

Sample questions (Correct answers in bold)

General nanoscience and technology

1. Which of the following statements **CORRECTLY** describe the importance of nanotechnology?
 - I. Nanomaterials, like SNAs, are of the same size scale as cellular machinery and many common biological molecules, which facilitates their ability to interact with them.
 - II. As the size of a nanomaterial is reduced, there is a greater percentage of atoms in the bulk, which enables them to better interact with light and electrons.
 - III. When the size of a semiconductor material is reduced to the nanometer scale, the number of atoms becomes small enough to change the band gap.
 - A. I only
 - B. I and II
 - C. I and III**
 - D. II and III
 - E. I, II, and III

2. Select the **CORRECT** combination of valid statement(s) below.
 - I. Photons are used as radiation sources in SEM and TEM microscopy techniques as photons allow for ultra-high resolution and dynamic interactions with solids
 - II. Smaller nanoparticles will have higher total surface area and as such are ideal candidates for catalysis and solar energy conversion
 - III. Nanoscale objects have one dimension (length, width, or depth) that measures between 1 and 100 nm
 - IV. A 4-nm CdSe quantum dot will have a higher energy emission than an 8-nm CdSe one.
 - V. The Meissner Effect is the observation of light scattering in a colloid whereby the size of the particles will affect how light reflected
 - A. I, II, and IV
 - B. I, II, III, and V
 - C. II, III, and IV**
 - D. III and IV
 - E. None of the above combination of statements (A – D) is correct

Polymers and DNA

3. Consider the following statements and select correct combination of **TRUE** statements.
 - I. Polymer chains can be connected through covalent bonds (e.g., via vulcanization) or intermolecular forces cross-linking (e.g., via hydrogen bonding)
 - II. Addition polymerization generally combines monomers with double or triple bonds to form a polymer with the loss of a small molecule
 - III. Thermoplastics are polymers that become pliable above a critical temperature and solidifies back into its original structure upon cooling
 - IV. DNA and RNA are natural polymers made up of nucleotides
 - A. I, II, and III
 - B. I, III, and IV**
 - C. II, III, and IV

- D. IV only
E. None of the above answer choices (A-D) is correct
4. Which of the following are examples of polymers?
1. SiO₂
 2. DNA
 3. Teflon
 4. Polyethylene
 5. Wool
- A. 4 only
B. 3 and 4
C. 3, 4, and 5
D. 2, 3, 4, and 5
E. 1, 2, 3, 4, and 5
5. DNA is an example of a natural polymer, where the repeating units are called nucleotides. Which of the following statements regarding DNA is **CORRECT**?
- I. DNA is an example of a copolymer.
 - II. Each type of nucleotide pair forms a different number of hydrogen bonds. The guanine-cytosine pair would be predicted to have a greater binding affinity than the adenine-thymine pair based on the number of hydrogen bonds.
 - III. The double-helix structure of DNA places the charged-phosphate groups along the outside of the structure.
 - IV. The sequence 3'AGCGCGAT5' is complementary to 5'TCGCGCTA3'.
 - V. Nucleotides are added together via an addition polymerization reaction.
- A. I only
B. II and III
C. II, III, and V
D. I, II, III, and IV
E. I, II, III, IV, and V
6. Which of these DNA strands will have the greatest strength of binding?
- A. 3' ATGCAT 5' and 3' TACGTA 5'
 - B. 3' AGGTTA 5' and 3' TAACCT 5'
 - C. 3' TGCGCA 5' and 3' TGCGCA 5'**
 - D. 3' AGAGAG 5' and 3' CTCTCT 5'
 - E. 3' AGAGAG 5' and 3' AGAGAG 5'
7. Arrange the following DNA sequences in terms of increasing dehybridization temperature:
- I. 3' AGTCTA 5' and 3' TCAGAT 5'
 - II. 3' GCTAGC 5' and 3' GCTAGC 5'
 - III. 3' TATGC 5' and 3' GCATA 5'
 - IV. 3' AGGGGAT 5' and 3' ATCCCCT 5'
 - V. 3' ATTTA 5' and 3' TAAAT 5'

- A. $V < III < II < I < IV$
- B. $IV < I < II < III < V$
- C. $V < III < II < IV < I$
- D. $I < V < III < II < IV$**
- E. $I < III < V < II < IV$

