

Goals

(1) Develop theories of properties of solids

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

structural properties - bulk, shear moduli

- "electronic structure" $\leftarrow K = -V \frac{dP}{dV}$ $dV = -\frac{1}{K} V dP$

metal, insulator, semiconductor

- optical properties - color, transparency

$$\text{Ideal gas } V = \frac{NKT}{P}$$

$$dV = -\frac{NKT}{P^2} dP$$

$$= -\frac{1}{P} V dP$$

$$\text{at } T=c$$

- Exotic properties

 \leftarrow can depend on ω

magnetism

superconductivity

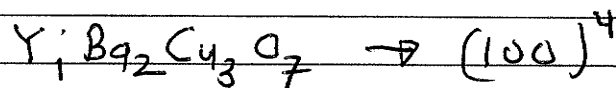
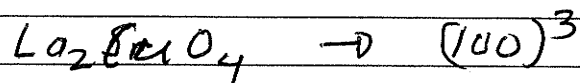
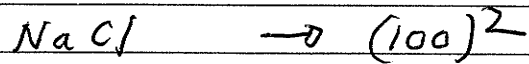
(2) Understand experiments which reveal properties

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

(1) \leftrightarrow (2) Crucial to develop theory of response
of solid to external probe (experiment)

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

(1) 100 or so elements in periodic table



(2) Hydrogen atom 1 proton + 1 electron

Laguerre polynomials, Spherical Harmonics...

in solving Schroedinger Eqn.

Now 10^{23} e^- and nuclei

(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 $T \rightarrow$ superconductivity

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

I-1'

Bohr magneton

Keep in mind some numbers

$$\mu_B = \frac{e\hbar}{2m_e} = 9.27 \cdot 10^{-24} \text{ J/T}$$

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

(magnetism)

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

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

1 mole of proton has mass of 1 gm

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

$$\approx ? \quad A: 2-3 \text{ \AA}$$

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

$$Z = 108 \text{ protons + neutrons}$$
$$A = 47 \text{ protons}$$

$$1 \text{ mole of Ag} \rightarrow 108 \text{ gm} \approx 10 \text{ cm}^3$$

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

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

1 \AA Angstrom

atomic separation in gas at STP $\sim 10 \times$ larger

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

\downarrow instead of 10 cm^3

project:

$$I - 2'$$

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

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

Facts about atoms (constituents of solids)

$$\text{Bohr radius } \frac{\hbar^2}{me^2} = 0.529 \cdot 10^{-8} \text{ cm}$$

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... Then 3d
$n=4$	$l=0$	$m=0$	$s=\pm 1/2$	K Ca First fill 4s

project:

I-3'

More sizes

$$10^{-7} \text{ cm}$$

$$10^{-9} \text{ m}$$



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

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

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

$$= 3 \cdot 10^8 \text{ m/s}$$

λ (visible light) \gg a = spacing between atoms
in solid

mismatch

visible light is not a good way
to probe lattice constant

x ray scattering 0.01 - 10 nm = 0.1 - 100 Å matches a

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

x ray energy? $E = hf = 6.63 \cdot 10^{-34} \text{ J} \left\{ \begin{array}{l} 3 \cdot 10^{19} \\ 3 \cdot 10^{16} \end{array} \right. \sim 2 \cdot 10^{-14} \text{ J}$

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

Neutron scattering

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

↑
want $\cdot 10^{-10}$ m to match $a \sim 1 \text{ \AA}$

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

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

turns out this is

quite close to energy

of lattice vibrations in solid

(phonons)

$$E_{\text{neutron}} \sim E_{\text{phonon}}$$

$$\lambda_{\text{neutron}} \sim \lambda_{\text{phonon}}$$

} good match in both

\Rightarrow neutrons great

at looking at

lattice vibrations