Tutorial 5

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Land Acknowledgment

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I wish to acknoledge this land on which the University of Toronto operates. For thousands of years it has been the traditional land of the Huron-Wendat, the Seneca, and most recently the Mississaugas of the Credit River. Today, this meeting place is still the home of many Indigenous people from across Turtle Island and we are grateful to have the opportunity to work on this land.

Health Resources

- Health & Wellness Peer Support Service
  - Chat with a trained UofT student peer
  - In person or virtual
    - Robarts Library, Room 1152
    - Engineering and Computer Science Library, Room 2402C
  - 11 a.m. to 4 p.m., Wednesdays to Fridays
  - More info: https://studentlife.utoronto.ca/service/peer-support/

Anouncements

- The next quiz will be taking place this Friday (October 21st)
  - Grades can be expected by Sunday or Monday
- Problem Set 2 will be posted soon (Hopefully Monday)
- Grades for Problem Set 1 will be posted as soon as they are done being graded
- No tutorials next week because of term test

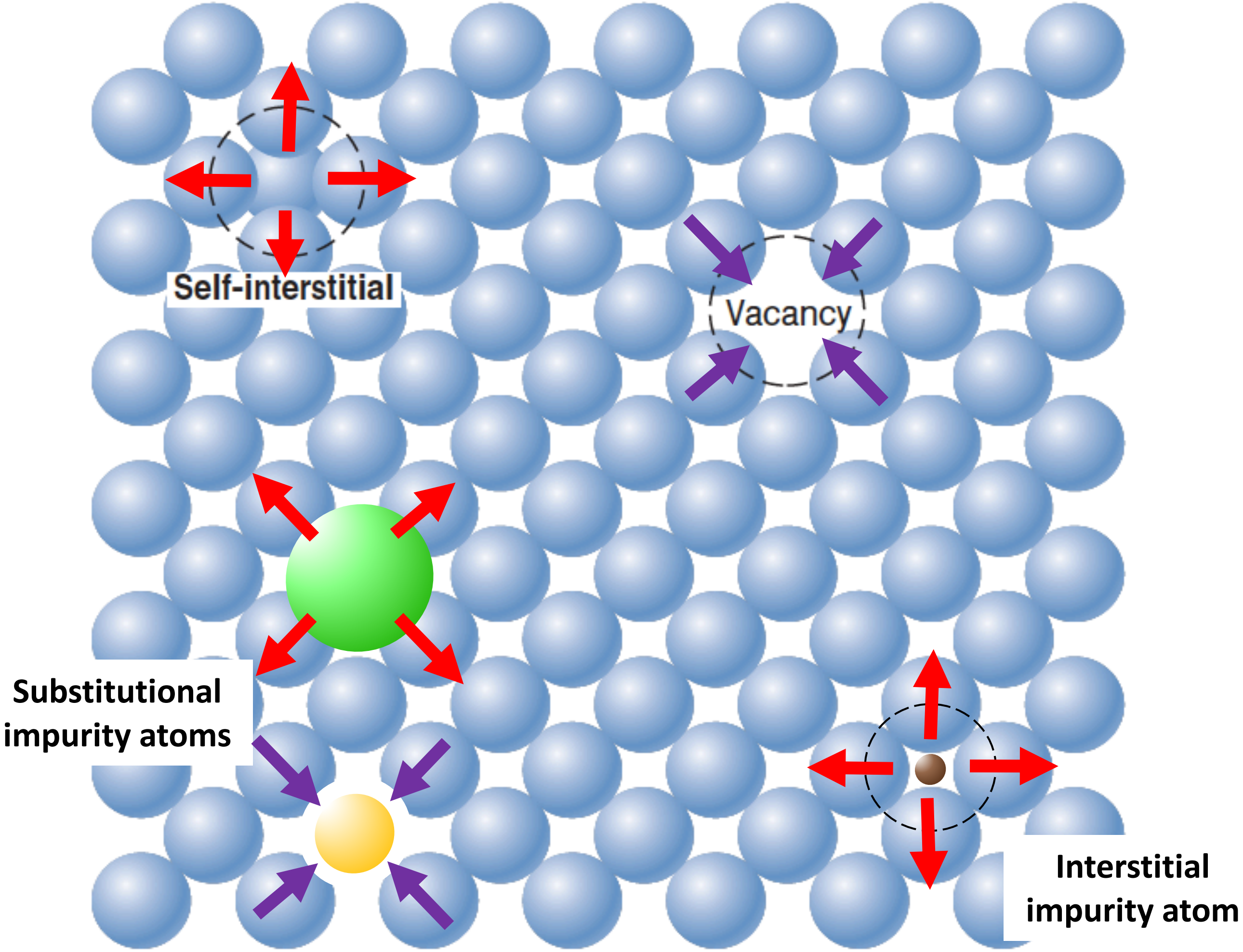
Theory Review

- Defects in crystals
  - 0D: point defects
  - 1D: dislocations
  - 2D: interfaces
  - 3D: other phases