Programmable Atom Equivalents

8. Which atomic or nanoparticle crystal lattice has the greatest number of nearest neighbors?
- A. Simple Cubic
 - B. BCC
 - C. FCC**
 - D. ZnS (Diamond)
9. DNA-nanoparticle conjugates possess a synergistic combination of chemical and physical properties resulting from each of the individual components that make up the structure. For example, solutions of these the gold nanoparticle versions of these conjugates are bright red in color, owing to the unique optical properties of the gold nanoparticle cores, and they assemble via DNA binding interactions, owing to novel chemical and biological recognition properties of the DNA. Which statements regarding DNA-nanoparticle conjugate structures are **INCORRECT**?
- A. The amount of DNA that can be packed onto the surface of the gold nanoparticle is limited by the repulsion between the negatively charged DNA strands.
 - B. The overall size of the structure, also known as the hydrodynamic radius, can be manipulated by changing both the nanoparticle size and DNA length.
 - C. Nanoparticles functionalized with self-complementary sequences will not bind together.**
 - D. Consider nanoparticles connected via DNA-hybridization. The greater the length of the complementary DNA region, the higher the dissociation (or melting) temperature will be.
 - E. When gold nanoparticles assemble via DNA binding interactions, their optical spectra broadens and blue-shifts.
10. In class, we discussed two sets of design rules for crystal structures: Pauling's rules for ionic solids and the design rules for DNA-nanoparticle superlattices. We used Pauling's rules to help understand some components of DNA-nanoparticle superlattices, but there were also major differences between these two sets of rules. Which of the following statements **CORRECTLY** describes these similarities and differences?
- A. The size of the building blocks (ions or nanoparticles) remains fixed in both systems.
 - B. Ions are held together by atomic orbital overlap, whereas DNA-nanoparticle conjugates are connected via DNA hybridization.
 - C. Only for DNA-nanoparticle conjugates does the crystal structure maximize the number of nearest neighbors.
 - D. "Bond strength" can be altered by changing the atomic or electronic structure of the ion or nanoparticle.
 - E. Both systems predict crystal structure, in part, by the relative sizes of the building blocks.**
11. A series of DNA nanoparticle superlattices are synthesized. All have a 10-nm Au nanoparticle core and 10-nm radius of single-stranded DNA. The only difference between the particles is the

composition of the DNA. When put into solution, some form a FCC structure, while others do not form a structure at all. Based upon the DNA strands listed below, rank the following particles in order from the one that will form the weakest lattice to the one that will form the strongest lattice. Choose one answer.

SNA 1: 3'GCGCGC5'

SNA 2: 3'GCGGCG5'

SNA 3: 3'ATATAT5'

SNA 4: 3'GCTAGC5'

- A. SNA 3 < SNA 4 < SNA 2 = SNA 1
- B. SNA 2 < SNA 3 < SNA 4 < SNA 1**
- C. SNA 1 < SNA 2 < SNA 3 < SNA 4
- D. SNA 4 < SNA 3 < SNA 2 < SNA 1
- E. SNA 3 < SNA 4 < SNA 2 < SNA 1

12. Part A: A unit cell describes the repeating arrangement of atoms or ions within a crystalline lattice. The edge length of the unit cell can be described in terms of the atomic or ionic radii of its components. Given that Cs^+ has an ionic radius of 167 pm and Cl^- has an ionic radius of 181 pm, what will be the edge length of the unit cell? Remember, Pauling's rules for ionic solids place the cation in the center and coordinate anions around this center. Use this result as your unit cell.

- A. 0.989 nm
- B. 0.700 nm
- C. 0.402 nm**
- D. 0.603 nm
- E. 1.050 nm

Part B: Replace the ions in Part A with DNA-nanoparticle conjugates ("artificial atoms"). Which of the following combinations of nanoparticle (NP) radius, DNA length, and DNA sequence will yield a CsCl superlattice?

- A. Particle 1: 10 nm NP, 5 nm DNA, complementary
Particle 2: 10 nm NP, 5 nm DNA, complementary
- B. Particle 1: 20 nm NP, 10 nm DNA, self-complementary
Particle 2: 20 nm NP, 10 nm DNA, self-complementary (same as particle 1)
- C. Particle 1: 15 nm NP, 5 nm DNA, complementary
Particle 2: 15 nm NP, 10 nm DNA, complementary
- D. Particle 1: 10 nm NP, 10 nm DNA, complementary
Particle 2: 15 nm NP, 5 nm DNA, complementary**
- E. Particle 1: 13 nm NP, 6 nm DNA, self-complementary
Particle 2: 20 nm NP, 8 nm DNA, self-complementary

13. Which of the following crystal structure assignments appropriately correlate to the given nanoparticle diameter (NP), DNA length, and DNA sequence?

