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## Introductory day - APS110 Intro Chemistry and Materials Science

- **Section 3** - Prof Timothy P Bender - [tim.bender@utoronto.ca](mailto:tim.bender@utoronto.ca) - 'inbox' on Quercus

### ➤ **Land Acknowledgment**

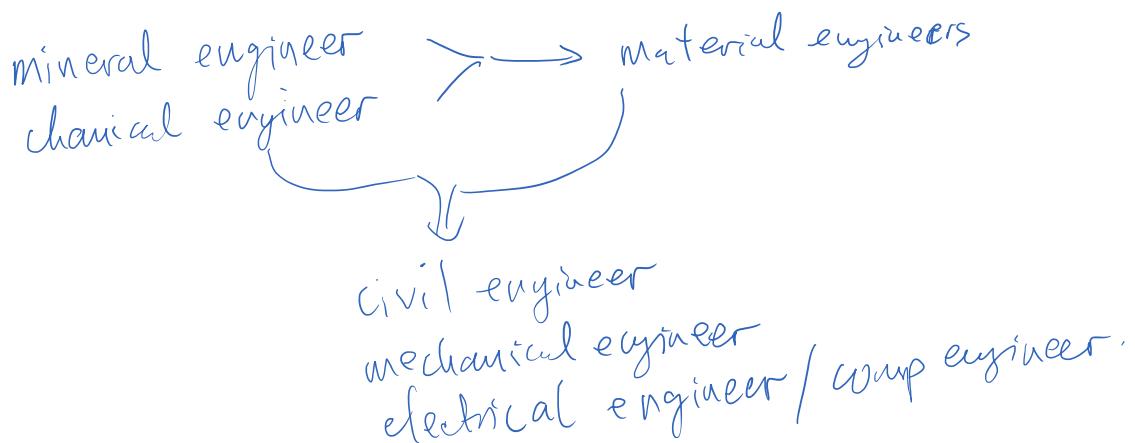
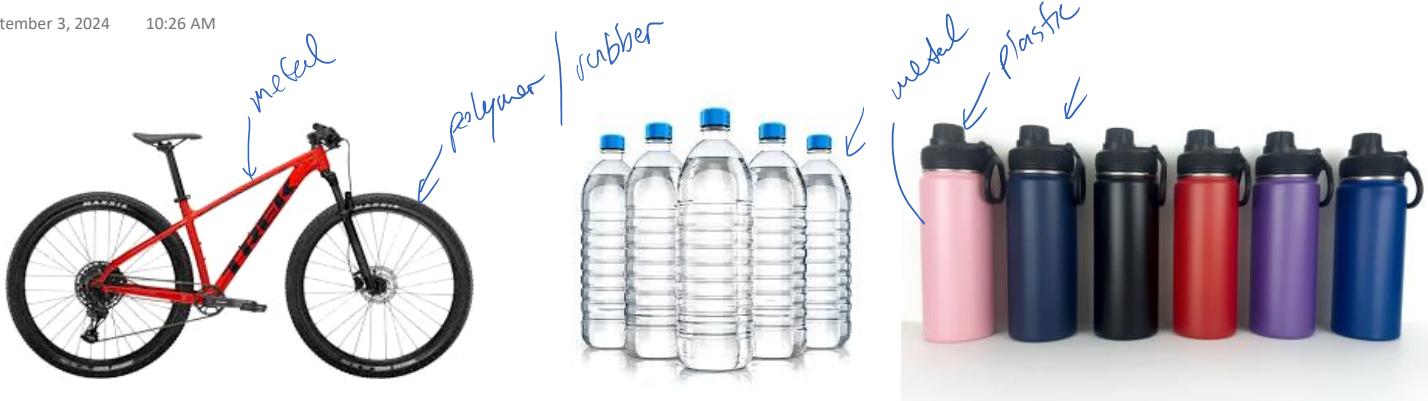
I would like to acknowledge the land on which the University of Toronto operates. For thousands of years it has been the traditional land of the Huron-Wendat, the Seneca, and most recently, the Mississaugas of the Credit River. Today, this meeting place is still the home to many Indigenous people from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

- 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.

... slides from First Year Dean's office

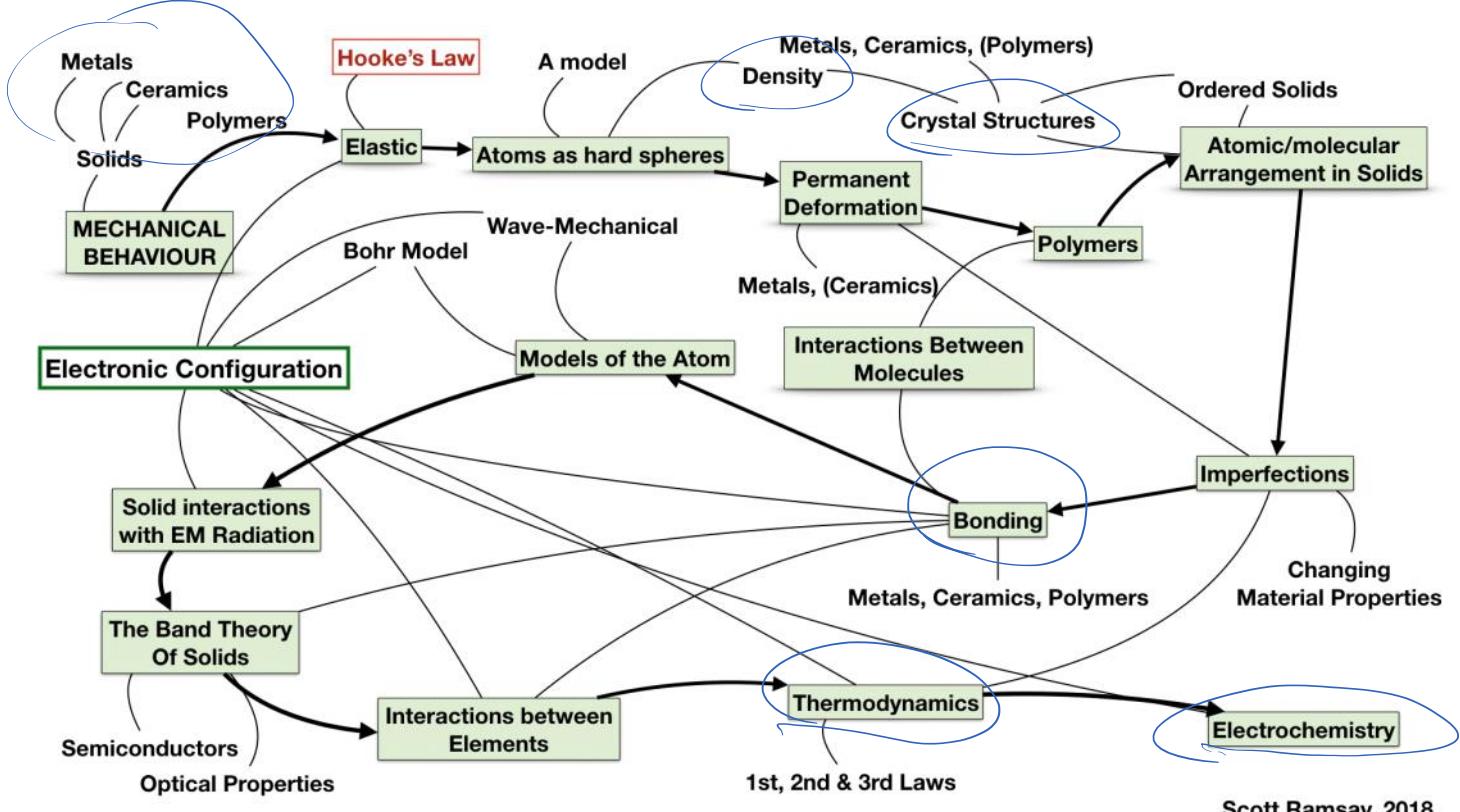
# Introduction

September 3, 2024 10:26 AM



# Introduction 2

September 3, 2024 11:20 AM



# Syllabus

September 3, 2024 10:21 AM

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

**Prof Timothy P. Bender**

**Prof Frank Gu**

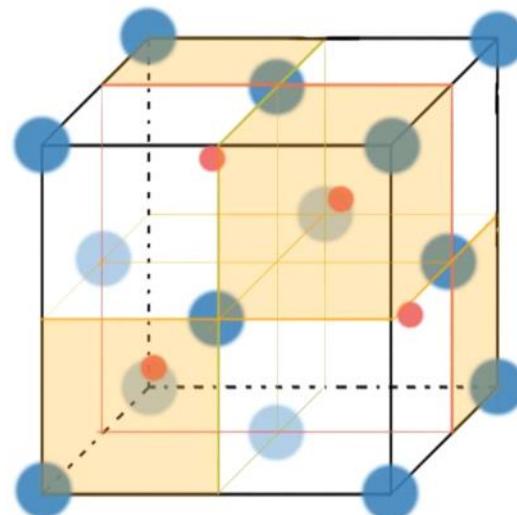
Tim Bender and Frank Gu

Department of Chemical Engineering

Scott Ramsay **Prof Scott Ramsay**

Department of Materials Science & Engineering

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**

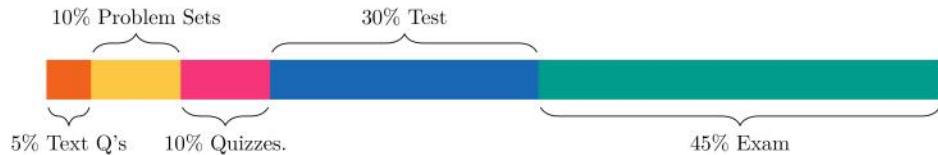
Prof. Tim Bender, PhD | [tim.bender@utoronto.ca](mailto:tim.bender@utoronto.ca) | LEC0103

Prof. Frank Gu, PhD, PEng | [f.gu@utoronto.ca](mailto:f.gu@utoronto.ca) | LEC0102

Prof. Scott Ramsay, PhD, PEng | [scott.ramsay@utoronto.ca](mailto: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. Rationalize 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> 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](http://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](http://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](mailto: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.

Ehy Sci -

Track One -

CHÉ -

WSE -

Civ -

Mia -

MEC -

ECE -

# Introduction 3

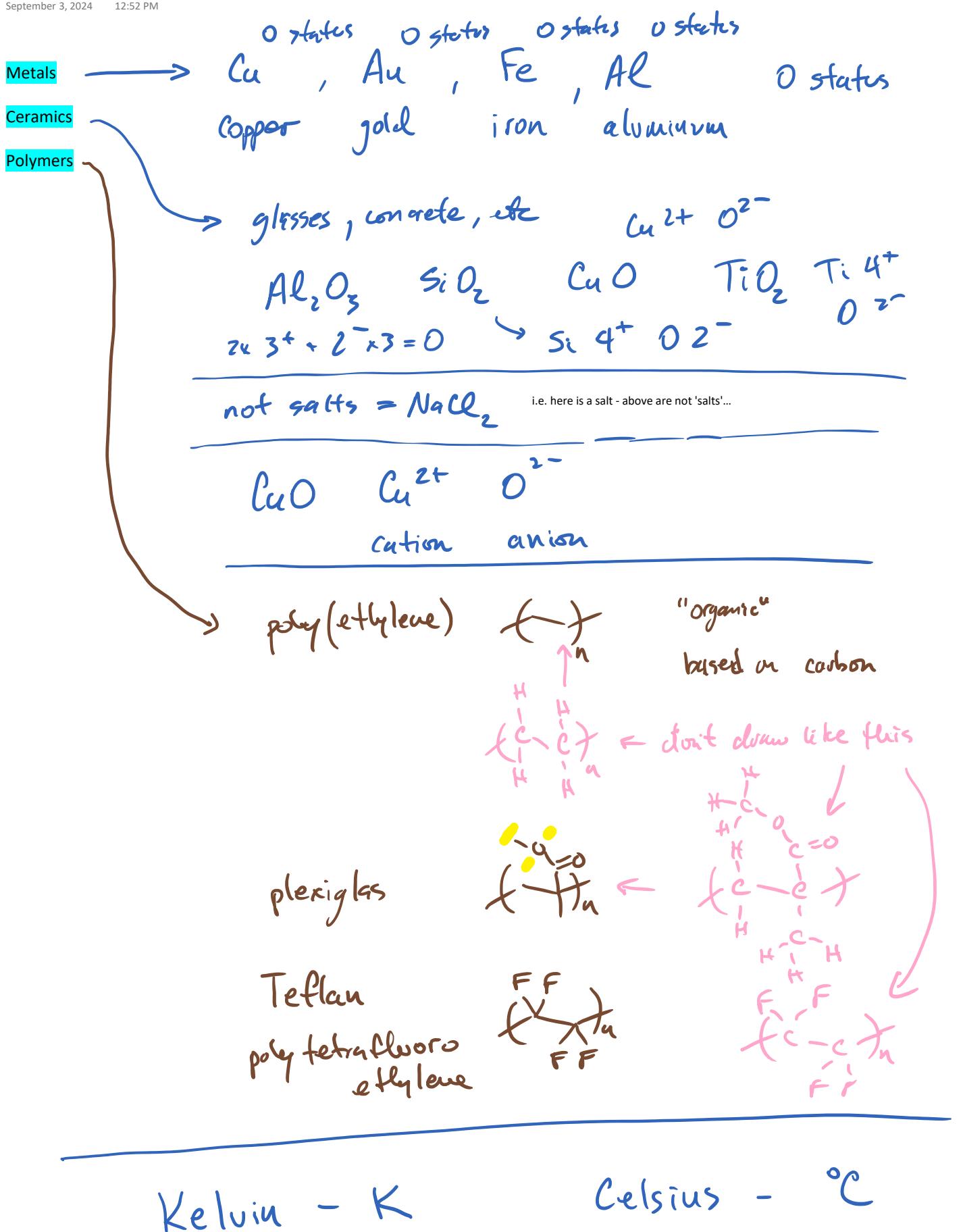
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## **Rough plan for tutorials is:**

Short review (<10 min)

Mock quiz (~30 min, self-graded)

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



water  
boiling point

# Periodic table - atom mass

September 5, 2024

2:21 PM

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

# PERIODIC TABLE OF ELEMENTS

1 <b>H</b> Hydrogen 1.0080	2 <b>He</b> Helium 4.00260
3 <b>Li</b> Lithium 7.0	4 <b>Be</b> Beryllium 9.012183
11 <b>Na</b> Sodium 22.9897693	12 <b>Mg</b> Magnesium 24.305
19 <b>K</b> Potassium 39.098	20 <b>Ca</b> Calcium 40.08
21 <b>Sc</b> Scandium 44.95591	22 <b>Ti</b> Titanium 47.87
23 <b>V</b> Vanadium 50.941	24 <b>Cr</b> Chromium 51.996
25 <b>Mn</b> Manganese 54.93804	26 <b>Fe</b> Iron 55.84
27 <b>Co</b> Cobalt 58.9319	28 <b>Ni</b> Nickel 58.693
29 <b>Cu</b> Copper 63.55	30 <b>Zn</b> Zinc 65.4
31 <b>Ga</b> Gallium 69.72	32 <b>Ge</b> Germanium 72.63
33 <b>As</b> Arsenic 74.92159	34 <b>Se</b> Selenium 78.97
35 <b>Br</b> Bromine 79.90	36 <b>Kr</b> Krypton 83.80
37 <b>Rb</b> Rubidium 85.468	38 <b>Sr</b> Strontium 87.6
39 <b>Y</b> Yttrium 88.9058	40 <b>Zr</b> Zirconium 91.22
41 <b>Nb</b> Niobium 92.9064	42 <b>Mo</b> Molybdenum 96.0
43 <b>Tc</b> Technetium 97.90721	44 <b>Ru</b> Ruthenium 101.1
45 <b>Rh</b> Rhodium 102.9055	46 <b>Pd</b> Palladium 106.4
47 <b>Ag</b> Silver 107.868	48 <b>Cd</b> Cadmium 112.41
49 <b>In</b> Indium 114.82	50 <b>Sn</b> Antimony 118.71
51 <b>Sb</b> Antimony 121.76	52 <b>Te</b> Tellurium 127.8
53 <b>I</b> Iodine 128.0045	54 <b>Xe</b> Xenon 131.28
55 <b>Cs</b> Cesium 132.9054520	56 <b>Ba</b> Barium 137.33
72 <b>Hf</b> Hafnium 178.5	73 <b>Ta</b> Tantalum 180.9479
74 <b>W</b> Tungsten 183.8	75 <b>Re</b> Rhenium 186.21
76 <b>Os</b> Osmium 190.2	77 <b>Ir</b> Iridium 192.22
78 <b>Pt</b> Platinum 195.08	79 <b>Au</b> Gold 196.96657
80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.383
82 <b>Pb</b> Lead 207	83 <b>Bi</b> Bismuth 208.9804
84 <b>Po</b> Polonium 208.98243	85 <b>At</b> Astatine 209.98715
86 <b>Rn</b> Radon 222.01758	87 <b>Fr</b> Francium 223.01973
88 <b>Ra</b> Radium 226.02641	104 <b>Rf</b> Rutherfordium 267.122
105 <b>Db</b> Dubnium 268.126	106 <b>Sg</b> Seaborgium 271.134
107 <b>Bh</b> Bohrium 274.164	108 <b>Hs</b> Hassium 277.152
109 <b>Mt</b> Meitnerium 278.156	110 <b>Ds</b> Darmstadtium 281.165
111 <b>Rg</b> Roentgenium 282.169	112 <b>Cn</b> Copernicium 285.177
113 <b>Nh</b> Nihonium 286.183	114 <b>Fl</b> Flerovium 289.191
115 <b>Mc</b> Moscovium 290.198	116 <b>Lv</b> Livermorium 293.205
117 <b>Ts</b> Tennessine 294.211	118 <b>Og</b> Oganesson 294.214
57 <b>La</b> Lanthanum 138.9055	58 <b>Ce</b> Cerium 140.12
59 <b>Pr</b> Praseodymium 140.9077	60 <b>Nd</b> Neodymium 144.24
61 <b>Pm</b> Promethium 144.91276	62 <b>Sm</b> Samarium 150.4
63 <b>Eu</b> Europium 151.96	64 <b>Gd</b> Gadolinium 157.2
65 <b>Tb</b> Terbium 158.9235	66 <b>Dy</b> Dysprosium 162.50
67 <b>Ho</b> Holmium 164.93033	68 <b>Er</b> Erbium 167.26
69 <b>Tm</b> Thulium 168.93422	70 <b>Yb</b> Ytterbium 173.04
71 <b>Lu</b> Lutetium 174.967	89 <b>Ac</b> Actinium 227.02778
90 <b>Th</b> Thorium 232.038	91 <b>Pa</b> Protactinium 231.0359
92 <b>U</b> Uranium 238.0289	93 <b>Np</b> Neptunium 237.04817
94 <b>Pu</b> Plutonium 244.06420	95 <b>Am</b> Americium 243.05138
96 <b>Cm</b> Curium 247.07035	97 <b>Bk</b> Berkelium 247.07031
98 <b>Cf</b> Californium 251.07959	99 <b>Es</b> Einsteinium 252.0830
100 <b>Fm</b> Fermium 252.09811	101 <b>Md</b> Mendelevium 258.08843
102 <b>No</b> Nobelium 259.10100	103 <b>Lr</b> Lawrencium 262.110

# Periodic table - atom radius

September 5, 2024 2:22 PM

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

# PERIODIC TABLE OF ELEMENTS

**PubChem**

**metals**

**metalloids**

Atomic Number	Symbol	Name	Atomic Radius (van der Waals), pm
1	H	Hydrogen	120
3	Li	Lithium	182
4	Be	Beryllium	153
11	Na	Sodium	227
12	Mg	Magnesium	173
19	K	Potassium	275
20	Ca	Calcium	231
21	Sc	Scandium	211
22	Ti	Titanium	187
23	V	Vanadium	189
24	Cr	Chromium	189
25	Mn	Manganese	197
26	Fe	Iron	194
27	Co	Cobalt	192
28	Ni	Nickel	163
29	Cu	Copper	140
30	Zn	Zinc	139
31	Ga	Gallium	187
32	Ge	Germanium	153
33	As	Arsenic	186
34	Se	Selenium	190
35	Br	Bromine	183
36	Kr	Krypton	202
37	Rb	Rubidium	303
38	Sr	Stron튬	249
39	Y	Yttrium	219
40	Zr	Zirconium	198
41	Nb	Niobium	207
42	Mo	Molybdenum	209
43	Tc	Technetium	209
44	Ru	Ruthenium	207
45	Rh	Rhodium	198
46	Pd	Palladium	202
47	Ag	Silver	172
48	Cd	Cadmium	158
49	In	Inidium	193
50	Sn	Tin	171
51	Sb	Antimony	206
52	Te	Tellurium	206
53	I	Iodine	198
54	Xe	Xenon	216
55	Cs	Cesium	343
56	Ba	Barium	268
57	Hf	Hafnium	212
58	Ta	Tantalum	217
59	W	Tungsten	210
60	Re	Rhenium	217
61	Os	Osmium	216
62	Ir	Iridium	202
63	Pt	Platinum	209
64	Au	Gold	166
65	Hg	Mercury	209
66	Tl	Thallium	196
67	Pb	Lead	202
68	Bi	Bismuth	207
69	Po	Polonium	197
70	At	Astatine	202
71	Rn	Radon	220
87	Fr	Rutherfordium	150
88	Ra	Dubnium	139
104	Rf	Seaborgium	132
105	Db	Bohrium	128
106	Sg	Methylmercury	128
107	Bh	Darmstadtium	132
108	Hs	Roentgenium	138
109	Mt	Copernicium	147
110	Ds	Nihonium	170
111	Rg	Flerovium	180
112	Cn	Moscovium	187
113	Nh	Livermorium	183
114	Fl	Tennessee	138
115	Mc	Oganesson	
116	Lv		
117	Ts		
118	Og		
57	La	Lanthanum	240
58	Ce	Cerium	235
59	Pr	Praseodymium	239
60	Nd	Neodymium	229
61	Pm	Promethium	238
62	Sm	Samarium	239
63	Eu	Europlum	233
64	Gd	Gadolinium	237
65	Tb	Terbium	221
66	Dy	Dysprosium	229
67	Ho	Holmium	216
68	Er	Erbium	235
69	Tm	Thulium	227
70	Yb	Ytterbium	242
71	Lu	Lutetium	221
89	Ac	Actinium	260
90	Th	Thorium	237
91	Pa	Protactinium	243
92	U	Uranium	240
93	Np	Neptunium	221
94	Pu	Plutonium	243
95	Am	Americium	244
96	Cm	Curium	248
97	Bk	Berkelium	244
98	Cf	Californium	248
99	Es	Einsteinium	245
100	Fm	Fermium	
101	Md	Mendelevium	
102	No	Nobelium	
103	Lr	Lawrencium	

# Periodic table - density

September 6, 2024 8:11 AM

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

# PERIODIC TABLE OF ELEMENTS



1 <b>H</b> Hydrogen 0.00008988	3 <b>Li</b> Lithium 0.934	4 <b>Be</b> Beryllium 1.86	1 <b>H</b> Hydrogen 0.00008988	Atomic Number <b>Symbol</b> Name Density, g/cm³		5 <b>B</b> Boron 2.37	6 <b>C</b> Carbon 2.2670	7 <b>N</b> Nitrogen 0.0012506	8 <b>O</b> Oxygen 0.001429	9 <b>F</b> Fluorine 0.001696	10 <b>Ne</b> Neon 0.001785					
11 <b>Na</b> Sodium 0.97	12 <b>Mg</b> Magnesium 1.74	21 <b>Sc</b> Scandium 2.99	22 <b>Ti</b> Titanium 4.5	23 <b>V</b> Vanadium 6.0	24 <b>Cr</b> Chromium 7.15	25 <b>Mn</b> Manganese 7.3	26 <b>Fe</b> Iron 7.874	27 <b>Co</b> Cobalt 8.86	28 <b>Ni</b> Nickel 8.912	29 <b>Cu</b> Copper 8.933	30 <b>Zn</b> Zinc 7.134					
19 <b>K</b> Potassium 1.53	20 <b>Ca</b> Calcium 1.54	37 <b>Rb</b> Rubidium 1.53	38 <b>Sr</b> Strontium 2.64	39 <b>Y</b> Yttrium 4.47	40 <b>Zr</b> Zirconium 6.52	41 <b>Nb</b> Niobium 8.57	42 <b>Mo</b> Molybdenum 10.2	43 <b>Tc</b> Technetium 11	44 <b>Ru</b> Ruthenium 12.1	45 <b>Rh</b> Rhodium 12.4	46 <b>Pd</b> Palladium 12.0					
55 <b>Cs</b> Cesium 1.93	56 <b>Ba</b> Barium 3.62	72 <b>Hf</b> Hafnium 13.3	73 <b>Ta</b> Tantalum 16.4	74 <b>W</b> Tungsten 19.3	75 <b>Re</b> Rhenium 20.8	76 <b>Os</b> Osmium 22.57	77 <b>Ir</b> Iridium 22.42	78 <b>Pt</b> Platinum 31.46	79 <b>Au</b> Gold 19.382	80 <b>Hg</b> Mercury 13.5336	81 <b>Tl</b> Thallium 11.8	82 <b>Pb</b> Lead 11.342				
87 <b>Fr</b> Francium	88 <b>Ra</b> Radium 5	104 <b>Rf</b> Rutherfordium	105 <b>Db</b> Dubnium	106 <b>Sg</b> Seaborgium	107 <b>Bh</b> Bohrium	108 <b>Hs</b> Hassium	109 <b>Mt</b> Meitnerium	110 <b>Ds</b> Darmstadtium	111 <b>Rg</b> Roentgenium	112 <b>Cn</b> Copernicium	113 <b>Nh</b> Nihonium	114 <b>Fl</b> Flerovium	115 <b>Mc</b> Moscovium	116 <b>Lv</b> Livermorium	117 <b>Ts</b> Tennessine	118 <b>Og</b> Oganesson
.		57 <b>La</b> Lanthanum 6.15	58 <b>Ce</b> Cerium 6.70	59 <b>Pr</b> Praseodymium 6.77	60 <b>Nd</b> Neodymium 7.01	61 <b>Pm</b> Promethium 7.26	62 <b>Sm</b> Samarium 7.52	63 <b>Eu</b> Europium 5.24	64 <b>Gd</b> Gadolinium 7.90	65 <b>Tb</b> Terbium 8.23	66 <b>Dy</b> Dysprosium 8.55	67 <b>Ho</b> Holmium 8.80	68 <b>Er</b> Erbium 9.07	69 <b>Tm</b> Thulium 9.32	70 <b>Yb</b> Ytterbium 6.90	71 <b>Lu</b> Lutetium 9.84
..		89 <b>Ac</b> Actinium 10.07	90 <b>Th</b> Thorium 11.72	91 <b>Pa</b> Protactinium 15.37	92 <b>U</b> Uranium 18.99	93 <b>Np</b> Neptunium 20.23	94 <b>Pu</b> Plutonium 19.84	95 <b>Am</b> Americium 13.69	96 <b>Cm</b> Curium 15.01	97 <b>Bk</b> Berkelium 14	98 <b>Cf</b> Californium	99 <b>Es</b> Einsteinium	100 <b>Fm</b> Fermium	101 <b>Md</b> Mendelevium	102 <b>No</b> Nobelium	103 <b>Lr</b> Lawrencium

# Periodic table - melting point

September 6, 2024 8:18 AM

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

# PERIODIC TABLE OF ELEMENTS



1 <b>H</b> Hydrogen 13.81	3 <b>Li</b> Lithium 453.65	4 <b>Be</b> Beryllium 1600	1 <b>H</b> Hydrogen 13.81	Atomic Number <b>Symbol</b> Name Melting Point, K	2 <b>He</b> Helium 0.95												
11 <b>Na</b> Sodium 370.85	12 <b>Mg</b> Magnesium 923																
19 <b>K</b> Potassium 336.53	20 <b>Ca</b> Calcium 1115	21 <b>Sc</b> Scandium 1814	22 <b>Ti</b> Titanium 1941	23 <b>V</b> Vanadium 2180	24 <b>Cr</b> Chromium 2180	25 <b>Mn</b> Manganese 1519	26 <b>Fe</b> Iron 1811	27 <b>Co</b> Cobalt 1768	28 <b>Ni</b> Nickel 1728	29 <b>Cu</b> Copper 1357.77	30 <b>Zn</b> Zinc 892.68	31 <b>Ga</b> Gallium 302.91	32 <b>Ge</b> Germanium 1211.4	33 <b>As</b> Arsenic 1090	34 <b>Se</b> Selenium 493.85	35 <b>Br</b> Bromine 265.95	36 <b>Kr</b> Krypton 115.79
37 <b>Rb</b> Rubidium 312.48	38 <b>Sr</b> Strontium 1050	39 <b>Y</b> Yttrium 1795	40 <b>Zr</b> Zirconium 2128	41 <b>Nb</b> Niobium 2750	42 <b>Mo</b> Molybdenum 2886	43 <b>Tc</b> Technetium 2430	44 <b>Ru</b> Ruthenium 2607	45 <b>Rh</b> Rhodium 2237	46 <b>Pd</b> Palladium 1828.05	47 <b>Ag</b> Silver 1234.93	48 <b>Cd</b> Cadmium 594.22	49 <b>In</b> Indium 429.75	50 <b>Sn</b> Tin 505.08	51 <b>Sb</b> Antimony 903.78	52 <b>Te</b> Tellurium 722.66	53 <b>I</b> Iodine 386.85	54 <b>Xe</b> Xenon 161.36
55 <b>Cs</b> Cesium 301.59	56 <b>Ba</b> Barium 1000	-	72 <b>Hf</b> Hafnium 2506	73 <b>Ta</b> Tantalum 3290	74 <b>W</b> Tungsten 3695	75 <b>Re</b> Rhenium 3459	76 <b>Os</b> Osmium 3306	77 <b>Ir</b> Iridium 2719	78 <b>Pt</b> Platinum 2041.59	79 <b>Au</b> Gold 1337.33	80 <b>Hg</b> Mercury 234.32	81 <b>Tl</b> Thallium 677	82 <b>Pb</b> Lead 600.61	83 <b>Bi</b> Bismuth 544.55	84 <b>Po</b> Polonium 527	85 <b>At</b> Astatine 575	86 <b>Rn</b> Radon 202
87 <b>Fr</b> Francium 300	88 <b>Ra</b> Radium 973	..	104 <b>Rf</b> Rutherfordium 1324	105 <b>Db</b> Dubnium 2023	106 <b>Sg</b> Seaborgium 1845	107 <b>Bh</b> Bohrium 1408	108 <b>Hs</b> Hassium 917	109 <b>Mt</b> Meitnerium 913	110 <b>Ds</b> Darmstadtium 1449	111 <b>Rg</b> Roentgenium 1618	112 <b>Cn</b> Copernicium 1323	113 <b>Nh</b> Nihonium 1173	114 <b>Fl</b> Florium 1133	115 <b>Mc</b> Moscovium 1800	116 <b>Lv</b> Livermorium 1802	117 <b>Ts</b> Tennessine 1092	118 <b>Og</b> Oganesson 1900
			57 <b>La</b> Lanthanum 1191	58 <b>Ce</b> Cerium 1071	59 <b>Pr</b> Praseodymium 1204	60 <b>Nd</b> Neodymium 1284	61 <b>Pm</b> Promethium 1315	62 <b>Sm</b> Samarium 1347	63 <b>Eu</b> Europium 1095	64 <b>Gd</b> Gadolinium 1588	65 <b>Tb</b> Terbium 1628	66 <b>Dy</b> Dysprosium 1685	67 <b>Ho</b> Holmium 1747	68 <b>Er</b> Erbium 1802	69 <b>Tm</b> Thulium 1818	70 <b>Yb</b> Ytterbium 1092	71 <b>Lu</b> Lutetium 1936
			89 <b>Ac</b> Actinium 1324	90 <b>Th</b> Thorium 2023	91 <b>Pa</b> Protactinium 1845	92 <b>U</b> Uranium 1408	93 <b>Np</b> Neptunium 917	94 <b>Pu</b> Plutonium 913	95 <b>Am</b> Americium 1449	96 <b>Cm</b> Curium 1618	97 <b>Bk</b> Berkelium 1323	98 <b>Cf</b> Californium 1173	99 <b>Es</b> Einsteinium 1133	100 <b>Fm</b> Fermium 1800	101 <b>Md</b> Mendelevium 1100	102 <b>No</b> Nobelium 1106	103 <b>Lr</b> Lawrencium 1900

# Periodic table - 'standard state'

September 6, 2024 8:24 AM

# PERIODIC TABLE OF ELEMENTS

1 <b>H</b> Hydrogen Gas	2 <b>He</b> Helium Gas
3 <b>Li</b> Lithium Solid	4 <b>Be</b> Beryllium Solid
11 <b>Na</b> Sodium Solid	12 <b>Mg</b> Magnesium Solid
19 <b>K</b> Potassium Solid	20 <b>Ca</b> Calcium Solid
37 <b>Rb</b> Rubidium Solid	38 <b>Sr</b> Strontium Solid
55 <b>Cs</b> Cesium Solid	56 <b>Ba</b> Barium Solid
87 <b>Fr</b> Francium Solid	88 <b>Ra</b> Radium Solid
21 <b>Sc</b> Scandium Solid	22 <b>Ti</b> Titanium Solid
23 <b>V</b> Vanadium Solid	24 <b>Cr</b> Chromium Solid
25 <b>Mn</b> Manganese Solid	26 <b>Fe</b> Iron Solid
27 <b>Co</b> Cobalt Solid	28 <b>Ni</b> Nickel Solid
29 <b>Cu</b> Copper Solid	30 <b>Zn</b> Zinc Solid
31 <b>Ga</b> Gallium Solid	32 <b>Ge</b> Germanium Solid
33 <b>As</b> Arsenic Solid	34 <b>Se</b> Selenium Solid
35 <b>Br</b> Bromine Liquid	36 <b>Kr</b> Krypton Gas
39 <b>Y</b> Yttrium Solid	40 <b>Zr</b> Zirconium Solid
41 <b>Nb</b> Niobium Solid	42 <b>Mo</b> Molybdenum Solid
43 <b>Tc</b> Technetium Solid	44 <b>Ru</b> Ruthenium Solid
45 <b>Rh</b> Rhodium Solid	46 <b>Pd</b> Palladium Solid
47 <b>Ag</b> Silver Solid	48 <b>Cd</b> Cadmium Solid
49 <b>In</b> Indium Solid	50 <b>Sn</b> Tin Solid
51 <b>Sb</b> Antimony Solid	52 <b>Te</b> Tellurium Solid
53 <b>I</b> Iodine Solid	54 <b>Xe</b> Xenon Gas
72 <b>Hf</b> Hafnium Solid	73 <b>Ta</b> Tantalum Solid
74 <b>W</b> Tungsten Solid	75 <b>Re</b> Rhenium Solid
76 <b>Os</b> Osmium Solid	77 <b>Ir</b> Iridium Solid
78 <b>Pt</b> Platinum Solid	79 <b>Au</b> Gold Solid
80 <b>Hg</b> Mercury Liquid	81 <b>Tl</b> Thallium Solid
82 <b>Pb</b> Lead Solid	83 <b>Bi</b> Bismuth Solid
84 <b>Po</b> Polonium Solid	85 <b>At</b> Astatine Solid
86 <b>Rn</b> Radon Gas	87 <b>Og</b> Oganesson Gas (Expected)
104 <b>Rf</b> Rutherfordium Solid	105 <b>Db</b> Dubnium Solid
106 <b>Sg</b> Seaborgium Solid	107 <b>Bh</b> Bohrium Solid
108 <b>Hs</b> Hassium Solid	109 <b>Mt</b> Meitnerium Solid
110 <b>Ds</b> Darmstadtium Solid (Expected)	111 <b>Rg</b> Roentgenium Solid (Expected)
112 <b>Cn</b> Copernicium Solid (Expected)	113 <b>Nh</b> Nihonium Solid (Expected)
114 <b>Fl</b> Flerovium Solid (Expected)	115 <b>Mc</b> Moscovium Solid (Expected)
116 <b>Lv</b> Livermorium Solid (Expected)	117 <b>Ts</b> Tennessine Solid (Expected)
118 <b>Og</b> Oganesson Gas (Expected)	119 <b>Un</b> Unununium Solid (Expected)
57 <b>La</b> Lanthanum Solid	58 <b>Ce</b> Cerium Solid
59 <b>Pr</b> Praseodymium Solid	60 <b>Nd</b> Neodymium Solid
61 <b>Pm</b> Promethium Solid	62 <b>Sm</b> Samarium Solid
63 <b>Eu</b> Europium Solid	64 <b>Gd</b> Gadolinium Solid
65 <b>Tb</b> Terbium Solid	66 <b>Dy</b> Dysprosium Solid
67 <b>Ho</b> Holmium Solid	68 <b>Er</b> Erbium Solid
69 <b>Tm</b> Thulium Solid	70 <b>Yb</b> Ytterbium Solid
71 <b>Lu</b> Lutetium Solid	
89 <b>Ac</b> Actinium Solid	90 <b>Th</b> Thorium Solid
91 <b>Pa</b> Protactinium Solid	92 <b>U</b> Uranium Solid
93 <b>Np</b> Neptunium Solid	94 <b>Pu</b> Plutonium Solid
95 <b>Am</b> Americium Solid	96 <b>Cm</b> Curium Solid
97 <b>Bk</b> Berkelium Solid	98 <b>Cf</b> Californium Solid
99 <b>Es</b> Einsteinium Solid	100 <b>Fm</b> Fermium Solid
101 <b>Md</b> Mendelevium Solid	102 <b>No</b> Nobelium Solid
103 <b>Lr</b> Lawrencium Solid	

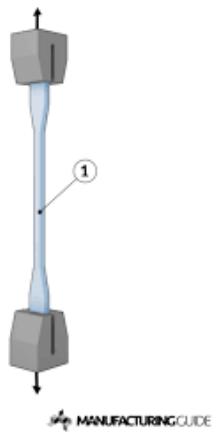
# Hooke's Law

September 5, 2024 2:34 PM

$$F = k\delta x$$

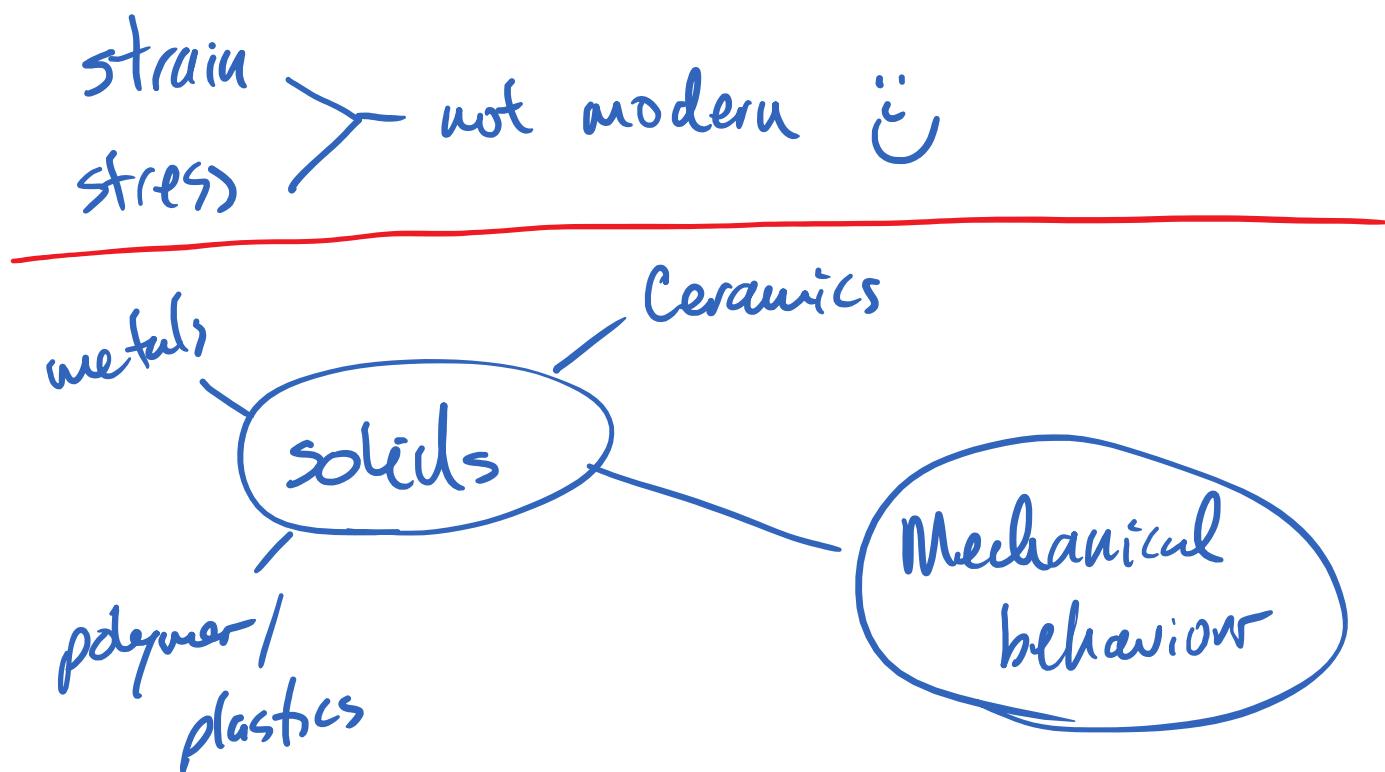
# Tensile Test

September 5, 2024 2:59 PM



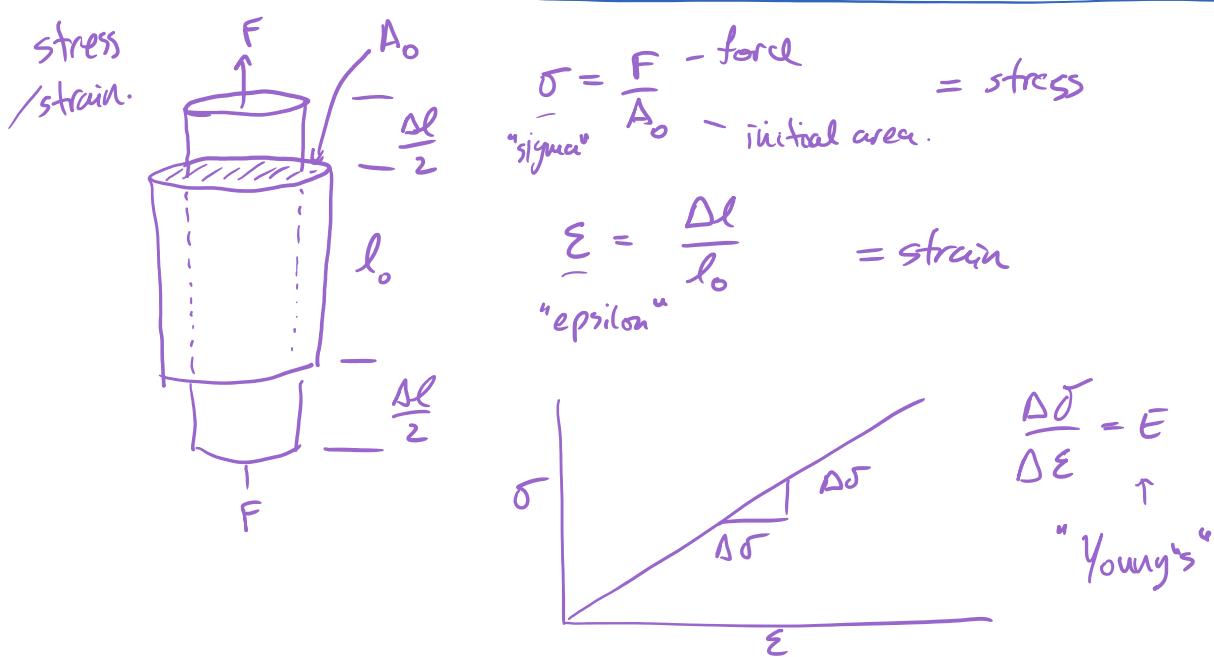
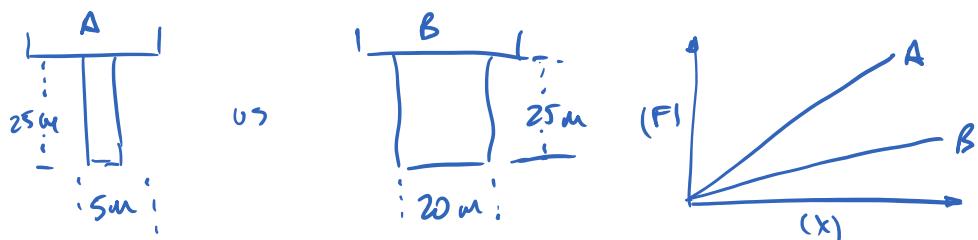
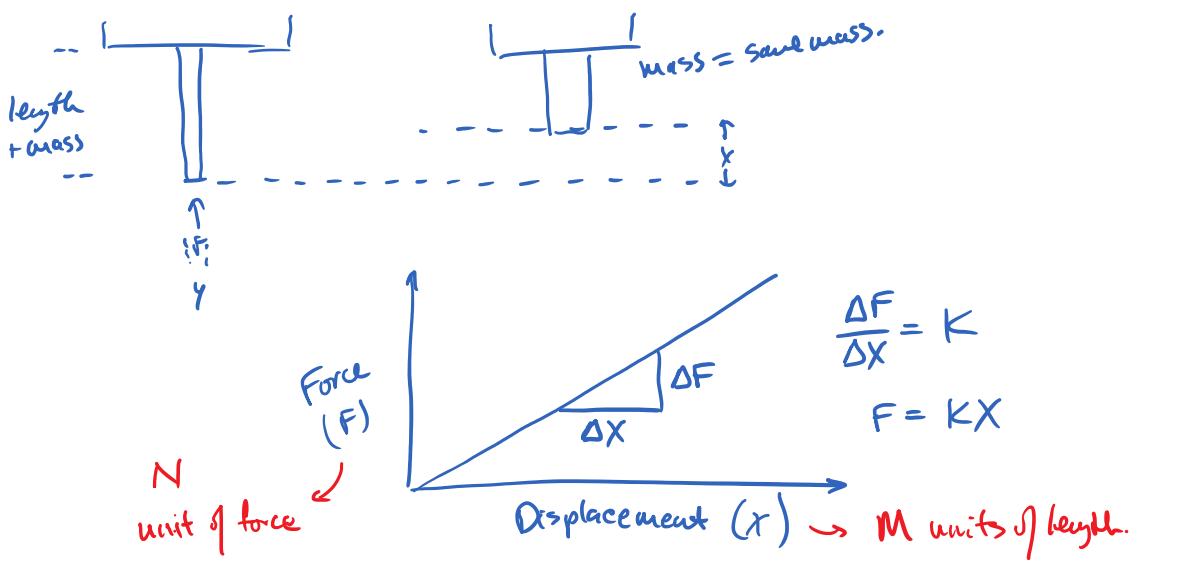
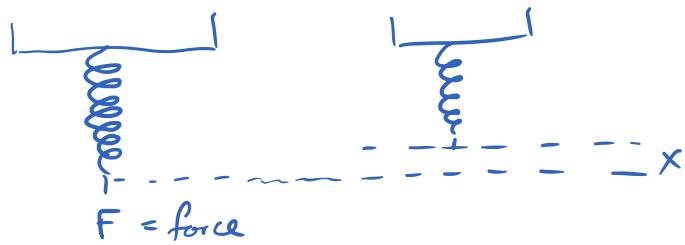
MANUFACTURINGGUIDE

