MSE160 [Winter 2023] – Problem Set # 2

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Problem 1 –

Define the following terms and label them on a stress-strain curve: proportional limit, ultimate tensile strength (UTS), Yield Strength, linear elastic region. (8 pts)

Definitions of Terms:

Proportional Limit: The proportional limit corresponds to the region of the largest stress where the stress is proportional to the strain on the engineering stress-strain curve. Specifically, it marks the end of the linear elastic region after which material begins to non-linearly plastically deform.

Ultimate Tensile Strength (UTS): The ultimate tensile strength is the maximum stress that a material can withstand before fracturing while being stretched or pulled. This can be observed as the peak of the engineering stress-strain curve.

Yield Strength: The yield strength is a material property that describes a point on the engineering stress-strain curve where the material begins to deform plastically and for metallic stress-strain this also corresponds to the point where the behavior will stop being linearly proportional. To standardize the process of determining the yield strength, the convention of 0.2 % offset yield strength is utilized.

Linear Elastic Region: Linear elastic region is a region on the graph where the stress and strain have a linear proportional relationship defined by the slope, E, the young's modulus. This region lies from the beginning of the stress-strain curve to the proportional limit. It signifies the region of stress and strain where the material can be deformed and can return to its original configuration.

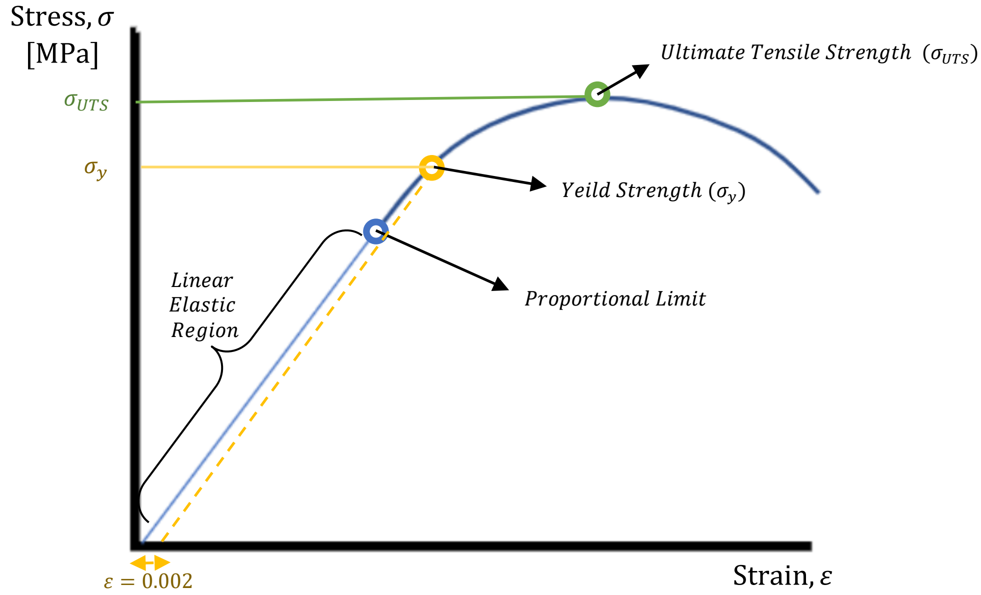


Figure 1: Annotated Stress-Strain Curve

Problem 2 –

Define the terms found in the Arrhenius equation. What does this equation tell us about the relationship between temperature and vacancies? (2 pts)

The Arrhenius equation is given by:

$$N_v = N \mathrm{e}^{\frac{-Q_v}{k\mathrm{T}}}$$

where N_v = **The number of vacancies in a crystal**

N = The Total Number of Atoms

k = Boltzmann's Constant $(1.380649 \times 10^{-23}\ m^2\ kg\ s^{-2}\ K^{-1})$ *(The Boltzmann's constant, k, is a fundamental physical constant that describes the average kinetic energy of a gas with its thermodynamic temperature.)*

T = Absolute Temperature (K) *(Absolute temperature, T, is the temperature measured on a kelvin scale.)*

$\boldsymbol{Q_v}$ **= Activation Energy for vacancy formation**

<u>How does the equation describe the relationship between temperature and vacancies?</u>

