# Nonlinear Transport Phenomena from Emergent Electromagnetic Field in Weyl Semimetals

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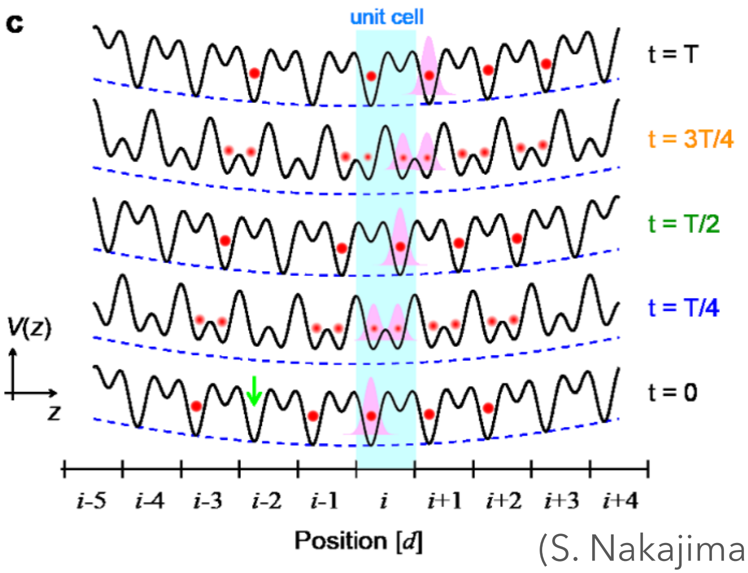
# Charge Pumping and $\Omega_{kt}$

- ✓ Charge pumping by an adiabatic process.
- ✓ Amount of charge pumped:

$$Q = \int dt\, dk\, \Omega_{kt}(k), \quad \Omega_{kt} = i\langle \partial_t u_k(t) | \partial_k u_k(t) \rangle - (k \leftrightarrow t).$$

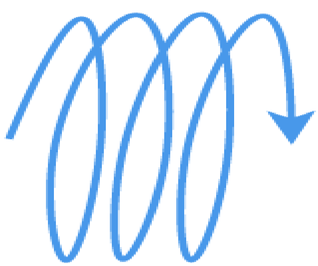
- ✓ In the wave-packet theory: $\dot{\vec{r}} = \partial_{\vec{k}} \varepsilon_{\vec{k}} - \Omega_{kt}$.

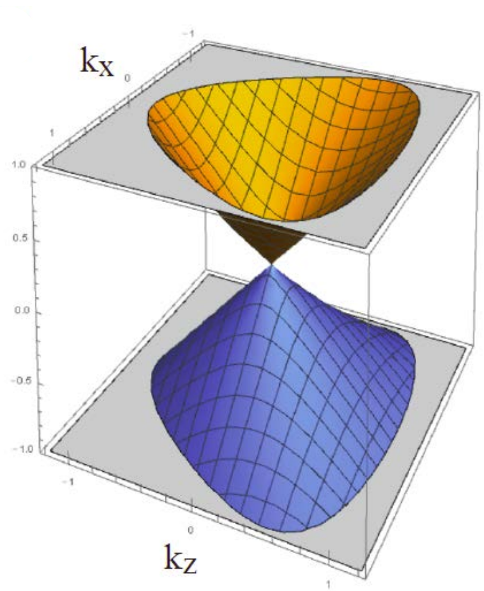



(S. Nakajima *et al.*, Nature Phys. `16)

# Photovoltaic Effect in Weyl Semimetals

$E_x = E\cos(\omega t), E_y = E\sin(\omega t)$






$$H = \sum_\alpha R_\alpha \sigma_\alpha$$

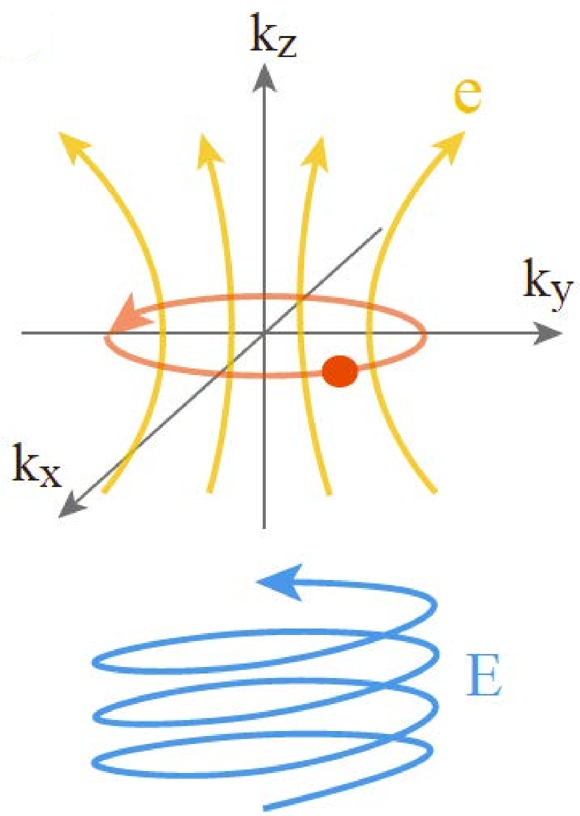
$$R_x^\pm = vk_x + gE_y + \frac{\alpha_3}{2}k_x k_z$$

