Progression of Photoemission Spectroscopy

Physics 590B
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Contents

- Photoelectric effect
- Photoemission Spectroscopy (PES)
- Angle-Resolved Photoemission Spectroscopy (ARPES)
- Laser-ARPES
Photoelectric Effect

• Hertz Experiment (1886): Discovered photoelectric effect

• Thomson and Lenard (1897-1902): Demonstrated that electrically charged particles are liberated from a metal surface when it is illuminated (Nobel prize 1906, 1905)

• Explained by Einstein (1905): Revolutionary explanation about photoelectric effect (rejected by physics community)

• Robert Millikan (1916): put all his effort into the photoelectric effect, hoping to disprove Einstein’s hypothesis (Nobel prize 1923)

• Nobel prize (1921)

https://www.wikipedia.org/
• Electromagnetic Wave

• Energy of light increases as intensity increases

• Kinetic energy of the electrons would be determined by the intensity

Classical Theory

Experiment

• The kinetic energy was a function of the frequency

• Kinetic energy was independent of the intensity

physics.stackexchange.com

staemtit.com/science
Photoelectric effect

- Energy was only transferred from one photon to one electron.
- The escaping electron’s kinetic energy is greater for a greater light frequency.
- Energy of incident photons must be sufficient to overcome the work function.

\[ E_{\text{kin}} = hf - w \]
Photoemission Spectroscopy (PES)

- In 1960, Dr. Siegbahn and his research group.

- 1981, Dr. Seighbahn, nobel prize

http://www.physics.uwo.ca
PES

- Mainly for chemical analysis (also known as Electron spectroscopy for chemical analysis)
- UHV (ultra high vacuum) $\sim 10^{-9} \text{Torr}$
- Energy conservation $E_{\text{kin}} = h\nu - E_B - w$
- X-ray and UV source (10-1000eV)
- Surface sensitive technique
ARPES

- Parallel Momentum conservation

\[ K_{\parallel} = \sqrt{\frac{2mE_{\text{kin}}}{\hbar^2}} \sin \theta = \sqrt{\frac{2mE_{\text{kin}}}{\hbar^2} k_x^2 + k_y^2} \]

- Energy conservation

\[ E_{\text{kin}} = h\nu - |E_B| - w \]
• Direct information about band structure

• Applied to small samples (~μm)

• Surface sensitive technique

Takeshi Kondo, PRL 110, 217601 (2013)
ARPES  
(Advantages)
ARPES
(Limitation)

- Not bulk sensitive
- Flat surface
- Requires UHV ($\sim 10^{-11} Torr$)
- No pressure or magnetic field dependent study
- Requires reasonable resistivity
ARPES
(He lamp)

- Beam size is 2-3 mm
- Fixed photon energy (21.1 eV, 23.1 eV, 40.8 eV)
- Spectral bandwidth ~1 meV
- Less expansive than Synchrotron (30K$ vs 100 M$)
ARPES
(He lamp)

- Photons are emitted by He plasma gas
- Plasma is usually generated ~ 1 Torr
- Differentially pumped discharge lamp
Laser-ARPES

- Photon energy
  \( (\lambda = 800 - 1000\,nm) \sim 5-7eV \)
- Beam spot is \( \sim 10\,\mu m \)
- Bandwidth <1meV
- High photon flux
Laser-ARPES

- Improved energy resolution
- Improved bulk sensitivity (Resistivity, superconductivity etc.)
- Decreased space charge effect
Laser-ARPES invincible?

- Small K space coverage
- Limited photon energy range
- Electron analyzer usually don’t like low kinetic energy
### Summary

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<thead>
<tr>
<th></th>
<th>Discharge lamp (He Lamp)</th>
<th>Laser</th>
<th>Synchrotron</th>
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</thead>
<tbody>
<tr>
<td><strong>Energy</strong></td>
<td>21.2 eV (He I α)</td>
<td>5~ 7eV</td>
<td>1eV~1000eV</td>
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<tr>
<td></td>
<td>23.1 eV (He II α),</td>
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<tr>
<td></td>
<td>40.8 eV (He II)</td>
<td></td>
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<tr>
<td><strong>Intensity</strong></td>
<td>~ $10^{13}$ photons/s</td>
<td>~ $10^{15}$ photons/s</td>
<td>~ $10^{13}$ photons/s</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>5meV</td>
<td>Sub meV</td>
<td>1-50meV</td>
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<tr>
<td><strong>Beam Spot</strong></td>
<td>~1mm</td>
<td>~10 μm</td>
<td>~50 μm</td>
</tr>
<tr>
<td><strong>Momentum range</strong></td>
<td>1-2 BZ</td>
<td>Partial BZ</td>
<td>Several BZ</td>
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