AC 2011-1926: DEVELOPING A MATERIALS COURSE TEACHING TOOL KIT TO PROMOTE EASE OF IMPLEMENTATION OF INNOVATIVE CLASSROOM INSTRUCTIONAL MATERIALS

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Developing a Materials Course Teaching Tool Kit to Promote Ease of Implementation of Innovative Classroom Instructional Materials and Practice

Abstract

Many types of innovative teaching strategies and materials have been created in STEM (science, technology, engineering, and math) disciplines over time, but only a limited number have been widely adapted. Most classes in undergraduate engineering are still taught via lectures or the "transmission" mode of teaching, which has been shown to be the least effective method for student learning. This is due, in part, to the fact that there are major problems related to "ease of implementation" of innovative teaching and learning strategies and materials in STEM, and particularly so for engineering. To begin to address this need, a collection of innovative materials, activities, and assessments across nine topics of an introductory materials class has been created as a "Teaching Tool Kit" available on the web at http://concept.asu.edu/. To increase the potential for instructors adapting tools, the tool kit was designed to modify, but still fit within, the framework of an already-existing publisher's book and slide set. As such, the primary component in the tool kit is the nine topic-based, multi-class module note sets developed by modifying an already-existing set of chapter slides. Additionally, the innovative individual tools, which are embedded and integrated into the class modules, have also been broken out as separate "tools" so they can be used with any book or any set of instructor notes. This is a critical aspect for promoting ease-of-implementation, because this modularized approach allows faculty to utilize the tool kit resources to whatever degree they deem desirable. The tools available include topic-based sets of: team-based classroom activities; pre-post topic assessments; and student learning aids of visual glossaries and concept-context maps. The development of the innovative teaching tools was based on major principles for effective learning described in the book, *How People Learn*, as well as the pedagogical content knowledge developed from long-term research on student learning in materials courses. Tools for assessing prior knowledge include the Materials Concept Inventory and Pre-post Topic Concept Quizzes. Eliciting such information is critical in informing creation of innovative teaching materials. Constructivist materials and activities to support conceptual framework development included: Mini-Lecture Misconception Informed Slide Sets, Concept-in-Context Class Activities, Concept-In-Context Homework, Concept-Context Maps, Concept-Context Quizzes, and Visual Glossaries. A tool created to promote metacognition was the Daily Reflection sheet which prompted students to describe their Most Interesting, Muddiest, and Learn-About-Learning Points. The tools were created to promote thoughtful and meaningful team dialogue, as well as awareness of both value and difficulties of learning content in a student-centered classroom. Overall, this tool kit is meant for any instructor of an introductory materials course, regardless of level of teaching expertise. By making innovative course tools accessible, such as found in the tool kit, we also hope to promote the development of pedagogical content knowledge in engineering educators. We also believe that the strategies and tools described have characteristics of a general model that could be adapted to other courses and potentially achieve broader impact. The specific data on the effect of these materials on student learning, along with detailed explanations of tool development methods are described and discussed in the paper.

Introduction

Many types of innovative strategies and materials have been created in STEM disciplines over time, but only a limited number have been widely adapted. Most classes in undergraduate engineering are still taught via lectures or the "transmission" mode of teaching, which has been shown to be the least effective method for student learning. This is due, in part, to the fact that there are major problems related to acceptance, implementation, and wider use of innovative teaching and learning strategies and materials in STEM, and particularly so in engineering[1]. Henderson and Dancy[2] have cited a number of reasons that inhibit adaptation of innovation in STEM instruction. One is the lack of time due to large teaching loads and/or research responsibilities which can cause time constraints. Another is little departmental and/or peer support or lack of role models or mentors to help transition an instructor to student engagement-based teaching. Classroom learning environments with long rows of table or chairs can inhibit student collaboration and the interactions in which they can negotiate their own conceptual understanding in order to construct their own knowledge. Another reason is inadequate time to cover a desired amount of content which can occur when time-consuming, interactive learning activities sacrifice the amount of content covered. A last factor is student resistance to unfamiliar instructional methods and reduction in content covered. In order to promote adoption of more effective approaches to learning these issues need to be addressed in any program that is promoting the use of innovative strategies, practices, and materials.

Henderson and Dancy made some suggestions to address issues cited above to inform curriculum material developers of possible ways to improve implementation of innovative STEM teaching and learning strategies and material[2]. Providing easily modifiable materials to help engage faculty in modifying or redesigning their instruction. This supports the contention that innovative materials must be easy to use. Another suggestion is in fidelity of implementation of an innovation. For example, effective learning should not only include use of classroom clickers by themselves, but also in engaging in social construction of knowledge by peer discussion of clicker responses. The last suggestion is to facilitate implementation of innovation by working with peers through workshops and colloquia. This needs to be done to provide personal support and build self efficacy for instructors who want to implement innovative materials and practices in their classrooms. These concepts and ideas about implementation and diffusion of innovative teaching materials in STEM were used to inform development of materials described in this paper.

Adaptation of more effective teaching and learning requires that new materials be not only be easily adaptable, but also are aligned with the knowledge and understanding developed over the past two decades of how people learn. As such, the major principles for effective learning are described in the book, *How People Learn.* It states that, for more effective teaching and learning, instructors need to heed three major principles. One is that instructors should be aware of students' prior knowledge and experience and misconceptions in order to inform classroom instruction and materials. A second principle is that instructors should create opportunities for students to engage with one another in order to develop deeper content understanding such they will begin to organize their facts and ideas into a conceptual framework that facilitates recall and transfer of concepts to new applications. A third principle is that instructors should promote and facilitate student reflection so they become more metacognitive learners who can develop their own expertise by defining learning goals and monitoring their own progress. By using these principles in conjunction with easy implementation it can be possible to design and develop innovative, effective, research-based curriculum resources which are accessible to instructors and also foster the development of their pedagogical content knowledge.

A relevant research question here is, "How can the principles of research on how people learn be implemented in practice with an innovative, effective, easily-implemental set of teaching and instructional materials?" Another question that is complementary to the first relates to the efficacy of the materials, "What is the effectiveness of such a set of innovative instruction materials on student attitude, learning and retention?"

Background Literature

The innovations and approach used in developing innovative materials always followed the principle of making materials relevant and significant to students during instruction. As such, we will refer to the materials discussed here as Concept Learning In Context (CLIC) instruction. The goal is to show that examples of real-world applications need to be linked to abstract concepts to illustrate relevance and significance of content. This enhances motivation and self efficacy.

Mental Models and Conceptual Change

Constructivism espouses the belief that students learn most effectively by constructing their own knowledge and refers to learning as conceptual change[3-5]. *How People Learn*[6] discusses how cognitive processes act to achieve conceptual change, which occurs through modification of a student's conceptual framework. The framework is comprised of mental models, which are transformed representations of real-world systems or phenomena called modeled target systems or phenomena[7]. As such, mental models are defined as simplified, conceptual representations that are personalized interpretations of modeled target systems or phenomena in the world around us. Thus, the transformed, modeled target systems or phenomena turn into the mental models which become more visible or comprehensible to the individual[8]. Useful mental models allow us to understand, explain, and predict behavior of systems and phenomena, whereas faulty mental models, which lead to misconceptions, cannot. Use of CLIC in the materials course was used to uncover misconceptions which a teacher can address by adjusting instruction. An application of this approach might be a team activity where the goal is to analyze a stated misconception and the develop a correct model. An example would be: strengthening the film in a polyethylene grocery bag stretched by hand. A misconception, making atomic bonds stronger, is replaced through team collaboration by the correct normative model, reorientation of randomly-oriented, covalently-bonded chains to align with the strain direction so the strong, now-aligned covalent chain bonds can withstand higher stress and give the film higher strength.

An individual communicates his/her mental models with some form of external representation, which are expressed models. They might be verbal or written descriptions, equations, sketches, diagrams, graphs, physical models, computer models, or other forms of representation[9]. Thus, the expressed models reveal students' “ways of thinking” when elicited by appropriate questions or activities. In fact, when students use a mental model in their conceptual framework and express it in various forms, they are, in effect, explaining their ideas or “modeling a concept”. These expressed mental models, or modeled concepts, can be used as indicators to track conceptual change as measured by techniques such as the concept inventories, interviews, drawn schematics, journaling, etc. As such, assessments that inquire about "multimodal" representation of concepts are better able to triangulate students' conceptual understanding of a topic.

Using *How People Learn* Principles to Design and Create Instructional Materials

Development of CLIC materials was guided by three major teaching and learning principles of the book, *How People Learn*. One principle is that students must have their facts and ideas organized in a conceptual framework that facilitates retrieval and transfer of concepts to new contexts and applications. As such, content for a materials engineering course needs to foster learning so that students learn to bridge ideas from concrete contexts of a material in a familiar item (window) and/or system component (motorcycle windshield) or a historical event (Titanic) to the abstract concept and principles that relate a material's (metal, ceramic, or polymer) internal microstructural features (bonding, crystal structure, grain size, etc.) to its macroscopic properties (such as stiffness, strength, and ductility). One of the formative assessments uses a second *How People Learn* principle, which is that, for effective instruction, an instructor needs to know, understand, and address *students' prior knowledge and misconceptions*. The Pre-post Topic Concept Quizzes reveal prior knowledge and misconceptions before a topic is taught; then it is given again and is able to evaluate conceptual change and misconception repair at the end of the topic[10]. Misconceptions still present from the pre-test were classified as robust. Another formative assessment is the daily Class-End Points-of-Reflection assessment. These included: "Most Interesting, Muddiest, and What Did You Learn About Your Learning?" These assessments provide instructor feedback for modifying upcoming classes. For students, they promote the third major principle of *How People Learn*, that of developing metacognition to facilitate skills like concept organization and relationships and monitoring one's own learning progress.

A Process for Redesign of Instructional Materials for More Effective Student Learning.

The instructional materials were developed by restructuring an already-existing set of book publisher chapter slide-set materials by using the principles described in the book, *How People Learn*. The modified, already-existing publisher's materials were used to promote easy adoption of the teaching innovations by other instructors since the modified materials could be reasonably well aligned with their own unmodified already-existing publisher's materials. This addresses the important factor of ease of implementation. Next, formative and summative assessments were developed to assess student knowledge at the levels of daily instruction, pre-post multi-class topic instruction, and before and after the course (pre-post course). Then the results from these assessments were collected and analyzed in order to reveal issues in student prior knowledge which included knowledge gaps, misconceptions, robust misconceptions, and difficult concepts. Finally, materials that were previously redesigned to promote student engagement, were again modified and adjusted, now newly informed by prior knowledge issues, in order to address the major impediments and barriers to student learning like misconceptions. Thus, the process that was used realigns the instructional materials, as well as the classroom practice, by active engagement of students in teams, with the principles described in *How People Learn*.

Assessing Student Prior Knowledge, Misconceptions, and Conceptual Gain.

Pre-post Topic Concept Quizzes are formative assessments that have been created for eight topics in the Introductory Materials Class. They are given prior to instruction on a topic to assess prior knowledge, which elicits information not only about scientifically correct concepts, but also about knowledge gaps and misconceptions[11]. If the same tool is administered as a Post-Topic Concept Quiz it informs instructors if knowledge gaps and misconceptions have been repaired or, if still present, can be classified as robust misconceptions. Thus, the Pre-post Topic Concept Quizzes are tools that have been used to measure effectiveness of instruction and conceptual change. A rubric can also be used to provide a quantitative measure of conceptual gain.