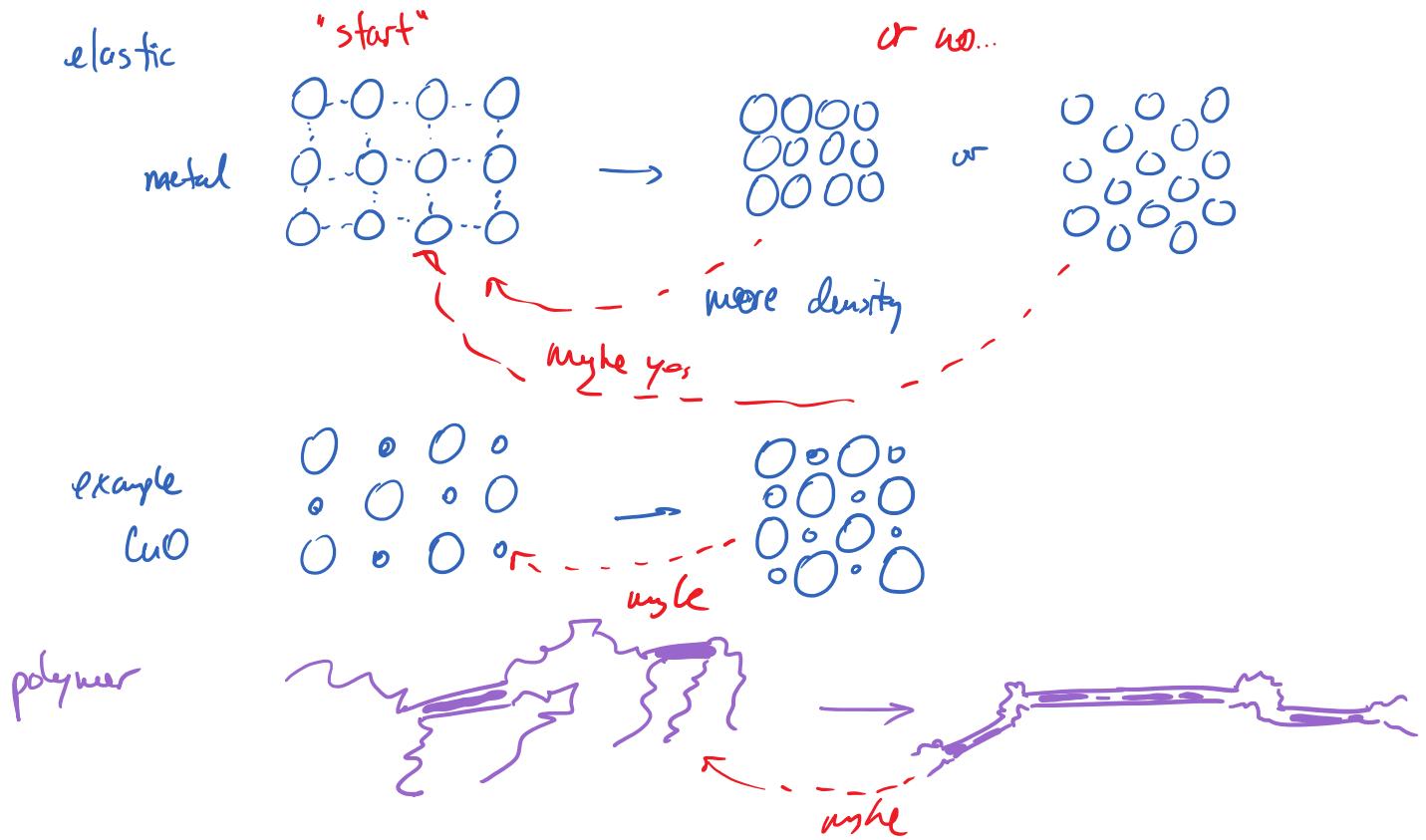
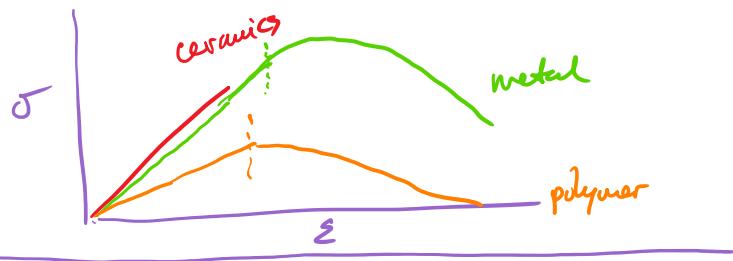




## Hooke's Law

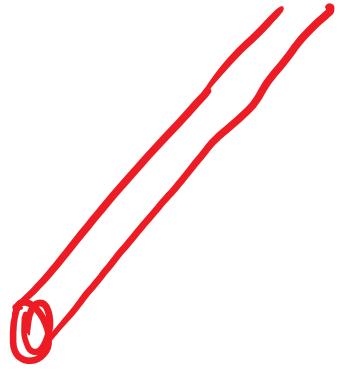
September 5, 2024 2:34 PM





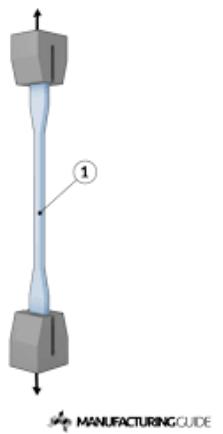
... just an example

September 9, 2024 9:16 AM



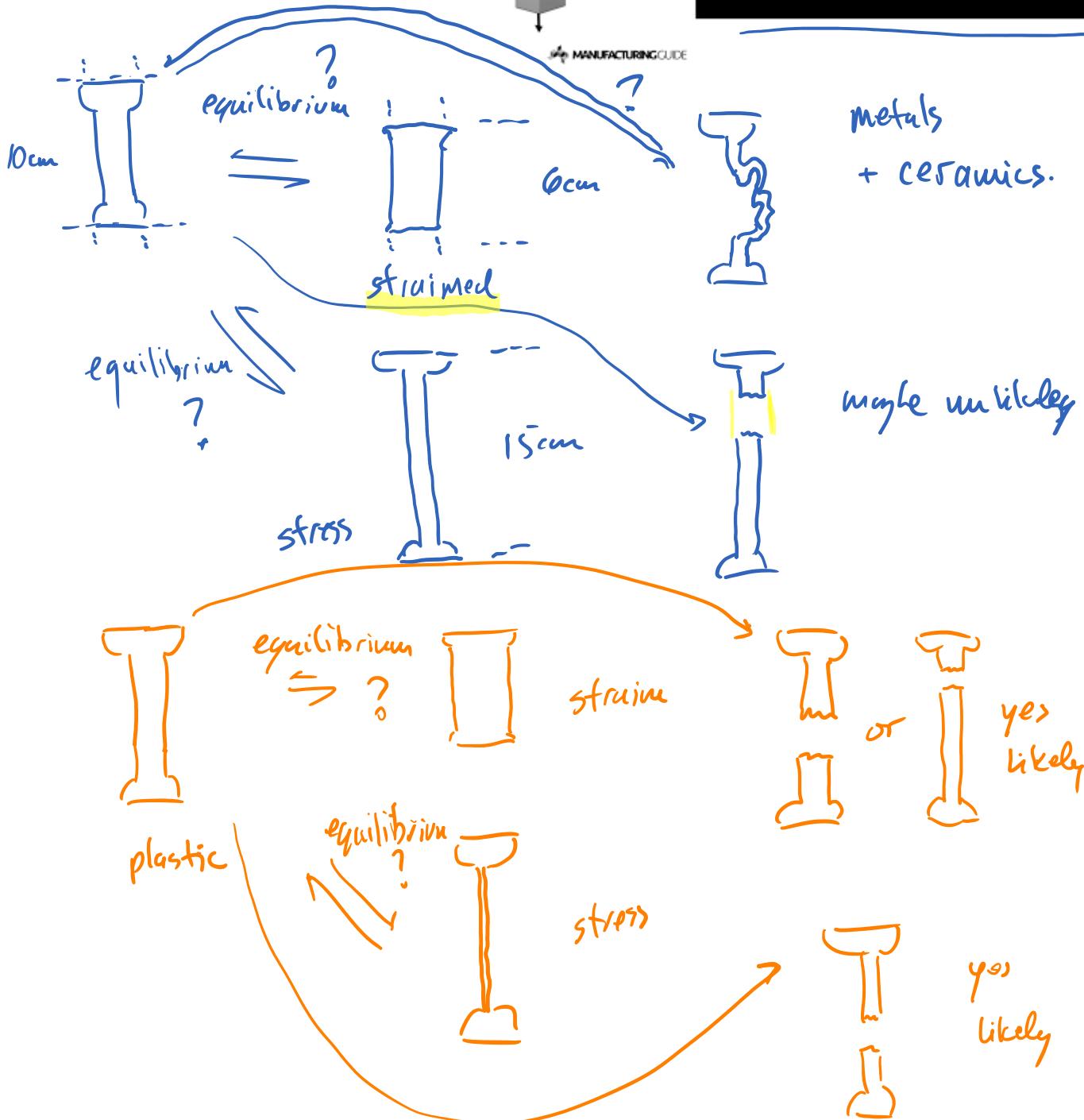
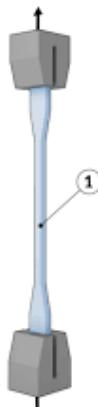
# Tensile Test

September 5, 2024 2:59 PM



MANUFACTURINGGUIDE





## "Bending" method

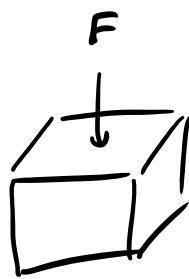
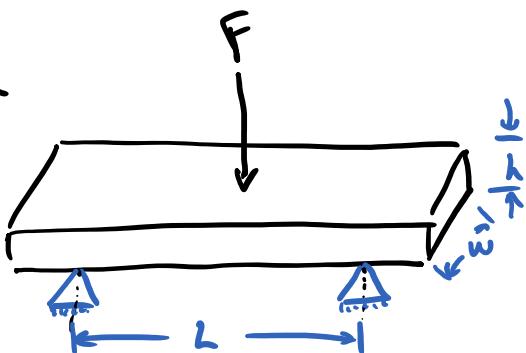
September 11, 2024

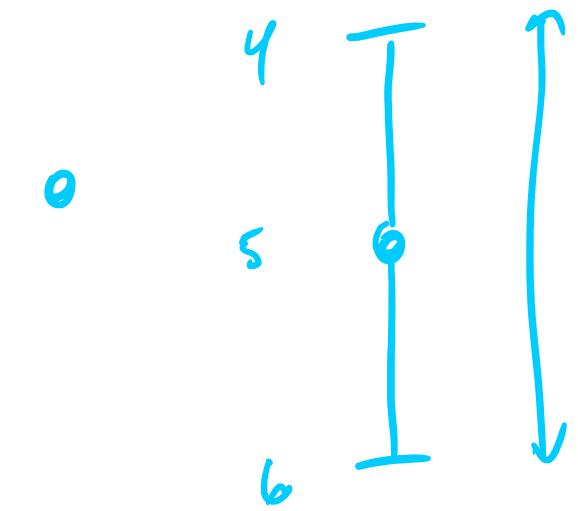
3:40 PM

$$\sigma_{3\text{-pt}} = \frac{3FL}{2wh^2}$$

local / power length  
width height

→ pt = 3 point bend strength





Density → Sept 16, 2024 / Monday

Demo

**"Bending" method**

$$F = n P_a \quad n = \text{number}$$

$$\delta_{3\text{-pt}} = \frac{3Pq}{2wh^2}$$

$$\delta_{3\text{-pt}} = \frac{3Pq \text{ mm}}{2 \text{ min mm}^2}$$

=  $n \text{ Pa/mm}^2$  type  
during  
glass :)

$$\delta_{3\text{-pt}} = \frac{3FL}{2wh^2}$$

width height

$\Rightarrow p_t = 3 \text{ point bend strength}$

Demo

#1 glass

$$h - 4.8 \text{ mm} = 0.48 \text{ cm}$$

$$w - 152 \text{ mm} = 15.2 \text{ cm}$$

$$L - 250 \text{ mm} = 25 \text{ cm} \text{ data } \#1 \times$$

$$382 \text{ mm} = 38.2 \text{ cm} \text{ data } \#2 \times$$

$$116 \text{ mm} = 11.6 \text{ cm} \text{ data } \#3 \checkmark$$

#2

$$h - 2 \text{ mm} = 0.2 \text{ cm}$$

$$w - 152 \text{ mm} = 15.2 \text{ cm}$$

$$L - 116 \text{ mm} = 11.6 \text{ cm} \text{ data } \#3 \checkmark$$

$$382 \text{ mm} = 38.2 \text{ cm} \text{ data } \#2 \times$$

$$250 \text{ mm} = 25 \text{ cm} \text{ data } \#1 \times$$

metal

$$h - 4.0 \text{ mm} = 0.40 \text{ cm}$$

$$w - 154 \text{ mm} = 15.4 \text{ cm}$$

$$L - 250 \text{ mm} = 25.0 \text{ cm} \sim 1\text{st glass}$$

$$382 \text{ mm} = 38.2 \text{ cm} - \text{worse than 1st glass}$$

$$116 \text{ mm} = 11.6 \text{ cm} - \text{seems "ok"}$$

plastic

$$h - 6.0 \text{ mm} = 0.6 \text{ cm}$$

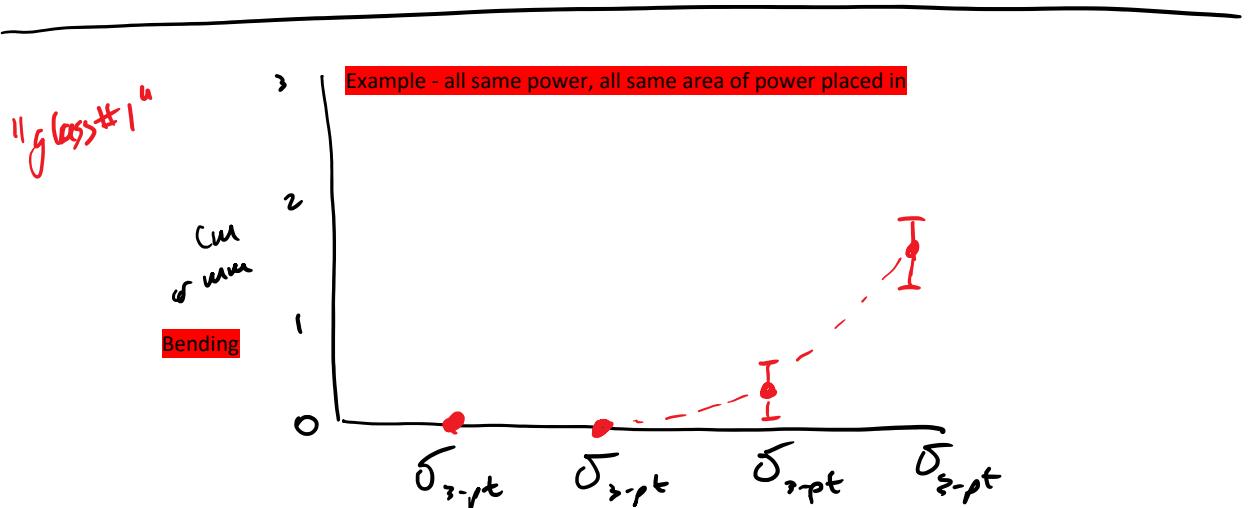
$$w - 156.0 \text{ mm} = 15.6 \text{ cm}$$

L

$$250 \text{ mm} = 25.0 \text{ cm} \quad \times$$

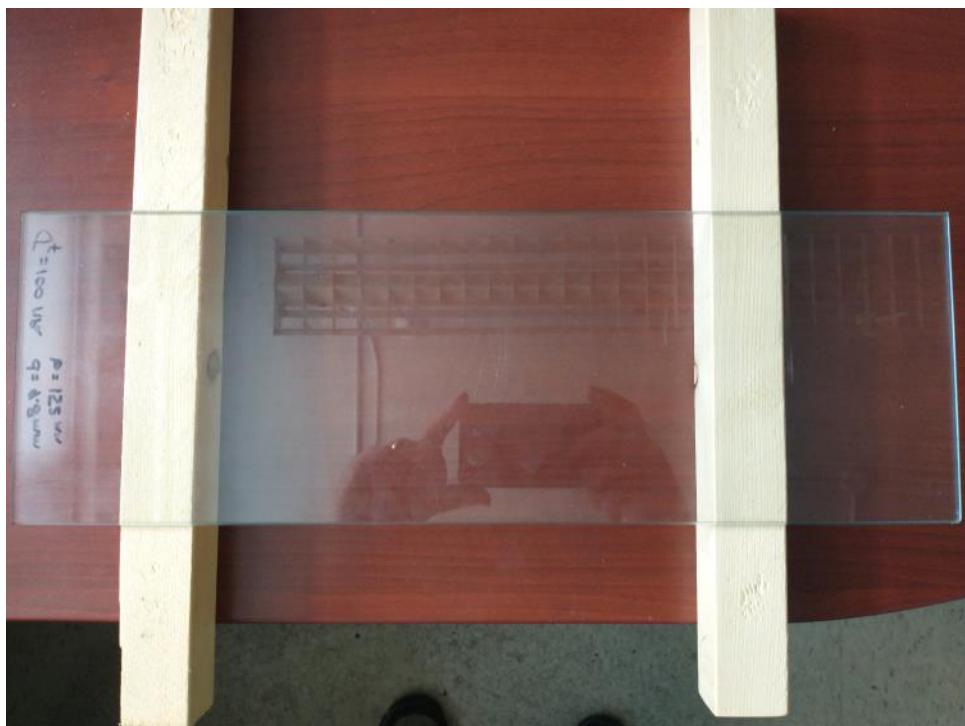
$$382 \text{ mm} = 38.2 \text{ cm} \quad \times$$

$$114 \text{ mm} = 11.6 \text{ cm} \quad \text{maybe}$$



# Glass 1

September 13, 2024 4:14 PM



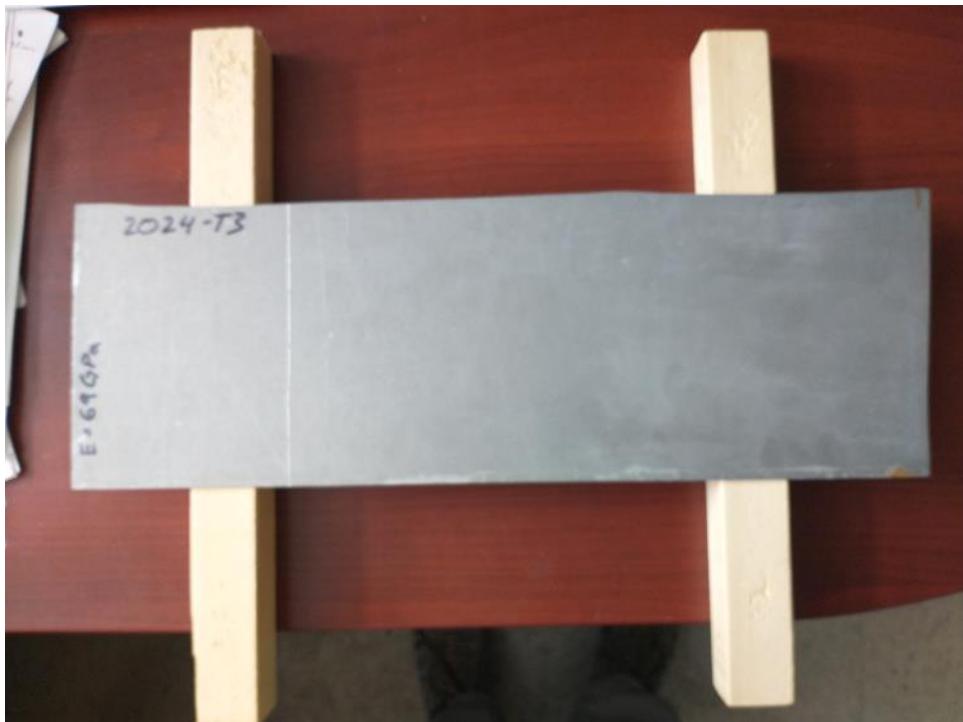
# Glass 2

September 13, 2024 4:14 PM



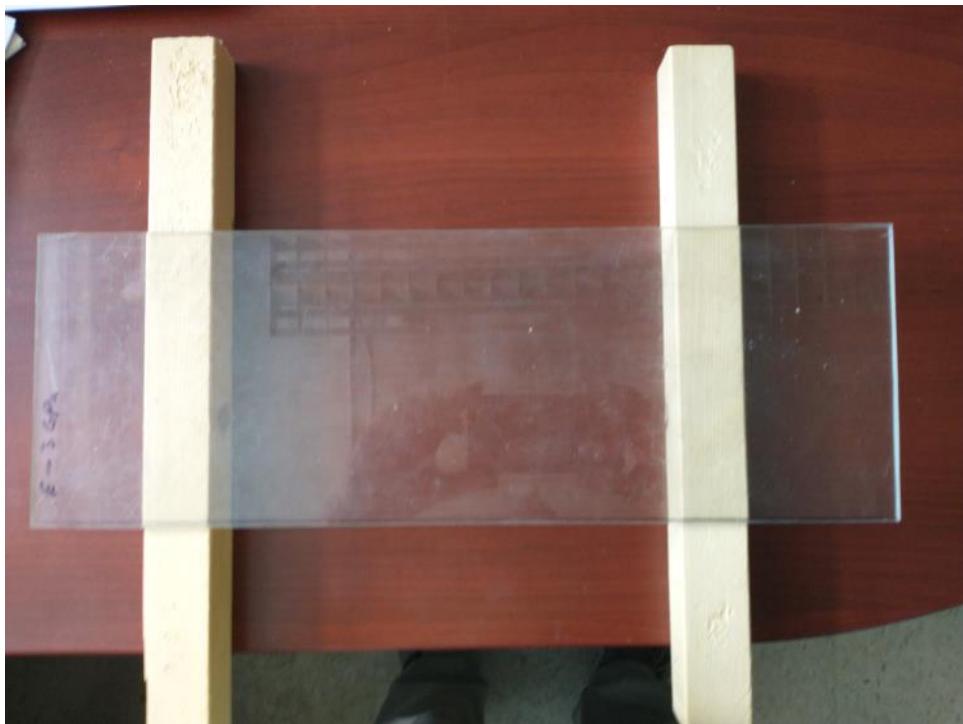
# Metal

September 13, 2024 4:14 PM



# Plastic

September 13, 2024 4:15 PM



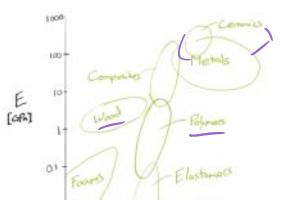
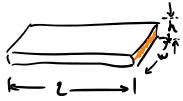
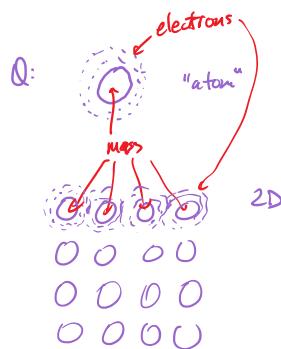
**Density**

Figure 1: plot of Young's modulus versus density on logarithmic axes.



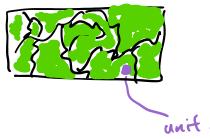
$$\begin{aligned} h &= 4.0 \text{ mm} = 0.4 \text{ cm} \\ w &= 154 \text{ mm} = 15.4 \text{ cm} \\ L &= 406.2 \text{ mm} = 40.62 \text{ cm} \end{aligned}$$

$$\text{area} \Rightarrow A = h \times w$$



Mass  $\Rightarrow M = A \times L \times \rho$   
 $= h \times w \times L \times \rho$

$\rho$  = density

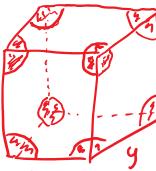


maybe cm can be engineered

2D

0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

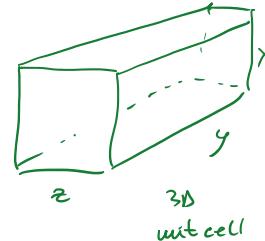
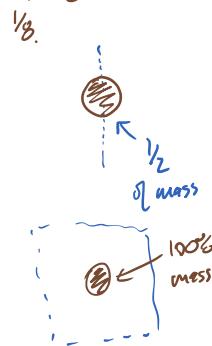
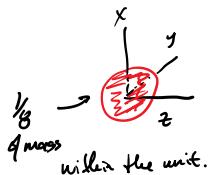
3D unit cell  
- data available



"square"



metal



8% - CuO - 100%

also applies  
to the ceramics

Density

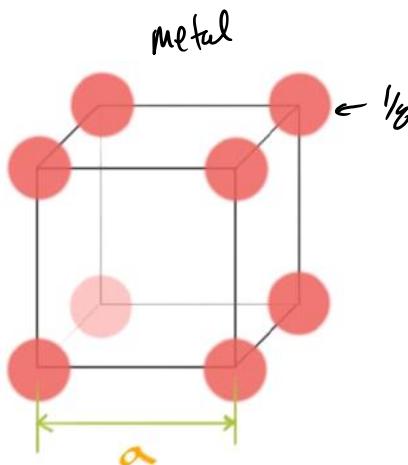
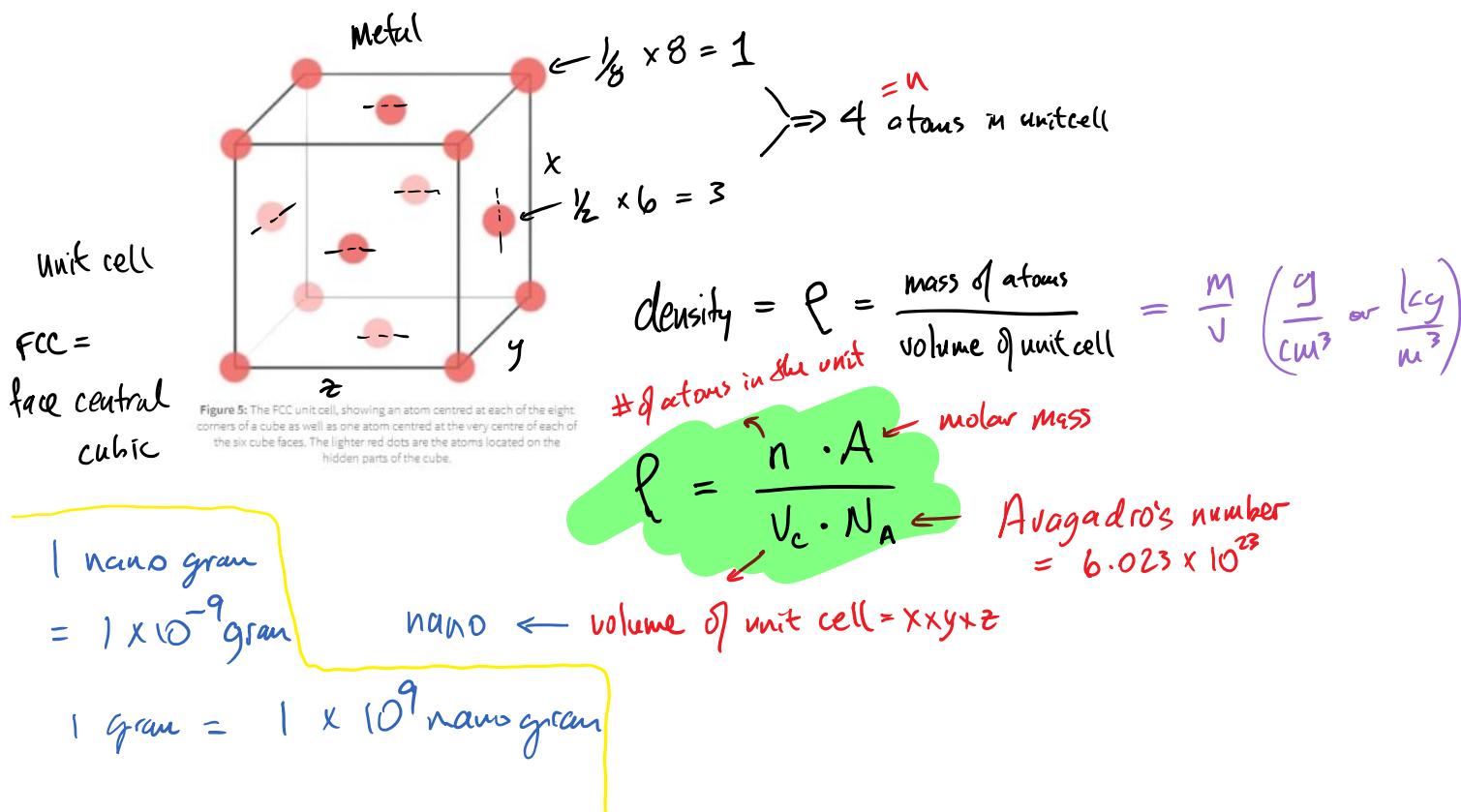


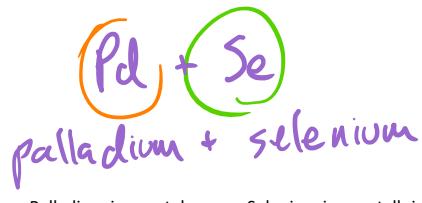
Figure 4: The simple cubic unit cell, showing an atom centred at each of the eight corners of a cube. The lighter red dots are the atoms located on the hidden parts of the cube. The cube edge length is known as the lattice parameter and is denoted with the letter  $a$ .



# Ceramics

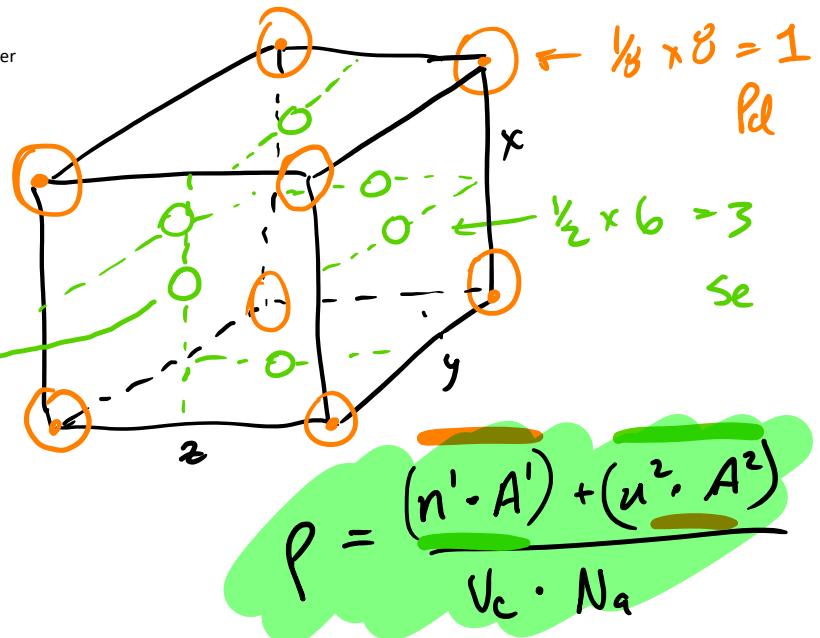
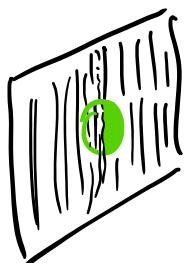
September 18, 2024 3:39 PM

Metals + metalloids can be mixed together



Palladium is a metal

Selenium is a metalloid

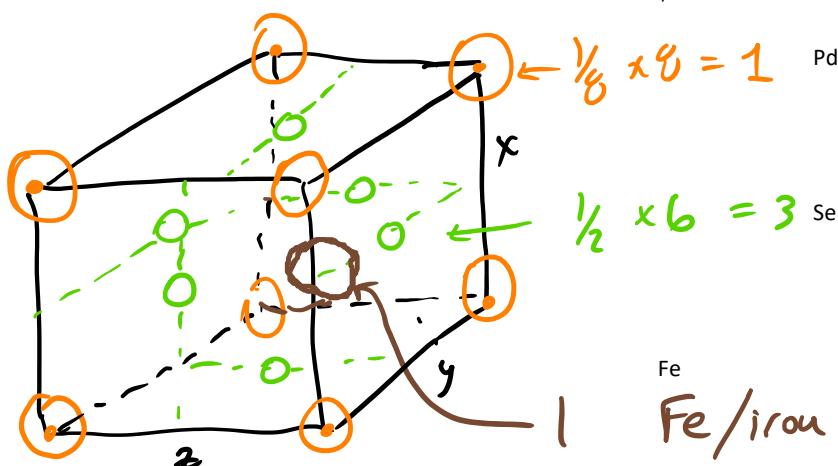


FYI - the atomic radius was not considered for this artwork and discussion - if data found you will atomic radiiuses

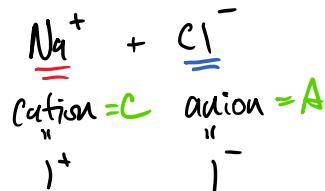
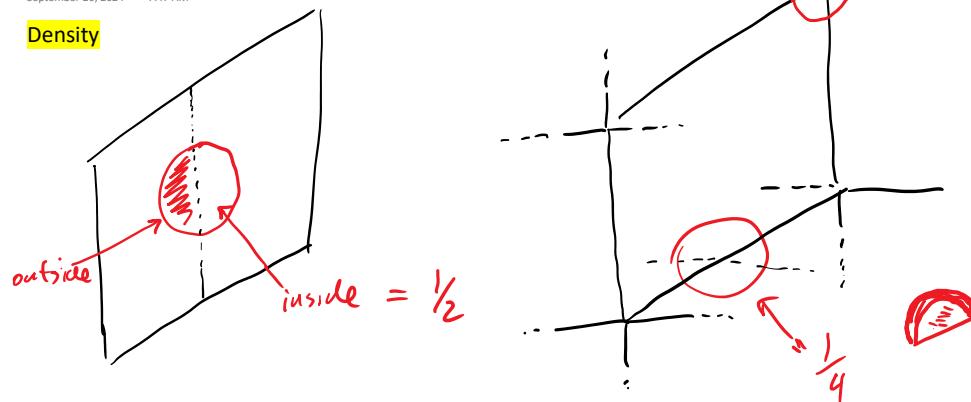
Another example

another example  
3 metals present.

