$$\eta = \frac{L - 2x}{\ell}$$

MSE 2034 – Gift 3
Equation Sheet

$$\overline{M_n} = \Sigma x_i M_i = \frac{\sum n_i M_i}{\sum n_i}$$

$$\overline{M_w} = \Sigma w_i M_i = \frac{\sum n_i M_i^2}{\sum n_i M_i}$$

$$DP_n = \frac{\overline{M_n}}{m}$$

$$\%\ crystallinity = \frac{\rho_c(\rho_s - \rho_a)}{\rho_s(\rho_c - \rho_a)} X\ 100$$

atomic weight of all anions

$$\rho = \frac{n\ A}{V_c\ N_A} \text{ — } (\Sigma A_c + \Sigma A_A)$$

sum of atomic weight of all cations

$$E_r(t) = \frac{\sigma(t)}{\varepsilon_o}$$ } relaxation modulus

$$L = Nd \sin\left(\frac{\theta}{2}\right)$$

$$r = d\sqrt{N}$$

$$E = E_o(1 - 1.9P + 0.9P^2)$$

$$P_M = P_{M_o} \exp\left\{-\frac{Q_p}{R\,T}\right\}$$

$$\sigma(t) = \sigma(0)\ exp\left(-\frac{t}{\tau}\right)$$

$$E_c(u) = E_m V_m + E_p V_p$$

$$E_c(l) = \frac{E_m E_p}{E_p V_m + E_m V_p}$$

$$l_c = \frac{\sigma_f^* d}{2\tau_c}$$

$$E_{cl} = E_m V_m + E_f V_f$$

$$\frac{F_F}{F_m} = \frac{E_f V_f}{E_m V_m}$$

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

$$\frac{1}{E_{ct}} = \frac{V_m}{E_m} + \frac{V_f}{E_f}$$

$$E_{ct} = \frac{E_m E_f}{E_m V_f + E_f V_m}$$

$$\sigma_{cl}^* = \sigma_m'(1 - V_f) + \sigma_f^* V_f$$

$$\sigma_{cd}^* = \sigma_f^* V_f\left(1 - \frac{l_c}{2l}\right) + \sigma_m'(1 - V_f)$$

$$\sigma_{cd'}^* = \frac{l\tau_c}{d} V_f + \sigma_m'(1 - V_f)$$

$$E_{cd} = E_m V_m + K E_f V_f$$

$$TS = TS_\infty - \frac{A}{\overline{M_n}}$$

$$\sigma_{fs} = \frac{3F_f L}{2bd^2} = \frac{F_f L}{\pi R^3}$$

Measurement of flexural strength

longitudinal modulus

Composite Data

Properties of Unreinforced (pure) and Reinforced Polycarbonates with <u>Randomly Oriented</u> E-Glass Fibers

$$\sigma_c = \sigma_m V_m + \sigma_f V_f$$

$$\varepsilon_c = \varepsilon_m = \varepsilon_f$$

isostrain

$$E_{cl} = E_m V_m + E_f V_f$$

comp — matrix — fiber

		Fiber Reinforcement (vol%)		
Property	***Unreinforced***	***20***	***30***	***40***
Specific gravity	1.19–1.22	1.35	1.43	1.52
Tensile strength [MPa]	59–62	110	131	159
Modulus of elasticity [GPa]	2.24–2.345	5.93	8.62	11.6
Elongation (%)	90–115	4–6	3–5	3–5
Impact strength, notched Izod (lb_f/in.)	12–16	2.0	2.0	2.5

