Electron Interactions, Excitons and Carbon Nanotube Fluorescence Spectroscopy

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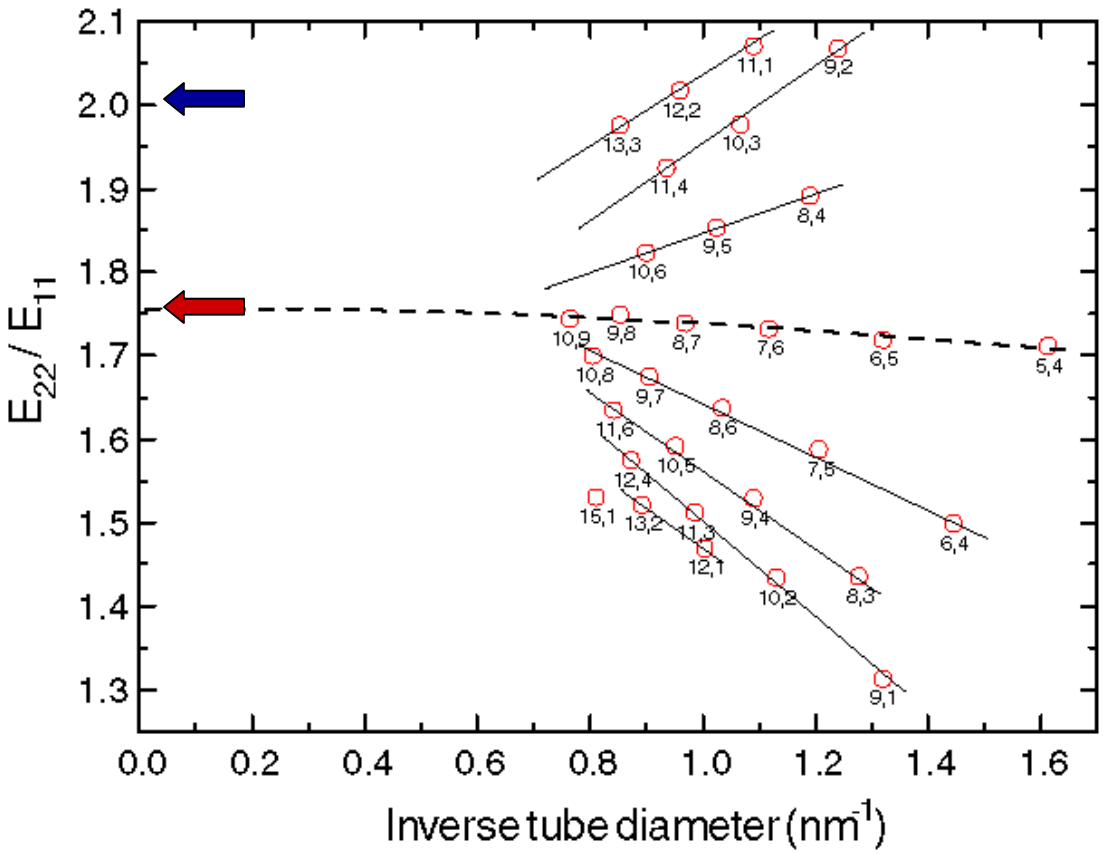
Interactions: self energy v. e-h effects

Nonlinear scaling of excitation energies from a "2D" interacting theory

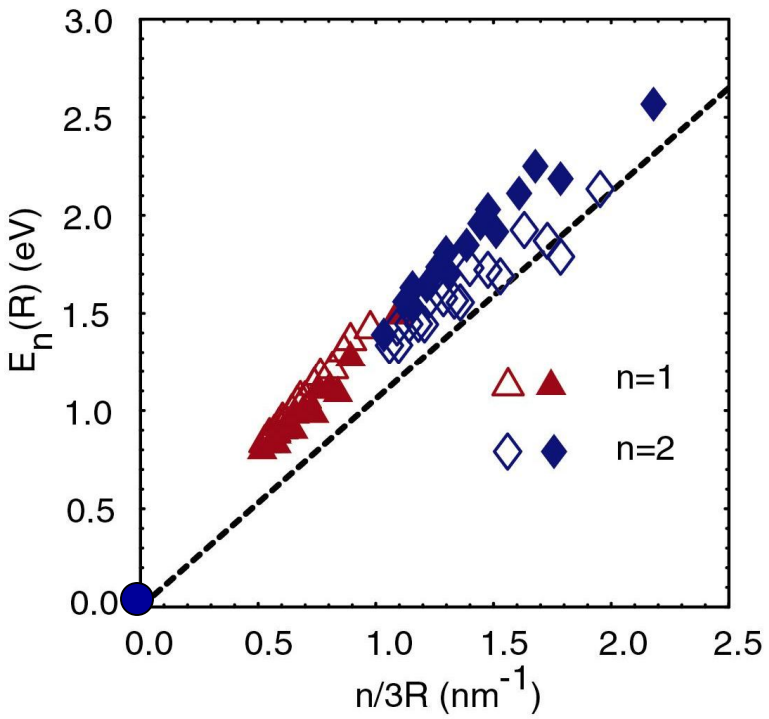
Ratio Problem*: the ratio of absorption/emission frequencies < 2 in *Large R Limit

