Chapter 12 Structures and properties of ceramics

- ☐ Bonding in ceramics
- ☐ Imperfection in ceramics
- ☐ Electric properties of ceramics
- ☐ Ceramic phase diagrams
- ☐ Brittle fracture of ceramics
- ☐ Stress-strain behavior
- ☐ Mechanisms of plastic deformation

Ceramic bonding

☐ **Bonding:**

--Mostly ionic, some covalent.

--% ionic character increases with difference in electronegativity.

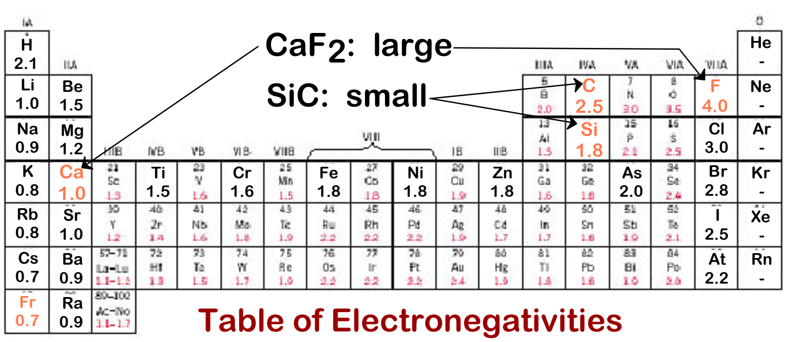
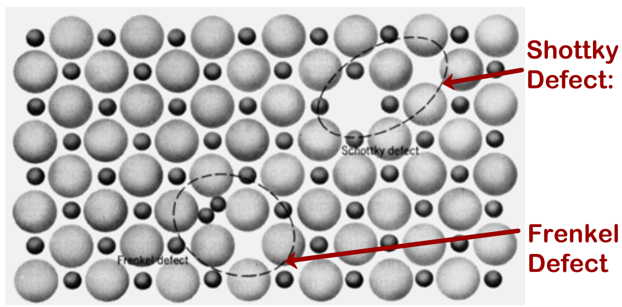


Table of Electronegativities

Imperfections in ceramics

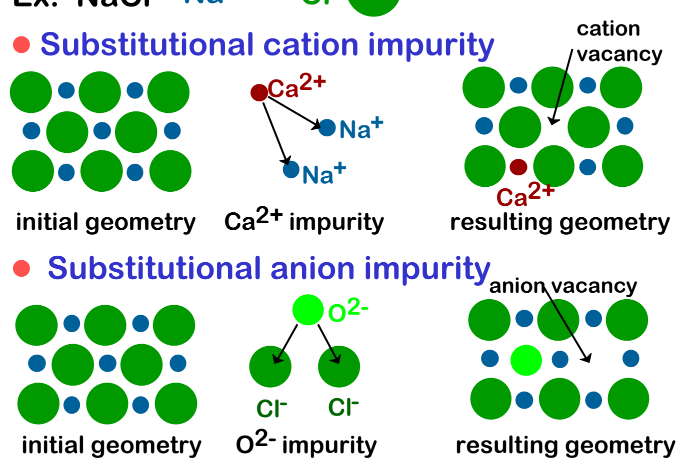
- Schottky defects: **--a paired set of cation and anion vacancies.**
- Frenkel defects: an atom from a lattice site to an interstitial position



Point defects in Ionic Crystals

- **Impurities must also satisfy charge balance**

- **Ex: NaCl** Na^+ Cl^-



Point Defects in Ionic Crystals

- Defect examples for other ionic crystal systems
  - In simple ionic crystals, both Schottky and Frenkel defects occur, but the concentration of one type generally exceeds that of the other
    - Schottky defects dominate in alkali halides
    - Cation Frenkel defects dominate in AgCl and AgBr
    - Anion Frenkel defects dominate in CaF_2 and fluorites

Electric Properties

- Electrical conductivity: the mobility of charged point defects

$$\sigma = n(\mu^{+} + \mu^{-})e$$

$$\approx n\mu^{+}e \approx \exp(-\frac{Ea}{KT})$$

Since the cation vacancy is more mobile than anion vacancy

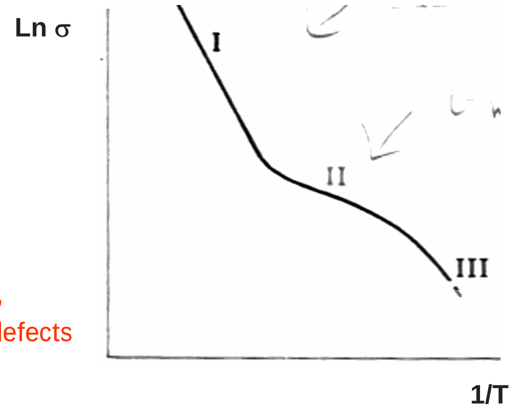
n-- defect concentration

e-- charge

μ-- mobility

Electric Properties (continue)

