AC 2012-4072: DEVELOPMENT OF A CRYSTAL SPATIAL VISUALIZATION SURVEY FOR INTRODUCTORY MATERIALS CLASSES

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Development of a Crystal Spatial Visualization Survey for Introductory Materials Classes

Abstract

Spatial visualization ability is a key skill for engineering students and practitioners in many engineering disciplines. In material science and engineering, it is a critical skill for understanding and modeling relationships between materials structure at the microscopic structural level and the macroscopic property level. An important microstructural feature of materials is their crystal structure, which plays an important role in determining some of a material's macroscopic properties, such as yield and tensile strength. As such, it is quite useful to be able to visualize two-dimensional projections of atom locations on different planes for a given crystal structure for which deformation mechanisms in metals can be described with simple sketches of planar atomic packing diagrams. However, this critical spatial visualization skill is also difficult for some students to learn, understand, and use. Thus, the research question for this paper is, "What are students' misconceptions and prior knowledge associated with drawing 2-D images of hard sphere atom models of planar packing for different metal structures and how can they be characterized". Answering this question should provide knowledge and insight about student learning issues with potential for developing more effective pedagogy for teaching and learning about crystallography of materials' structures. To uncover prior knowledge and misconceptions, students from 4 semesters of materials classes were given worksheets prior to instruction and asked to sketch planar packing images of (100), (110), and (111) planes for simple cubic, face centered cubic, and body centered cubic crystal structures. The sketched images were analyzed and revealed a number of characteristic misconceptions that included: missing atoms, extra atoms, misplaced atoms, non-touching atoms, and touching atoms. Other misconceptions were also present but with much lower frequencies of occurrence. After instruction, the frequency of misconceptions was much reduced and the most frequent types of misconceptions had also changed. From these results, a 10-item, multiple choice, Crystal Spatial Visualization Survey was created. The survey was given as a pre-post test during the Spring 2012 term of a materials course and reproduced reasonably well the results of the earlier hand-sketched results of a similar visualization test. Additional testing with more students in other settings will be needed to verify the reliability of the Crystal Spatial Visualization Survey. As such, it is a preliminary instrument that has good potential as a crystal structure pretest for being a quick and reliable method to test students baseline ability of visualizing 2-D projections as well as a post-test to measure the effectiveness of instruction on understanding and visualization ability of students for crystal structures. Issues about student understanding and instruction are discussed in the paper.

Introduction

Over the past two decades new approaches for more effective teaching and learning in STEM (science, technology, engineering, and math) have been developed. The major principles are described in the book, *How People Learn*[1]. 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 that 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. In focusing on the first principle, awareness of prior knowledge, it is critical to have an approach to reveal students' prior knowledge and understanding of a given topic in order to develop improved strategies for teaching that topic. In introductory materials science and engineering courses, one of the key topics to understanding the basis for the properties of materials is the topic of crystal structures. An important aspect of instruction on crystal structures is for students to develop an ability to visualize two-dimensional projections of atom locations on different planes for a given crystal structure. This is so students will be able to understand and describe relationships between a material's crystal structure and its macroscopic properties such as deformation mechanisms and the role they play in determining the yield and tensile strength of a material. As such, it would be useful to have a simple means of characterizing a student's misconceptions and baseline knowledge and understanding of crystal structures as well as the effectiveness of instruction about the topic of crystal structures. Thus, the research question for this paper is, "What are students' misconceptions and prior knowledge associated with drawing hard sphere atom models of planar packing for different metal structures and how can they be characterized". Answering this question should provide knowledge for developing more effective pedagogy for teaching and learning about crystallography of materials' structures.

