

3.091 Exam 2 2021

Your name: _____

Recitation Instructor: _____

Exam 2 consists of 4 questions.

Write your answers directly on these pages or on another medium.

State your assumptions and show calculations that support your conclusions.

Honor Code for Online Exam 2

I pledge that I have worked independently, that I have not discussed this test with anyone else, and that the answers that I am submitting are the products of my work.

Signature: _____



1. (25 Points) The heartbroken Star-Lord and the Guardians of the Galaxy receive a message about Gamora's location via space mail. Sadly, Baby Groot got to the package first and faithfully labeled the contents "I am Groot". The package is a vial filled with a violet-blue gas, which reminds Drax of his days roaming Jupiter's moon Io and its sulfur-rich atmosphere.

Drax naively suggests that the gas could simply be S_2 but the other Guardians want to confirm if S_2 even exists!

- a) Draw an energy-level diagram for the molecular orbitals (MOs) for S_2 . Note, only the valence shell participates in bonding. The energy ordering of the MOs in sulfur is $\sigma_p, \pi_p, \pi_p^*, \sigma_p^*$. Label each MO. (6 points)

- b) Indicate the filling of electrons in the MO energy diagram in part (a). (6 points)

- c) Using your sketch of the electronic configuration of S_2 and the corresponding bond order, elaborate whether this molecule exists. Justify your reasoning. (6 points)

- d) As the Guardians embark on a cross-galactic trip to Io, Rocket is preparing the ship to be able to land on this enigmatic Moon. Their ship typically uses magnetic thrusters to land, so they need to figure out whether Io's S_2 -rich atmosphere will pose a problem.

Based on your electron distribution across MOs in S_2 from part (b), comment whether S_2 will or will not get attracted to the magnets on the ship's landing gears.
(7 points)

2. (30 Points) Rocket has grown weary of parenting Baby Groot, and took up intergalactic herbology in hopes of getting his companion to grow up faster. He learned that watering Baby Groot with antimony (Sb) - fluorine (F) compounds can indeed help him grow.

Rocket finds some Sb and F in the back of the ship and starts synthesizing!

- a) The first compound Rocket creates is SbF_3 . Draw the Lewis structure for this molecule. (5 points)
- b) Draw the molecular geometry of SbF_3 following VSEPR rules. Make sure your drawing is clear and legible. (5 points)

Unfortunately, Rocket's experiment produces a solid – which is hard to water Baby Groot with. He tries again, this time supplying the reaction with an infinite amount of fluorine.

- c) Let's say there are infinite extra F atoms to react with the Sb atom. The goal is to make an antimony-fluorine compound that is both nonpolar and neutral (no-charge). What compound will be made? (6 points)
- d) Support your answer in part (c) by providing the Lewis structure and a drawing of the molecular geometry of this new compound. (5 points)

- e) What is the hybridization of the Sb atom in SbF_3 and in the newly created compound from part (c)? **(4 points)**

Hybridization of Sb in SbF_3 :

Hybridization of Sb in the new compound:

- f) How will the melting point of this new compound differ from the melting point of SbF_3 ? Explain your reasoning. **(5 points)**

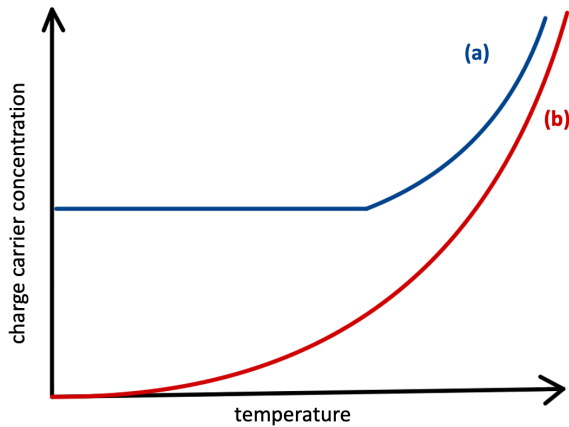
3. (25 points) Upon arrival on Io, the Guardians decide to split up to cover more ground in search of Gamora. Unfortunately, Rocket's communication device has broken and he's lost contact with the others. Rocket needs to jerry-rig a transistor to repair his comm device and regain contact with the crew.

