

Introduction

September 3, 2024 10:26 AM

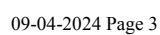


mineral engineer
chemical engineer

material engineers

civil engineer
mechanical engineer
electrical engineer / comp engineer.

September 3, 2024 11:20 AM



Course Syllabus for APS110/164 - Engineering Chemistry and Materials Science

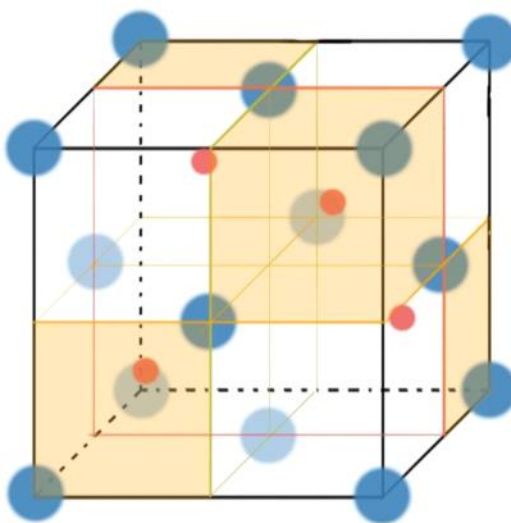
Prof Timothy P. Bender

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Fall 2024



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1 Land Acknowledgment

It is important to acknowledge the land that the University of Toronto itself is situated on. Therefore, we would like to acknowledge this 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 we are grateful to have the opportunity to work on this land.

2 Who is going to teach you

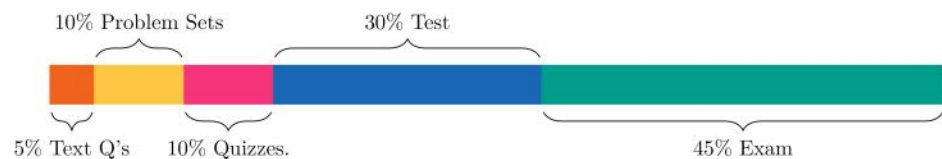
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Prof. Scott Ramsay, PhD, PEng | scott.ramsay@utoronto.ca | LEC0101

3 Mark Breakdown

The final grade that you earn in this course will be distributed across several items, as shown here.



- **Online Textbook Questions**

These are completed online through the TopHat textbook.

- **Problem Sets**

These will be posted on Quercus at least one week prior to the due date and your answers must be uploaded to Quercus as a single PDF document. You may work together with classmates on these, but you must not copy one another directly.

- **Online Quercus Quizzes**

These will be completed on Quercus as timed 30 minute quizzes. The quiz will be available for a 24 hour period on the posted date, however once you begin you will only have one 30 minute attempt at the quiz.

- **Term Test**

The test will be in person and follow the same format as previous tests, typically 10 - 15 MCQ followed by 4-5 short answer questions. Typically the time to complete the test is one hour.

- **Final Exam**

This is run during the final exam period, in person. It follows the same format as in previous years and is 2.5 hours in duration.

4 Course Level Learning Outcomes

These are the high level learning objectives. Be sure to familiarize yourself with the detailed learning objectives for this course. By the end of this course, students should be able to:

1. Articulate at least one logical characterization scheme for matter
2. Describe the uniaxial mechanical behaviour of metals, ceramics, and polymers
3. Describe the elastic behaviour of matter under shear loading
4. Distinguish between crystalline and non-crystalline matter in terms of long-range and short-range order
5. Explain and perform basic calculations involving the most common crystal structures of matter
6. Describe the generalized mechanical behaviour of plastic, elastomeric, and brittle polymers in uniaxial tension
7. Describe the mechanisms for elastic and permanent deformation in metals, ceramics, and polymers
8. Rationlize the optical and electrical behaviour of matter in terms of the Band Theory of solids

9. Explain, compare, and contrast the primary bonds as well as secondary bonds
10. Explain the zeroth, first, second, and third laws of Thermodynamics
11. Describe the spontaneity of a process in terms of the change in entropy
12. Analyze and interpret a binary phase diagram

5 What you'll learn in this course

This course is structured around the principle of structure-property relationship. This relationship refers to an understanding of the microstructure of a solid, that is, the nature of the bonds between atoms and the spatial arrangement of atoms, which permits the explanation of observed behaviour. Observed materials behaviour includes mechanical, electrical, magnetic, optical, and corrosive behaviour. Topics covered in this course include: structure of the atom, models of the atom, electronic configuration, the electromagnetic spectrum, band theory, atomic bonding, optical transparency of solids, molecular bonding, hybridized orbitals, crystal systems, imperfections in solids, materials thermodynamics, free energy, phase equilibrium, and chemical equilibrium.