By taking the logarithm of the equation above:

$$\log N_v = \log N \mathrm{e}^{\frac{-Q_v}{k\mathrm{T}}}$$

$$\log N_v = \log N + \log \mathrm{e}^{\frac{-Q_v}{k\mathrm{T}}} = \log N - \frac{Q_v}{k\mathrm{T}}$$

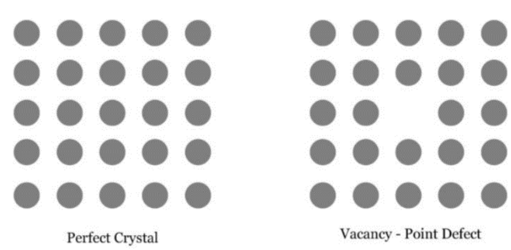
Using a rearranged form of the relationship defined by the Arrhenius equation we know that as temperature increases, the number of vacancies increase in crystal sample increase. This is because a larger temperature signifies a small $\frac{-Q_v}{k\mathrm{T}}$ term assuming all other factors/variables are constant. As a result, it means that higher temperature produce higher vacancies and lower temperature produce lower number of vacancies.

Problem 3 –

In a maximum of two sentences (for each term), define the following and provide an example of each: zero-dimensional defects, one-dimensional defects, two-dimensional defects, and three-dimensional defects. (4 pts)

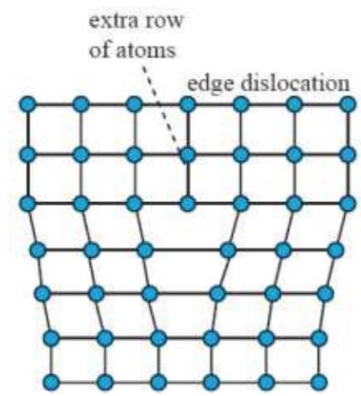
- **Zero-dimensional defects**: The term zero-dimensional defects describes point defects (e.g. vacancies, interstitial and substitutional impurities). A point defect usually occurs when one or more atoms of a crystalline solid leave their original lattice position/site and/or foreign atoms occupy the interstitial sites of crystal.

  Example of a zero-dimensional defect: A **vacancy** is produced when an atom is missing from the original lattice site, creating an empty lattice site – see figure on the right.



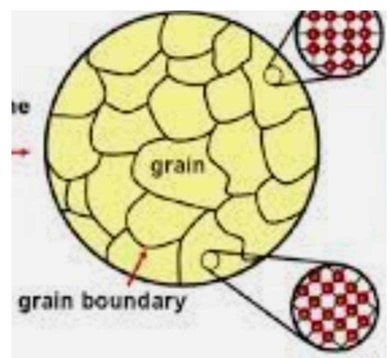
- **One-dimensional defects:** The term one-dimensional defect (also known as a linear defect) describes dislocations which constitutes lines across which the crystallographic registry is not preserved (or is lost). This can be of either edge dislocation or screw dislocation.

  Example of a one-dimensional defect: An **edge dislocation** occurs when a half plan of atoms are introduced midway inside a crystal which as a result distorts the planes of nearby atoms.



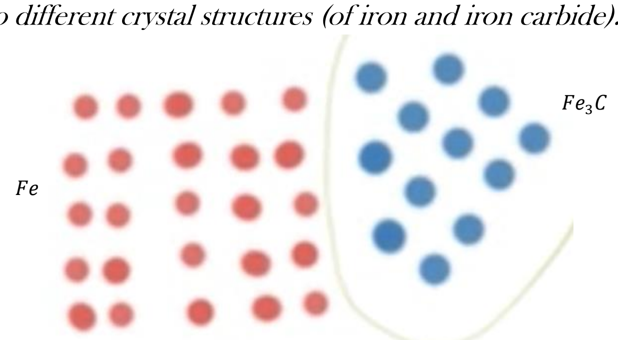
- **Two-dimensional defects:** Two-dimensional defects are interfacial imperfections, that occur on free surfaces and interfaces. These occur typically where distinct crystallites are joined together for example at grain boundaries typically differing by orientation.

  Example of a two-dimensional defect: A **grain boundary** is an example of a two-dimensional imperfection which describes the region where two crystals are in contact. It is a planar defect which differs by orientation of the crystals. Typically occur on metal cans.



- **Three-dimensional defects:** Three-dimensional defect is simply a second phase in solid or pores (i.e voids) or precipitates. It occurs when a region of solid has a different crystal structure or volume comprising a different component.