3 metals present

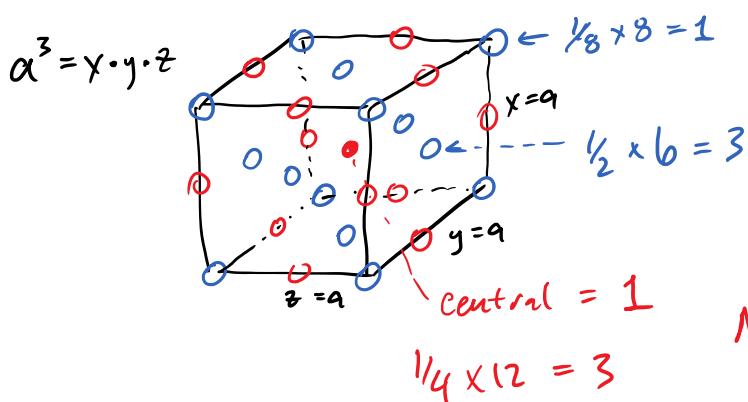


## Density



$$\rho = \frac{(n_A \cdot A_A) + (n_c \cdot A_c)}{V_c \cdot N_A}$$

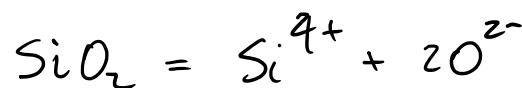
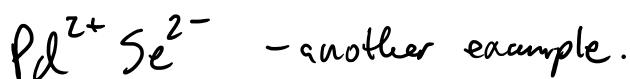
$\uparrow$  volume of unit cell  $\uparrow$  Avagadro's number



$$\text{Cl} \quad 3+1=4$$

$$4=4$$

$$\text{Na} \quad 3+1=4$$



# Periodic Table

September 20, 2024 7:50 AM

# PERIODIC TABLE OF ELEMENTS



$1x$

1	H	Hydrogen
3	Li	Lithium
4	Be	Beryllium
11	Na	Sodium
12	Mg	Magnesium
19	K	Potassium
20	Ca	Sodium
21	Sc	Scandium
22	Ti	Titanium
23	V	Vanadium
24	Cr	Chromium
25	Mn	Manganese
26	Fe	Iron
27	Co	Cobalt
28	Ni	Nickel
29	Cu	Copper
30	Zn	Zinc
31	Ga	Gallium
32	Ge	Dermanium
33	As	Arsenic
34	Se	Selenium
35	Br	Bromine
36	Kr	Krypton
37	Rb	Rubidium
38	Sr	Sodium
39	Y	Yttrium
40	Zr	Zirconium
41	Nb	Niobium
42	Mo	Molybdenum
43	Tc	Technetium
44	Ru	Ruthenium
45	Rh	Rhodium
46	Pd	Palladium
47	Ag	Silver
48	Cd	Cadmium
49	In	Indium
50	Sn	Tin
51	Sb	Antimony
52	Te	Tellurium
53	I	Iodine
54	Xe	Xenon
55	Cs	Cesium
56	Ba	Barium
57	La	Lanthanum
58	Ce	Cerium
59	Pr	Praseodymium
60	Nd	Neodymium
61	Pm	Promethium
62	Sm	Samarium
63	Eu	Europium
64	Gd	Gadolinium
65	Tb	Terbium
66	Dy	Dysprosium
67	Ho	Holmium
68	Er	Erbium
69	Tm	Thulium
70	Yb	Ytterbium
71	Lu	Lutetium
87	Fr	Francium
88	Ra	Radium
104	Rf	Rutherfordium
105	Db	Dubnium
106	Sg	Seaborgium
107	Bh	Bohrium
108	Hs	Hassium
109	Mt	Meltinrium
110	Ds	Darmstadtium
111	Rg	Roentgenium
112	Cn	Copernicium
113	Nh	Nihonium
114	Fl	Flerovium
115	Mc	Moscovium
116	Lv	Livermorium
117	Ts	Tennessee
118	Og	Oganesson
89	Ac	Actinium
90	Th	Thorium
91	Pa	Protactinium
92	U	Uranium
93	Np	Neptunium
94	Pu	Plutonium
95	Am	Americium
96	Cm	Curium
97	Bk	Berkelium
98	Cf	Californium
99	Es	Einsteinium
100	Fm	Fermium
101	Md	Mendelevium
102	No	Nobelium
103	Lr	Lawrencium

1

H

Hydrogen  
1.0080

Atomic Number  
Symbol

Name  
Atomic Mass, u

$Mg^{2+}$

PubChem

5	B	Boron
6	C	Carbon
7	N	Nitrogen
8	O	Oxygen
9	F	Fluorine
10	Ne	Neon

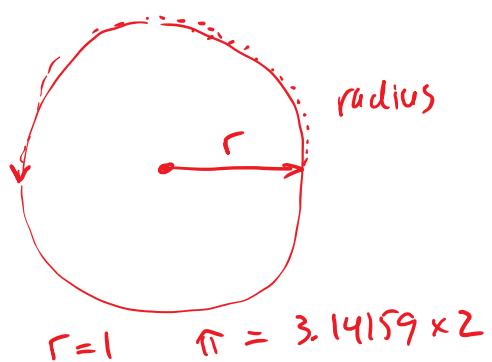
2

He

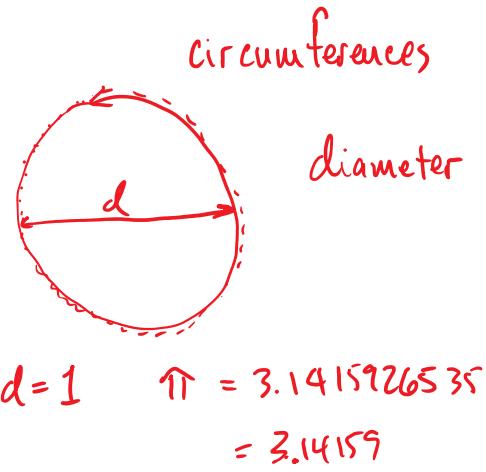
Helium  
4.00260

19	K	Potassium
20	Ca	Sodium
21	Sc	Scandium
22	Ti	Titanium
23	V	Vanadium
24	Cr	Chromium
25	Mn	Manganese
26	Fe	Iron
27	Co	Cobalt
28	Ni	Nickel
29	Cu	Copper
30	Zn	Zinc
31	Ga	Gallium
32	Ge	Dermanium
33	As	Arsenic
34	Se	Selenium
35	Br	Bromine
36	Kr	Krypton
37	Rb	Rubidium
38	Sr	Sodium
39	Y	Yttrium
40	Zr	Zirconium
41	Nb	Niobium
42	Mo	Molybdenum
43	Tc	Technetium
44	Ru	Ruthenium
45	Rh	Rhodium
46	Pd	Palladium
47	Ag	Silver
48	Cd	Cadmium
49	In	Indium
50	Sn	Tin
51	Sb	Antimony
52	Te	Tellurium
53	I	Iodine
54	Xe	Xenon
55	Cs	Cesium
56	Ba	Barium
57	La	Lanthanum
58	Ce	Cerium
59	Pr	Praseodymium
60	Nd	Neodymium
61	Pm	Promethium
62	Sm	Samarium
63	Eu	Europium
64	Gd	Gadolinium
65	Tb	Terbium
66	Dy	Dysprosium
67	Ho	Holmium
68	Er	Erbium
69	Tm	Thulium
70	Yb	Ytterbium
71	Lu	Lutetium
87	Fr	Francium
88	Ra	Radium
104	Rf	Rutherfordium
105	Db	Dubnium
106	Sg	Seaborgium
107	Bh	Bohrium
108	Hs	Hassium
109	Mt	Meltinrium
110	Ds	Darmstadtium
111	Rg	Roentgenium
112	Cn	Copernicium
113	Nh	Nihonium
114	Fl	Flerovium
115	Mc	Moscovium
116	Lv	Livermorium
117	Ts	Tennessee
118	Og	Oganesson
89	Ac	Actinium
90	Th	Thorium
91	Pa	Protactinium
92	U	Uranium
93	Np	Neptunium
94	Pu	Plutonium
95	Am	Americium
96	Cm	Curium
97	Bk	Berkelium
98	Cf	Californium
99	Es	Einsteinium
100	Fm	Fermium
101	Md	Mendelevium
102	No	Nobelium
103	Lr	Lawrencium

Face-centre Cubic

Atomic Packing Factor (APF)

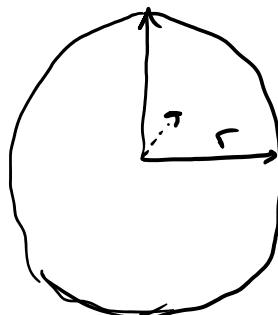
2D



diameter

$$d=1 \quad \pi = 3.1415926535 \\ = 3.14159$$

**Volume =  $\frac{4}{3} \pi r^3$**   
of an atom / 1 atom.



3D

$$1 \text{ pm} = 1 \text{ e}^{-10} \text{ cm}$$

$$1 \text{ cm} = 1 \text{ e}^{10} \text{ pm}$$

APF - atomic packing factor

$$APF = \frac{\text{volume spheres}}{\text{volume unit cell}}$$

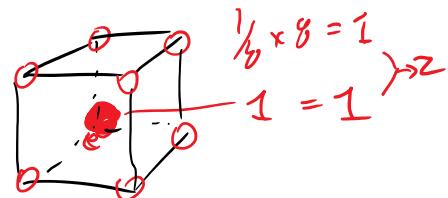
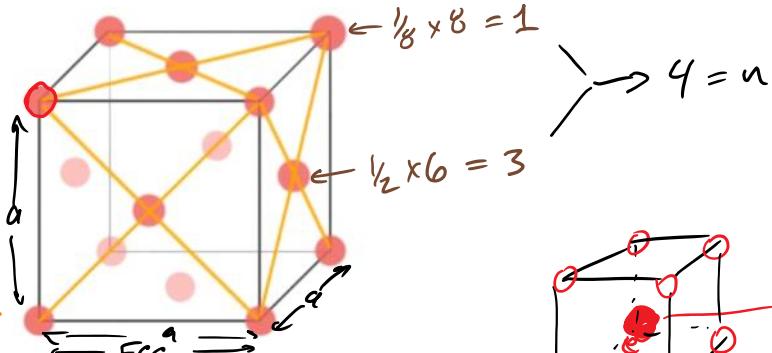
atoms

$$APF = \frac{n \cdot \frac{4}{3} \pi R^3}{a^3}$$

only metals.

$$= \frac{n \cdot \frac{4}{3} \pi R^3}{x \cdot y \cdot z}$$

= only 1 metal



Fe / iron  
 $\hookrightarrow 194 \text{ pm}$

FCC - face centred cubic

$$a_{\text{FCC}} = 2\sqrt{2}R$$

$$= 548.7096 \text{ pm}$$

$$\begin{aligned} \sqrt{2} &= 1.4142 ? \\ \sqrt{4} &= 2 ? \end{aligned}$$

Yes is a yes

$$APF = \frac{n \cdot \frac{4}{3} \pi R^3}{\text{FCC}^3} = \frac{n \cdot \frac{4}{3} \pi R^3}{(2\sqrt{2}R)^3}$$

iron

$$APF = \frac{4 \cdot \frac{4}{3} \cdot 3.14159 \cdot (194 \text{ pm})^3}{(548.7096 \text{ pm})^3} = 668451.0380$$

density

# Periodic Table

September 23, 2024 10:54 AM

# PERIODIC TABLE OF ELEMENTS

**Atomic Number**

**Symbol**

**Name**

**Atomic Radius (van der Waals), pm**

**picometer**

**R**

**pm**

**PubChem**

1 H Hydrogen 120	2 He Helium 140
3 Li Lithium 182	4 Be Beryllium 153
11 Na Sodium 227	12 Mg Magnesium 173
19 K Potassium 275	20 Ca Calcium 231
21 Sc Scandium 211	22 Ti Titanium 187
23 V Vanadium 179	24 Cr Chromium 189
25 Mn Manganese 197	26 Fe Iron 194
27 Co Cobalt 192	28 Ni Nickel 163
29 Cu Copper 140	30 Zn Zinc 139
31 Ga Gallium 187	32 Ge Germanium 211
33 As Arsenic 185	34 Se Selenium 190
35 Br Bromine 163	36 Kr Krypton 202
37 Rb Rubidium 303	38 Sr Strontium 249
39 Y Yttrium 219	40 Zr Zirconium 186
41 Nb Niobium 207	42 Mo Molybdenum 209
43 Tc Technetium 209	44 Ru Ruthenium 207
45 Rh Rhodium 195	46 Pd Palladium 202
47 Ag Silver 172	48 Cd Cadmium 158
49 In Indium 193	50 Sn Tin 217
51 Sb Antimony 196	52 Te Tellurium 206
53 I Iodine 198	54 Xe Xenon 216
55 Cs Cesium 343	56 Ba Barium 268
72 Hf Hafnium 212	73 Ta Tantalum 217
74 W Tungsten 210	75 Re Rhenium 217
76 Os Osmium 216	77 Ir Iridium 202
78 Pt Platinum 209	79 Au Gold 166
80 Hg Mercury 209	81 Tl Thallium 196
82 Pb Lead 202	83 Bi Bismuth 207
84 Po Polonium 197	85 At Astatine 202
86 Rn Radon 220	87 Fr Francium 348
88 Ra Radium 283	104 Rf Rutherfordium 150
105 Db Dubnium 139	106 Sg Seaborgium 132
107 Bh Bohrium 128	108 Hs Hassium 126
109 Mt Meitnerium 128	110 Ds Darmstadtium 132
111 Rg Roentgenium 138	112 Cn Copernicium 147
113 Nh Nihonium 170	114 Fl Flerovium 180
115 Mc Moscovium 187	116 Lv Livermorium 183
117 Ts Tennessine 138	118 Og Oganesson
57 La Lanthanum 240	58 Ce Cerium 238
59 Pr Praseodymium 239	60 Nd Neodymium 229
61 Pm Promethium 238	62 Sm Samarium 229
63 Eu Europium 233	64 Gd Gadolinium 237
65 Tb Terbium 221	66 Dy Dysprosium 229
67 Ho Holmium 216	68 Er Erbium 235
69 Tm Thulium 227	70 Yb Ytterbium 242
71 Lu Lutetium 221	
89 Ac Actinium 260	90 Th Thorium 237
91 Pa Protactinium 243	92 U Uranium 240
93 Np Neptunium 221	94 Pu Plutonium 243
95 Am Americium 244	96 Cm Curium 245
97 Bk Berkelium 244	98 Cf Californium 245
99 Es Einsteinium 245	100 Fm Fermium 245
101 Md Mendelevium 243	102 No Nobelium 242
103 Lr Lawrencium 220	

BCC  $\rightarrow$  FCCBCC : Body Centred Cubic (Crystal Structure/Nanostructure)stress  $\rightarrow$  strain

$$CN_{BCC} = 8$$

coordination number

$$n_{BCC} = 2$$

$$APF_{BCC} = \frac{n \frac{4}{3} \pi R^3}{a^3}$$

$$= \frac{n \frac{4}{3} \pi R^3}{\left(\frac{4}{\sqrt{3}} R\right)^3} = 0.68$$

$R = \text{pm? nm? cm?}$

$$4 \times \frac{1}{4} = 1$$

$$8 \times \frac{1}{2} = 4$$

"  
5

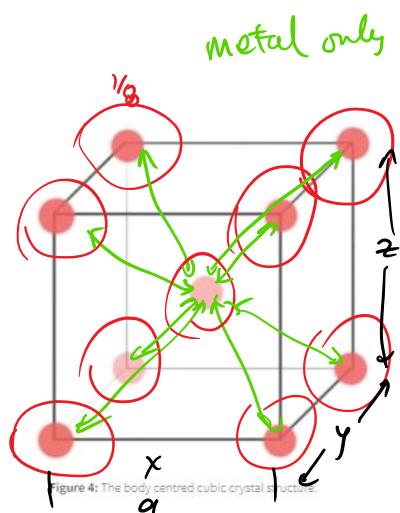


Figure 4: The body centred cubic crystal structure.

metals

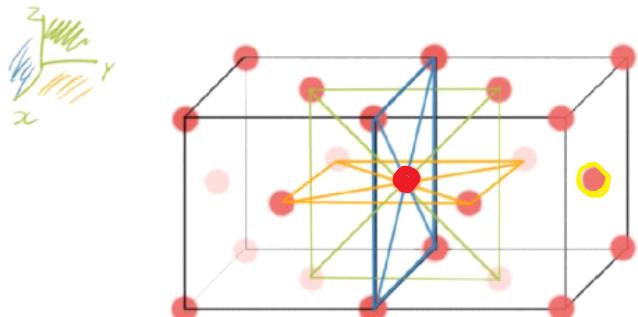
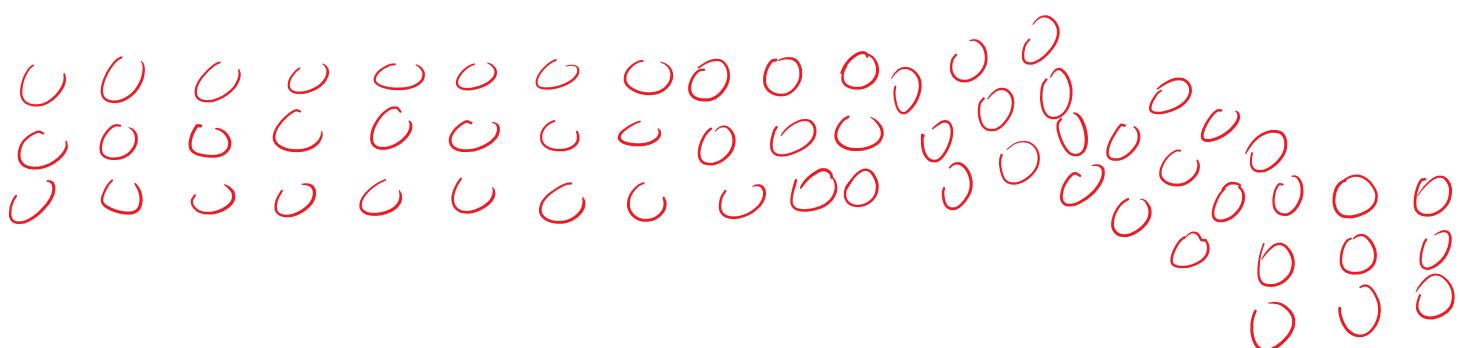


Figure 6: The coordination number for atoms in FCC. The right side face-centred atom makes contact with four atoms in the right side plane, with four atoms in the face-centred positions in the original unit cell, and with four atoms in the face-centred positions in the unit cell to the right.



## Octahedron

September 25, 2024 9:43 AM

$$6 = \text{coordinate\_number}$$

$$\text{CN}_{\text{BCC}} = 6$$

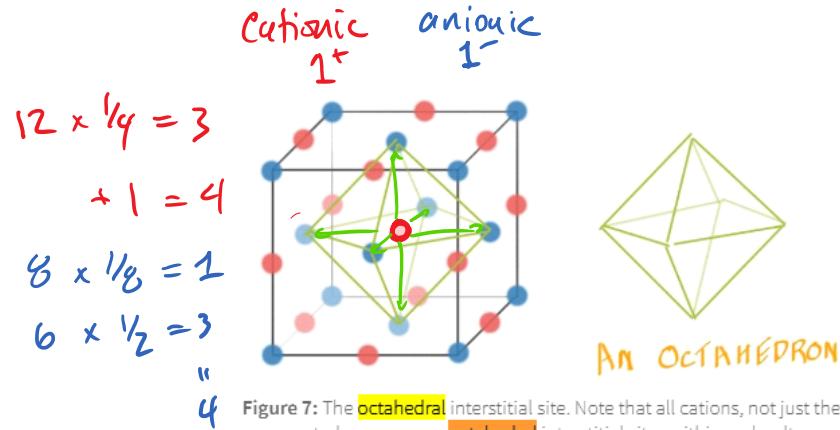


Figure 7: The **octahedral** interstitial site. Note that all cations, not just the central one, occupy **octahedral** interstitial sites within rock salt.

$$4 = 4$$

balance

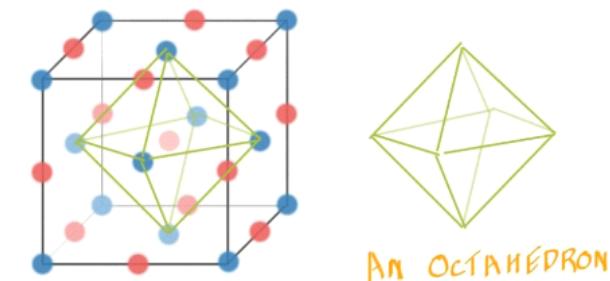


Figure 7: The **octahedral** interstitial site. Note that all cations, not just the central one, occupy **octahedral** interstitial sites within rock salt.

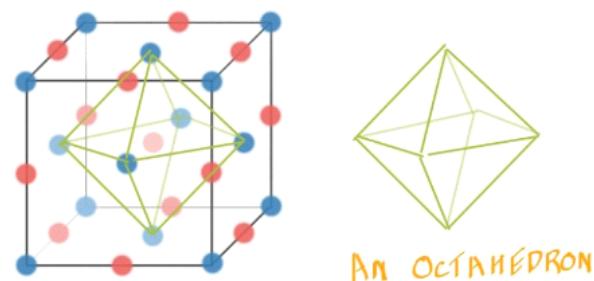


Figure 7: The **octahedral** interstitial site. Note that all cations, not just the central one, occupy **octahedral** interstitial sites within rock salt.

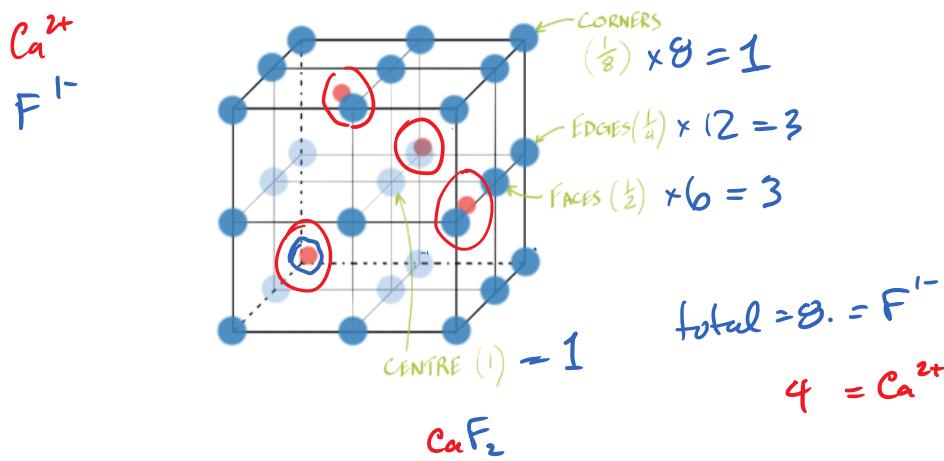


Figure 8. There are 8 anions within the calcium fluorite ceramic crystal structure. The fraction of an atom for each position type is shown here.

$$\text{Ca} = 231 \mu\text{m} = 2.31 \times 10^{-8} \text{ cm} = 0.231 \text{ nm}$$

$$\text{F} = 135 \mu\text{m} = 1.35 \times 10^{-8} \text{ cm} = 0.135 \text{ nm}$$

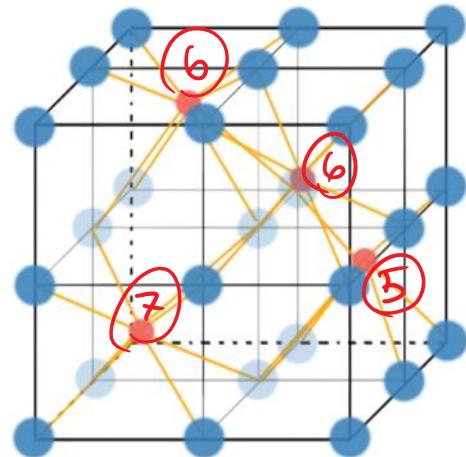


Figure 6. The calcium fluorite ceramic crystal structure. Anions represented as blue dots are in a simple cubic lattice with half of the simple cubic interstitial sites occupied by cations. Cations touch their 8 nearest neighbour anions along the cube diagonals, as illustrated by the orange lines.

## The Size of Interstitial Sites

$$\sin 45^\circ = \frac{1}{\sqrt{2}} = \frac{1}{1.414}$$

$$\sin 45^\circ = \frac{2R_A}{2R_A + 2R_C}$$

$$\frac{R_C}{R_A} = \frac{1 - \sin 45^\circ}{\sin 45^\circ}$$

$$= \frac{1 - \frac{1}{1.414}}{\frac{1}{1.414}}$$

$$\frac{R_C}{R_A} = 0.414$$

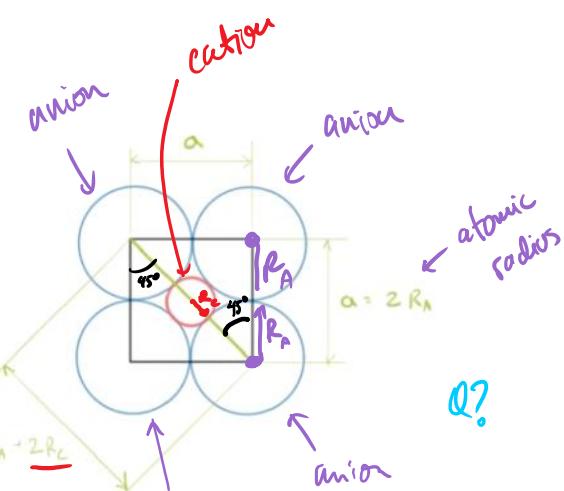
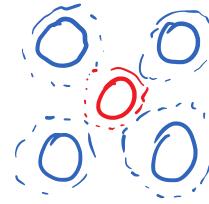
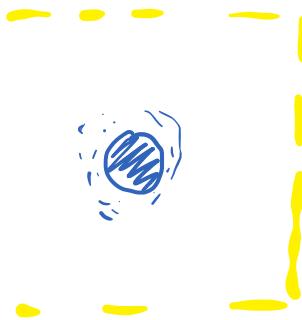
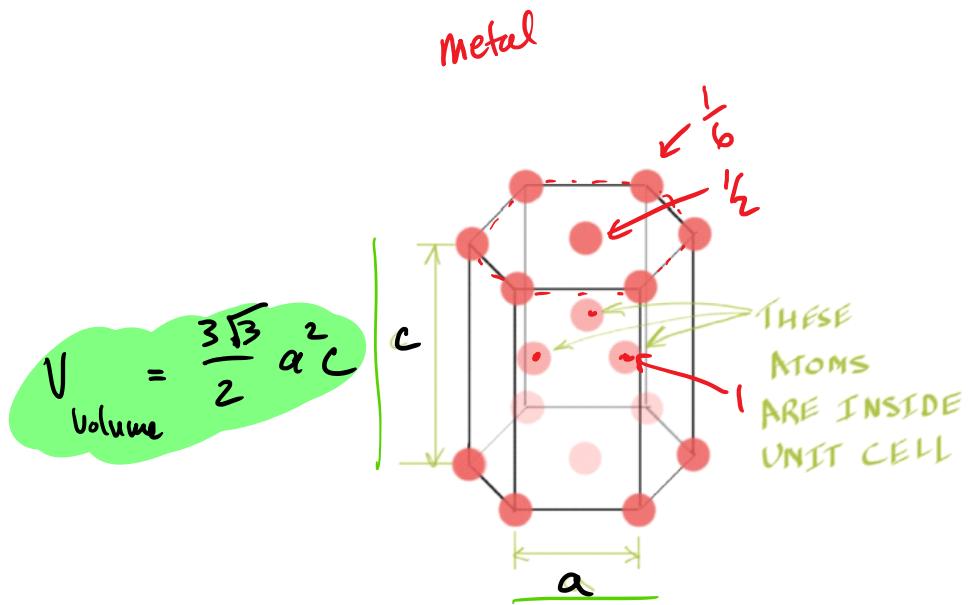


Figure 9: A 2D slice through the octahedral interstitial site at the geometrically ideal radius ratio when the anions are touching one another and the cation is just big enough to fit into the site without pushing the anions apart.

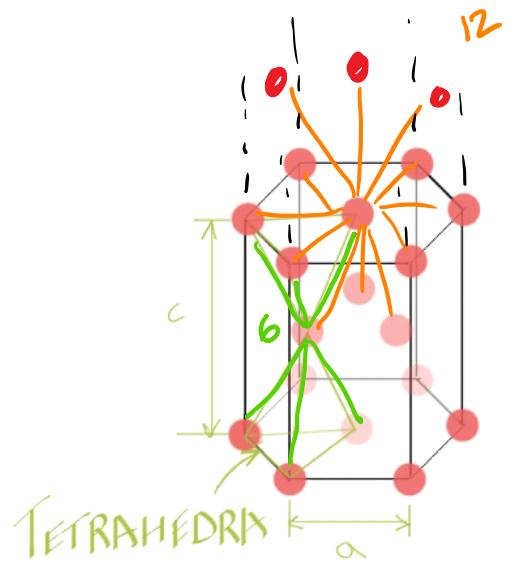


## Hexagonal

September 26, 2024 7:53 PM

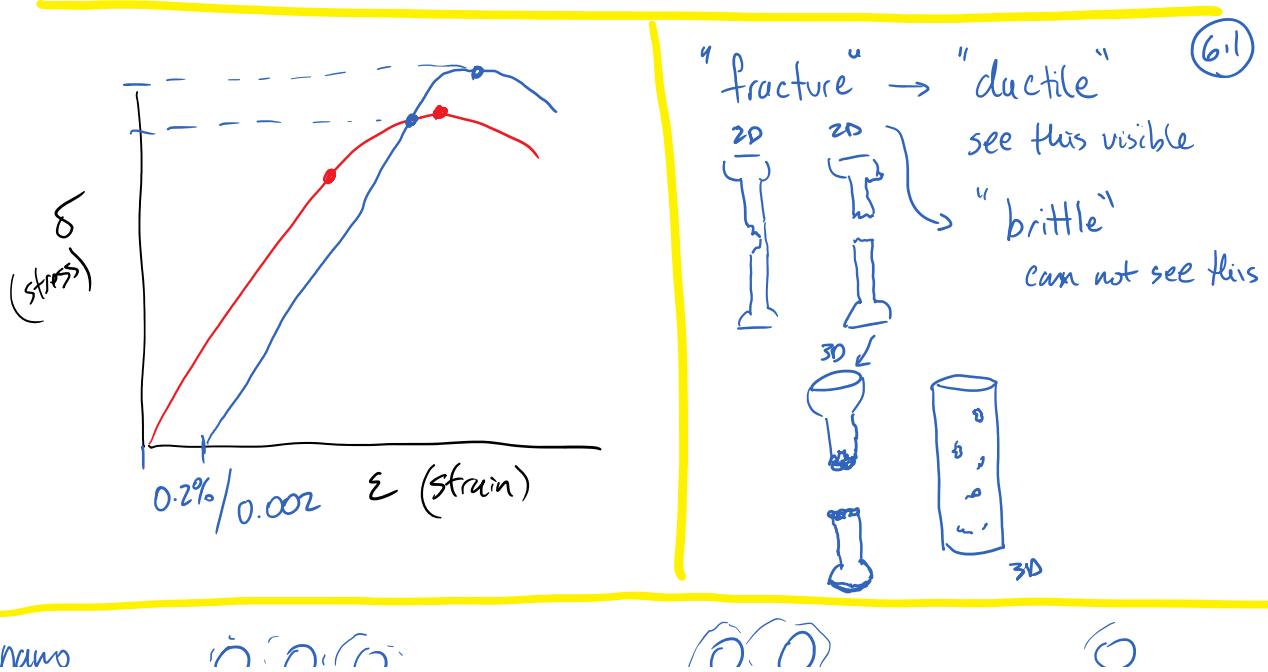
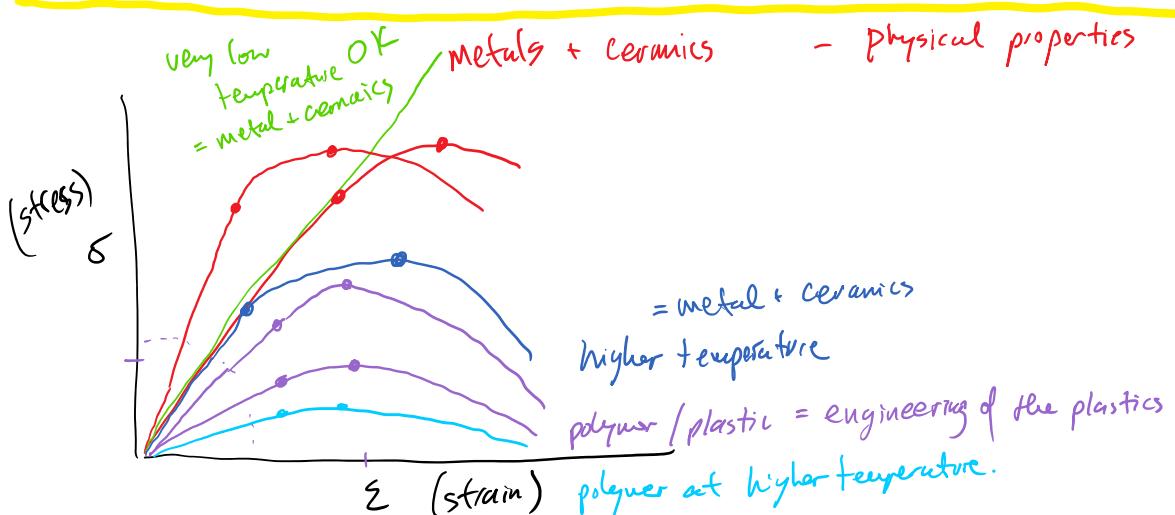
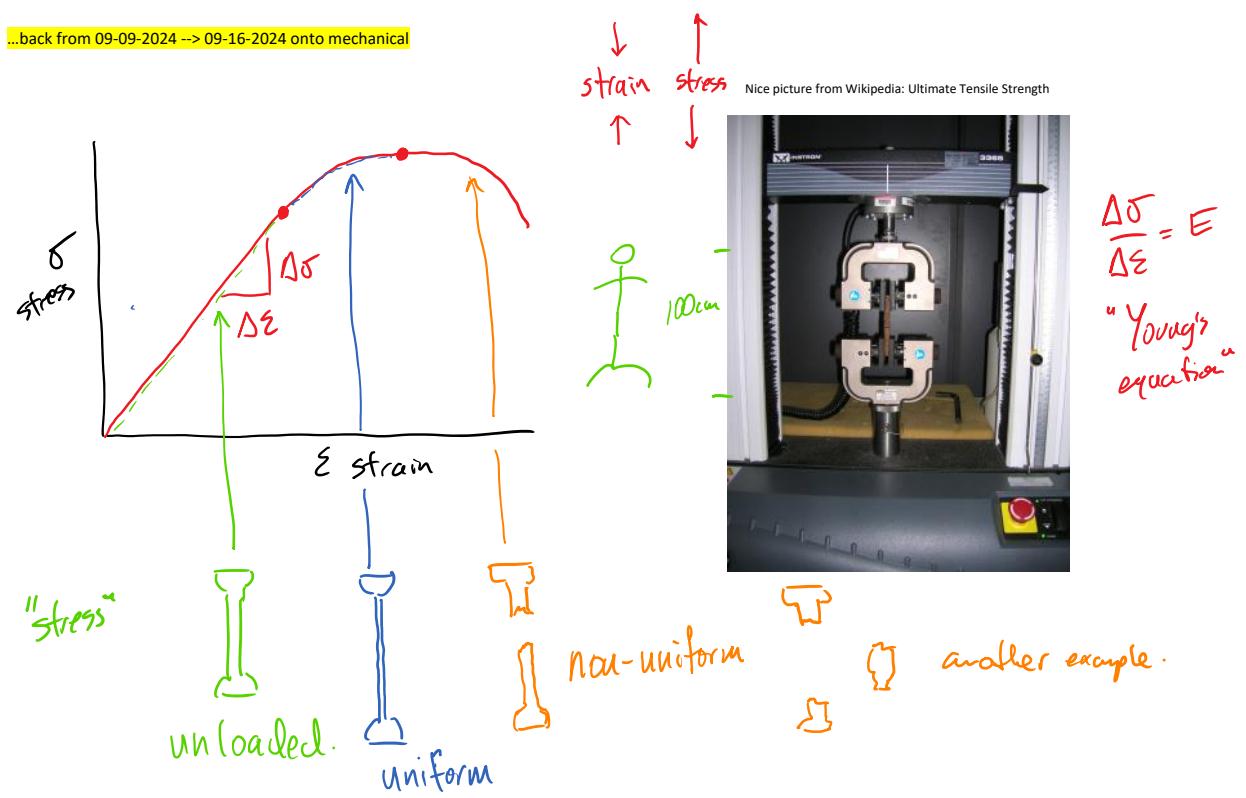


**Figure 11:** A hexagonal close packed unit cell. Note that the three atoms in the middle are inside the unit cell and are part of a close packed plane that is identical to the top and bottom planes.

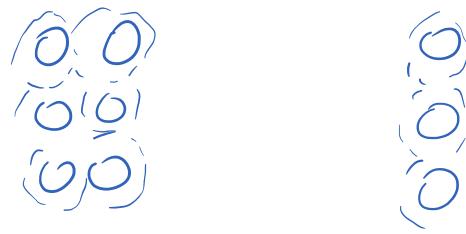
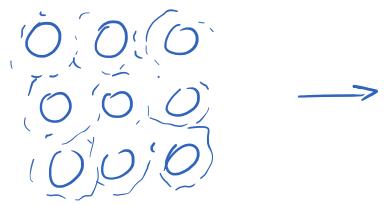


**Figure 12:** A hexagonal close packed unit cell showing the positioning of the three middle atoms nested into the low spots between three atoms on the bottom plane.

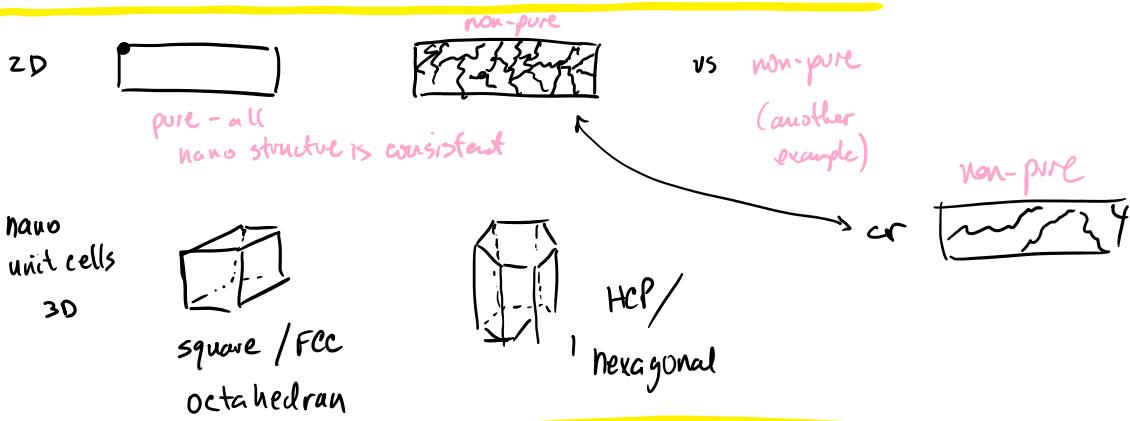
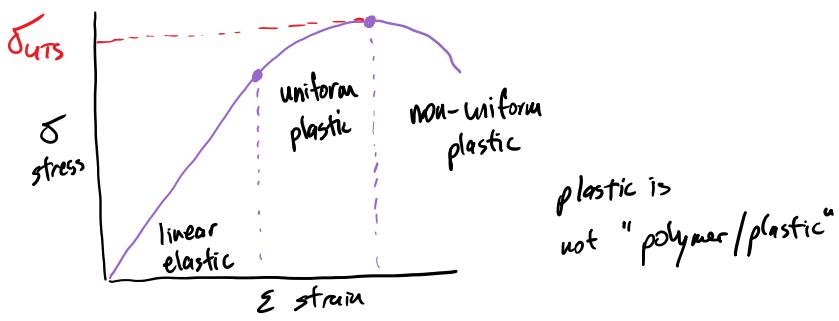
...back from 09-09-2024 --&gt; 09-16-2024 onto mechanical



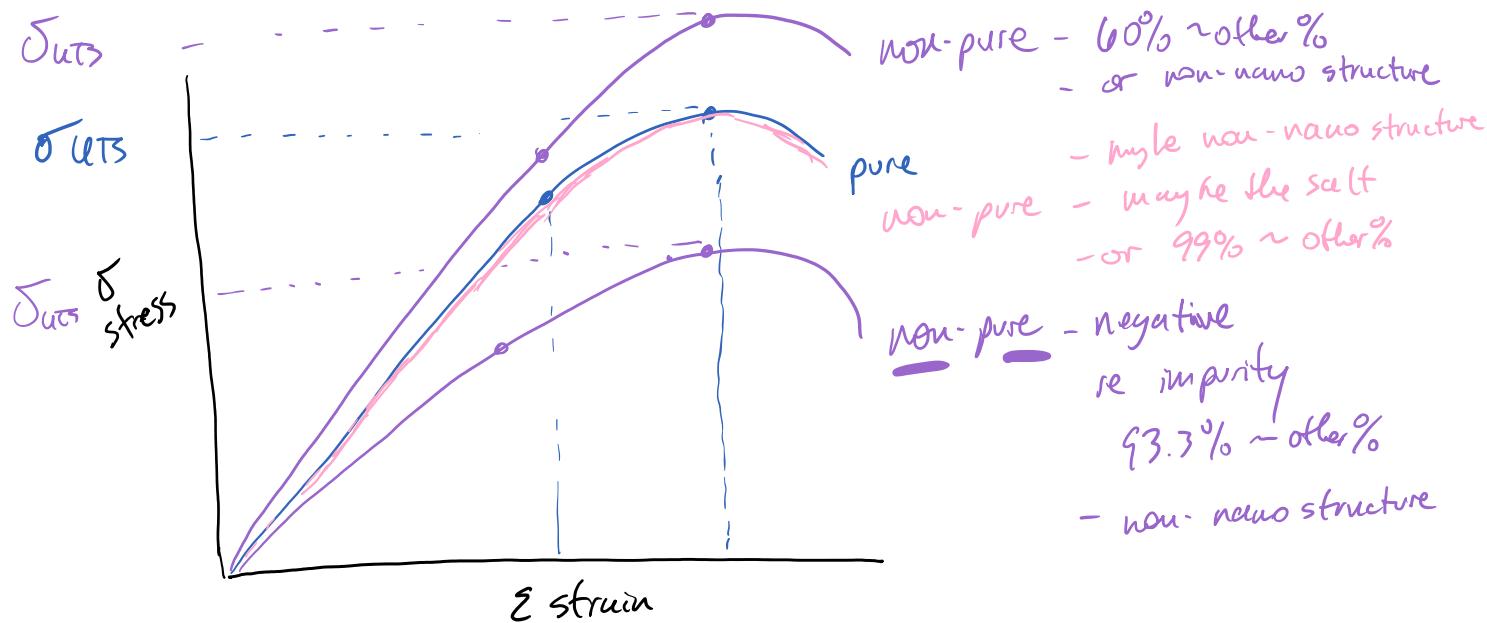
macro  
structure



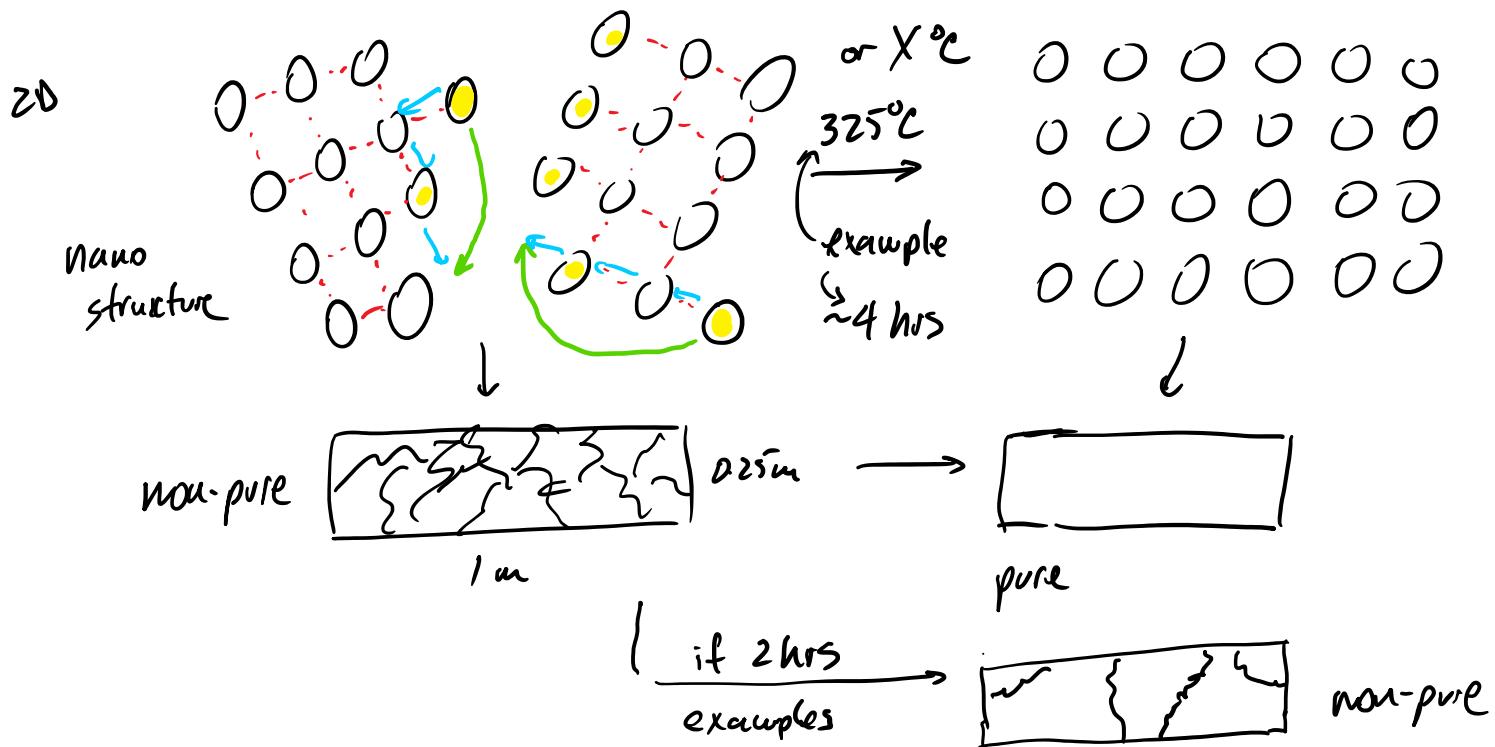
## UTS - Ultimate Tensile Strength



①	<b>pure</b>	<table border="0"> <tr><td>0</td><td>-</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>0</td><td>-</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>0</td><td>-</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> </table>	0	-	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	100% metal																				
0	-	0	0	0	0	0	0	0	0																																												
0	-	0	0	0	0	0	0	0	0																																												
0	-	0	0	0	0	0	0	0	0																																												
	2D	<table border="0"> <tr><td>0</td><td>-</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>0</td><td>-</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> <tr><td>0</td><td>-</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr> </table>	0	-	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0																					
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## Thermodynamics and Kinetics

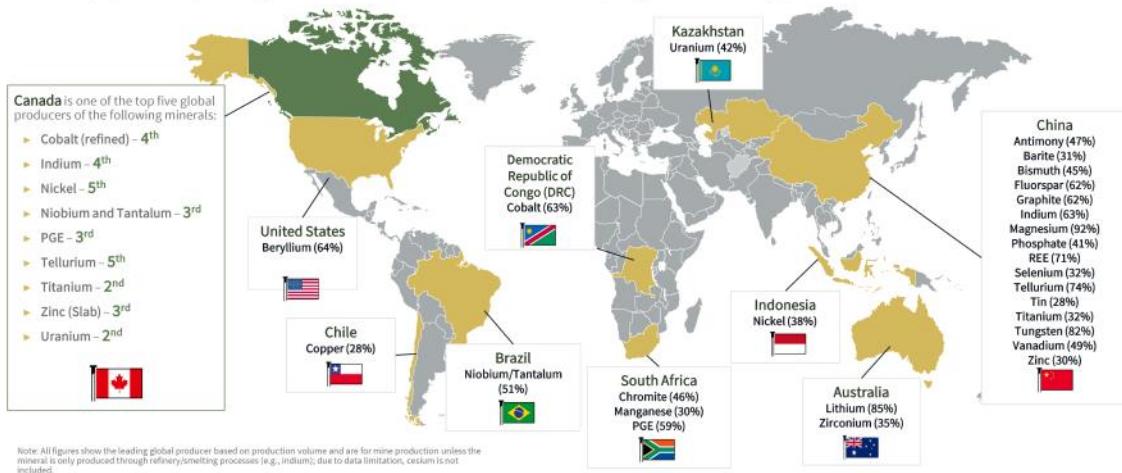


# Printout - 2022 Ontario Mining Report

October 4, 2024 10:15 AM

## 2.3 Leading Critical Minerals Producers

- To understand the global market and supply chain for critical minerals, global mineral production data was assessed in order to identify the top producer for each mineral and their respective market shares. Based on 2019 production volumes, China dominates the global critical minerals mining market with the highest production share in 16 minerals included on Ontario's critical minerals list.
- Ontario's endowment with critical mineral deposits represents an opportunity for the province to produce and market responsibly procured natural resources to some of the major jurisdictions, including the US and the EU, whose advanced industries rely on global minerals' supply chains.