$$R_y^\pm = vk_y - gE_x + \frac{\alpha_3}{2}k_y k_z$$

$$R_z^\pm = v_z k_z + \frac{\alpha_1}{2}(k_x^2 + k_y^2 - 2k_z^2)$$

Circularly polarized light onto a generalized Weyl Hamiltonian

# Emergent Electromagnetic Induction




$$\Omega_{k_a t}(\vec{k}) = \partial_t A^a(\vec{k}) - \partial_a A^t(\vec{k})$$

k-dependence of $\Omega_{k_a t}$

- ✓ Plot of $(\Omega_{k_x t}, \Omega_{k_z t})$ at $k_y = 0$. Length of vectors given by

$$\propto \log(\sqrt{\Omega_{k_x t}^2 + \Omega_{k_z t}^2}).$$

- ✓ Dipole like structure of $\Omega_{kt}$.
- ✓ For linear Weyl semimetals, the summation inside the Fermi surface cancels out; no dc component.

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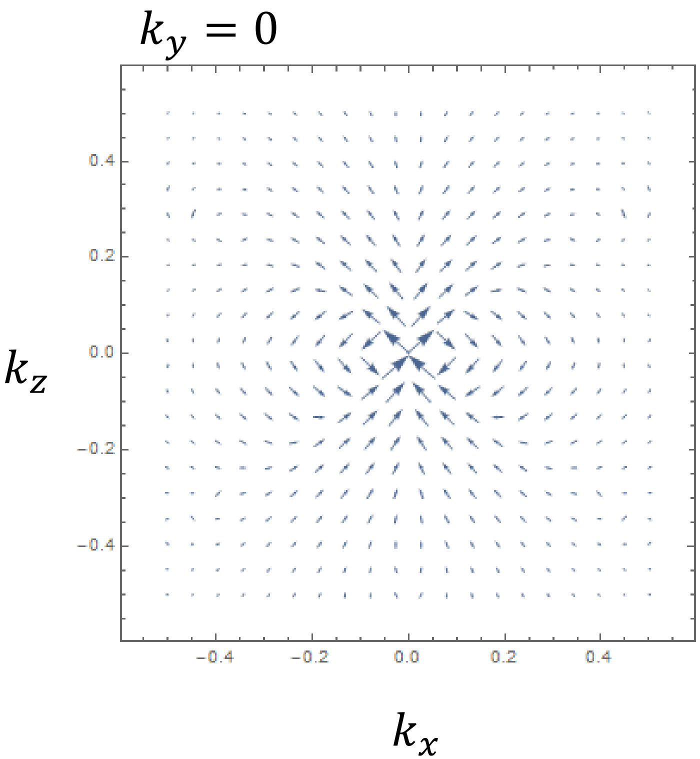


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# Calculation of Current

Electric Current:

$$j_\alpha(t) = \int \frac{d^d k}{(2\pi)^d}\, \Omega_{k_\alpha t}(\vec{k},t) f(\vec{k},t)$$

dc current of the Weyl semimetals:

$$J_z^{\pm} = \pm\pi \frac{16(10v^4 - 10v^2v_z^2 + 8v_z^4)\alpha_1^2 + 28vv_z(5v^2 - 14v_z^2)\alpha_1\alpha_3 - 79v^2v_z^2\alpha_3^2}{630\, v^6 v_z^4} \mu^2 g^2 \omega E^2,$$

Second harmonic generation (in linearly polarized light):

$$J_z^{\pm}(2\omega) = \mp\pi e\tau \frac{(6v^2 - 4v_z^2)\alpha_1\alpha_3 - 3vv_z\alpha_3^2}{15v^4v_z^3} \mu^2 g\omega E^2 \sin(2\omega t)$$