Materials Science Test

Science Olympiad Tryouts 2020-2021

Shivansh Gour

Question #1 (1a: Physical Characteristics of different materials--metals, ceramics, polymers, composites)
Andy does some experiments to find that Material A is slightly harder than Gypsum. The melting point of Material A is observed to be 420 K higher than Chromium's melting point. Material A is also a pure substance and is a very poor conductor of heat. The melting point of Material B is about twice as high as Arsenic's melting point. Material B is slightly softer than Corundum, is made of 2 metals, and is a very good conductor of heat. Andy wants to make a special knife that can be used in a volcano that has an average temperature of 2000 degrees Celsius and does not burn his hand (he will not have gloves on). Identify Material A as a metal, ceramic, polymer, or composite. Then, identify Material B as a metal, ceramic, polymer, or composite. Explain which material Andy should use to make his knife, why he should use that material, and describe any drawbacks Andy might experience by using that material.

Answer #1 (1a: Physical Characteristics of different materials--metals, ceramics, polymers, composites)

- Material A is characterized by a high melting point (Chromium has a melting point of 2180 K, making Material A's melting point 2600 K), brittleness, being a pure substance, and poor conduction capabilities. From this, we can eliminate metals from the choices because metals are good conductors. We can also eliminate composites and polymers, because composites and polymers are not typically pure substances. This makes it a ceramic.
- Material B is characterized by a high melting point (Arsenic has a melting point of 1090 K, making Material B's melting point 2180 K), being very hard, being an alloy (a combination of two metals) and good conduction capabilities. Since Material B is an alloy, it must be a metal.
- Andy should use Material A.
    - First, convert 2000 degrees Celsius to Kelvin for simplicity: 2273.15 K.
    - Andy's requirements are:
        - Must not melt in an average temperature of 2273.15 K
            - So that the knife can be used
        - Is a poor conductor
            - Due to the fact that the heat must not travel from the knife into his hand
    - Material B melts before it reaches temperatures of 2273.15 K and is a good conductor, so Material B should not be used.
    - Material A melts after it reaches temperatures of 2273.15 K and is a poor conductor, so Material A should be used.
- The drawbacks of using Material A is that since it has a low score on the Mohs Hardness Scale, it can break fairly easily, a problem Andy would not face if he could choose Material B, since Material B has a high score on the Mohs Hardness Scale.

Question #2 (2a: Material stiffness--Young's Modulus)
Andy is conducting an experiment on a piece of top-secret tactical string he's made, which he's dubbed "Material C". This strand of Material C has an original diameter of 7 millimeters and an original length of 23 meters. He pulls the string with a force of 500 N. The final length of the string is 25 meters. Determine the stress, strain, and elastic modulus (Young's modulus) of the strand. *(Assume π as 3.14).*

Answer #2 (2a: Material stiffness--Young's Modulus)

- First, organize the given data, reformat it in order to use the same units, and denote the data with variables:
    - Diameter: 7 mm = .007 m, denoted as D
    - Initial Length: 23 m, denoted as L_i
    - Force: 500 N, denoted as F
    - Final Length: 25 m, denoted as L_f
- Second, find the stress, denoted as σ:
    - $\sigma = F/A$, where A is the area of the base of the cylindrical rope strand.
        - A = πr^2, where r is the radius of the base of the cylindrical rope strand.
            - r = D/2 = $\frac{.007m}{2}$ = .0035m
        - $A = \pi r^2 = (.0035m)^2(3.14) = 0.000038465m^2$
    - $\sigma = 500N/0.000038465m^2 = 12998830.1053N/m^2 = 1.29988301053 \times 10^7\ N/m^2$
- Third, find the strain, denoted as ε:
    - $\varepsilon = \frac{\Delta L}{L_i}$
        - $\Delta L = L_f - L_i = 25m - 23m = 2m$
    - $\varepsilon = \frac{\Delta L}{L_i} = \frac{2m}{23m} = 2/23$*(kept as a fraction in order to be precise)*
- Finally, find the elastic modulus, denoted as E:
    - $E = \frac{\sigma}{\varepsilon} = \frac{1.29988301053 \times 10^7\ N/m^2}{2/23} = 1.4948654621095 \times 10^8\ N/m^2$

Question #3 (2b: Material resistance to compression--Bulk Modulus)
Through numerous experiments, Andy finds that Material D has a Bulk Modulus of $7 * 10^{17} N/m^2$. He wants to decrease the volume of Material D by 50%. How much pressure should Andy apply in order to achieve his goal?

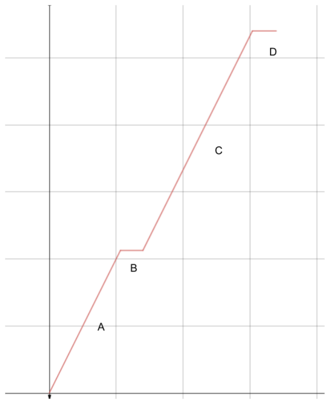
Answer #3 (2b: Material resistance to compression--Bulk Modulus)

- Denoting the bulk modulus as k:
  - $k = -V\frac{dP}{dV}$, where dP is the pressure intensity and -dV/V is the volumetric strain.
  - This can be translated as k=intensity/strain.
- Since we need to find the pressure intensity, we rearrange the formula by isolating intensity.
  - intensity = $k * strain$
- Denoting intensity as I and strain as S:
  - $I = kS$
- Now, we calculate S:
  - 50% = .5 = $5 * 10^{-1}$
- Now calculate the required pressure:
  - $I = ks = (7 * 10^{17} N/m^2)(5 * 10^{-1}) = 3.5 * 10^{17} N/m^2$

Question #4 (2c: Material stiffness under shear load--Shear Modulus)
Andy has a metallic cube with a side length of 42 meters. The metallic cube is bolted down to the floor of his unfinished basement. Assume the displacement of the cube is y meters when a tangential force of x newtons is applied to the top side of the cube. Determine the shearing stress, the shearing strain, and the shear modulus of the cube in terms of x and y. Then, find an equational relationship between x and y. Finally, find the shear modulus, in decimal form rounded to the nearest hundredth when the cube is displaced 3 meters due to a 21 N force.