## 2.4 Substitutability and Importance in Major Jurisdictions

- Some industrial applications can use multiple source materials, while others require very particular and limited inputs. In order to assess the substitutability of each critical mineral, this report analyzes each mineral's applications and availability of alternative materials with comparable properties and performance for the most common industrial needs.
- Assessing substitutability with the mineral's criticality status in major jurisdictions (as defined by national critical minerals frameworks in each country included in the analysis) provides a view of the overall economic and strategic importance of these minerals on a global scale.

Table 7: Ontario's Critical Minerals: Substitutability and Importance in Major Jurisdictions

Mineral	Status in Ontario	Substitutability (Low-High)	Minerals Included on Critical Minerals List						Total Jurisdictions
			EU	US	UK	Canada	Japan	Australia	
Antimony	Exploration Project	Moderate	✓	✓	✓	✓	✓	✓	6/6
Barite	Advanced Mineral Projects	Moderate	✓	✓					2/6
Beryllium	Exploration Potential	Low	✓	✓	✓			✓	4/6
Bismuth	Exploration Potential	High	✓	✓		✓		✓	4/6
Cesium	Exploration Potential	Moderate		✓		✓			2/6
Chromite	Advanced Mineral Projects	Low		✓		✓	✓	✓	4/6
Copper	Produced and Processed	Low				✓		✓	2/6
Cobalt	Produced and Processed	Moderate	✓	✓	✓	✓	✓	✓	6/6
Fluorspar	Exploration Potential	High	✓	✓	✓	✓			4/6
Graphite	Advanced Mineral Projects	Moderate	✓	✓	✓		✓	✓	5/6
Indium	Produced	Low	✓	✓	✓	✓	✓	✓	6/6
Lithium	Advanced Mineral Projects	Moderate	✓	✓		✓	✓	✓	5/6

Note: Status in Ontario indicated the most advanced stage for a given mineral. Most minerals that are produced as of 2021 also have advanced mineral projects and exploration potential. Complete critical minerals lists of comparable jurisdictions are provided in [Appendix B](#).  
Sources: United States Geological Survey (USGS); Critical Minerals lists of the EU, the US, the United Kingdom (UK), Japan, Canada, and Australia (Critical mineral lists of major jurisdictions).



OMA Critical Minerals Analysis

Page 11

## 2.4 Substitutability and Importance in Major Jurisdictions (continued)

Mineral	Status in Ontario	Substitutability (Low-High)	Minerals Included on Critical Minerals List						
			EU	US	UK	Canada	Japan	Australia	Total Jurisdictions
Magnesium	Advanced Mineral Projects	High	✓	✓	✓	✓	✓		5/6
Manganese	Exploration Potential	Low		✓		✓	✓	✓	4/6
Molybdenum	Exploration Potential	Low				✓		✓	2/6
Nickel*	Produced and Processed	High		✓		✓		✓	3/6
Niobium/Tantalum	Advanced Mineral Projects/ Exploration Potential	Moderate	✓/✓	✓/✓	✓/✓	✓/✓	✓/✓	✓/✓	6/6
Phosphate	Exploration Potential	Low	✓						1/6
PGE	Produced and Processed	Moderate	✓	✓	✓	✓	✓	✓	6/6
REE	Exploration Potential	Moderate	✓	✓	✓	✓	✓	✓	6/6
Selenium	Produced and Processed	Moderate						✓	1/6
Tellurium	Produced and Processed	Moderate		✓		✓			2/6
Tin	Exploration Potential	High		✓		✓		✓	3/6
Titanium	Exploration Potential	Moderate	✓	✓		✓	✓	✓	5/6
Tungsten	Exploration Potential	Low	✓	✓	✓	✓	✓	✓	6/6
Uranium	Processed Only	Moderate		✓		✓			2/6
Vanadium	Exploration Potential	Moderate	✓	✓		✓	✓		4/6
Zinc*	Produced	High		✓		✓			2/6
Zirconium	Exploration Potential	Moderate		✓			✓	✓	3/6

Notes: \*Nickel and Zinc were added to the US Critical Minerals List based on the 2021 US Administration review. Complete critical minerals lists of comparable jurisdictions are provided in [Appendix B](#).  
 Sources: USGS; Critical Minerals lists of the EU, the US, UK, Japan, Canada, and Australia (Critical mineral lists of major jurisdictions).



OMA Critical Minerals Analysis

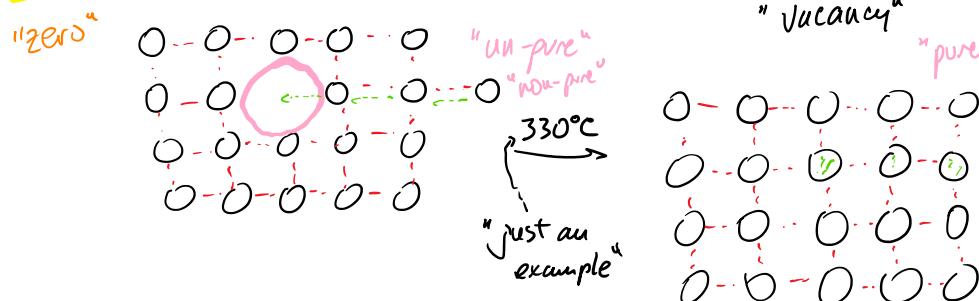
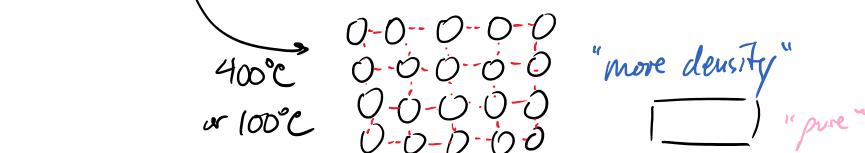
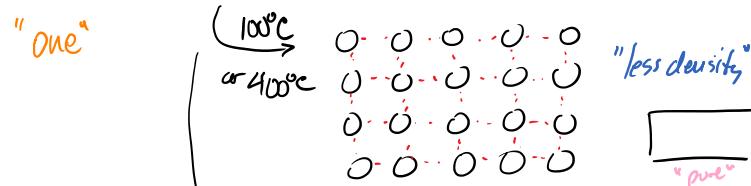
Page 12



## Thermodynamics and Kinetics

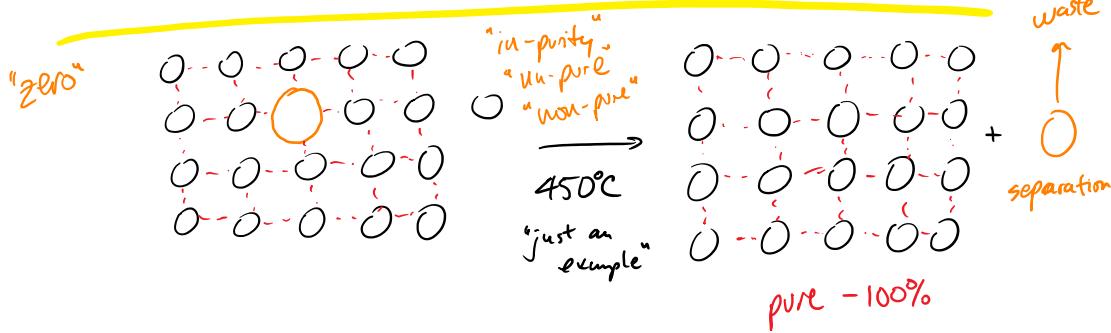
## Crystalline Imperfections → nano-engineering of the structures

- Zero - dimensional - vacancy, impurity
- One - dislocation
- Two - grain, boundary

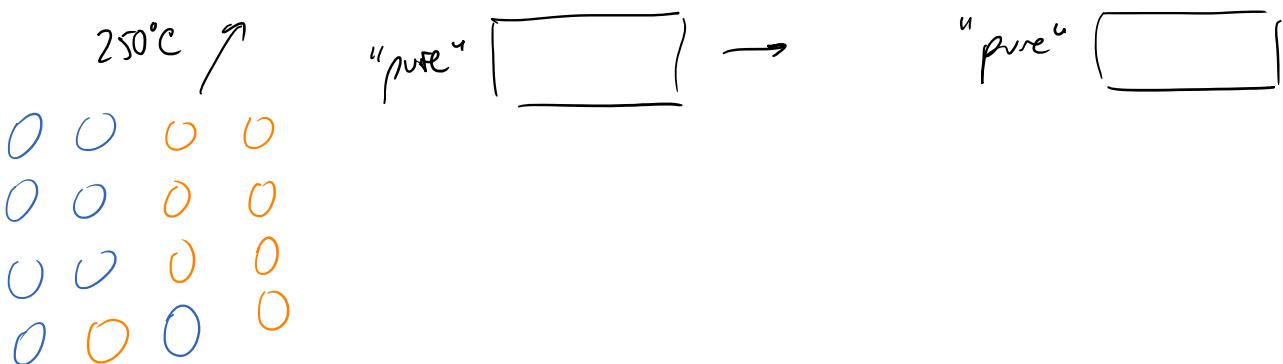
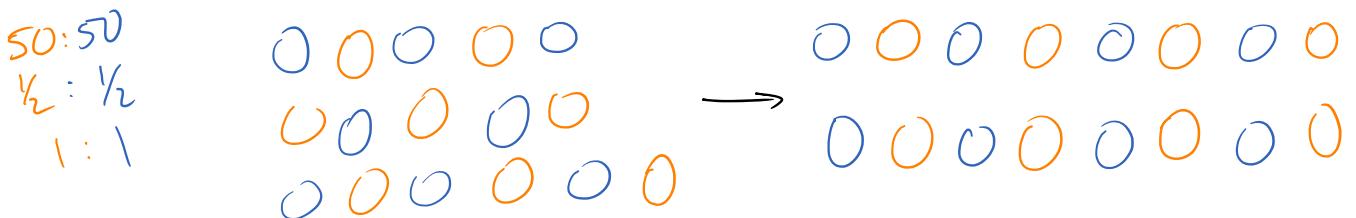
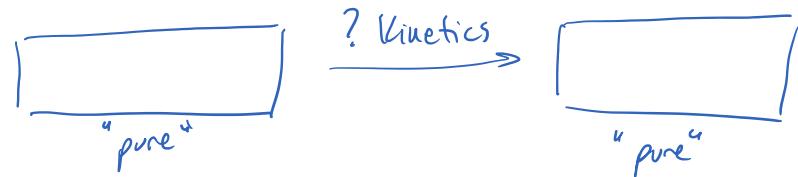
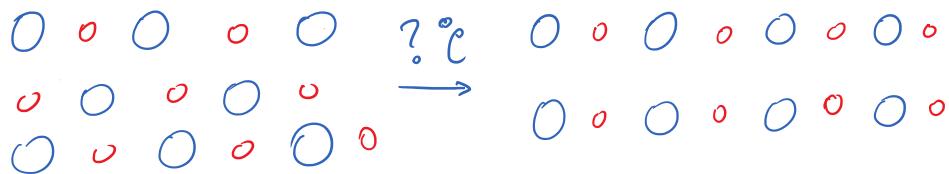
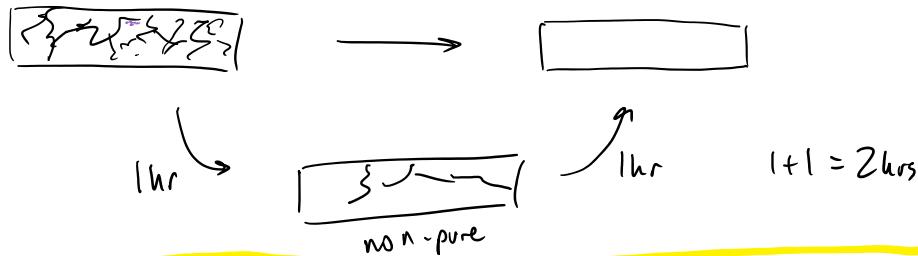
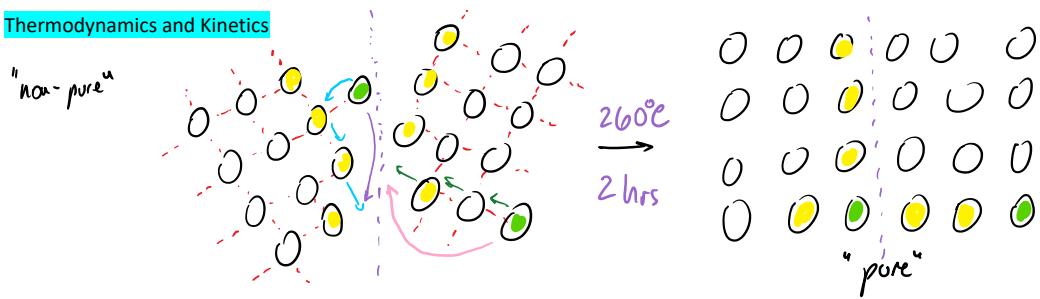


$$\frac{N_v}{N} = \exp\left(\frac{-Q_u}{kT_x}\right)$$

↑ # of vacancy  
↓ energy  
↑ total  
temperature  
Boltzmann number



## Thermodynamics and Kinetics



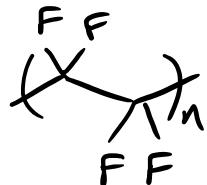
"non-pure"



FYI = Monday Oct 21, 2024. mid-term

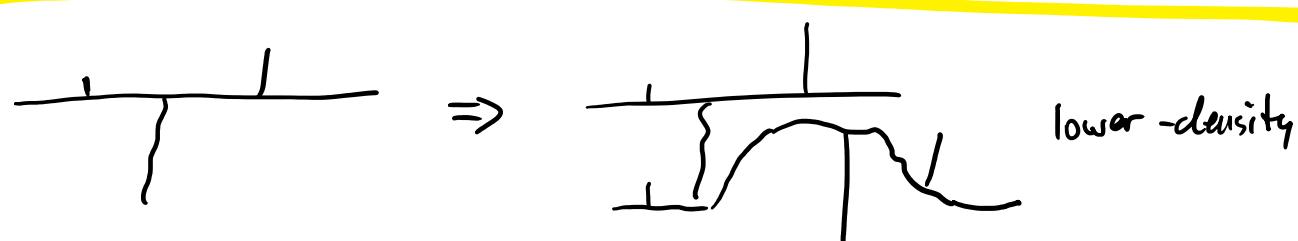
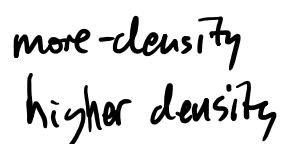
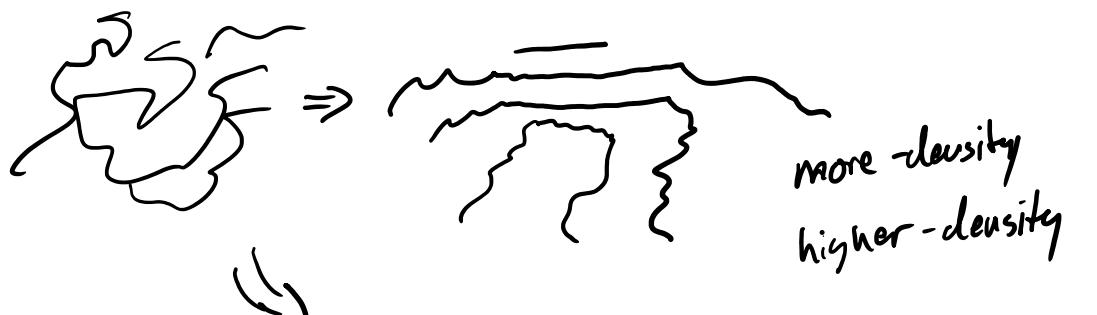
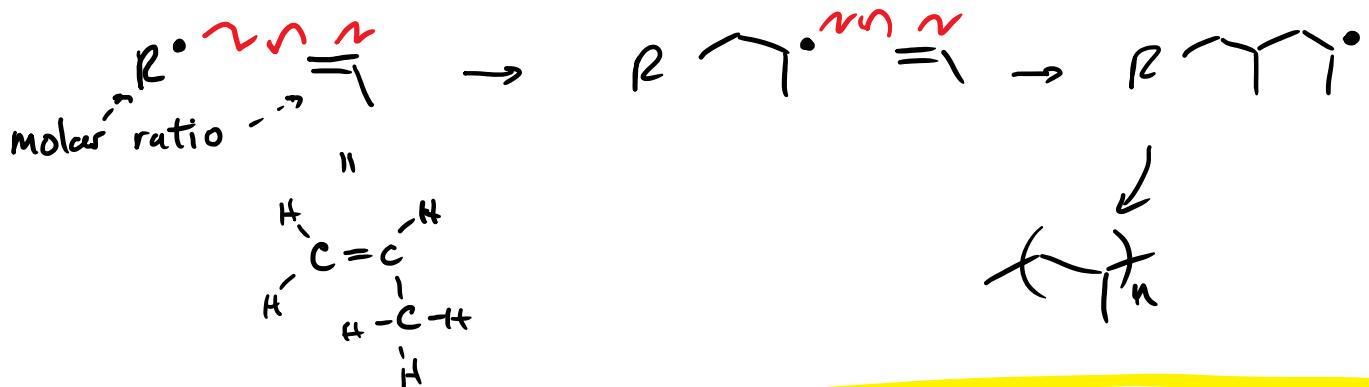
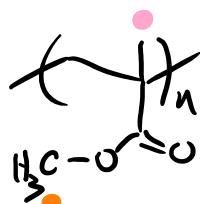
# Introducing Polymers

#4 poly tetra fluoro ethylene  
= Teflon



always linear

#5 poly methyl meth acrylate



cross-coupling



"higher density"

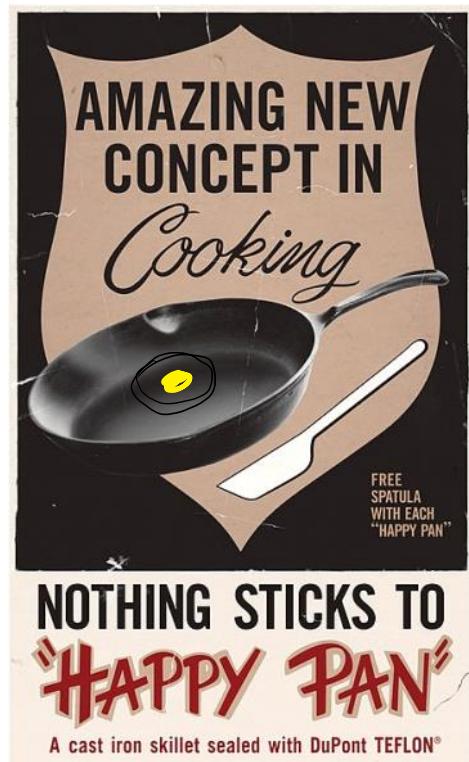
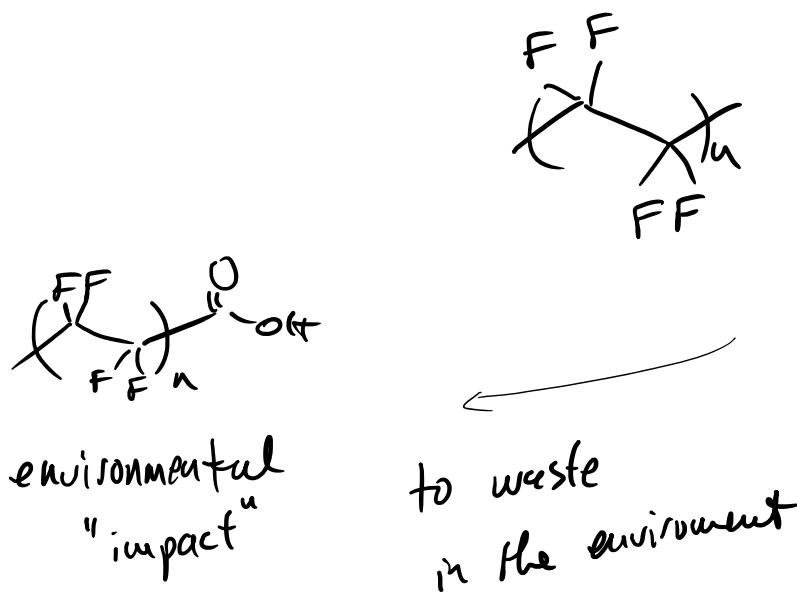
# Recyclable Polymers

October 10, 2024 10:53 AM

**Table 30.1** Recyclable Polymers

Recycling code	Polymer name	Structure	Recycled product	
1	PET Polyethylene terephthalate		fleece jackets carpeting plastic bottles	
2	<u>HDPE</u> <u>High-density polyethylene</u>	#1		Tyvek insulation sports clothing
3	PVC Poly(vinyl chloride)	#3		floor mats
4	<u>LDPE</u> <u>Low-density polyethylene</u>	#1		trash bags
5	PP Polypropylene	#2		furniture
6	PS Polystyrene	#6	=	molded trays trash cans

Non-recycling - founded in 1930-1960s



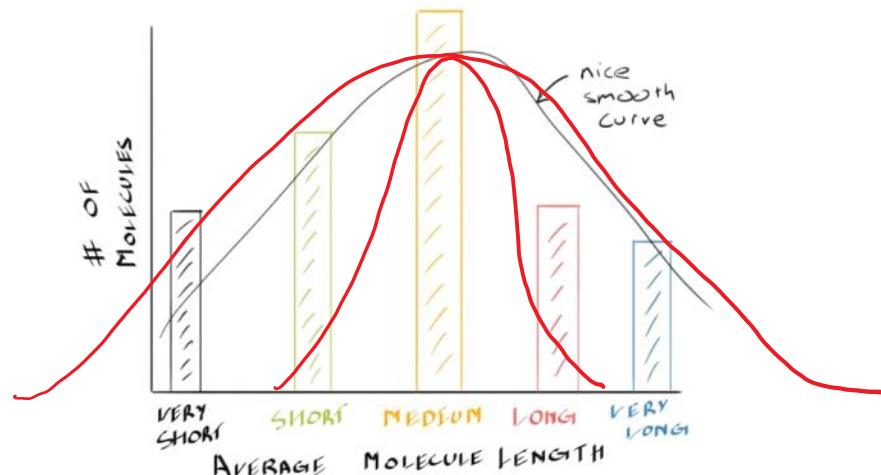


Figure 13. The molecular weight distribution for the hypothetical polymer sample in Figure 12. Our grouping into only five length groupings is very coarse and the actual distribution would be smooth, as shown by the nice smooth curve.

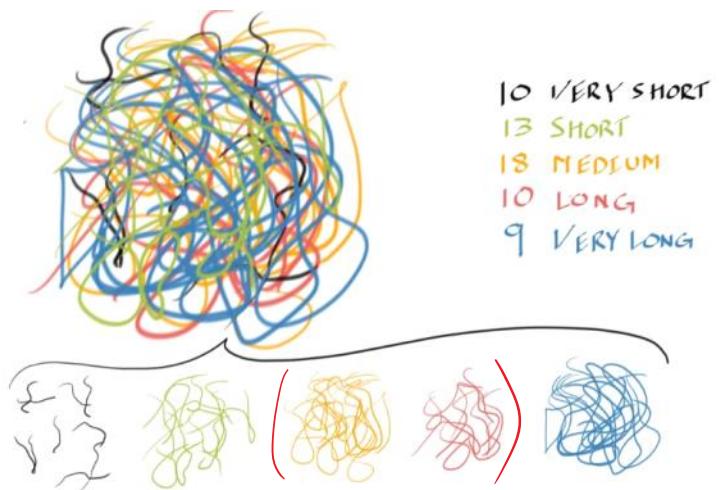
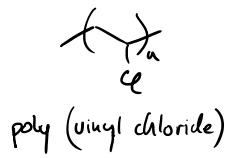
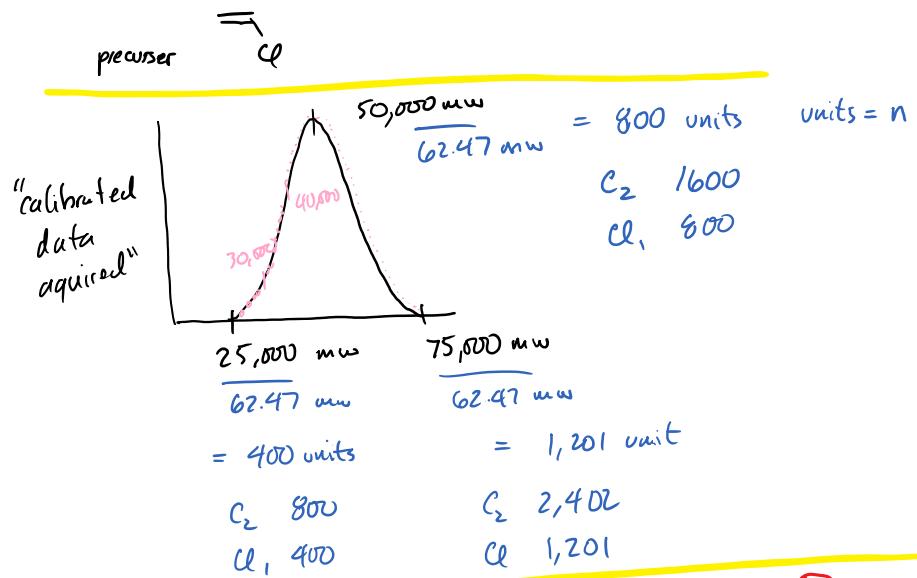


Figure 12. A hypothetical polymer sample consisting of some "very short" molecules, some "short" molecules, some "medium" molecules, some "long" molecules, and some "very long" molecules.

Polymers



$$\begin{aligned} C_2 & 12.01 \times 2 = 24.02 \text{ mw} \\ H_3 & 1.00 \times 3 = 3.00 \text{ mw} \\ Cl_1 & 35.45 \times 1 = 35.45 \text{ mw} \\ & \hline 62.47 \text{ mw} \end{aligned}$$



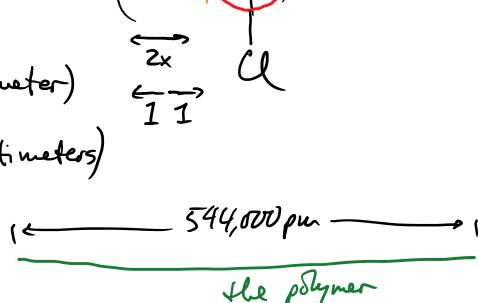
for the 50,000 mw peak. radius 170 pm

$$C_{\text{radius}} = 170 \text{ pm} \times 2 \times 1600$$

$$= 544,000 \text{ pm} \text{ (picometer)}$$

$$= 5.44 \times 10^{-5} \text{ cm} \text{ (centimeters)}$$

$$= 544 \text{ nm}$$

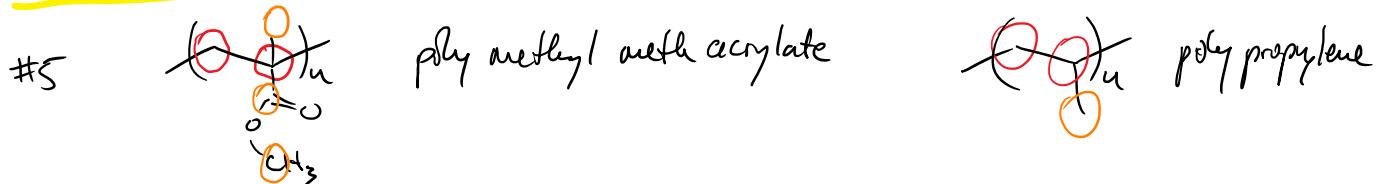


25,000 nm

272,000 pm

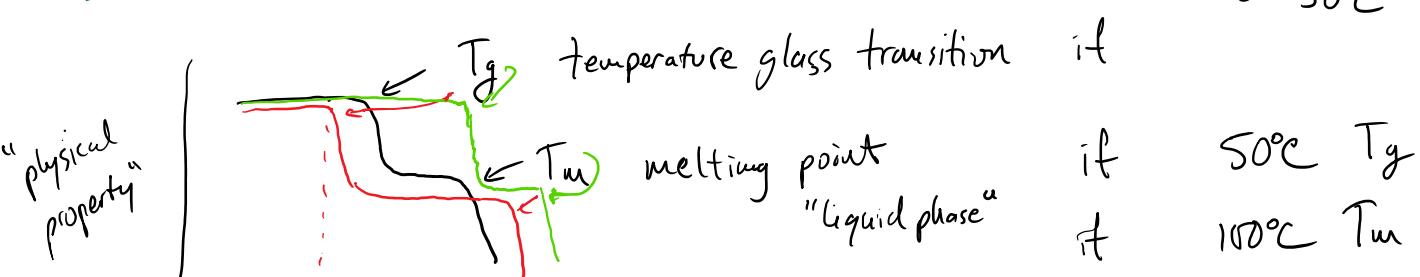
75,000 nm

816,680 pm

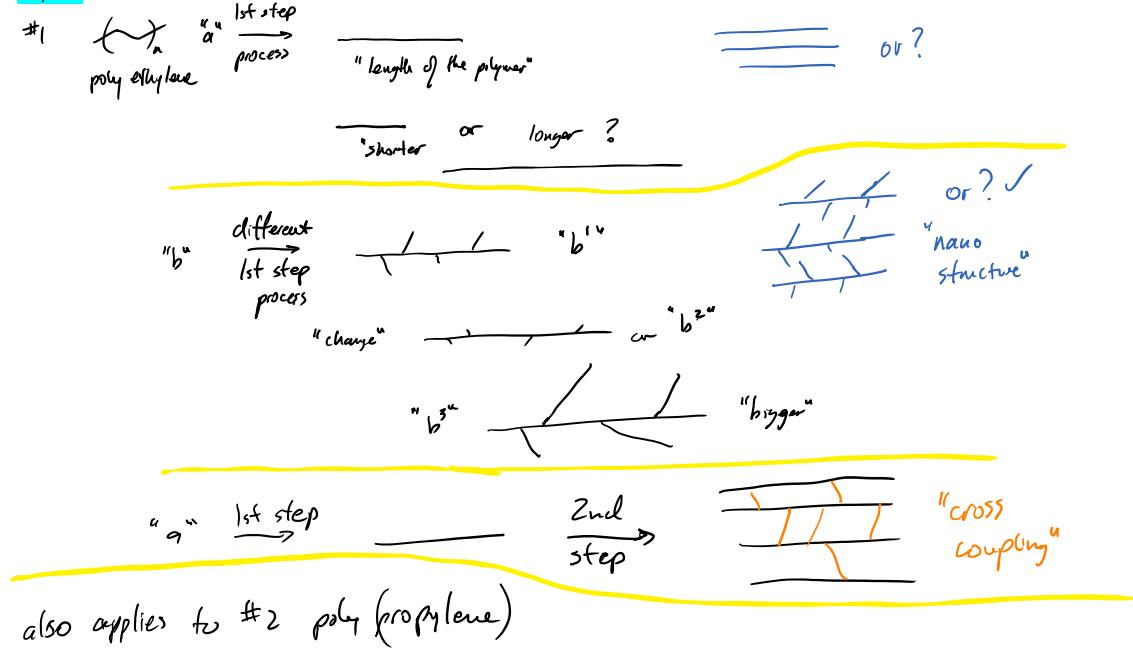


"fires"

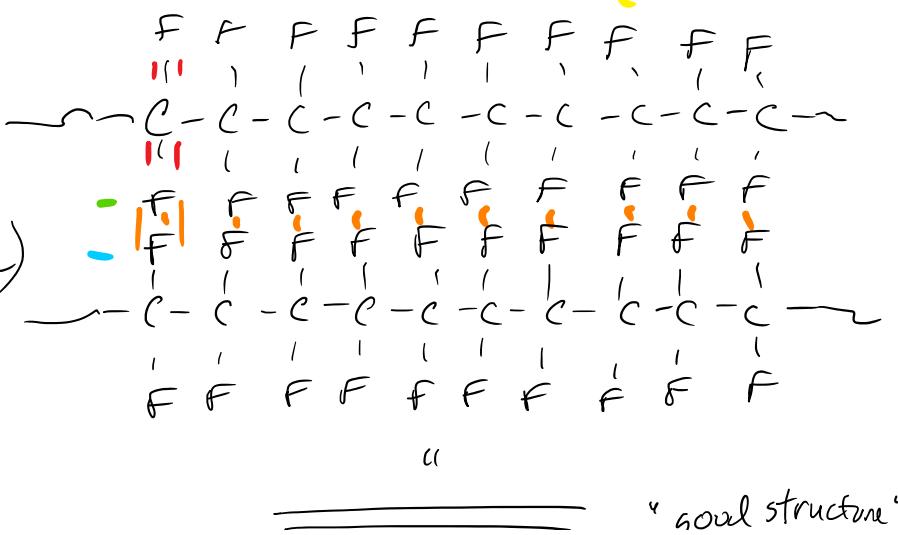
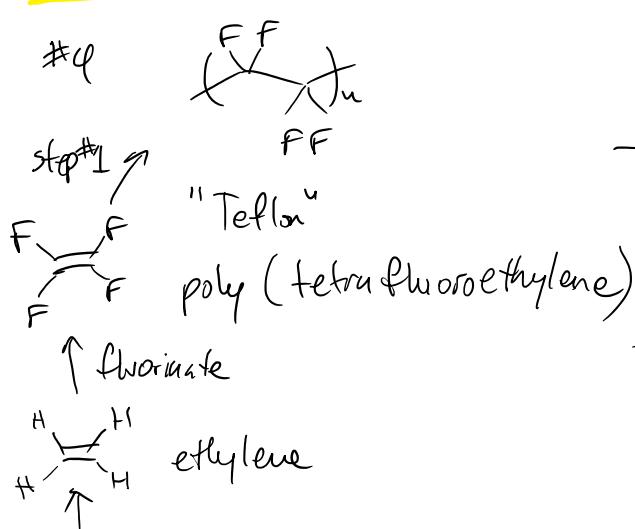
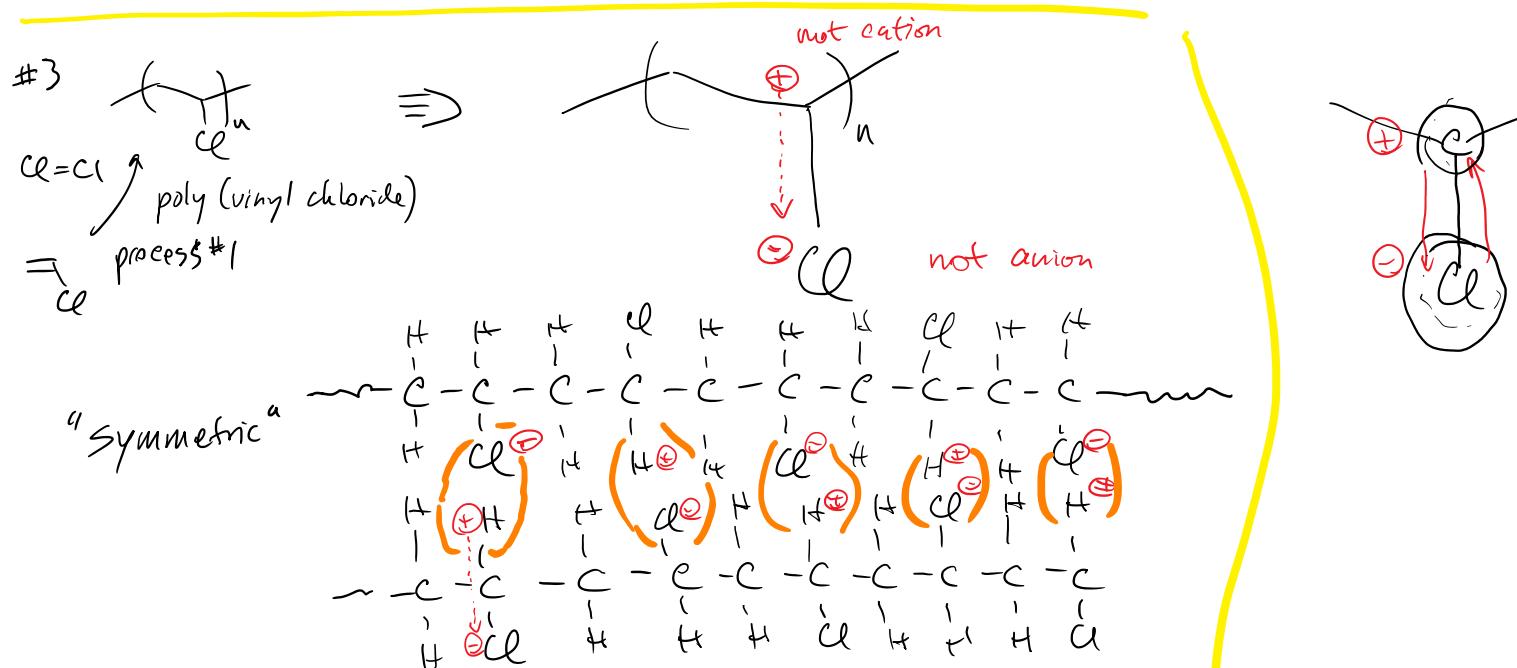
$\sim -50^\circ\text{C}$



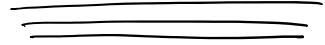
## Polymers

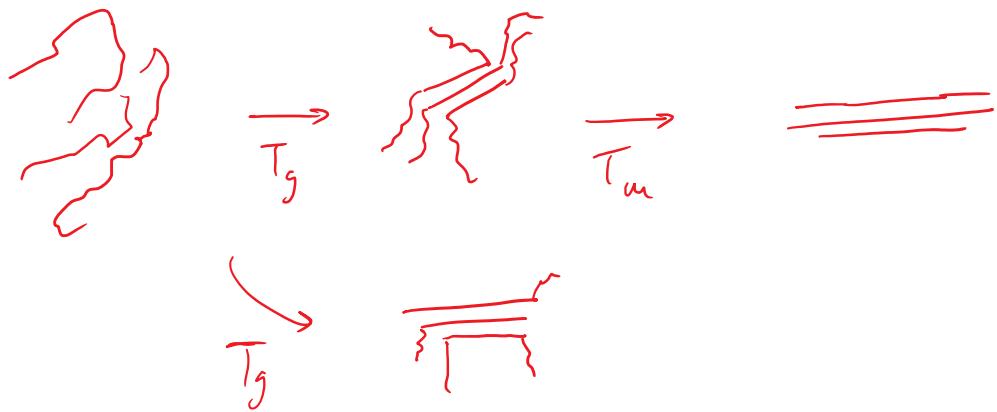
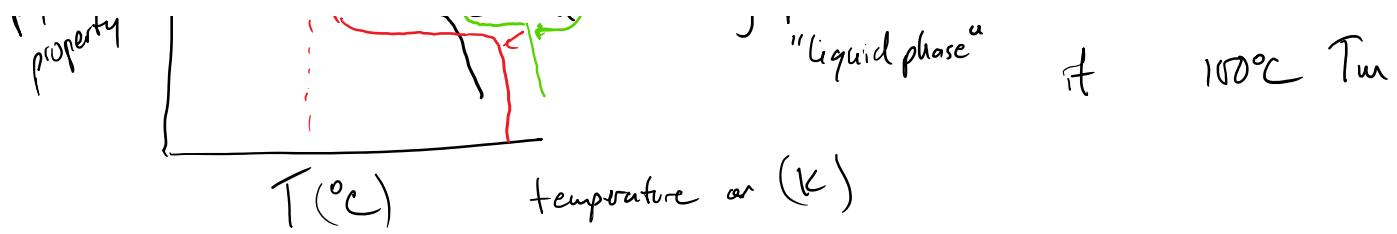


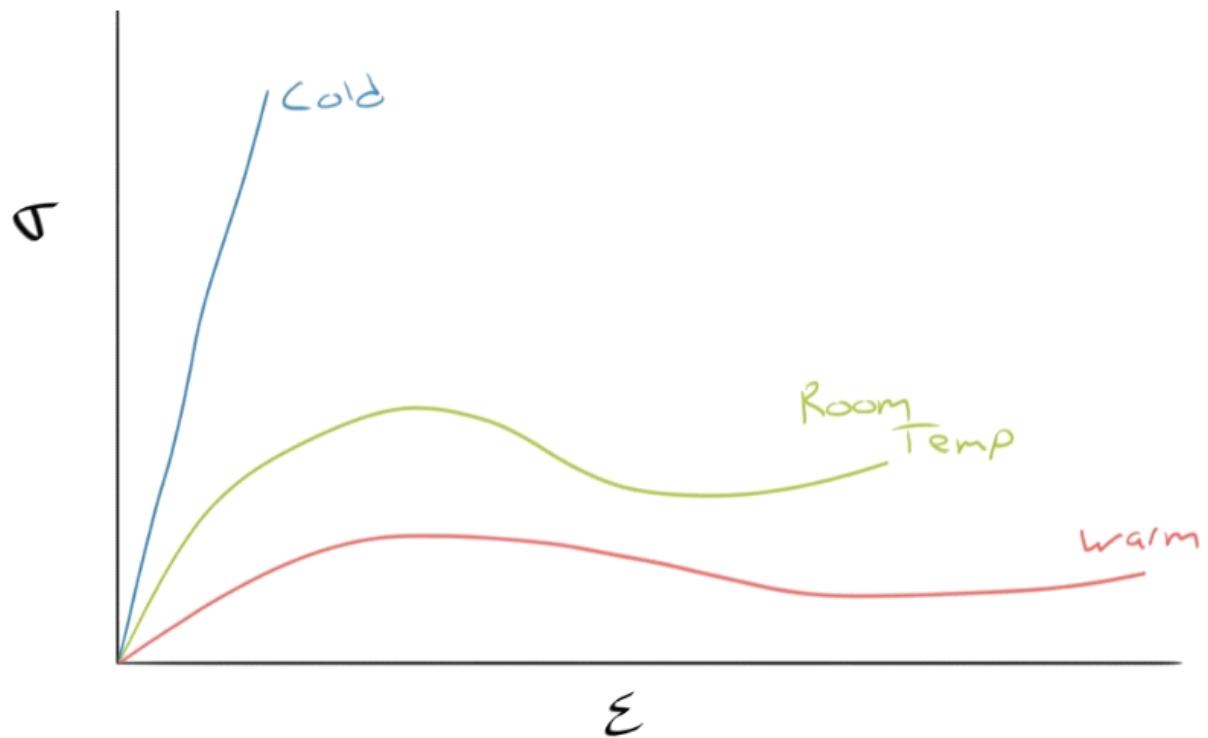
also applies to #2 poly(propylene)



$\nearrow$  H enzyme  
oil

"  
  
"goal structure"





**Figure 19.** A stress-strain curve for a hypothetical plastic polymer at three temperatures. It is not uncommon for polymers to experience significant changes in mechanical properties with relatively small changes in temperature.