- I. Particle 1: 10 nm NP, 5 nm DNA, 3' AGAGA 5'
Particle 2: 10 nm NP, 5 nm DNA, 3' TCTCT 5'
Crystal Structure: Body-centered cubic
- II. Particle 1: 10 nm NP, 5 nm DNA, 3' AGAGA 5'

Particle 2: 10 nm NP, 5 nm DNA, 3' AGAGA 5'
 Crystal Structure: Face-centered cubic

III. Particle 1: 15 nm NP, 5 nm DNA, 3' ATGTCA 5'
 Particle 2: 10 nm NP, 10 nm DNA, 3' TACAGT 5'
 Crystal Structure: CsCl (BCC-like)

IV. Particle 1: 20 nm NP, 10 nm DNA, 3' TAGCTA 5'
 Particle 2: 20 nm NP, 10 nm DNA, 3' TAGCTA 5'
 Crystal Structure: None predicted

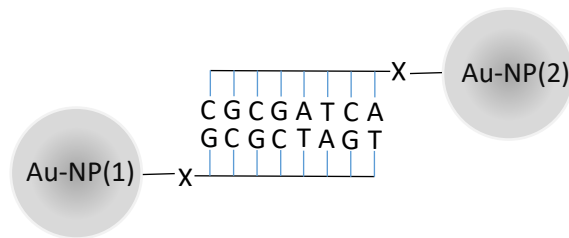
- A. I only
- B. IV only
- C. I and III
- D. I and IV
- E. II, III, and V

14. Consider the following statements about Programmable Atom Equivalents (PAE) and select the correct combination of **TRUE** statements.

- I. A 10-nm gold nanoparticle will arrange itself to maximize the number of DNA duplex bond forms while a 20-nm gold nanoparticle will attempt to minimize the number of DNA duplexes formed due to its larger size
- II. The assembly and packing behavior of a PAE is dictated by the overall hydrodynamic radius rather than the size of the nanoparticle or the length of the oligonucleotide considered separately
- III. A 15-nm nanoparticle with a 5-nm DNA strand of 3'ATATAT 5' can form an FCC structure with another similar nanoparticle
- IV. A 10-nm nanoparticle with a 5-nm DNA strand will produce the same lattice as a 20-nm nanoparticle with a 10-nm DNA strand assuming the strands have the same complementary pairing

- A. I, II, and III
- B. I, III, and IV
- C. II and III
- D. II, III, and IV**
- E. None of the above answer choices (A-D) is correct

15. Consider the following DNA mediated assembly of two gold nanoparticles and select correct combination of **TRUE** statements.

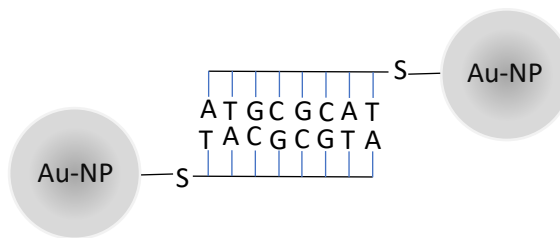


- I. The DNA sequences are self-complementary with a sulfur linker (X)
- II. The DNA sequences are complementary and will most likely form a BCC lattice
- III. There are 21 hydrogen bonds formed between the complementary Watson-Crick base pairs

IV. If similar concentrations of Au-NP(1) and Au-NP(2) are assembled in solution, it can be expected that multiple thermodynamic products with different lattices will be observed

- A. I, III, and IV
- B. II and III**
- C. II, III, and IV
- D. III and IV
- E. None of the above answer choices (A-D) is correct

16. By considering the following sample duplex formed in the DNA-mediated assembly of two gold nanoparticles of the same radius, determine which lattice type(s) is most likely to be formed if only one thermodynamic product is obtained.



- A. Face Centered Cubic (FCC)**
- B. Body Centered Cubic (BCC)
- C. Simple Cubic (SC)
- D. A statistical mixture of SC, BCC, and FCC (1:1:1)
- E. None of the above choices (A – D) is correct

17. Programmable Atom Equivalents (PAEs) are analogous to ionic solids as the DNA-mediated assembly of nanoparticles can also be predicted by a set of design rules. If PAEs formed from the following SNAs have the same hydrodynamic radius and metal nanoparticle core, order them by increasing lattice strength.