Answer #4 (2c: Material stiffness under shear load--Shear Modulus)
- Determining the shearing stress, denoted as S_1, in terms of x and y:
  - $S_1 = F/A$, where F is the force applied and A is the area of the base of the cube.
    - F = x N
    - A = 1764 m^2
  - $S_1 = \frac{x}{1764}\ N/m^2$
- Determining the shearing strain, denoted as S_2, in terms of x and y:
  - $S_2 = D/h$, where D is the displacement and h is the height.
    - D = y m
    - h = 42 m
  - $S_2 = \frac{y}{42}$
- Determining the shear modulus, denoted as S, in terms of x and y:
  - $S = S_1/S_2 = (\frac{x}{1764}N/m^2)/(y/42) = \frac{42x}{1764y}N/m^2 = \frac{x}{42y}N/m^2$
- Finding the equational relationship between x and y:
  - In order to find the equational relationship, we must solve for either x or y by rearranging the shear modulus:
    - Solving for x:
      - $S = \frac{xN}{42ym^2}$
      - $42ym^2S = xN$
      - $x = (42ym^2S)/N$
      - $x = 42yS\,m^2/N$
        - In other words, the tangential force applied to the cube is equal to 42 times the displacement times the shear modulus meters squared per newton.
    - Solving for y:
      - $S = \frac{xN}{42ym^2}$
      - $42ym^2S = xN$
      - $y = \frac{xN}{42m^2S}$

- $y = \frac{x}{42S}\ N/m^2$



   - In other words, the displacement is equal to the force divided by 42 times the shear modulus newtons per square meter.
- Finding the shear modulus when the cube is displaced 3 meters due to a 21 N force:
   - Using the generalized term $S = \frac{x}{42y} N/m^2$:
      - $S = \frac{21}{42(3)} N/m^2 = 1/6\ N/m^2 = 0.17\ N/m^2$

Question #5 (3d: Melting Point of materials)

Andy finds a new material in the forest, that he's dubbed Material E. Above is the heating curve of Material E. Material E is solid at room temperature. The heating curve can be represented as the piecewise function:
$y = \{0 \le x \le 532: 2x\}, \{532 \le x \le 700: z_1\}, \{700 \le x \le 1518: 2x - 336\}, \{1518 \le x \le 1696: z_2\}$.
Explain what the sections A, B, C, and D represent on the heating curve. Then, determine the melting point of Material E. After, find the values of z_1 and z_2 and explain what they represent. Then, find the melting point of Iron, which is 747.15 K higher than Material E, in Rankine. Finally, by the melting point, which of these materials is most likely to be Material E: Aluminum, Silver, Gold, Copper, or Platinum. Assume the heating curve uses Celsius.

Answer #5 (3d: Melting Point of materials)

- Explaining the Sections:
   - Section A represents the solid form of Material E, where it is increasing heat but remains as a solid.
   - Section B represents the temperature where Material E is changing from solid to liquid, better known as the Melting/Freezing point of Material E.
   - Section C represents the liquid form of Material E, where it is increasing heat but remains as a liquid.
   - Section D represents the temperature where Material E is changing from liquid to gas, better known as the Condensation point or Vaporization point (Heat of Vaporization).
- Determining the Melting Point:
   - Since Section B represents the melting point of Material E, we must find the equation in the piecewise function that represents Section B. From the graph, we can tell that Section B and Section A have a common point at x=532. Since Section B must be a horizontal line, the equation for Section B is the same as the melting point. So, all we need to do is find the value of 2x when x=532. 2*532=1064. Therefore, the melting point of Material E is 1064 degrees Celsius.
- Finding the Values of z_1 and z_2, and Explaining What They Represent:
   - z_1 is the equation for Section B. This means that $z_1 = 1064$, which was found by determining the melting point.

- z_2 is the equation for Section D. We can apply the same logic we applied to part 2 of the question (Determining the Melting Point), except using x=1518 and the equation y=2x-336. 2(1518)-336 = 2700. This means that $z_2 = 2700$.
- z_1 and z_2 represent the same things as the sections they are associated with.
  - Therefore, they represent the Melting/Freezing point of Material E and Condensation/Vaporization point of Material E, respectively.

- Find the melting point of Iron:
  - First, convert 747.15 K to Celsius for simplicity: 474 C.
  - Now, add 474 to Material E's melting point, which gets us 1538 degrees Celsius.
  - Finally, convert this to Rankine, which is 3260.07 R.
- Finally, Material E is most likely to be Gold, since both Gold and Material E have a melting point of 1064 degrees Celsius.

Question #6 (2a: Material stiffness--Young's Modulus)
Andy has a concrete cube that has a side length of 5 meters. It can support a mass of 10000 kg. Assume that the cube's Young's Modulus is $20 * 10^9 N/m^2$. Finally, assume the acceleration due to gravity as 9.8 m/s/s. Calculate the cube's stress, strain, and change in height.Then, find a general solution for the cube's change in height if it has a side length of x meters instead of 5. Finally, use the general solution to find the particular solution if the cube had a side length of 7 meters instead of 5.