Another formative assessment used is the daily, class-end Points-of-Reflection assessment[12]. These points included: "Most Interesting Point" (with a 1-5 Likert scale), "Muddiest Point" (with a 1-5 Likert scale), and a "What Did You Learn About Your Learning?" point. The Muddiest Point can reveal what students consider to be a "Difficult Concept" when a large fraction of the class rates a given concept at a 4-5 average on the Likert scale. High rating averages of the "Most Interesting Point" can reveal positive student attitude on a given topic, and can help motivate students in their classroom performance. The "What Did You Learn About Your Learning" point is intended to promote metacognition, and sometimes does so, but is a topic that needs more development. Two summative assessments were used for the class. The first, the Materials Concept Inventory, measures pre-and-post course concept knowledge and thus conceptual gain. The second instrument, a Support of Student Learning Survey, measures student attitudes about support of their learning by use of CLIC strategies, materials, activities, and assessments. Eliciting such information is critical in informing creation and continuous improvement of innovative and misconception-informed teaching materials. In effect, students are involved in designing their own instruction, which is an important point in strategies used for creating more effective instructional materials.

Promoting Student Metacognition with Class Reflection Points

At the conclusion of every class, students filled out a Class Reflection. Each Class Reflection had three points for students to reflect on. Likert scales of 1 to 5 were also included for the first two points. The ***Point of Interest*** allowed students to think about and convey parts of content that they find interesting and intriguing. They began to recognize topics that interested them which promoted future appreciation of knowledge. The instructor identified with the learner and saw what information sparked interests in the students' thoughts. The response to the ***Muddiest Point*** forced students to identify content topics which they had trouble understanding. By asking students to reflect on their difficulties in understanding, they learned to identify conceptual weaknesses. Frequent thought of these weaknesses enabled students to be proactive in their learning in the future. The instructor was able to catch conceptual gaps as they occurred and reduce the probability for students to develop robust misconceptions. The ***Learn about Learning Point*** asked students to identify what was learned about their own learning. This question enforced metacognitive thought processes in students which gave an opportunity to develop successful strategies for how to learn. Each class reflection was cataloged for each student throughout the semester. This resulted in a semester long progression of each student's thinking about each of the reflection points. Samples are presented from selected students were studied for trends in conceptual and metacognitive development. Their responses were coded through emergent themes coding. And their progress was followed through their Class Reflection Points, Topical Module Assessments, and Support for Student Learning Survey.

Results and Discussion of Innovative Teaching and Learning Materials Created

The tools in the Teaching Tool Kit that were created in the CLIC project included the following.

- **Concept-in-Context Multi-Class Teaching Modules Informed by Misconceptions.** A set of teaching and learning modules for nine topical areas were created which incorporated several innovations. All modules are available on the web site http://concept.asu.edu. The innovations included in each module are listed below and an example for the Atomic Bonding Module appears in the appendix. The components that are embedded within each of the multi-class modules are outlined briefly here:
- **Pre-post Topic Concept Quizzes** to elicit knowledge gaps and misconceptions and to measure conceptual change, and knowledge gap and misconception repair.
- **Concept-in-Context Mini-Lecture Slide Sets** for the 2-5 classes on each topic. A complete set of *modified* publisher slide sets was developed for all course topics. Initially, other instructors would not use the experimental slide set, since it deviated too much from their own course materials. Thus, the decision was made to take the innovative aspects of the experimental materials and embed them in a book publisher's chapter slide sets. The innovations infused into publishers slides included the innovations listed below.
- **Concept-in-Context Connections Worksheets** were structured to visually bridge the concrete macroscopic properties of the materials that compose real-world items and the abstract structural features of the materials that is the basis for their properties. Concept-Context worksheets contextualized complex concepts and allowed students to organize their ideas for a specific topic. For these worksheets, students were given an "answer bank" for different technical aspects of 6-9 real-world objects or scenarios. From the answer bank, students filled in the one specifically appropriate answer for the particular, specific characteristic of each object. Worksheets were created for "Materials Science of Household Components" as well as systems which used different materials. These included systems for "Airplane Components", "Auto Components", "Motorcycle Components", "Bicycle Components", and "Integrated Circuit Components" Other worksheets were used to elicit students' abilities to interpret graphical and visual representations of phenomena. When this multimodal expression occurred, it was possible for the instructor to observe student graphical and visual expressions of student mental models.
- **Visual Glossary of Terminology Slides** help visualization of concepts, contexts, processing, testing, properties, and performance for a topic. They improve recall and foster connections between concrete objects and phenomena and abstract principles behind them.
- **Concept-Context Maps and Concept-Context Map Quizzes** have been created during the third year of an NSF grant for most topics. These are intended to facilitate students' construction of a conceptual framework for topical content in a given area. They help map out content, show connections, and help define terminology, as well as illustrate familiar contexts for abstract concepts that are used in a topical area. These have proven to be quite popular with students for following and clarifying mini-lecture materials during class. A variation on the CC Map has been created whereby a number of "bubbles" containing

concepts or information have their content removed and incorporated into a "word bank" of 10 to 15 terms. This then becomes a so-called CC Map Quiz which is used as a team activity.

- **Daily Class-End Points of Reflection Slide** (submitted by anonymous ID) that include:
  - **Most Interesting Point –** *student values class interest aligning with personal interest*
  - **Muddiest Point –** *students specify difficulty; instructor uses responses to adjust class*
  - **Learned About Your Learning Point –** *helps develop student metacognitive skill*
- **Homework Problems Slides** frequently use real-world applications as a concept-in-context. Examples of components described above are in the appendix. Although nine modules have been completed, they continue to be revised for more effective student learning. Recently, a CCMap quiz on next class material was added to homework to promote class preparation.
- **Web Site for Project Information and a Teaching Tool Kit**. A web portal has been created http://concept.asu.edu which has information on project participants and publications and also a Teaching Tool Kit with the following components: nine topical modules with 2 – 5 note sets; team-based activities for all 25 classes; Concept-in-Context Maps and Quizzes showing topical concept relationships; and Visual Glossaries of Terminology for all topics.

Results and Discussion of Prior Knowledge Elicited

Pre-post Topic Concept Quizzes were used to uncover and assemble an enriched assembly of student knowledge gaps and misconceptions. More robust misconceptions were specified when a pre-topic misconception was still present on Post-Topic Concept Quiz. The details of the approach are discussed in the first paragraph of the background literature in the section on "Assessing Student Prior Knowledge, Misconceptions, and Conceptual Gain".

Bonding: Covalent bonding is a “bond between a nonmetal and a metal.”
A van der Waals bond is “a weak bond where atoms are magnetized.”
Ionic bonding is defined by “two metals that bond together by transferring electrons.”
Robust Misconception: Ionic bonds occur if “electrons are given up by magnetic attraction.”

Unit Cells: For FCC, students drew atoms in (1 1 1) not touching when they should have.
For BCC, students drew atoms in (1 1 0) that touched when they should not have
Robust Misconception: Extra atom in middle of the (1 1 1) plane in BCC drawing

Deformation: ***Paper Clip Deformation***
“Metallic bonds stretching, atoms getting further apart.”
“Atoms rub together creating heat and breaking the particles up, melt the clip.”
Robust Misconception: Grain boundaries “move,” “stretch,” or “bend.”

Polymers: Rubber Band Stretching “Atoms are becoming softer and more brittle”
Plastic Fork Breaking “Atoms snap at the atomic level”
PE Bag Stretching “Atoms become softer as they are stretched and begin to break”

Electrical Properties: ***Add a small amount of copper to zinc***
“The conductivity increases because the copper is very conductive”
“Conductivity decreases due to barriers to the motion of dislocations”
Add a small amount of As to Si – what is effect on conductivity?
“The conductivity decreases because of the impurity with less conductivity”
"The conductivity “reduces more grain boundaries”
“When As is added, it becomes less conductive because it’s a group V” element
Robust Misconceptions: “It goes down; an impurity is in the way.”

Results on the Effect of CLIC on Student Performance

Hake gains for teaching were 5% to 40% higher compared to lecture-based teaching as shown below. This is consistent with results using student engagement methods in university general science classes. Redish, Saul and Steinberg showed significant gains in university physics from using inquiry learning in a studio lab as measured by comparative gains on the FCI[13]. Crouch and Mazur report significant FCI gains in using "Peer Instruction" which uses student pair discussion of class-based clicker questions[14]. Beichner & Saul report in SCALE-UP studio physics courses with pre-class questions and inquiry activities students: have enhanced conceptual understanding, problem-solving ability, and motivation; fail less frequently than in conventional courses; and perform better in subsequent courses in physics and engineering[15]. They found there were also decreases in failure rate, which was highest among female and minority students, which they attribute to supportive social interactions. In a another course for a biology concept test, normalized gain increased from 15% to 52% when lectures used JiTT, with further increase to 60% if JiTT + inquiry was used.

Measuring Student Achievement with the Materials Concept Inventory

Results from the MCI showed that gains for the CCLI approach were significantly higher in all 5 selected topical areas. This was due to uncovering hidden misconceptions and then addressing them with inquiry activities and instruction. Results from MCI test administered in 2009 CLIC versus 2002 lecture based classes are shown in Figure 1 with abbreviated questions in Table 1.

