Read the article entitled, Enhancement of the Thermal Stability and Thermoelectric Properties of Yb14MnSb11 by Ce Substitution (*Chem. Mater.* **2020**, *32*, 9268−9276, <https://pubs.acs.org/doi/10.1021/acs.chemmater.0c03043>) and answer the discussion questions.

1. Using the introduction to the paper, describe what is needed for a material for it to be considered as a useful thermoelectric material.
2. By looking online, see if you can find an explanation of thermoelectric properties. (Try searching NASA and thermoelectric materials, or power generation and thermoelectrics.) Explain the basic idea behind thermoelectric materials. How does it work? Cite your reference(s).
3. Why are these materials important to NASA’s space program?
4. Look at the crystal structure of Yb14MnSb11. You may use the COD (Crystallographic Open Data base, <http://qiserver.ugr.es/cod/index.php>, COD ID 7024693 ) to find the Crystallographic Information File (CIF) for Yb14MnSb11 and VESTA (a free downloadable software to create 3D structures) to visualize the crystal structure (<https://jp-minerals.org/vesta/en/>).
   1. Describe the crystal structure of Yb14MnSb11 by identifying the structural units found in the unit cell.
   2. How are electrons counted / distributed in the sub-units within the structure? What type(s) of bonding is/are being assumed in the discussion?
   3. Assuming that the oxidation state of Sb is 3-, what is the oxidation state of Mn in the MnSb4 tetrahedron? What is the dn count of the manganese ion?
   4. Provide a crystal field splitting diagram for Mn. Should this be high spin or low spin? Paramagnetic or diamagnetic? Explain how you reached your conclusion.
   5. What is the oxidation state of Yb and Ce in these compounds?
5. Why were the authors trying to incorporate Ce to replace some of the Yb in this compound?
6. How are the samples prepared? Write a balanced chemical reaction to produce the Ce-doped material.
7. Why does the electrical resistivity increase with Ce and increasing amounts of Mn in the compound?
8. What is the impact of oxide impurities on the electrical resistivity of the material?