Background

Spatial Visualization

There is a strong relationship of spatial ability and success in science and engineering which is well documented[2-4]. In engineering, Hsi, Linn, and Bell found that spatial ability predicted course grades and that strong spatial skills were necessary for success on course exams[5]. In addition, instruction in spatial strategies improved problem solving and contributed to confidence in engineering, especially for women. Peters, Chisholm, and Laeng also found that initial gender differences favoring males were reduced with practice[6]. No gender differences were found for performance in the associated course. Piburn, et. al. found a relationship between visualization and success in geology. Moreover, they found that spatial visualization scores were as strong a predictor of success on a geology test as was prior knowledge[7]. They also found that practice on spatial tasks eliminated gender differences. Additionally, Sorby & Baartmans found that a course developed specifically to strengthen visualization skills of engineering students led to greater persistence in engineering, higher GPAs upon graduation, and better spatial skills for students taking the course than for students who did not [8]. Thus, it can be seen that spatial visualization is an important factor in learning engineering that may be influenced by group dynamics and may be related to problem solving, retention, and GPA. The work in this research may also have the potential to test similar impacts on student affective factors in materials courses.

Assessment of Topical Knowledge with Pre-Post Topical Quizzes

Constructivist pedagogy is now being used teach some introductory material classes[9]. Students' conceptual baseline and conceptual gain have been assessed across a semester with the Materials

Concept Inventory (MCI) which is a 30-item, multiple-choice, pre-post course instrument[10-12]. This summative instrument measures a student's baseline conceptual knowledge of a subject at the semester beginning and conceptual gain after administration at semester end. There are two questions on the MCI related to crystal structures. Students are asked to determine for a cube how many faces, edges, and body diagonals there are in a cube. Surprisingly, students at the beginning of the course only get all items correct at about 60% to 70% of the time. By the end of the course it improves to 75% to 85%, but never reaches a level of 90% and higher. This demonstrates the difficulty that students have with spatial visual thinking. To determine in more detail the issues students have about crystal geometry a Pre-Post Topic Quiz was developed for crystal structures that was essentially an activity in which students sketched images of atoms on different planes as deduced from looking at 2-D images of cubic crystal structures. The results of these earlier tests is discussed later. The crystal structure sketching activities were pre-post topic tests used to inform instruction and measure conceptual change. A pre-topic test measures baseline conceptual knowledge and reveals misconceptions and knowledge gaps present. After instruction, the same test measures conceptual gain and remaining misconceptions which are classified as robust misconceptions. These topic tests assess with finer granularity and greater depth a student's conceptual understanding of a given topic, as well as revealing students' misconceptions and knowledge gaps for that topic. These are summative across a given topic but, in a sense, they are really formative assessments because they assess a small segment of content within the course. Daily activities of this type are formative assessments that are used as immediate feedback tools to inform the instructor of student understanding of the current content. Formative feedback at this stage of instruction has been shown to be very effective and can be carried out in real time and crystal structure assessments may be expanded into this area.

Methods

Development of the Crystal Spatial Visualization Survey

A paper and pencil assessment was created to test students crystal structure spatial visualization skills and then administered to students before the topic was presented. This has been administered for the past 4 semesters to 30 to 40 students per class. The types and frequencies of misconceptions were derived from looking at the frequencies of the misconceptions in the quizzes. A typical pre-test is shown below in Figure 1. Figures 2 and 3 show new multiple choice question sets for BCC and FCC crystal structures with the intersecting planes being (100), (110), and (111). For a given question 4 of 5 multiple-choice answers were generated from misconceptions from pre- and post topic concept quizzes. In general it was found that there were six main types of misconceptions. They were: missing atoms; extra atoms; displaced atoms; spaces between atoms when there should be none; atoms touching when they shouldn't; and different sized atoms. The 10-item test is included in Appendix A and could be used directly.

A few examples of matching answers between the sketched images and the new survey will be given. In the sketch, the FCC (100) is correct and matches test answer 1B. The incorrect answer for FCC (110) matches test misconception 2D. The sketch FCC (111) matches misconception test answer 3E. The sketch BCC (100) matches correct test answer 4E. The sketch BCC (110) correct answer matches answer 5D. Finally sketch BCC (111) matches the misconception test answer 6B. In the next section the results of the new multiple choice survey will be discussed.