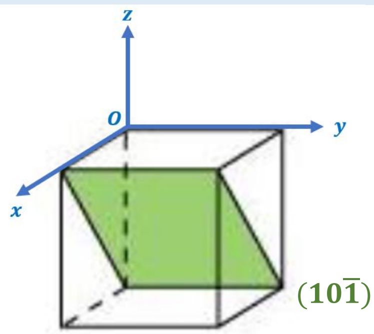
  *Example of a three-dimensional defect: And example would be a **second-phase** of iron carbide in steel. Herein there are two different crystal structures (of iron and iron carbide).*



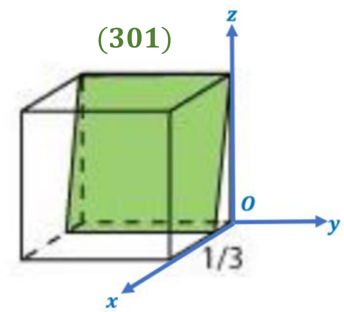
Problem 4 –

Determine the miller indices of the planes shown in the following figures. (8 pts)

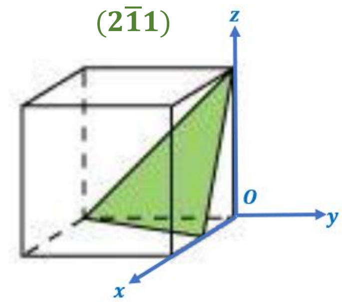
Part A



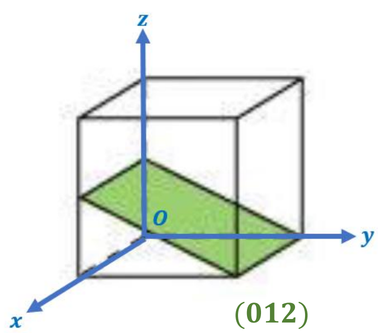
Part B



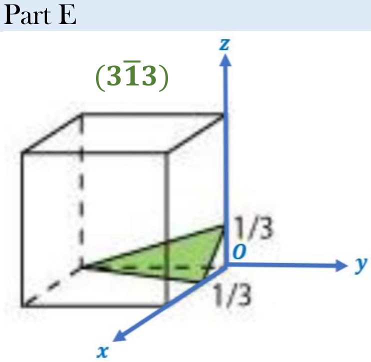
Part C



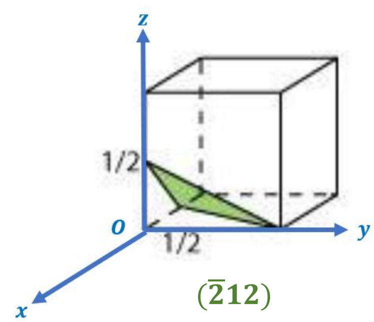
Part D



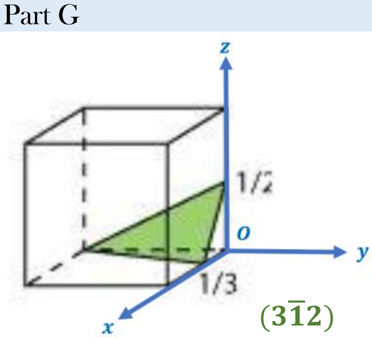
Part E



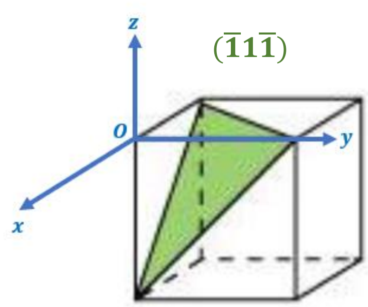
Part F

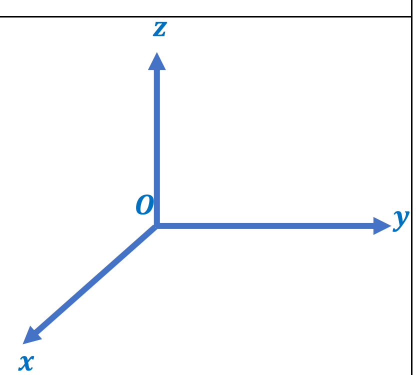


Part G



Part H





Problem 5 –

A beam of X-rays of wavelength 0.074 nm is diffracted by (110) plane of rock salt with lattice constant of 0.28 nm. Find angle of incidence for the x-rays (θ) for a second-order reflection (4pts)