Rocket stumbles upon a chunk of silicon that could do just the trick. A quick chemical analysis with a pocket scanner determines that this piece of Si contains 2 ppm of Sb.

- a) Is this silicon n-type or p-type? What is the majority carrier for this type of doping? Explain your reasoning. (2 points)
- b) Determine the concentration of the majority charge carriers (in cm^{-3}) in this piece of Si. Silicon atomic density is 10^{19} mm^{-3} . (4 points)
- c) Draw a schematic energy diagram for the Sb-doped Si, labelling all critical features. Numerical answers not required, qualitative sketch only. (5 points)

Temperatures are known to fluctuate violently between Io's surface and its core. Rocket needs to know how his comm device will operate at different temperatures.

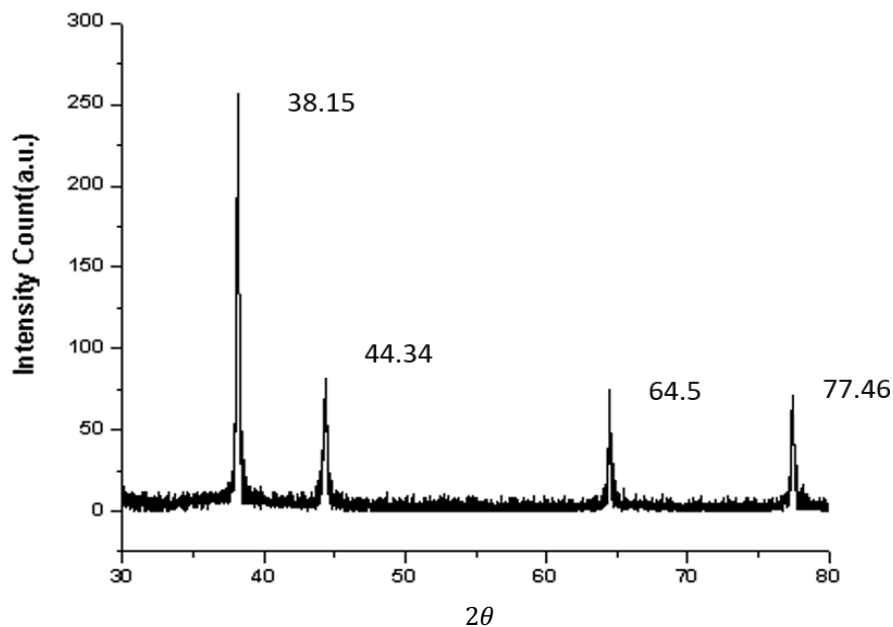
- d) In the following plot, identify which of the two curves corresponds to intrinsic (undoped) Si and which represents extrinsic (doped) Si. Explain your reasoning. (8 points)



- e) How would the extrinsic curve change if the concentration of Sb-dopant in Si doubled? Draw the new curve on the plot above. Label important points. Explain your reasoning. (6 points)

4. (20 Points) Rocket reunites with the rest of the Guardians, yet their search is fruitless as Gamora disappeared from Io without a trace... Or was there a trace? Mantis finds a shiny shard of what appears to be a piece of Gamora's sword with a trace of another metal on it. If the Guardians can figure out who Gamora was fighting, they may be able to find her...

Using a portable diffractometer that every ravager has on hand, the Star-Lord measures the following X-ray diffraction (XRD) spectrum of a mystery metal. The diffractometer uses the K_α radiation of a Cu source ($\lambda_{K_\alpha} = 1.542 \text{ \AA}$).



- a) For each of the four X-ray diffraction peaks, identify the (hkl) plane that produced it. (10 points)

- b) Based on the peak assignment, determine the crystal structure of the mystery metal. **(4 points)**
- c) Determine the lattice parameter of the mystery metal. Express in Angstroms. **(4 points)**
- d) Using a table of the common galactic metals below, suggest the potential material that landed on Gamora's sword. **(2 points)**

Metal	Lattice constant (Å)
Aluminum	4.05
Gold	4.07
Molybdenum	3.15
Nickel	3.50
Silver	4.09
Tin	4.95