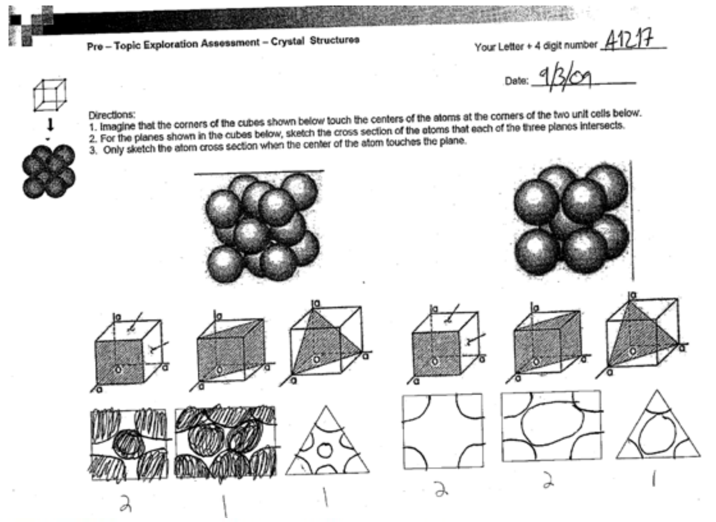

Figure 1 – Student Pre-Topic Concept Quiz for BCC and FCC crystals for the (100), (110), and (111) planes

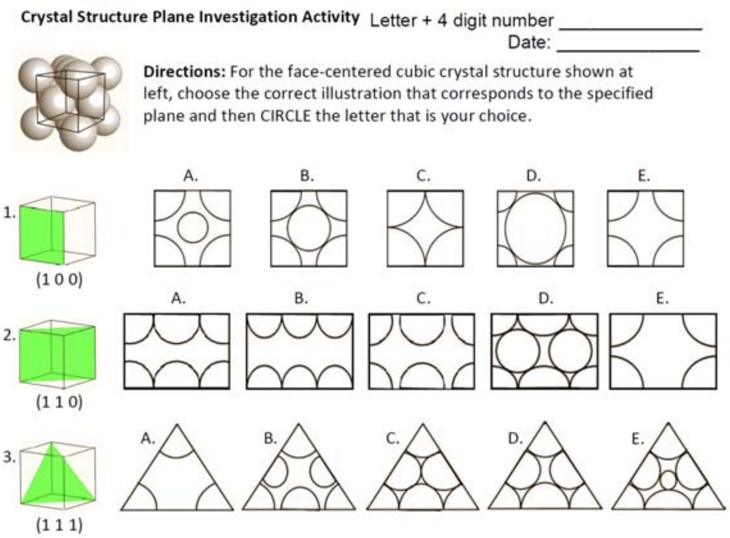

Figure 2 – Pre-Topic Concept Quiz for FCC crystal for the (100), (110), and (111) planes

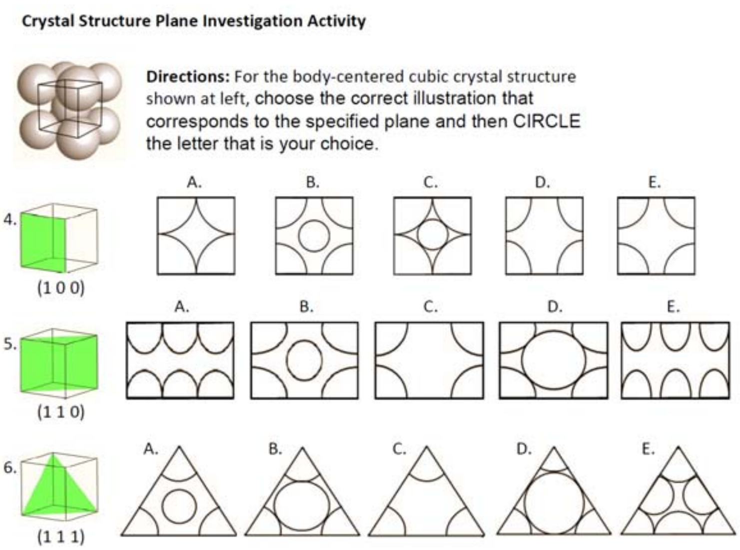

Figure 3 – Pre-Topic Concept Quiz for BCC crystal for the (100), (110), and (111) planes