Answer #6 (2a: Material stiffness--Young's Modulus)

- First, write all the given data with denotations:
  - Length = 5 m, denoted as L
  - Mass = 10000 kg, denoted as M
  - Young's Modulus = $2 * 10^{10} N/m^2$, denoted as Y
  - Acceleration = 9/8 m/s/s, denoted as a
- Now we can find the stress, denoted as S_1:
  - $S_1 = F/A$, where F is the applied force and A is the area of the cube's base.
    - Through Newton's Second Law, F=ma, so F in S_1 is:
      - $F = ma = 10000kg * 9.8m/s^2 = 98000\, kgm/s^2 = 98000\, N$
    - Area:
      - $A = (5m)^2 = 25\, m^2$
  - $S_1 = 98000N/25m^2 = 3920\, N/m^2 = 3.92 * 10^3\, N/m^2$
- Now, we can find the strain of the cube, denoted as S_2:
  - $Y = S_1/S_2$ is the formula for Young's Modulus using our denotations. Rearranging this for S_2 gives us:
    - $S_2 = S_1/Y$
  - This gives us $S_2 = \frac{3920\, N/m^2}{2*10^{10}\, N/m^2} = 1.96 * 10^{-7}$
- Finally, we need to find the change in height, which we will denote as Δh:

    - $S_2 = \frac{\Delta h}{h_0}$, where h_0 is the original height. In our case, $h_0 = 5\, m$. Rearranging this for Δh gives us:
        - $\Delta h = S_2 h_0$
    - This gives us $\Delta h = 1.96 * 10^{-7} * 5\, m = 9.8 * 10^{-7}\, m$
- Finding the general solution for the change in height:
    - $S_1 = F/A = 98000\, N/\, (xm)^2$
    - $S_2 = S_1/Y = \frac{98000N}{(xm)^2}/2 * 10^{10}N$
    - $\Delta h = \frac{98000N}{x^2m^2}/(2 * 10^{10}\, N)\ \ *\ \ x\, m = (4.9 * 10^{-6})/x\, m$
- Finding the particular solution when the height is 7:
    - Let f(x) equal the generalized term Δh
    - $f(x) = (4.9 * 10^{-6})/x \rightarrow f(7) = (4.9 * 10^{-6})/7 = 7 * 10^{-7}\, m$

Question #7 (2b: Material resistance to compression--Bulk Modulus)
Andy has a small ball made of a new material, Material F. When Material F experiences a force of $2 * 10^5\, N/m^2$, it reduces in volume by 23%. Find the bulk modulus of Material F.

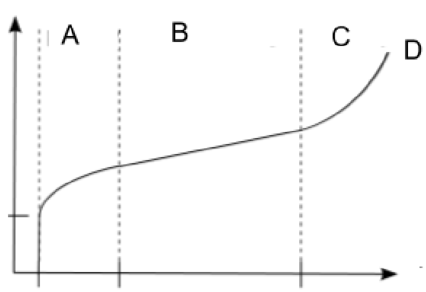
Answer #7 (2b: Material resistance to compression--Bulk Modulus)
- Givens:
    - Volumetric Strain: $23\% = 23 * 10^{-2}$
    - Volumetric Stress: $2 * 10^5\, N/m^2$
- Calculating the Bulk Modulus, denoted as K:
    - K = S_2/S_1, where S_2 is the volumetric stress and S_1 is the volumetric strain.
    - K = $(2 * 10^5)\, N/m^2\, /\, (23 * 10^{-2}) = 8.69565217 * 10^5\, N/m^2$

Question #8 (2c: Material stiffness under shear load--Shear Modulus)
Recall Andy's metallic cube from question number 4. Using the generalized terms you found in that question, determine the following values: the shear modulus when it's displaced 5 m due to a 24 N force; the displacement when a force of 26 N is applied and the shear modulus is $4.5 * 10^{10}\ N/m^2$; and finally, the force when the cube is displaced 10 m and the shear modulus is $1.2 * 10^2$.

Answer #8 (2c: Material stiffness under shear load--Shear Modulus)

- The generalized term for the shear modulus is $S = \frac{x}{42y} N/m^2$:
  - $S = \frac{24}{42(5)}\ N/m^2 = 1.11627906 * 10^{-1}\ N/m^2$
- The generalized term for the displacement is $y = \frac{x}{42S}\ N/m^2$:
  - $y = \frac{x}{42S}\ N/m^2 = \frac{26}{42(4.5*10^{10}\ N/m^2)}\ N/m^2 = 1.275661 * 10^{-11}\ m$
- The generalized term for the force is $x = 42yS\ m^2/N$:
  - $x = 42yS\ m^2/N = 42(10m)(1.2 * 10^2\ N/m^2)\ m^2/N\ = 5.04 * 10^4\ N$

Question #9 (2e: Material permanent deformation under constant load--Creep Rate)



Above is a cold flow graph of a new material Andy made, Material G. Explain what sections A, B, and C represent on the graph and describe what happens to the strain rate in each section. Then, explain what point D represents. After, describe what the x and y axes on the graph represent. Finally, explain what cold flow is and describe why Andy may want to take it into consideration when he's building something using Material G.