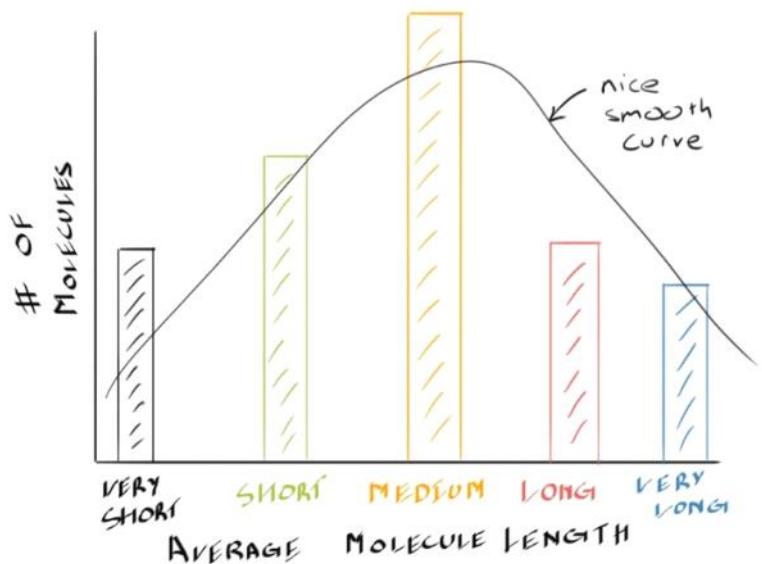
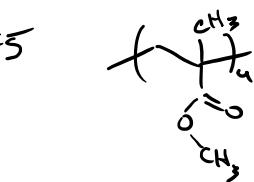


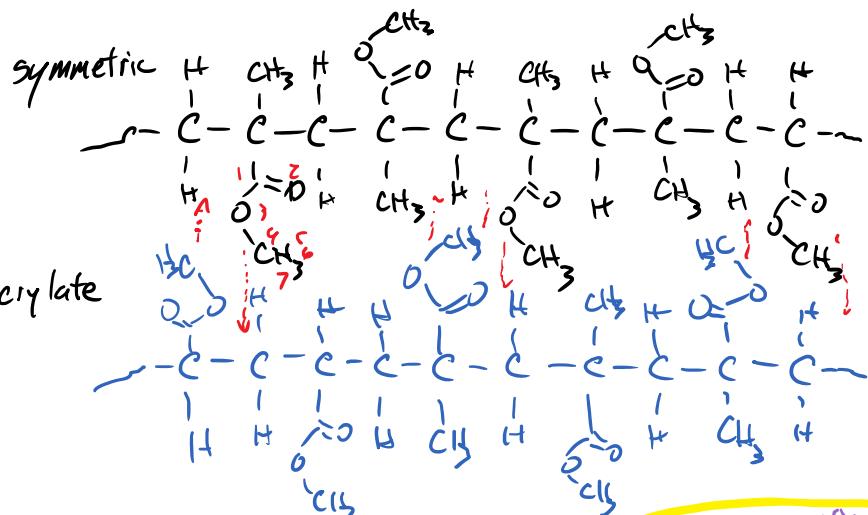
Figure 13. The molecular weight distribution for the hypothetical polymer sample in Figure 12. Our grouping into only five length groupings is very coarse and the actual distribution would be smooth, as shown by the nice smooth curve.

## Polymers

#5

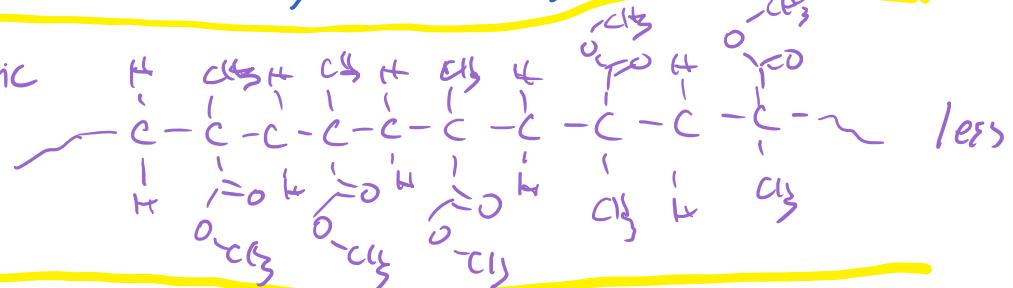


poly methyl methacrylate



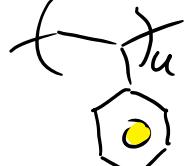
better mechanics

asymmetric



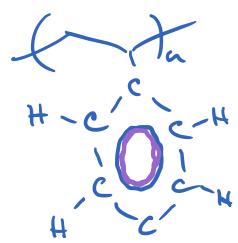
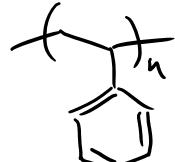
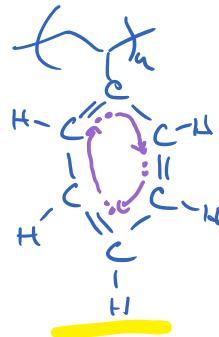
less

#6

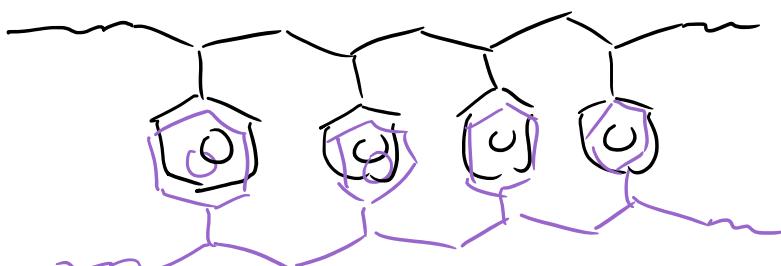


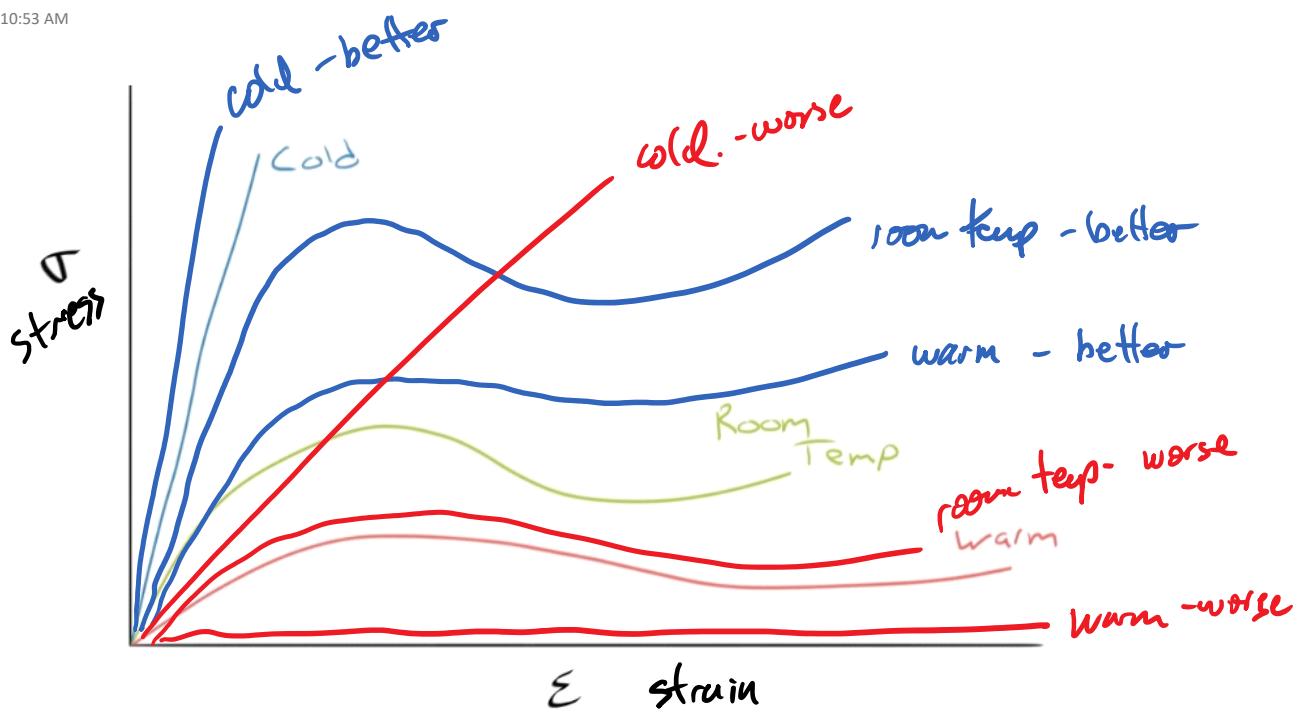
- aromatic ring

poly(styrene)

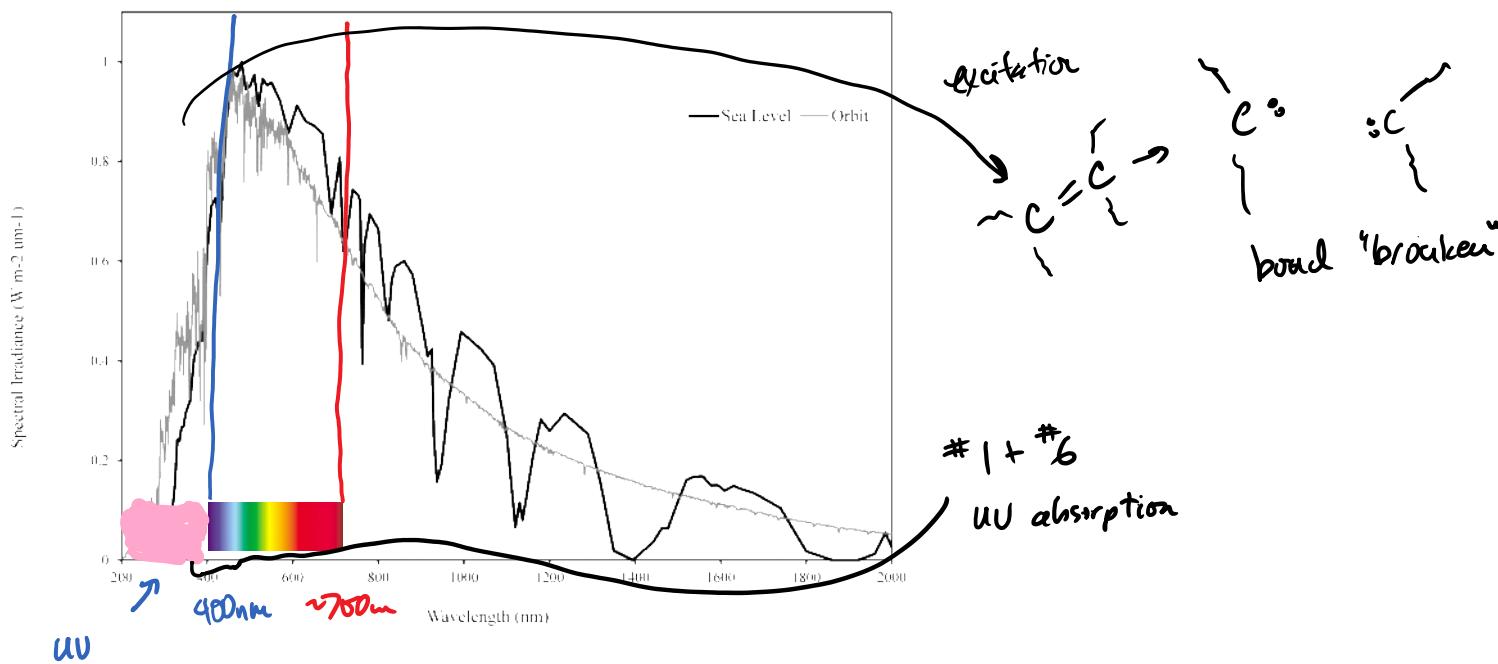
each benzene  
is the same

good mechanical

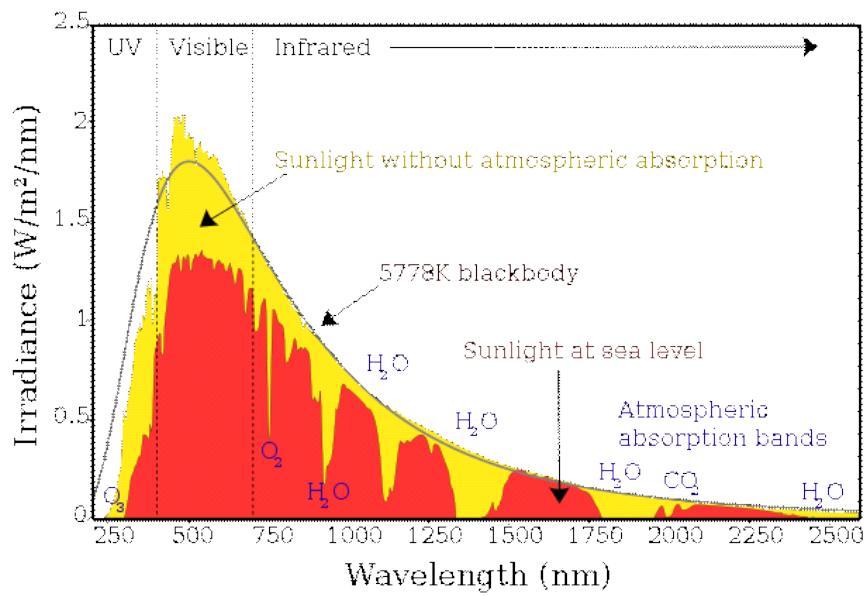




**Figure 19.** A stress-strain curve for a hypothetical plastic polymer at three temperatures. It is not uncommon for polymers to experience significant changes in mechanical properties with relatively small changes in temperature.



## Spectrum of Solar Radiation (Earth)



### Spectrum of Solar Radiation (Earth)

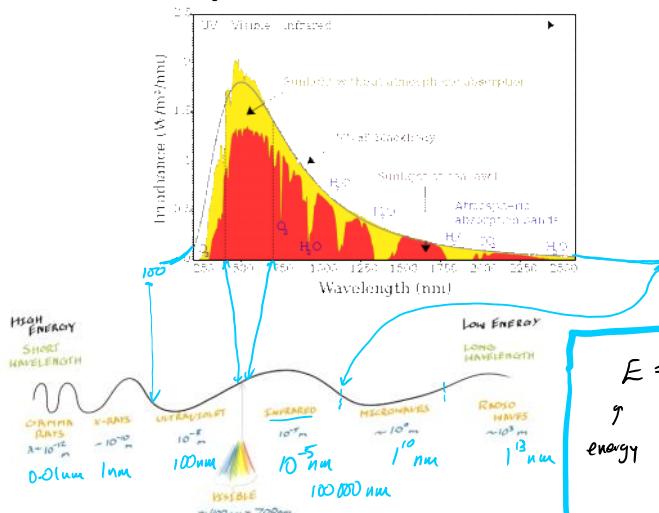
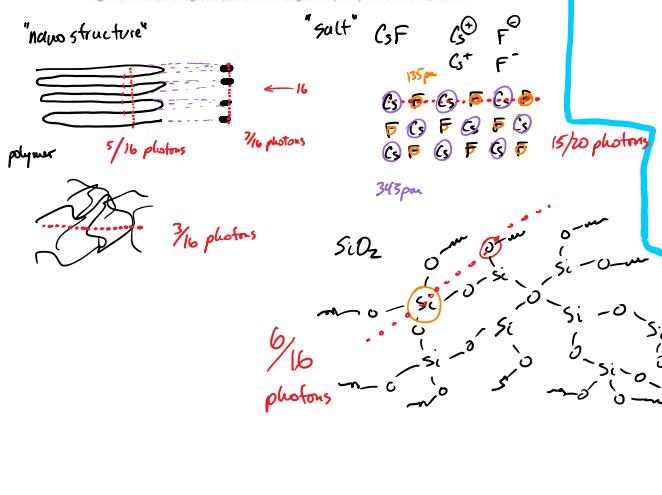


Figure 1. The electromagnetic spectrum. Visible light is only a tiny little bit of the spectrum.



$$E = \frac{hc}{\lambda}$$

h =  $6.626 \times 10^{-34} J \cdot s$  Planck constant

c =  $3 \times 10^8 \frac{m}{s}$  speed of "light"

$$\lambda = \text{wavelength} = 650 \text{ nm}$$

$$= 650 \times 10^{-9} \text{ m}$$

$$= 6.50 \times 10^{-7} \text{ m}$$

$$= \frac{(6.626 \times 10^{-34} J \cdot s)(3 \times 10^8 \frac{m}{s})}{650 \times 10^{-9} \text{ m}}$$

$$E = 3.06 \times 10^{-19} \text{ J}$$

"electron charge energy"

J - electron charge

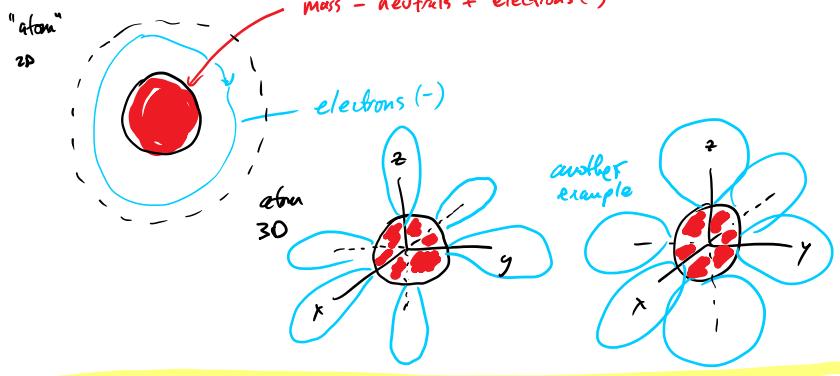
1 eV - 1 volt

$$1 \text{ eV} = E (1e^- \text{ through } 1V) = 1.602 \times 10^{-19} C \cdot 1 \frac{J}{C}$$

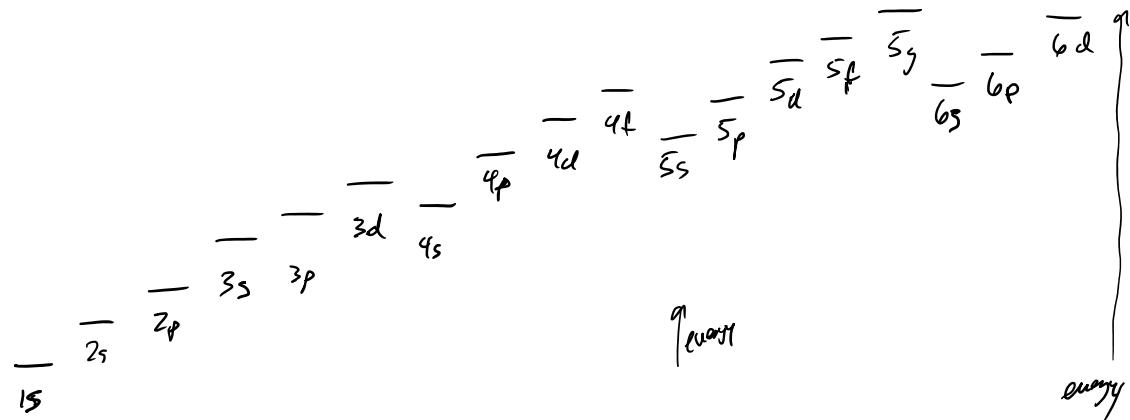
$$= 1.602 \times 10^{-19} \frac{J}{eV}$$

$$E = \frac{3.06 \times 10^{-19} \text{ J}}{1.602 \times 10^{-19} \text{ eV}} = 1.91 \text{ eV}$$

mass - neutrals + electrons (+)



~~1s~~  
~~2s 2p~~  
~~3s 3p 3d~~  
~~4s 4p 4d 4f~~  
~~5s 5p 5d 5f~~  
~~6s 6p 6d 6f~~  
~~7s 7p 7d 7f~~  
~~8s 8p 8d 8f~~  
~~2 6 10 14~~



# Periodic Table - Electron Configuration

November 1, 2024 9:12 AM

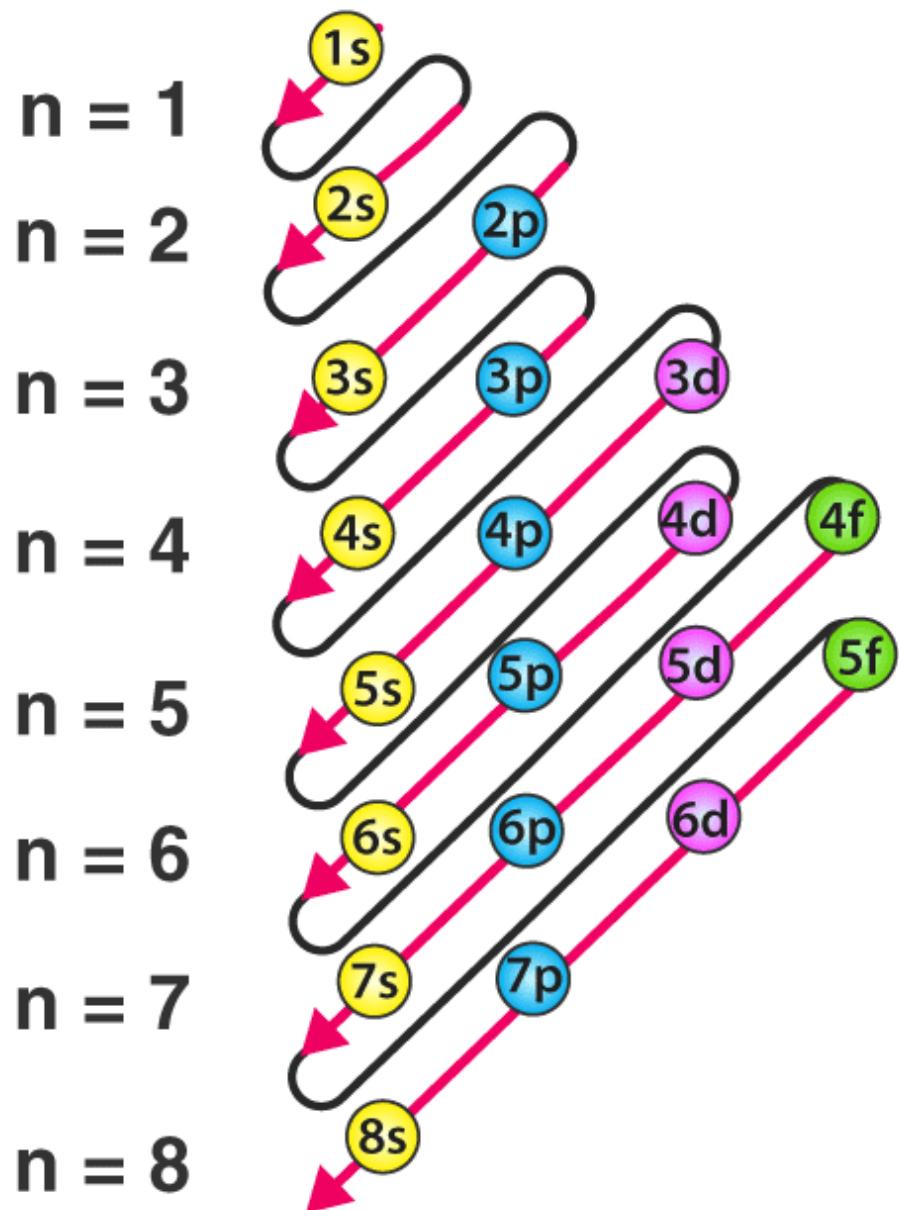
# PERIODIC TABLE OF ELEMENTS

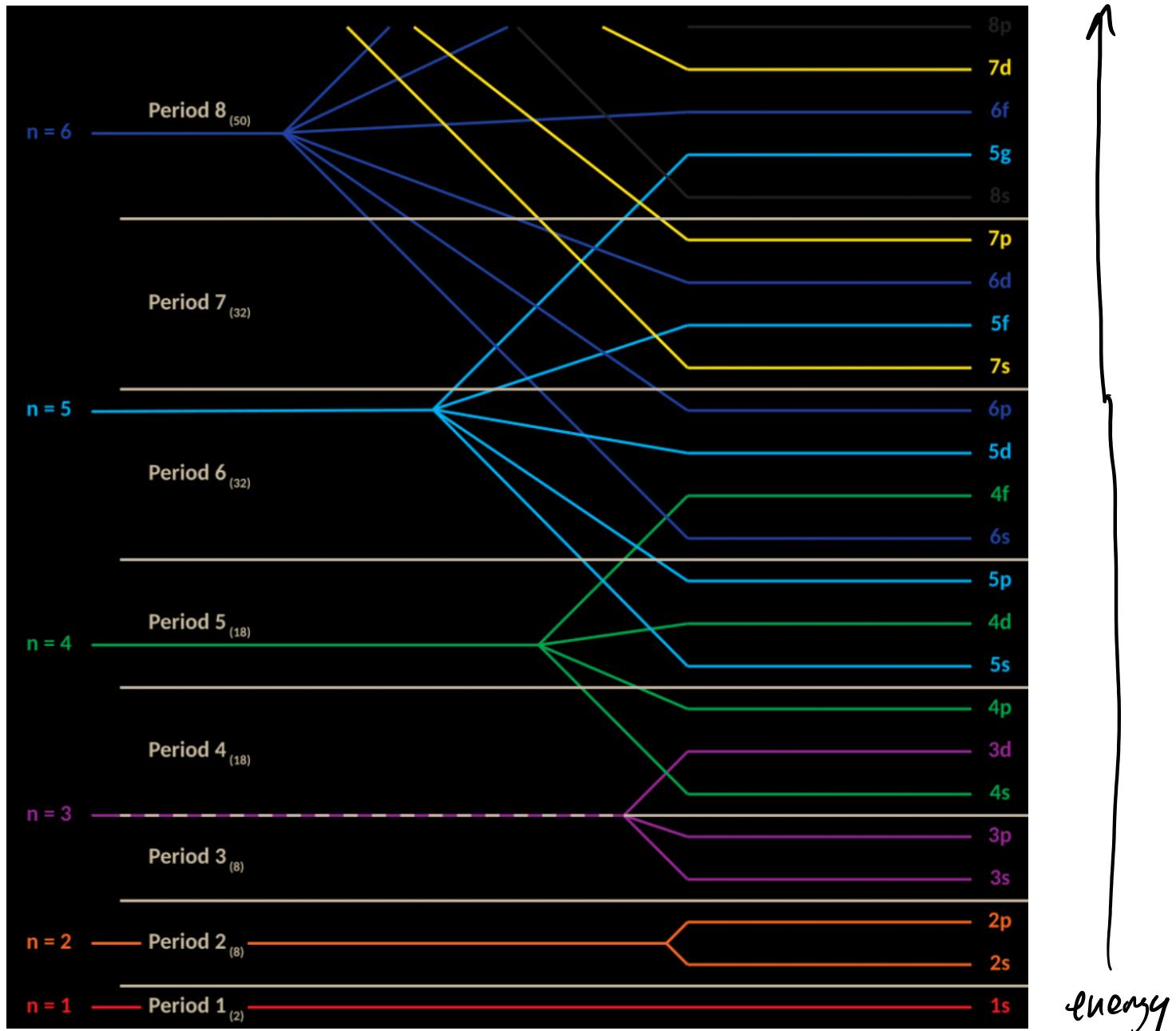
**PubChem**

1 H	2 He
3 Li	4 Be
11 Na	12 Mg
19 K	20 Ca
37 Rb	38 Sr
55 Cs	56 Ba
87 Fr	88 Ra
21 Sc	22 Ti
39 Y	40 Zr
72 Hf	73 Ta
104 Rf	105 Db
58 Ce	59 Pr
89 Ac	90 Th
60 Nd	61 Pm
90 Pa	91 U
62 Sm	93 Np
92 Pu	94 Am
63 Eu	95 Cm
95 Bk	96 Cf
64 Gd	97 Es
65 Tb	98 Fm
66 Dy	99 Md
67 Ho	100 No
68 Er	101 Lr
69 Tm	102 Lu
70 Yb	103 Hg
71 Lu	

**Handwritten Annotations:**

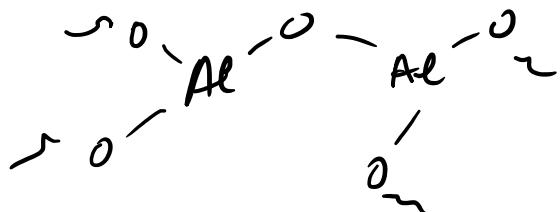
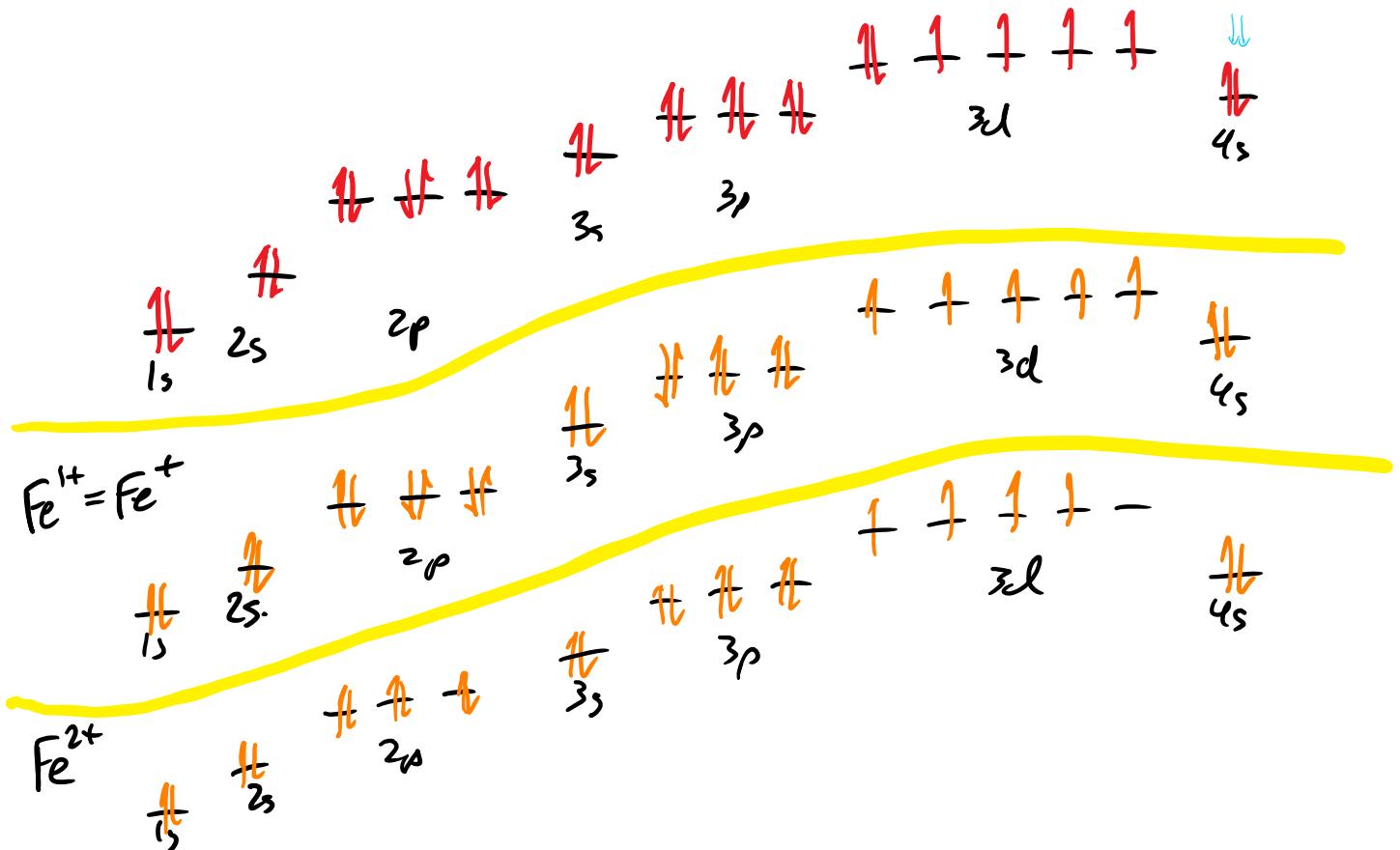
- Hydrogen - H:  $[He] 1s^2$
- Helium - He:  $[He] 1s^2$
- Lithium - Li:  $[He] 2s^2 2p^1$
- Beryllium - Be:  $[He] 2s^2 2p^2$
- Sodium - Na:  $[He] 2s^2 2p^6 3s^1$
- Magnesium - Mg:  $[He] 2s^2 2p^6 3s^2$
- Iron - Fe:  $[Ar] 3s^2 3p^6 3d^6 4s^2$  (highlighted with a red circle)
- Boron - B:  $[He] 2s^2 2p^1$
- Carbon - C:  $[He] 2s^2 2p^2$
- Nitrogen - N:  $[He] 2s^2 2p^3$
- Oxygen - O:  $[He] 2s^2 2p^4$  (highlighted with a red circle)
- Fluorine - F:  $[He] 2s^2 2p^5$
- Neon - Ne:  $[He] 2s^2 2p^6$
- Argon - Ar:  $[Ne] 3s^2 3p^6 = 1s^2 2s^2 2p^6 3s^2 3p^6$
- Krypton - Kr:  $[Ar] 4s^2 3d^10 4p^6 = 1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4s^2 4p^6$
- Xenon - Xe:  $[Kr] 5s^2 4d^10 5p^6$
- Radon - Rn:  $[Xe] 6s^2 4f^14 6d^10 6p^6$
- Oxygen - O<sub>2</sub>:  $[He] 2s^2 2p^4$





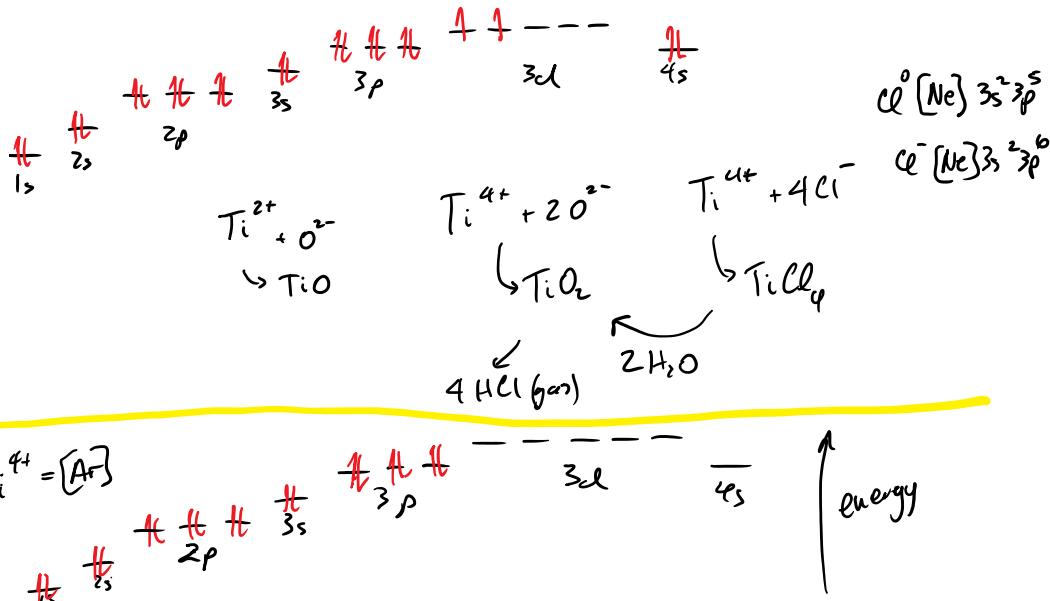
Iron (Fe) - example

$$\text{Fe} = [\text{Ar}] 4s^2 3d^6 = 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$$