- I. NP- 3' GTGCGCAC 5'
- II. NP- 3' GCATATGC 5'
- III. NP- 3' ATTGCAAT 5'
- IV. NP- 3' GATATATC 5'
- V. NP- 3' GTGCGCAC 5'

- A. III < II < IV < V < I
- B. V < I < II < III < IV
- C. III < IV < V = II < I
- D. IV = III < II < I = V**
- E. None of the above choices (A – D) is correct

18. Which of the following statements is/are **FALSE**? Select all that apply.

- A. The apparent color of a nanoparticle depends on its size, shape, and composition.
- B. DNA hybridization is the process by which spherical nucleic acids convert to antisense DNA.**

- C. **Increasing the number of nanoparticles for a given volume decreases the ratio of the surface area to volume.**
- D. Nanostructures are used in catalysis, solar energy harvesting, and energy storage.
- E. **DNA-mediated assembly of gold nanoparticles allows manipulation of particle size and spacing between nanoparticles, but not the crystallographic symmetry.**

19. DNA can be attached to nanoparticles and used to dictate their assembly. A number of design rules have been established for the construction of nanoparticle superlattices from DNA-modified particles. Which of these statements regarding DNA-nanoparticle assembly is **CORRECT**?

- I. The lattice parameters, or the spacing between the nanoparticles, can be adjusted by changing the DNA length.
- II. The preferred crystal structure maximizes the number of DNA hybridization events.
- III. If one type of particle, coated uniformly in a single type of DNA with self-complementary sticky ends, is allowed to assemble, the predicted crystal structure will be BCC.
- IV. Similar to Pauling's Rules for ionic solids, this technique cannot change the properties of the building blocks used in its construction
- V. Nanoparticle superlattices can be disassembled by lowering the temperature, which causes the DNA strands to de-hybridize.

- A. **I and II**
- B. II and V
- C. I, II, III, and V
- D. I, II, IV and V
- E. I, II, III, IV, and V

20. Which of the following is **NOT TRUE** about the difference between atomic lattices and DNA-nanoparticle superlattices?

- A. **The distance between building blocks is fixed in both systems.**
- B. The size of a nanoparticle building block can be changed without changing composition.
- C. The size of an atomic building block cannot be changed without changing composition.

21. Which of the following **CORRECTLY** describe the use of DNA-nanoparticle conjugates in the construction of a BCC (or BCC-like) crystal structure?

- I. One particle type with a self-complementary DNA sequence can be used to construct a BCC lattice.
- II. Two particle types with complementary, but not self-complementary DNA sequences will result in the formation of a BCC lattice.
- III. Formation of a BCC lattice can be explained in terms of Pauling's rules, where particles (ions or DNA-nanoparticle conjugates) with similar sizes will pack with a coordination number of 8.
- IV. BCC-like crystal structures (such as CsCl) can be achieved with unequal NP sizes through adjustment of the DNA length.

- A. I and III
- B. II and III
- C. II and IV
- D. I, III, and IV
- E. **II, III, and IV**

Medical Applications of SNAs

22. Which of the following statements **CORRECTLY** describes the NanoFlare spherical nucleic acid (SNA) construct and how it operates?

- I. When the flare strand is bound to the SNA, luminescence should not be observed.
- II. SNAs enter cells without the need of any additional treatment.
- III. Flare strands are released upon binding of the target mRNA sequence.
- IV. In the presence of a target mRNA sequence, cells will exhibit luminescence (light up).

- A. II only
- B. I, II, and III
- C. I, III, and IV
- D. II, III, and IV
- E. I, II, III, and IV**

23. Arrange the steps in order for the process of anti-sense gene knockdown using spherical nucleic acids (SNAs):

- I. mRNA hybridizes with the SNA-bound DNA.
- II. Protein expression is inhibited due to inability for ribosomes to translate target mRNA.
- III. mRNA is transcribed from DNA in the cell nucleus.
- IV. mRNA enters the cell cytoplasm.
- V. Condition associated with protein expression is mitigated.

- A. IV, III, I, II, V
- B. V, II, IV, I, III
- C. IV, I, III, II, V
- D. III, IV, I, II, V**
- E. I, III, IV, II, V

24. We discussed three methods for how spherical nucleic acids (SNAs) can be used to bind and detect mRNA: NanoFlares, gene knockdown via the anti-sense mechanism, and colorimetric detection (Verigene system). Which of the following statements **INCORRECTLY** describe how SNAs function in these systems?

- A. In the NanoFlare system, the gold nanoparticle core of an SNA “turns off” the flare (fluorophore).
- B. In the anti-sense gene knockdown mechanism, the DNA bound to the SNA serves to bind a complementary mRNA sequence. This hybridization results in elevated translation of the target mRNA sequence into its corresponding protein.**
- C. Colorimetric detection utilizes scattering from the nanoparticle core of an SNA (and any additional gold or silver reduced onto that core), also known as the Tyndall effect, to detect mRNA in bodily fluids.
- D. In the NanoFlare system, the DNA bound to the SNA serves to bind a complementary mRNA sequence. This hybridization displaces the flare strand and allows mRNA detection by luminescence.