project:

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Solid State Physics

Room 185

Physics 140 A

MW 11:30 - 12:50

leopard.physics.ucdavis.edu/rts/p140a/p140a_W2012.html

Goals

(1) Develop theories of properties of solids

- crystal structure - (defects, glasses)
  how far apart are nuclei? pattern to arrangement?
  vibrations - conduction of sound/heat

  structural properties - bulk, shear moduli
  $K = -V\frac{dP}{dV}$ $\quad dV = -\frac{1}{K}V\,dP$

  Ideal gas $V = \frac{NkT}{P}$
  $dV = -\frac{NkT}{P^2}dP$
  $= -1/P\, V\, dP$
  at T = c

- "electronic structure"

  metal, insulator, semiconductor
- optical properties - color, transparency
  (can depend on ω)
- Exotic properties

  magnetism

  superconductivity

(2) Understand experiments which reveal properties

- neutron scattering, x ray scattering
- conductivity, Hall Effect
- de Haas van Alphen
  Josephson effect
  nuclear magnetic resonance

(1) ~~4~~ (2) Crucial to develop theory of response of solid to external probe (experiment)

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A vast, challenging field [Amazing we can do anything!]

(1) 100 or so elements in periodic table

$NaCl \to (100)^2$

$La_2 BaCuO_4 \to (100)^3$

$Y_1 Ba_2 Cu_3 O_7 \to (100)^4$

(2) Hydrogen atom 1 proton + 1 electron

Laguerre polynomials, Spherical Harmonics, ..

in solving Schroedinger Eqn.

Now 10^{23} e^- and nucleii

(3) Not only different "ingredients" (1)

but different dimensionalities

$d=0$ nanodots
$d=1$ nanotubes
$d=2$ magnetic multilayer
$d=3$ bulk

(4) And different "environments"

low T $\to$ superconductivity

high P $\to$ { magnet $\to$ nonmagnetic
insulator $\to$ metal
lattice structure changes }

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Bohr magneton

Keep in mind some numbers $\mu_B = \frac{e\hbar}{2m_e} = 9.27 \cdot 10^{-24}$ J/T

(magnetism)

$m_{electron} = 9.11 \cdot 10^{-31}$ kg

$m_{proton} = 1.67 \cdot 10^{-27}$ kg

N_A = Avogadro = $6 \cdot 10^{23}$

} 1 mole of proton has mass of 1 gm

a = typical lattice constant (spacing between atoms) in solid

≈ ? A : 2-3 Å

Figure it out! Silver $\rho = 10.5$ gm/cm^3

Z = 108 protons + neutrons

A = 47 protons

1 mole of Ag → 108 gm ≈ 10 cm^3

$$V_{atom} = \frac{10 \text{ cm}^3}{6 \cdot 10^{23}} = \frac{1}{6} 10^{-22} \text{ cm}^3 = 17 \cdot 10^{-24} \text{ cm}^3$$

$$a = \sqrt[3]{V_{atom}} \sim 2.5 \cdot 10^{-8} \text{ cm}$$

10^{-8} cm = 1 Å Angstrom

atomic separation in gas at STP ~ 10 x larger

1 mole occupies 22.4 liters = $22.4 \cdot 10^3$ cm^3

↕ instead of

10 cm^3

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$$E_n = \boxed{\frac{-me^4}{2\hbar^2}} \frac{1}{n^2}$$

← Rydberg 13.6 eV $2.18 \cdot 10^{-18}$ J

Facts about atoms (constituents of solids)

Bohr radius $\hbar^2/me^2 = 0.529 \underbrace{10^{-8}\ \text{cm}}_{\text{Å}}$

perhaps not a surprise: atomic spacing in crystal is comparable to Bohr radius. (size of atom)

$n=1$	$l=0$	$m=0$	$s=\pm 1/2$	H He
$n=2$	$l=0$	$m=0$	$s=\pm 1/2$	Li Be
	$l=1$	$m=-1,0,1$	$s=\pm 1/2$	B C N O F Ne
$n=3$	$l=0$	$m=0$	$s=\pm 1/2$	Na Mg
	$l=1$	$m=-1,0,1$	$s=\pm 1/2$	Al Si P S Cl Ar
	$l=2$			Sc Ti...
$n=4$	$l=0$	$m=0$	$s=\pm 1/2$	K Ca

then 3d

first fill 4s

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10^{-7} cm

10^{-9} m

More sizes

wavelength of visible light λ 390 - 750 nm $\approx$ 3900 - 7500 Å

f 400 - 790 $\cdot 10^{12}$ sec^{-1}

$\lambda f = c = 7500 \cdot 10^{-10}$ m $\cdot 400 \cdot 10^{12}$ sec^{-1}

$= 3 \cdot 10^8$ m/s

λ (visible light) >> a = spacing between atoms in solid) mismatch

visible light is not a good way to probe lattice constant

x ray scattering .01 - 10 nm = .1 - 100 Å matches a

$3 \cdot 10^{19} - 3 \cdot 10^{16}$ Hz

x ray energy ? $E = h\nu = 6.63 \cdot 10^{-34}$ J $\begin{cases} 3 \cdot 10^{19} \\ 3 \cdot 10^{16} \end{cases} \sim 2 \cdot \begin{matrix} 10^{-14} \\ 10^{-17} \end{matrix}$ J

or in eV = $1.6 \cdot 10^{-19}$ J E ≈ 200 - 20000 eV

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Neutron scattering

$$p = h/\lambda = 6.6 \cdot 10^{-34} / 2 \cdot 10^{-10} = 3.3 \cdot 10^{-24}$$

↑ want 10^{-10} m to match $a \sim 1$ Å

$$E = p^2/2m = (3.3 \cdot 10^{-24})^2 / 2(1.67 \cdot 10^{-27})$$

$$\approx 3 \cdot 10^{-21} \text{ J} \approx 10^{-2} \text{ eV}$$

turns out this is quite close to energy of lattice vibrations in solid (phonons)

$E_{neutron} \sim E_{phonon}$
$\lambda_{neutron} \sim \lambda_{phonon}$
} good match in both ⇒ neutrons great at looking at lattice vibrations