Figure 1. MCI Test Results- 2009 CLIC versus 2002 Lecture Based Classes

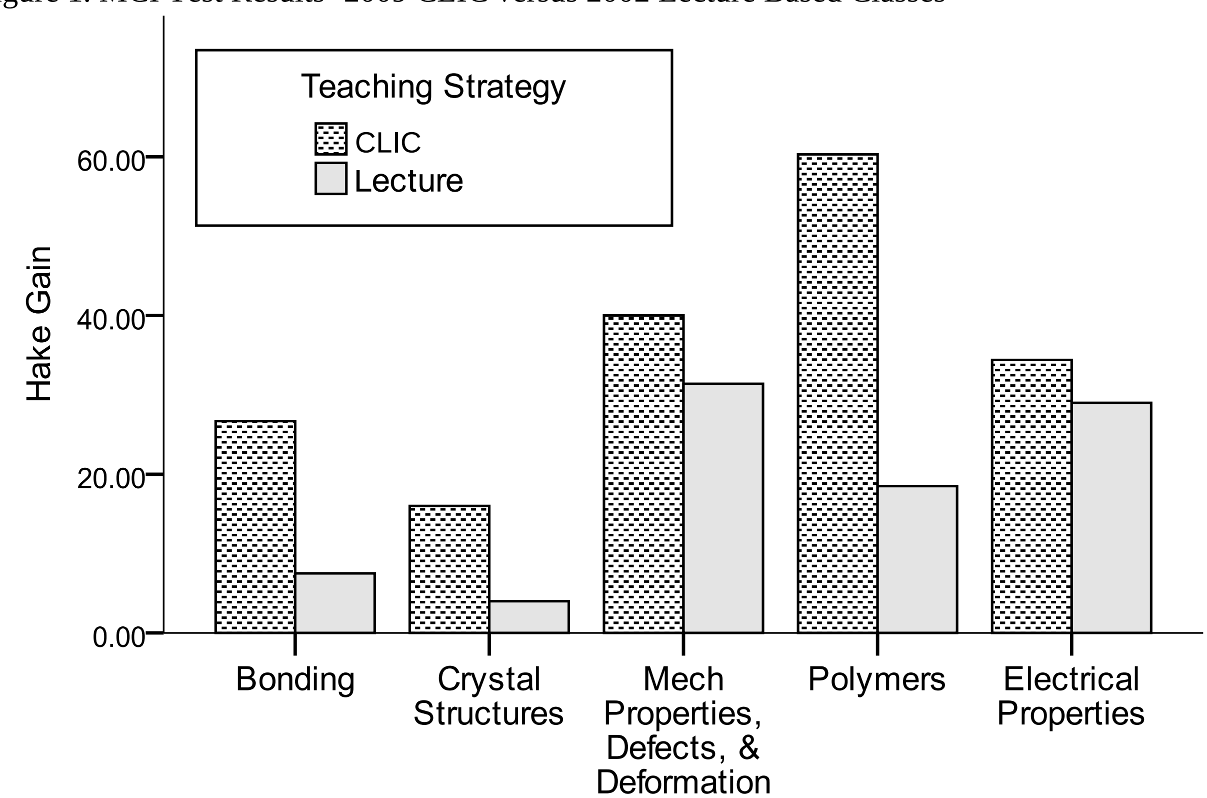

Table 1. Comparative Gains of Topic Relevant Questions by Teaching Strategy

Topic	Lec Gain	CCLI Gain
Bonding	***7.5***	***23.67***
MCI 5: Melting points of most plastics are lower than most metals because:	7.0	16.76
MCI 29: A polymer rubber band stretches more than a metal paper clip because:	8.0	30.59
Crystal Structure	***4.0***	***16.02***
MCI 9: Number of lines connecting opposite corners of a cube through center	10.0	-0.39
MCI 10: In a cube there are *** sides and *** edges	-2.0	32.43
Mechanical Properties, Defects, & Deformation	***31.4***	***40.01***
MCI 18: copper wire from hardware store softens when heated because	14.0	51.90
MCI 19: Metal rod pulled through a tapered hole strengths because:	21.0	57.74
MCI 20: Addition of a few % of Al to Fe will changes strength to:	39.0	60.00
MCI 21: Metal 1% volume of particles added so ___ would make metal strongest:	9.0	25.86
MCI 22: If a small steel rod bent 45 degrees, so final position after release is:	67.0	55.15
MCI 23: Materials with significantly different strengths in tension and compression:	30.0	-4.49
MCI 24: Why does copper dent when hit with a hammer whereas glass breaks?	40.0	33.93
Polymers	***18.5***	***60.32***
MCI 28: The following materials are polymers:	29.0	29.73
MCI 29: A polymer rubber band can stretch more than a metal paper clip because:	8.0	30.59
Electrical Properties	***29.0***	***34.36***
MCI 13: Impurity like As added to Si ______ conductivity.	30.0	53.02
MCI 14: Aluminum is a better electrical conductor than is glass because aluminum:	21.0	-0.51
MCI 15: If a small amount of Cu is added to Fe _____ electrical conductivity :	36.0	50.56

Note: Gains are Hake Gains (gain/100-pre score).

The gains displayed in the graph from Fall and Spring 2009 show that the CLIC project approach was more effective than earlier 2002 lecture-based instruction. However, the graph also shows that there are significant issues in achieving more effective learning with the topics of bonding, crystal structures, and electrical properties. Improved approaches are being tested to address issues in these areas. The results demonstrate the potential to use feedback from instruction for areas that are in need of the most attention.

Measuring Student Attitude with Support of Student Learning Survey

An additional outcome not originally planned in CLIC was a summative survey administered at the end of class to determine students' attitudes toward course instructional strategies and materials. The results are shown in Table 2. and are discussed next. Socio-constructivist student engagement strategies of team-based discussion and problem solving were very well received with 86% to 91% supportive or very supportive (SVP) responses. Classroom activities of worksheets and hands-on activities were also well valued at 81% and 85% SVP. Worksheets and class note sets are available on the project web site at http://concept.asu.edu/ . Student learning aids of visual glossaries and concept-context maps were also well received at 84% and 77% SVP. The CCMap use will also be expanded to create more CCMap blank-bubble quizzes for use as in-class activities. Mini-lectures were valued at 71% SVP which will hopefully improve with the feedback from students being used to improve the mini-lectures. The in-class formative assessments of Pre-post Topic Concept Quizzes and Daily Reflection Points were not highly valued by students at 50% and 42% SVP. As such, student feedback on these tools will be solicited to develop strategies to improve their student-perceived value to their learning. Overall ratings of the CLIC teaching and learning strategies for the materials class was well valued at 80%. The value of CLIC approach can be seen by the fact that 72% SVP of students would like to see similar strategies used in their other classes.

Table 2. Support of Student Learning Survey

Instructional Strategies (Average of S09, F09, S10, F10)	**Not at All Supportive** 1	**Not Supportive** 2	**Neutral** 3	**Supportive** 4	**Very Supportive** 5	4+5
Team based problem solving	1%	2%	6%	48%	43%	91%
Team based discussions	2%	3%	9%	46%	44%	86%
Teams present problem solutions	2%	7%	20%	40%	30%	70%
Pre-post Topic Concept Quizzes	5%	12%	28%	39%	13%	50%
Daily reflection sheets	14%	12%	33%	27%	15%	42%
Visual glossaries of terminology	1%	2%	12%	44%	39%	84%
Mini-Lectures	2%	10%	16%	41%	31%	71%
Homework	2%	6%	16%	48%	27%	75%
Tests	1%	7%	21%	44%	27%	71%
Hands-on Activities	1%	3%	15%	41%	37%	81%
Concept in Context Worksheets	0%	3%	16%	43%	37%	85%
Concept maps of all course topics	3%	3%	16%	48%	29%	77%
Undergraduate Teaching Assistant working with teams	0%	13%	35%	32%	19%	51%
Overall Rating of Strategies Used to Support Learning	2%	5%	7%	34%	71%	80%
I would like some instructional strategies from MSE 250 used in other engineering courses	2%	4%	22%	33%	62%	72%

Results on the Effect of CLIC on Student Persistence

In the four semesters during which ASU materials courses were taught with CLIC student engagement methods, persistence increased to 95% compared to persistence of 85% with earlier lecture-based classes. This improvement agrees with the results of Marrs, Blake, and Gavrin[16] (2003). They found, compared to lecture-based introductory biology courses, that in courses taught with JiTT and inquiry activities, students withdrawing or receiving a D or F dropped from 33% to 18%. These results in this CLIC study impact one of the major concerns of engineering education, that of retention. Motivational and affective beliefs that students bring to learning contexts directly affect their persistence and effort (Pintrich & Schunk, 2002). Two aspects of motivation have been shown to impact learning the most. These are the degree to which students think that they are capable of completing a learning task (*self-efficacy*)[17] and the degree to which they think that the activity is valuable[18,19]. Students interested in the short-term value of what they are learning are more likely to use learning strategies that facilitate quick learning, rather than deep understanding. The instructional strategies in CLIC use real world contexts for embedding course concepts which we have previously referred to as "Concept-in-Context" (Krause et. al., 2010). This is a key feature of CLIC instruction. Motivation can increase by embedding a concept in a familiar context, especially if it is a compelling context which also has personal, social, or historical dimensions. Students' motivation can increase when they recognize and identify with a concept's relevance, significance, and possible value to their own future. As discussed earlier, when students are learning to bridge ideas from concrete contexts of a material with the familiar, such as a motorcycle windshield, to abstract principles they also recognize their own relationship to these concrete contexts. When presented with situations related to these contexts, students can be better motivated to learn and continue on in engineering.

Summary and Conclusions

There are different normative models for science concepts used in instruction in introductory materials courses. While science instruction aims at creating and understanding fundamental models of phenomena of the natural world, engineering materials instruction strives to utilize the understanding and models acquired from science to relate the structure of a material to a material's to macroscopic properties as well as the processing of a given material into real-world items and components. These different goals result in differing methods of modeling, understanding, and teaching applications of scientific concepts. One goal of introductory engineering science courses is to shift engineering students from a natural science learning orientation to an engineering design, innovation, and manufacturing orientation. In order for this transition to occur, both faculty and students must be aware of the need for this transformation. Students may enter introductory engineering courses able to explain phenomena, but not necessarily able to apply that knowledge of scientific phenomena to engineering design and innovation. Additionally, students must be aware of the transition so that they do not become frustrated from the different orientation of instruction in their engineering science classes. They need to remain open-minded and comfortable with the potential advantage of achieving conceptual change about the nature of engineering. By frequently utilizing multimodal expression of student mental models, this transition can be monitored.

The integrated, contextualized, and multimodal CLIC materials that were delivered enabled students to express concepts in multiple representations. Students showed significant gains in conceptual understanding of materials science concepts. Students were able to convey their thinking, attitude, and issues through Class Reflections and the Support for Student Learning Survey. In general, students felt that the modules were very supportive to their learning. This data suggests that the modules are not only effective, but are respected by students, and may account for improved class retention.

A set of pedagogical and teaching materials that incorporates frequent multimodal expressions of student mental models have been shown to elicit misconceptions, monitor student conceptual change, and increase conceptual understanding of relationships between macroscopic properties of materials and their internal structural characteristics that underlie the macroscopic properties. In using scientific concepts to explain properties of real-world materials in engineering applications, students' progress in transitioning from a natural science understanding to an engineering framework. In observing this transition faculty can ensure that students are able to understand the structure, processing, and properties of real world materials with respect to the macro-micro connections that exists among the families of materials. Once students make this transition with the support of pedagogy like what has been discussed, they may develop the ability to apply and adapt this understanding for their individual disciplinary needs.

Acknowledgement

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References

1. Borrego, M, Froyd, J.E., and Hall, T.S. (2010). "Diffusion of Engineering Education Innovations : A Survey of Awareness and Adoption Rates in U.S. Engineering Departments," *Journal of Engineering Education*, vol. 99, 2010, pp. 185-207.
2. Henderson, C. and Dancy, M. (2007) Barriers to the Use of Research-Based Instructional Strategies: The Influence of Both Individual and Situational Characteristics. *Physical Review Special Topics: Physics Education Research,* 3 (2), 020102-1 - 020102-14.
3. Von Glaserfield, E. (1987). *The Construction of Knowledge: Contributions of Conceptual Semantics* (Seaside, CA: Intersystems Publications, Inc.).
4. Von Glaserfield, E. (1995). *Radical Constructivism: A Way of Knowing and Learning* (Washington, DC: The Falmer Press).
5. Vygotsky, L. (1962) *Thought and Language,* T. E. Hanfmann & G. Vaka (Eds.), Cambridge, MA: MIT Press.
6. Donovan, M. S., Bransford, J. D. & Pellegrino, J. W. (Eds.) (1999). *How people learn: Bridging research and practice.* National Academy Press, Washington, DC.
7. Norman, D. (1983) Some observations on mental models. In *Mental Models*, D. Gentner and A. Stevens (Eds.), Hillsdale, NJ, Erlbaum.

8. Gilbert, J. (1995) The role of models and modeling in some narratives in science learning. *1995 Annual Meeting of the American Educational Research Association*, San Francisco, CA.

9. Boulter, C. J., & Buckley, B. C. (2000). Constructing a typology of models in science education, in Gilbert, J. K., & Boulter, C. J. (Eds.), *Developing models in science education*. Dordrecht, Netherlands, Kluwer Academic Publishers.

10. Kelly, J., Krause, S., and Baker, S. (2010). A Pre-Post Topic Assessment Tool for Uncovering Misconceptions and Assessing Their Repair and Conceptual Change. 2010 Frontiers in Education Annual Conference.

11. Krause, S., Kelly, J., Triplett, J., Eller, A., and Baker, D. (2010). Uncovering and Addressing Some Common Types of Misconceptions in Introductory Materials Science and Engineering Courses. Journal of Materials Education, 32(5- 6), 255-272.

12. Kelly, J., Graham, A., Eller, A, Baker, D., Tasooji, A., and Krause, S. (2010). Supporting student learning, attitude, and retention through critical class reflections. 2010 ASEE Annual Conference Proceedings.