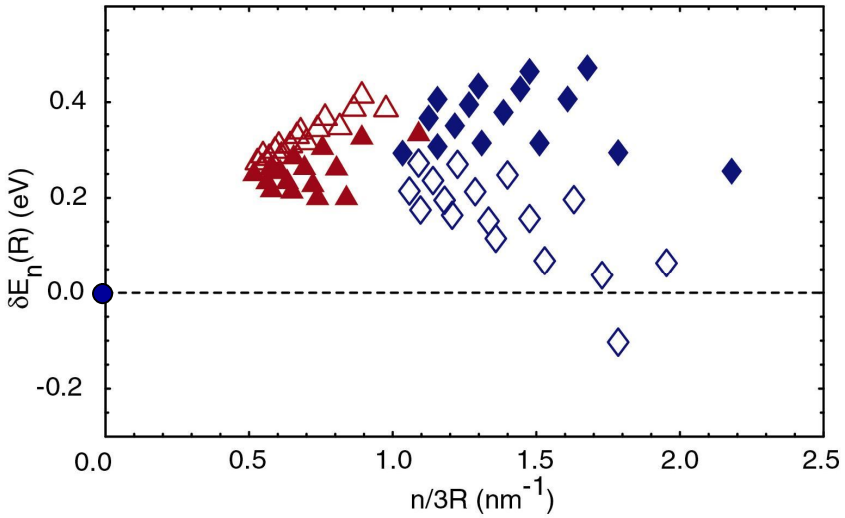


Data: S.M. Bachilo et al. Science 298, 2361 (2002)

***Blue Shift Problem*: E_{11} and E_{22} are blue shifted wrt linearized theory**

BUT with separatrix on single scaling curve (n/R)

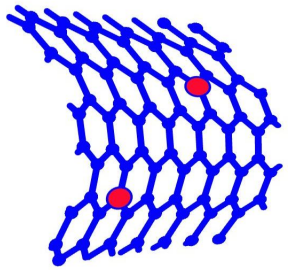




(nearly armchair tubes at border)

$$V(r) = \frac{e^2}{r} = V_{\text{short}}(r) + V_{\text{long}}(r)$$

Short Range Interaction : (a < r < 2πR)



Two Dimensional

Leads to nonlinear q log q shift in dispersion of graphene, and nonlinearity in $E_{nn}(1/R)$

Long Range Interaction : (r > 2πR)

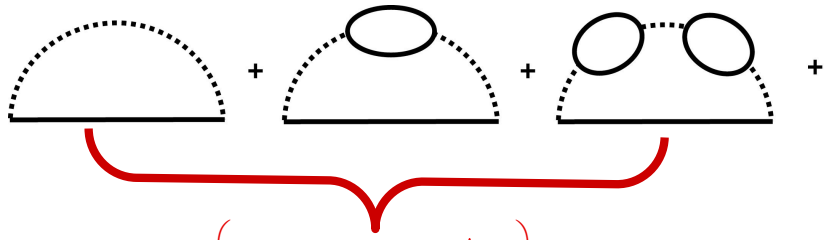
One Dimensional

Unscreened for large separation

Interactions renormalize quasiparticle dispersion E(q) of two dimensional graphene

Noninteracting: $E(q) = \hbar v_F q + O(1/R^2)$

Interacting:



$$E(q) = \hbar v_F q \left(1 + \frac{g}{4}\log\left(\frac{\Lambda}{q}\right)\right) + O(1/R^2);$$