5.1 How all of that fits into this course

In the detailed learning objective/lecture schedule provided on Quercus you'll find a chronological listing of the topics that will be covered in this course. You'll notice that the topical sections seem to jump around a bit. Good observation! This is because there are so many interrelated concepts in this course (and with other courses) and we will move into new topics as our level of understanding grows and we encounter new unanswered questions. As we build increasingly detailed levels of understanding we'll be able to return to older topics with a new appreciation. Beautiful.

You will only be assessed on what is covered in the learning objectives.

6 What you should know before this course

We will assume that you have already learned some basic topics. Some of these topics are important enough that I will cover them again, however most will not and so if you are a little rusty on any of them you will want to review them. I am happy to suggest helpful resources if needed.

- The basic structure of the atom (protons, neutrons, electrons, atomic number)
- The periodic table
- Hooke's Law as applied to springs ($F=Kx$)
- Proficiency with arithmetic and trigonometry
- Proficiency with basic mathematical functions including the exponential function and the logarithmic function
- The Cartesian coordinate system

7 Things to help you succeed

7.1 Textbooks that you'll find useful

Required Textbook

We'll be using an online textbook, hosted by [Top Hat](#). You'll need to purchase the online textbook and enroll in the course using the join code indicated on Quercus.

NOTE: you should only be charged \$37.80 plus tax. Do not pay more than this. If Top Hat asks you for more than this, please let me know.

Other Texts An excellent textbook that you may want to refer to if you are thirsty for more information or just need another perspective on a topic is *Fundamentals of Materials Science & Engineering*, 4th or 5th Edition, by William D. Callister, Jr., John Wiley & Sons, Inc.

Callister provides excellent coverage of nearly all of the topics in this course, however, when we cover thermodynamics and chemical equilibrium you may need more than Callister has to offer.

For the thermodynamics section, please refer to the following freely available text on the Open Textbook Library:

- Entire Text: [General Chemistry: Principles, Patterns, and Applications](#)
- [Direct link to thermodynamics chapter.](#)
- [Direct link to chemical equilibrium chapter.](#)

7.2 Videos

All of the lectures in this course will be made available through [Prof. Ramsay's YouTube channel](#) along with short videos on all of the topics.

8 Other important things that you should know

8.1 Communication with instructors

You may contact the instructors via email and we will do our best to respond in a timely fashion, however, we do receive a high volume of emails and occasionally will unintentionally overlook an email. If you do not receive a response from either of us within 12 - 24 hours or so, please email again.

We also encourage you to post questions on the course discussion board where your classmates will then also be able to benefit from the responses.

Please review discussion postings before posting your own to avoid redundant topics.

8.2 Deadlines

A deduction of 20% of the total possible points on an assignment will be awarded for each day that an assignment is late, beginning at one minute after the deadline and again for every 24 hour period thereafter.

9 Mental Health and Wellness

As a university student, you may experience a range of health and/or mental health issues that may result in significant barriers to achieving your personal and academic goals. The University of Toronto offers a wide range of free and confidential services and programs that may be able to assist you. We encourage you to seek out these resources early and often.

- [Student Life Website](#)
- [Health and Wellness Website](#)

If, at any point during the year, you find yourself feeling distressed and in need of more immediate support, visit the [Feeling Distressed Webpage](http://www.studentlife.utoronto.ca/feeling-distressed): <http://www.studentlife.utoronto.ca/feeling-distressed> for more campus resources.

Off campus, immediate help is available 24/7 through Good2Talk, a post-secondary student helpline at 1-866-925-5454.

All students in the Faculty of Engineering have an Academic Advisor who can advise on academic and personal matters. You can find your department's Academic Advisor here:

<http://undergrad.engineering.utoronto.ca/advising-support-services/academic-advising/>

10 Institutional policies and support

10.1 ACADEMIC INTEGRITY

Academic integrity is essential to the pursuit of learning and scholarship in a university, and to ensuring that a degree from the University of Toronto is a strong signal of each student's individual academic achievement. As a result, the University treats cases of cheating and plagiarism very seriously. The University of Toronto's Code of Behaviour on Academic Matters (www.governingcouncil.utoronto.ca/policies/behaveac.htm) outlines the behaviours that constitute academic dishonesty and the processes for addressing academic offences. Potential offences include, but are not limited to:

In papers and assignments:

1. Using someone else's ideas or words without appropriate acknowledgement.
2. Submitting your own work in more than one course without the permission of the instructor.
3. Making up sources or facts.
4. Obtaining or providing unauthorized assistance on any assignment.

On tests and exams:

1. Using or possessing unauthorized aids.
2. Looking at someone else's answers during an exam or test.
3. Misrepresenting your identity.

In academic work:

1. Falsifying institutional documents or grades.
2. Falsifying or altering any documentation required by the University.

All suspected cases of academic dishonesty will be investigated following procedures outlined in the Code of Behaviour on Academic Matters. If you have questions or concerns about what constitutes appropriate academic behaviour or appropriate research and citation methods, you are expected to seek out additional information on academic integrity from your instructor or from other institutional resources. Please also refer to:

www.utoronto.ca/academicintegrity/resourcesforstudents.html.