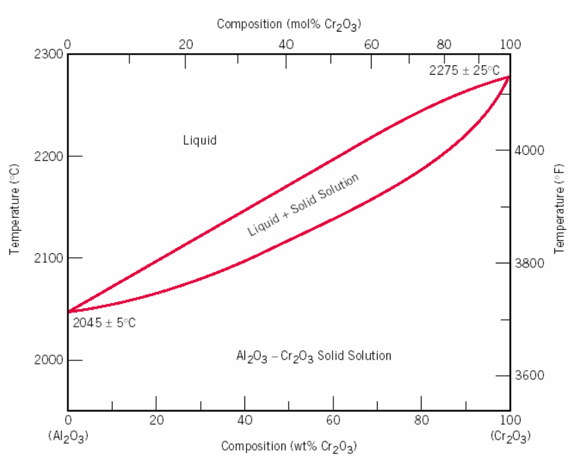
- Electrical conductivity
  - Region I: Schottky defects
    $E_a = E^{+}_{m} + 1/2(E_{+} + E_{-})$
  - Region II: Cation vacancies
    $E_a = E^{+}_{m}$
  - Region III: cation vacancies, impurity ions, clustering of defects



Effect of temperature on electrical conductivity of a NaCl crystal containing a small conc. of a divalent cation

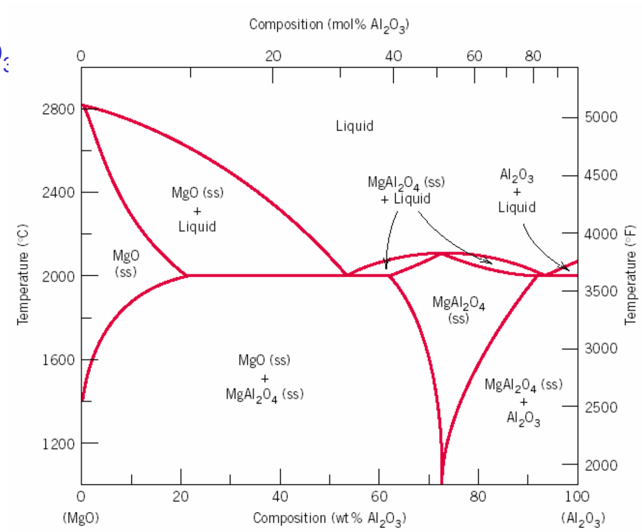
Ceramic phase diagram

- The Al_2O_3-Cr_2O_3 system
  - Isomorphous
  - In solid solution Al^{3+} substitute Cr^{3+}
  - Al and Cr should have have similar radius and same charge
  - Both Al_2O_3 and Cr_2O_3 have the same crystal structure



Ceramic phase diagram

- The Mg_2O-Al_2O_3 system
- Intermediate phase -- spinel compound

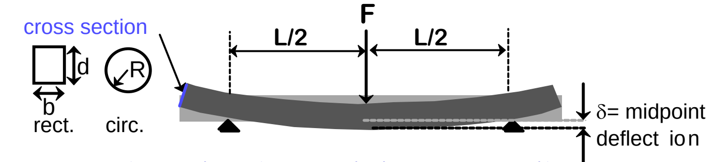


Stress-strain behavior

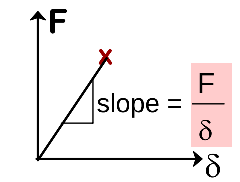
- Flectural testing replace tensile testing
- Reasons for not a standard tension test
  - difficult to prepare and test specimens having a required geometry
  - difficult to grip brittle materials without fracturing them
  - ceramics fail after only about 0.1% strain and samples are difficult to align without experiencing bending stress

Measuring elastic modulus

- Room T behavior is usually elastic, with brittle failure.
  3-Point Bend Testing often used.
- Tensile tests are difficult for brittle materials.



- Determine elastic modulus according to:



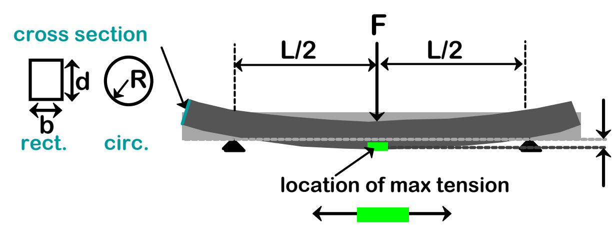
linear-elastic behavior

$$E = \frac{F}{\delta}\frac{L^3}{4bd^3} = \frac{F}{\delta}\frac{L^3}{12\pi R^4}$$

rect. cross section | circ. cross section

Measuring strength

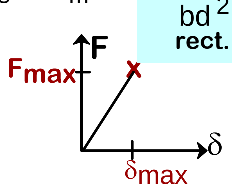
- 3-point bend test to measure room T strength.