Pure PC

Critical fiber length

$$\text{fiber length} > \frac{\sigma_f\, d}{2\ \tau_c}$$

σ_f = fiber UTS
d = fiber diameter
τ_c = shear strength of fiber matrix

Characteristics of Several Fiber-Reinforcement Materials

Material	***Specific Gravity***	***Tensile Strength [GPa]***	***Specific Strength (GPa)***	***Modulus of Elasticity [GPa]***	***Specific Modulus (GPa)***
Aluminum oxide	3.95	1.38	0.35	379	96
Aramid (Kevlar 49™)	1.44	3.6–4.1	2.5–2.85	131	91
Carbon	1.78–2.15	1.5–4.8	0.70–2.70	228–724	106–407
E-glass	2.58	3.45	1.34	72.5	28.1
Boron	2.57	3.6	1.40	400	156
Silicon carbide	3.0	3.9	1.30	400	133
UHMWPE (Spectra 900™)	0.97	2.6	2.68	117	121

$$\frac{1}{E_{ct}} = \frac{V_m}{E_m} + \frac{V_f}{E_f}$$

$$E_{ct} = \frac{E_m E_f}{V_m E_f + V_f E_m}$$

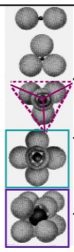
fiber
matrix
composite

$$\varepsilon_c = \varepsilon_m V_m + \varepsilon_f V_f$$

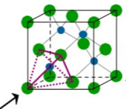
- Coordination Number increases with $\frac{r_{cation}}{r_{anion}}$

To form a stable structure, how many anions can surround around a cation?

r_{cation}/r_{anion}	Coord. Number	
< 0.155	2	linear
0.155 - 0.225	3	triangular
0.225 - 0.414	4	tetrahedral
0.414 - 0.732	6	octahedral
0.732 - 1.0	8	cubic

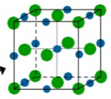


Adapted from Table 12.2, Callister & Rethwisch 10e.



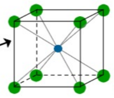
ZnS (zinc blende)

Adapted from Fig. 12.4, Callister & Rethwisch 10e



NaCl (sodium chloride)

Adapted from Fig. 12.2, Callister & Rethwisch 10e.



CsCl (cesium chloride)

Adapted from Fig. 12.3, Callister & Rethwisch 10e.

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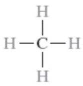
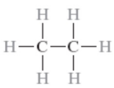
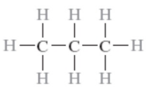
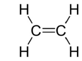
Table 14.1 Compositions and Molecular Structures for Some of the Paraffin Compounds: C_nH_{2n+2}

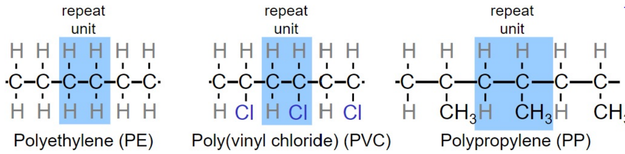
Name	*Composition*	*Structure*	*Boiling Point (°C)*
Methane	CH_4		−164
Ethane	C_2H_6		−88.6
Propane	C_3H_8		−42.1
Butane	C_4H_{10}		−0.5
Pentane	C_5H_{12}		36.1
Hexane	C_6H_{14}		69.0

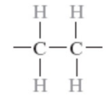
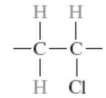
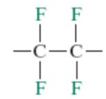
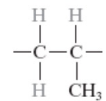
- Frenkel Defect
  -- a cation vacancy-cation interstitial pair.
- Shottky Defect
  -- a paired set of cation and anion vacancies.

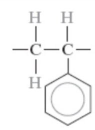
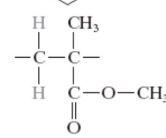
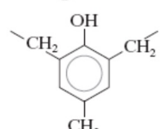
– Double bond found in ethylene or ethene - C_2H_4

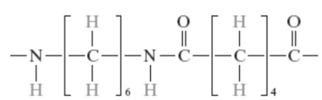
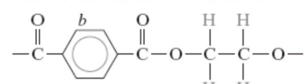
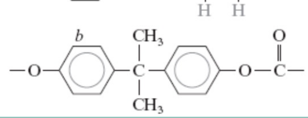


– Triple bond found in acetylene or ethyne - C_2H_2



Polymer	*Repeat Unit*
Polyethylene (PE)	
Poly(vinyl chloride) (PVC)	
Polytetrafluoroethylene (PTFE)	
Polypropylene (PP)	