Normally, students will be required to submit their course essays to the University's plagiarism detection tool for a review of textual similarity and detection of possible plagiarism. In doing so, students will allow their essays to be included as source documents in the tool's reference database, where they will be used solely for the purpose of detecting plagiarism. The terms that apply to the University's use of this tool are described on the Centre for Teaching Support & Innovation web site (<https://uoft.me/pdt-faq>).

10.2 Inclusion

All students, staff, and faculty at the University of Toronto have a right to learn, work and create in a welcoming, respectful, inclusive and safe environment. In this class we are all responsible for our language, actions and interactions. Discriminatory speech or actions of any kind will not be permitted, and do not align with the values of our Faculty. As a class we will support each other's learning by creating an inclusive learning environment, one which is based on mutual respect for the dignity and worth of every person.

If you experience or witness any form of discrimination, please reach out to the Engineering Equity Diversity & Inclusion Action Group online, an academic advisor, a U of T Equity Office, or any FASE faculty or staff member that you feel comfortable approaching.

10.3 Accessibility needs

Students with diverse learning styles and needs are welcome in this course. Please feel free to approach me or contact Accessibility Services (accessibility.services@utoronto.ca) so we can assist you in achieving academic success in this course. If you require accommodations for a disability, or have any accessibility concerns about the course, the classroom or course materials, please contact Accessibility Services as soon as possible. Services and support The following are some important links to help you with academic and/or technical service and support

- General student services and resources at Student Life
- Full library service through University of Toronto Libraries
- Resources on conducting online research through University Libraries Research
- Resources on academic support from the Academic Success Centre
- Learner support at the Writing Centre
- Information about Accessibility Services
- Information for Technical Support/Blackboard Support (Portal Info)

10.4 Copyright

If a student wishes to copy or reproduce lecture presentations, course notes or other similar materials provided by instructors, he or she must obtain the instructor's written consent beforehand. Otherwise all such reproduction is an infringement of copyright and is absolutely prohibited.

10.5 Recordings of online sessions

This course, including your participation, will be recorded on video and will be available to students in the course for viewing remotely and after each session. Course videos and materials belong to your instructor, the University, and/or other source depending on the specific facts of each situation, and are protected by copyright. In this course, you are permitted to download session videos and materials for your own academic use, but you should not copy, share, or use them for any other purpose without the explicit permission of the instructor. For questions about recording and use of videos in which you appear please contact your instructor.

Eng Sci -

Track One -

CHÉ -

MSÉ -

Civ -

Min -

MEC -

ECE -

Introduction 3

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Rough plan for tutorials is:

Short review (<10 min)

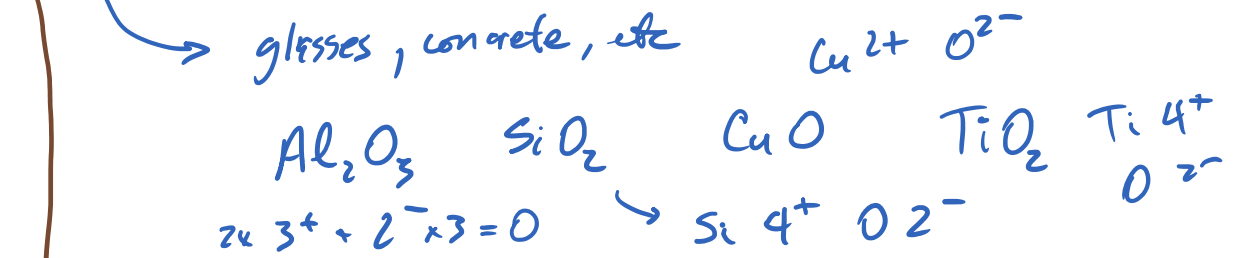
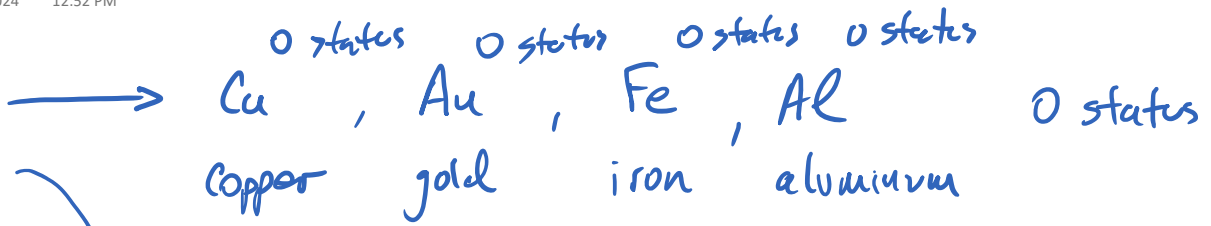
Mock quiz (~30 min, self-graded)

Problem solving with classmates/TA (~3 problems presented by TA)