- Why they exist?
  - Entropy
  - Metastability

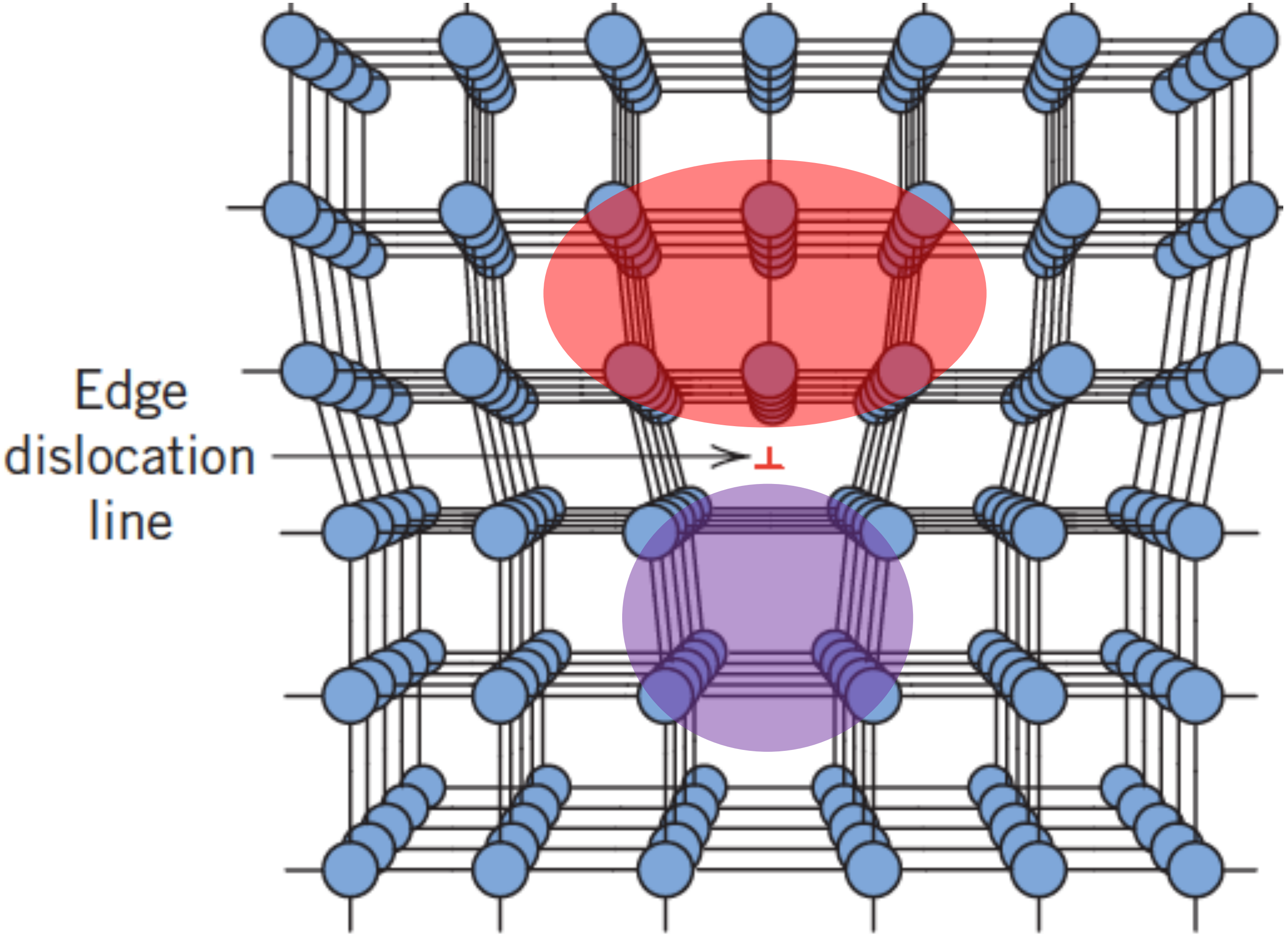
Theory Review

- 0D Defects
  - Substitutional or interstitial
  - Same atom or impurity
  - Vacancies
    - $\frac{N_V}{N} = e^{\frac{-Q_V}{kT}}$
      - N_V: number of vacancies
      - N: number of sites
      - Q_V: vacancy formation energy [eV]
      - k: Boltzmann's constant
        - $k = 8.62 \times 10^{-5}$ eV/K
      - T: temperature [K]
  - Residual stresses:
    - Compression
    - Tension



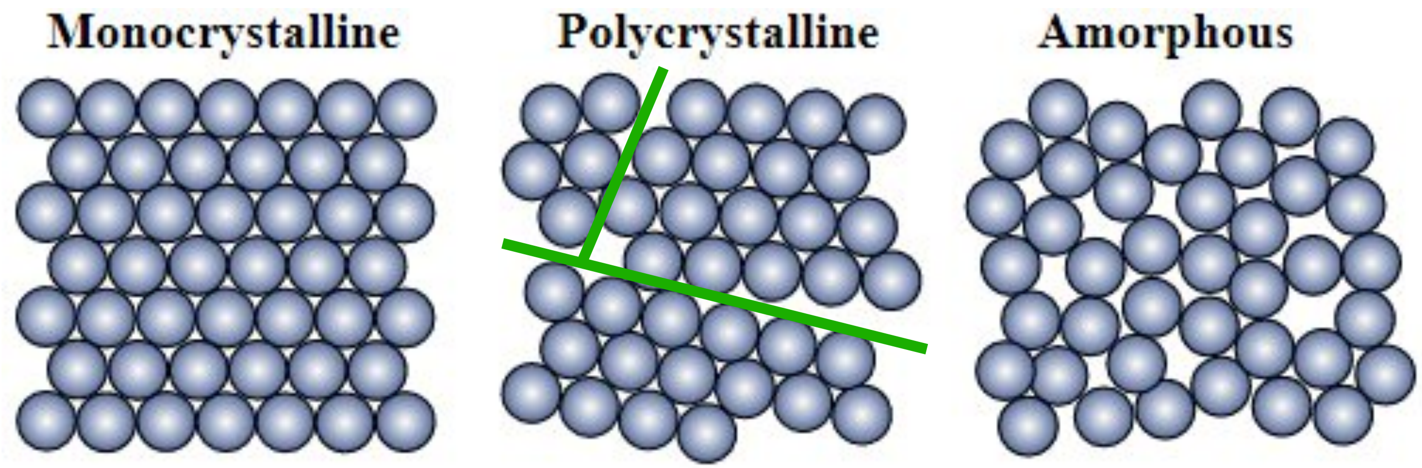
Theory Review

- 1D Defects
  - Dislocations
  - Residual stresses:
    - Compression
    - Tension