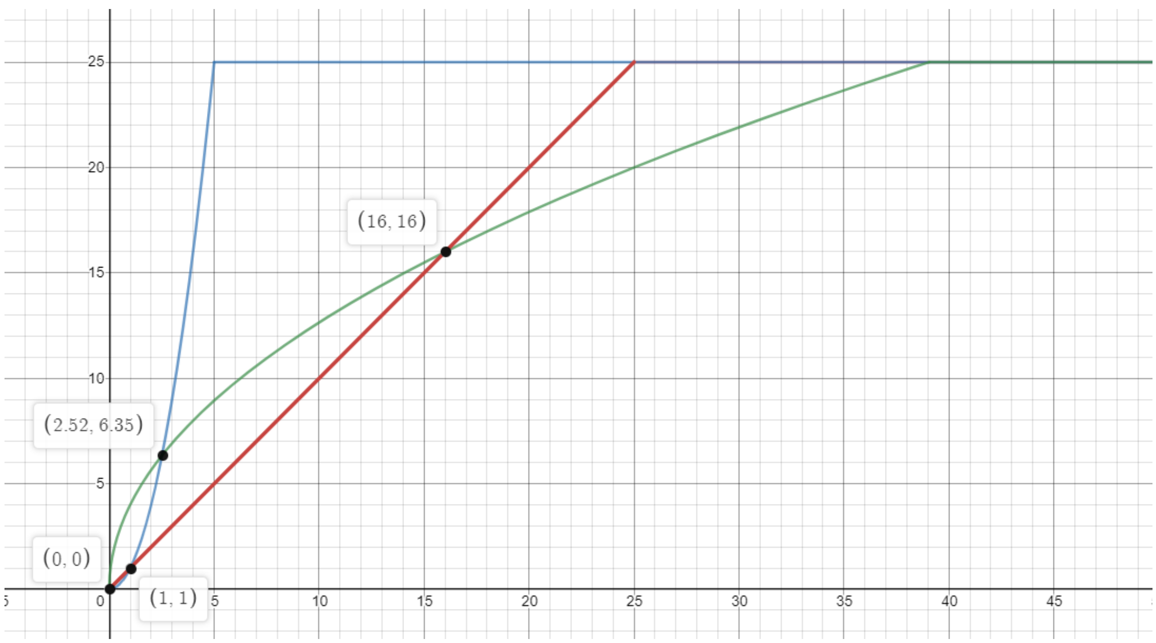
Answer #9 (2e: Material permanent deformation under constant load--Creep Rate)

- Explaining the Sections:
    - Section A represents the initial stage of the cold flow, or the primary creep. This is when a high strain rate is decreasing through time.
    - Section B represents the second stage of the cold flow, or the secondary or steady-state creep. This section is when strain rate reaches a minimum, constant rate.

- Section C represents the final stage of the cold flow, or the tertiary creep. This is when the strain rate increases at an exponential rate, approaching, in this case, Material G's fracture point or rupture point.

- Explaining Point D:
  - Point D represents the end of the cold flow, as well as the end of the tertiary creep. Point D is when Material G fractures.
- Describing the x and y Axes of the Graph:
  - Creep curves use a creep strain vs time graph.
  - Therefore, the x-axis represents time while the y-axis represents the creep strain.
- Explaining Cold Flow:
  - Cold flow is the deformation of a material under applied loads that depends on time. In other words, it is when a material permanently deforms over time due to mechanical stress. This usually occurs in high temperatures, however it can occur in lower temperatures, such as lead in room temperature, although it will take longer to reach its fracture point. The material, as a result of cold flow, may also increase in length. This, along with the fracture point, may make it harder for Andy to sustain something for a long period of time, as the cold flow could still affect Material G.

Question #10 (2f: Concepts of viscosity and viscoelasticity)



Andy has three liquids, L1, L2, and L3. He wants to order them from least viscosity to greatest viscosity. In order to compare the viscosities, Andy used three 25 cm tall graduated cylinders. First, he poured each liquid into one graduated cylinder each. Then, he dropped a ball bearing into each liquid, and measured how long the bearing took to get to the bottom of the cylinders. Above is a distance time graph of each ball bearing, where the distance is in cm and time is in seconds, with the red curve, f(x) being for L1, the blue curve, g(x) being for L2, and the green curve, h(x), being for L3. When f(x) < 25, f(x)=x. When g(x) < 25, g(x) = x^2. When h(x) < 25, h(x) = $4\sqrt{x}$. Andy also wants to be able to find the instantaneous velocities of each ball bearing. First, find the general terms for the instantaneous velocities of each ball bearing before they reach the bottom of the cylinder. Then, order the three liquids from least viscosity to greatest. Finally, determine the instantaneous velocity of the ball bearing in L3's graduated cylinder at 16 seconds.

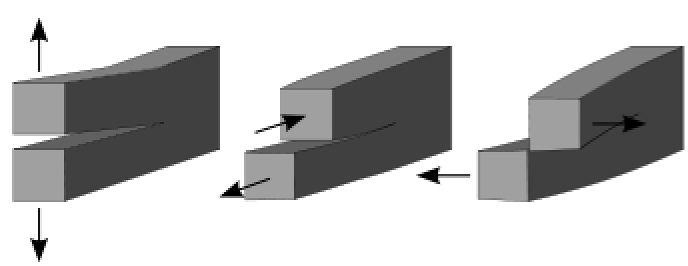
Answer #10 (2f: Concepts of viscosity and viscoelasticity)