Metals

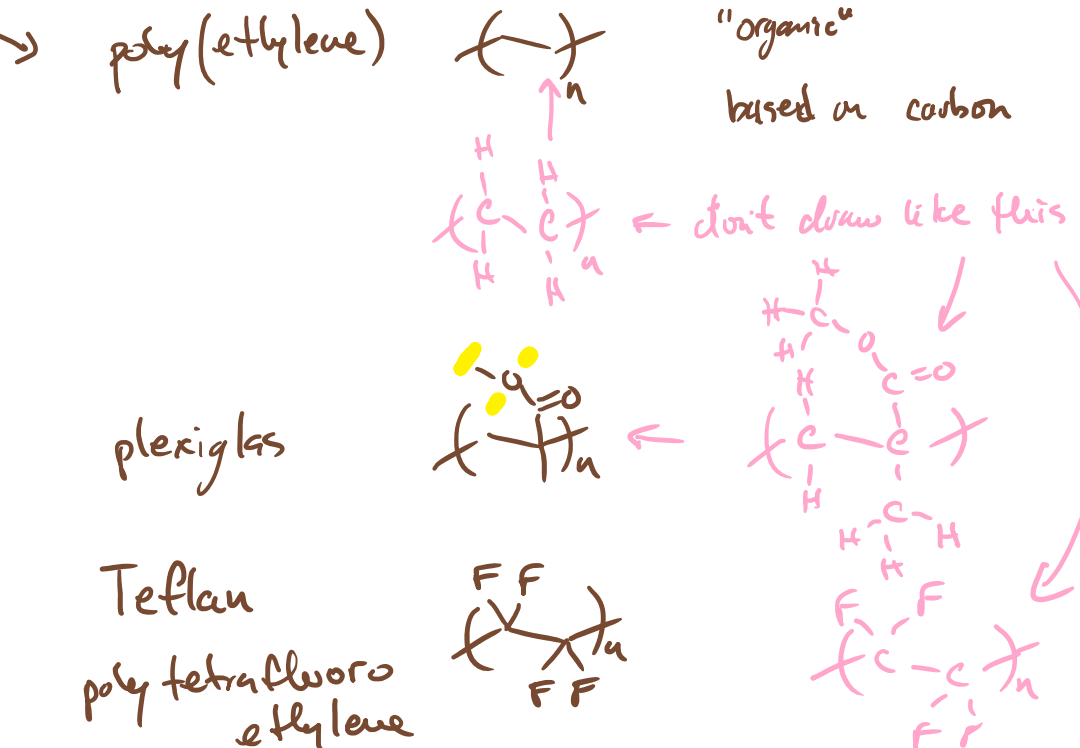
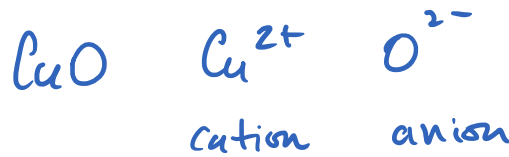
Ceramics

Polymers



not salts = NaCl_2

i.e. here is a salt - above are not 'salts'...



Kelvin - K

Celsius - °C

$0\text{K} = -273.15^\circ\text{C}$

$100^\circ\text{C} = 373.15\text{K}$

water
boiling point

Periodic table - atom mass

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<https://pubchem.ncbi.nlm.nih.gov/>