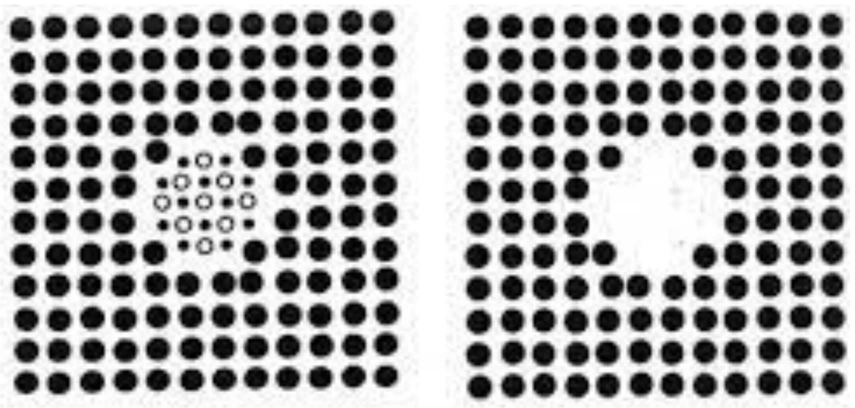
Theory Review

- 2D Defects
  - **Grain boundaries**
    - Inhibits dislocation movement
  - Free surfaces



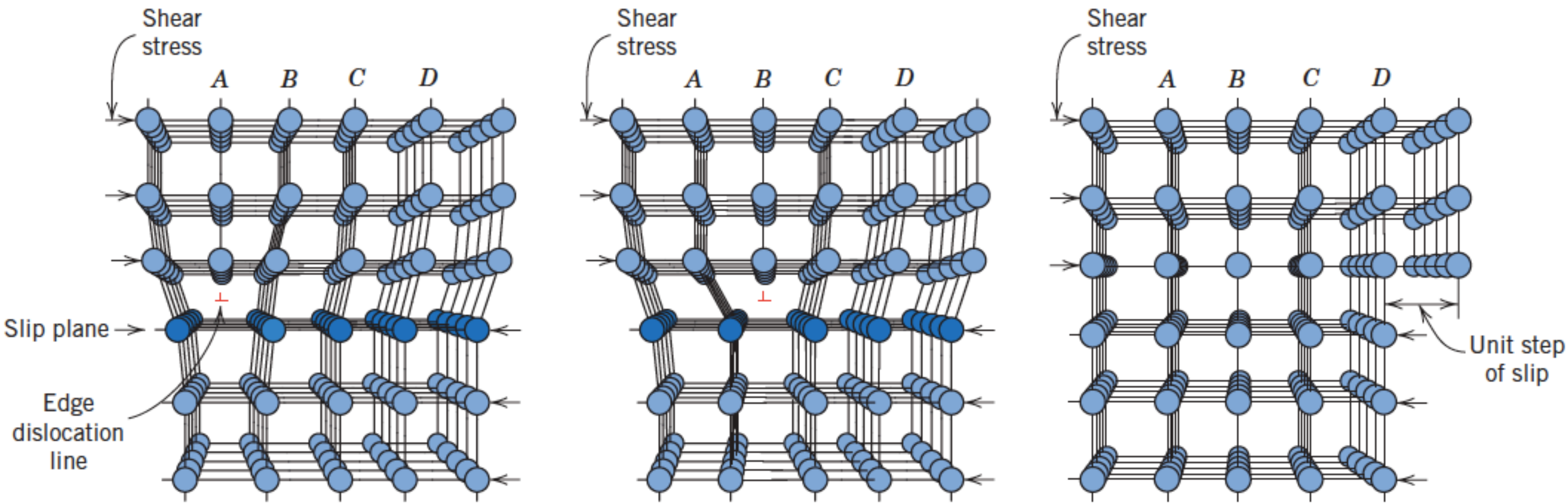
(single grain) (multiple grains) (no long-range order)

- 3D Defects
  - Second phases
  - Voids



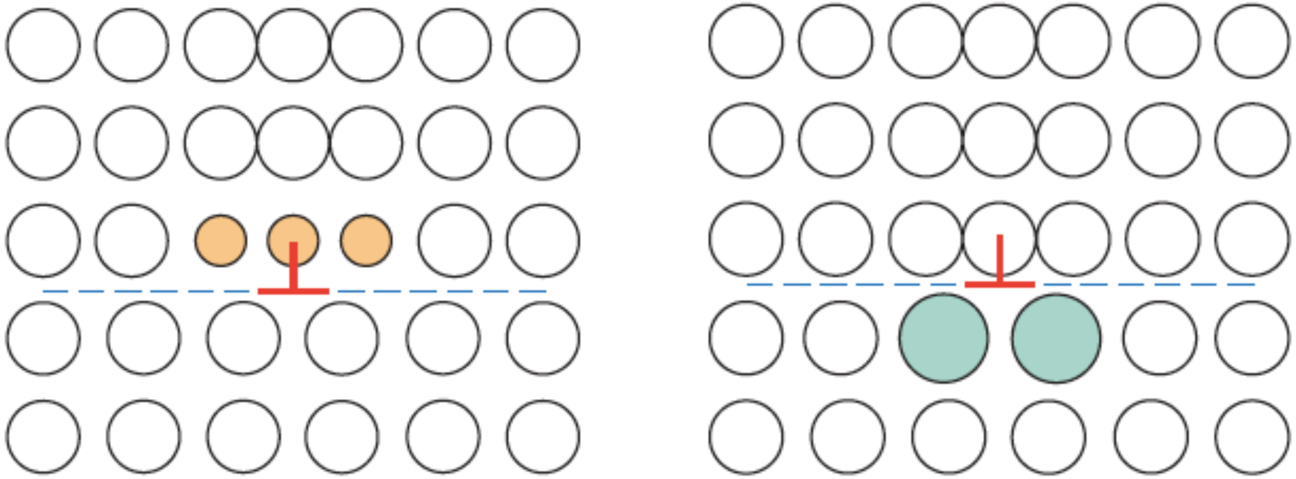
Theory Review

- The real mechanism of plastic deformation: dislocation movement



Theory Review

- Strengthening a metal
  - Make dislocation movement harder
    - **Strain Hardening**: creates new dislocations and they repel or anihilate one another
    - **Grain size reduction**: creates new grain boundaries
    - **Solid solution**: adds impurities which stabilize dislocations (fig below)



