_{loop} \approx \Omega_{n,z}(\mathbf{k})\,\pi\,(\delta k)^2 = \Omega_{n,z}(\mathbf{k})\,\pi\left(\frac{eE}{\hbar\omega}\right)^2$$

results in the energy shift

$$\varepsilon_n^{(a)}(\mathbf{k}) = \frac{\hbar\,\phi_{\rm loop}}{T} = \frac{(eE)^2\,\Omega_{n,z}(\mathbf{k})}{2\,\hbar\omega}$$



Orbital Chern insulators in twisted graphene



Serlin *et al.*, *Science* **367**, 900 (2020)
UCSB, also Stanford, Cornell, Barcelona

Anomalous quantum Hall effect
= Topological Memory
= Orbital Ferromagnetism

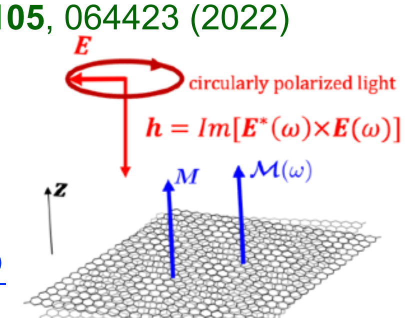
Application 1:
Optical control of orbital magnetization

Pershoguba & Yakovenko, PRB **105**, 064423 (2022)

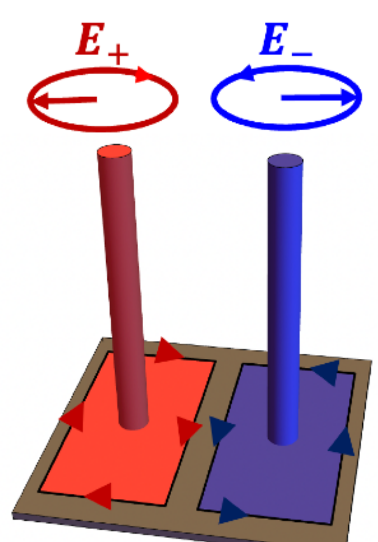
The energy shift of a Chern insulator depends on the helicity h of light

$$U^{(a)} = -\frac{1}{4}\mathbf{h}\cdot\mathscr{M}(\omega),$$

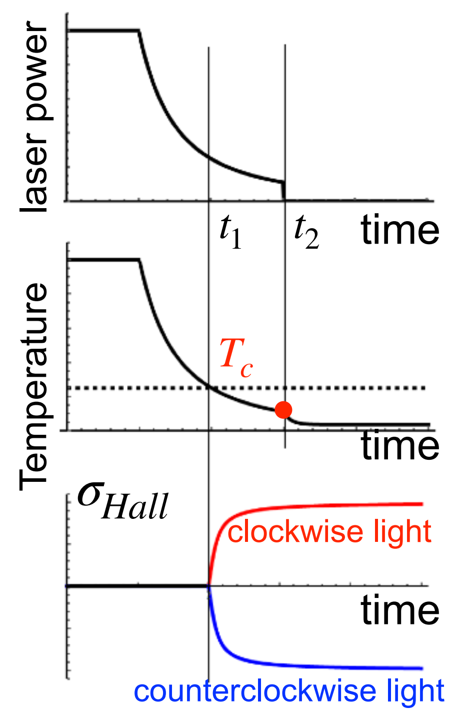
$$\mathscr{M}(\omega) = \mathscr{A}e^2\int\frac{d^2k}{(2\pi)^2}\frac{\varepsilon_{mn}^2(\mathbf{k})}{\varepsilon_{mn}^2(\mathbf{k})-(\hbar\omega)^2}\frac{\boldsymbol{\Omega}_n(\mathbf{k})}{\hbar\omega}$$



Optical writing of topological domains



Cool through T_c in the presence of circular light

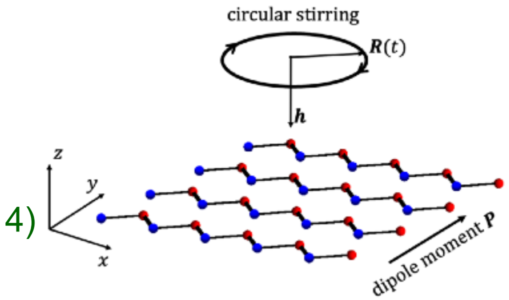


Application 2:
Inducing DC current by AC fields

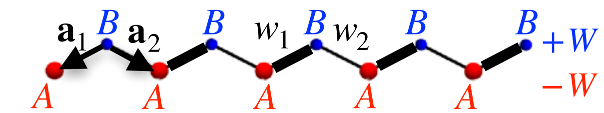
Pershoguba & Yakovenko,
Annals of Phys, **447**, 169075 (2022);

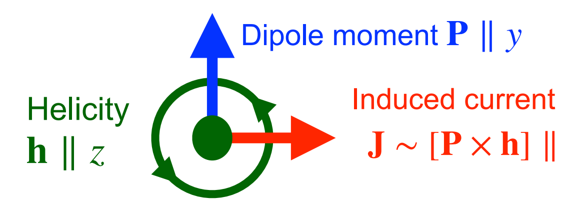
Stirred optical lattice filled with bosons

Jotzu, …, Esslinger,
Nature **515**, 237 (2014)

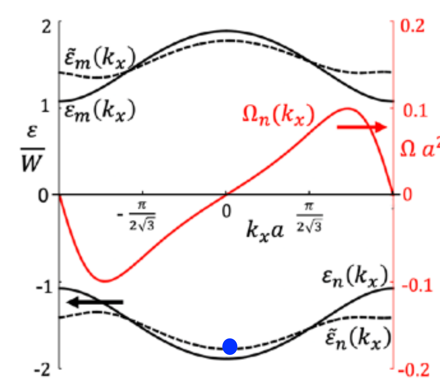


Symmetry of the induced current

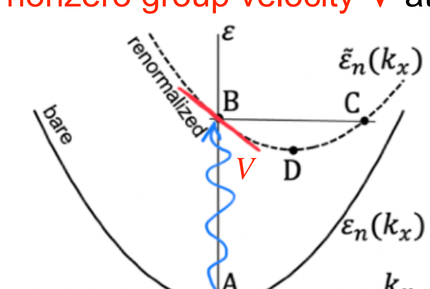




Bare and renormalized energy dispersion



The renormalized energy dispersion has a nonzero group velocity $\mathbf{V}$ at $\mathbf{k}=\mathbf{0}$:



Due to stirring, bosons promoted from A to B.

They bounce between B and C in a finite system.

$$\mathbf{V} = -\frac{\varepsilon_{mn}^2(0)}{\varepsilon_{mn}^2(0)-(\hbar\omega)^2}\frac{1}{4\,\hbar\omega}\frac{\partial[\mathbf{h}\cdot\boldsymbol{\Omega}_n(\mathbf{k})]}{\hbar\,\partial\mathbf{k}}\bigg|_{\mathbf{k}=0} = \frac{w_1 w_2 W\;\mathbf{h}\cdot[\mathbf{a}_1\times\mathbf{a}_2]}{2\,\hbar^2\omega\,|\mathbf{w}(0)|\left[4|\mathbf{w}(0)|^2-(\hbar\omega)^2\right]}(\mathbf{a}_1-\mathbf{a}_2)$$