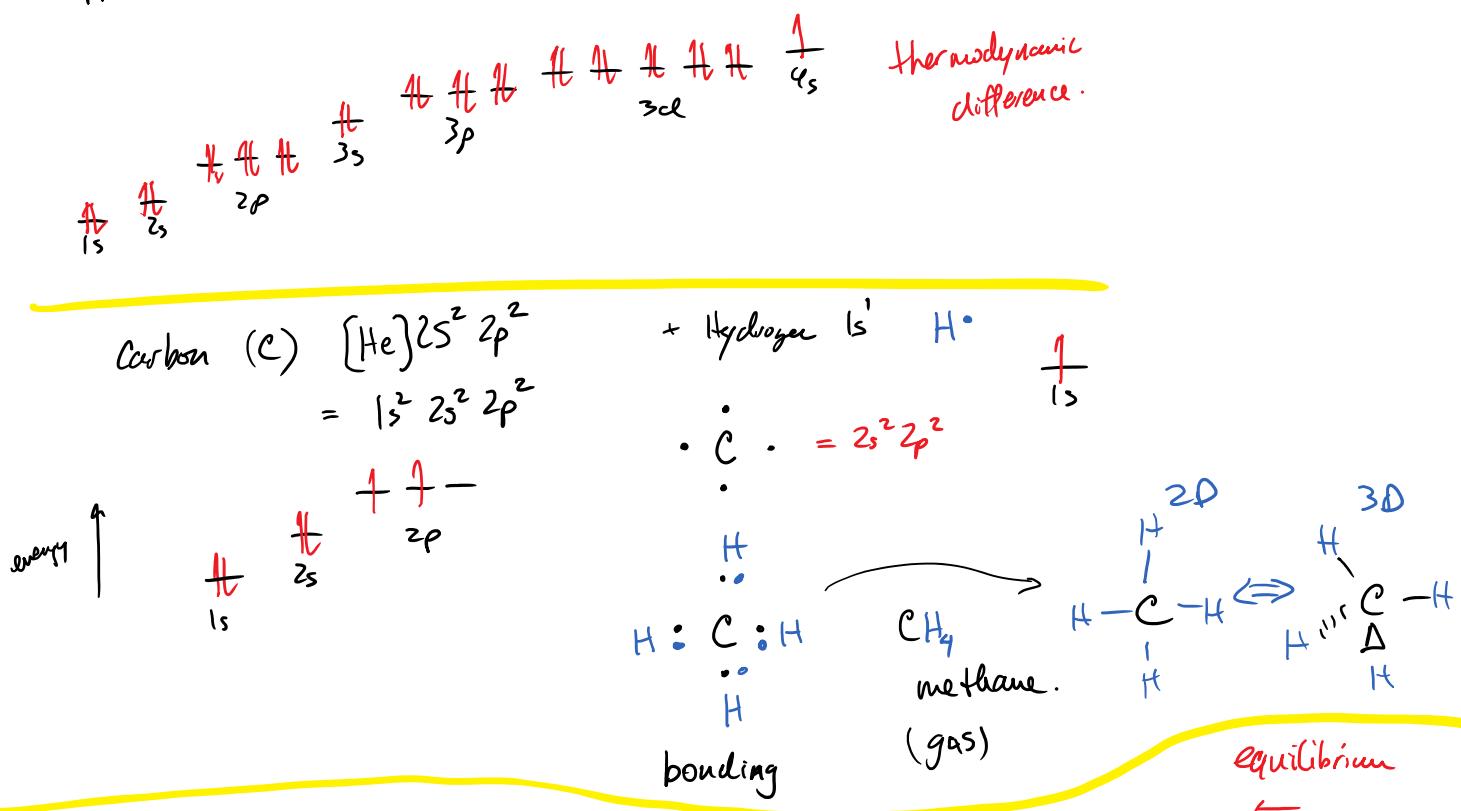


## Electron/Electronic Configuration

titanium ( $Ti$ )  $[Ar] 3s^2 3d^2 = Ti^0$



copper ( $Cu$ )  $[Ar] 3s^1 3d^9$



Carbon dioxide  $CO_2$

Oxygen  $[He] 2s^2 2p^4$



# Periodic Table - Electron Configuration

November 8, 2024 2:00 PM

# PERIODIC TABLE OF ELEMENTS



Atomic Number  
Symbol  
Name  
Electron Configuration

<b>1</b> <b>H</b> Hydrogen $1s^1$	<b>1</b> <b>H</b> Hydrogen $1s^1$	<b>2</b> <b>He</b> Helium $1s^2$
<b>3</b> <b>Li</b> Lithium $1s^2 2s^1$	<b>4</b> <b>Be</b> Beryllium $1s^2 2s^2$	
<b>11</b> <b>Na</b> Sodium $1s^2 2s^2 2p^1$	<b>12</b> <b>Mg</b> Magnesium $1s^2 2s^2 2p^2$	
<b>19</b> <b>K</b> Potassium $1s^2 2s^2 2p^6 3s^1$	<b>20</b> <b>Ca</b> Calcium $1s^2 2s^2 2p^6 3s^2$	<b>5</b> <b>B</b> Boron $1s^2 2s^2 2p^1$
<b>37</b> <b>Rb</b> Rubidium $1s^2 2s^2 2p^6 3s^2 3p^1$	<b>38</b> <b>Sr</b> Strontium $1s^2 2s^2 2p^6 3s^2 3p^2$	<b>13</b> <b>Al</b> Aluminum $1s^2 2s^2 2p^1 3s^2 3p^1$
<b>55</b> <b>Cs</b> Cesium $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$	<b>56</b> <b>Ba</b> Barium $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$	<b>14</b> <b>Si</b> Silicon $1s^2 2s^2 2p^2 3s^2 3p^2$
<b>87</b> <b>Fr</b> Francium $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 4p^1$	<b>88</b> <b>Ra</b> Radium $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 4p^2$	<b>15</b> <b>P</b> Phosphorus $1s^2 2s^2 2p^3 3s^2 3p^3$
	<b>21</b> <b>Sc</b> Scandium $1s^2 2s^2 2p^6 3s^2 3p^1 3d^1$	<b>16</b> <b>S</b> Sulfur $1s^2 2s^2 2p^4 3s^2 3p^4$
	<b>22</b> <b>Ti</b> Titanium $1s^2 2s^2 2p^6 3s^2 3p^2 3d^2$	<b>17</b> <b>Cl</b> Chlorine $1s^2 2s^2 2p^5 3s^2 3p^5$
	<b>23</b> <b>V</b> Vanadium $1s^2 2s^2 2p^6 3s^2 3p^3 3d^3$	<b>18</b> <b>Ar</b> Argon $1s^2 2s^2 2p^6 3s^2 3p^6$
	<b>24</b> <b>Cr</b> Chromium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5$	
	<b>25</b> <b>Mn</b> Manganese $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$	
	<b>26</b> <b>Fe</b> Iron $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$	
	<b>27</b> <b>Co</b> Cobalt $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7 4s^1$	
	<b>28</b> <b>Ni</b> Nickel $1s^2 2s^2 2p^6 3s^2 3p^6 3d^8 4s^1$	
	<b>29</b> <b>Cu</b> Copper $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4s^1$	
	<b>30</b> <b>Zn</b> Zinc $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4s^2$	
	<b>31</b> <b>Ga</b> Gallium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4s^2 4p^1$	
	<b>32</b> <b>Ge</b> Germanium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4s^2 4p^2$	
	<b>33</b> <b>As</b> Arsenic $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4s^2 4p^3$	
	<b>34</b> <b>Se</b> Selenium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4s^2 4p^4$	
	<b>35</b> <b>Br</b> Bromine $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4s^2 4p^5$	
	<b>36</b> <b>Kr</b> Krypton $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4s^2 4p^6$	
	<b>39</b> <b>Y</b> Yttrium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^1$	
	<b>40</b> <b>Zr</b> Zirconium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^2 4f^1$	
	<b>41</b> <b>Nb</b> Niobium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^4 4f^1$	
	<b>42</b> <b>Mo</b> Molybdenum $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4f^1$	
	<b>43</b> <b>Tc</b> Technetium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4f^1$	
	<b>44</b> <b>Ru</b> Ruthenium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7 4f^1$	
	<b>45</b> <b>Rh</b> Rhodium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^9 4f^1$	
	<b>46</b> <b>Pd</b> Palladium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^1$	
	<b>47</b> <b>Ag</b> Silver $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^1$	
	<b>48</b> <b>Cd</b> Cadmium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^1$	
	<b>49</b> <b>In</b> Indium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^1$	
	<b>50</b> <b>Sn</b> Tin $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^1$	
	<b>51</b> <b>Sb</b> Antimony $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^1$	
	<b>52</b> <b>Te</b> Tellurium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^1$	
	<b>53</b> <b>I</b> Iodine $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^1$	
	<b>54</b> <b>Xe</b> Xenon $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^1$	
*	<b>72</b> <b>Hf</b> Hafnium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4f^1$	
*	<b>73</b> <b>Ta</b> Tantalum $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4f^1$	
*	<b>74</b> <b>W</b> Tungsten $1s^2 2s^2 2p^6 3s^2 3p^6 3d^4 4f^2$	
*	<b>75</b> <b>Re</b> Rhenium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4f^2$	
*	<b>76</b> <b>Os</b> Osmium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4f^2$	
*	<b>77</b> <b>Ir</b> Iridium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7 4f^2$	
*	<b>78</b> <b>Pt</b> Platinum $1s^2 2s^2 2p^6 3s^2 3p^6 3d^8 4f^2$	
*	<b>79</b> <b>Au</b> Gold $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^2$	
*	<b>80</b> <b>Hg</b> Mercury $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^2$	
*	<b>81</b> <b>Tl</b> Thallium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^2$	
*	<b>82</b> <b>Pb</b> Lead $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^2$	
*	<b>83</b> <b>Bi</b> Bismuth $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^2$	
*	<b>84</b> <b>Po</b> Polonium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^2$	
*	<b>85</b> <b>At</b> Astatine $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^2$	
*	<b>86</b> <b>Rn</b> Radon $1s^2 2s^2 2p^6 3s^2 3p^6 3d^10 4f^2$	
**	<b>104</b> <b>Rf</b> Rutherfordium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4f^1 5d^1$	
**	<b>105</b> <b>Db</b> Dubnium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4f^2$	
**	<b>106</b> <b>Sg</b> Seaborgium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^4 4f^2$	
**	<b>107</b> <b>Bh</b> Bohrium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3 4f^2$	
**	<b>108</b> <b>Hs</b> Hassium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^2 4f^2$	
**	<b>109</b> <b>Mt</b> Meitnerium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^2$	
**	<b>110</b> <b>Ds</b> Darmstadtium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^0 4f^2$	
**	<b>111</b> <b>Rg</b> Roentgenium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^2$	
**	<b>112</b> <b>Cn</b> Copernicium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^0 4f^2$	
**	<b>113</b> <b>Nh</b> Nihonium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^2$	
**	<b>114</b> <b>Fl</b> Flerovium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^0 4f^2$	
**	<b>115</b> <b>Mc</b> Moscovium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^2$	
**	<b>116</b> <b>Lv</b> Livermorium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^0 4f^2$	
**	<b>117</b> <b>Ts</b> Tennessee $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^2$	
**	<b>118</b> <b>Og</b> Oganesson $1s^2 2s^2 2p^6 3s^2 3p^6 3d^0 4f^2$	
*	<b>57</b> <b>La</b> Lanthanum $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^1$	
*	<b>58</b> <b>Ce</b> Curium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^2$	
*	<b>59</b> <b>Pr</b> Praseodymium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^3$	
*	<b>60</b> <b>Nd</b> Neodymium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^4$	
*	<b>61</b> <b>Pm</b> Promethium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^5$	
*	<b>62</b> <b>Sm</b> Samarium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^6$	
*	<b>63</b> <b>Eu</b> Europium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^7$	
*	<b>64</b> <b>Gd</b> Gadolinium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^8$	
*	<b>65</b> <b>Tb</b> Terbium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^9$	
*	<b>66</b> <b>Dy</b> Dysprosium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^10$	
*	<b>67</b> <b>Ho</b> Holmium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^11$	
*	<b>68</b> <b>Er</b> Erbium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^12$	
*	<b>69</b> <b>Tm</b> Thulium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^13$	
*	<b>70</b> <b>Yb</b> Ytterbium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^14$	
*	<b>71</b> <b>Lu</b> Lutetium $1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4f^15$	

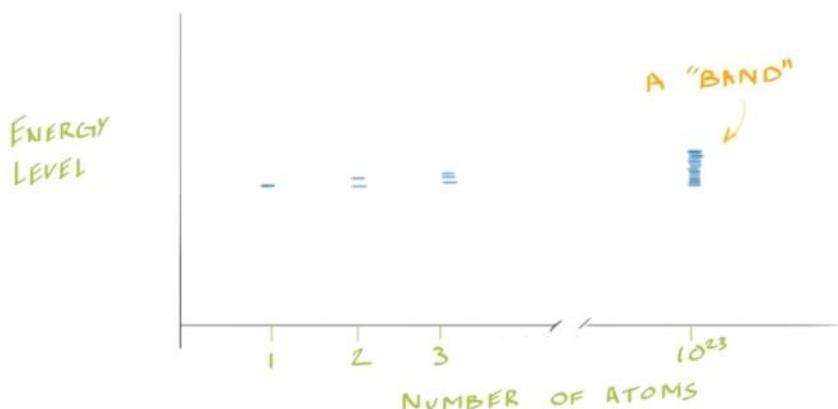
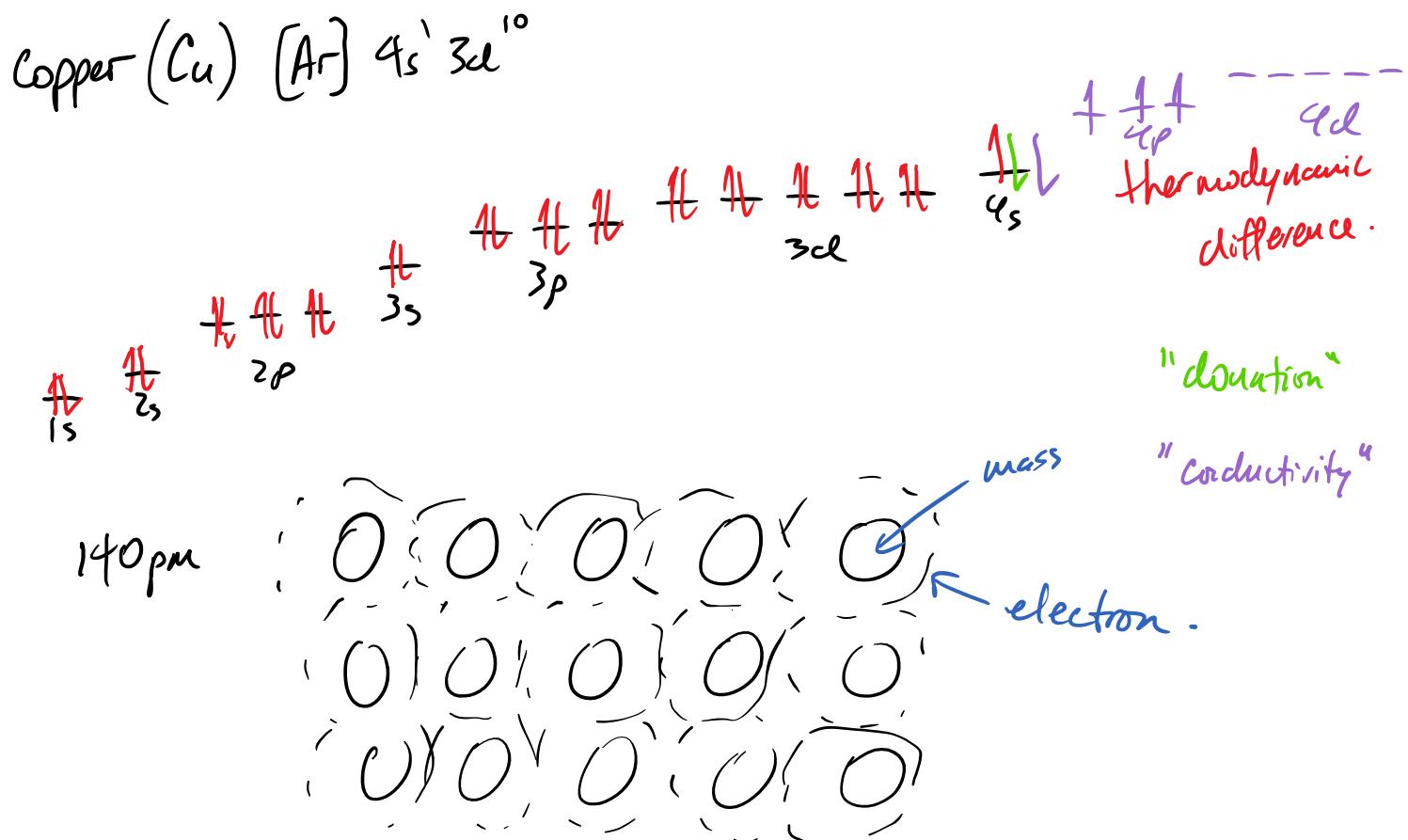


Figure 11. A schematic depiction of a particular energy level in an isolated atom, two atoms, three atoms, and so on up to a massive collection of atoms, as in a solid. The number of energy levels in a solid, for a corresponding single energy level in an isolated atom, is equal to the number of atoms, so that when we have a solid there are so many closely spaced energy levels as to be essentially continuous. We call this a band.

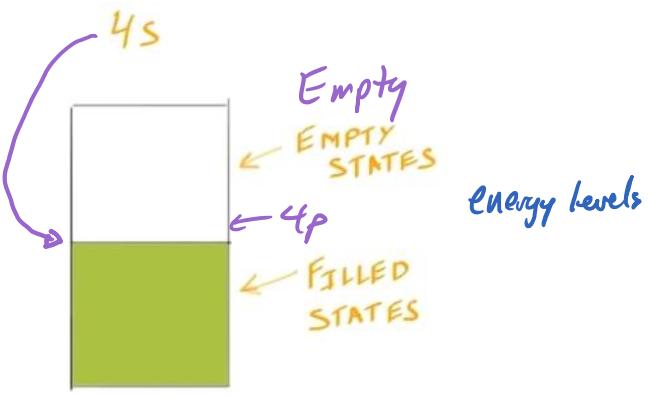
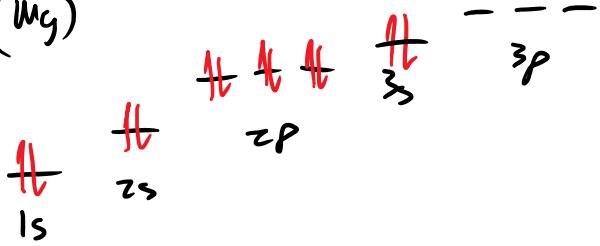
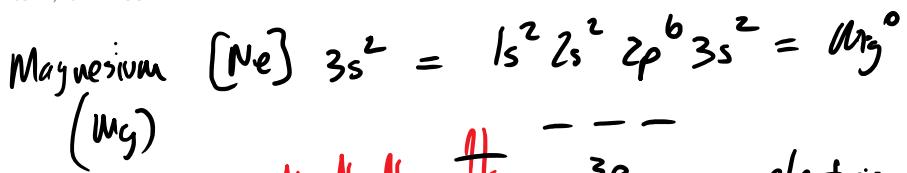


Figure 12. The band structure for copper.

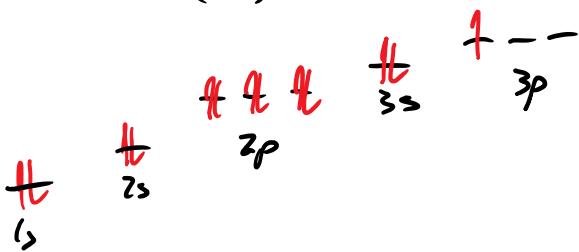
## Magnesium, Aluminum

November 11, 2024 8:54 AM



electric conductivity

- weak / not good
- semi-conductor



electric conductivity (back in  
the day)

- "ok" conductivity

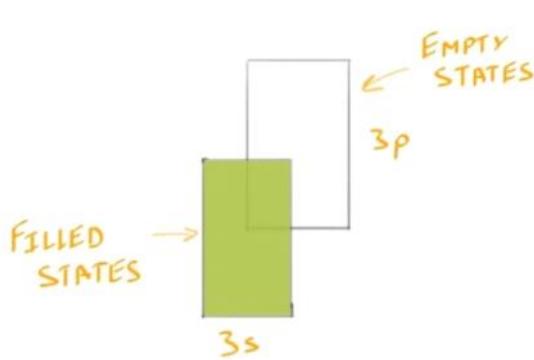


Figure 13. The band structure for magnesium.

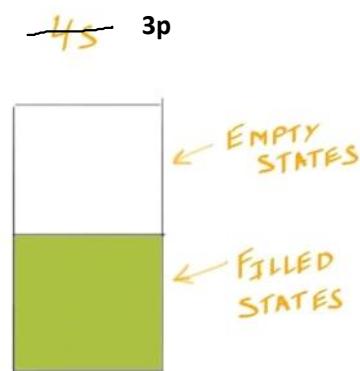
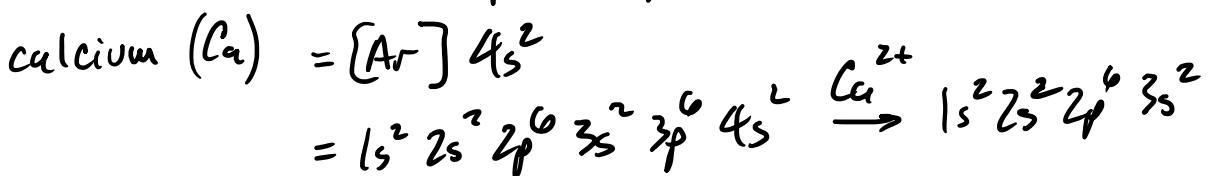
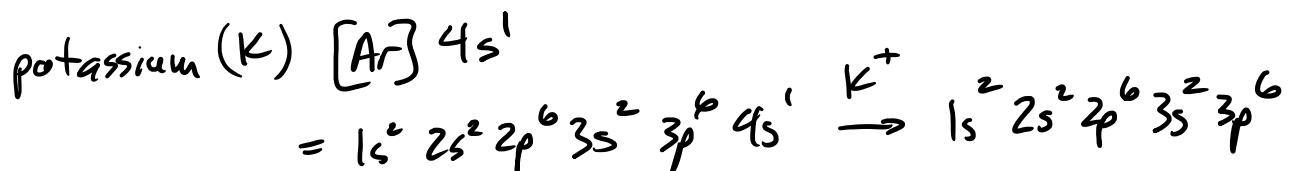
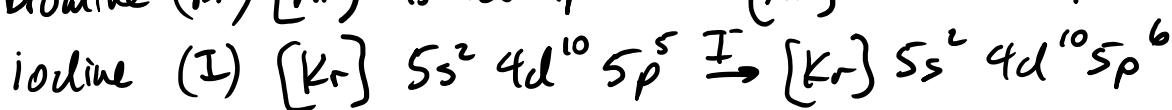
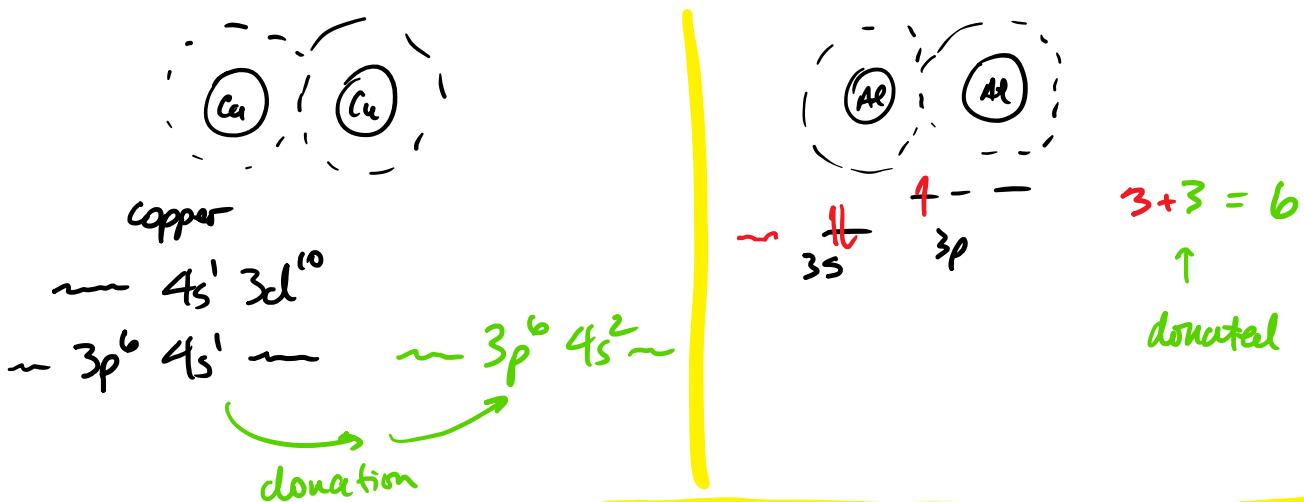


Figure 12. The band structure for aluminum

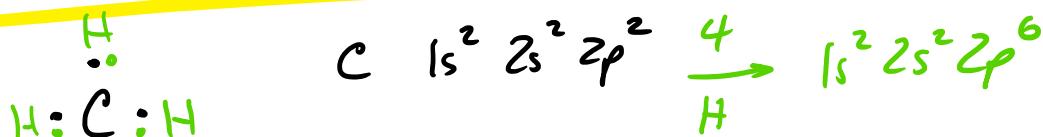
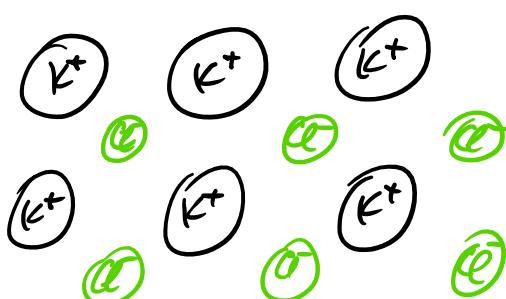
Octet rule "ns<sup>2</sup> np<sup>6</sup>" - "stable"/more stable

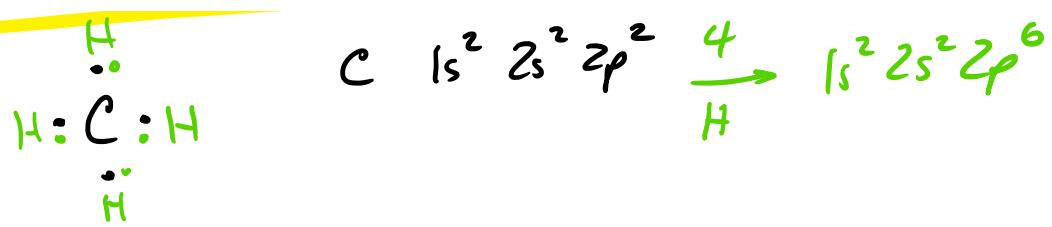


175 pm

KCl

275 pm





# Periodic Table - Electron Configuration

November 8, 2024 2:00 PM

# PERIODIC TABLE OF ELEMENTS



<b>1</b> <b>H</b> Hydrogen $1s^1$	<b>2</b> <b>He</b> Helium $1s^2$
<b>3</b> <b>Li</b> Lithium $[He]2s^1$	<b>4</b> <b>Be</b> Beryllium $[He]2s^2$
<b>11</b> <b>Na</b> Sodium $[He]2s^1$	<b>12</b> <b>Mg</b> Magnesium $[He]2s^2$
<b>19</b> <b>K</b> Potassium $[Ar]3s^1$	<b>20</b> <b>Ca</b> Calcium $[Ar]3s^2$
<b>37</b> <b>Rb</b> Rubidium $[Ar]3s^2$	<b>38</b> <b>Sr</b> Strontium $[Ar]3s^2$
<b>55</b> <b>Cs</b> Cesium $[Ar]3s^2$	<b>56</b> <b>Ba</b> Barium $[Ar]3s^2$
<b>87</b> <b>Fr</b> Francium $[Rn]5s^1$	<b>88</b> <b>Ra</b> Radium $[Rn]5s^2$
<b>21</b> <b>Sc</b> Scandium $[Ar]3d^14s^2$	<b>22</b> <b>Ti</b> Titanium $[Ar]3d^24s^2$
<b>23</b> <b>V</b> Vanadium $[Ar]3d^34s^2$	<b>24</b> <b>Cr</b> Chromium $[Ar]3d^54s^1$
<b>25</b> <b>Mn</b> Manganese $[Ar]3d^54s^2$	<b>26</b> <b>Fe</b> Iron $[Ar]3d^64s^2$
<b>27</b> <b>Co</b> Cobalt $[Ar]3d^74s^2$	<b>28</b> <b>Ni</b> Nickel $[Ar]3d^84s^2$
<b>29</b> <b>Cu</b> Copper $[Ar]3d^104s^1$	<b>30</b> <b>Zn</b> Zinc $[Ar]3d^104s^2$
<b>31</b> <b>Ga</b> Gallium $[Ar]3d^104s^24p^1$	<b>32</b> <b>Ge</b> Germanium $[Ar]3d^104s^24p^2$
<b>33</b> <b>As</b> Arsenic $[Ar]3d^104s^24p^3$	<b>34</b> <b>Se</b> Selenium $[Ar]3d^104s^24p^4$
<b>35</b> <b>Br</b> Bromine $[Ar]3d^104s^24p^5$	<b>36</b> <b>Kr</b> Krypton $[Ar]3d^104s^24p^6$
<b>39</b> <b>Y</b> Yttrium $[Ar]3d^14s^2$	<b>40</b> <b>Zr</b> Zirconium $[Ar]3d^24s^2$
<b>41</b> <b>Nb</b> Niobium $[Ar]3d^44s^2$	<b>42</b> <b>Mo</b> Molybdenum $[Ar]3d^54s^2$
<b>43</b> <b>Tc</b> Technetium $[Ar]3d^54s^2$	<b>44</b> <b>Ru</b> Ruthenium $[Ar]3d^74s^2$
<b>45</b> <b>Rh</b> Rhodium $[Ar]3d^84s^2$	<b>46</b> <b>Pd</b> Palladium $[Ar]3d^94s^2$
<b>47</b> <b>Ag</b> Silver $[Ar]3d^104s^2$	<b>48</b> <b>Cd</b> Cadmium $[Ar]3d^104s^2$
<b>49</b> <b>In</b> Indium $[Ar]3d^104s^24p^1$	<b>50</b> <b>Sn</b> Tin $[Ar]3d^104s^24p^2$
<b>51</b> <b>Sb</b> Antimony $[Ar]3d^104s^24p^3$	<b>52</b> <b>Te</b> Tellurium $[Ar]3d^104s^24p^4$
<b>53</b> <b>I</b> Iodine $[Ar]3d^104s^24p^5$	<b>54</b> <b>Xe</b> Xenon $[Ar]3d^104s^24p^6$
<b>72</b> <b>Hf</b> Hafnium $[Ar]3d^44f^15s^2$	<b>73</b> <b>Ta</b> Tantalum $[Ar]3d^54f^15s^2$
<b>74</b> <b>W</b> Tungsten $[Ar]3d^64f^25s^2$	<b>75</b> <b>Re</b> Rhenium $[Ar]3d^74f^25s^2$
<b>76</b> <b>Os</b> Osmium $[Ar]3d^84f^25s^2$	<b>77</b> <b>Ir</b> Iridium $[Ar]3d^94f^25s^2$
<b>78</b> <b>Pt</b> Platinum $[Ar]3d^104f^25s^2$	<b>79</b> <b>Au</b> Gold $[Ar]3d^104f^25s^2$
<b>80</b> <b>Hg</b> Mercury $[Ar]3d^104f^25s^2$	<b>81</b> <b>Tl</b> Thallium $[Ar]3d^104f^25s^2$
<b>82</b> <b>Pb</b> Lead $[Ar]3d^104f^25s^2$	<b>83</b> <b>Bi</b> Bismuth $[Ar]3d^104f^25s^2$
<b>84</b> <b>Po</b> Polonium $[Ar]3d^104f^25s^2$	<b>85</b> <b>At</b> Astatine $[Ar]3d^104f^25s^2$
<b>86</b> <b>Rn</b> Radon $[Ar]3d^104f^25s^2$	<b>104</b> <b>Rf</b> Rutherfordium $[Ar]3d^24f^15s^2$
<b>105</b> <b>Db</b> Dubnium $[Ar]3d^24f^25s^2$	<b>106</b> <b>Sg</b> Seaborgium $[Ar]3d^24f^25s^2$
<b>107</b> <b>Bh</b> Bohrium $[Ar]3d^24f^25s^2$	<b>108</b> <b>Hs</b> Hassium $[Ar]3d^24f^25s^2$
<b>109</b> <b>Mt</b> Meitnerium $[Ar]3d^24f^25s^2$	<b>110</b> <b>Ds</b> Darmstadtium $[Ar]3d^24f^25s^2$
<b>111</b> <b>Rg</b> Roentgenium $[Ar]3d^24f^25s^2$	<b>112</b> <b>Cn</b> Copernicium $[Ar]3d^24f^25s^2$
<b>113</b> <b>Nh</b> Nihonium $[Ar]3d^24f^25s^2$	<b>114</b> <b>Fl</b> Flerovium $[Ar]3d^24f^25s^2$
<b>115</b> <b>Mc</b> Moscovium $[Ar]3d^24f^25s^2$	<b>116</b> <b>Lv</b> Livermorium $[Ar]3d^24f^25s^2$
<b>117</b> <b>Ts</b> Tennessine $[Ar]3d^24f^25s^2$	<b>118</b> <b>Og</b> Oganesson $[Ar]3d^24f^25s^2$
<b>57</b> <b>La</b> Lanthanum $[Ce]4f^15s^2$	<b>58</b> <b>Ce</b> Curium $[Ce]4f^15s^2$
<b>59</b> <b>Pr</b> Praseodymium $[Ce]4f^35s^2$	<b>60</b> <b>Nd</b> Neodymium $[Ce]4f^45s^2$
<b>61</b> <b>Pm</b> Promethium $[Ce]4f^55s^2$	<b>62</b> <b>Sm</b> Samarium $[Ce]4f^75s^2$
<b>63</b> <b>Eu</b> Europium $[Ce]4f^95s^2$	<b>64</b> <b>Gd</b> Gadolinium $[Ce]4f^105s^2$
<b>65</b> <b>Tb</b> Terbium $[Ce]4f^125s^2$	<b>66</b> <b>Dy</b> Dysprosium $[Ce]4f^135s^2$
<b>67</b> <b>Ho</b> Holmium $[Ce]4f^145s^2$	<b>68</b> <b>Er</b> Erbium $[Ce]4f^155s^2$
<b>69</b> <b>Tm</b> Thulium $[Ce]4f^165s^2$	<b>70</b> <b>Yb</b> Ytterbium $[Ce]4f^175s^2$
<b>71</b> <b>Lu</b> Lutetium $[Ce]4f^185s^2$	
<b>89</b> <b>Ac</b> Actinium $[Rb]5f^16s^2$	<b>90</b> <b>Th</b> Thorium $[Rb]5f^26s^2$
<b>91</b> <b>Pa</b> Protactinium $[Rb]5f^36s^2$	<b>92</b> <b>U</b> Uranium $[Rb]5f^46s^2$
<b>93</b> <b>Np</b> Neptunium $[Rb]5f^56s^2$	<b>94</b> <b>Pu</b> Plutonium $[Rb]5f^66s^2$
<b>95</b> <b>Am</b> Americium $[Rb]5f^76s^2$	<b>96</b> <b>Cm</b> Curium $[Rb]5f^86s^2$
<b>97</b> <b>Bk</b> Berkelium $[Rb]5f^96s^2$	<b>98</b> <b>Cf</b> Californium $[Rb]5f^{10}6s^2$
<b>99</b> <b>Es</b> Einsteinium $[Rb]5f^{11}6s^2$	<b>100</b> <b>Fm</b> Fermium $[Rb]5f^{12}6s^2$
<b>101</b> <b>Md</b> Mendelevium $[Rb]5f^{13}6s^2$	<b>102</b> <b>No</b> Nobelium $[Rb]5f^{14}6s^2$
<b>103</b> <b>Lr</b> Lawrencium $[Rb]5f^{15}6s^2$	

# Periodic Table - Electron Configuration

November 8, 2024 2:00 PM

# PERIODIC TABLE OF ELEMENTS



<b>1</b> <b>H</b> Hydrogen $1s^1$	<b>2</b> <b>He</b> Helium $1s^2$
<b>3</b> <b>Li</b> Lithium $[He]2s^1$	<b>4</b> <b>Be</b> Beryllium $[He]2s^2$
<b>11</b> <b>Na</b> Sodium $[He]2s^1$	<b>12</b> <b>Mg</b> Magnesium $[He]2s^2$
<b>19</b> <b>K</b> Potassium $[Ar]3s^1$	<b>20</b> <b>Ca</b> Calcium $[Ar]3s^2$
<b>37</b> <b>Rb</b> Rubidium $[Kr]3s^1$	<b>38</b> <b>Sr</b> Strontium $[Kr]3s^2$
<b>55</b> <b>Cs</b> Cesium $[Xe]3s^1$	<b>56</b> <b>Ba</b> Barium $[Xe]3s^2$
<b>87</b> <b>Fr</b> Francium $[Rn]3s^1$	<b>88</b> <b>Ra</b> Radium $[Rn]3s^2$
<b>21</b> <b>Sc</b> Scandium $[Ar]3d^14s^2$	<b>22</b> <b>Ti</b> Titanium $[Ar]3d^24s^2$
<b>23</b> <b>V</b> Vanadium $[Ar]3d^34s^2$	<b>24</b> <b>Cr</b> Chromium $[Ar]3d^54s^1$
<b>25</b> <b>Mn</b> Manganese $[Ar]3d^54s^2$	<b>26</b> <b>Fe</b> Iron $[Ar]3d^64s^2$
<b>27</b> <b>Co</b> Cobalt $[Ar]3d^74s^2$	<b>28</b> <b>Ni</b> Nickel $[Ar]3d^84s^2$
<b>29</b> <b>Cu</b> Copper $[Ar]3d^104s^1$	<b>30</b> <b>Zn</b> Zinc $[Ar]3d^104s^2$
<b>31</b> <b>Ga</b> Gallium $[Ar]3d^104s^24p^1$	<b>32</b> <b>Ge</b> Germanium $[Ar]3d^104s^24p^2$
<b>33</b> <b>As</b> Arsenic $[Ar]3d^104s^24p^3$	<b>34</b> <b>Se</b> Selenium $[Ar]3d^104s^24p^4$
<b>35</b> <b>Br</b> Bromine $[Ar]3d^104s^24p^5$	<b>36</b> <b>Kr</b> Krypton $[Ar]3d^104s^24p^6$
<b>39</b> <b>Y</b> Yttrium $[Ar]3d^14s^2$	<b>40</b> <b>Zr</b> Zirconium $[Ar]3d^24s^2$
<b>41</b> <b>Nb</b> Niobium $[Ar]3d^44s^2$	<b>42</b> <b>Mo</b> Molybdenum $[Ar]3d^54s^2$
<b>43</b> <b>Tc</b> Technetium $[Ar]3d^54s^2$	<b>44</b> <b>Ru</b> Ruthenium $[Ar]3d^74s^2$
<b>45</b> <b>Rh</b> Rhodium $[Ar]3d^84s^2$	<b>46</b> <b>Pd</b> Palladium $[Ar]3d^94s^2$
<b>47</b> <b>Ag</b> Silver $[Ar]3d^104s^2$	<b>48</b> <b>Cd</b> Cadmium $[Ar]3d^104s^2$
<b>49</b> <b>In</b> Indium $[Ar]3d^104s^24p^1$	<b>50</b> <b>Sn</b> Tin $[Ar]3d^104s^24p^2$
<b>51</b> <b>Sb</b> Antimony $[Ar]3d^104s^24p^3$	<b>52</b> <b>Te</b> Tellurium $[Ar]3d^104s^24p^4$
<b>53</b> <b>I</b> Iodine $[Ar]3d^104s^24p^5$	<b>54</b> <b>Xe</b> Xenon $[Ar]3d^104s^24p^6$
<b>72</b> <b>Hf</b> Hafnium $[Xe]4f^15d^14s^2$	<b>73</b> <b>Ta</b> Tantalum $[Xe]4f^15d^14s^2$
<b>74</b> <b>W</b> Tungsten $[Xe]4f^25d^44s^2$	<b>75</b> <b>Re</b> Rhenium $[Xe]4f^25d^54s^2$
<b>76</b> <b>Os</b> Osmium $[Xe]4f^35d^64s^2$	<b>77</b> <b>Ir</b> Iridium $[Xe]4f^35d^74s^2$
<b>78</b> <b>Pt</b> Platinum $[Xe]4f^45d^94s^2$	<b>79</b> <b>Au</b> Gold $[Xe]4f^45d^104s^2$
<b>80</b> <b>Hg</b> Mercury $[Xe]4f^55d^14s^2$	<b>81</b> <b>Tl</b> Thallium $[Xe]4f^55d^14s^2$
<b>82</b> <b>Pb</b> Lead $[Xe]4f^65d^14s^2$	<b>83</b> <b>Bi</b> Bismuth $[Xe]4f^65d^14s^2$
<b>84</b> <b>Po</b> Polonium $[Xe]4f^65d^24s^2$	<b>85</b> <b>At</b> Astatine $[Xe]4f^65d^24s^2$
<b>86</b> <b>Rn</b> Radon $[Xe]4f^65d^24s^2$	<b>104</b> <b>Rf</b> Rutherfordium $[Xe]4f^15d^14s^2$
<b>105</b> <b>Db</b> Dubnium $[Xe]4f^25d^14s^2$	<b>106</b> <b>Sg</b> Seaborgium $[Xe]4f^25d^24s^2$
<b>107</b> <b>Bh</b> Bohrium $[Xe]4f^25d^34s^2$	<b>108</b> <b>Hs</b> Hassium $[Xe]4f^25d^44s^2$
<b>109</b> <b>Mt</b> Meitnerium $[Xe]4f^25d^54s^2$	<b>110</b> <b>Ds</b> Darmstadtium $[Xe]4f^25d^64s^2$
<b>111</b> <b>Rg</b> Roentgenium $[Xe]4f^25d^74s^2$	<b>112</b> <b>Cn</b> Copernicium $[Xe]4f^25d^84s^2$
<b>113</b> <b>Nh</b> Nihonium $[Xe]4f^25d^94s^2$	<b>114</b> <b>Fl</b> Flerovium $[Xe]4f^25d^104s^2$
<b>115</b> <b>Mc</b> Moscovium $[Xe]4f^25d^104s^2$	<b>116</b> <b>Lv</b> Livermorium $[Xe]4f^25d^104s^2$
<b>117</b> <b>Ts</b> Tennessine $[Xe]4f^25d^104s^2$	<b>118</b> <b>Og</b> Oganesson $[Xe]4f^25d^104s^2$
<b>57</b> <b>La</b> Lanthanum $[Ce]4f^74s^2$	<b>58</b> <b>Ce</b> Curium $[Ce]4f^74s^2$
<b>59</b> <b>Pr</b> Praseodymium $[Ce]4f^94s^2$	<b>60</b> <b>Nd</b> Neodymium $[Ce]4f^104s^2$
<b>61</b> <b>Pm</b> Promethium $[Ce]4f^124s^2$	<b>62</b> <b>Sm</b> Samarium $[Ce]4f^144s^2$
<b>63</b> <b>Eu</b> Europium $[Ce]4f^154s^2$	<b>64</b> <b>Gd</b> Gadolinium $[Ce]4f^174s^2$
<b>65</b> <b>Tb</b> Terbium $[Ce]4f^184s^2$	<b>66</b> <b>Dy</b> Dysprosium $[Ce]4f^204s^2$
<b>67</b> <b>Ho</b> Holmium $[Ce]4f^214s^2$	<b>68</b> <b>Er</b> Erbium $[Ce]4f^224s^2$
<b>69</b> <b>Tm</b> Thulium $[Ce]4f^234s^2$	<b>70</b> <b>Yb</b> Ytterbium $[Ce]4f^244s^2$
<b>71</b> <b>Lu</b> Lutetium $[Ce]4f^254s^2$	
<b>89</b> <b>Ac</b> Actinium $[Rb]7s^2$	<b>90</b> <b>Th</b> Thorium $[Rb]7s^2$
<b>91</b> <b>Pa</b> Protactinium $[Rb]7s^27p^6$	<b>92</b> <b>U</b> Uranium $[Rb]7s^27p^6$
<b>93</b> <b>Np</b> Neptunium $[Rb]7s^27p^6$	<b>94</b> <b>Pu</b> Plutonium $[Rb]7s^27p^6$
<b>95</b> <b>Am</b> Americium $[Rb]7s^27p^6$	<b>96</b> <b>Cm</b> Curium $[Rb]7s^27p^6$
<b>97</b> <b>Bk</b> Berkelium $[Rb]7s^27p^6$	<b>98</b> <b>Cf</b> Californium $[Rb]7s^27p^6$
<b>99</b> <b>Es</b> Einsteinium $[Rb]7s^27p^6$	<b>100</b> <b>Fm</b> Fermium $[Rb]7s^27p^6$
<b>101</b> <b>Md</b> Mendelevium $[Rb]7s^27p^6$	<b>102</b> <b>No</b> Nobelium $[Rb]7s^27p^6$
<b>103</b> <b>Lr</b> Lawrencium $[Rb]7s^27p^6$	

**Insulators**

- ceramics -  $\text{Al}_2\text{O}_3$   $\text{SiO}_2$   $\text{CuO}$   $\text{TiO}_2$

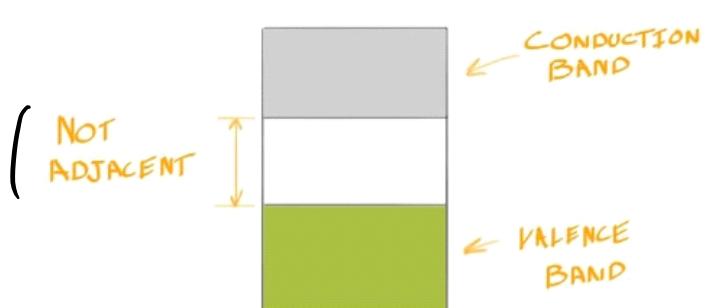
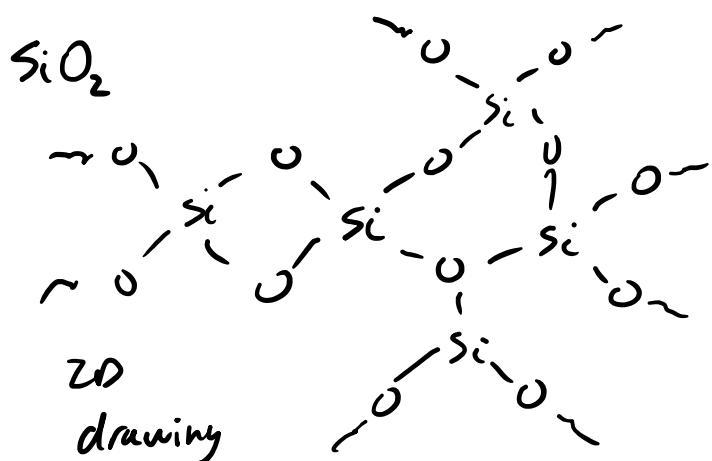


Figure 14. The band structure for an insulator, showing the valence and conduction bands with a large gap between them.