PERIODIC TABLE OF ELEMENTS

→

→

1

H

Hydrogen

1.0080

3

Li

Lithium

7.0

4

Be

Beryllium

9.012183

11

Na

Sodium

22.9897693

12

Mg

Magnesium

24.305

19

K

Potassium

39.098

20

Ca

Calcium

40.08

21

Sc

Scandium

44.95591

22

Ti

Titanium

47.87

23

V

Vanadium

50.941

24

Cr

Chromium

51.996

25

Mn

Manganese

54.93804

26

Fe

Iron

55.84

27

Co

Cobalt

58.93319

28

Ni

Nickel

58.693

29

Cu

Copper

63.55

30

Zn

Zinc

65.4

31

Ga

Gallium

69.72

32

Ge

Germanium

72.63

33

As

Arsenic

74.92159

34

Se

Selenium

78.97

35

Br

Bromine

79.90

36

Kr

Krypton

83.80

37

Rb

Rubidium

85.468

38

Sr

Strontium

87.6

39

Y

Yttrium

88.9058

40

Zr

Zirconium

91.22

41

Nb

Niobium

92.9064

42

Mo

Molybdenum

96.0

43

Tc

Technetium

97.90721

44

Ru

Ruthenium

101.1

45

Rh

Rhodium

102.9055

46

Pd

Palladium

106.4

47

Ag

Silver

107.868

48

Cd

Cadmium

112.41

49

In

Indium

114.82

50

Sn

Tin

118.71

51

Sb

Antimony

121.76

52

Te

Tellurium

127.6

53

I

Iodine

126.9045

54

Xe

Xenon

131.29

55

Cs

Cesium

132.9054520

56

Ba

Barium

137.33

72

Hf

Hafnium

178.5

73

Ta

Tantalum

180.9479

74

W

Tungsten

183.8

75

Re

Rhenium

186.21

76

Os

Osmium

190.2

77

Ir

Iridium

192.22

78

Pt

Platinum

195.08

79

Au

Gold

196.96657

80

Hg

Mercury

200.59

81

Tl

Thallium

204.383

82

Pb

Lead

207

83

Bi

Bismuth

208.9804

84

Po

Polonium

209

85

At

Astatine

209

86

Rn

Radon

222

87

Fr

Francium

223

88

Ra

Radium

226

104

Rf

Rutherfordium

261

105

Db

Dubnium

268

106

Sg

Seaborgium

271

107

Bh

Bohrium

274

108

Hs

Hassium

277

109

Mt

Meitnerium

278

110

Ds

Darmstadtium

281

111

Rg

Roentgenium

282

112

Cn

Copernicium

285

113

Nh

Nihonium

286

114

Fl

Flerovium

289

115

Mc

Moscovium

290

116

Lv

Livermorium

293

117

Ts

Tennessine

294

118

Og

Oganesson

294

57

La

Lanthanum

138.9055

58

Ce

Cerium

140.12

59

Pr

Praseodymium

140.9077

60

Nd

Neodymium

144.24

61

Pm

Promethium

144.91276

62

Sm

Samarium

150.4

63

Eu

Europium

151.96

64

Gd

Gadolinium

157.2

65

Tb

Terbium

158.92535

66

Dy

Dysprosium

162.50

67

Ho

Holmium

164.93033

68

Er

Erbium

167.26

69

Tm

Thulium

168.93422

70

Yb

Ytterbium

173.04

71

Lu

Lutetium

174.967

89

Ac

Actinium

227

90

Th

Thorium

232

91

Pa

Protactinium

231

92

U

Uranium

238

93

Np

Neptunium

237

94

Pu

Plutonium

244

95

Am

Americium

243

96

Cm

Curium

247

97

Bk

Berkelium

247

98

Cf

Californium

251

99

Es

Einsteinium

252

100

Fm

Fermium

257

101

Md

Mendelevium

258

102

No

Nobelium

259

103

Lr

Lawrencium

262

1

H

Hydrogen

1.0080

Atomic Number

Symbol

Name

Atomic Mass, u

PubChem

5

B

Boron

10.81

6

C

Carbon

12.011

7

N

Nitrogen

14.007

8

O

Oxygen

15.999

9

F

Fluorine

18.99840316

10

Ne

Neon

20.180

11

Al

Aluminum

26.981538

12

Si

Silicon

28.085

13

P

Phosphorus

30.97376209

14

S

Sulfur

32.07

15

Cl

Chlorine

35.45

16

Ar

Argon

39.9

Periodic table - atom radius

September 5, 2024 2:22 PM

<https://pubchem.ncbi.nlm.nih.gov/>

PERIODIC TABLE OF ELEMENTS

1 H Hydrogen 1		PubChem																2 He Helium 2																	
3 Li Lithium 3		4 Be Beryllium 4		<div>1 H Hydrogen 120</div> <div>Atomic Number</div> <div>Symbol</div> <div>Name</div> <div>Atomic Radius (van der Waals), pm</div>																		5 B Boron 5		6 C Carbon 6		7 N Nitrogen 7		8 O Oxygen 8		9 F Fluorine 9		10 Ne Neon 10			
11 Na Sodium 11		12 Mg Magnesium 12		<div>metals</div>																		13 Al Aluminum 13		14 Si Silicon 14		15 P Phosphorus 15		16 S Sulfur 16		17 Cl Chlorine 17		18 Ar Argon 18			
19 K Potassium 19		20 Ca Calcium 20		21 Sc Scandium 21		22 Ti Titanium 22		23 V Vanadium 23		24 Cr Chromium 24		25 Mn Manganese 25		26 Fe Iron 26		27 Co Cobalt 27		28 Ni Nickel 28		29 Cu Copper 29		30 Zn Zinc 30		31 Ga Gallium 31		32 Ge Germanium 32		33 As Arsenic 33		34 Se Selenium 34		35 Br Bromine 35		36 Kr Krypton 36	
37 Rb Rubidium 37		38 Sr Strontium 38		39 Y Yttrium 39		40 Zr Zirconium 40		41 Nb Niobium 41		42 Mo Molybdenum 42		43 Tc Technetium 43		44 Ru Ruthenium 44		45 Rh Rhodium 45		46 Pd Palladium 46		47 Ag Silver 47		48 Cd Cadmium 48		49 In Indium 49		50 Sn Tin 50		51 Sb Antimony 51		52 Te Tellurium 52		53 I Iodine 53		54 Xe Xenon 54	
55 Cs Cesium 55		56 Ba Barium 56		72 Hf Hafnium 72		73 Ta Tantalum 73		74 W Tungsten 74		75 Re Rhenium 75		76 Os Osmium 76		77 Ir Iridium 77		78 Pt Platinum 78		79 Au Gold 79		80 Hg Mercury 80		81 Tl Thallium 81		82 Pb Lead 82		83 Bi Bismuth 83		84 Po Polonium 84		85 At Astatine 85		86 Rn Radon 86			
87 Fr Francium 87		88 Ra Radium 88		104 Rf Rutherfordium 104		105 Db Dubnium 105		106 Sg Seaborgium 106		107 Bh Bohrium 107		108 Hs Hassium 108		109 Mt Meitnerium 109		110 Ds Darmstadtium 110		111 Rg Roentgenium 111		112 Cn Copernicium 112		113 Nh Nihonium 113		114 Fl Flerovium 114		115 Mc Moscovium 115		116 Lv Livermorium 116		117 Ts Tennessine 117		118 Og Oganesson 118			
57 La Lanthanum 57		58 Ce Cerium 58		59 Pr Praseodymium 59		60 Nd Neodymium 60		61 Pm Promethium 61		62 Sm Samarium 62		63 Eu Europium 63		64 Gd Gadolinium 64		65 Tb Terbium 65		66 Dy Dysprosium 66		67 Ho Holmium 67		68 Er Erbium 68		69 Tm Thulium 69		70 Yb Ytterbium 70		71 Lu Lutetium 71							
89 Ac Actinium 89		90 Th Thorium 90		91 Pa Protactinium 91		92 U Uranium 92		93 Np Neptunium 93		94 Pu Plutonium 94		95 Am Americium 95		96 Cm Curium 96		97 Bk Berkelium 97		98 Cf Californium 98		99 Es Einsteinium 99		100 Fm Fermium 100		101 Md Mendelevium 101		102 No Nobelium 102		103 Lr Lawrencium 103							

'metalloids'