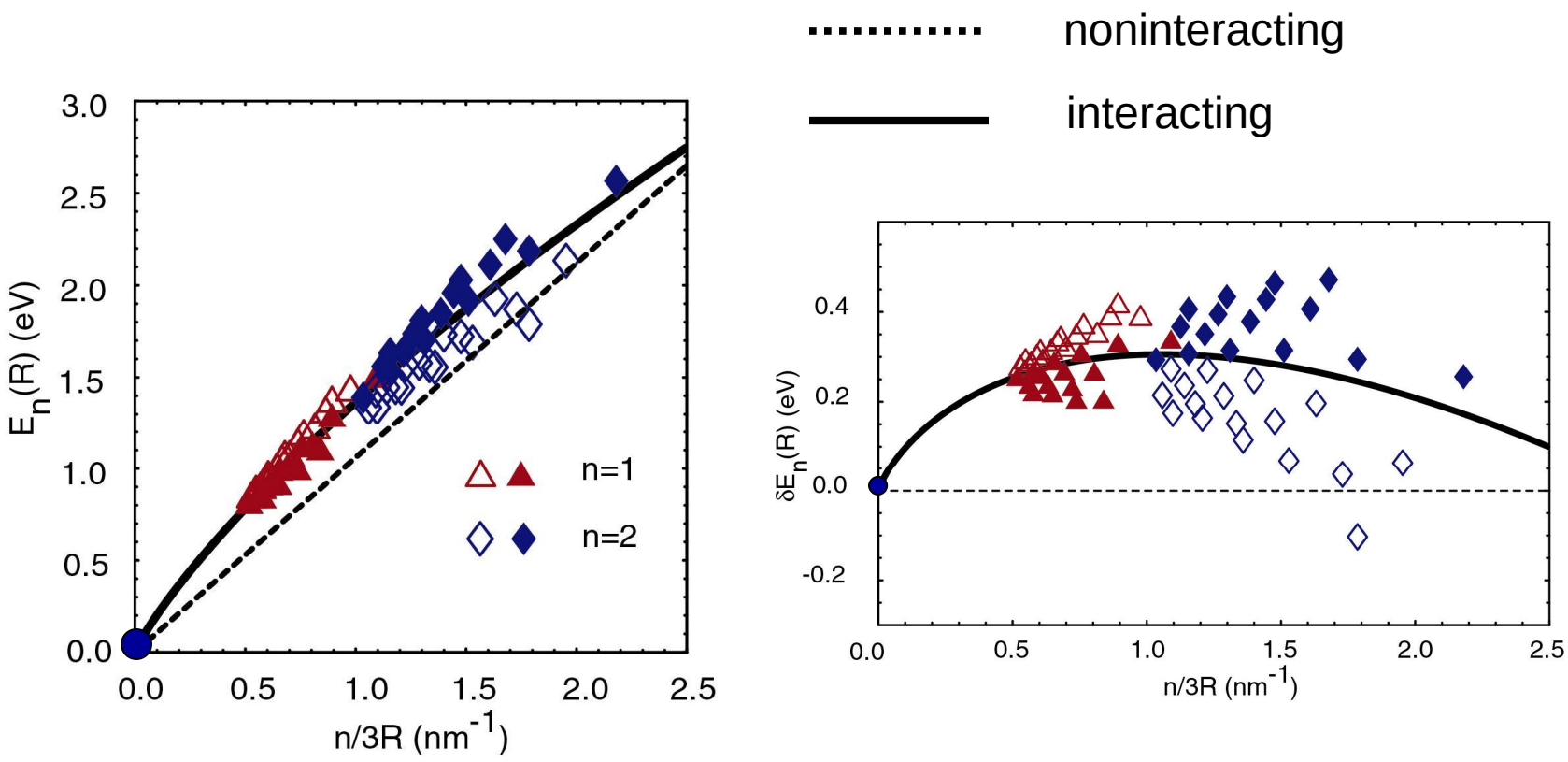
$$g = e^2 / \hbar v_F$$

This is <u>exact</u> for q -> 0, with a scale dependent v_F and g :

(scales to perturbative regime at small q)

See also: J. Gonzalez, F. Guinea and M.A.H. Vozdeniano
Phys. Rev. B 62, 4273 (2002)

