Introduction to Glass Science and Technology
CERAMIC ENGINEERING 103/SP12

Instructor: **Richard K. Brow,** 322 McNutt Hall, 341-6812, brow@mst.edu

Office Hours: Tuesdays and Thursdays, 8:30-10:00 AM and by appointment (any time).

Textbook: "Introduction to Glass Science and Technology," 2nd edition, by J. E. Shelby, Springer Verlag (2005). Pertinent information may also be found in such texts as "Introduction to Ceramics," by W. D. Kingery, et al., and "Fundamentals of Inorganic Glasses," by A. K. Varshneya

Lecture Materials: Lecture notes and copies of the PowerPoint slides are available on the Cer103 Blackboard site.

Homework: Ten sets of homework problems related to various chapters in the text and to the classroom lectures will be assigned, collected and graded. Each homework set is worth 20 points and must ***be turned in before class on the date indicated for full credit to be awarded***. Homework sets are posted on Blackboard and due dates are indicated there, as well on the attached schedule. Similar problems will be included in exams.

Clicker Quizzes: Clicker quizzes will be given on occasion throughout the semester. Typically, these quizzes will be given at the beginning of a lecture and will review information from a previous lecture. Each quiz will be worth 10 points. In addition, we will use the clickers throughout the lectures to poll the class on concepts and to aid classroom discussions. Clickers will not be used to take attendance. It is the responsibility of every student to bring his or her clicker to every class, and to only use that clicker for which they are personally registered.

Exams: Four one-hour examinations (100 points each) and a comprehensive final will be given. Students will have the option of dropping one exam score and replacing it with the score on the final exam, or not taking the final exam and accepting their grade after the fourth exam. Copies of exams given in previous years are available on the Cer103 Blackboard site.

Grading: Final grades will be determined from the following percentages of total points:

Grade	point %
A	90-100
B	80-89
C	70-79
D	60-69
F	<60

Grades for exams, quizzes and homeworks will be recorded on the Cer103 Blackboard site. If you have any questions about a recorded grade or your grade status in this course, please do not hesitate to contact Prof. Brow.

Attendance: Missed quizzes and exams may be taken *only* if prior arrangements are made with the instructor. It is your responsibility to attend classes.

Academic Alert System: The purpose of the Academic Alert System (http://academicalert.mst.edu) is to improve the overall academic success of students by improving communication among students, instructors and advisors; reducing the time required for students to be informed of their academic status; and informing students of actions necessary by them in order to meet the academic requirements in their courses.

Disability Support Services: http://dss.mst.edu
Any student inquiring about academic accommodations because of a disability will be referred to Disability Support Services so that appropriate and reasonable accommodative services can be determined and recommended. Disability Support Services is located in 204 Norwood Hall. Their phone number is 341-4211 and their email is dss@mst.edu. *"If you have a documented disability and anticipate needing accommodations in this course, you are strongly encouraged to meet with the instructor early in the semester. You will need to request that the Disability Services staff send a letter to the instructor verifying your disability and specifying the accommodation you will need before arrangements can be made your accommodation."*

Academic Dishonesty: **http://registrar.mst.edu/academicregs/index.html**
The Student Academic Regulations handbook describes the student standard of conduct relative to the System's Collected Rules and Regulations section 200.010, and offers descriptions of academic dishonesty including cheating, plagiarism or sabotage. The Missouri S&T policy on academic dishonesty (e.g. cheating, plagiarism) allows the instructor to make a judgment about the student's grade on the work in question and requires that alleged cases of academic dishonesty be reported to the Primary Administrative Officer.

Course Goals: Outlined on the following pages (and arranged according to the chapters in the course text) are some of the skills that will be acquired by students who successfully complete this course. At the conclusion of this course, a student should have the ability to apply ceramic science and engineering principles to describe the relationships between the compositions, properties and structures of common oxide glasses, as well as to be able to describe their use and production.

Chapter 1: Introduction

- Define a glass in terms of its structure and the glass transformation.
- Describe what happens to the properties (volume, enthalpy, etc.) of a glass-forming melt when it is cooled to room temperature, and contrast that behavior with that from a crystallizing melt.
- Describe the structural differences between a crystalline solid and a non-crystalline solid.
- Define the 'glass transition'.

Chapter 2: Principles of Glass Formation

- Define homogeneous and heterogeneous nucleation. Describe the differences between stable, metastable, and unstable phases.
- Describe the temperature-dependence of thermodynamic driving forces and kinetic barriers to nucleation. Explain the importance of surface tension and glass viscosity.
- Explain the temperature-dependencies of nucleation and growth rates and identify important features including the metastable zone for undercooling and the glass transition.
- Use time-temperature-transformation (TTT) curves to calculate critical cooling rates for glass formation.
- Use the nucleation and growth rate curves to explain heat-treatment schedules for producing glass-ceramics.
- Describe some of the advantages and disadvantages of glass-ceramics.