PERIODIC TABLE OF ELEMENTS

1

H

Hydrogen

0.00008988

3

Li

Lithium

0.534

4

Be

Beryllium

1.85

11

Na

Sodium

0.97

12

Mg

Magnesium

1.74

1

H

Hydrogen

0.00008988

Atomic Number

Symbol

Name

Density, g/cm³

5

B

Boron

2.37

6

C

Carbon

2.2670

7

N

Nitrogen

0.0012506

8

O

Oxygen

0.001429

9

F

Fluorine

0.001696

10

Ne

Neon

0.0008999

13

Al

Aluminum

2.70

14

Si

Silicon

2.3296

15

P

Phosphorus

1.82

16

S

Sulfur

2.067

17

Cl

Chlorine

0.003214

18

Ar

Argon

0.0017837

19

K

Potassium

0.89

20

Ca

Calcium

1.54

21

Sc

Scandium

2.89

22

Ti

Titanium

4.5

23

V

Vanadium

6.0

24

Cr

Chromium

7.15

25

Mn

Manganese

7.3

26

Fe

Iron

7.874

27

Co

Cobalt

8.86

28

Ni

Nickel

8.912

29

Cu

Copper

8.933

30

Zn

Zinc

7.134

31

Ga

Gallium

5.91

32

Ge

Germanium

5.323

33

As

Arsenic

5.778

34

Se

Selenium

4.809

35

Br

Bromine

3.11

36

Kr

Krypton

0.003733

37

Rb

Rubidium

1.53

38

Sr

Strontium

2.64

39

Y

Yttrium

4.47

40

Zr

Zirconium

6.52

41

Nb

Niobium

8.57

42

Mo

Molybdenum

10.2

43

Tc

Technetium

11

44

Ru

Ruthenium

12.1

45

Rh

Rhodium

12.4

46

Pd

Palladium

12.0

47

Ag

Silver

10.501

48

Cd

Cadmium

8.69

49

In

Indium

7.31

50

Sn

Tin

7.287

51

Sb

Antimony

6.685

52

Te

Tellurium

6.232

53

I

Iodine

4.93

54

Xe

Xenon

0.005887

55

Cs

Cesium

1.93

56

Ba

Barium

3.62

•

72

Hf

Hafnium

13.3

73

Ta

Tantalum

16.4

74

W

Tungsten

19.3

75

Re

Rhenium

20.9

76

Os

Osmium

22.57

77

Ir

Iridium

22.43

78

Pt

Platinum

21.46

79

Au

Gold

19.382

80

Hg

Mercury

13.5336

81

Tl

Thallium

11.8

82

Pb

Lead

11.342

83

Bi

Bismuth

9.807

84

Po

Polonium

9.32

85

At

Astatine

7

86

Rn

Radon

0.00873

87

Fr

Francium

88

Ra

Radium

5

••

104

Rf

Rutherfordium

105

Db

Dubnium

106

Sg

Seaborgium

107

Bh

Bohrium

108

Hs

Hassium

109

Mt

Meitnerium

110

Ds

Darmstadtium

111

Rg

Roentgenium

112

Cn

Copernicium

113

Nh

Nihonium

114

Fl

Flerovium

115

Mc

Moscovium

116

Lv

Livermorium

117

Ts

Tennessine

118

Og

Oganesson

57

La

Lanthanum

6.15

58

Ce

Cerium

6.770

59

Pr

Praseodymium

6.77

60

Nd

Neodymium

7.01

61

Pm

Promethium

7.26

62

Sm

Samarium

7.52

63

Eu

Europium

5.24

64

Gd

Gadolinium

7.90

65

Tb

Terbium

8.23

66

Dy

Dysprosium

8.55

67

Ho

Holmium

8.80

68

Er

Erbium

9.07

69

Tm

Thulium

9.32

70

Yb

Ytterbium

6.90

71

Lu

Lutetium

9.84

89

Ac

Actinium

10.07

90

Th

Thorium

11.72

91

Pa

Protactinium

15.37

92

U

Uranium

18.95

93

Np

Neptunium

20.25

94

Pu

Plutonium

19.84

95

Am

Americium

13.89

96

Cm

Curium

13.51

97

Bk

Berkelium

14

98

Cf

Californium

99

Es

Einsteinium

100

Fm

Fermium

101

Md