Results and Discussion

As previously discussed, the types of misconceptions that appear in the student hand-drawn test in Figure 1 were replicated in the new Crystal Spatial Visualization Survey (CSVS) in Figures 2 and 3 for the FCC and BCC crystal structures for the (100), (110), and (111) planes. In February 2012, during the Spring 2012 term, 26 students took both pretest before instruction and posttest after instruction. The results of the student sketches, will now be extended to the results of the Crystal Visualization Survey in Figure 4 to show that multiple choice answers do, in fact, usually represent typical freehand sketched responses. On Figure 4 the capital M stands for Misconception and the capital C stands for Correct answer.

For the FCC (100), 70% of the 26 students chose 1B and got that right, as did the sketching student. The instruction further increased the understanding with a post test score of 95% of the 26 students correct. Conversely for the FCC (110), 70% of the 26 students chose the misconception 2D, as did the sketching student. This frequently chosen misconception of the two extra atoms is probably caused by students who believe that two of the face-centered atoms on the sides of the cube impinge upon the FCC (110) plane. However, after instruction the choice of this misconception drops from 70% to 15% while the correct answer 2A increases from 23% to 75%. Finally, for the FCC (111), the student sketch is represented in the survey by 3B where the atoms were in the correct positions, but they did not touch as they should have. Only 8% of the 26 students selected that choice, while a much higher percentage of students, about 70%, selected the wrong answer because atoms were not touching as shown in 3B. Instead, in the survey, the correct answer of 3C, where all atoms touch in the close-packed planes, was chosen by 47% of the students. The most frequently chosen misconception at 37% was 3D, where just two of the atoms did not touch where they should have. Unfortunately, after instruction, the percentage of the correct answer only increased from 47% to 48%, indicating that there is a need for improvement in instruction regarding atom projections on to the FCC (111) plane.

For the BCC structure, the sketched answer for the BCC(100) was the correct 4E, as was so for 40% of all students. After instruction the correct answer increased to 83%. For the BCC (110) the sketched image was the correct test choice of 5D as was so for 67% of all students. This increased to 95% after instruction. Finally, for the BCC(111) the student sketched the misconception test answer of 6B as did 47% of the students. This answer was incorrect because it included the center atom for the BCC which is a common mistake. This center atom should not be included since the atom center does not lie on the plane. The correct answer of 6C was only chosen by 9% of the students on the pre-test. It is not encouraging to see that the percentage of students choosing the correct answer only rose to 35%. The instruction on crystal planes and structures needs improved pedagogy to address this issue.

Overall, there was generally good registry between the one example of a sketched set of images for 2-D representation of atom positions from different crystal structures on the characteristic (100), (110), and (111) planes. The one drawback with respect to the results of the survey compared to the sketched images was that the survey misconception images did not have as high a frequency of misconceptions in which atoms did not touch one another but should have. It is likely that when students see the correct answer on the test survey, or at least answers that show atoms touching, they prefer those choices.