Chapter 3: Glass Melting

- Identify the names and chemical compositions of important raw materials
- Identify the five categories of glass batch materials and provide examples of each
- Perform batch calculations to a) calculate glass compositions in mole% and wt%; b) calculate the batch composition needed to produce a glass with a specified composition (mole% or wt%); c) calculate the glass composition that results from melting a specified batch.
- Describe decomposition and fining reactions that occur as a glass batch reacts and melts.

Chapter 4: Immiscibility/Phase Separation

- Describe the two different mechanisms for phase separation.
- Describe the differences between 'stable' and 'metastable' phase separation. Which is more difficult to avoid when quenching a melt?
- Know how to determine immiscibility in glass-forming systems.
- Explain the effects of immiscibility on the properties of glasses.

Chapter 5: Structure of Glasses

- Identify the valence and size of cations and anions that are typically found in glasses.
- Use Pauling's Rules to predict preferred cation and anion coordination environments.
- List Zachariasen's four rules for oxide glass formation and use those rules to predict the glass-forming tendency of various oxides.
- Explain the differences between glass formers, intermediates, and modifiers, in terms of ion valence and size (Zachariasen), single bond strengths (Sun), Coulombic field strengths (Dietzel), electronegativity/bond ionicity (Stanworth).
- Describe the effects of glass formers, intermediates, and modifiers on structure and properties
- Describe glass structure in terms of building blocks, connectivity, dimensionality, intermediate range order, and morphology.

- Calculate the bridging and nonbridging oxygens concentrations and the tetrahedral Q^n-distributions for simple silicate glasses.
- Explain the relationships between structure and properties of aluminosilicate glasses.
- Describe a boroxyl ring and explain the borate anomaly in terms of the properties and structures of borate glasses
- Predict the concentration of tetrahedral borate sites (N_4) in a binary xR_2O $(1-x)B_2O_3$ glass.
- Describe the chain-structures of phosphate glasses; calculate the number of bridging and nonbridging oxygens and the distributions of Q^n-tetrahedra for xR_2O $(1-x)P_2O_5$ compositions.
- Identify other important glass-forming systems.
- Know the approximate compositions of commercially important glasses, including soda-lime silicates, borosilicates (e.g., Pyrex, Vycor), aluminosilicates (E-glass), etc.
- Describe aspects of commercial manufacturing processes for common glass products, including fibers, flat glass, and containers.

Chapter 6: Viscosity and Relaxation Behavior

- Know the definition for viscosity and common units.
- Know viscosity values for standard glass processing temperatures; i.e., practical melting point, working point, etc.
- Know the definition for viscoelasticity and be able to describe viscoelasticity using a Maxwell element model.
- Know the mathematical formula for a simple (Maxwell) exponential stress relaxation curve.
- Describe techniques for measuring viscosity over different viscosity ranges.
- Describe the temperature dependence of viscosity. Define long and short glasses, fragile and strong liquids. How do the parameters in the Vogel-Fulcher-Tamman equation differ between a strong and fragile liquid? Which has the greater activation energy near T_g? Describe the parameters in the Corning viscosity model and explain how they are used tyo describe the temperature dependence of viscosity.
- Predict how changes in glass composition affect viscosity- role of modifying oxides, alumina additions, silicates vs. borates, etc.
- Describe the 'Fictive Temperature' concept and use it to explain thermal history effects on glass properties, like viscosity and density.

Chapter 7: Density and Thermal Expansion

- Density, molar volume, thermal expansion coefficient; describe how each is determined.
- Use the concept of free volume to describe how changes in composition affect the density and molar volume of glass.
- Use the Condon-Morse potential to explain thermal expansion. Predict how changes in composition will affect the thermal expansion coefficient.
- Use the fictive temperature paradigm to describe the effects of thermal history on the thermal expansion curves. Identify T_g and T_d on these curves.

Chapter 8: Transport Properties

- Identify examples of important glass properties that are dependent on mass transport phenomena.
- Discuss Fick's first law and explain the role of the Diffusion Coefficient and compositional gradients on mass transport behavior.
- Know the Nernst-Einstein relationship for diffusion and conductivity.