Theory Review

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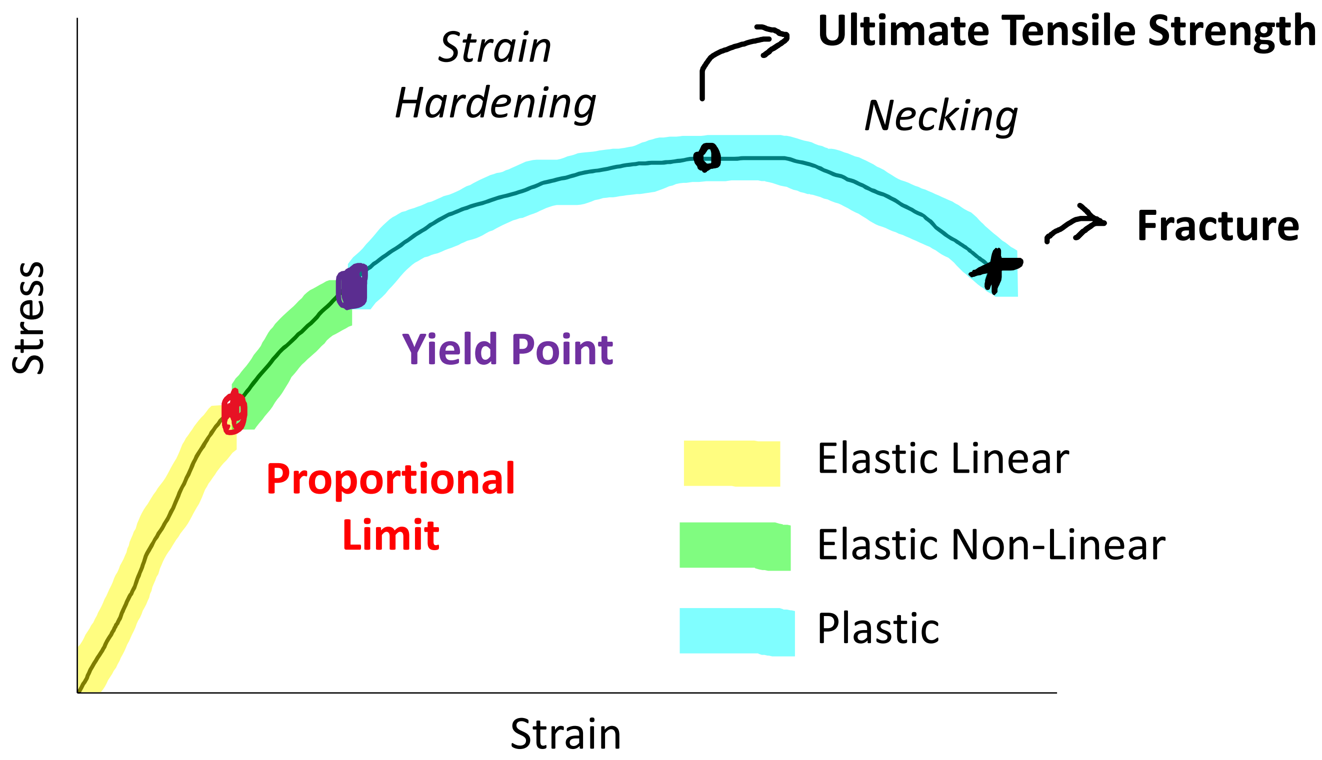
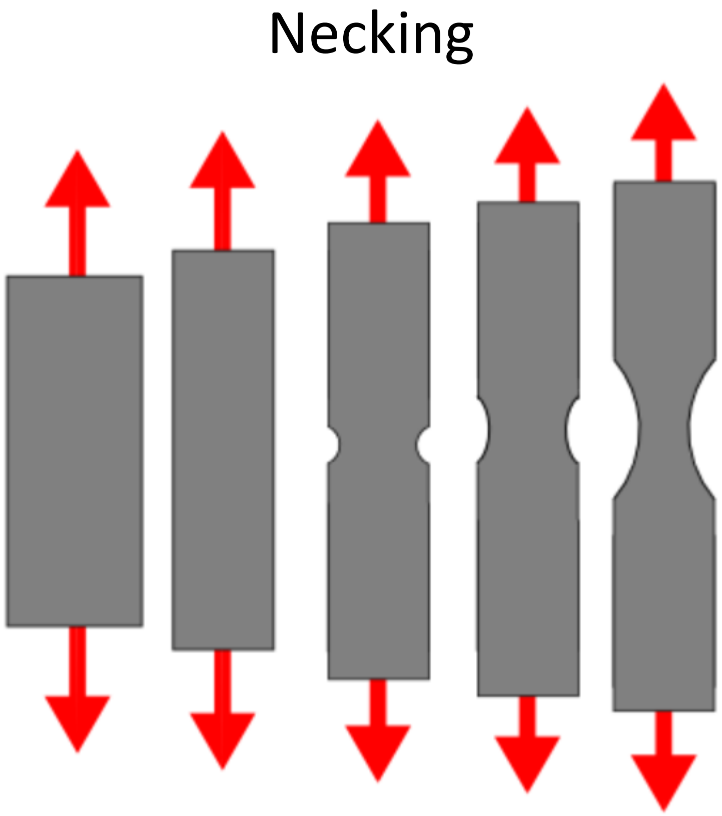
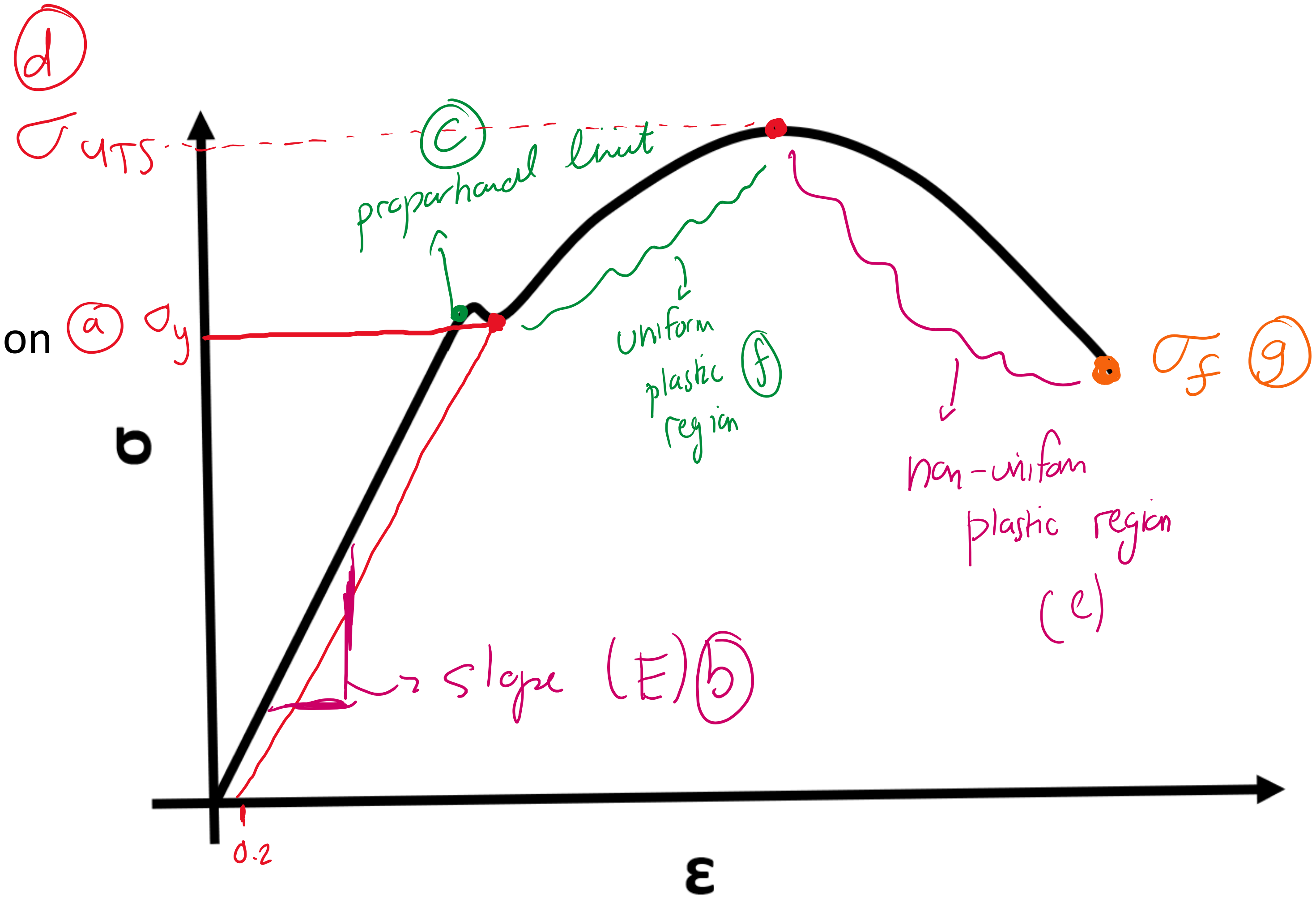
- The stress-strain curve revisited