13. Redish, E. F., Saul, J. M., & Steinberg, R. N. (1997). On the effectiveness of active-engagement microcomputer-based laboratories, *American Journal of Physics*, *65, 45-54.*

14. Crouch, C. H., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics*, *69*, 970-977.

15. Beichner, R. & Saul, J. (2003). Introduction to the SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs) Project. *2003 Proceedings of the International School of Physics "Enrico Fermi," Varenna, Italy.*

16. Marrs, K A., Blake, R., & Gavrin. A. (2003). Use of warm up exercises in Just in Time Teaching: Determining students prior knowledge and misconceptions in biology, chemistry, and physics. *Journal of College Science Teaching, 32*, 42-47.

17. Pajares, F. (1996). Self-efficacy beliefs in academic settings. *Review of Educational Research, 66*(4), 543-578.

18. Malka, A., & Covington, M. V. (2005). Perceiving school performance as instrumental to future goal attainment: Effects on graded performance. *Contemporary Educational Psychology, 30*(1), 60-80

19. Wigfield, A. (1993). Why should I learn this? Adolescents' achievement values for different activities. In P. R. Pintrich & M. L. Maehr (Eds.), *Advances in motivation and achievement: Motivation and adolescent development.* (Vol. 8). Greenwich, Conn.: JAI Press.

Appendix

Example of a Topical Slide Set for Atomic Bonding

Features that are included in the slide set are:

Pre-post Topic Concept Quiz On Bonding (Slide 2)

Concept-Context Map for Bonding and The Periodic Table (Slide 6)

Activity for Concept-Context Map for Bonding & Properties Fill-in-the-Blank (Slide 10)

Activity Motorcycle Components Materials Selection (Slide 20 - 21)

Visual Glossary for Atomic Bonding (Slide 22 - 23)

Concept-Context Homework Assignment (Slide 24 - 26)

Daily Reflection Sheet (Slide 27)

Ch. 2: Atomic Structure & Interatomic Bonding I: Periodic Table Relationships

ISSUES TO ADDRESS...

- What promotes bonding?
- What types of bonds are there?
- What are the bonding relationships found between elements on Periodic Table?
- What macroscopic properties are related to bonding?

Class 2 – Chapter 2: Bonding & Periodic Table Topic #1.1

Pre-Topic Concept Quiz on Bonding

Pre Module Concept Exploration on Bonding Your Letter + 4 digit number ______________ Date ___________ M or F

1. In the space below, briefly describe and sketch a picture of each of the different types of bonding listed:
2.

Type of Bonding	Brief Description	Sketch
Covalent		
Ionic		
Metallic		
van der Waals		

3. For each object listed below, list 2 important property requirements of the application which the material must have and also the type(s) of bonding present for the material given.
4.



Object	2 Properties Required of Material	Type of Bonding
Polymer Water Pipe		
Metal Paper Clip		
Glass Whisky Bottle		

Atomic Structure

- atom – electrons (-) 9.11×10^{-31} kg
  protons (+), neutrons (0) } 1.67×10^{-27} kg
- Z [=] atomic number = # of protons in nucleus of atom
  = # of electrons in neutral element
- A [=] atomic mass unit = amu = 1/12 mass of ^{12}C

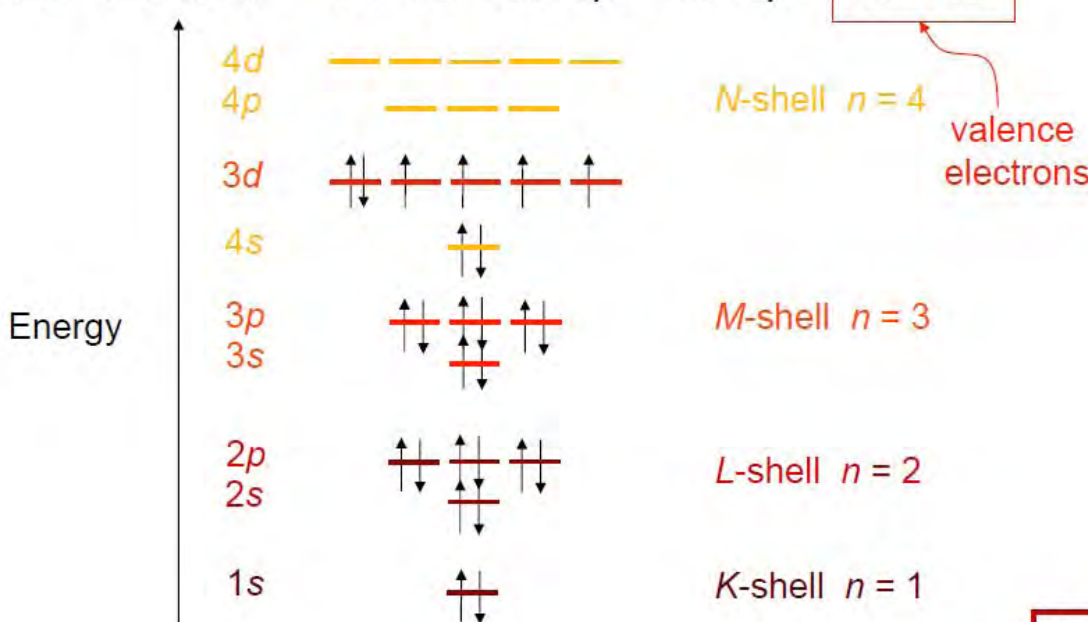
  Atomic wt = weight of 6.022×10^{23} molecules or atoms

  1 amu/atom = 1g/mol
- C = 12.011 amu/atom or g/mole
- H = 1.008 amu/atom or g/mole

Electronic Configurations

Quantum #	Designation
n = principal (energy level-shell)	*K, L, M, N, O* (1, 2, 3, etc.)
l = subsidiary (orbitals)	*s, p, d, f* (0, 1, 2, 3,..., n -1)

ex: Fe - atomic # = 26 $1s^2$ $2s^2 2p^6$ $3s^2 3p^6$ $3d^6$ $4s^2$



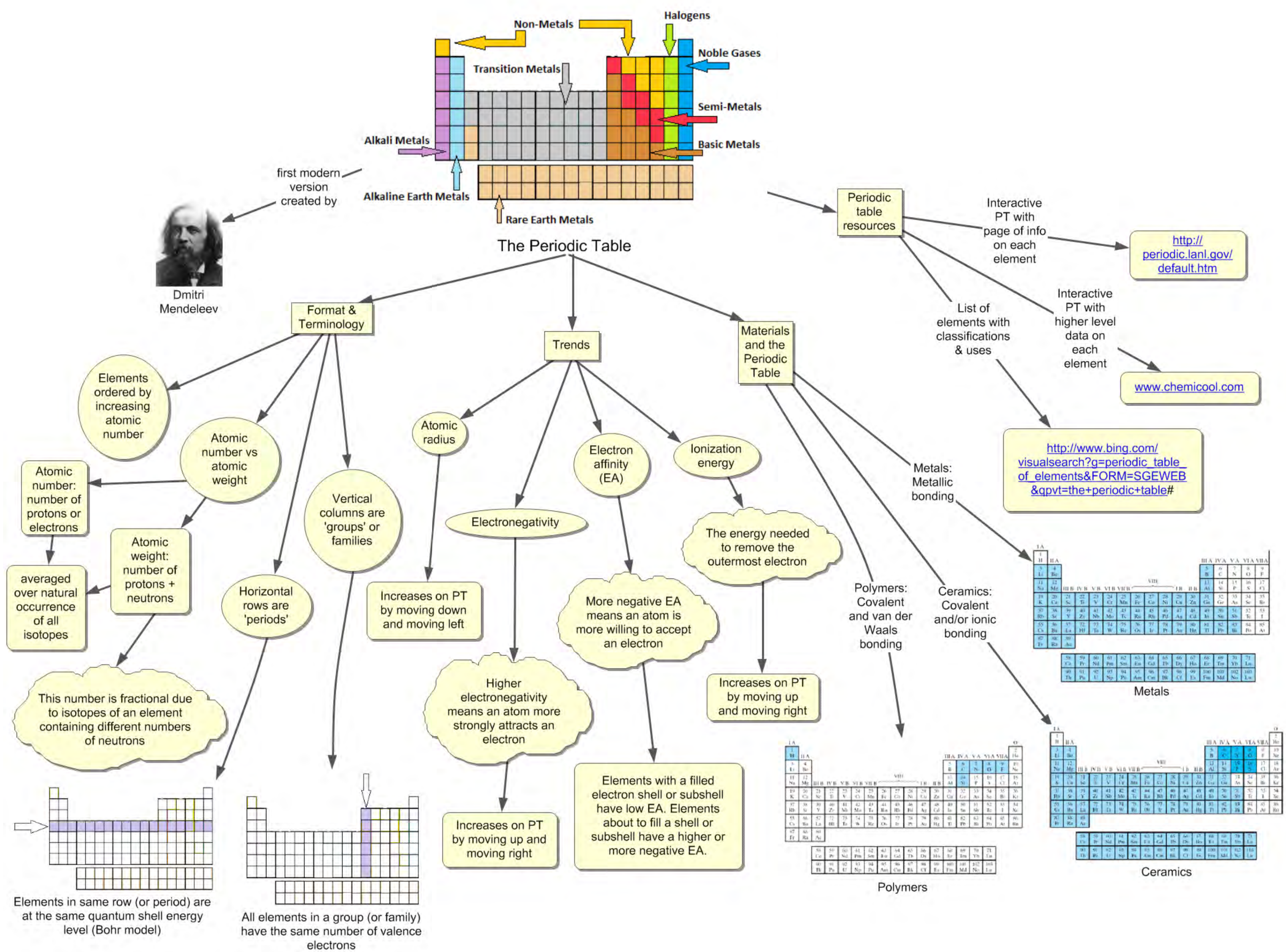
Survey of Elements

- **Most elements:** Outer valence shell not filled - not stable.