- Describe the Anderson-Stuart model for ionic conductivity and use it to explain the effects of composition and structure on conductivity. Calculate activation energies from $\sigma(T)$ data.
- Describe the mixed alkali effect and know its consequences for conductivity and chemical durability.
- Describe the dissolution processes (ion exchange, congruent network dissolution) that affect glasses and the role played by composition. Describe the effects of pH on glass durability.
- Explain the differences between weathering and aqueous corrosion

Chapter 9: Mechanical Properties
- Know the definition for elastic modulus and common units.
- Use the Condon-Morse curve to describe bonding effects on modulus.
- Understand how the parameters in the Orowan equation affect ultimate strength
- Use the Griffith equation to describe the role of cracks/defects/flaws in determining the practical strength of glass and use the Weibull formalism to explain strength distributions.
- Describe techniques for strengthening glass. Explain why glasses are stronger in compression than tension.
- Describe tempering
- Know the difference between permanent and transient thermal stresses and explain how each is created.
- Describe the relationships between static/dynamic fatigue and chemical durability.
- Use the thermal shock equation to calculate temperature gradients that cause glasses to fail.

Chapter 10: Optical Properties
- Use Snell's Law to define refractive index.
- Say the word 'goniometer' without snickering.
- Define dispersion and explain how the Abbe number is used to quantify dispersion.
- Predict the effects of compositional changes and thermal history on refractive index and dispersion.
- Know the general differences in composition between 'flint' and 'crown' glasses and be able to show where these glasses can be found on an Abbe diagram (index vs. Abbe #).
- Calculate molar and ionic refractivities to predict how a particular change in composition will affect refractive index.
- Describe what is responsible for the UV cutoff and the IR-edge, predict how changes in composition will affect both, and describe technological situations where the UV cutoff and the IR-edge are important.
- Explain the function of optical fibers.
- Use the ligand field theory to explain the effects of composition (transition metal and rare earth oxides) and structure (coordination number, valence, anion bonding, etc.) on color. What is the chromophore responsible for amber glasses?
- Describe how the development of nano-scale metal and semiconductor particles impart color to glass.
- Describe the role of rare earth ions in the development of solid state amplifiers

Date	Lecture Topic
1/9/12	Introduction; Definitions, glass transition (*Chap. 1)*
1/11/12	*Chap 2:* Intro to nucleation; nucleation & growth kinetics
1/13/12	TTT curves; glass ceramics
1/16/12	**MLK Day/No Classes**
1/18/12	*Chapter 3:* Raw materials, Melting reactions;
1/20/12	Fining reactions and Batch calculations; **HW#1 Due**
1/23/12	Batch Calculation Homework Review
1/25/12	Review of crystal chemistry principles; Ion field strengths
1/27/12	Acid/base concepts; Pauling's Rules**; HW#2 Due**
1/30/12	*Chapter 4:* Liquid immiscibility; introduction
2/1/12	Immiscibility domes; applications; **HW#3 Due**
2/3/12	**EXAM #1**
2/6/12	*Chapter 5:* Zachariasen's Random Network Theory;
2/8/12	Bonding considerations; glass formers and modifiers
2/10/12	Silicate chemistry, rules, Q-distributions and NBO/BO calculations
2/13/12	Aluminosilicate glasses: structures & applications; **HW#4 Due**
2/15/12	Binary borate glasses; the 'borate anomaly'; aluminoborate glass
2/17/12	Borosilicate glasses, phosphates;
2/20/12	Other oxide glass-forming systems; **HW#5 Due**
2/22/12	Commercial glasses; compositions and applications;
2/24/12	Commercial manufacturing practices; **HW#6 Due**
2/27/12	**EXAM #2**
2/29/12	*Chapter 6:* Melt viscosity, definitions, important temperatures, Visco-elasticity and exponential relaxation kinetics
3/2/12	Measurement techniques, VFT and other equations
3/5/12	Effects of composition on glass viscosity**;**
3/7/12	Thermal history effects; Concept of 'Fictive Temperature'**; HW#7 Due**
3/9/12	*Chapter 7:* density & thermal expansion; density examples
3/12/12	Effects of composition on ρ and CTE
3/14/12	*Chapter 8:* Transport properties; diffusion/random walk; activation nrgs
3/16/12	**No Class, St. Pat's Break**
3/19/12	Ionic conductivity
3/21/12	Ion exchange processes, **HW#8 Due**
3/23/12	**EXAM #3**
3/26-3/30/12	**No Class, Spring Break**
4/2/12	Chemical durability
4/4/12	Weathering reactions; gas permeation
4/6/12	*Chapter 9:* Mechanical properties, elastic moduli, hardness;
4/9/12	Theoretical strength
4/11/12	Chemical strengthening, thermal tempering, fatigue
4/13/12	*Chapter 10:* Optical properties; refractive index; **HW#9 Due**
4/16/12	UV/IR absorption; dispersion;
4/18/12	Color intro; Ligand field theories
4/20/12	Color examples, redox behavior,
4/23/12	Scattering effects
4/25/12	Glass lasers; telecommunication applications of glass; **HW#10 Due**
4/27/12	**EXAM#4**
4/30-5/4/12	**FINAL EXAM**