Sample Problems

1. On the generalized stress and strain curve for a typical metal as presented below, clearly identify each of the following characteristic:
   a. 0.2% offset yield strength
   b. Young's modulus
   c. Proportional limit
   d. Ultimate tensile strength
   e. Region of non-uniform plastic deformation
   f. Region of uniform plastic deformation
   g. Fracture strength



Sample Problems

2) Below is the same stress-strain curve given in the problem set. Assume now that the behaviour below is for a sample with a cross-sectional width and depth of 19 mm by 3.2mm and 610mm long. Determine the following when a force of 110kN is applied onto a steel sample with a Young's modulus of 207 GPa.

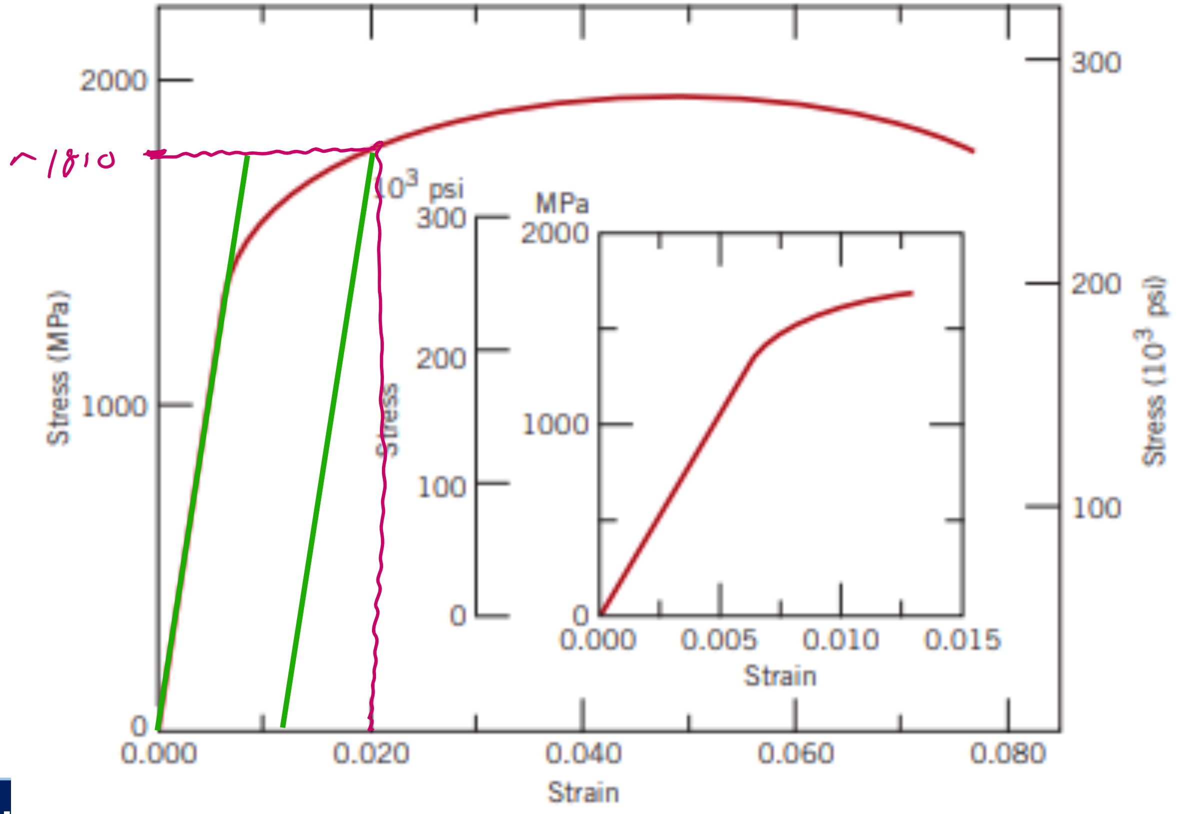
a. Total, elastic and plastic strain
b. Final sample length after unloading