Element	Atomic #	Electron configuration	
Hydrogen	1	$1s^1$	
Helium	2	$1s^2$	(stable)
Lithium	3	$1s^2 2s^1$	
Beryllium	4	$1s^2 2s^2$	
Boron	5	$1s^2 2s^2 2p^1$	
Carbon	6	$1s^2 2s^2 2p^2$	
...		...	
Neon	10	$1s^2 2s^2 2p^6$	(stable)
Sodium	11	$1s^2 2s^2 2p^6 3s^1$	
Magnesium	12	$1s^2 2s^2 2p^6 3s^2$	
Aluminum	13	$1s^2 2s^2 2p^6 3s^2 3p^1$	
...		...	
Argon	18	$1s^2 2s^2 2p^6 3s^2 3p^6$	(stable)
...	...	...	
Krypton	36	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$	(stable)

Adapted from Table 2.2, *Callister & Rethwisch 8e.*

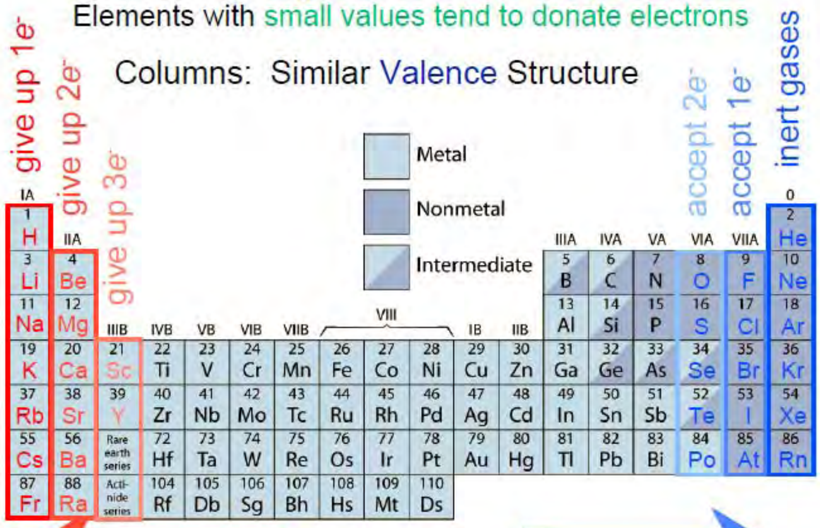
- Why? Valence shell stabilized by e^- transfer (ionic bond) or sharing (covalent bond) or by delocalization (metallic bond)


The Periodic Table
Non-Metals
Halogens
Noble Gases
Transition Metals
Semi-Metals
Basic Metals
Alkali Metals
Alkaline Earth Metals
Rare Earth Metals
first modern version created by
Dmitri Mendeleev
Periodic table resources
Interactive PT with page of info on each element
http://periodic.lanl.gov/default.htm
Interactive PT with higher level data on each element
www.chemicool.com
List of elements with classifications & uses
http://www.bing.com/visualsearch?g=periodic_table_of_elements&FORM=SGEWEB&qpvt=the+periodic+table#
Format & Terminology
Elements ordered by increasing atomic number
Atomic number vs atomic weight
Atomic number: number of protons or electrons
Atomic weight: number of protons + neutrons
averaged over natural occurrence of all isotopes
This number is fractional due to isotopes of an element containing different numbers of neutrons
Horizontal rows are 'periods'
Vertical columns are 'groups' or families
Elements in same row (or period) are at the same quantum shell energy level (Bohr model)
All elements in a group (or family) have the same number of valence electrons
Trends
Atomic radius
Increases on PT by moving down and moving left
Electronegativity
Higher electronegativity means an atom more strongly attracts an electron
Increases on PT by moving up and moving right
Electron affinity (EA)
More negative EA means an atom is more willing to accept an electron
Elements with a filled electron shell or subshell have low EA. Elements about to fill a shell or subshell have a higher or more negative EA.
Ionization energy
The energy needed to remove the outermost electron
Increases on PT by moving up and moving right
Materials and the Periodic Table
Metals: Metallic bonding
Metals
Ceramics: Covalent and/or ionic bonding
Ceramics
Polymers: Covalent and van der Waals bonding
Polymers

The Periodic Table and Electronegativity

Electronegativity ranges from 0.7 to 4.0,
Elements with large values tend to accept electrons
Elements with small values tend to donate electrons

Columns: Similar Valence Structure



Adapted from Fig. 2.6, *Callister & Rethwisch 8e.*

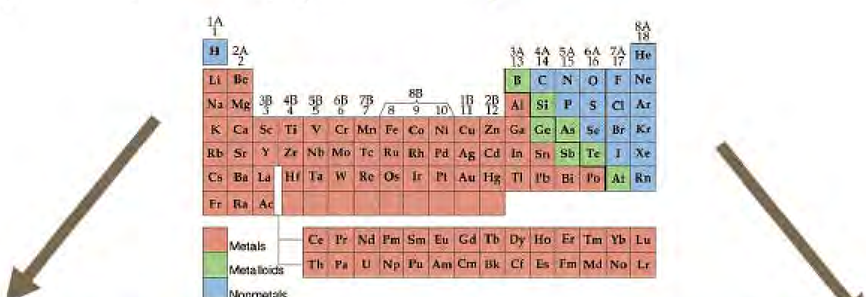
Electropositive elements:
Readily give up electrons
to become + ions.

Electronegative elements:
Readily acquire electrons
to become - ions.

Chapter 2 - 7

How Does Materials Science Differ From Chemistry? - CLIC

- **Goal of science** - Understand nature and be able to model its phenomena
- **Goal of engineering** - Apply science and math to design and create new components, devices, systems and processes to benefit society



Chemists use Periodic Table to Understand
- Bonding
- Chemical reactions
- Thermochemistry
- Solutions

Engineers use Periodic Table to Understand:
- Bond strength & mechanical properties
- Electronic structure & electrical properties
- Crystal structure, defects, grain structure
- Solubility, phase diagrams - microstructure
- Diffusivity
- Processing of metals, polymers, ceramic

Periodic Table Types of Materials - CLIC

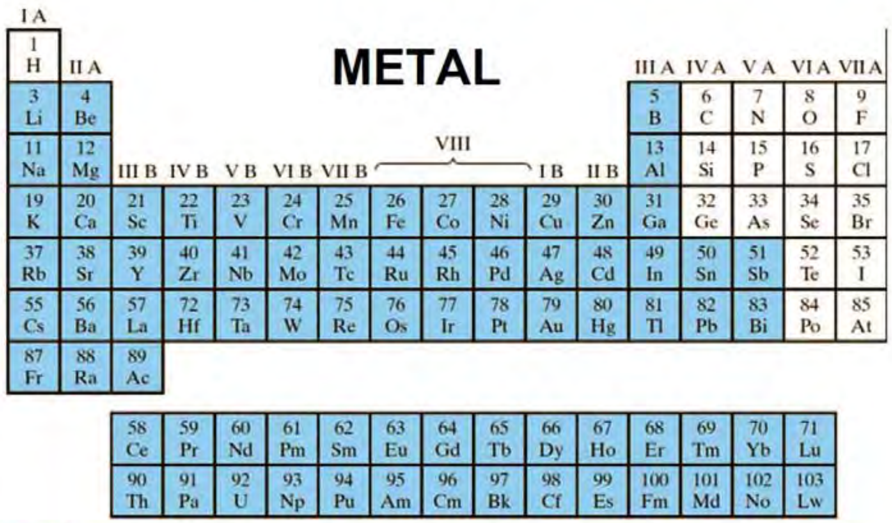


Figure 1-3 *Periodic table of the elements with those elements that are inherently metallic in nature in color.*

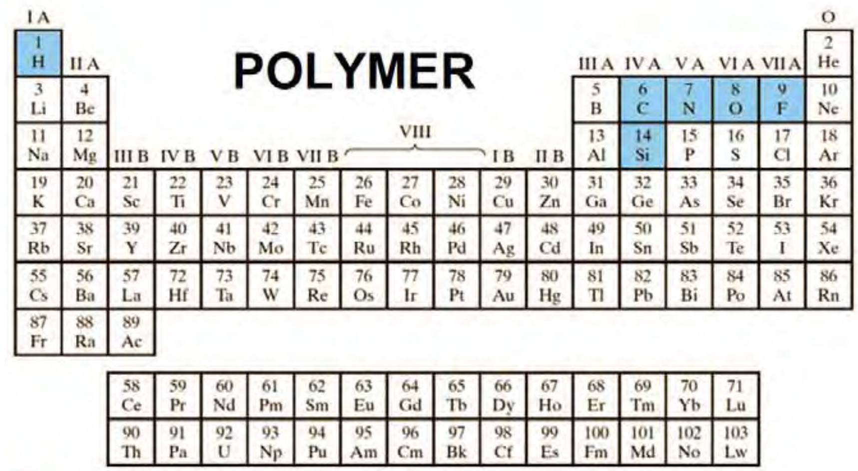


Figure 1-12 *Periodic table with the elements associated with commercial polymers in color.*

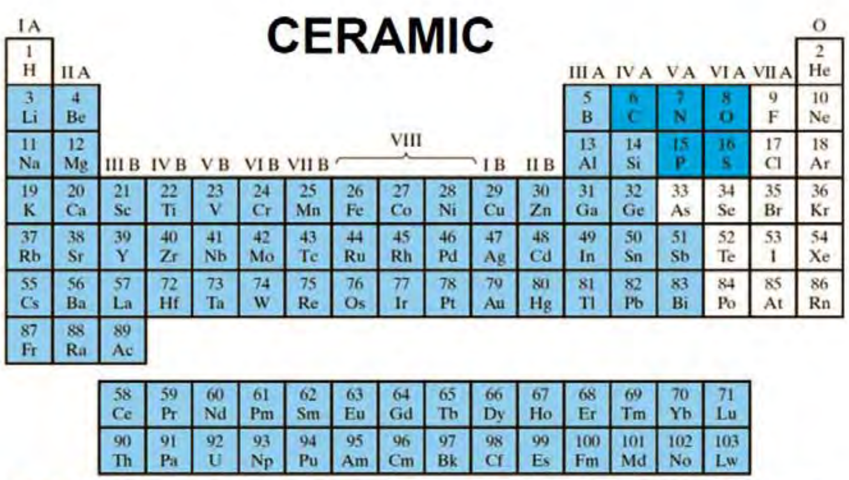


Figure 1-5 *Periodic table with ceramic compounds indicated by a combination of one or more metallic elements (in light color) with one or more nonmetallic elements (in dark color). Note that elements silicon (Si) and germanium (Ge) are included with the metals in this figure, but were not in Figure 1–3. This is because, in elemental form, Si and Ge behave as semiconductors (Figure 1–16). Elemental tin (Sn) can be either a metal or a semiconductor, depending on its crystalline structure.*