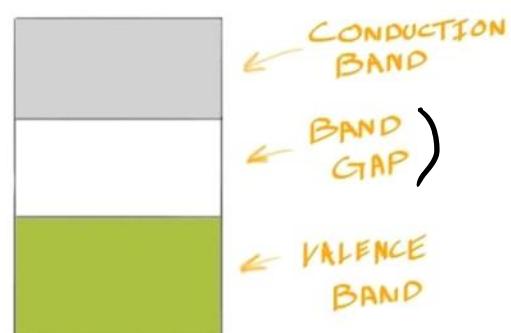
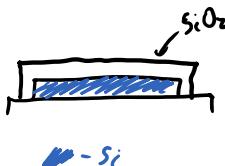
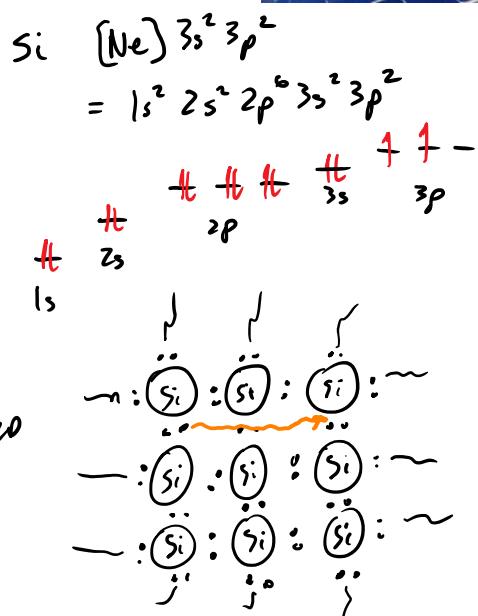


Figure 15. The band structure for an insulator, with the band gap identified as well as the valence and conduction bands.



silicon



$sp^3$  hybrids  
 $sp^3$  hybridization  
 $\begin{matrix} \text{+1} & \text{-1} & \text{+1} & \text{-1} \\ \text{3s} & \text{3p} & \text{3s} & \text{3p} \end{matrix}$  "donated"  
only when bonded.

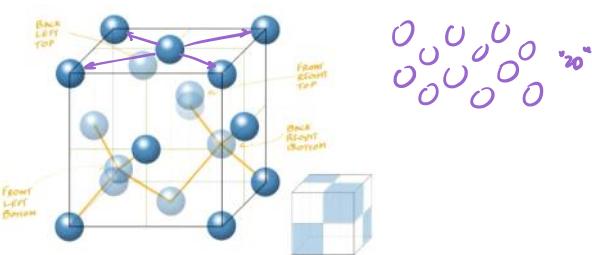
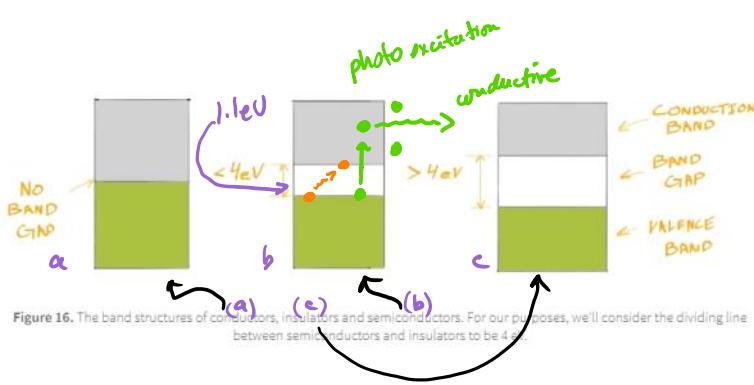


Figure 19. The structure of diamond cubic. This structure can be thought of as an FCC lattice of atoms with the same atoms occupying half of the available tetrahedral interstitial sites, in alternating positions. The alternating positions are illustrated with the shaded "sub-cube" faces in the second cube.

# Periodic Table - Electron Configuration

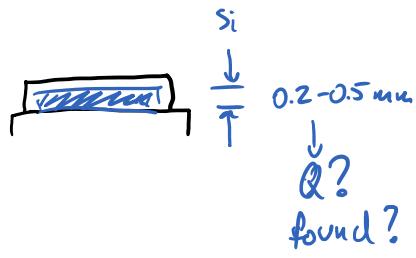
November 8, 2024 2:00 PM

# PERIODIC TABLE OF ELEMENTS



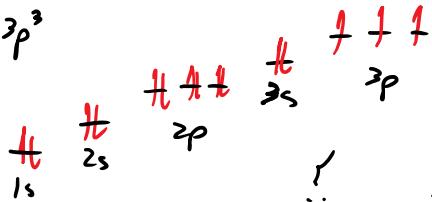
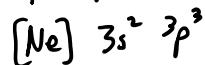
<b>1</b> <b>H</b> Hydrogen $1s^1$	<b>2</b> <b>He</b> Helium $1s^2$
<b>3</b> <b>Li</b> Lithium $[He]2s^1$	<b>4</b> <b>Be</b> Beryllium $[He]2s^2$
<b>11</b> <b>Na</b> Sodium $[He]2s^1$	<b>12</b> <b>Mg</b> Magnesium $[He]2s^2$
<b>19</b> <b>K</b> Potassium $[Ar]3s^1$	<b>20</b> <b>Ca</b> Calcium $[Ar]3s^2$
<b>37</b> <b>Rb</b> Rubidium $[Ar]3s^2$	<b>38</b> <b>Sr</b> Strontium $[Ar]3s^2$
<b>55</b> <b>Cs</b> Cesium $[Ar]3s^2$	<b>56</b> <b>Ba</b> Barium $[Ar]3s^2$
<b>87</b> <b>Fr</b> Francium $[Rn]5s^1$	<b>88</b> <b>Ra</b> Radium $[Rn]5s^2$
<b>21</b> <b>Sc</b> Scandium $[Ar]3d^14s^2$	<b>22</b> <b>Ti</b> Titanium $[Ar]3d^24s^2$
<b>23</b> <b>V</b> Vanadium $[Ar]3d^34s^2$	<b>24</b> <b>Cr</b> Chromium $[Ar]3d^54s^1$
<b>25</b> <b>Mn</b> Manganese $[Ar]3d^54s^2$	<b>26</b> <b>Fe</b> Iron $[Ar]3d^64s^2$
<b>27</b> <b>Co</b> Cobalt $[Ar]3d^74s^2$	<b>28</b> <b>Ni</b> Nickel $[Ar]3d^84s^2$
<b>29</b> <b>Cu</b> Copper $[Ar]3d^104s^1$	<b>30</b> <b>Zn</b> Zinc $[Ar]3d^104s^2$
<b>31</b> <b>Ga</b> Gallium $[Ar]3d^104s^24p^1$	<b>32</b> <b>Ge</b> Germanium $[Ar]3d^104s^24p^2$
<b>33</b> <b>As</b> Arsenic $[Ar]3d^104s^24p^3$	<b>34</b> <b>Se</b> Selenium $[Ar]3d^104s^24p^4$
<b>35</b> <b>Br</b> Bromine $[Ar]3d^104s^24p^5$	<b>36</b> <b>Kr</b> Krypton $[Ar]3d^104s^24p^6$
<b>39</b> <b>Y</b> Yttrium $[Ar]3d^14s^2$	<b>40</b> <b>Zr</b> Zirconium $[Ar]3d^24s^2$
<b>41</b> <b>Nb</b> Niobium $[Ar]3d^44s^2$	<b>42</b> <b>Mo</b> Molybdenum $[Ar]3d^54s^2$
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<b>45</b> <b>Rh</b> Rhodium $[Ar]3d^84s^2$	<b>46</b> <b>Pd</b> Palladium $[Ar]3d^94s^2$
<b>47</b> <b>Ag</b> Silver $[Ar]3d^104s^2$	<b>48</b> <b>Cd</b> Cadmium $[Ar]3d^104s^2$
<b>49</b> <b>In</b> Indium $[Ar]3d^104s^24p^1$	<b>50</b> <b>Sn</b> Tin $[Ar]3d^104s^24p^2$
<b>51</b> <b>Sb</b> Antimony $[Ar]3d^104s^24p^3$	<b>52</b> <b>Te</b> Tellurium $[Ar]3d^104s^24p^4$
<b>53</b> <b>I</b> Iodine $[Ar]3d^104s^24p^5$	<b>54</b> <b>Xe</b> Xenon $[Ar]3d^104s^24p^6$
<b>72</b> <b>Hf</b> Hafnium $[Ar]3d^44f^25s^2$	<b>73</b> <b>Ta</b> Tantalum $[Ar]3d^54f^25s^2$
<b>74</b> <b>W</b> Tungsten $[Ar]3d^64f^25s^2$	<b>75</b> <b>Re</b> Rhenium $[Ar]3d^74f^25s^2$
<b>76</b> <b>Os</b> Osmium $[Ar]3d^84f^25s^2$	<b>77</b> <b>Ir</b> Iridium $[Ar]3d^94f^25s^2$
<b>78</b> <b>Pt</b> Platinum $[Ar]3d^104f^25s^2$	<b>79</b> <b>Au</b> Gold $[Ar]3d^104f^25s^2$
<b>80</b> <b>Hg</b> Mercury $[Ar]3d^104f^25s^2$	<b>81</b> <b>Tl</b> Thallium $[Ar]3d^104f^25s^2$
<b>82</b> <b>Pb</b> Lead $[Ar]3d^104f^25s^2$	<b>83</b> <b>Bi</b> Bismuth $[Ar]3d^104f^25s^2$
<b>84</b> <b>Po</b> Polonium $[Ar]3d^104f^25s^2$	<b>85</b> <b>At</b> Astatine $[Ar]3d^104f^25s^2$
<b>86</b> <b>Rn</b> Radon $[Ar]3d^104f^25s^2$	<b>104</b> <b>Rf</b> Rutherfordium $[Ar]3d^24f^15s^2$
<b>105</b> <b>Db</b> Dubnium $[Ar]3d^24f^25s^2$	<b>106</b> <b>Sg</b> Seaborgium $[Ar]3d^24f^25s^2$
<b>107</b> <b>Bh</b> Bohrium $[Ar]3d^24f^25s^2$	<b>108</b> <b>Hs</b> Hassium $[Ar]3d^24f^25s^2$
<b>109</b> <b>Mt</b> Meitnerium $[Ar]3d^24f^25s^2$	<b>110</b> <b>Ds</b> Darmstadtium $[Ar]3d^24f^25s^2$
<b>111</b> <b>Rg</b> Roentgenium $[Ar]3d^24f^25s^2$	<b>112</b> <b>Cn</b> Copernicium $[Ar]3d^24f^25s^2$
<b>113</b> <b>Nh</b> Nihonium $[Ar]3d^24f^25s^2$	<b>114</b> <b>Fl</b> Flerovium $[Ar]3d^24f^25s^2$
<b>115</b> <b>Mc</b> Moscovium $[Ar]3d^24f^25s^2$	<b>116</b> <b>Lv</b> Livermorium $[Ar]3d^24f^25s^2$
<b>117</b> <b>Ts</b> Tennessine $[Ar]3d^24f^25s^2$	<b>118</b> <b>Og</b> Oganesson $[Ar]3d^24f^25s^2$
<b>57</b> <b>La</b> Lanthanum $[Ce]4f^15s^2$	<b>58</b> <b>Ce</b> Curium $[Ce]4f^15s^2$
<b>59</b> <b>Pr</b> Praseodymium $[Ce]4f^35s^2$	<b>60</b> <b>Nd</b> Neodymium $[Ce]4f^45s^2$
<b>61</b> <b>Pm</b> Promethium $[Ce]4f^55s^2$	<b>62</b> <b>Sm</b> Samarium $[Ce]4f^75s^2$
<b>63</b> <b>Eu</b> Europium $[Ce]4f^95s^2$	<b>64</b> <b>Gd</b> Gadolinium $[Ce]4f^105s^2$
<b>65</b> <b>Tb</b> Terbium $[Ce]4f^125s^2$	<b>66</b> <b>Dy</b> Dysprosium $[Ce]4f^135s^2$
<b>67</b> <b>Ho</b> Holmium $[Ce]4f^145s^2$	<b>68</b> <b>Er</b> Erbium $[Ce]4f^155s^2$
<b>69</b> <b>Tm</b> Thulium $[Ce]4f^165s^2$	<b>70</b> <b>Yb</b> Ytterbium $[Ce]4f^175s^2$
<b>71</b> <b>Lu</b> Lutetium $[Ce]4f^185s^2$	
<b>89</b> <b>Ac</b> Actinium $[Rn]5f^15s^2$	<b>90</b> <b>Th</b> Thorium $[Rn]5f^25s^2$
<b>91</b> <b>Pa</b> Protactinium $[Rn]5f^35s^2$	<b>92</b> <b>U</b> Uranium $[Rn]5f^45s^2$
<b>93</b> <b>Np</b> Neptunium $[Rn]5f^55s^2$	<b>94</b> <b>Pu</b> Plutonium $[Rn]5f^65s^2$
<b>95</b> <b>Am</b> Americium $[Rn]5f^75s^2$	<b>96</b> <b>Cm</b> Curium $[Rn]5f^85s^2$
<b>97</b> <b>Bk</b> Berkelium $[Rn]5f^95s^2$	<b>98</b> <b>Cf</b> Californium $[Rn]5f^{10}5s^2$
<b>99</b> <b>Es</b> Einsteinium $[Rn]5f^{11}5s^2$	<b>100</b> <b>Fm</b> Fermium $[Rn]5f^{12}5s^2$
<b>101</b> <bmd< b=""> Mendelevium <math>[Rn]5f^{13}5s^2</math></bmd<>	<b>102</b> <b>No</b> Nobelium $[Rn]5f^{14}5s^2$
<b>103</b> <b>Lr</b> Lawrencium $[Rn]5f^{15}5s^2$	

Dopants (Extrinsic) - to the semiconductors



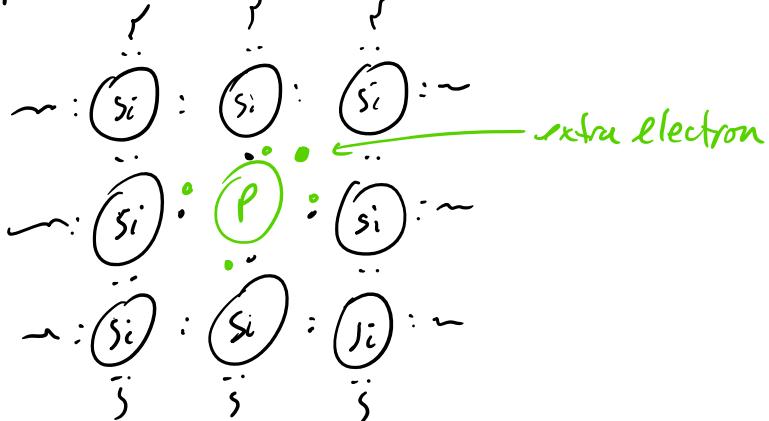
n-type - more electron(s)

P - phosphorous



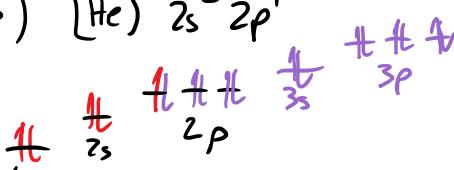
$$P = Si$$

low molar ratio

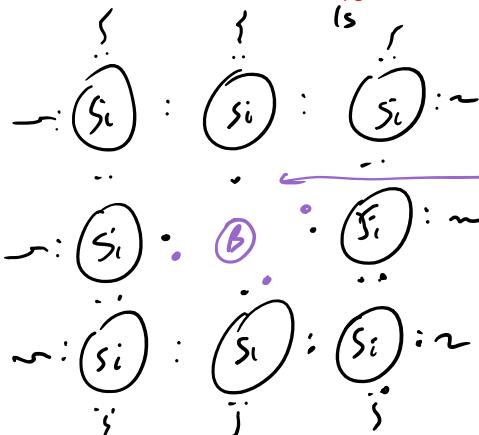


p-type

Boron (B)  $[\text{He}] \ 2s^2 \ 2p^1$

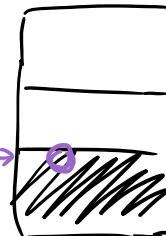


$\Rightarrow$  adding electron present



missing an electron

accept electrons.  $\rightarrow$



# Periodic Table - Electron Configuration

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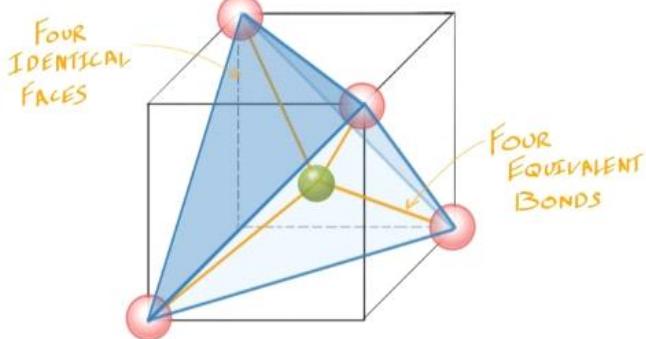
# PERIODIC TABLE OF ELEMENTS



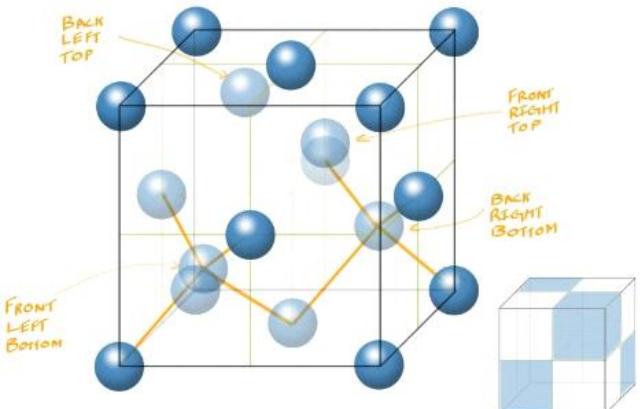
<b>1</b> <b>H</b> Hydrogen $1s^1$	<b>2</b> <b>He</b> Helium $1s^2$
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<b>84</b> <b>Po</b> Polonium $[Ar]3d^104s^2$	<b>85</b> <b>At</b> Astatine $[Ar]3d^104s^2$
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<b>71</b> <b>Lu</b> Lutetium $[Ce]4f^175s^2$	

**Reminder :-): September 18 --> September 27 - applies to conductors and semi-conductors**

### Book Section 9:



**Figure 18.** The **tetrahedral** interstitial site at the centre of a cube. Note that the coordination number is also 4, in addition to the number of faces on the solid formed by this site, however the name comes from the solid geometry, not the coordination number.



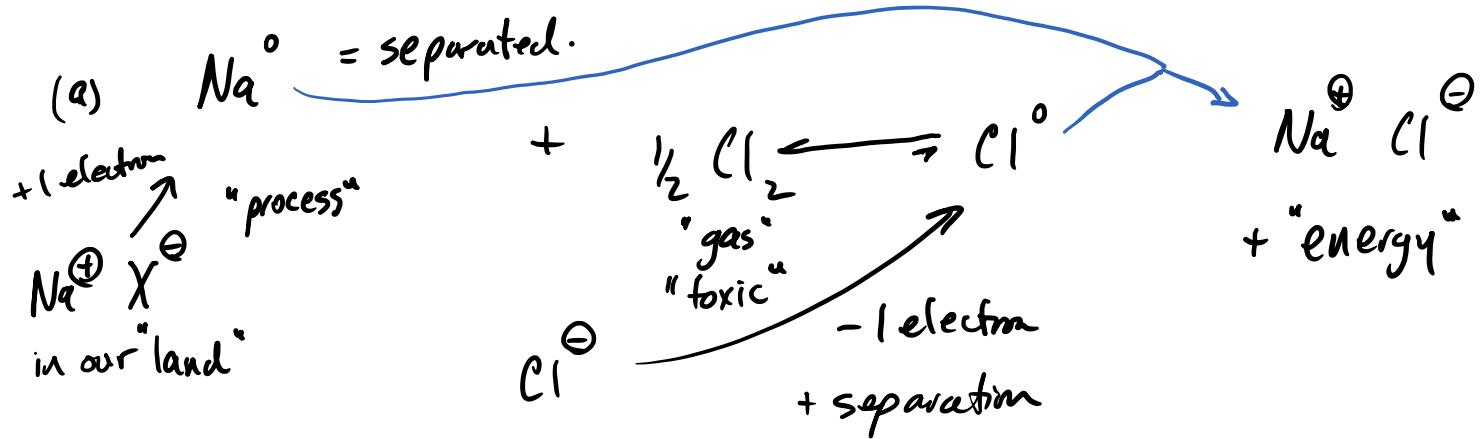
**Figure 19.** The structure of diamond cubic. This structure can be thought of as an FCC lattice of atoms with the same atoms occupying half of the available **tetrahedral** interstitial sites, in alternating positions. The alternating positions are illustrated with the shaded "sub-cube" faces in the second cube.

[Calculations link:](#)

<https://can01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fyoutu.be%2FHmR9vfLk5-E&data=05%7C02%7Ctim.bender%40utoronto.ca%7C403a272b50f0498ee98f08dd07e3e7be%7C78aac2262f034b4d9037b46d56c55210%7C0%7C0%7C638675397604841544%7CUnknown%7CTWFpbGsb3d8evJfbXB0eU1hcGkiOnRvdWUsIYIOiiwljAuMDAwMCisIiAiOiiXaW4zMiIsIkFOlioiTWFpbCisIldUljoifQ%3D%3D%7C0%7C%7C%7C&sdata=0gZDFaFGt3unleV80ZptnCiaTddjRf7vEQmyrPIOt5w%3D&reserved=0>

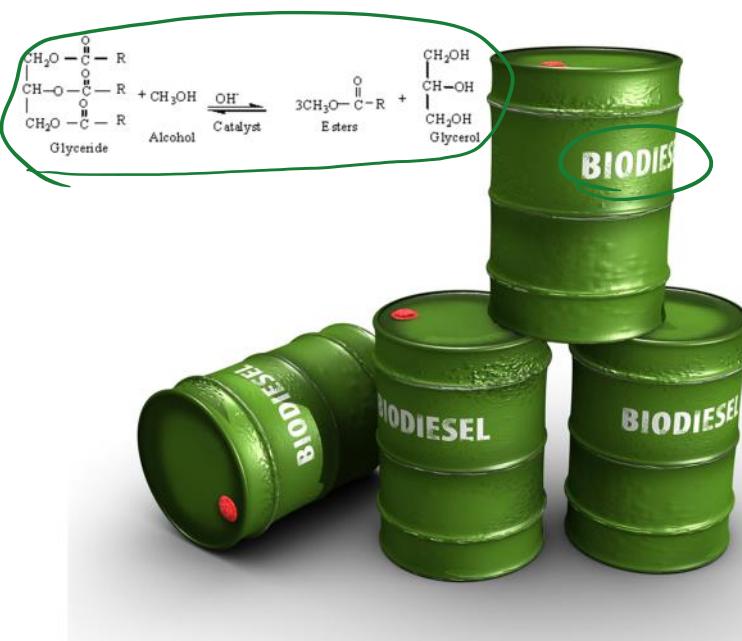
# Thermodynamics

November 18, 2024 10:33 AM



# Biofuels

November 18, 2024 11:02 AM



**bioX**  
CORPORATION | Better Fuel For A Cleaner World



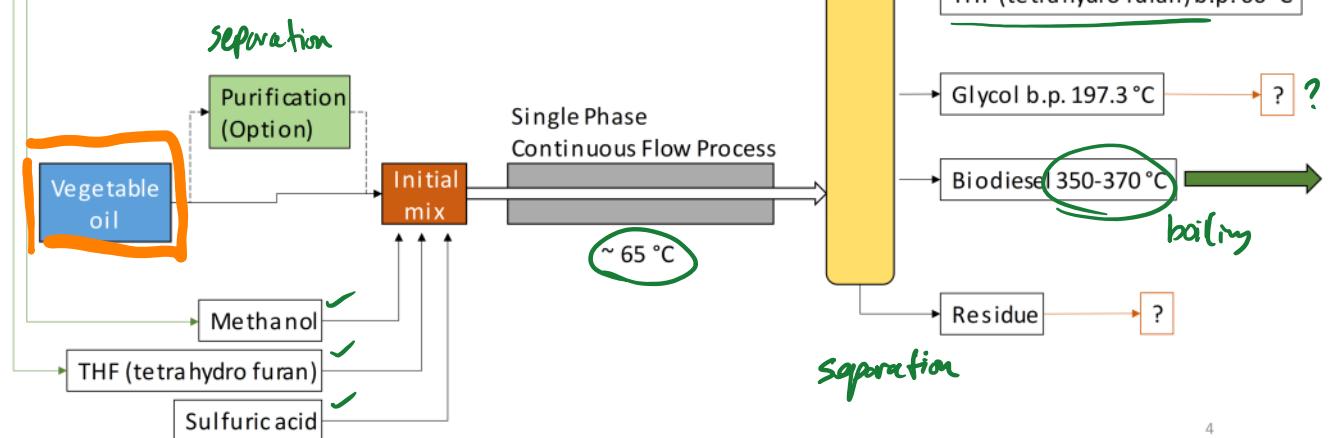
 Chemical Engineering & Applied Chemistry  
UNIVERSITY OF TORONTO

**world energy**

1

## Continuous flow process – BIOX/WorldEnergy Developed by CHE UoT

recycled



4

## Thermodynamics

(a)  
Free Time → Kinetics

Free Money → economic wise

Free Energy → means from where?

(b) Spontaneous → process proceeds  
without needing energy

temperature      winter       $-20^{\circ}\text{C}$        $\nearrow$  if spontaneous @  $10^{\circ}\text{C}$   
                    summer       $+35^{\circ}\text{C}$

wrong mix — can also be our "air"

(c) temperature	$^{\circ}\text{K}$ - Kelvin temperature	$273.15^{\circ}\text{K}$	- yes
	$^{\circ}\text{C}$ - Celsius temperature	$0^{\circ}\text{C}$	- yes
	$^{\circ}\text{F}$ - Fahrenheit	$32^{\circ}\text{F}$	- no.

↓

to Thermodynamics  
calculations

# Thermodynamics - names etc.

November 18, 2024 11:07 AM

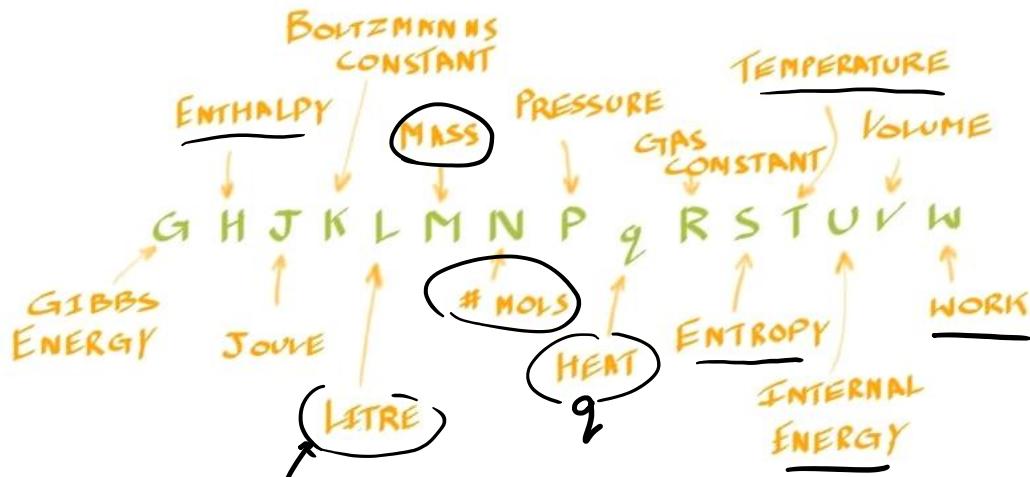


Figure 1. The thermodynamic alphabet.

measure - metric unit of volume -  $\text{dm}^3$  - cubic decimeter

$\text{cm}^3$  - centimeters

$\text{m}^3$  - metres



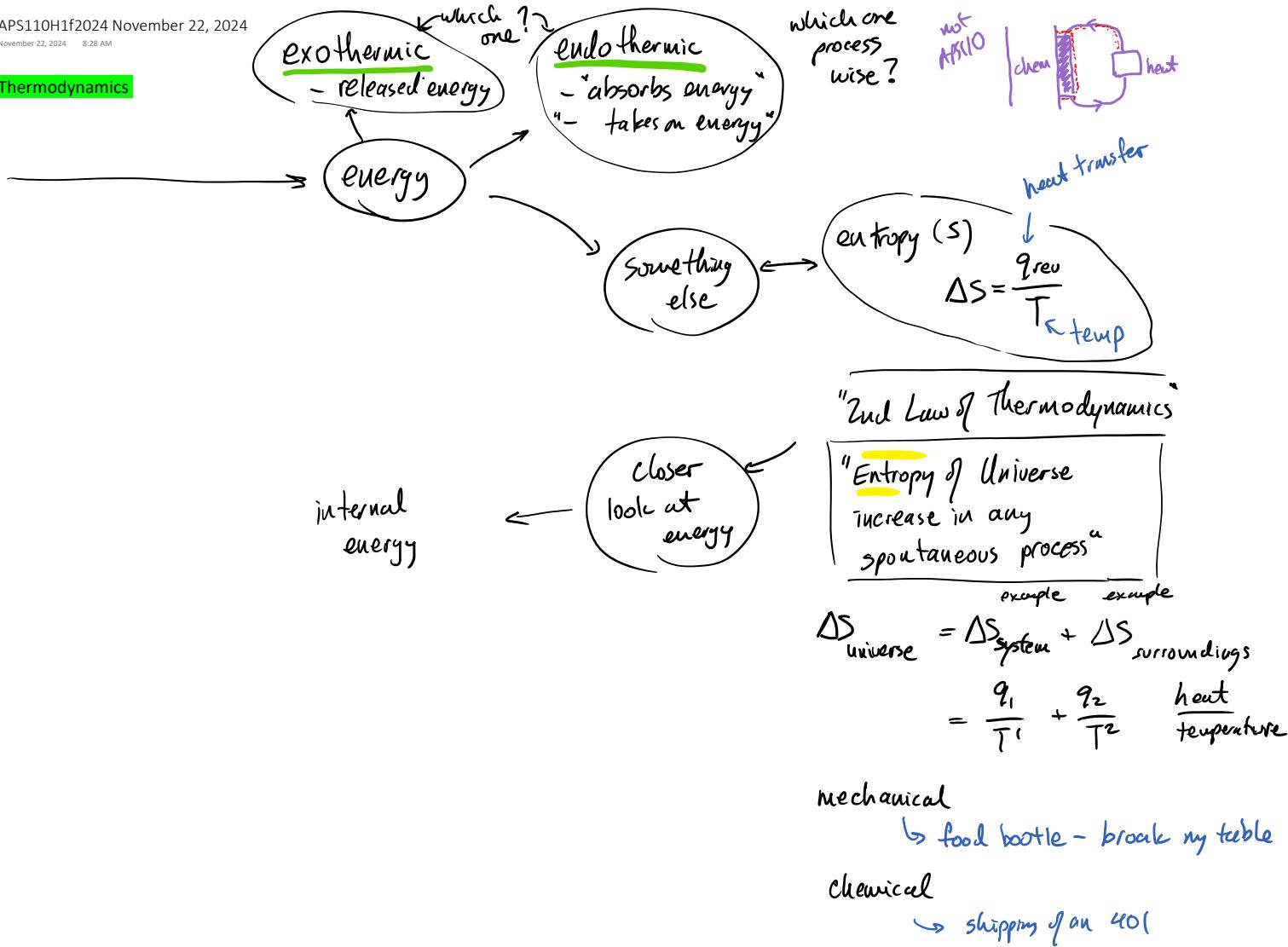
water  $\sim \frac{1}{3}$

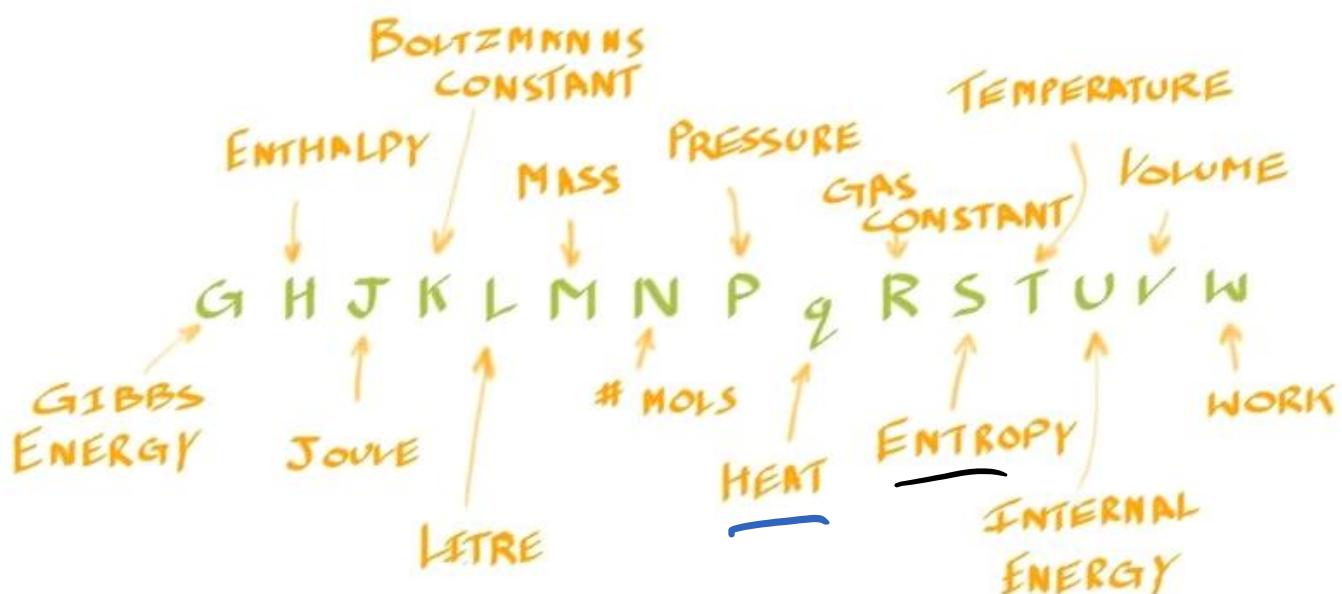
# Thermodynamics

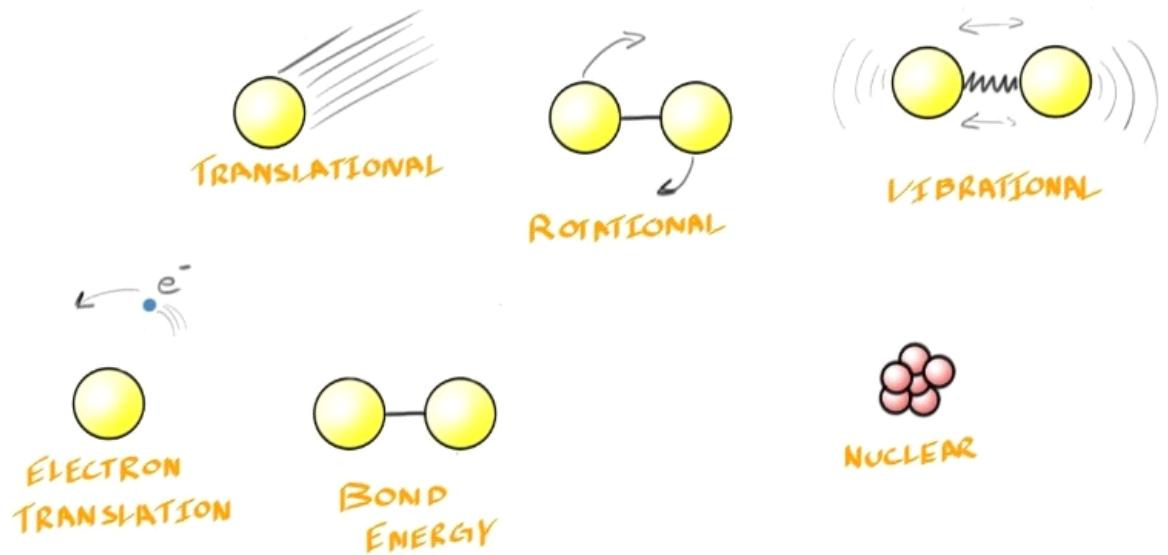
November 20, 2024 7:52 AM

Why do  
some things  
happen on their own?  
mechanical? or  
a chemical process?

## Thermodynamics

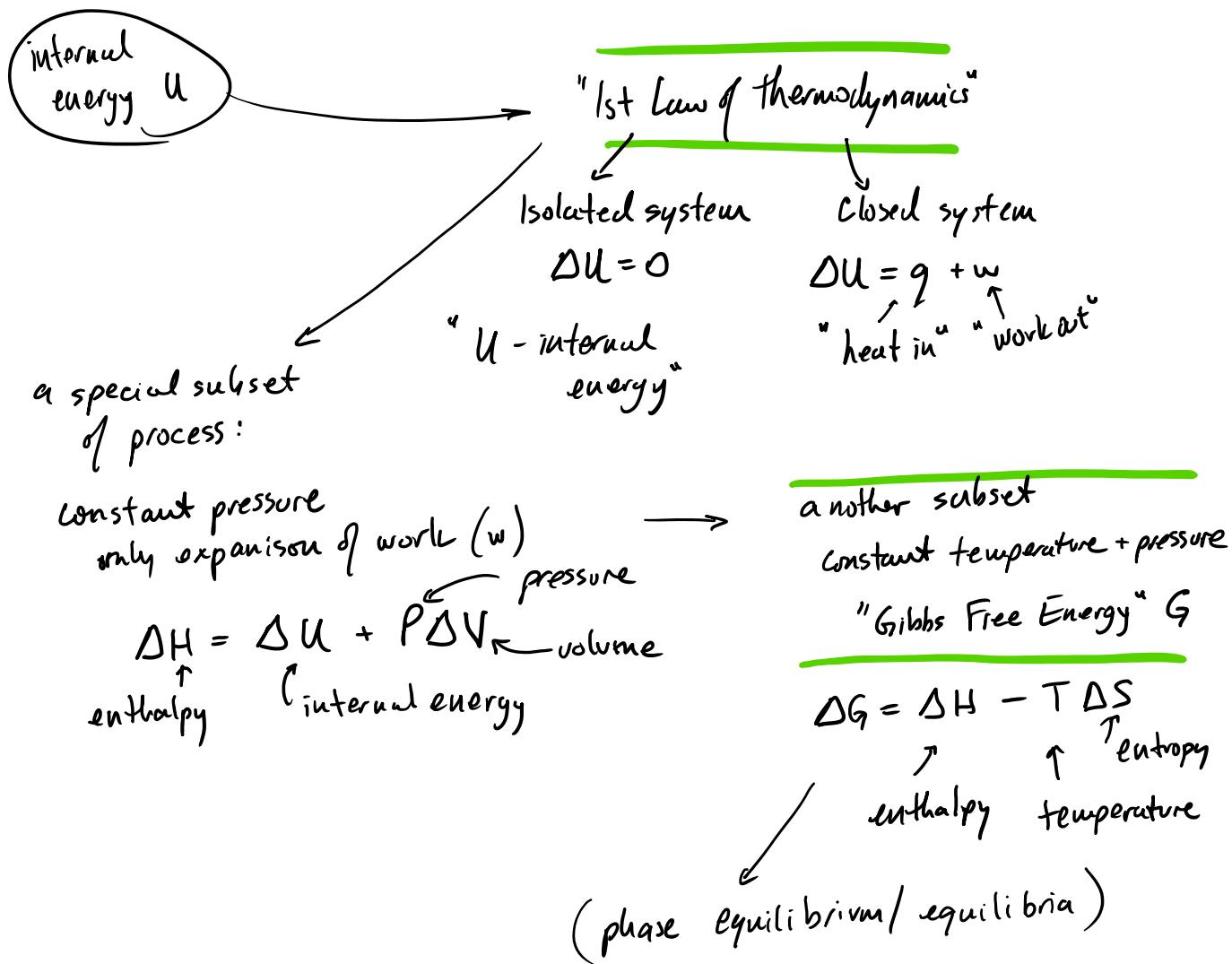


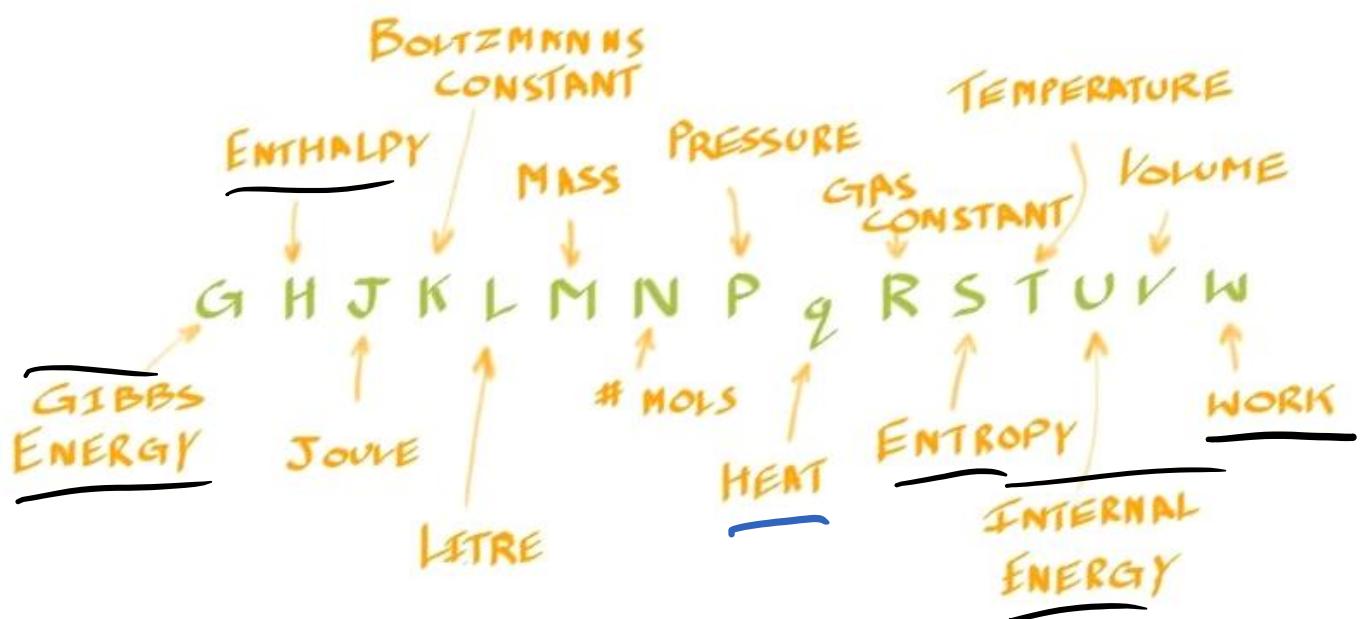


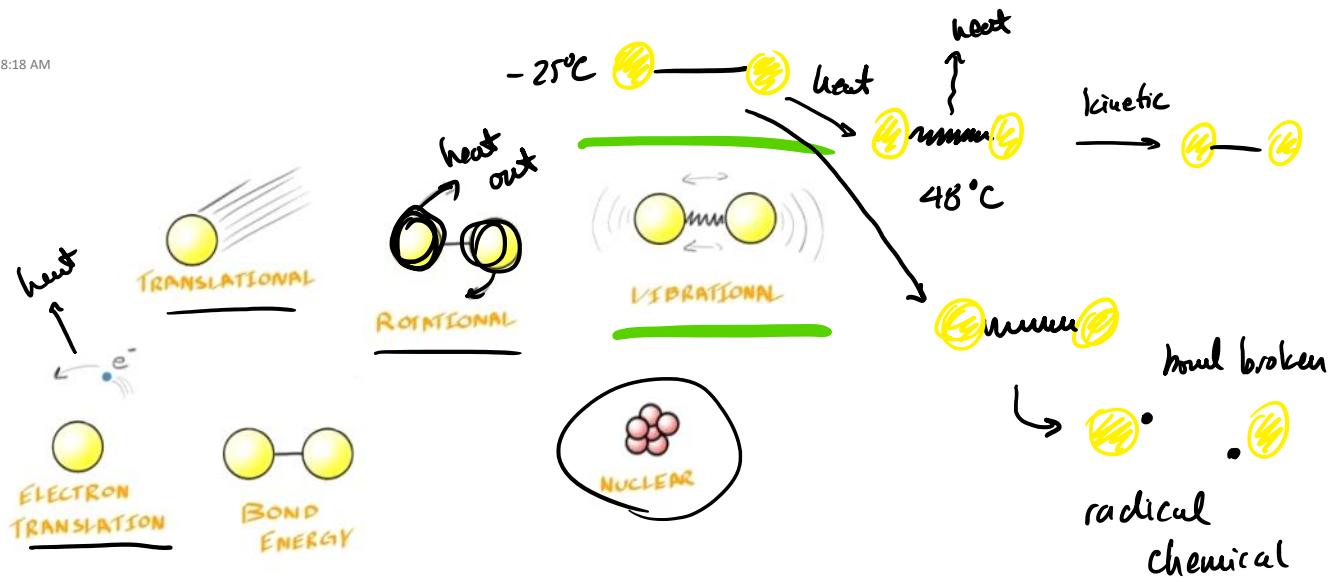


**Figure 3.** Some of the potential forms of energy contributing to the internal energy. Don't let this intimidate you; we don't need to calculate each of these, and we don't really care especially about the specific nature of the internal energy. We only concern ourselves with changes to the internal energy.