a)

$$\sigma = F/A_0 = F/bd$$

$$= \frac{110{,}000\,N}{(19\times10^{-3}\,m)(3.2\times10^{-3}\,m)} = 1810\,MPa$$

$$\varepsilon_t = 0.020$$



Sample Problems

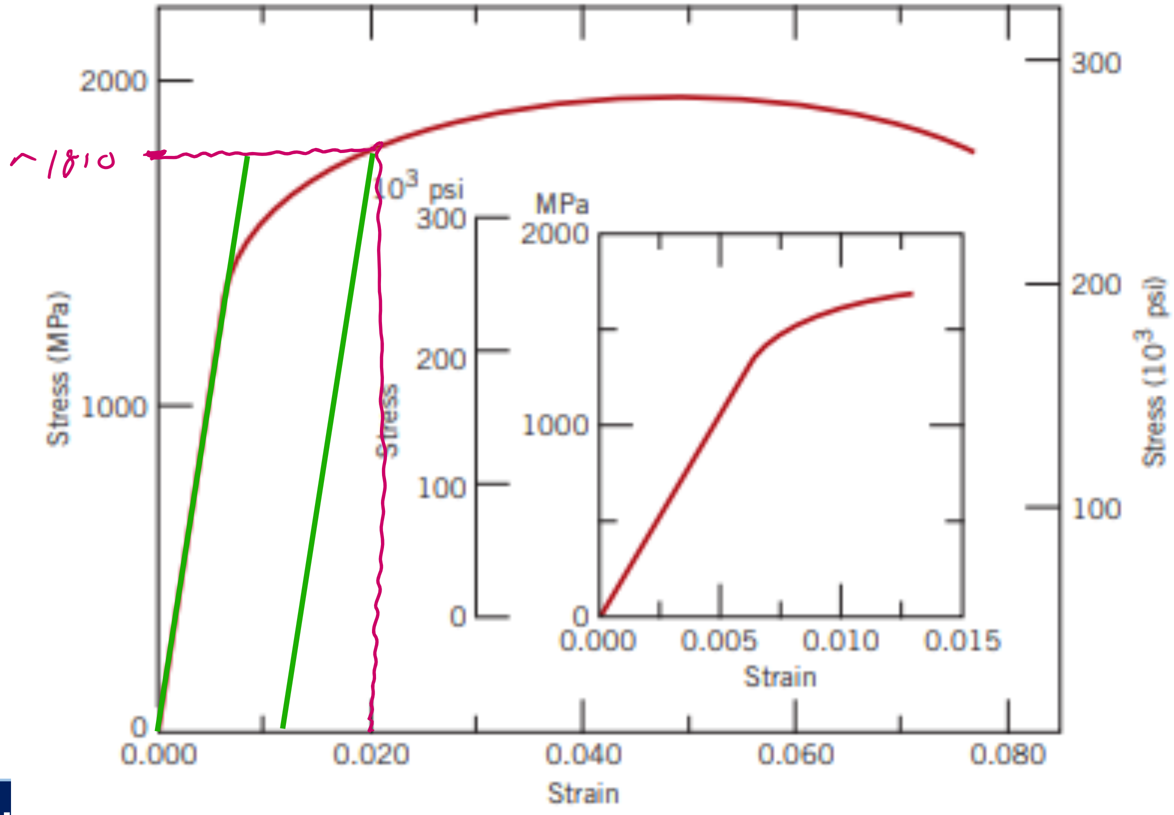
$$\varepsilon_e = \sigma / E = \frac{1810 \text{ MPa}}{207 \text{ GPa}} = 0.0087$$

$$\therefore \varepsilon_p = \varepsilon_t - \varepsilon_e = 0.0113$$

b) $l_f = l_0 (1 + \varepsilon_p)$

$= 610 \text{ mm} (1 + 0.0113)$

$= 616.7 \text{ mm}$



Sample Problems

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3. (a) Calculate the fraction of atom sites that are vacant for copper (Cu) at its melting temperature of 1084°C. Assume an energy for vacancy formation of 0.90 eV/atom.

$$\frac{N_v}{N} = \exp\left(\frac{-Q_v}{kT}\right)$$

$$= \exp\left[-0.90\,\text{eV/atom} / 8.62\times10^{-5} \cdot 1357\right]$$

$$= 4.56\times10^{-4}$$

(b) Repeat this calculation at room temperature (25°C). What is the ratio of N_V/N at the melting temperature vs. room temperature?

$$\frac{N_v}{N} = \exp\left(\frac{-Q_v}{kT}\right)$$

$$= \exp\left[\frac{-0.9}{8.62\times10^{-5} \cdot 298}\right]$$

$$= 6.079\times10^{-16}$$

Quizz (not graded)

