Introductory Chemistry from a Materials Perspective

by Scott Ramsay, PhD, PEng

1 Introductions

LEARNING GOALS

Learning Objectives

By the end of this lecture students should be able to:

1. Recall the course instructors
2. Locate the contact information for the course staff
3. Identify where to find course learning resources
4. Locate the course syllabus, including mark breakdown
5. Summarize the outline for this course
6. Name the three major material classes (Metals, ceramics, and polymers)
7. Give examples of at least two materials in each class
8. Elaborate on the shortcomings of this classification scheme
9. Defend the benefits of this classification scheme

About the Author

I'm originally from Vancouver (beautiful place, you should visit if you have the chance). I did my undergraduate degree at UBC in Materials Engineering. I came to U of T for a masters and liked it so much I ended up doing a PhD also. I was fortunate also to have an amazing supervisor, Prof. Bob Pilliar. After my PhD I wanted a change of pace so I worked in financial services for a couple of years while also teaching a couple of fourth year biomaterials courses in the evenings. I returned full time to U of T in 2009 and have taught a wide range of courses in Materials Science, from introductory materials science to thermodynamics, diffusion, materials selection, manufacturing, biomaterials, and building science. I like teaching and people tell me that I'm quite good at it (*Here's a tough question that I ponder quite a bit: how do you quantify good teaching? What metric do we use? Online course evaluations suffer from a number of biases, as do third party online rating websites. Is attendance in lectures meaningful? View counts of online videos seem simple, but are people watching because I sound like Christopher Walken or because they are really learning something? Even academic achievement - grades - is a difficult metric. I'm fortunate enough to teach some absolutely outstanding students who would likely perform really well even if I just mumbled and drew lines on the chalkboard. If you have the answer, please let me know!*).

In addition to my graduate degrees I'm also a registered professional engineer, licensed in Ontario. I'm currently an Associate Professor, Teaching Stream at the University of Toronto.

I'm really passionate about teaching solid state chemistry and have completed a number of teaching studies to help improve my teaching and the student experience. I'm always looking for ways to continue improving my teaching so please don't hesitate to reach out to me if you have some suggestions.

Land Acknowledgment

I would like to acknowledge the land on which the University of Toronto operates. For thousands of years it has been the traditional land of the Huron-Wendat, the Seneca, and most recently, the Mississaugas of the Credit River. Today, this meeting place is still the home to many Indigenous people from across Turtle Island and I am grateful to have the opportunity to work on this land.

Some Ground Rules and Expectations

The world is going through some challenging times currently. I hope that as you gain the specialized knowledge from this and your other courses you'll always consider how you can apply it to improve society and the quality of life for everyone on the earth. Okay, that got heavy and maybe a little sappy. I'll try not to do that too much in this text. But this is the introductory section where I set out my expectations for my class, so I hope you'll indulge me just a little more.

When a student enters into my classroom, they do so of their own free will and I assume they do so because they want to learn. You must not take that opportunity away from your classmates by speaking too loudly during class or otherwise being distracting. You can expect that I will arrive to class on time and prepared to deliver my lecture. You can expect that I will not use offensive language and that I will work to create a welcoming, supportive, and comfortable learning environment.

I expect that you will not use racist, sexist, misogynistic, homophobic, or otherwise offensive language. I expect that you will be respectful of your classmates and their desire to learn in a comfortable environment.

Volunteer Note-takers Needed

Accessibility Services needs dependable volunteer note-takers to assist students living with a disability to achieve academic success. Volunteers report that by giving to the U of T community their class attendance and note taking skills improve. All you have to do is attend classes regularly and submit your notes consistently:

1. Register Online as a Volunteer Note-Taker at: https://clockwork.studentlife.utoronto.ca/custom/misc/home.aspx
2. Follow the link that says Volunteer Notetakers
3. Select your course and upload a sample of your notes
4. Once you have been selected as a note-taker you'll get an email notifying you to upload your notes

If you have any questions, please call Accessibility Services, open Monday- Friday 9:00am-5:00pm and Tuesdays 9:00 AM-6:00 PM at notetaking@utoronto.ca or 416-978-6186. Volunteers may receive co-curricular credit or a certificate of appreciation. Your support is much appreciated!

