QFT approach to graphene

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Loewe's 65 Fest, Santiago, December 2017

A bit of history...

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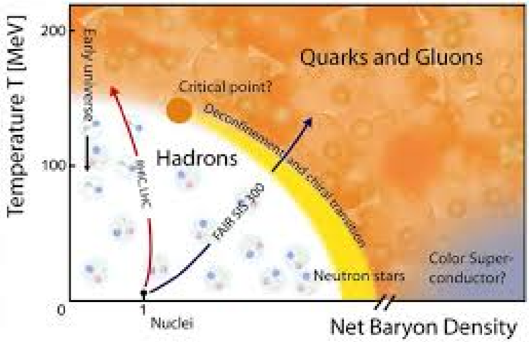

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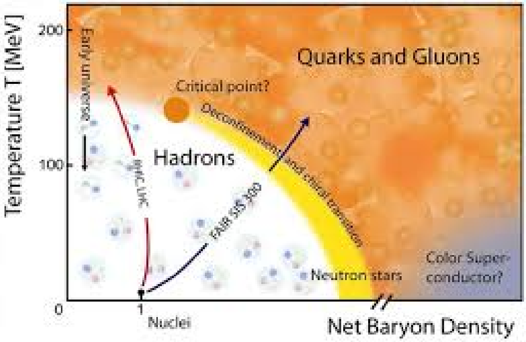

SDE+FESR

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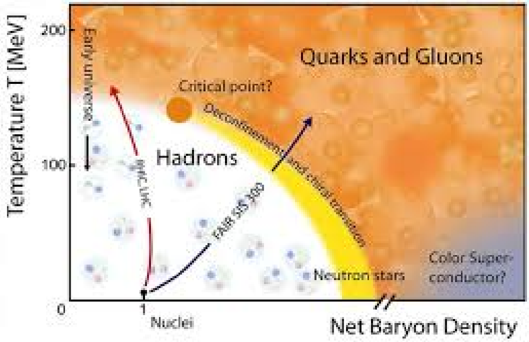

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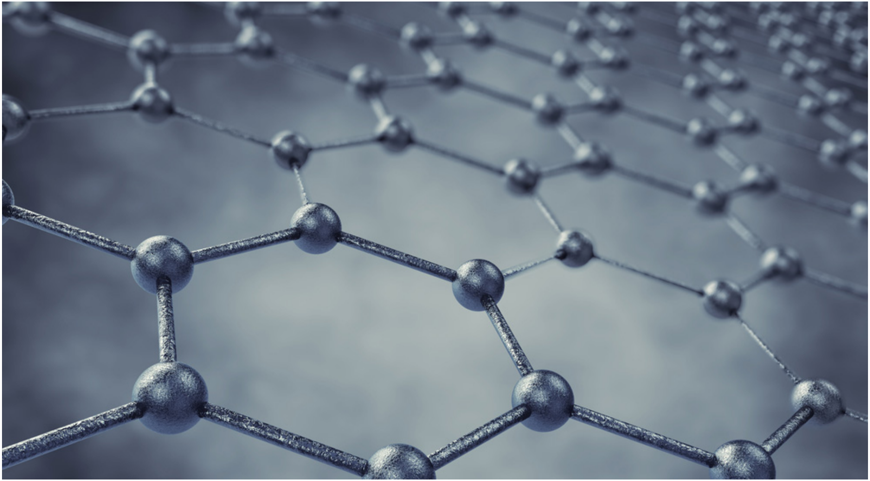

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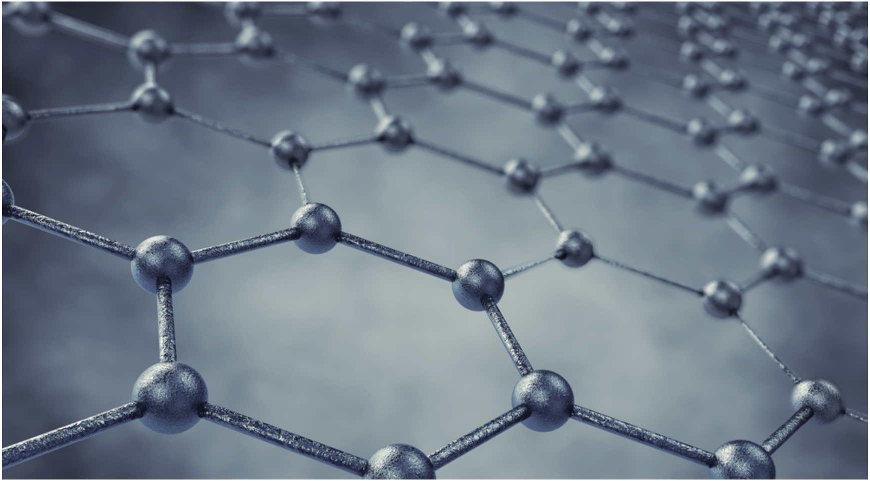
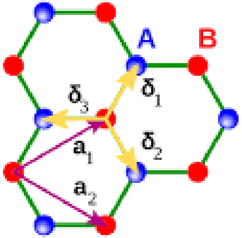
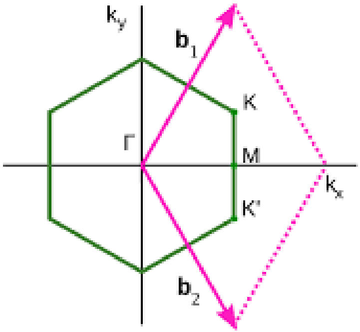