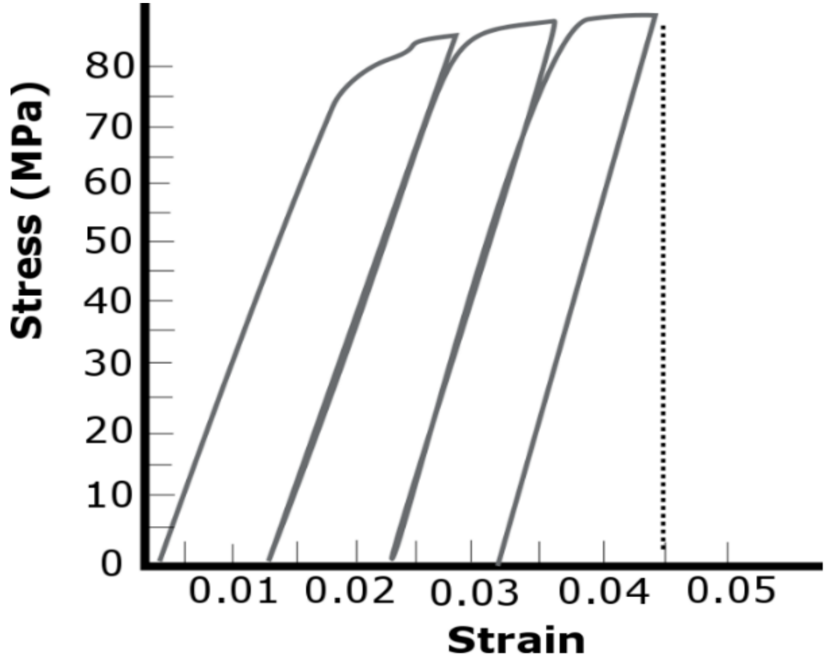
1. The Young's modulus is related to which of the following?
    a. The slope of the interatomic force separation curve taken at the equilibrium interatomic spacing
    b. The slope of the interatomic energy separation curve taken at the equilibrium interatomic spacing Region between the ultimate tensile strength and fracture
    c. The slope of the interatomic force separation curve taken at r=0
    d. Both a) and c)

2. Which of the following most closely describes the beginning of non-uniform plastic deformation in a metallic sample?
    a. The proportional limit
    b. The 0.2% offset yield strength
    c. The ultimate tensile strength
    d. None of the above

Quizz (not graded)

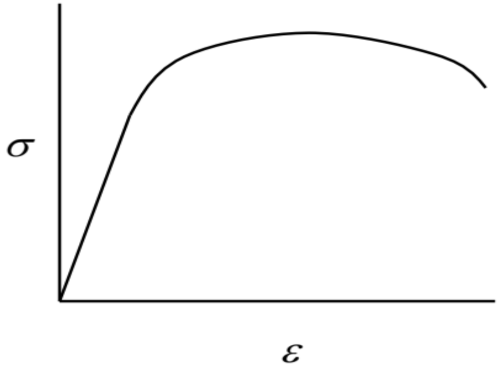
3. In the following tensile testing results (fig top right), what is the final plastic strain experienced by the sample?

   a. 0.045 b. 0.032
   c. 90 MPa d. 0.013



4. A metallic sample is loaded in tension and exhibits the stress-strain behaviour shown in the figure (bottom right). Which of the following is the best description of why the sample failed at the location where the neck first formed?

   a. Because the neck always forms in the middle of the reduced section.
   b. Because the metal got weaker when it necked.
   c. Because the metal did not strengthen fast enough to account for the local decrease in cross-sectional area.
   d. Because the metal got weaker and the cross-sectional area decreased.



Quizz (not graded)

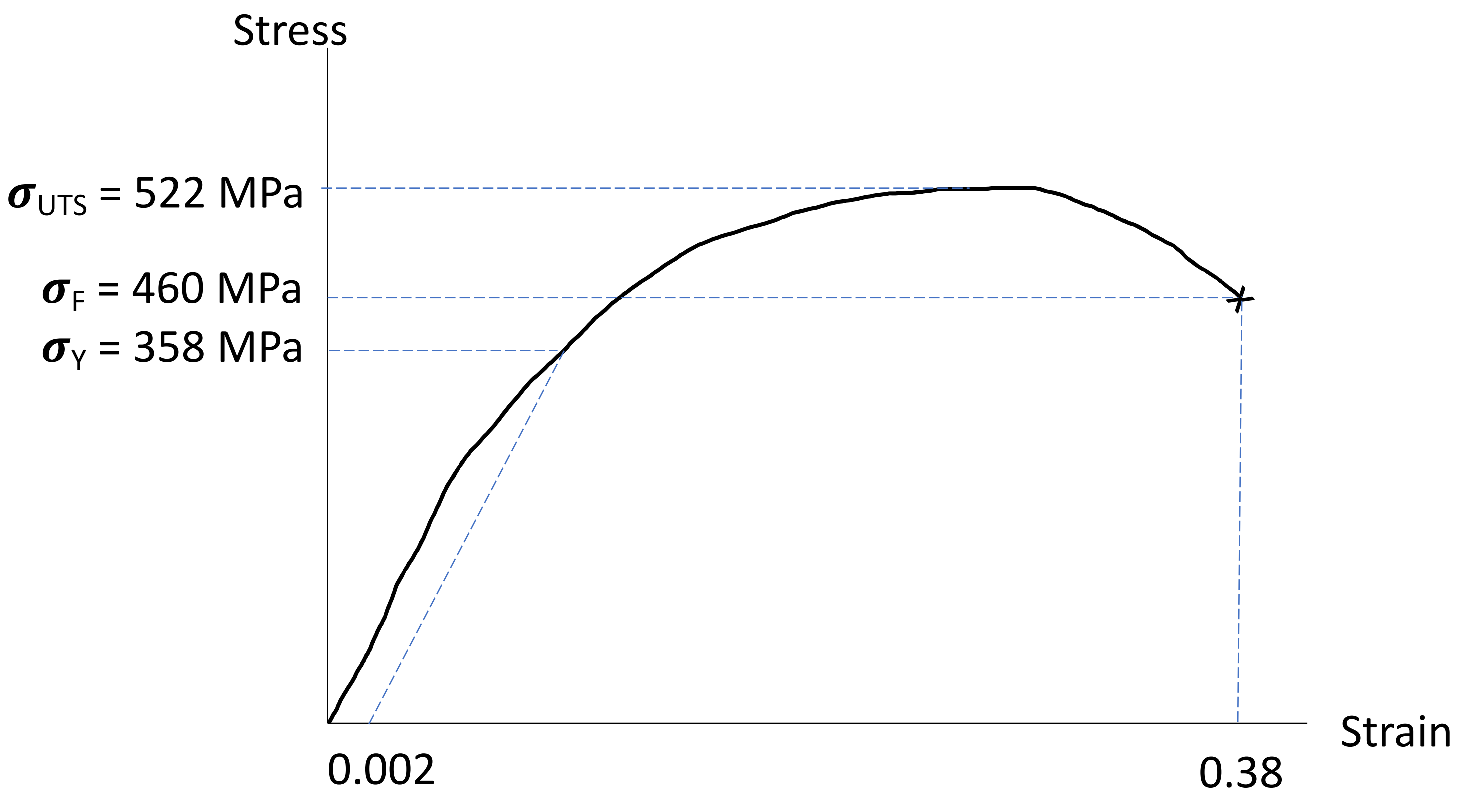
5. Which of the following best describes the Boltzmann distribution for a system at infinitely high temperature?
   a. The particles occupy only the highest energy state.
   b. The particles occupy a distribution that peaks at the highest energy state and trails off towards the lower energy states.
   c. The particles are distributed evenly across all of the possible energy states.
   d. The particles occupy only the lowest energy state.