## Thermodynamics



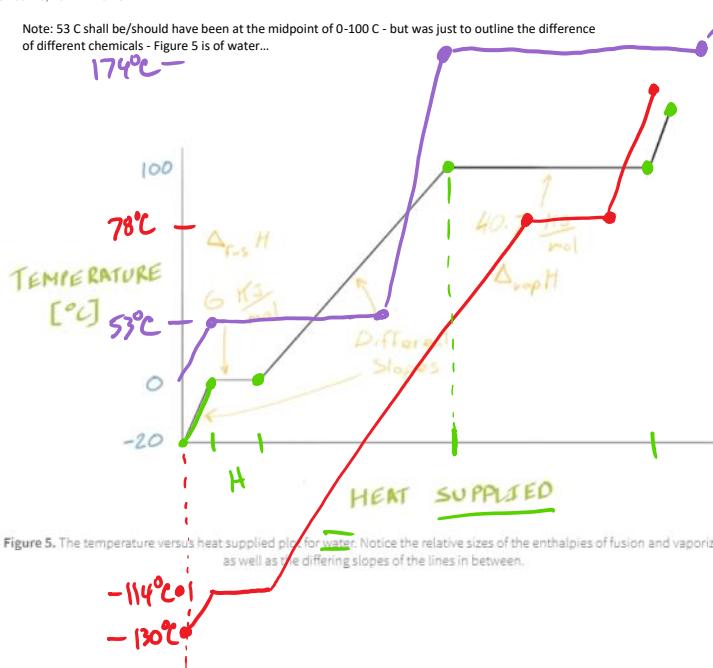




**Figure 3.** Some of the potential forms of energy contributing to the internal energy. Don't let this intimidate you; we don't need to calculate each of these, and we don't really care especially about the specific nature of the internal energy. We only concern ourselves with changes to the internal energy.



Note: 53°C shall be/should have been at the midpoint of 0-100°C - but was just to outline the difference of different chemicals - Figure 5 is of water...



"maybe"  
"maybe"



1,4-dichlorobenzene  
chemical solvent

$$\text{slope} = \frac{\Delta T}{q} \quad \begin{matrix} \text{temperature} \\ \text{heat} \end{matrix}$$

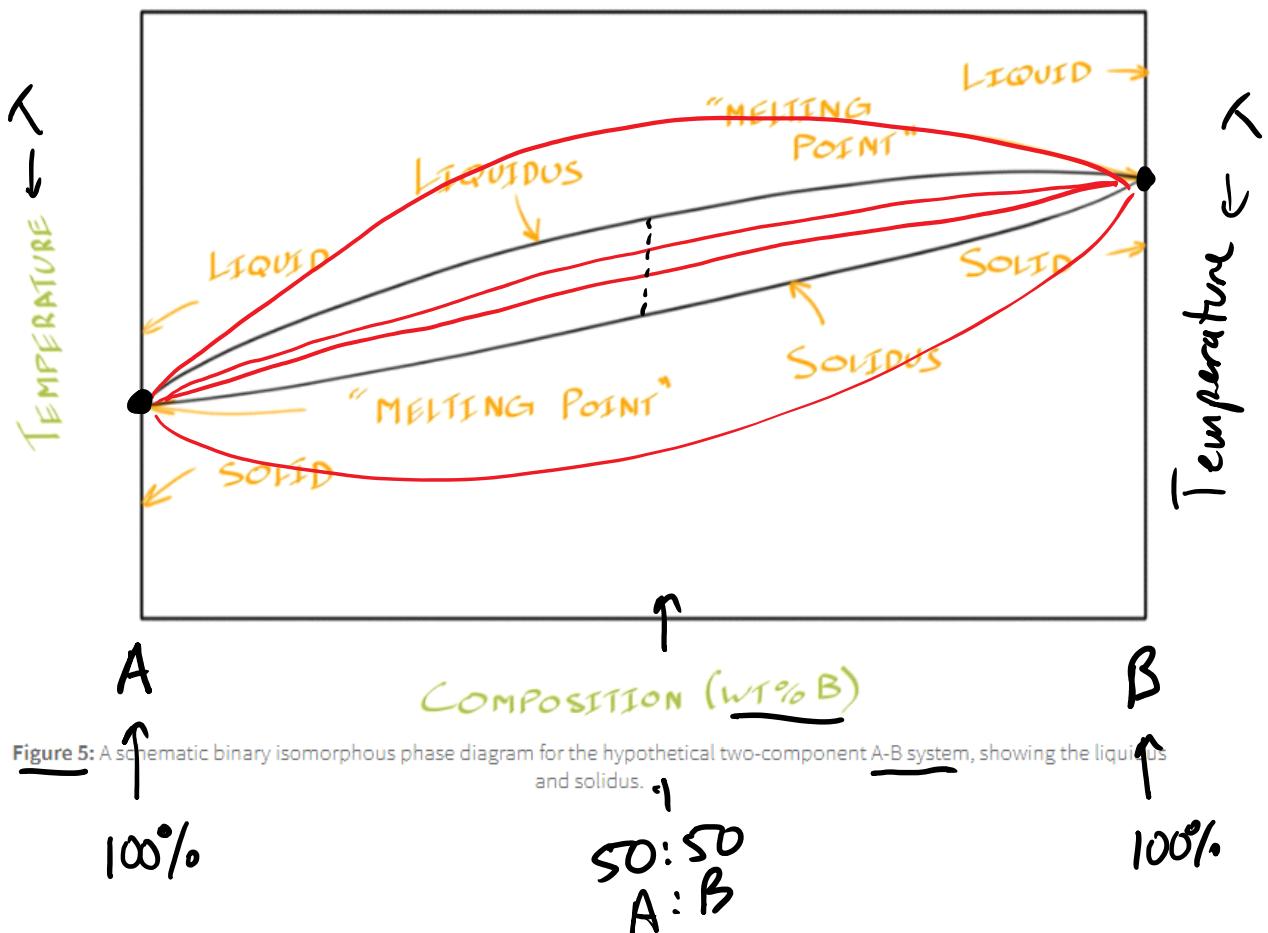
$$q = \frac{1}{\text{slope}} \Delta T$$

$$q = n C_p \Delta T \quad \begin{matrix} \text{temperature} \\ \text{molar heat} \end{matrix}$$

#mol capacity -

$$q = m c \Delta T \quad \begin{matrix} \text{constant pressure} \\ \text{temp. specific heat} \end{matrix}$$

## Thermodynamics



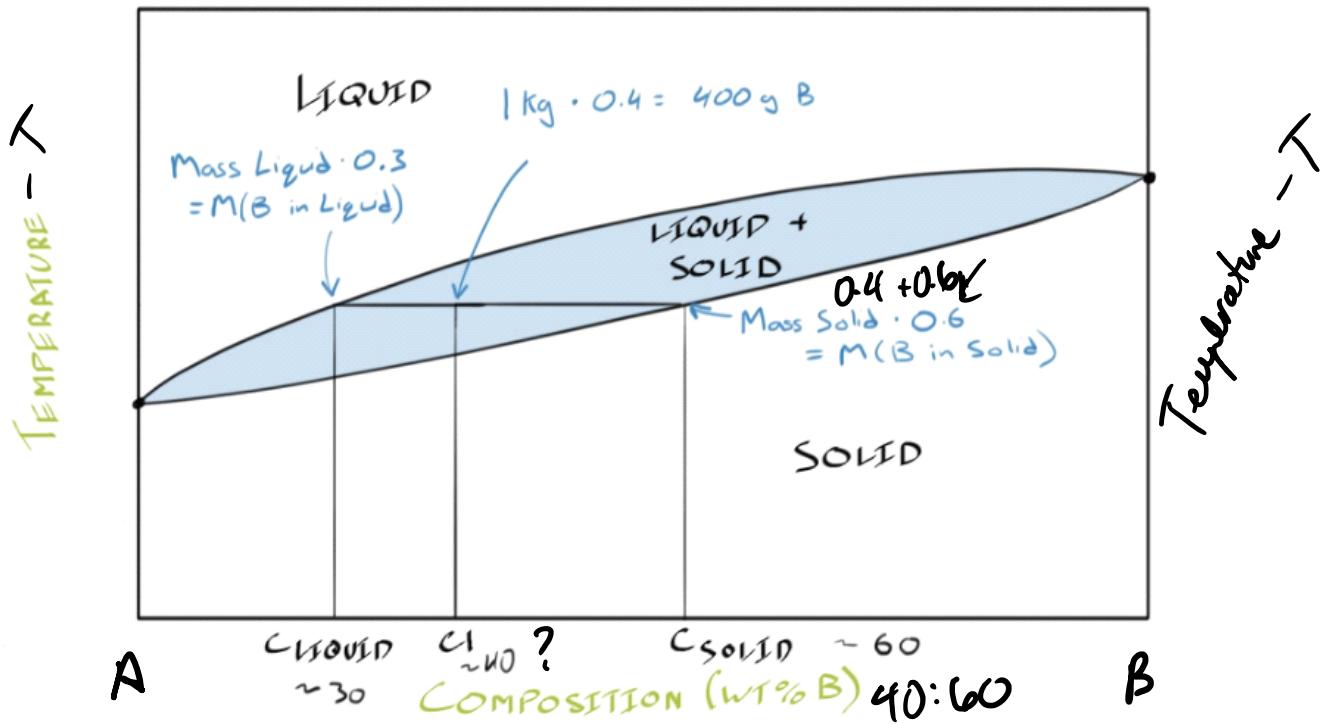
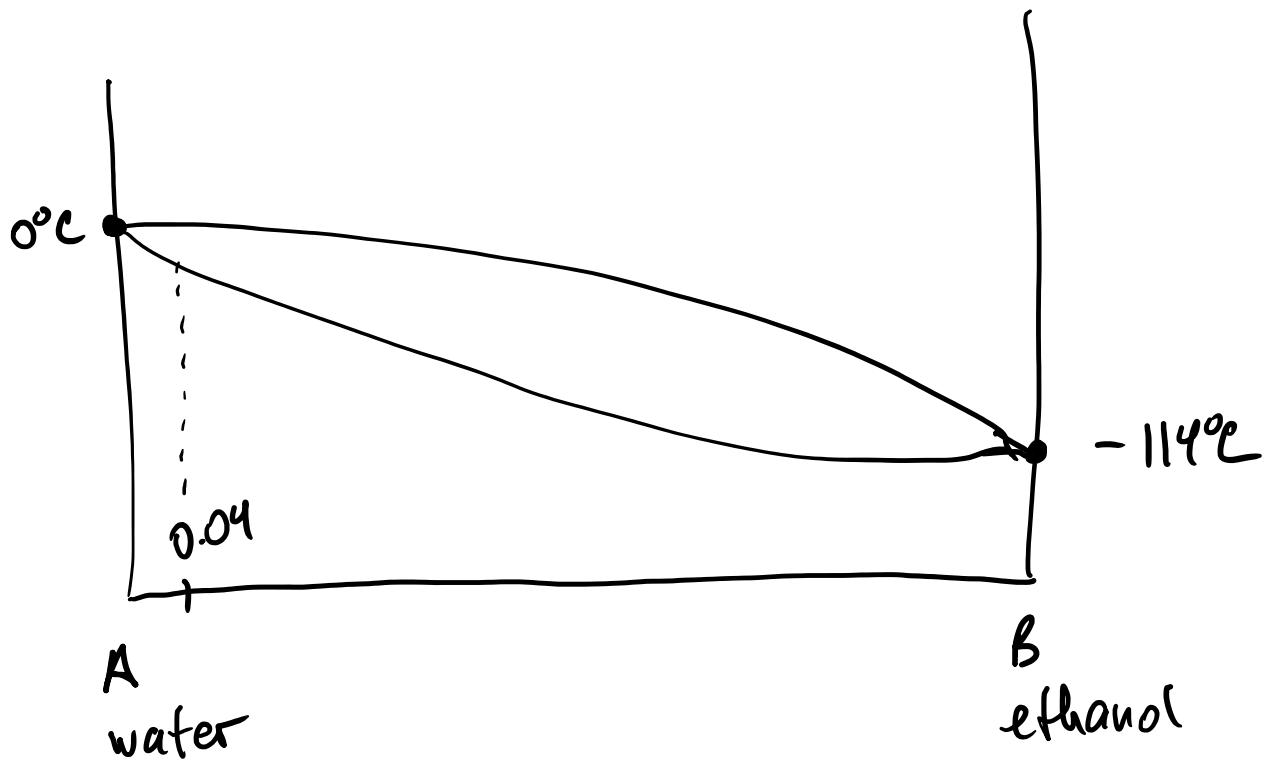


Figure 11: A 1 kg sample having a composition of 40 wt% B contains 400 grams of component B, separated into a mass of B in the liquid,  $M(\text{B in Liq})$  and a mass of B in the solid,  $M(\text{B in Solid})$ .



## Electrochemistry

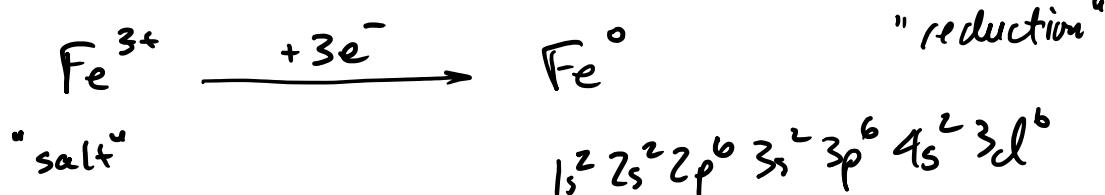
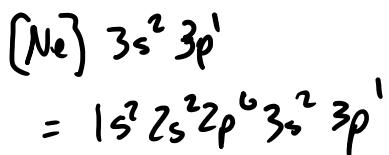
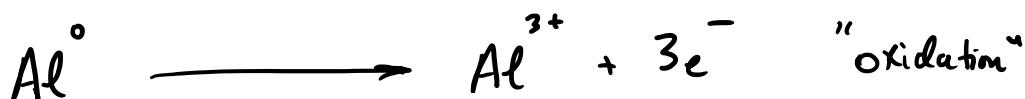
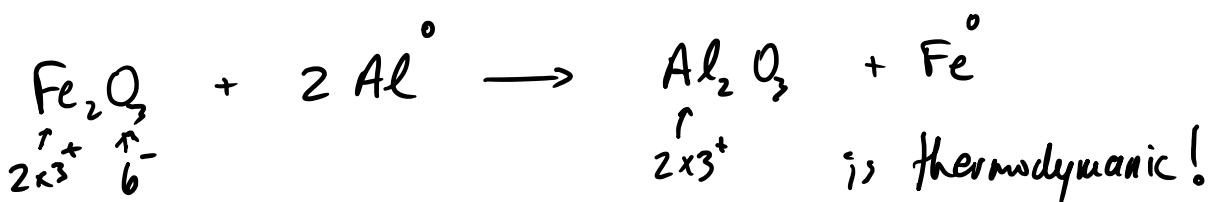
November 26, 2024 4:51 PM

### Section 13: Q&A

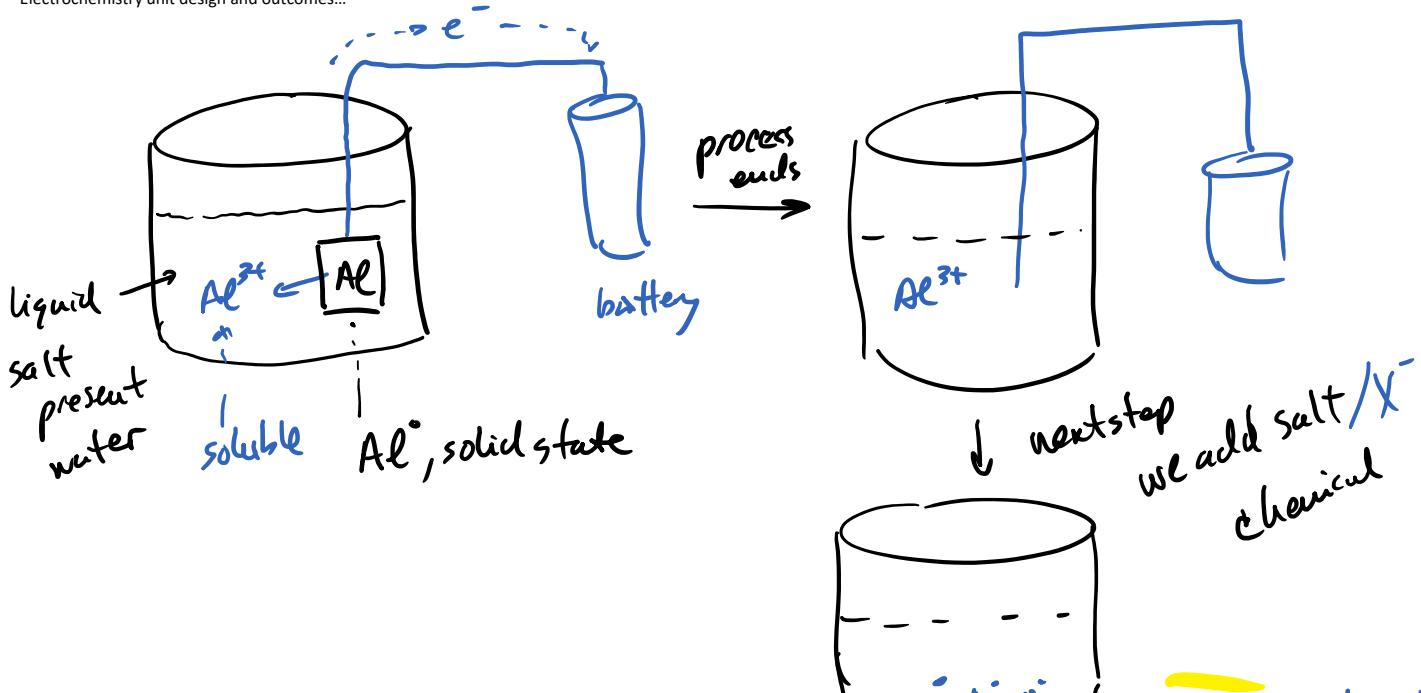
R? Q: Yes on my notes it was Section 12: "...this chapter is terrible" - so yes it is Section 12  
And for Section 13: "I'm so funny... to discuss a few things... before we can drive into electrochemistry"  
... so sorry I was thinking of that note I had on hand to be related to electrochemistry - but here is the  
true comments of Section 12 and Section 13....

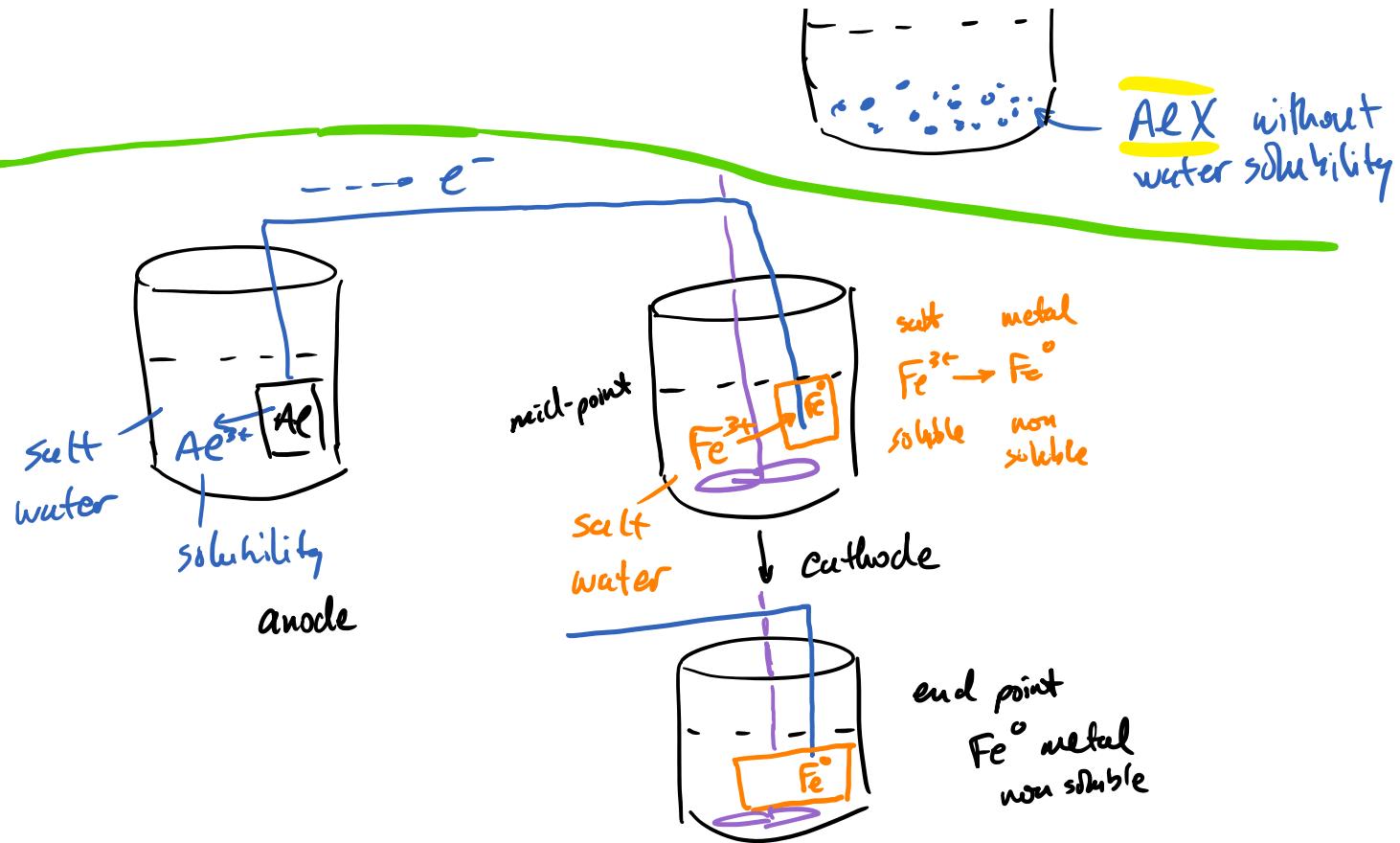
## Splitting up oxidation and reduction

The aluminothermic reduction of iron reaction (Reaction 10) is a nice stepping stone to transition into the business that this chapter is supposed to be about: electrochemistry! You see, as the name implies, iron is being *reduced*. This means that iron is gaining electrons (perhaps you've heard that LEO the lion says, "GER," reminding us that we Lose Electrons in Oxidation and Gain Electrons in Reduction). We can write out just the most simple thing that is happening to iron in the reaction

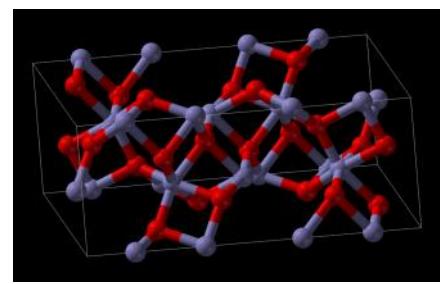


Electrochemistry unit design and outcomes...









3D

Reduction Reaction	$E^\circ$ (V)
$\text{Li}^+_{(\text{aq})} + \text{e}^- \rightarrow \text{Li}_{(\text{s})}$	- 3.045
$\text{Zn}^{2+}_{(\text{aq})} + 2\text{e}^- \rightarrow \text{Zn}_{(\text{s})}$	- 0.763
$\text{Fe}^{2+}_{(\text{aq})} + 2\text{e}^- \rightarrow \text{Fe}_{(\text{s})}$	- 0.44 <span style="color:red">-</span>
$2\text{H}^+_{(\text{aq})} + 2\text{e}^- \rightarrow \text{H}_2(\text{g})$	0.000
$\text{Cu}^{2+}_{(\text{aq})} + 2\text{e}^- \rightarrow \text{Cu}_{(\text{s})}$ <i>copper</i>	+ 0.337
$\text{Pt}^{2+}_{(\text{aq})} + 2\text{e}^- \rightarrow \text{Pt}_{(\text{s})}$ <i>platinum</i>	+ 1.2

Table 1. Standard reduction potentials for a few half-cell reactions. Table 1.

# PERIODIC TABLE OF ELEMENTS

**PubChem**

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

**Re-Introduction**

**Metals** → Cu<sup>+</sup>, Fe<sup>+</sup>, Al<sup>+</sup> etc.

**Ceramics** → Al<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub>, CuO "non-salts"

"salt" NaCl, LiF, CaF<sub>2</sub> etc

**Polymers** → (1) poly ethylene terephthalate (PET) not ABS/IO.

(2) low density poly(ethylene)

(3) poly(vinyl chloride)

(4) high density poly(ethylene) n-length

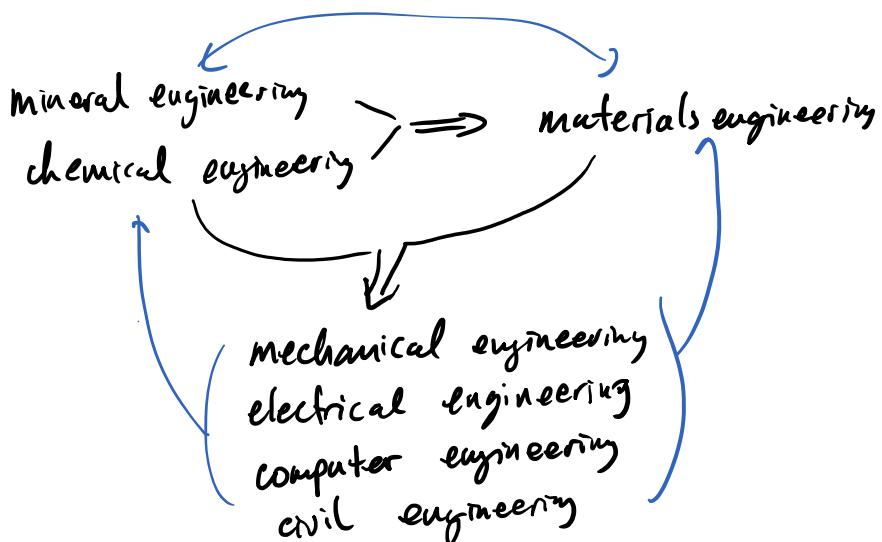
(5) poly(propylene) q or polymer

(6) poly(styrene)  $\equiv$  Ph =

**Chemicals**

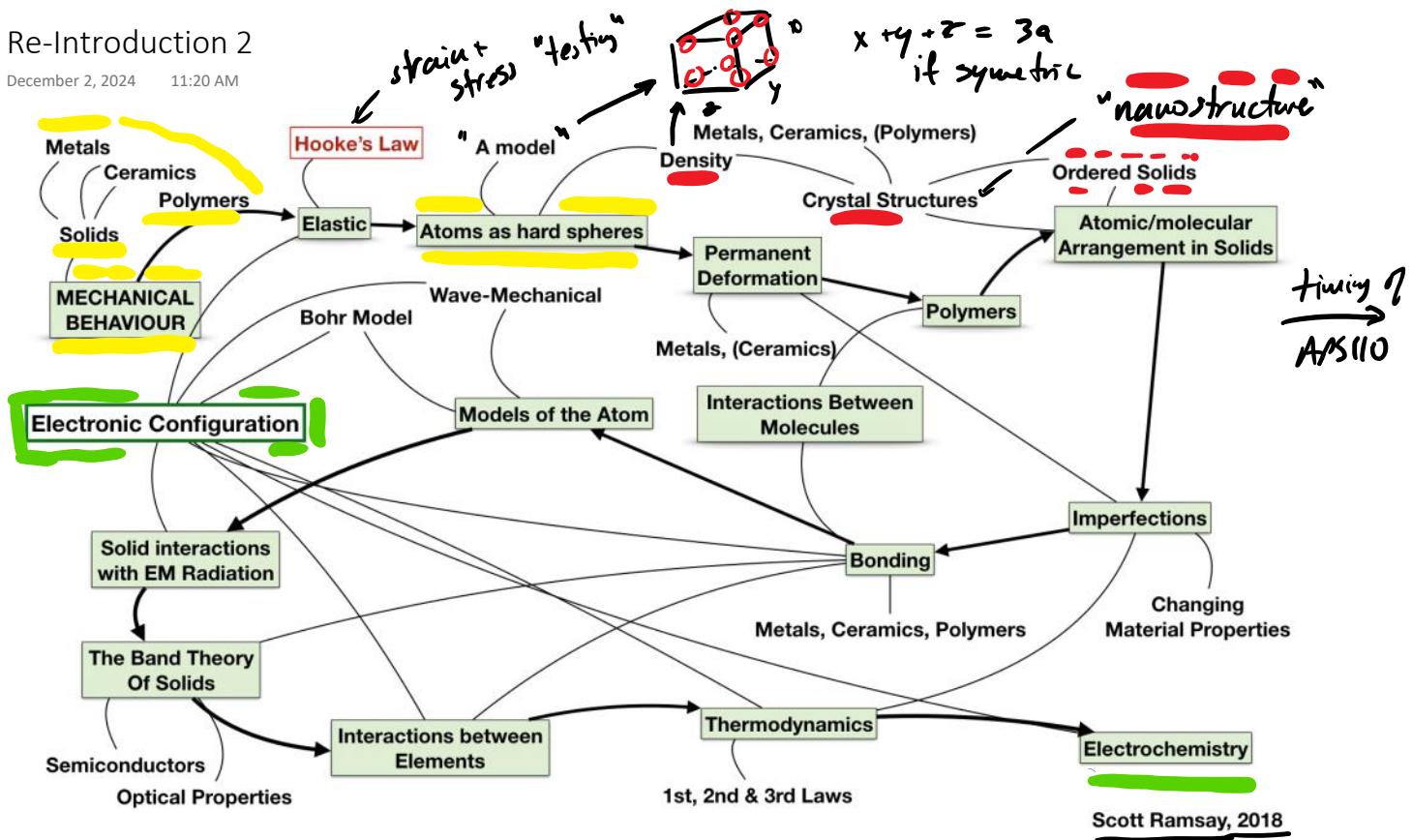
## Re-Introduction

December 2, 2024 10:26 AM



## Re-Introduction 2

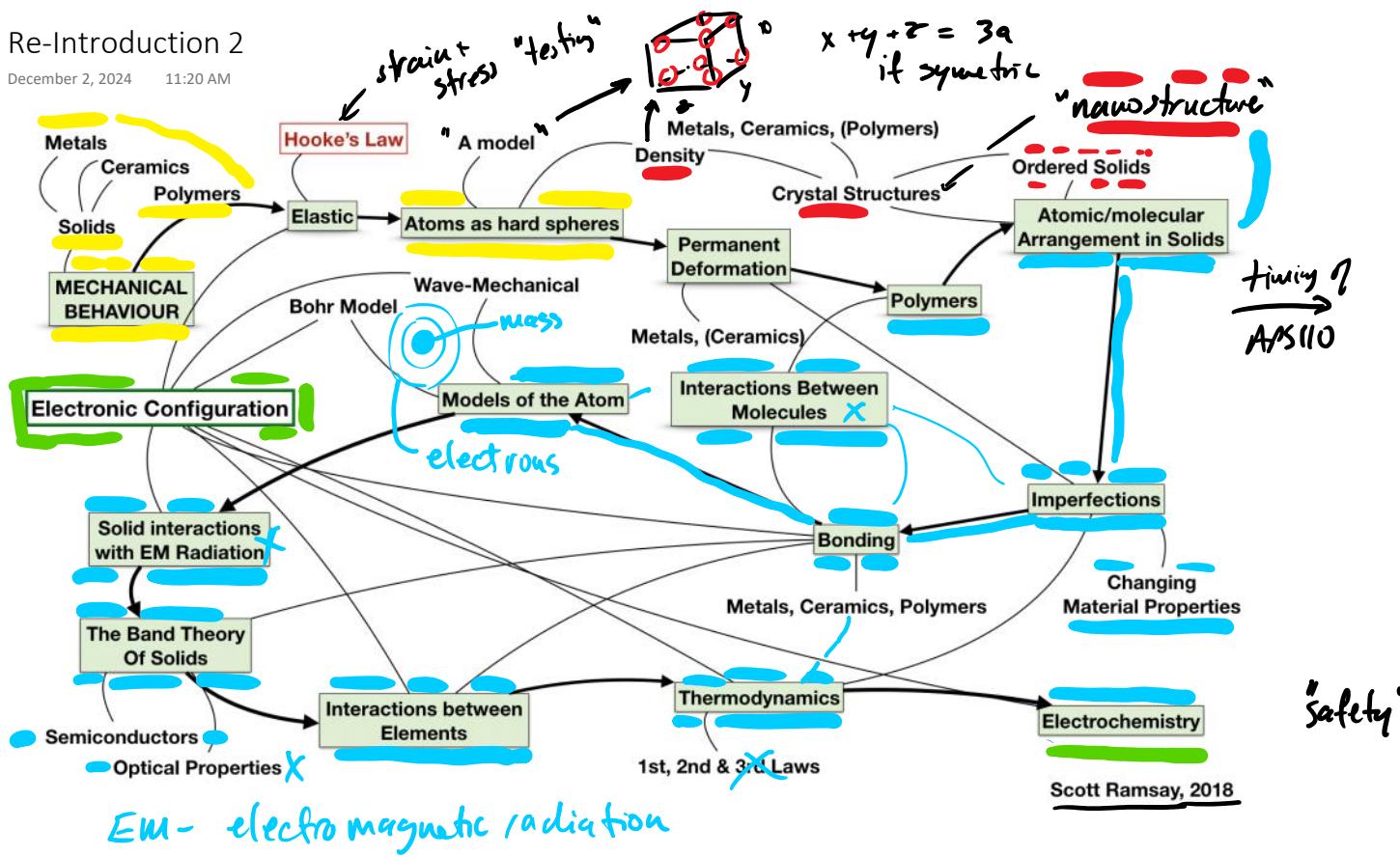
December 2, 2024 11:20 AM



Re-introduction: → next page

## Re-Introduction 2

December 2, 2024 11:20 AM



# PERIODIC TABLE OF ELEMENTS

<b>1</b>	<b>H</b>
Hydrogen	120
<b>3</b>	<b>Li</b>
Lithium	182
<b>4</b>	<b>Be</b>
Beryllium	153
<b>11</b>	<b>Na</b>
Sodium	227
<b>12</b>	<b>Mg</b>
Magnesium	173

par - nur  
"close"

→ cur "close"  
"longer"

Atomic Number

**H**  
Hydrogen  
120

**Symbol**

Name

Atomic Radius (van der Waals), pm  
*piconometer*

PubChem

<b>5</b>	<b>B</b>	<b>6</b>	<b>C</b>	<b>7</b>	<b>N</b>	<b>8</b>	<b>O</b>	<b>9</b>	<b>F</b>	<b>10</b>	<b>Ne</b>
Boron	192	Carbon	170	Nitrogen	155	Oxygen	162	Fluorine	135	Neon	154
<b>13</b>	<b>Al</b>	<b>14</b>	<b>Si</b>	<b>15</b>	<b>P</b>	<b>16</b>	<b>S</b>	<b>17</b>	<b>Cl</b>	<b>18</b>	<b>Ar</b>
Aluminum	164	Silicon	210	Phosphorus	180	Sulfur	180	Chlorine	175	Argon	188
<b>31</b>	<b>Ga</b>	<b>32</b>	<b>Ge</b>	<b>33</b>	<b>As</b>	<b>34</b>	<b>Se</b>	<b>35</b>	<b>Br</b>	<b>36</b>	<b>Kr</b>
Gallium	187	Germanium	211	Arsenic	185	Selenium	190	Bromine	183	Krypton	202
<b>37</b>	<b>Rb</b>	<b>38</b>	<b>Sr</b>	<b>39</b>	<b>Y</b>	<b>40</b>	<b>Zr</b>	<b>41</b>	<b>Nb</b>	<b>42</b>	<b>Mo</b>
Rubidium	303	Strontium	249	Yttrium	219	Zirconium	188	Niobium	207	Molybdenum	209
<b>43</b>	<b>Tc</b>	<b>44</b>	<b>Ru</b>	<b>45</b>	<b>Rh</b>	<b>46</b>	<b>Pd</b>	<b>47</b>	<b>Ag</b>	<b>48</b>	<b>Cd</b>
Technetium	209	Ruthenium	207	Rhenium	195	Palladium	202	Silver	172	Cadmium	158
<b>55</b>	<b>Cs</b>	<b>56</b>	<b>Ba</b>	<b>72</b>	<b>Hf</b>	<b>73</b>	<b>Ta</b>	<b>74</b>	<b>W</b>	<b>75</b>	<b>Re</b>
Cesium	343	Barium	268	Hafnium	212	Tantalum	217	Tungsten	210	Rhenium	217
<b>87</b>	<b>Fr</b>	<b>88</b>	<b>Ra</b>	<b>104</b>	<b>Rf</b>	<b>105</b>	<b>Db</b>	<b>106</b>	<b>Sg</b>	<b>107</b>	<b>Bh</b>
Francium	348	Radium	283	Rutherfordium	150	Dubnium	139	Seaborgium	132	Berrium	128
<b>57</b>	<b>La</b>	<b>58</b>	<b>Ce</b>	<b>59</b>	<b>Pr</b>	<b>60</b>	<b>Nd</b>	<b>61</b>	<b>Pm</b>	<b>62</b>	<b>Sm</b>
Lanthanum	240	Cerium	235	Praseodymium	239	Neodymium	229	Promethium	236	Samarium	229
<b>89</b>	<b>Ac</b>	<b>90</b>	<b>Th</b>	<b>91</b>	<b>Pa</b>	<b>92</b>	<b>U</b>	<b>93</b>	<b>Np</b>	<b>94</b>	<b>Pu</b>
Actinium	260	Thorium	237	Protactinium	243	Uranium	240	Neptunium	221	Plutonium	243
<b>63</b>	<b>Eu</b>	<b>64</b>	<b>Gd</b>	<b>65</b>	<b>Tb</b>	<b>66</b>	<b>Dy</b>	<b>67</b>	<b>Ho</b>	<b>68</b>	<b>Er</b>
Europium	233	Gadolinium	237	Terbium	221	Dysprosium	229	Holmium	216	Erbium	235
<b>95</b>	<b>Am</b>	<b>96</b>	<b>Cm</b>	<b>97</b>	<b>Bk</b>	<b>98</b>	<b>Cf</b>	<b>99</b>	<b>Es</b>	<b>100</b>	<b>Fm</b>
Americium	264	Curium	245	Berkelium	244	Californium	245	Einsteinium	246	Fermium	242
<b>101</b>	<b>Md</b>	<b>102</b>	<b>No</b>	<b>103</b>	<b>Lr</b>						
Mendelevium		Nobelium		Lawrencium							

# PERIODIC TABLE OF ELEMENTS

**PubChem**

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