- Finding the General Terms for Instantaneous Velocity:
    - The instantaneous velocity of the ball bearing before it reaches the bottom of the cylinder is equal to the slope of the derivative of each function before they reach 25. Knowing this, all we have to do is take the derivative of each function to find the general terms.
    - L1:
        - f(x) = x, f'(x) = 1
    - L2:
        - g(x) = x^2, g'(x) = 2x
    - L3:
        - h(x) = $4\sqrt{x}$, h'(x) = $\frac{d}{dx}(4x^{1/2}) = 2/\sqrt{x}$
- Ordering the Viscosities:
    - Since g'(x) is always greater than or equal to f'(x) and h'(x) for all integers, x, greater than 0, L2 has the lowest viscosity (because the material with the lowest viscosity will allow the ball to go at its fastest).
    - To find the highest viscosity one, we do a graphical analysis of f(x) and h(x). f(x) reaches 25 cm before h(x), implying that the ball bearing reaches the bottom of the cylinder in f(x) before in h(x). Therefore, L1 must be less viscous than L3.
    - In order from least to greatest viscosities:
        - L2, L1, L3
- Determining the Instantaneous Velocity of the Ball in L3 at 16 Seconds:
    - All we need to do is find h'(16), which equals ½.
    - Therefore, the instantaneous velocity of the ball in L3 at 16 seconds is 0.5 cm/s.

Question #11 (2d: Material resistance to fracture--Fracture Toughness)
Andy wants to conduct a fracture test on a material he's so very creatively named, Material H. However, he does not understand some of the terms used in Continuum Mechanics. Describe the three fracture modes. Define stress intensity factor. Explain the Griffith Theory of Fractures. And finally, define fracture toughness.

Answer #11 (2d: Material resistance to fracture--Fracture Toughness)

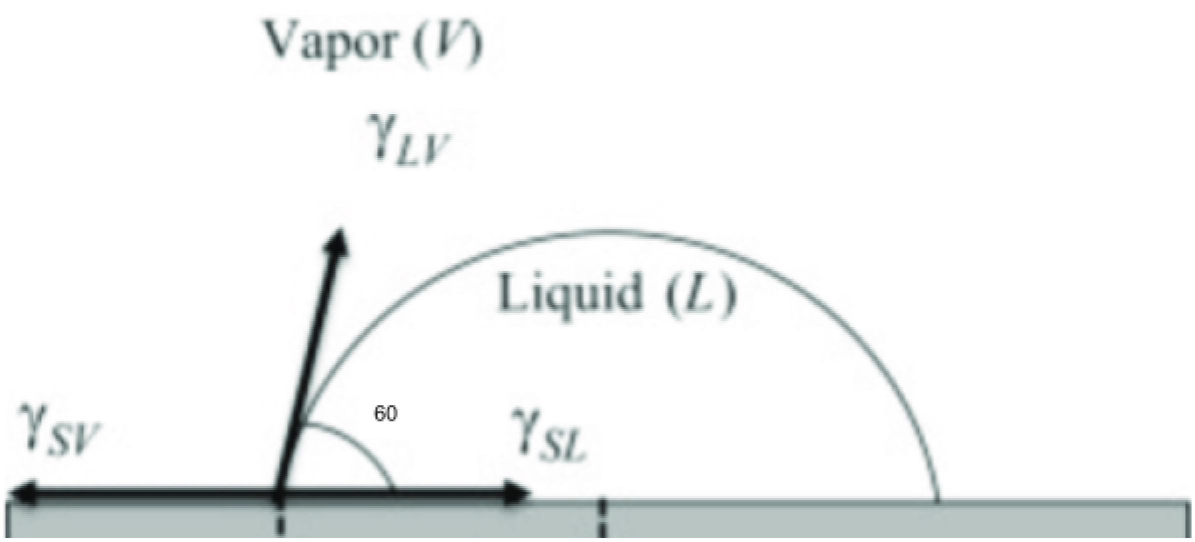
- Describing the Three Fracture Modes:



    - Mode 1:
        - When there is a stress orthogonal to the crack. Kind of like splitting logs with an axe. Also known as Opening Mode.
    - Mode 2:
        - When there is a stress perpendicular to the crack front but parallel to the crack itself. Kind of like pushing one part of a log while pulling the other to split it. Also known as Sliding Mode.

- Mode 3:
    - When the stress is parallel to the crack front and the crack. Kind of like rotating half a log one way and half the other way to split it. Also known as Tearing Mode.
- Defining Stress Intensity Factor:
    - Stress Intensity Factor is the magnitude of the stress at the tip of the crack, and is used to predict the effects of the crack and when the material will fracture..
- Explaining the Griffith Theory:
    - The Griffith Theory says that a crack will increase when the reduced potential energy due to a crack growing is greater than or equal to the increased surface energy due to new surfaces, which are generated through the crack.
    - In simpler terms, the crack will grow as long as the loss of potential energy is greater than or equal to than the gain of surface energy.
- Defining Fracture Toughness:
    - Fracture toughness is the ability of a cracked substance to resist fracture.
    - In other words, it is how resilient a cracked substance is, or how *tough* it is.

Question #12 (3b: Hydrophobicity vs. Hydrophilicity of a material)



Andy has 3 materials, Material I, Material J, and Material K. Above is a profile picture of a water drop on Material I. Materials J and K's profile pictures are not given, however they have contact angles of 123 degrees and 89 degrees respectively. Determine if Materials I, J, and K are hydrophobic or hydrophilic. Assume the contact angles cannot be contaminated.

