

# Physics 123B

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# Course Organization

- Text: “Introduction to Solid State Physics”, by Kittel
- Grading: HW 25%, Mid-term 25%, Final 50%
- TA: Jason Iaconis
- Office hours
  - LB: Thurs, 2:30-4:00, Kohn 2315 (KITP)
  - Jason: Wed, 3:30-5:00, PSR

# Review questions I

- What is a crystal?
  - A: a periodic arrangement of atoms
- How do we describe this structure mathematically?
  - A: through Bravais lattice (primitive vectors) + Basis; symmetry; unit cell
- How do we study structure experimentally?
  - A: x-rays; neutrons; AFM/STM...

# Review Questions 2

- What does (elastic) x-ray scattering measure?
  - A: reciprocal lattice. define it.
- What are phonons?
  - A: normal modes of small oscillations of atoms
- What are acoustic and optical phonons? How many branches of each are there in NaCl?
  - A: acoustic modes have  $\omega \sim k$ ; 3 of each per unit cell.

# Review Questions 3

- How does the phonon heat capacity depend on  $T$  at low and high  $T$ , i.e. what is the power law?
  - A:  $C \sim T^3$  at low  $T$ ,  $C = \text{const.}$  at high  $T$ .
- What is the characteristic temperature separating these two limits called?
  - A: Debye temperature
- Give an example of another physical property phonons contribute to
  - A: thermal conductivity, sound, thermal expansion

# Review Questions 4

- In the free electron model, what is the Fermi energy, and what is a typical value for it?
  - A:  $E_F$  separates occupied and empty states. It is of order a few eV  $= 10^4$ - $10^5$  K
- What is the temperature dependence of the electronic heat capacity at low T?
  - A: it is linear in T
- Is the electronic or phononic contribution to heat capacity typically larger at room temperature? Why?
  - A: phonons. Because all the phonon entropy is released over the Debye temperature, while the electron entropy is released over the Fermi energy, and  $E_F \gg kT_D$

# Review Questions 5

- What is the “Drude model”/Ohm’s law expression for the conductivity of the free electron gas?
  - A:  $\sigma = n e^2 \tau / m$ , where  $\tau$  is a collision time/relaxation time
- What determines the collision time at room temperature and at low temperature?
  - A: usually phonons at room temperature, and impurities at low temperature.
- What is the Hall coefficient, and what does it measure, in the free electron model?
  - A: it is the ratio of the hall resistivity to magnetic field, and it measures  $-1/(n e)$  (the density of electrons)

# Review Questions 6

- Is the electronic or phononic contribution to thermal conductivity usually more important in metals at room temperature?
  - A: electronic. This might be surprising since the phonon heat capacity dominates. But there is an extra factor of velocity  $v$  in the thermal conductivity,  $K = C v l$ , and  $v_F \gg v_{\text{sound}}$ .
- What is the form of the wavefunction of an electron in an ideal periodic solid?
  - A: It has the Bloch form of a plane-wave times a periodic function
- What is the crystal momentum, and how is it different from the true momentum?
  - A: The crystal momentum is defined as  $\hbar$  times the wavevector appearing in the Bloch form. It is different from the true momentum because the electron scatters off of the lattice, and therefore is in a superposition state of many momenta which differ by reciprocal lattice vectors. So the crystal momentum is only defined up to a Bragg momentum

# Review Questions 7

- What is an energy band?
  - A: Electronic states have energies  $\epsilon_n(k)$  which are periodic in wavevector/crystal momentum and have discrete  $n$ . Each such function is a band, and spans a finite range of energy.
- How many orbitals are there in a band?
  - A: Each band contains 2 orbitals (including electron spin) per primitive unit cell of the lattice. Equivalently, there is one crystal momentum per p.u.c.
- Both Francium and Radium (atomic number 87 and 88, respectively) have b.c.c. crystal structures in elemental form. Can you say whether either one is metallic?
  - A: Fr *must* be metallic in b.c.c. form, since it has an odd number of electrons per atom and bcc is a Bravais lattice with one atom per p.u.c. (Here we assume it does not become magnetic). In fact radium is also metallic, though it does not need to be.

# Review Questions 8

- What is a semiconductor?
  - A: it is a material which is an insulator at  $T=0$  with a relatively small (usually  $<2\text{eV}$ ) band gap.
- What is a direct and indirect gap?
  - A: a direct gap is the minimum energy needed to go from the valence to conduction band conserving  $k$ . An indirect gap is a smaller energy transition which does not conserve  $k$ .
- How can the gap be measured?
  - A: optics can measure both direct and indirect gap. Activation energy of the conductivity can measure the gap.