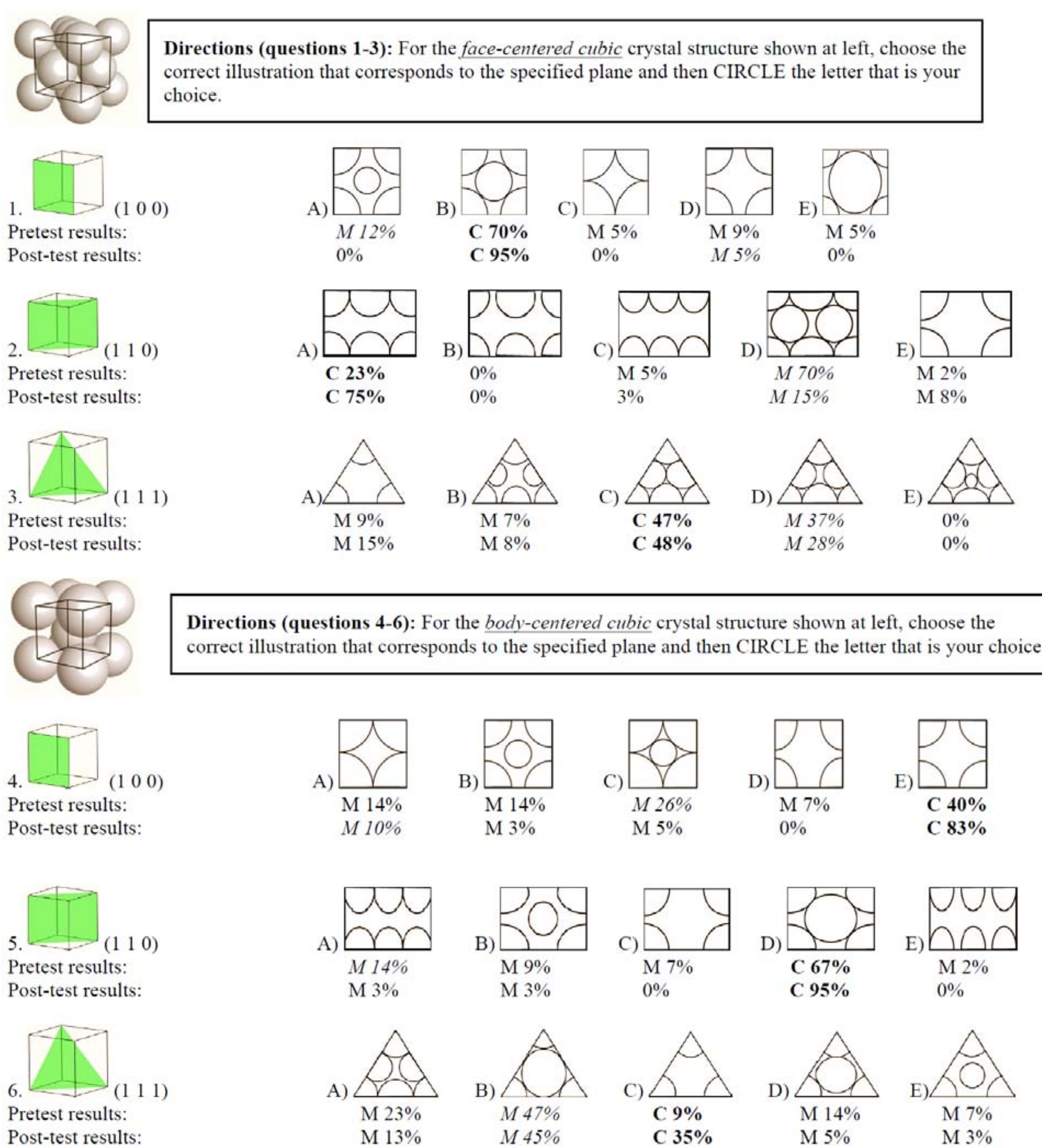

Figure 4. Pre-Post Topic Quiz results for FCC and BCC crystal structures. For any given plane the top value is the % correct pretest and the bottom value is the %correct posttest. The letter M stand for Misconception (for wrong answers) and the C stands for correct.

Summary and Conclusions

A new assessment tool, the Crystal Structure Spatial Visualization Survey, has been created to assess students' crystal spatial visualization skills and understanding. It can be used as a topic pre-test to uncover student misconceptions about crystal structures and planes and also establish a baseline of conceptual knowledge about crystal structures. Given as a post-topic test it can measure conceptual gain which may reflect the effectiveness of instruction crystal structures. In a test of the instrument on 26 students who had received instruction in the topic the average percentage correct increased from 44% correct to 75% correct. More effective instructional methods need to be devised to increase student understanding of crystal structures. Results from a larger and more varied population of students will be needed to establish the psychometrics of the instrument. It would be interesting to find out what other instructors might find in other settings to see where differences might arise from, especially for underrepresented populations. In order to promote broader usage and testing of the survey it will be loaded on to two web sites where it can be administered and graded via computer. The web sites are the ciHub and the AIChE Concept Warehouse. At the present time it is a useful tool that has been tested for a limited population, but has the potential to be a catalyst to motivate more effective instruction on the topic of Crystal Structures.

