

## Chapter 20: Thermal Properties

Issues to address...

- How does a material respond to heat?
- How do we define and measure...
  - heat capacity
  - coefficient of thermal expansion
  - thermal conductivity
  - thermal shock resistance
- How do ceramics, metals, and polymers rank?

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## Heat Capacity

- General: The ability of a material to absorb heat
- Quantitative: Energy required to increase T

heat capacity:  $\frac{\text{J}}{\text{mol-K}}$  →  $C = \frac{dQ}{dT}$

energy:  $\frac{\text{J}}{\text{mol}}$  (points to dQ)

temperature change: K (points to dT)

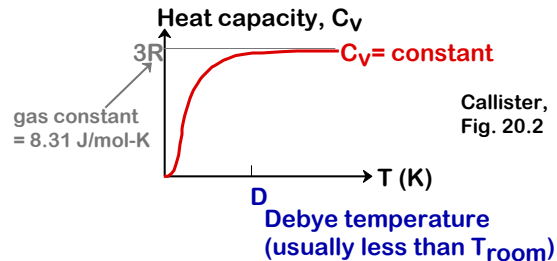
- Two ways to measure heat capacity:
  - $C_p$ : Heat capacity at constant pressure
  - $C_v$ : Heat capacity at constant volume

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## Heat Capacity vs T

- Heat capacity increases with temperature reaches a limiting value of  $3R$



- Atomic view: Energy is stored as atomic vibrations. As T goes up, so does avg. energy of atomic vibr.

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## Comparison: Heat Capacity Values

	$c_p$ (J/kg-K) at room temperature	$C_p$ : (J/mol-K)
• <b>Polymers</b>		
Polypropylene	1925	
Polyethylene	1850	
Polystyrene	1170	
Teflon	1050	
• <b>Ceramics</b>		
Magnesia (MgO)	940	
Alumina (Al <sub>2</sub> O <sub>3</sub> )	775	
Glass	840	
• <b>Metals</b>		
Aluminum	900	
Steel	486	
Tungsten	128	
Gold	138	

data from Callister, Table 20.1

Significantly larger for polymers: why?

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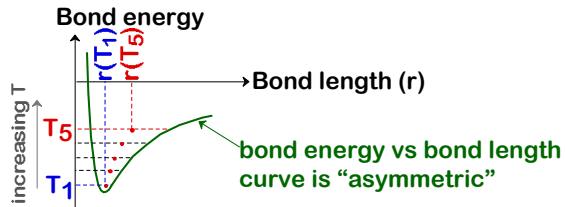
## Thermal Expansion

- Materials change size when heating

$$\frac{L_{\text{final}} - L_{\text{init}}}{L_{\text{init}}} = \alpha (T_{\text{final}} - T_{\text{init}})$$

coefficient of thermal expansion (1/K)

- Atomic View: Mean bond length increases with T



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## Comparison: Thermal Expansion Values

Material	$\alpha$ ( $10^{-6}/K$ ) at room temperature	Notes
<b>Polymers</b>		
Polypropylene	145-180	data from Callister, Table 20.1
Polyethylene	106-198	
Polystyrene	90-150	
Teflon	126-216	
<b>Metals</b>		Generally decreases with increasing bond energy
Aluminum	23.6	
Steel	12	
Tungsten	4.5	
Gold	14.2	
<b>Ceramics</b>		Why?
Magnesia (MgO)	13.5	
Alumina (Al <sub>2</sub> O <sub>3</sub> )	7.6	
Soda-lime glass	9	
Silica (cryst. SiO <sub>2</sub> )	0.4	

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## Thermal Conductivity

- General: The ability of a material to transfer heat
- Quantitative:

heat flux:  $\frac{J}{m^2 s}$

$$q = -k \frac{dT}{dx}$$

Temperature gradient (K/m)

thermal conductivity  $\frac{J}{m K s}$

- Atomic View: Atomic vibrations in hotter regions carry energy (vibrations) to cooler regions)

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## Comparison: Thermal Conductivities

Material	k (W/m-K)	Energy Transfer
<b>Metals</b>		By vibration of atoms and motion of electrons
Aluminum	247	
Steel	52	
Tungsten	178	
Gold	315	
<b>Ceramics</b>		data from Callister, Table 20.1
Magnesia (MgO)	38	By vibration of atoms
Alumina (Al <sub>2</sub> O <sub>3</sub> )	39	
Soda-lime glass	1.7	
Silica (cryst. SiO <sub>2</sub> )	1.4	
<b>Polymers</b>		By vibration/rotation of chain molecules
Polypropylene	0.12	
Polyethylene	0.46-0.50	
Polystyrene	0.13	
Teflon	0.25	

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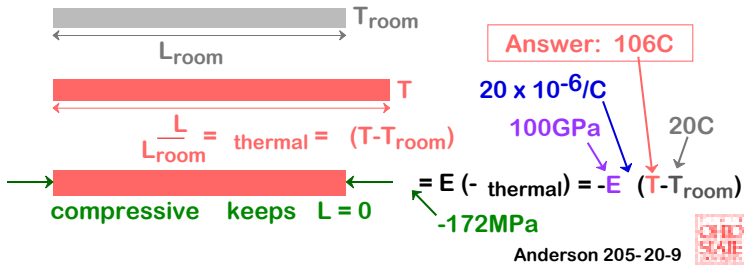
## Example: Thermal Stress

- Occurs due to:
  - uneven heating/cooling
  - mismatch in thermal expansion

### Example Problem 20.1

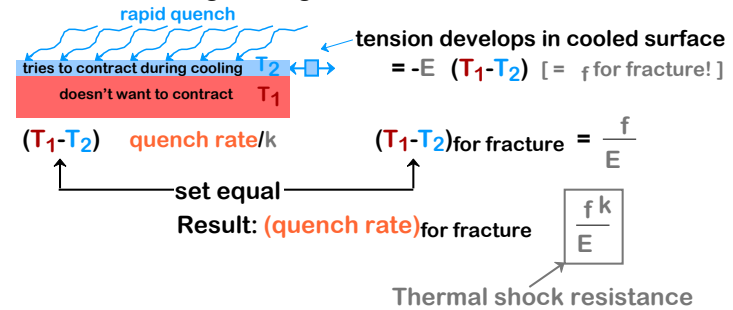
A brass rod is stress-free at room temperature (20C). It is heated up but prevented from lengthening.

At what T does the stress reach a compression of 172MPa?



## Thermal Shock Resistance

- Occurs due to:
  - uneven heating/cooling



- A large thermal shock resistance means a large quench rate is needed to fracture!

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## Thermal Protection System

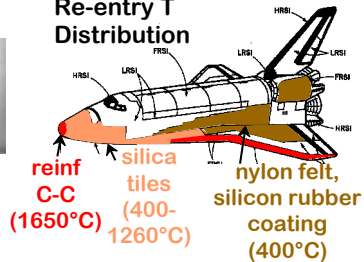
### Space Shuttle Orbiter



Fig. 23.0, Callister

### Re-entry T Distribution

Fig. 23.16, Callister



silica tiles (400- 1260°C)

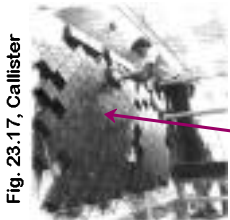
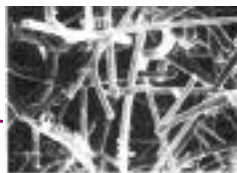


Fig. 23.17, Callister



~90% porous!  
 silica fibers w/aluminum borosilicate fibers (strength)

100µm

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