

1. Preface
  - (a) Quantum materials are really cool
  - (b) Correlated systems are really cool
  - (c) Probably the most exciting systems right now
  - (d) What are the major questions?
  - (e) Description of the book - dissemination of results, and instruction manual
2. Introduction to ultrafast optics in correlated electron systems
  - (a) Correlated systems - an overview
  - (b) Important aspects of correlated systems for this thesis
    - i. Charge density wave (example: 1T-TaS<sub>2</sub>)
    - ii. Kondo effect and Magnetic order (example: CaMn<sub>2</sub>Bi<sub>2</sub>)
    - iii. Multiferroics (example: CuBr<sub>2</sub>)
  - (c) Spectroscopy versus control
    - i. Ultrafast spectroscopy
      - A. Comparison of nonequil. vs equil. spectroscopy
      - B. Excitation of coherent collective modes
      - C. In multiferroics
    - ii. Ultrafast control
      - A. Incoherent versus incoherent control
      - B. In magnets
3. SHG theory
  - (a) Space groups and point groups
  - (b) Response tensors
    - i. Multiple contributions to SHG
  - (c) Symmetry of tensors - the free energy
    - i. SHG does not mean inversion broken
    - ii. Presence of absorption
  - (d) Bond model
  - (e) Phenomenological GL model of SHG
    - i. Free energy is  $\mathbf{p} \cdot \mathbf{e}$
    - ii. Free energy for SHG can be written like ...
    - iii.  $\chi_{ijk} = \chi_{ijkl} O_l$  (but fully general) is a valid expression for the free energy
    - iv. Free energy needs to be a real and totally symmetric scalar
    - v. This gives us constraints on  $\chi_{ijk}$ .

- vi. Time reversal affects SHG
  - vii. SHG also measures domains
- (f) Quantum model
  - i. Wavelength dependence of SHG
- 4. SHG practical
  - (a) Basic idea
    - i. Connection to last chapter - want to probe as many elements as possible
    - ii. We have control over the fields and the outgoing polarization
    - iii. Our choices: oblique incidence, large spot size, single color, PMT detector
    - iv. Schematic description of the setup
  - (b) Before you build the setup
    - i. Choice of oblique vs. normal incidence - which tensor elements do you want to probe?
    - ii. Scaling of SHG signal with volume, pulse width - microscopy or not? Domain size?
  - (c) Construction of the setup
    - i. Description of the setup that we built
    - ii. Automated polarization rotators
    - iii. Better to use hollow bore stepper motors
    - iv. Choice of detector
    - v. Alignment
      - A. Aligning the circles
      - B. Checking that the symmetry looks good
      - C. Waveplates
  - (d) Considerations for time-resolved
    - i. Location of pump mirror
    - ii. Alignment of normal incidence
    - iii. Choice of pump wavelength (OPA)
    - iv. Polarization rotation (why do it?)
    - v. Pump scatter
  - (e) Data analysis (static)
  - (f) Data analysis (time-resolved)
- 5. Appendix A: Failed experiments