High Level Overview of What We'll Cover in This Course

This course will focus on the chemistry of materials in the solid state. This is because every engineer, regardless of specific discipline will interact with solids and should understand the fundamentals responsible for the behaviour of solids. Materials science is about understanding matter at a small scale – around the atomic scale – and marvelling at how what we know about matter at this small scale allows us to explain what happens at the larger scale – around the human scale. What's even more exciting is that when we understand matter at the small scale, sometimes we can get it to do terrific things. Important things. Things that you might not expect, and things that we hope can improve society and the world.

The sequence of topics in this course has been designed with the hope that it will guide students through the course in a natural, curiosity driven manner. We begin with a topic that is very familiar - the *elastic* mechanical behaviour of solids. We will then look more deeply at this elastic behaviour to understand the cause at the atomic level. With each new topic area we'll see how our current level of understanding is inadequate and we'll then add new knowledge. With this new knowledge we'll also be able to re-visit some previous topics.

Figure 1 shows a rough content map showing how will proceed through this course.

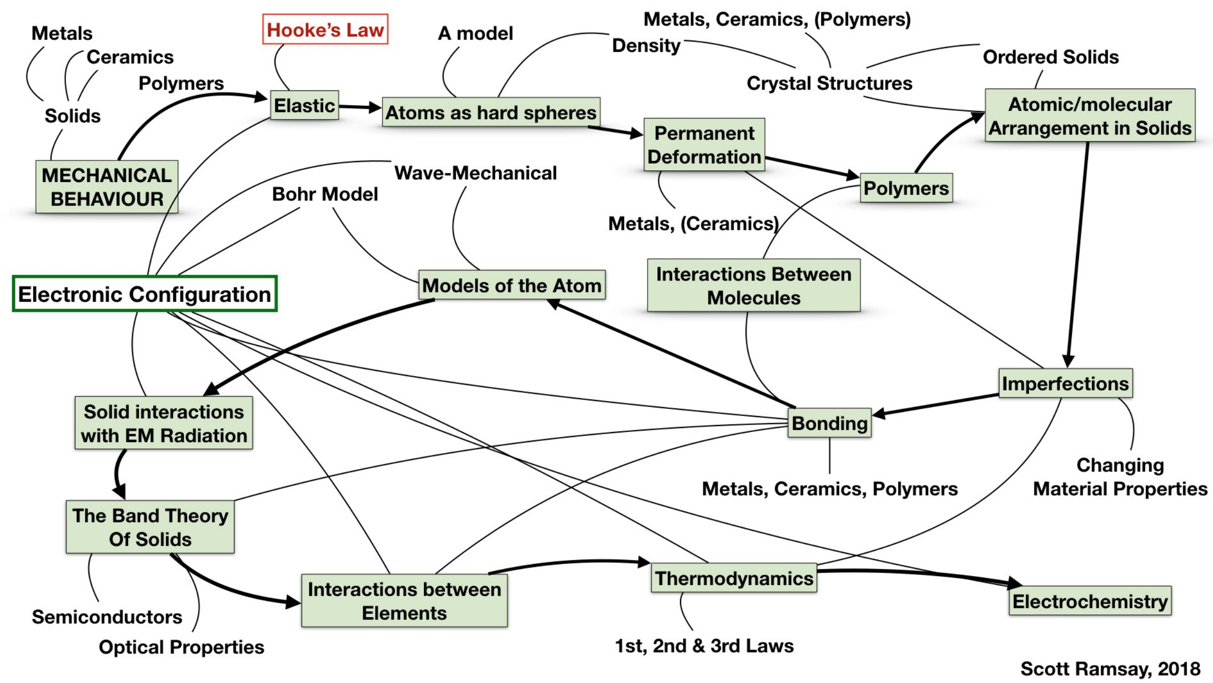

Figure 1: High Level Introductory Content Map

Some General Advice

Your engineering undergraduate degree will be challenging. You'll gain a lot of technical information but you'll also learn a lot about yourself and how you best learn. Don't be afraid to try out new study techniques. Also, don't be afraid, once you've given them a good try, to conclude that certain techniques don't work for you. Some students find that re-writing their notes at the end of the day helps them to learn concepts. This is probably not a good use of time for most engineering students in most engineering courses because it takes a lot of time and your engineering program is very demanding of your time. However, it may work for you in some courses. Generally, its a good idea to study with other students at least some of the time. Try taking turns teaching each other difficult concepts. Don't let yourselves drift off topic and start watching cat videos or something.