Saúl Hernández, David Valenzuela

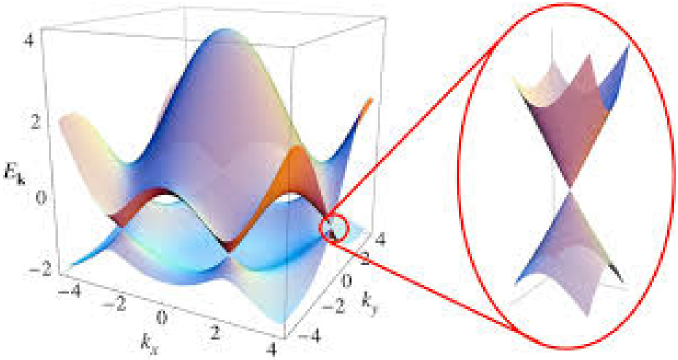
A bit of history...

Graphene





Graphene



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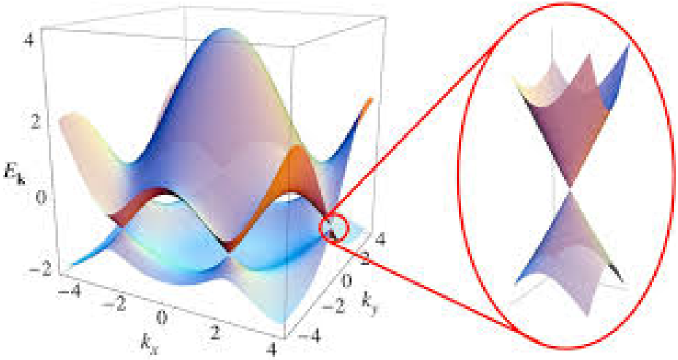


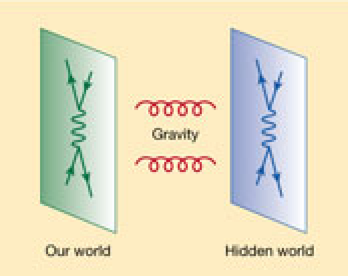
Massless Dirac equation, $H = v_F(\vec{\sigma} \cdot \vec{p})$

Graphene

- Brane-world scenarios

Graphene

- Brane-world scenarios



Planar Dirac fermions

$$\{\gamma^\mu, \gamma^\nu\} = 2g^{\mu\nu}$$

Two irreducible representations

$$\gamma^0 = \sigma_3, \qquad \gamma^1 = i\sigma^1 , \qquad \gamma^2 = \pm i\sigma^2$$

No chiral symmetry

$$\Gamma = i\gamma^0\gamma^1\gamma^2 = \pm iI$$

Mass term $m\bar{\psi}\psi$ breaks Parity and Time reversal

Planar Dirac fermions

$$\{\gamma^\mu, \gamma^\nu\} = 2g^{\mu\nu}$$

Reducible representation, ordinary γ-matrices

Two chiral-like transformations

$$\psi \to e^{i\alpha\gamma_5}\psi \;, \qquad \psi \to e^{i\beta\gamma^3}\psi$$

Two mass terms $m\bar{\psi}\psi$, $m_h\bar{\psi}\tau\psi$, $\tau = [\gamma^3, \gamma_5]/2$.

LKFT in Reduced $\text{QED}_{4,3}$: Graphene

- We start from the action [1]

$$I_{d_\gamma,d_e}[A_{\mu_\gamma},\psi_{d_e}] = \int d^{d_\gamma}x\ \mathcal{L}_{d_\gamma,d_e},$$

[1] A. Ahmad, J.J. Cobos-Martínez, Y. Concha y AR, Phys. Rev D**93**, 094035 (2016).

