**Part 1 (50 points)**

These questions refer to the article that was handed out in class on Mon, Dec. 5. If you do not have a copy of the article with you, I can provide one. Hand in your copy of the article with your exam.

1. (7 points) The authors report that copper is the best-known catalyst for converting carbon dioxide into useful products.
2. (2 points) Fill in the blanks below with the formulas of four of the useful products. *Make sure that one of the products you list is the product highlighted in this article.*



1. (3 points) Fill in the table below for CO2 and the four products you listed.

|  |  |
| --- | --- |
| **Chemical Species** | **Oxidation Number of Carbon** |
| CO2 |  |
|  |  |
|  |  |
|  |  |
|  |  |

1. (2 points) What do the authors mean by “closing the carbon cycle”? (*Hint:* Think about where the CO2 in the atmosphere is coming from.)

2. (5 points) High resolution TEM was used to directly measure the lattice spacing and confirm the nanoparticles were made of Cu with a little bit of Cu2O (Figure 2).

1. (3 points) Name another technique we learned about this fall that could be used to measure the distance between planes in the crystalline nanoparticles.
2. (2 points) Why wasn’t the technique you listed in part (a) used in this case?

3. (5 points) Describe the three types of electrodes tested and why each was important. Define any acronyms used (for example, CNS).

4. (10 points) To measure the electroreduction of CO2, the authors saturated a 0.1 M sodium bicarbonate solution with CO2 and put the electrode being tested in the solution. Then they measured the current generated when various reducing potentials were applied to the electrode.

1. (2 points) Which two chemical analysis techniques were used to identify and quantify the products formed?

technique used for liquid products \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

technique used for gaseous products \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. (4 points) Use Figure 4A and the text to approximate the major *carbon-containing* products for each type of electrode at each potential range. The potentials are measured versus the reversible hydrogen electrode (RHE). [This is not particularly important.]

|  |  |  |
| --- | --- | --- |
|  | **– 0.9 V and more positive** | **–1.0 V and more negative** |
| **CNS** | major product:  other products: | major product:  other products: |
| **Cu / glassy carbon** | major product:  other products: | major product:  other products: |
| **Cu / CNS** | major product:  other products: | major product:  other products: |

1. (2 points) What is the optimum applied potential for ethanol generation at the Cu/CNS electrode? What is the Faradaic efficiency at this potential?
2. (2 points) What does the word “selectivity” mean, especially in the context of the research described in this article?

5. (12 points) The carbon nanospike electrode was made of several layers of graphene doped with small amounts of nitrogen atoms.

1. (3 points) Sketch a single layer of graphene, including double and single bonds.

*Remember that graphene is pure carbon, and be careful not to exceed the octet rule for your central carbons. Any carbons on the outer edge of your diagram will be attached to other carbons not shown.*

1. (1 point) How are the carbon atoms hybridized?
2. (1 point) Do you expect graphene to be a good conductor of electricity? Why or why not?
3. (2 points) From context, what do the authors mean by C1 and C2 products?
4. (2 points) The authors state that usually copper catalysts result in the reduction of CO2 to form ethane and/or ethylene. Describe why the authors think the π conjugation of the graphene sheets contributes to the lack of ethylene or ethane formation in the CNS / Cu electrodes.
5. (3 points) What is happening more / better on the Cu/CNS electrode to lead to more C2 products as compared to the glassy carbon / Cu or bare CNS electrodes?

6. (5 points) There is another reaction that competes with the CO2 for electrons and is often favored over the reduction of CO2.

1. (3 points) Write the half reaction for this competing reduction, including reactant, electrons, and product.
2. (2 points) Why do the authors choose to measure the reduction of CO2 in a neutral KHCO3 solution instead of acidic conditions?