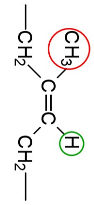
Polymer	*Repeat Unit*
Polystyrene (PS)	
Poly(methyl methacrylate) (PMMA)	
Phenol-formaldehyde (Bakelite)	

Polymer	*Repeat Unit*
Poly(hexamethylene adipamide) (nylon 6,6)	
Poly(ethylene terephthalate) (PET, a polyester)	
Polycarbonate (PC)	

cis

cis-isoprene (natural rubber)

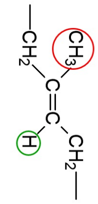
H atom and CH_3 group on same side of chain



trans

trans-isoprene (gutta percha)

H atom and CH_3 group on opposite sides of chain



- Estimate of σ'_{cd} for discontinuous fibers:

1. When $l > l_c$

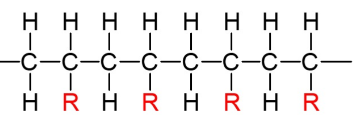
$$\sigma'_{cd} = \sigma'_f V_f \left(1 - \frac{l_c}{2l}\right) + \sigma'_m (1 - V_f)$$

2. When $l < l_c$

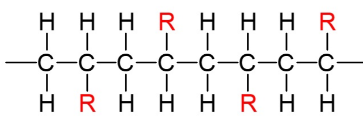
$$\sigma'_{cd} = \frac{l \tau_c}{d} V_f + \sigma'_m (1 - V_f)$$

Tacticity – stereoregularity or spatial arrangement of R units along chain

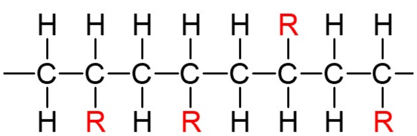
isotactic – all R groups on same side of chain



syndiotactic – R groups alternate sides



atactic – R groups randomly positioned



Composite ...

Particle-reinforced   Fiber-reinforced

Estimate of E_{cd} for discontinuous fibers:

-- valid when fiber length < $15\frac{\sigma_f d}{\tau_c}$

-- Elastic modulus in fiber direction:

$$E_{cd} = E_m V_m + K E_f V_f$$

efficiency factor:

-- aligned: $K = 1$ (aligned parallel)
-- aligned: $K = 0$ (aligned perpendicular)
-- random 2D: $K = 3/8$ (2D isotropy)
-- random 3D: $K = 1/5$ (3D isotropy)

- Matrix phase:
  -- Purposes are to:
  - transfer stress to dispersed phase
  - protect dispersed phase from environment

  -- Types: MMC, CMC, PMC

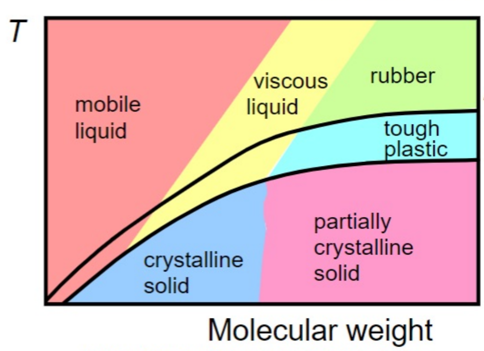
  metal ceramic polymer

- Dispersed phase:
  -- Purpose:
  MMC: increase σ_y, TS, creep resist.
  CMC: increase K_{Ic}
  PMC: increase E, σ_y, TS, creep resist.

  -- Types: particle, fiber, structural

- Thermoplastics:
  -- little crosslinking
  -- ductile
  -- soften w/heating
  -- polyethylene
  polypropylene
  polycarbonate
  polystyrene

- Thermosets:
  -- significant crosslinking
  (10 to 50% of repeat units)
  -- hard and brittle
  -- do NOT soften w/heating
  -- vulcanized rubber, epoxies,
  polyester resin, phenolic resin



Adapted from Fig. 15.19, Callister & Rethwisch 10e.
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