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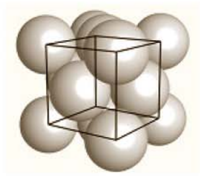
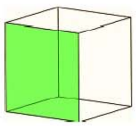
Appendix A - Crystal Spatial Visualization Survey

Crystal Structure Plane Investigation Activity Letter + 4 digit number ______________

Date: ______________

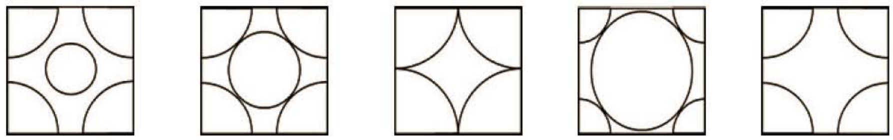


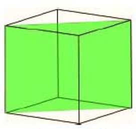
Directions: For the face-centered cubic crystal structure shown at left, choose the correct illustration that corresponds to the specified plane and then CIRCLE the letter that is your choice.

1. 

(1 0 0)

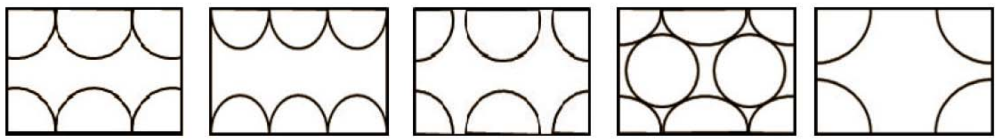
A. B. C. D. E.

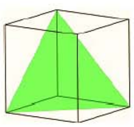


2. 

(1 1 0)

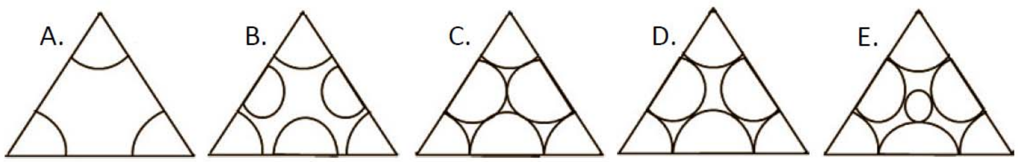
A. B. C. D. E.



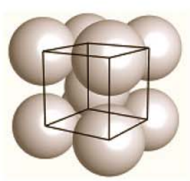
3. 

(1 1 1)

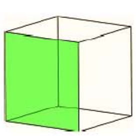
A. B. C. D. E.



Crystal Structure Plane Investigation Activity

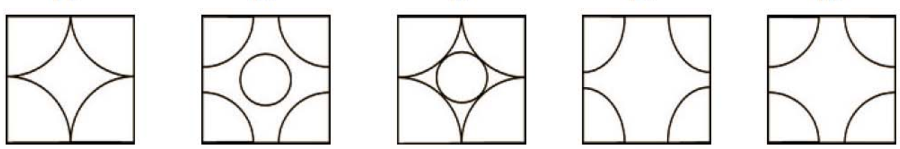


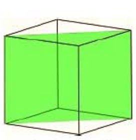
Directions: For the body-centered cubic crystal structure shown at left, choose the correct illustration that corresponds to the specified plane and then CIRCLE the letter that is your choice.

4. 

(1 0 0)

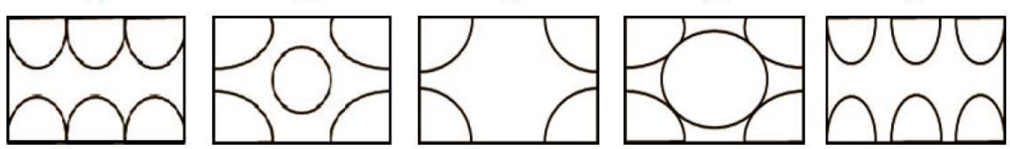
A. B. C. D. E.