6. A hypothetical metal has a 0.2% offset yield strength of 358 MPa, an ultimate tensile strength of 522 MPa, and a fracture strength of 460 MPa at a fracture strain of 0.38
   a. Sketch the stress-strain curve based on the provided information
   b. A sample of this metal, originally 1m in length with a cross section of 2 mm x 2 mm is loaded along its long axis. Just before fracture, while the load is still applied, the length is 1.3m and when the load is released, the length is 1.18m. Calculate the modulus of elasticity in GPa.

Quizz (not graded) – Solutions

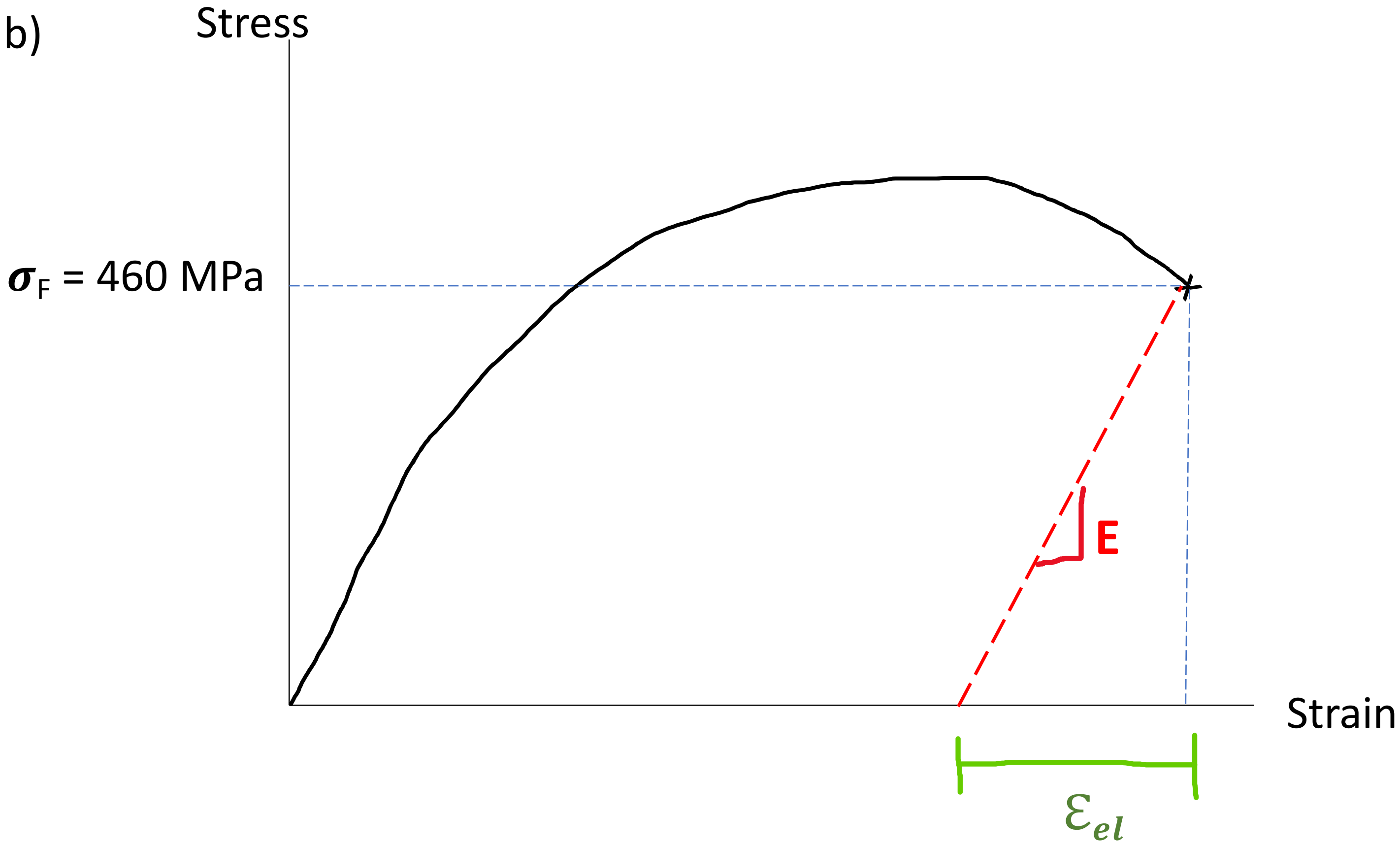
1. A
2. C
3. B
4. C
5. C

6. a)



Quizz (not graded) – Solutions

6. b)



$$E = \frac{\boldsymbol{\sigma}_F}{\mathcal{E}_{el}}$$

$$\mathcal{E}_{el} = \frac{1.3 - 1.18}{1}$$

$$E = 3.8\ GPa$$