Practice Tests and Exams to Study

There is one study technique that I can confidently say is a good idea for the vast majority of students. Ready for it? Write practice exams. I post all of my exams on my website along with solutions. When you write past exams, be sure to replicate the real test environment as much as possible. Print off the test without the solutions. Print the equation sheet, get out your calculator and pen or pencil and put away your phone. Lock yourself up in a room with no distractions and time yourself. The goal should be to make yourself a little nervous. If you get stressed out when practicing you'll be less likely to get as nervous during the real test. Write the test with the actual time limit and here is the important part: don't look at the solutions! Even if you come to a question that you have no idea how to do, there is absolutely no value in going to the solutions unless you have struggled at it first. I mean, really struggled. Like, angry and frustrated kind of struggle. "Ramsay, why did you tell me to struggle? I'm frustrated and feel like I'm wasting my time and I think you're a cotton headed ninny muggins." When you struggle like this your brain starts making new connections and this is when a lot of learning actually occurs. In fact, I've tried to develop this course to keep you riding that delicate edge between what you know and what you don't. "So, this course is going to be very frustrating?" Well, at times, yes, but I'm fairly confident you'll have a good time and learn an awful lot along the way.

So, anyway, struggle while you write practice tests and then only after you've really struggled, take a break and then come back to your test with the marking key and mark your own work. Then print off the questions that you struggled with again and repeat.

Learn How to Learn

Also, if you're looking for a great resource on learning I'd highly recommend a course offered for free on Coursera (www.coursera.org) called *Learning How to Learn* by Barb Oakley. I took this course in one of the first times it was offered and I really wish I'd been able to take it back when I was an undergraduate. I had the pleasure of meeting Barb a few years ago at a conference. What a terrific person she is: so passionate about helping people learn and a real wealth of knowledge. Google "learning how to learn" and you'll find the course on Coursera. It's a great course even just to watch the videos.

Use the Resources Available to You

What else? Don't let yourself fall behind in this course. Be sure to reach out for help as soon as you realize there is something you don't understand. I've prepared a number of resources to help you along the way, including my short topic videos, these notes, my regular lecture recordings, my lectures themselves along with the demos I enjoy so much. Don't be shy to reach out to me after class to set up an appointment if you can't make it to my office hours. Reach out to your TA also. Just try not to fall behind because the topics build on each other.

Take Care of Yourself

It may sound like an obvious statement, but really try to eat a healthy diet and get enough sleep. Your brain performs at its best when you are well rested and nourished by a healthy diet. It is a fallacy to think that you can "catch up on your sleep." Sleep debt doesn't work this way. You need to get regular sleep.

Finally, please take care of your mental health and that of your friends. Watch for signs in yourself and your friends that you or they may need to talk or need any other support.

I truly hope that you enjoy this course and I look forward to teaching you.

The Three Material Classes

Video

Please visit the textbook on a web or mobile device to view video content.

Link to this video on U of T servers

So, to get things started I'd like to set out a simple classification scheme that we will use throughout this course to guide our learning and also to help organize and simplify many of our discussions. We are going to learn about the way solids materials behave. This understanding of how materials behave will take us down to roughly the atomic level where we will learn fundamental concepts that underlie our current understanding of essentially all of the world's materials. I say *essentially* to cover myself since there are almost always exceptions and current research is constantly uncovering specific circumstances in which our current way of thinking (based on our current *models*) does not accurately explain a result. Anyway, if we aim to understand all of the world's materials, surely we'll need a way of discussing them. There are certainly many possible schemes that we could use to organize all of the world's materials and none of them would be perfect. So, let's settle on a simple and generally effective one. Here it is: metals, ceramics, and polymers.

EXERCISE YOUR KNOWLEDGE

Q1.1.1
Review

Which of the following is a reasonable classification scheme for all of the materials in the world?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a	Metals, conductors, and insulators
b	Metals, ceramics, and polymers
c	Metals, ductile materials, and brittle materials
d	Brittle materials, ductile materials, ceramics

Correct Answer:

✓ **b** - Metals, ceramics, and polymers

Show Submitted Answer   Hide Correct Answer   Check My Answer

Metals

Metals are perhaps the easiest to define since they correspond to the solids made by the metallic elements, but even then there are the metalloids like silicon, germanium, for example that don't always behave like metals. Metals are generally *ductile*, meaning that they can be deformed permanently (more on this later), electrically and thermally conductive, and shiny. Metals are almost always highly organized at the atomic level, or *crystalline* (more on this later, too!) A few examples of metals are sodium, titanium, chromium, iron, nickel, copper, silver, gold, lead, and roentgenium (oh, there are so many good ones, how do I name only a few?)