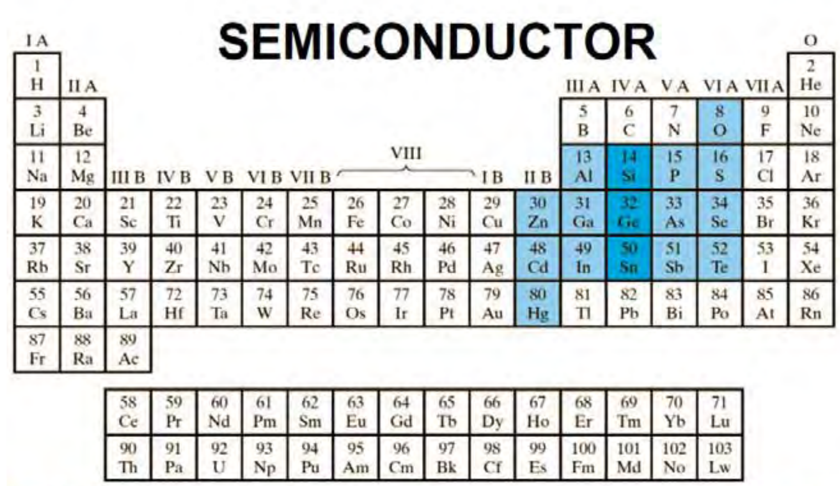
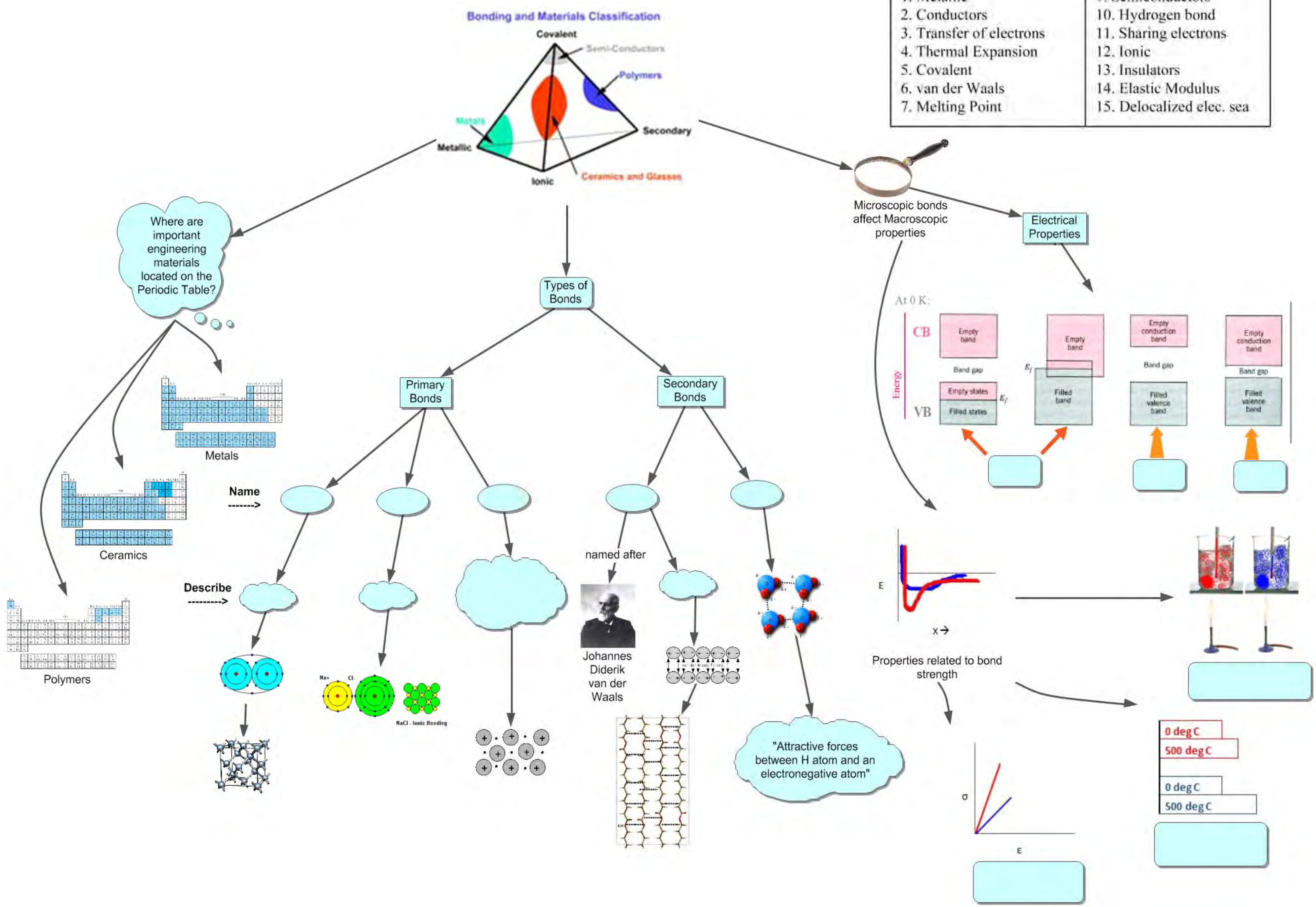
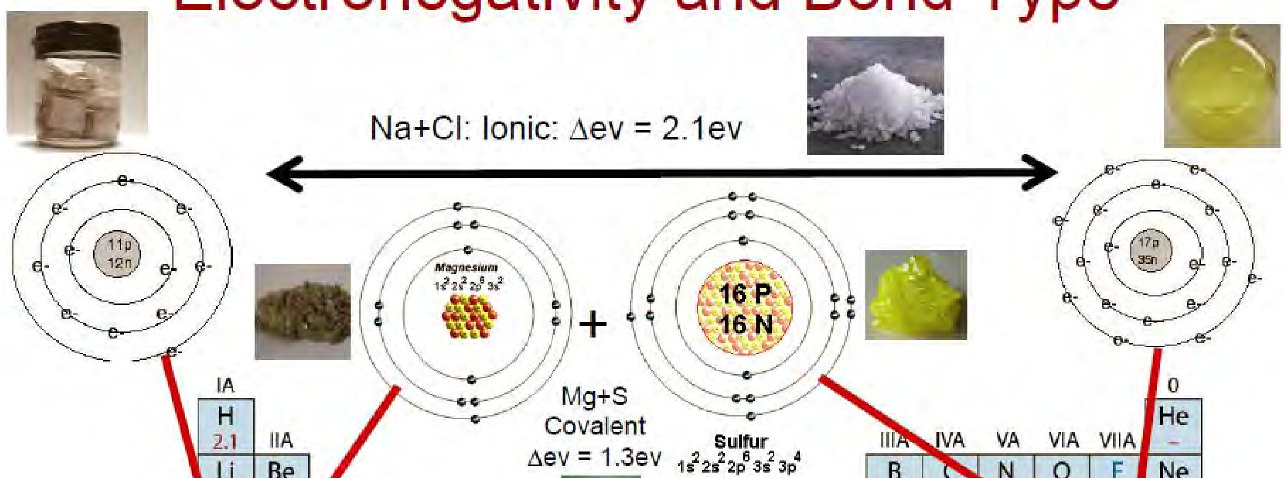


Figure 1-16 *Periodic table with the elemental semiconductors in dark color and those elements that form semiconducting compounds in light color. The semiconducting compounds are composed of pairs of elements fror columns III and V (e.g., GaAs) or from columns II and VI (e.g., CdS).*

Bonding Word Bank	
1. Metallic	8. Dipole forces
2. Conductors	9. Semiconductors
3. Transfer of electrons	10. Hydrogen bond
4. Thermal Expansion	11. Sharing electrons
5. Covalent	12. Ionic
6. van der Waals	13. Insulators
7. Melting Point	14. Elastic Modulus
	15. Delocalized elec. sea



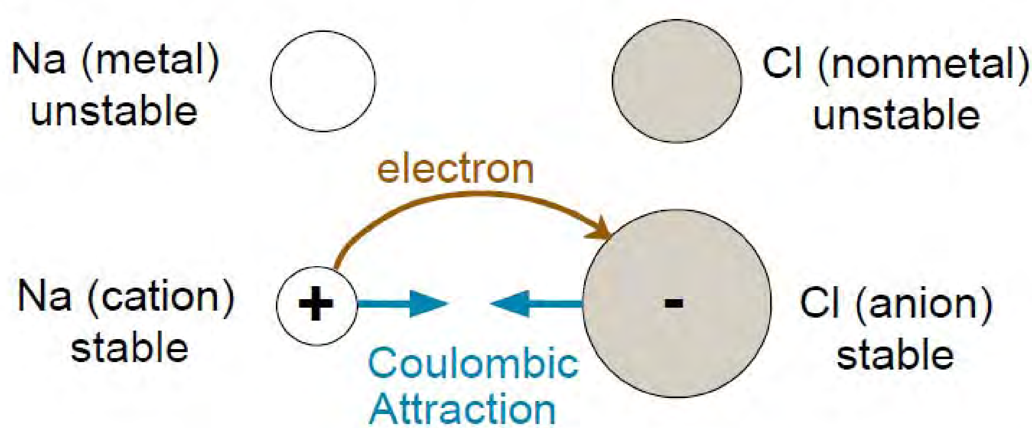
Electronegativity and Bond Type



IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII			IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
H 2.1																	He –
Li 1.0	Be 1.5											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne –
Na 0.9	Mg 1.2											Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0	Ar –
K 0.8	Ca 1.0	Sc 1.3	Ti 1.5	V 1.6	Cr 1.6	Mn 1.5	Fe 1.8	Co 1.8	Ni 1.8	Cu 1.9	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr –
Rb 0.8	Sr 1.0	Y 1.2	Zr 1.4	Nb 1.6	Mo 1.8	Tc 1.9	Ru 2.2	Rh 2.2	Pd 2.2	Ag 1.9	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe –
Cs 0.7	Ba 0.9	La–Lu 1.1–1.2	Hf 1.3	Ta 1.5	W 1.7	Re 1.9	Os 2.2	Ir 2.2	Pt 2.2	Au 2.4	Hg 1.9	Tl 1.8	Pb 1.8	Bi 1.9	Po 2.0	At 2.2	Rn –
Fr 0.7	Ra 0.9	Ac–No 1.1–1.7															

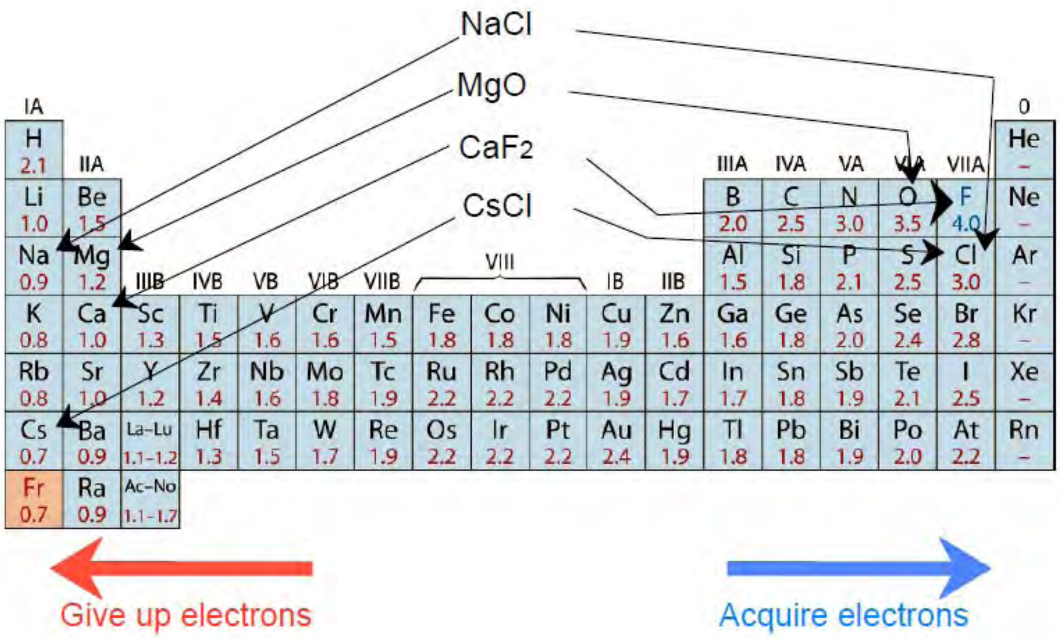
Primary Bonding - Ionic Bonding

- Occurs between metal (+) and nonmetal (-) ions.
- Mechanism is by electron transfer.
- Large difference in electronegativity (Δev ≥ 1.7ev).
- Example: NaCl (Na = 0.9 ev; Cl = 3.0 ev; Δev = 2.1 ev)



Examples: Ionic Bonding

Ceramics may be mainly ionic or mainly covalent or may have mixed bonding.
For simplicity: if Δev > 1.7ev bond is ionic; if Δev < 1.7ev bond is covalent

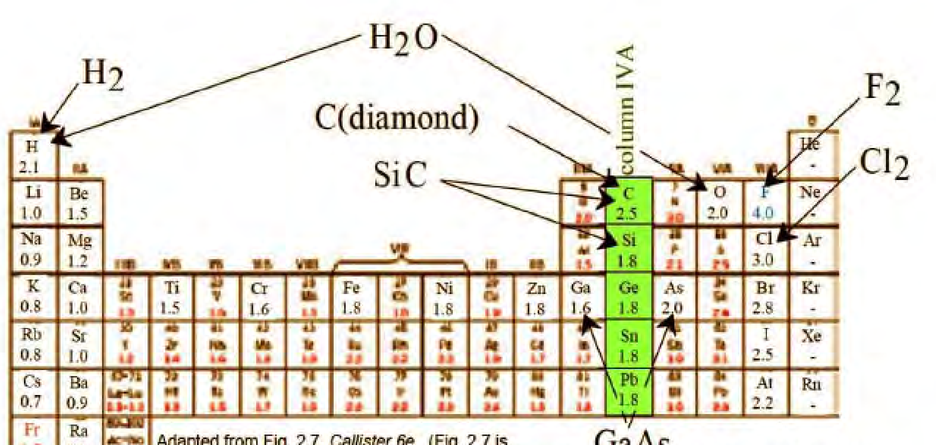


	Δev
NaCl	2.1
MgO	1.8
CaF_2	3.0
CsCl	2.3

Primary Bonding - Covalent Bonding

Ceramics may be mainly ionic or mainly covalent or may have mixed bonding.