Answer #12 (3b: Hydrophobicity vs. Hydrophilicity of a material)

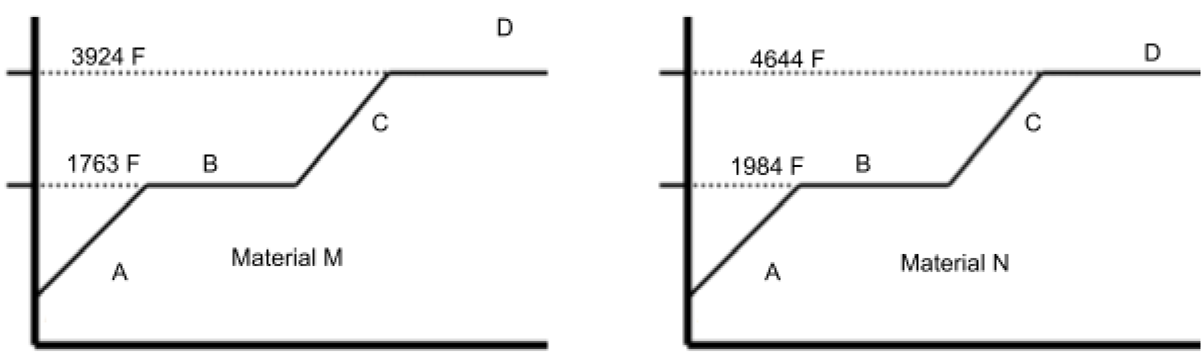
- Hydrophobic materials have contact angles with water of more than 90 degrees while hydrophilic materials have contact angles with water less than 90 degrees.
- From this:
    - Material I’s contact angle is less than 90, meaning it is hydrophilic.
    - Material J’s contact angle is greater than 90, meaning it is hydrophobic.
    - Material K’s contact angles is less than 90, meaning it is hydrophilic.

Question #13 (1a: Physical Characteristics of different materials--metals, ceramics, polymers, composites)
Andy wants to make a vase in pottery class. He has two materials to choose from, Material L and Material A (recall Material A from question 1). Material L has a hardness of 1 less than the hardness of Fluorite on the Mohs Hardness Scale. It has a melting point of 3000 K. Material L is also ferromagnetic with a Curie temperature of 1500 K. From all of this, decide whether Material L is a polymer, metal, composite, or ceramic. Then, determine which material Andy should use to make his vase.

Answer #13 (1a: Physical Characteristics of different materials--metals, ceramics, polymers, composites)
- Deciding What Material L Is:
    - Hardness of Material L:
        - Fluorite has a hardness of 4, making Material L’s score 3.
    - From this, Material L is characterized with a low hardness, high melting point, and ferromagnetism. Since Material L is ferromagnetic, Material L is most likely a metal.
- Determining Which Material Andy Should Use:
    - Pottery typically uses ceramic material as these are typically easier to mold by hand (think of metals and how you must mold those by melting them first). From

question 1, we established that Material A was a ceramic material. Therefore, Andy should use Material A to make his vase.

Question #14 (3d: Melting Point of materials)



Andy has created four more materials, Material M, Material N, Material O, and Material P. The heating curves of Materials M and N are shown above, in Fahrenheit. Material O has a boiling point of 2470 degrees Celsius. Material P has a boiling point of 4827 degrees Celsius. Each of the Materials M, N, O, and P can be identified as Carbon, Copper, Aluminum, or Silver based on their melting points and boiling points. Identify which material is which. Then, order the four materials by their melting points from highest to lowest. Finally, order the materials by their boiling points from lowest to highest.

Answer #14 (3d: Melting Point of materials)

- First convert the boiling points of O and P from Celsius to Fahrenheit for simplicity:
    - 4478 F and 8721 F, respectively.
- Identifying the Materials:
    - The melting points of Carbon, Copper, Aluminum, and Silver are 6422, 1984, 1221, and 1763, respectively.
        - The melting points of Silver and Material M are the same.
        - The melting points of Copper and Material N are the same.
    - The boiling points of Carbon and Aluminum are 8721 and 4478.
        - The boiling points of Material O and Aluminum are the same.
        - The boiling points of Material P and Carbon are the same.
    - Therefore, Materials M, N, O, and P are Silver, Copper, Aluminum, and Carbon, respectively.
- Ordering the Melting Points from Highest to Lowest:
    - From the identification, we can order the elements as Carbon, Copper, Silver, Aluminum.
    - Rewritten as letters:
        - P, N, M, O
- Ordering the Boiling Points from Lowest to Highest:
    - The boiling points of Copper and Silver are 4644 and 3924.
    - From the identification, we can order the elements as Silver, Aluminum, Copper, Carbon.
    - Rewritten as letters:
        - M, O, N, P

Question #15 (3a: Surface Tension and Contact Angles of liquids on a material)
Andy finds a water strider that is standing on a pond. He measures the length of the water strider to find that it is about 5 mm. The surface tension of the water is 16 N/m. Andy later drops a small piece of water on the water strider's back. From the profile picture, he determines that the contact angle is 126 degrees. Find the mass of the water strider and determine if it's hydrophobic or hydrophilic.

