USING ARPES IMAGING TO ANALYZE THE BAND STRUCTURE OF GRAPHENE

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JUSTIFICATION

- Electronic properties of carbon have many industry applications
  - Transistors
- C-face epitaxial graphene is of particular interest
  - High quality
  - Multilayer samples retain single layer properties

Image courtesy of J. Hass et al.
Recall that:

\[ \omega = \frac{2\pi}{T} \quad k = \frac{2\pi}{\lambda} \]

We can express \( E(k) \)
- “Dispersion curve”
- “Band structure”

In graphene, \( E(k) \) is linear:

\[ E(k) = \hbar v_F k \]

Of interest to us is when two cones intersect.
STRUCTURE MODELS

Tight-Binding Model

- Characterized by:
  - Reduced $v_F$ at intersection
  - van Hove singularity at intersection
  - High density of states at intersection

Continuum Formulation

- Characterized by:
  - Unchanged $v_F$ at intersection
  - Degenerate point at intersection
  - Low density of states at intersection
EXAMINING THE INTERSECTION

Tight-Binding Model

Continuum Formulation
**ANGLE-RESOLVED PHOTOEMISSION SPECTROSCOPY**

- Uses the photoelectric effect
- Measure energy and position of photoelectrons to construct three-dimensional dispersion curve
Analysis Techniques

Find intersection energy with $E(k_x)$
Examine constant energy surface at $E - E_F = -0.31 \text{ eV}$
As cones intersect, the low density of states is very visible…
**Conclusions**

- Work completed in 2010 demonstrated unchanged Fermi velocity at intersection point
- There is clearly no von Hove singularity – evidence suggests a degenerate point
- Tight-binding model is flawed
- More data must be analyzed to determine if continuum formulation is fully supported by experiment
IN THE CLASSROOM...

- **Negative Results and Experimenter Bias**
  - **Freshman Physics**
    - Discussion on Newton vs. Leibniz
    - Recreation of s’Gravesande’s clay experiment demonstrating the existence of kinetic energy
  - **AP/Honors Physics**
    - Research report on the evolution of a physical theory and the role of negative results and/or bias
      - examples: heat and *phlogiston*, Bohr/Einstein and quantum mechanics, cosmology, Michelson-Morley, Young’s Double Slit,...
    - **OPTIONAL:** More in-depth analysis of s’Gravesande’s experiment
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