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- With the Lagrangian

$$\begin{aligned}\mathcal{L}_{d_\gamma,d_e} &= \bar{\psi}(x)i\gamma^{\mu_e}D_{\mu_e}\psi(x)\delta^{(d_\gamma-d_e)}(x) - \frac{1}{4}F_{\mu_\gamma\nu_\gamma}F^{\mu_\gamma\nu_\gamma} \\ &\quad -\frac{1}{2\xi}(\partial_{\mu_\gamma}A^{\mu_\gamma})^2\end{aligned}$$

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Graphene

- The free photon propagator is

$$D_{\mu_\gamma \nu_\gamma}(p) = \frac{-i}{p^2}\left(g_{\mu_\gamma \nu_\gamma} - \frac{p_{\mu_\gamma} p_{\nu_\gamma}}{p^2}\right) + \xi \frac{p_{\mu_\gamma} p_{\nu_\gamma}}{(p^2)^2} \, ,$$

Graphene

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- but when reduced to a d_e-dimensional brane becomes

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Graphene

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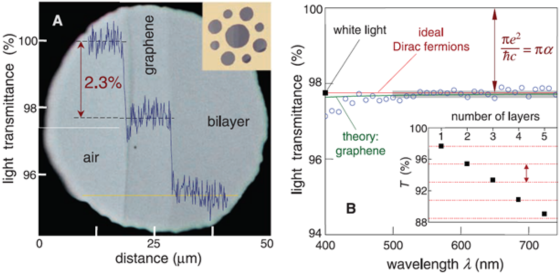
- with

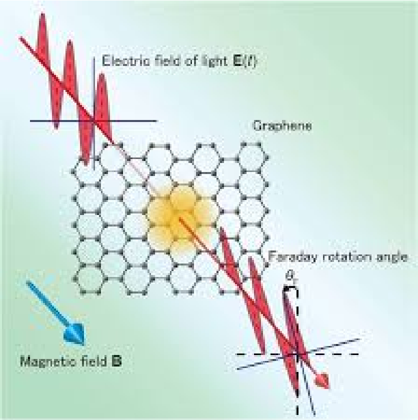
$$D(p^2) = \frac{i}{(4\pi)^{\varepsilon_e}}\frac{\Gamma(1-\varepsilon_e)}{(-p^2)^{1-\varepsilon_e}},$$

where $\varepsilon_e = (d_\gamma - d_e)/2$ and $\tilde{\xi} = (1-\varepsilon_e)\xi$.

Light Absorption in Graphene



Faraday Effect in Graphene



Vacuum Polarization Tensor

Modified Maxwell's equations

$$\partial_\mu F^{\mu\nu} + \delta(z)\Pi^{\nu\rho} A_\rho = 0 \ ,$$

Boundary conditions

$$A_\mu\Big|_{z=0^+} - A_\mu\Big|_{z=0^-} = 0$$
$$(\partial_z A_\mu)\Big|_{z=0^+} - (\partial_z A_\mu)\Big|_{z=0^-} = \Pi_\mu^\nu A_\nu$$

Observables

$$\mathcal{I} = 1 - Re(\sigma_{xx}) \ ,$$
$$\theta_F = -\frac{1}{2} Re(\sigma_{xy}) \ .$$

Vacuum Polarization Tensor

In vacuum

$$\Pi^{\mu\nu}(p) = \Psi(p^2)\left(g^{\mu\nu} - \frac{p^\mu p^\nu}{p^2}\right) + \Phi(p^2)\epsilon^{\mu\nu\alpha}p_\alpha$$
$$= \mathrm{Maxwell} + \mathrm{Chern} - \mathrm{Simons}$$

For a finite Haldane mass

$$I = 1 - \alpha\pi$$
$$\theta_F = \alpha$$

Vacuum Polarization Tensor

In a magnetic field

$$\Pi^{\mu\nu}(p) = \Psi(p^2)\left(g^{\mu\nu} - \frac{p^\mu p^\nu}{p^2}\right) + \Psi_\perp(p_\perp^2)\left(g_\perp^{\mu\nu} - \frac{p_\perp^\mu p_\perp^\nu}{p_\perp^2}\right)$$

For a *weak* magnetic field

$$\mathcal{I} = 1 - \alpha\pi(1 + 4\frac{(eB)^2}{\omega^4}).$$

Final remarks

- Natural extensions of *relativistic* QFT techniques in condensed matter systems
- Extensions
  - Finite temperature and density
  - Next-to-nearest neighbors Preliminary: Unchanged transparency.
  - Strain
  - Your choice...

FELIZ CUMPLE, MARCELO