The given Plane (hkl) = (110)

Because a rock salt is an FCC, we can determine the interplanar spacing, d, using the following formula:

$$d_{110} = \frac{a}{\sqrt{h^2 + k^2 + l^2}} = \frac{0.28\,nm}{\sqrt{1^2 + 1^2 + 0^1}} = \frac{0.28\,nm}{\sqrt{2}}$$

Using Braggs law, it is known that:

$$n\lambda = 2d_{hkl}\sin\theta$$

Since it is a second-order reflection, the value of the integer n = 2.

The wavelength of the beam of X-ray is given: 0.074 nm. Hence this equation can be rewritten as:

$$0.074\ [nm] = d_{110}\sin\theta$$

$$0.074 = \frac{0.28}{\sqrt{2}}\sin\theta$$

Rearranging the equation for Sin θ, where θ is the angle of incidence:

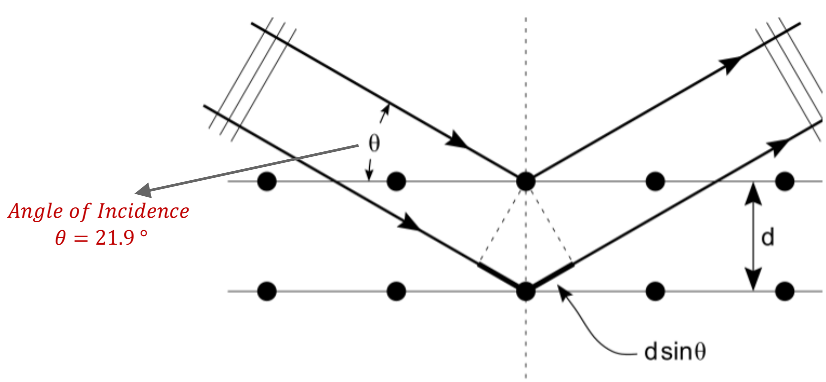
$$\sin\theta = \frac{0.074\sqrt{2}}{0.28}$$

Taking the arcsine of the irrational term to determine the angle of incidence, θ:

$$\theta = \sin^{-1}\left[\frac{0.074\sqrt{2}}{0.28}\right]$$

Hence the angle of incidence, θ, for this X-ray beam is:

$$\boxed{\begin{array}{c} \therefore \theta = 21.9° \ (3s.f.) \\ or \quad \theta = 0.383\ radians\ (3.s.f) \end{array}}$$



Problem 6 –

Convert the following values into the specified units. Express all final answers in scientific notation. (4pts)

a. 2×10^2 MPa to Pa
b. 1×10^2 m to µm
c. 5 Å to km Correct
d. 10 kg to mg
e. 2 pm to km
f. 502 nm to cm
g. 1.5 km to mm
h. $3.2\ MPa\ to\ GPa$

Part (a) → $2 \times 10^2\ MPa = 2 \times 10^2 \times 10^6\ Pa = \boxed{2 \times 10^8\ Pa}$

Part (b) → $1 \times 10^2\ m = 1 \times 10^2 \times 10^6\ \mu m = \boxed{1 \times 10^8\ \mu\mathrm{m}}$

Part (c) → $5\ \text{Å} = 5 \times 10^{-10}\ m = 5 \times 10^{-10} \times 10^{-3}\ km = \boxed{5 \times 10^{-13}\ km}$

Part (d) → $10\ kg = 10 \times 10^3\ g = 10 \times 10^3 \times 10^3\ mg = \boxed{1 \times 10^7\ mg}$

Part (e) → $2\ pm = 2 \times 10^{-12}\ m = 2 \times 10^{-12} \times 10^{-3}\ km = \boxed{2 \times 10^{-15}\ km}$

Part (f) → $502\ nm = 502 \times 10^{-9}\ m = (5.02 \times 10^2) \times 10^{-9} \times 10^2 = \boxed{5.02 \times 10^{-5}\ cm}$

Part (g) → $1.5\ km = 1.5 \times 10^3\ m = 1.5 \times 10^5\ cm = \boxed{1.5 \times 10^6\ mm}$

Part (h) → $3.2\ MPa = \boxed{3.2 \times 10^{-3}\ GPa}$