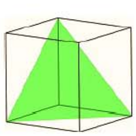


5. 

(1 1 0)

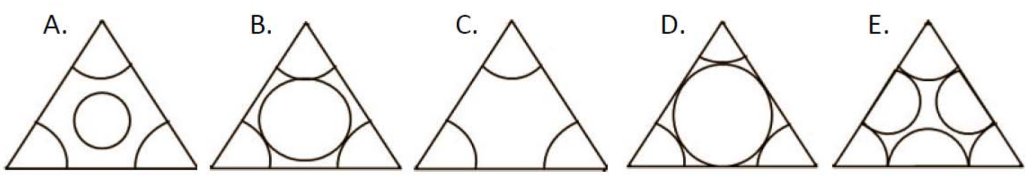
A. B. C. D. E.



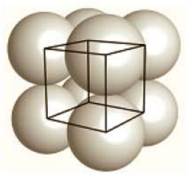
6. 

(1 1 1)

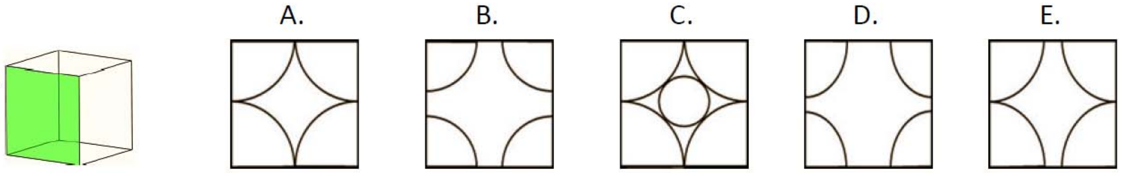
A. B. C. D. E.



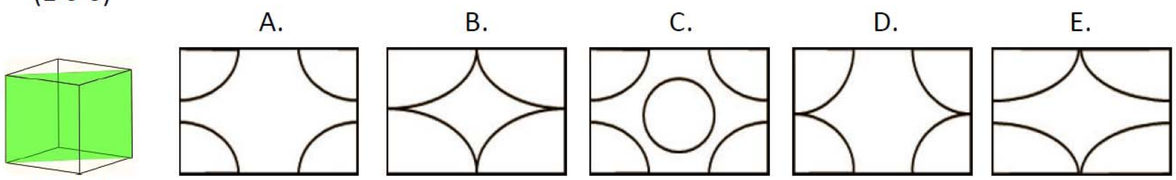
Crystal Structure Plane Investigation Activity



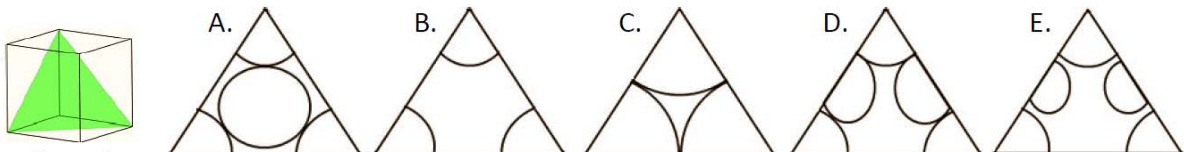
Directions: For the simple cubic crystal structure shown at left, choose the correct illustration that corresponds to the specified plane and then CIRCLE the letter that is your choice.

7. 

(1 0 0)

8. 

(1 1 0)

9. 

(1 1 1)

Crystal Structure Plane Investigation Activity

10. Which one of the following planed within its corresponding unit cell crystal structure is a close-packed plane? CIRCLE the letter chosen.

a) Face-centered Cubic (1 1 0)

b) Face-centered Cubic (1 0 0)

c) Body-centered Cubic (1 1 0)

d) Face-centered Cubic (1 1 1)

e) Body-centered Cubic (1 0 0)