Answer #15 (3a: Surface Tension and Contact Angles of liquids on a material)
- Finding the Mass of the Water Strider:
    - Knowing that surface tension, denoted as γ, is equal to surface force divided by the length, we can use this simple formula:
        - $\gamma = F/L$, where F is the surface force and L is the length.
    - Knowing that the surface tension is 16 N/m and the length is 5mm:
        - $F = 16\,N/m\ *\ 5mm = 16\,N/m *.005\,m = .08\,N$
    - This gives us the force. However, the force is not the same as mass. Here, we apply Newton's Second Law to find the mass:
        - F=ma
        - F = .08 N
        - a = 9.8 m/s/s (from the acceleration due to gravity)
        - So, solving for m:

- $m = F/a = 8.1632653 * 10^{-3}\ kg = 8.1632653\ g$
- Determining if it's Hydrophobic or Hydrophilic:
  - Since the contact angle is greater than 90 degrees, the strider is hydrophobic.

Question #16 (2a: Material stiffness--Young's Modulus)
Andy has a cord made out of Material Q. It has a radius of 2 mm and an original length of 5 meters. The final length is equal to x meters, when the cord is pulled with a force of y N. Find general solutions for the stress, strain, and Young's Modulus of Material Q. Then, find the dimensionless equational relationship between x and y. Finally, determine the pull force when the final length is 10 meters and the Young's Modulus is $2.2 * 10^{-2}\ N/m^2$.

Answer #16 (2a: Material stiffness--Young's Modulus)

- Stress (S_1):
  - $S_1 = F/A$, where F is the force and A is the area of the base of the cylinder.
    - F = y N
    - A = $0.000016\pi\ m^2$
  - $S_1 = \frac{y}{0.000016\pi}\ N/m^2$
- Strain (S_2):
  - $S_2 = \Delta L/L_0$, where ΔL is the change in length and L_0 is the original length.
    - $\Delta L = x - 5\ m$
    - $L_0 = 5\ m$

- $S_2 = \frac{x}{5} - 1$
- Young's Modulus (Y):
  - $Y = S_1/S_2 = (\frac{y}{0.000016\pi})(N/m^2) \div (\frac{x}{5} - 1) = (99471.83943243y)/(x - 5)\ N/m^2$
- Dimensionless Equational Relationship:
  - In terms of x and Y:
    - Starting with $Y = (99471.83943243y)/(x - 5)$, rearrange to solve for y:
      - $y = 0.00001005Yx - 0.00005026Y$
  - In terms of y and Y:
    - Starting with $Y = (99471.83943243y)/(x - 5)$, rearrange to solve for x:
      - $x = (99471.83943243y)/(Y) + 5$
- Pull Force:
  - Finding the stress:
    - $S_2 = 2 - 1 = 1$
    - This means that Y=S_1.
  - From the above, we can solve the equation $2.2 * 10^{-2} = y/0.000016\pi$ for y:
    - $y = 0.000016\pi * 2.2 * 10^{-2} = 1.10584061 * 10^{-6}\ N$

Question #17 (2c: Evaluating mechanical performance of materials)
Andy is taking a Materials Science test and needs you to quickly tell him some answers! First, define what a mechanical property is. Then, describe the Izod Test. Define what Tensile Testing is. Describe how you would perform the Izod Test. Describe how you would perform the Charpy Test. Finally, name the hardness scale made specifically for wood.

Answer #17 (2c: Evaluating mechanical performance of materials)
- A mechanical property is a physical property of a material that is independent of the amount of the material.
- The Izod Test is an impact test that finds the impact resistance of a material.
- Tensile Testing is when a material is put under constant tension until it fractures, and it helps find properties like the ultimate tensile strength of a material and maximum elongation of a material.
- You would perform the Izod Test by having a mechanical arm raised to a point of constant potential energy, and then released, hitting a u-shaped notch on the material.
- You would perform the Charpy Test much the same way as the Izod Test, except with a pendulum instead of a mechanical arm. The positioning of the notched material is also

different. In the Izod Test, the notched material is on a cantilever as opposed to a 3 point, screw like, configuration.

- The hardness scale made specifically for wood is called the Janka Hardness Test.

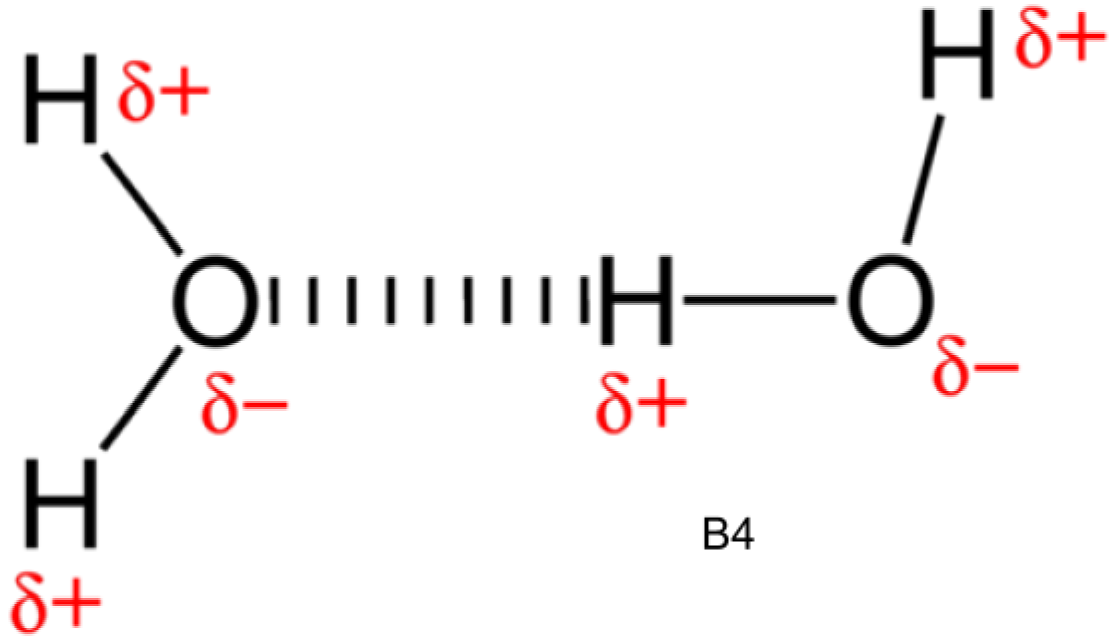
Question #18 (1b: Manufacturing techniques and natural occurrences of materials)
Andy has found a metal in its native state. He calls it Metal A. He wants to make a sword out of it, but he doesn't know what he should do. Describe the five alloy forming techniques Andy could use in one or two sentences each. Then describe the five alloy casting techniques he could use in one or two sentences each.

