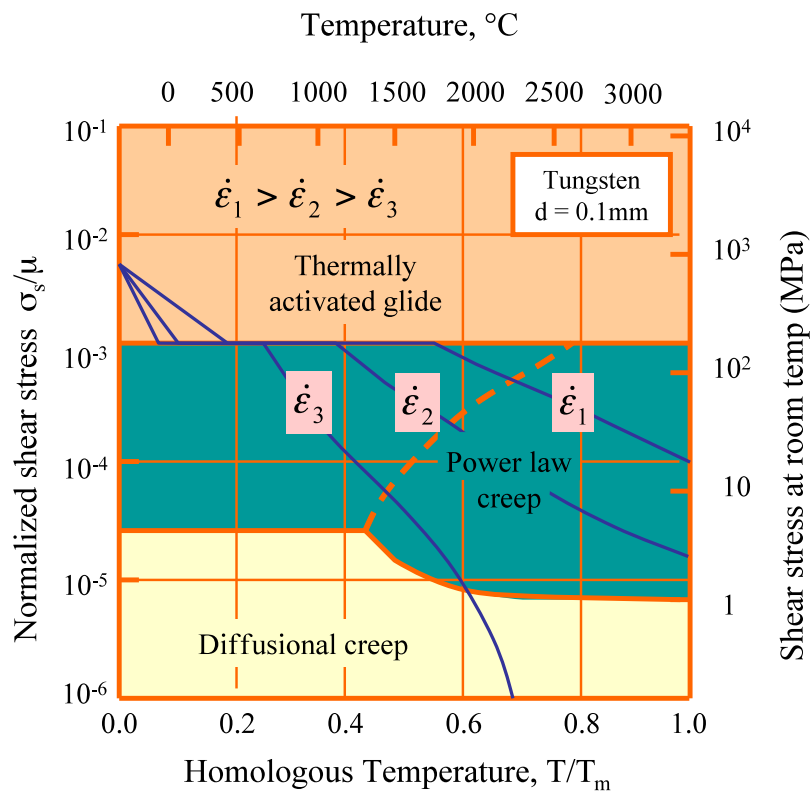1.  (20 minutes)
    a)  (15 minutes) Sketch the crystal structures for the following materials (Show the lattice parameter(s) and atoms per unit cell for each sketch):
        i.      BCC α-Fe (ferrite)
        ii.     FCC γ-Fe (austenite)
        iii.    HCP α-Zr.
    b)  (5 minutes) Estimate the theoretical density of BCC α-Fe at room temperature (Z=26, a=0.124 nm, M=55.854 g/mol).

2.  (20 minutes)  Most stainless steels have Cr and Ni as important alloying elements.
    a)  What is the effect on void swelling (reduced or increased) if (a) Ni content is continually increased or (b) Cr content is continuously increased?  (No need to explain the mechanism.)
    b)  Sketch a typical stress-strain diagram for austenitic stainless steel showing the relative behavior before and after a moderately high irradiation dose (e.g., 10 dpa). Why is there a change?

3.  (20 minutes) An edge dislocation is shown in the figure provided below.
    a)  (10 minutes) Which regions around the dislocation will preferentially trap interstitials and vacancies, respectively? Briefly explain why.
    b)  (5 minutes) Will a dislocation have the same efficiency to trap both interstitials and vacancies?
    c)  (5 minutes) Based on your answers, discuss the consequence in material degradation in nuclear energy systems.
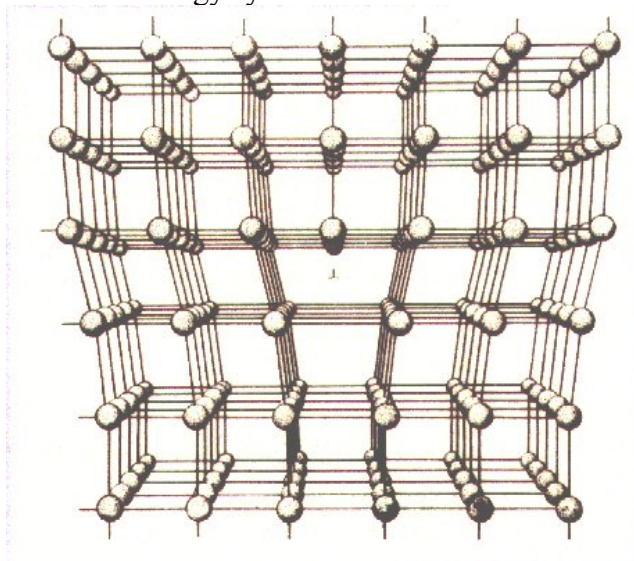
4. (10 minutes) The figure below shows what happens after precipitations are cut by a mobile dislocation. The arrows show the direction of dislocation motion. The shadowed region (gray) represents the new surfaces created after the cutting. What type of dislocation segment is this? Justify your answer with a brief explanation.
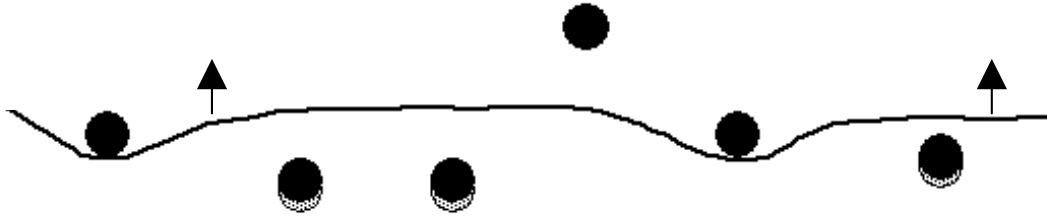