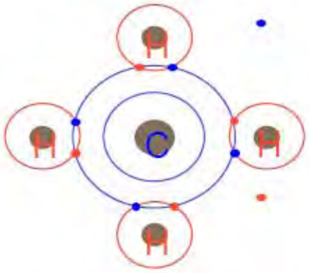
For simplicity: if Δev > 1.7ev bond is ionic; if Δev < 1.7ev bond is covalent



Adapted from Fig. 2.7, *Callister 6e*. (Fig. 2.7 is adapted from Linus Pauling, *The Nature of the Chemical Bond*, 3rd edition, Copyright 1939 and 1940, 3rd edition. Copyright 1960 by Cornell University.

	Δev
H20	1.4
SiC	0.7
GaS	0.4
GaN	1.4

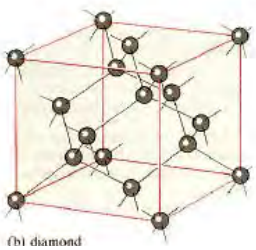
0-D, 1-D, 3-D Covalently Bonded Materials



Methane – 0-D Covalently Bond Gas

Polyethylene $[CH_2]_n$ 1-D Covalently Bond Polymer

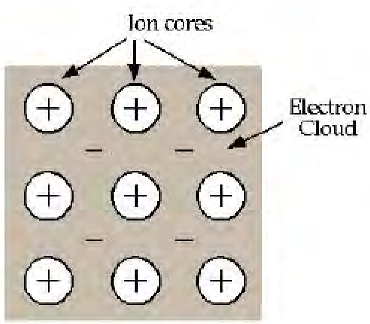
(a) $[CH_2]_n$



(b) diamond

Diamond – 3-D Covalently Bonded Ceramic

Metallic Bonding



Metals share so-called *delocalized* electrons, or a "sea of electron" (electron-glue).

Metallic bonds are moderately strong

Bonding energies (E_0): range:

850 kJ/mol (8.8 eV/atom) for W.

406 kJ/mol (8.8 eV/atom) for Fe.

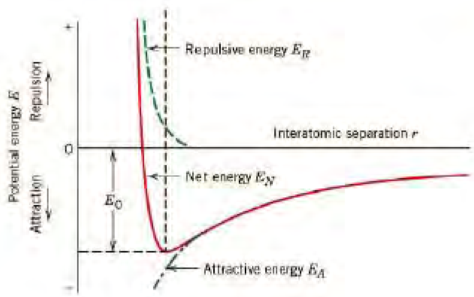
324 kJ/mol (8.8 eV/atom) for Al

Melting temperatures (T_{melt}~E_0):

3410 C for W.

1493 C for fe

660 C for al



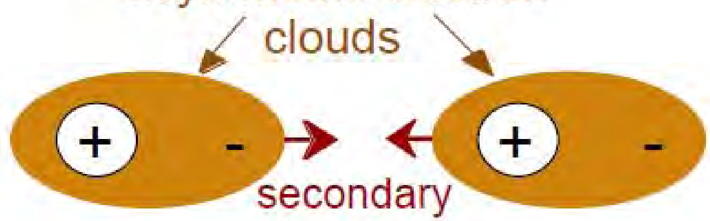
Stronger bonds lead to higher melting temperature:

atomic scale bonding ⇒ macroscale property.

Secondary Bonding

Arises from interaction between dipoles

- Fluctuating or temporary dipoles



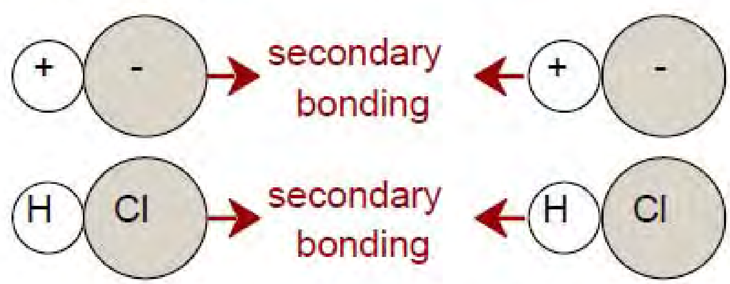
Example: Polymers

secondary bonding

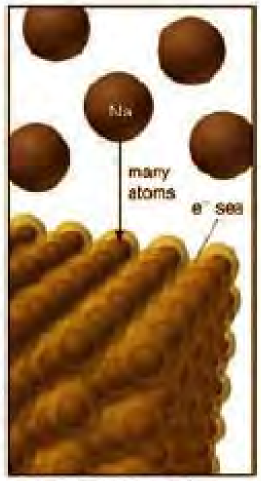
- Permanent dipoles-molecule induced

-general case:

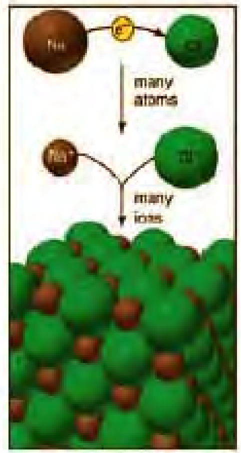
-ex: liquid HCl



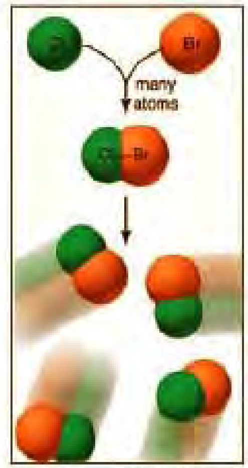
Bonding Types in Materials of Everyday Items : Metals, Ceramics & Polymers



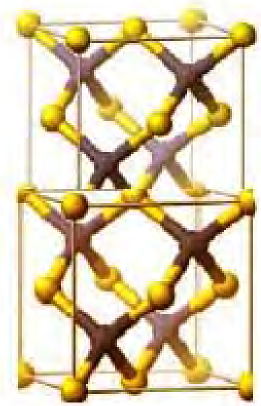
C Metallic bonding

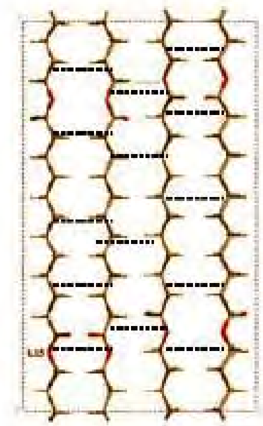


A Ionic bonding



B Covalent bonding





Metallic Bonding	Ionic Bonding	Covalent Molecule Bonding	Covalent Molecular Solid Bonding	Covalent Intramolecular + van der Waals Intermolecular Bonding
Tm = 700C	Tm = 900C	Tm = -50C	Tm = 3100C	Tm = 130C

10

Summary: Bonding

Type	Bond Energy	Comments
Ionic	Generally highest	Nondirectional (ceramics)
Covalent	Moderately high	Directional (3-D semiconductors, 3-D ceramics, 1-D polymer chains)
Metallic	Somewhat high	Nondirectional (metals)
Secondary	Small	Directional inter-chain (between polymer chains) inter-molecular

Materials Selection Activity - CLIC

Choose the most likely property, material, bonding, and process for these motorcycle items

	property	material	bonding	processing
i) motorcycle fender	______	________	________	________
ii) headlight lens	______	________	________	________
iii) motorcycle seat	______	________	________	________
iv) headlight filament	______	________	________	________
v) spark plug insulator	______	________	________	________

PROPERTIES	MATERIAL	BONDING	PROCESSING
I. transparent and impact resistant	1. tungsten - W	A. covalent	a. vacuum warm forming
II. stiff and ductile	2. polyvinylchloride	B. ionic	b. calendaring
III. flexible and tough	3. polycarbonate	C. metallic	c. wire drawing
IV thermal & electrical resistance	4. aluminum oxide (Al2O3)	D. van der Waals	d. metal stamping
V. thermally stable electrical conductor	5. steel – Fe + .2%C	E. covalent & van der Waals	e. sintering

Activity Instructions & Processing Definitions - CLIC

Activity Information

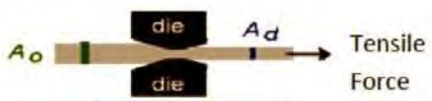
Learning Objectives and Outcomes

Learning Objective: Demonstrate the relationships between properties of a material and its atomic bonding and its and processing method and its performance application. These are some of the most important factors that come into play in the materials selection activity of the design process.
Learning Outcome: After completing this worksheet you will be able to look at an object and its important properties and identify the type of mat atomic bonding, and processing method used to make that object.

Directions:
1. Use all the answers from the Properties, Material, Bonding, and Processing boxes to fill in each column with one answer from the corresponding answers from each box should be used at least once, except for the Bonding Box where each choice which may be used more than once or not at al
2. Household Item -

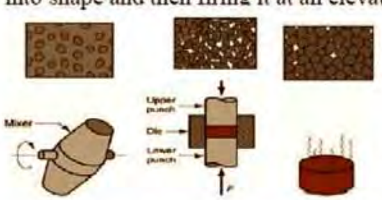
Materials Processing Methods

Drawing-Pulling a material through a reducing die with a tensile strength force applied to the emerging material.



vacuum thermoforming- softened thermoplastic sheet is placed on top of a mold and a vacuum pulls the sheet tightly over the mold allowing it to harden into the shape of the mold.

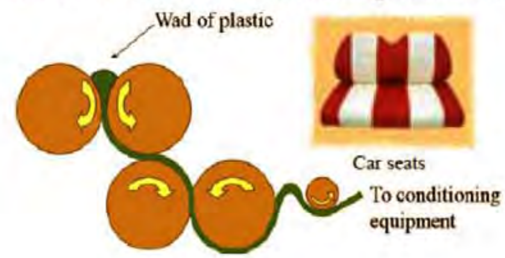
Sintering- Pressing diffused powdered aggregate into shape and then firing it at an elevated temperature.



a)Blending b)Compressing c)Sintering

metal sheet stamping- cold working a metal sheet where a stamping press pushes a die into the metal creating a complex shape.

calendar rolling- molten plastic is fed through a set of rollers that flatten the plastic into sheets

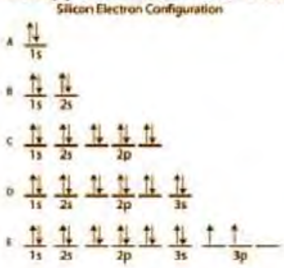


Visual Glossary of Bonding Terminology - 1 - CLIC

Visual Glossary of Bonding Terminology

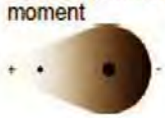
Mole Quantity of a substance corresponding to 6.023×10^{23} atoms or molecules

Pauli Exclusion Principle- Either one or two electrons with different spins can occupy an electron state at one time



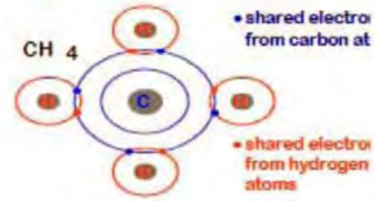
Periodic Table- The arrangement of elements in rows of increasing atomic number and columns of similar properties

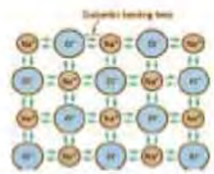
Polar Molecule- A molecule that has a nonzero permanent or temporary dipole moment



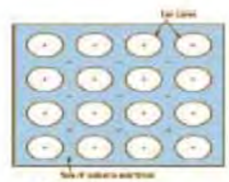
Primary Bonding- Ionic, covalent, and metallic bonds whose bonding energies are large and have strong interatomic bonds

Covalent





Ionic



Metallic

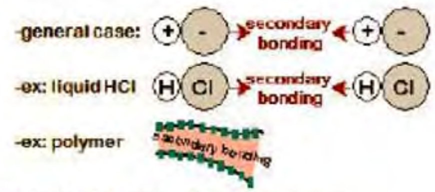
Quantum Mechanics- A subtopic of physics that deals with atomic systems

Quantum Numbers- Four numbers that represent an electron's state in an atom or ion:

- **n = Principal Quantum Number** and it corresponds to the electron's Energy Level
- ***l*** **= Azimuthal Quantum Number,** or orbital quantum number that identifies the Subenergy Level and Shape or Type of the Orbital l =0...n-1 s (l=0), p (l=1), d (l=2), f (l=3)
- ***m*** **= Magnetic Quantum Number,** it defines the orientation of the orbital in space; $m = -l \ldots 0 \ldots +l$
- ***s*** **= Spin Quantum Number** gives angular momentum of electron, referring to direction of spin. Electrons are found with only two spin directions opposite of one another, designated clockwise or counterclockwise as "+½" and "-½".