Answer #18 (1b: Manufacturing techniques and natural occurrences of materials)

- Forming Techniques:
  - Hot Working - when a metal is melted past its temperature of recrystallization.
  - Forging - breaking a piece of metal by consecutive blows or compression.
  - Rolling - sliding a piece of metal between two rolls, compressing the metal between the two rolls, which helps make sheets, strips, and foils of metal.
  - Extrusion - a cylindrical bar of metal is hammered through a tunnel-like orifice by a hydraulically powered ram, and the output is pieces of metal in the wanted shape.
  - Drawing - the metal is elongated by pulling it through an attenuated die.
- Casting Techniques:

- Sand Casting - sand is used as the mold, by packing sand in a pattern of the desired cast shape. A gating system is usually used in order to regulate the flow of the liquid metal.
- Die Casting - liquid metal is forced into the mold under pressure at a high speed, which is then used to make it solidify. Upon solidification, the mold is opened and the casted metal is ejected.
- Investment Casting - the mold is made from wax or plastic with low melting points. The mold is surrounded by a slurry, and then heated up, which melts the plastic away, leaving a new mold with the wanted shape.
- Lost Foam Casting - a version of investment casting that uses foam instead of wax or plastic, with sand packed around the mold. The metal is poured in, and takes the form of the mold.
- Continuous Casting - the metals are usually outputted ingot shaped (bar shaped), which is then rolled into a flat sheet of metal. This is typically used for preparations to start forming, because the flat sheet is easier to form than the ingot shape.

Question #19 (1c: Elemental composition and bonds present in various materials)



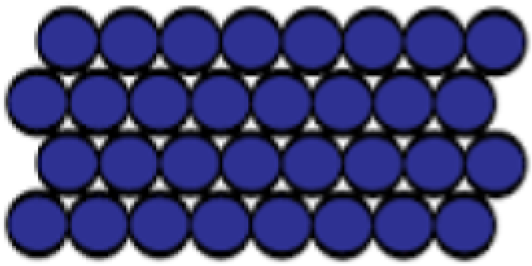
B4

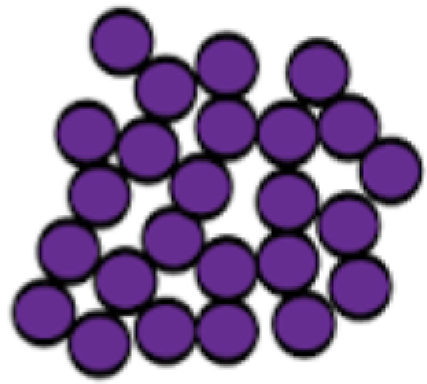
Andy has 4 bonds he wants to identify B1, B2, B3, and B4. B1, B2, and B3 are shown above. B3 is described as a sharing of electrons between two nonmetallic atoms. B3 will also not dissolve in water. Determine what type of bonds B1, B2, B3, and B4 are.

Answer #19 (1c: Elemental composition and bonds present in various materials)

- B1 is a polar covalent bond, shown by the fact that they share electrons and have different charges.
- B2 is an ionic bond, shown by the fact that the electrons are being transferred.
- B3 is a nonpolar covalent bond, characterized by the fact that the electrons are being shared between two nonmetals.
- B4 is a hydrogen bond, found by the fact that the Hydrogen atom is being attracted to a more electronegative group. Specifically, this bond is a hydrogen bond in water, supported by the fact that both molecules are water molecules.

Question #20 (3c: Common atomic packing structures in various materials)


Material T


Material U

Andy has a molecular model of a new Material he has made, Material R. Material R is a ceramic material, and its atoms show up in a periodic, lattice formation. Andy also has a molecular model of Material S, which has no discernible pattern. Moreover, above are two rough sketches of Materials T and U respectively. Identify the atomic packing structure of all four materials. Then, list the 7 possible crystalline structures. Finally, define the unit cell.

Answer #20 (3c: Common atomic packing structures in various materials)

- Identifying the Materials:
  - Material R is described as a periodic formation, implying that it is a crystalline structure.
  - Material S is described as an irregular formation, or nonperiodic formation. This implies that Material S is an amorphous, or noncrystalline, structure.
  - Material T has a periodic formation, meaning that it is crystalline.
  - Material U has an irregular formation, meaning that it is amorphous.
- The 7 Possible Crystalline Structures:
  - Cubic
  - Hexagonal
  - Tetragonal
  - Rhombohedral
  - Orthorhombic
  - Monoclinic
  - Triclinic
- Defining the Unit Cell:
  - The unit cell is the basic structure of a crystalline structure.
  - It is the smallest part of the crystalline structure that can be used to regenerate the whole structure using just linear translations in R^3.