Mendelevium

102

No

Nobelium

103

Lr

Lawrencium

Periodic table - melting point

September 6, 2024 8:18 AM

<https://pubchem.ncbi.nlm.nih.gov/>

PERIODIC TABLE OF ELEMENTS

1 H Hydrogen 13.81		PubChem																2 He Helium 0.95																							
3 Li Lithium 453.65		4 Be Beryllium 1560		1 H Hydrogen 13.81																5 B Boron 2348		6 C Carbon 3823		7 N Nitrogen 63.15		8 O Oxygen 54.36		9 F Fluorine 53.53		10 Ne Neon 24.56											
11 Na Sodium 370.95		12 Mg Magnesium 923																		13 Al Aluminum 933.437		14 Si Silicon 1687		15 P Phosphorus 317.3		16 S Sulfur 388.36		17 Cl Chlorine 171.65		18 Ar Argon 83.8											
19 K Potassium 336.53		20 Ca Calcium 1115		21 Sc Scandium 1814		22 Ti Titanium 1941		23 V Vanadium 2183		24 Cr Chromium 2180		25 Mn Manganese 1519		26 Fe Iron 1811		27 Co Cobalt 1768		28 Ni Nickel 1728		29 Cu Copper 1357.77		30 Zn Zinc 692.68		31 Ga Gallium 302.91		32 Ge Germanium 1211.4		33 As Arsenic 1090		34 Se Selenium 493.65		35 Br Bromine 265.95		36 Kr Krypton 115.79							
37 Rb Rubidium 372.46		38 Sr Strontium 1050		39 Y Yttrium 1795		40 Zr Zirconium 2128		41 Nb Niobium 2750		42 Mo Molybdenum 2896		43 Tc Technetium 2430		44 Ru Ruthenium 2607		45 Rh Rhodium 2237		46 Pd Palladium 1828.05		47 Ag Silver 1234.93		48 Cd Cadmium 594.22		49 In Indium 429.75		50 Sn Tin 505.08		51 Sb Antimony 903.78		52 Te Tellurium 722.66		53 I Iodine 386.85		54 Xe Xenon 161.36							
55 Cs Cesium 301.59		56 Ba Barium 1000		•		72 Hf Hafnium 2506		73 Ta Tantalum 3290		74 W Tungsten 3695		75 Re Rhenium 3459		76 Os Osmium 3306		77 Ir Iridium 2219		78 Pt Platinum 2041.55		79 Au Gold 1337.33		80 Hg Mercury 234.32		81 Tl Thallium 577		82 Pb Lead 600.61		83 Bi Bismuth 544.55		84 Po Polonium 527		85 At Astatine 575		86 Rn Radon 202							
87 Fr Francium 300		88 Ra Radium 973		**		104 Rf Rutherfordium		105 Db Dubnium		106 Sg Seaborgium		107 Bh Bohrium		108 Hs Hassium		109 Mt Meitnerium		110 Ds Darmstadtium		111 Rg Roentgenium		112 Cn Copernicium		113 Nh Nihonium		114 Fl Flerovium		115 Mc Moscovium		116 Lv Livermorium		117 Ts Tennessine		118 Og Oganesson							
•		57 La Lanthanum 1191		58 Ce Cerium 1071		59 Pr Praseodymium 1204		60 Nd Neodymium 1284		61 Pm Promethium 1315		62 Sm Samarium 1347		63 Eu Europium 1095		64 Gd Gadolinium 1586		65 Tb Terbium 1629		66 Dy Dysprosium 1685		67 Ho Holmium 1747		68 Er Erbium 1802		69 Tm Thulium 1818		70 Yb Ytterbium 1092		71 Lu Lutetium 1936											
**		89 Ac Actinium 1324		90 Th Thorium 2023		91 Pa Protactinium 1845		92 U Uranium 1408		93 Np Neptunium 917		94 Pu Plutonium 913		95 Am Americium 1449		96 Cm Curium 1618		97 Bk Berkelium 1323		98 Cf Californium 1173		99 Es Einsteinium 1133		100 Fm Fermium 1800		101 Md Mendelevium 1100		102 No Nobelium 1100		103 Lr Lawrencium 1900											