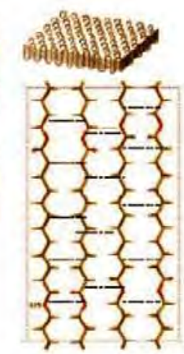
Quantum Number Tutorial - http://www.drrickmoleski.com/QuantumNumberTutorial-Quiz.pdf

Secondary Bonding- Van de Waals and Hydrogen bonding whose bonding energies and interatomic strength are weaker than the primary bonds



Valence Electron- Electrons in the outermost energy level that participate in interatomic bonding

Van der Waals Bond- A secondary interatomic bond between neighboring atomic or molecular dipoles (permanent or temporary).
For a **polymer** it represents the weak bonding between adjacent chains of covalently bonded atoms



Wave Mechanical Model- Atomic model where electrons are wave-like and have shapes determined by solution of Schrodinger's wave equation

Visual Glossary of Bonding Terminology - 2 - CLIC

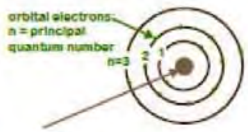
Visual Glossary of Bonding Terminology

Atomic Mass Unit (amu)- Mass of 1 gram / Avagodro's number eg. 1 C atom weighs 12 amu

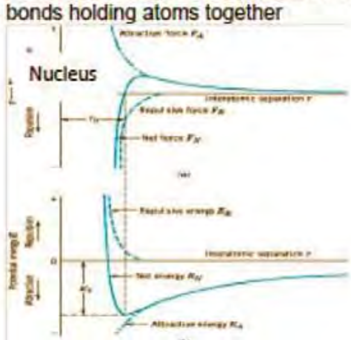
Atomic Number- Number of protons within the nucleus of an atom Carbon= 6

Atomic Weight- The average of all isotope atoms' weights of a single element

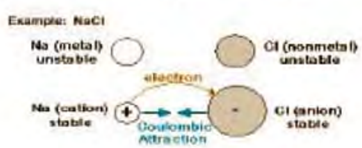
Bohr Atomic Model- Atomic model where electrons revolve around the nucleus in orbitals



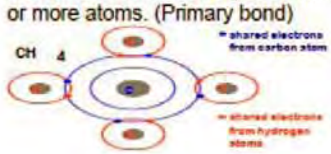
Bonding Energy- Energy required to break bonds holding atoms together



Coulombic Force- Attractive or repulsive force between two partially charged particles; force is attractive when the two particles are of opposite charges.



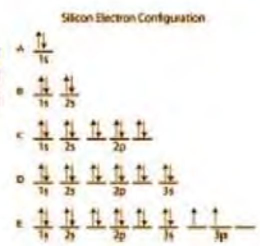
Covalent Bond- Sharing of electrons between two or more atoms. (Primary bond)



Dipole (Permanent)- slightly stronger attraction or repulsion force that temporary dipole between two polar molecules

Dipole (Temporary)- momentary attraction or repulsion between two polar molecules

Electron Configuration - Sequencre of filling in orbitals with electrons in a specific way



Electronegative Atom likely to accept electron

Electropositive- Atom likely to donate electron

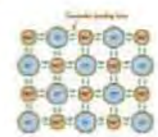
Electropositive Electronegative

Electron State- The energy level that an electron is in; there are four levels given by the four quantum numbers

Ground State- The lowest and most stable energy state from which an electron can then become excited

Hydrogen Bond - Strongest secondary bond between hydrogen atom (or molecule containing hydrogen) with an electron from adjacent atom

Ionic Bond- The transfer of electrons from two oppositely charged ions



Isotope- Atoms of the same element that have different numbers of neutrons and therefore different atomic mass

Metallic Bond- Mutual sharing of delocalized valence electrons by all atoms in a metal ("sea of electrons")

Homework #2 – Problem 1

Materials Science of Household Components Activity

Object	Important Properties	Family/ Material	**Atomic Bonding	Processing Method
Plumbing Pipe 	______	______	______	______
Trash Can 	______	______	______	______
Window Pane 	______	______	______	______
Knife Sharpener 	______	______	______	______
Garbage Bag 	______	______	______	______
Electrical Wiring 	______	______	______	______
Your Own Household Item:______	______	______	______	______

Properties	Family/ Material	Bonding	Processing
I. Transparent II. Water resistant & Tough III. Very Flexible IV. Very Hard V. Good Electrical Conductor VI. Stiff & Impact Resistant	1. Metal/ Copper (Cu) 2. Polymer/ Polyvinylchloride (PVC) 3. Polymer/ Polyethylene (PE) 4. Ceramic/ Silicon Carbide (SiC) 5. Metal/ Steel (Fe+ .2%C) 6. Ceramic/ Silicon Dioxide (SiO_2)	A. Covalent B. Ionic C. Metallic D. Van Der Waals E. Covalent & Van Der Waals **Bonding types may be used more than once	a. Film Blowing b. Extrusion c. Drawing d. Sheet Forming e. Sintering f. Floating on Molten Tin

Homework #2 – Problem 1 Instructions

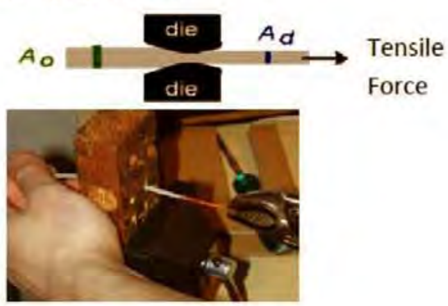
Learning Objectives and Outcomes

Learning Objective: Demonstrate the relationships between properties of a material and its atomic bonding and its and processing method and its performance application. These are some of the most important factors that come into play in the materials selection activity of the design process
Learning Outcome: After completing this worksheet you will be able to look at an object and its important properties and identify the type of mat atomic bonding, and processing method used to make that object.

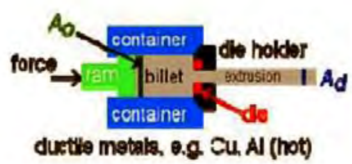
Directions:
1. Use all the answers from the Properties, Material, Bonding, and Processing boxes to fill in each column with one answer from the correspondin answers from each box should be used at least once, except for the Bonding Box where each choice which may be used more than once or not at a
2. Household Item -

Materials Processing Methods

Drawing-Pulling a material through a reducing die with a tensile strength force applied to the emerging material.

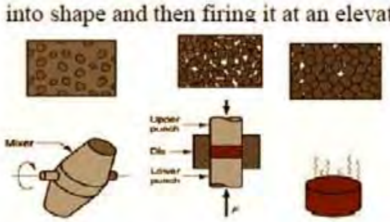


Extrusion- Pushing a material through a die orifice with compressive force such that the material comes out with a reduced cross section in the shape of the die opening.



Film Blowing- Blowing air into a hot tube that pushes the material out.

Sintering- Pressing diffused powdered aggregate into shape and then firing it at an elevated temperature.



a)Blending **b)Compressing** **c)Sintering**

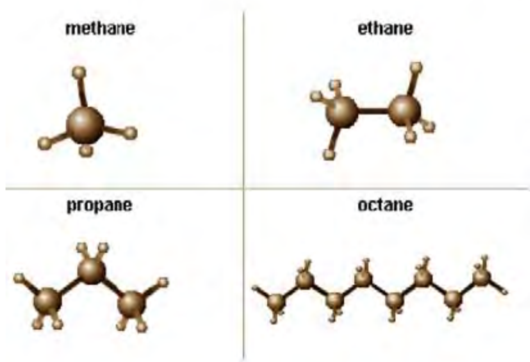
Sheet Forming- Deforming a material to make flat thin sheets that can be cut or pressed into desired shape.

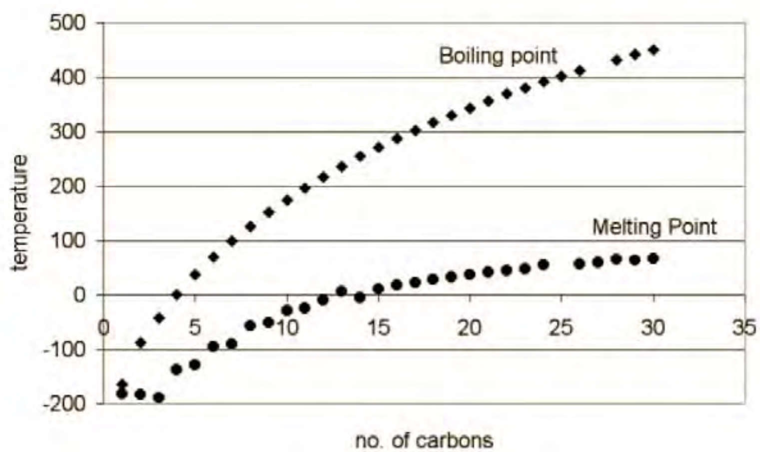
Float on Molten Tin- The material that is floating on the molten tin is able to be in a liquid state and maintain uniform thickness.

Homework #2 – Problems 2 & 3

2. Flash drives and other semiconductor devices are often built from Group IV elements that are 3-D covalently bonded solids like Si. Semiconductor conductivity is controlled by adding very small amounts of impurities called dopants. Si conductivity can be increased by a factor of 10^5 if 1 weight % of As (Group V impunity increases n-type carriers, electrons) is added to Si. What is the atomic % that has been added?

3. A polyethylene container has the same composition as a candle long chain paraffins [$n(CH_2) + 2H$] where n equals the number of C atoms. Suggest a reason that describes why the melting point, Tm, increases as the number of C atoms increases as shown in the graph below.





Points of Reflection on Today's Class

Letter + 4 digit number ______________ F

Class Topic: ________________________Date: ________________

Briefly describe your insights on the following points from ***today's*** class.

- **Point of Interest**: Describe what you found most interesting in this class

- **Muddiest Point:** Describe what was confusing or needed more detail?

- **Learning Point**: Describe what you learned about how you learn?