1. Answer these questions about Fick’s laws of diffusion:
   (a) Write a general expression for Fick’s first law and define all terms in the equation, and their dimensions.
   (b) Write a general expression for Fick’s second law and explain its basis (i.e., where it comes from).

2. The solution to the diffusion equation for a point source of strength $M$ (per unit length) located at the origin $x = 0$ in a one-dimensional system extending from $x = -\infty$ to $x = \infty$ is
   \[
   c(x, t) = \frac{M}{\sqrt{4\pi Dt}} \exp\left( -\frac{x^2}{4Dt} \right) \tag{1}
   \]
   (a) Use this solution to write an equation for the diffusion from a point source initially located at position $x = \Delta$ in a semi-infinite one-dimensional system extending from $x = 0$ to $x = \infty$.
   *Hint*: Solve this problem by superposing a second identical “image” point source of strength $M$ located at position $x = -\Delta$ so that the symmetry plane at $x = 0$ will be a plane of zero flux. See Fig. 1 below.
   (b) Demonstrate that the solution you obtain from part (a) has zero flux at $x = 0$ for all times.

3. The intrinsic point imperfections in potassium chloride, KCl, are Schottky defects that consist of charge-compensating cation and anion vacancies.
   (a) Write the formation reaction for a Schottky defect in KCl, using Kröger-Vink notation.
   (b) What specific point defects would you expect to be found in impure KCl that contained a small amount of CaCl$_2$?
   (c) Explain how the presence of CaCl$_2$ impurities in KCl might be apparent on an Arrhenius plot of cation diffusivity in KCl.
4. Martensitic transformations involve a shape deformation that is an invariant-plane strain (simple shear plus a strain normal to the plane of shear). The elastic coherency-strain energy associated with the shape change is often minimized if the martensite forms as thin plates lying in the plane of shear. Such a morphology can be approximated by an oblate spheroid with semiaxes \((r, r, c)\), with \(r \gg c\). The volume \(V\) and surface area \(S\) for an oblate spheroid are given by the relations:

\[
V = \frac{4\pi}{3} r^2 c \quad \text{and} \quad S = 2\pi r^2
\]

(2)

The coherency strain energy per unit volume transformed is given by

\[
\Delta f_\varepsilon = \frac{Ac}{r}
\]

(3)

(a) Find expressions for the size and shape parameters for a coherent critical nucleus of martensite. Use the data below to calculate values for these parameters.

(b) Find the expression for the activation barrier for the formation of a coherent critical nucleus of martensite. Use the data below to calculate the value of this quantity.

(c) Comment on the likelihood of coherent nucleation of martensite under these conditions.

**Data**

- \(\Delta f_B = -170 \text{ MJ/m}^3\) (chemical driving force at observed transformation temperature)
- \(\gamma = 150 \text{ mJ/m}^2\) (interphase boundary energy per unit area)
- \(A = 2.4 \times 10^3 \text{ MJ/m}^3\) (strain energy proportionality factor)

5. Use your knowledge of kinetic rate laws to answer the following:

(a) Annealing Alloy X, which is single-phase, for 2 hr at 800 K is found to increase the grain size from 25 \(\mu\)m to 50 \(\mu\)m. Estimate the time required at 800 K to increase the grain size from 50 \(\mu\)m to 100 \(\mu\)m.

(b) Annealing Alloy Y, which contains a dispersion of spherical precipitates in a matrix, for 2 hr at 800 K is found to increase the average precipitate particle radius from 25 nm to 50 nm. Estimate the time required to increase the average precipitate particle radius from 50 nm to 100 nm. *State key assumptions you’ve made in arriving at your answer.*

6. Using concepts from nucleation and growth kinetics, explain why a time-temperature-transformation diagram consists of curves with a characteristic “C” shape.

**Physical Constants**

- \(k_B = 1.38 \times 10^{-23} \text{ J/K} \) (Boltzmann’s constant)
- \(N_0 = 6.023 \times 10^{23} \) (Avogadro’s number)