

Mass Transfer

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Office hours: Wed 1pm-3pm, or by appointment

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Course website: avenue.mcmaster.ca

Lectures: Mondays, Wednesdays, Thursdays, 10:30-11:20, T13-127

Calendar Description

Phenomenological and mechanistic approaches to diffusion; boundary conditions; diffusion in fluids and solids; point defects in solids.

Prerequisite

MATLS 1M03 and both MATH 2A03 and 2C03, or both MATH 2Z03 and 2ZZ3 or registration in Level IV or above in Civil Engineering.

Course Description

Thermodynamics describes the equilibrium state of system at a specified temperature, pressure and composition, but can say nothing about the rate at which the system approaches equilibrium. Mass transfer in solids and liquids is the route by which materials tend toward equilibrium. The diffusion of atoms in solids and liquids plays an essential role in many important materials science processes such as the heat treatment of alloys, the doping of semiconductors and the sintering of ceramics. In 3E04 the physical mechanism of atomic motion in crystalline solids and the diffusion coefficient as a function of temperature will be discussed. In addition, the mathematics describing the concentration in a material as a function of position and time will be explored. Practical examples of diffusion in materials processing will be provided.

Course Objectives

In this course you will be introduced to the fundamentals of diffusive and convective mass transfer phenomena in solving process and materials related problems. At the end of the course, the students should understand the mechanisms of diffusion, application of solutions to steady-state and transient diffusion problems, the role of diffusion in the heat treatment of dilute alloys, concentrated alloys and fluids. When successfully completed, you will be able to apply these fundamentals to quantify transport phenomena that occur in various materials processing applications.

The required readings

The material covered in the course will follow closely the material presented in the text (see below). For content not included in the text, supplementary notes will be provided. The lecture notes are posted on the website.

“Mass Transfer in Solids and Fluids”, by D. S. Wilkinson.

Assessment

Individual Assignments: 25%

I anticipate 8-9 homework assignments, each of which must be submitted to the teaching assistant in tutorial. If there is no tutorial at that particular week, please submit your assignments to course dropbox, JHE-213 one week after they are assigned.

Midterm 1: 20%

Open book exam based on content covered in Chapters 1-3.

Midterm 2: 20%

Open book exam based on content covered in Chapters 5-6.

Final Examination: 35%

Open book exam based on content covered in the term. You will be asked to apply Fick’s laws and various solutions to Fick’s Law’s to solve engineering-based numerical problems.

Policy on Written Work and Late Submissions:

All written work will be marked on content and analysis as well as grammar, clarity of writing, and organization. More details about the marking scheme are posted on the course website. Late submissions will be penalized 20% per day. Late penalties will not be waived unless your Faculty/Program Office advises the instructor that you have submitted to that office the appropriate documentation to support your inability to submit the work by the due date.

Learning Outcomes

This course contributes to the assessment of the following program (student) outcomes:

- an understanding of the fundamentals of mathematics, science, and engineering science and their application in engineering.
- the ability to identify, formulate, model and solve engineering problems

Upon successful completion of this course, the student will be able to:

I. Define introductory and fundamental concepts of mass transfer

- Convert units of measurements from one system to another
- Define diffusion and convection modes of mass transfer.

- Give examples (at least 2 for each mode) of diffusion and convection modes of mass transfer that are directly related to materials engineering applications.

II. Write and explain the fundamentals equations of diffusion

- Write the Fick's Laws of diffusion.
- Define diffusion coefficient and list all the parameters that may affect its value.
- Explain the physical meaning of all the terms of Flux (diffusion) Equation
- Formulate and solve differential mass balances for diffusion of elements subjected to steady and transient boundary conditions in solid and simple fluids.
- Demonstrate effective interpretation of graphical data.

III. Develop and solve diffusion mass transfer problems

- Classify the various methods of transfer of mass
- Define the various concentrations, velocities, and fluxes that are used to describe the transfer of mass.
- Solve the concentration profile for one-dimensional, steady state problems in simple geometries.
- Solve the transient diffusion problems using error function or graphical methods in simple geometries.