EXERCISE YOUR KNOWLEDGE

Q1.2.1
Review

Which of the following are examples of metals? Choose all correct options.

1. An aluminum beverage container
2. Paper
3. A gold wedding ring
4. The bottom of a running shoe
5. A wooden table
6. A conventional glass window
7. The flexible covering on a computer power cord
8. A brick wall
9. The copper conductor in a computer power cord
10. The mortar that holds together bricks in a brick wall
11. A candle
12. The lining of a high temperature furnace
13. The frame of a conventional automobile
14. The tires on a car
15. The wheels on a car
16. A semiconductor
17. A carbon fibre reinforced polymer aircraft component

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a	1, 3, 9, 13, 15
b	10, 12, 16, 17
c	5, 6, 14
d	2, 7, 15

Correct Answer:

✓ a - 1, 3, 9, 13, 15

Show Submitted Answer Hide Correct Answer Check My Answer

Ceramics

The ceramics are probably easiest to define initially in terms of their mechanical properties; specifically, ceramics tend to be hard and brittle, meaning that they will crack instead of deforming if we apply an increasing load to them. Ceramics also tend to be non-conductive, both thermally and electrically. Chemically speaking, ceramics are often, although not always, metal oxides. More broadly, they tend to be compounds of more than one element and are often held together by ionic bonds (more on this later). They may be optically transparent, translucent or opaque. Ceramics may be either highly organized (crystalline) at the atomic level, or disorganized or *amorphous*. Some fairly clearly defined ceramics are sapphire (alumina or Al_2O_3), quartz (crystalline silica or SiO_2), concrete, window glass (*soda lime glass*). A few less examples that are sometimes described as being ceramics but could well be argued to belong to other classes include the various forms, or *allotropes* of pure carbon: diamond, graphite, buckyball, and carbon nanotubes.

EXERCISE YOUR KNOWLEDGE

Q1.2.3
Review

Which of the following are examples of ceramics? Choose all correct options.

1. An aluminum beverage container
2. Paper
3. A gold wedding ring
4. The bottom of a running shoe
5. A wooden table
6. A conventional glass window
7. The flexible covering on a computer power cord
8. A brick wall
9. The copper conductor in a computer power cord
10. The mortar that holds together bricks in a brick wall

11. A candle
12. The lining of a high temperature furnace
13. The frame of a conventional automobile

14. The tires on a car
15. The wheels on a car
16. A semiconductor
17. A carbon fibre reinforced polymer aircraft component

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a	6, 8, 10, 12
b	1, 3, 5, 8, 16
c	2, 5, 6, 14, 17
d	4, 7, 9, 11

Correct Answer:

✓ a - 6, 8, 10, 12

Show Submitted Answer   Hide Correct Answer   Check My Answer

Polymers

Polymers are the materials that the general public would typically call *plastics*, but you'll soon learn that this description is limited and does not capture all of the materials that would clearly be defined as polymers. Polymers tend to be ductile, but not as strong as metals. They are generally non-conductive both electrically and thermally, and chemically they are made from massive collections of atoms that are all held together by *covalent* bonds (you guessed it, more on this later). Polymers may be optically transparent, translucent, or opaque. A few well-known examples of polymers are polyethylene, polypropylene, polyvinyl chloride, epoxy, Teflon®, GoreTex®, and Styrofoam®.

EXERCISE YOUR KNOWLEDGE

Q1.2.2
Review

Which of the following are clear examples of polymers? Choose all correct options.
1. An aluminum beverage container

2. Paper
3. A gold wedding ring
4. The bottom of a running shoe
5. A wooden table
6. A conventional glass window
7. The flexible covering on a computer power cord
8. A brick wall
9. The copper conductor in a computer power cord
10. The mortar that holds together bricks in a brick wall
11. A candle
12. The lining of a high temperature furnace
13. The frame of a conventional automobile
14. The tires on a car
15. The wheels on a car
16. A semiconductor
17. A carbon fibre reinforced polymer aircraft component

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a	4, 7, 11, 14
b	1, 3, 8, 10
c	4, 5, 12, 13
d	5, 11, 16, 17

Correct Answer:

✓ a - 4, 7, 11, 14

Show Submitted Answer | Hide Correct Answer | Check My Answer

All images and videos are created by author.