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1 H Hydrogen Gas	<div> <div>PubChem</div> <div> <div>1</div> <div>Atomic Number</div> <div>H</div> <div>Symbol</div> <div>Hydrogen</div> <div>Gas</div> <div>Name</div> <div>Standard State</div> </div> </div>																2 He Helium Gas	
3 Li Lithium Solid	4 Be Beryllium Solid																	10 Ne Neon Gas
11 Na Sodium Solid	12 Mg Magnesium Solid																	18 Ar Argon Gas
19 K Potassium Solid	20 Ca Calcium Solid	21 Sc Scandium Solid	22 Ti Titanium Solid	23 V Vanadium Solid	24 Cr Chromium Solid	25 Mn Manganese Solid	26 Fe Iron Solid	27 Co Cobalt Solid	28 Ni Nickel Solid	29 Cu Copper Solid	30 Zn Zinc Solid	31 Ga Gallium Solid	32 Ge Germanium Solid	33 As Arsenic Solid	34 Se Selenium Solid	35 Br Bromine Liquid	36 Kr Krypton Gas	
37 Rb Rubidium Solid	38 Sr Strontium Solid	39 Y Yttrium Solid	40 Zr Zirconium Solid	41 Nb Niobium Solid	42 Mo Molybdenum Solid	43 Tc Technetium Solid	44 Ru Ruthenium Solid	45 Rh Rhodium Solid	46 Pd Palladium Solid	47 Ag Silver Solid	48 Cd Cadmium Solid	49 In Indium Solid	50 Sn Tin Solid	51 Sb Antimony Solid	52 Te Tellurium Solid	53 I Iodine Solid	54 Xe Xenon Gas	
55 Cs Cesium Solid	56 Ba Barium Solid	•	72 Hf Hafnium Solid	73 Ta Tantalum Solid	74 W Tungsten Solid	75 Re Rhenium Solid	76 Os Osmium Solid	77 Ir Iridium Solid	78 Pt Platinum Solid	79 Au Gold Solid	80 Hg Mercury Liquid	81 Tl Thallium Solid	82 Pb Lead Solid	83 Bi Bismuth Solid	84 Po Polonium Solid	85 At Astatine Solid	86 Rn Radon Gas	
87 Fr Francium Solid	88 Ra Radium Solid	••	104 Rf Rutherfordium Solid	105 Db Dubnium Solid	106 Sg Seaborgium Solid	107 Bh Bohrium Solid	108 Hs Hassium Solid	109 Mt Meitnerium Solid	110 Ds Darmstadtium Solid (Expected)	111 Rg Roentgenium Solid (Expected)	112 Cn Copernicium Solid (Expected)	113 Nh Nihonium Solid (Expected)	114 Fl Flerovium Solid (Expected)	115 Mc Moscovium Solid (Expected)	116 Lv Livermorium Solid (Expected)	117 Ts Tennessine Solid (Expected)	118 Og Oganesson Gas (Expected)	
•	•	•	57 La Lanthanum Solid	58 Ce Cerium Solid	59 Pr Praseodymium Solid	60 Nd Neodymium Solid	61 Pm Promethium Solid	62 Sm Samarium Solid	63 Eu Europium Solid	64 Gd Gadolinium Solid	65 Tb Terbium Solid	66 Dy Dysprosium Solid	67 Ho Holmium Solid	68 Er Erbium Solid	69 Tm Thulium Solid	70 Yb Ytterbium Solid	71 Lu Lutetium Solid	
••	••	••	89 Ac Actinium Solid	90 Th Thorium Solid	91 Pa Protactinium Solid	92 U Uranium Solid	93 Np Neptunium Solid	94 Pu Plutonium Solid	95 Am Americium Solid	96 Cm Curium Solid	97 Bk Berkelium Solid	98 Cf Californium Solid	99 Es Einsteinium Solid	100 Fm Fermium Solid	101 Md Mendelevium Solid	102 No Nobelium Solid	103 Lr Lawrencium Solid	

Hooke's Law

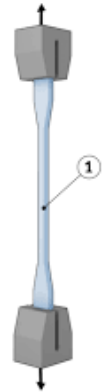
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2:34 PM

$$\vec{F} = -k\Delta x$$

Tensile Test

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MANUFACTURING GUIDE