IV. Develop and solve convection mass transfer problems

- Understand convective mass transfer
- Understand mass transfer analogies including their limitations
- Estimate and use of mass transfer coefficients to determine mass transfer rates for laminar and turbulent flows, internal and external flows, fully developed flow, flow with entry effects across phase boundaries, and forced and free convection and over geometries using empirical relations.

How the course relates to other course offerings and overall program(s) in the discipline

This course will give intellectual framework for a number of materials science courses such as phase transformation, materials processing, extractive metallurgy etc taught in years 3 and 4.

Teaching strategies

- Core concepts, theories and approaches to understand diffusion phenomena will be covered in lectures. Several examples will be discussed to demonstrate the use of diffusion in materials science and engineering.
- Teaching material, including course outline, notes, problems, assignments, and course announcements are available on the Avenue website.

Schedule of topics

Jan. 5, Introduction/Outline

Jan. 9, Fick's 1st and 2nd laws of diffusion

Jan. 11, Introduction to steady state diffusion (Chapter 2 in text)

Jan. 12, Permeability

Jan. 16, Pseudo-steady state problems, oxide growth

Jan. 18-23, Transient diffusion (Chapter 3 in text), planar source solution, semi-infinite and infinite diffusion couples, error functions

Jan. 25-30, Transient diffusion (Chapter 3 in text), finite diffusion couples

Feb. 1-6, Mechanisms of diffusion (Chapter 1 in text), interstitial and vacancy diffusion, migration energy, the diffusion coefficient, Arrhenius behavior, temperature effect

Feb. 8-9, Review

Feb. 13 Midterm 1

Feb. 15-16, Gas-solid reactions (Chapter 5 in text), gas mixtures, semiconductor doping

Feb. 27, Review of phase diagrams

Mar. 1- 6, Heat treatment of alloys (Chapter 6 in text), precipitate growth and dissolution

Mar. 8-9, Plate and spherical geometries, eutectic growth, plane front solidification

Mar. 13-16, Review and Midterm 2

Mar. 20-23, Diffusion in concentrated alloys (Chapter 7 in text), the Kirkendall effect, the interdiffusion coefficient, diffusion couples with intermediate phases

Mar. 27-30, Mass transport with convection (Chapter 8 in text), transient diffusion in fluids, the mass transfer coefficient.

Apr. 3-5, Alternative driving forces for diffusion (Chapter 10 in text), stress, chemical potential gradients, curvature.

Apr. 6, Review

Course Management System (CMS):

The student is required to check the system daily for assignment release/submission, course related material, and posted announcements. Handouts are posted on the website.

The instructor and university reserve the right to modify elements of the course during the term. The university may change the dates and deadlines for any or all courses in extreme circumstances. If either type of modification becomes necessary, reasonable notice and communication with the students will be given with explanation and the opportunity to comment on changes. It is the responsibility of the student to check his/her McMaster email and course websites weekly during the term and to note any changes.

Academic Integrity

“Academic dishonesty consists of misrepresentation by deception or by other fraudulent means and can result in serious consequences, e.g. the grade of zero on an assignment, loss of credit with a notation on the transcript (notation reads: “Grade of F assigned for academic dishonesty”), and/or suspension or expulsion from the university.

It is your responsibility to understand what constitutes academic dishonesty. For information on the various kinds of academic dishonesty please refer to the Academic Integrity Policy, specifically Appendix 3, located at http://www.mcmaster.ca/senate/academic/ac_integrity.htm

The following illustrates only three forms of academic dishonesty:

1. Plagiarism, *e.g.* the submission of work that is not one’s own or for which other credit has been obtained. Work of others must be referenced in the text by name or with superscripted numbers, and the reference information collected at the end of the report.
2. Improper collaboration in group work. Assignments must be done individually. The group projects are to be an equal collaboration by the students in the group.
3. Copying or using unauthorized aids in the examination.

Students will be required to submit their written report electronically to ensure that the work has proper citation of previous work.