5. (20 minutes) The figure below is a deformation map describing the creep behavior of tungsten ($T_m$=3410°C).
   a) What is creep?
   b) From the three regions marked in the figure (thermally activated glide, power law creep and diffusional creep), select two regions and explain the mechanisms.
   c) Which creep region in the figure will be most affected by radiation damage?
   d) Using $\sigma_s/\mu = 10^{-4}$, estimate the activation energy for Power Law Creep.

Temperature, °C



Redrawn from Frost and Ashby, *Deformation Mechanism* Maps, 1980

6. (20 minutes) The schematic diagram below shows the zirconium oxide layer formed on the exterior surface of Zircaloy during LWR operation.
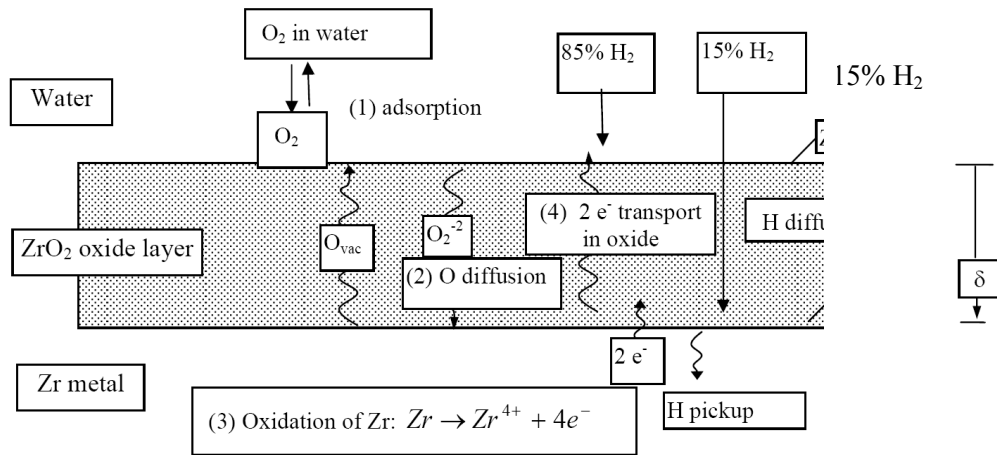


a) (15 minutes) The diagram shows a 4-step process for oxide layer growth. Describe each step. Which step controls the oxide layer growth rate?
b) (5 minutes) Sketch a plot describing the oxygen content in the Zircaloy cladding as a function of depth. Assume the oxide layer is ~10 μm thick and the oxygen content in the middle of the cladding is still below 1000 ppm.

7. (10 minutes) A stress-strain curve is given below for a hypothetical alloy.
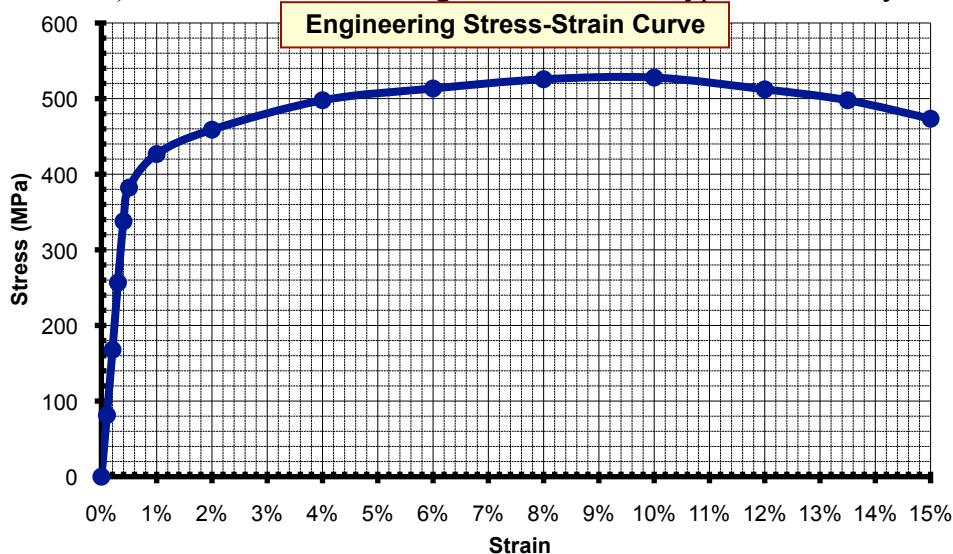


a) Estimate the modulus of elasticity, yield stress (0.2% offset), and ultimate tensile strength of this material.
b) Describe what is happening to the alloy microstructure in the elastic region.
c) Describe what is happening to the alloy microstructure just beyond the yield point.
d) Describe what is happening to the alloy microstructure at the point of maximum stress.