Map graphene quasiparticle energies to nanotube



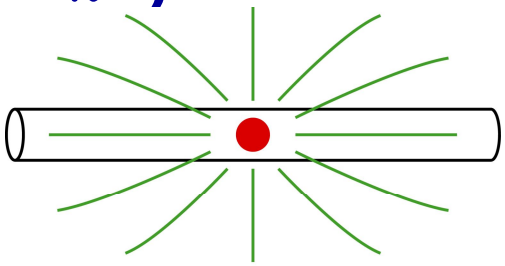
Resolves ratio problem and blue shift problem
….but why ? (misses 1D physics)

$$V(r) = \frac{e^2}{r} = V_{\text{short}}(r) + V_{\text{long}}(r)$$

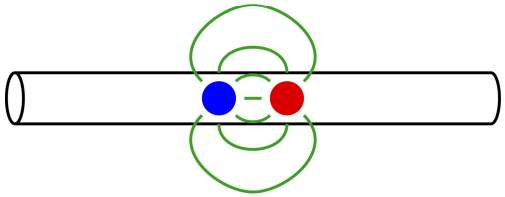
- **Long Range Interaction : (r > 2πR)**

One Dimensional
(unscreened at large r)

Renormalizes Band Gap



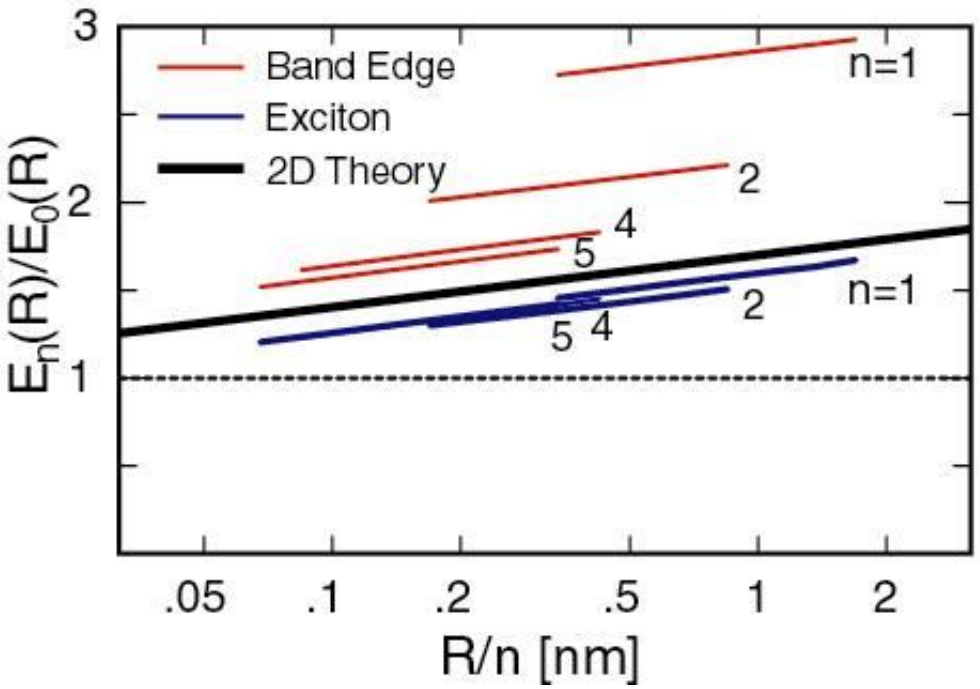
Binds Exciton



For e-h pair these effects compete and nearly cancel !

Single Particle and Particle - Hole Energies

multiband mixing with screened interaction



single particle gaps

2D qp's
excitons

noninteracting

See also: T. Ando, J. Phys. Soc. Japan 66,1066 (96)
Numerical Calculation in Screened Hartree Fock Approximation

Cancellation is Exact for Infinite Range Interaction

Bare Gap: 2Δ Interaction Energy: $V_o N^2/2$

Quasiparticle Gap:

$$E(N+1) + E(N-1) - 2E(N) = 2\Delta + V_o$$

Electron-Hole Gap: 2Δ

Summary

Model interaction effects using expansion in a/R

"One dimensional" interaction effects
(r > 2πR) ***are strong but nearly cancel***
self energy ↑ and excitonic binding ←

Exposes "two dimensional" effects **(a < r < 2πR)**
qp's inherit a nonlinear q log (Λ/q) dispersion
"scale dependent" v_F
gap ratios & blue shift from interactions