- Flexural strength:

$$\sigma_{fs} = \sigma_m^{fail} = \frac{1.5F_{max}L}{bd^2} = \frac{F_{max}L}{\pi R^3}$$

rect.



- Typ. values:

Material	σ_{fs} (MPa)	E(GPa)
Si nitride	700-1000	300
Si carbide	550-860	430
Al oxide	275-550	390
glass (soda)	69	69

Data from Table 12.5, *Callister 6e.*

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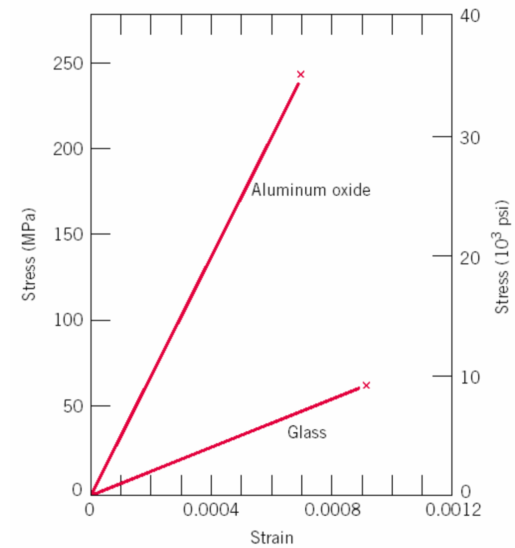
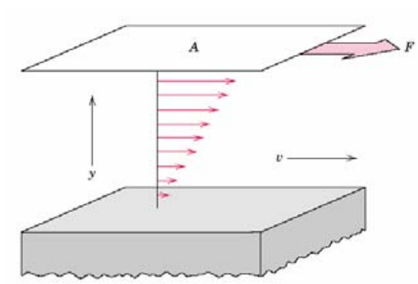
Elastic behavior

- Typical stress-strain behavior to fracture for aluminum oxide and glass



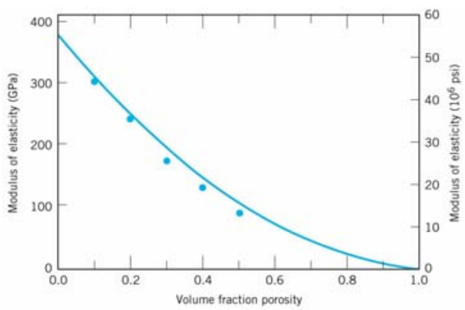
Mechanisms of plastic deformation

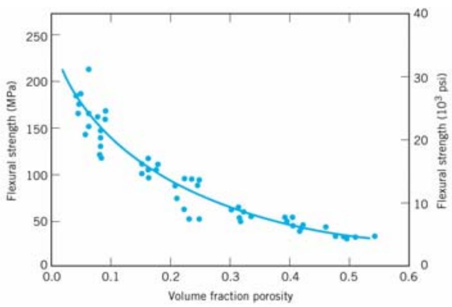
- Crystalline ceramics are brittle
  - Covalent bonds are relatively strong
  - There are limited numbers of slip systems
  - Dislocation structures are complex
- Noncrystalline ceramics
  - Plastic deformation does not occur by dislocation motion for noncrystalline ceramics
  - Viscosity is a measure of of non-crystalline material's resistance to deformation



Influence of porosity on mechanical behavior

- $E = E_0(1 - 1.9P + 0.9P^2)$
- $\sigma_{fs} = \sigma_0 \exp(-nP)$





Hardness

Table 13.6 Approximate Knoop Hardness (100 g load) for Seven Ceramic Materials

Material	*Approximate Knoop Hardness*
Diamond (carbon)	7000
Boron carbide (B_4C)	2800
Silicon carbide (SiC)	2500
Tungsten carbide (WC)	2100
Aluminum oxide (Al_2O_3)	2100
Quartz (SiO_2)	800
Glass	550

Summary

- **Ceramic materials have mostly ironic bonding& some covalent bonding.**
- **Defects**
  --must preserve charge neutrality
  --have a concentration that varies exponentially w/T.
- **Room T mechanical response is elastic, but fracture is brittle, with negligible ductility.**
- **Elevated T creep properties are generally superior to those of metals (and polymers).**