'Iolani Science Olympiad Tryout 1

Division C

MATERIALS SCIENCE TEST

Name ______________________________

Honolulu
2025

Preliminary information

- This exam is to be taken in **50 minutes**.
- You may use up to **TWO** standard, 8.5″ × 11″ sheets of paper as references.
- You may use a graphing calculator. **You may not use your phone, iPad, or any electronic devices with internet capabilities** for any purposes *other than timing yourself.*
- Once you have been working on the exam for 50 minutes, **you must stop answering questions** and turn it in.
- This test will be graded out of **67 points**.
- Ties will be broken as follows: If two people get the same test score, the person with the highest free-response score ranks higher. If both people moreover have the same free-response score, find the last question on the test for which one person got more points than the other. The winner is the person with the most points on that question.

1 Multiple-Choice Questions

1. (1 point) The theoretical maximum packing efficiency of the hexagonal close-packed structure is:
   - A. 67.0%
   - **B. 74.0%**
   - C. 52.4%
   - D. 80.0%

2. (1 point) A compound with $r_{\text{cat}}/r_{\text{an}} \approx 0.800$ is most likely to adopt which coordination geometry?
   - A. Linear (CN = 2)
   - B. Tetrahedral (CN = 4)
   - C. Octahedral (CN = 6)
   - **D. Cubic (CN = 8)**

3. (1 point) For a cubic crystal with $a = 4.00\,\text{Å}$ and Cu Kα radiation $\lambda = 1.54\,\text{Å}$, the (200) reflection appears at a Bragg angle $\theta \approx$
   - A. 11°
   - **B.** 22°
   - C. 44°
   - D. 68°

4. (1 point) In another cubic crystal ($a = 3.60\,\text{Å}$), the (111) peak is at $2\theta \approx 44°$ with Cu Kα. Using Mo Kα ($\lambda = 0.71\,\text{Å}$), the corresponding 2θ is nearest
   - A. 10°
   - **B.** 19°
   - C. 31°
   - D. 60°

5. (1 point) A tetragonal cell has $a = b = 4.00\,\text{Å}$, $c = 5.00\,\text{Å}$. The ratio d_{002}/d_{200} is
   - A. 0.80
   - B. 1.00

C. 1.25

D. 1.50

6. (1 point) A crystallographic plane intercepts the axes at $(\frac{1}{2}a, \infty, c)$. Its Miller indices (hkl) are

   A. (1 0 2)

   B. (2 0 1)

   C. (0 2 1)

   D. (1 2 0)

7. (1 point) In a BCC lattice, which family is systematically absent?

   A. {100}

   B. {110}

   C. {200}

   D. {211}

8. (1 point) In an FCC lattice, which reflection is allowed?

   A. (111)

   B. (210)

   C. (100)

   D. (310)

9. (1 point) In the CsCl structure, if $f_{\mathrm{Cs}} = f_{\mathrm{Cl}}$ exactly, which (hkl) would be extinct?

   A. (110)

   B. (200)

   C. (111)

   D. (002)

10. (1 point) In a Williamson–Hall plot of $\beta \cos\theta$ vs. $\sin\theta$, the intercept on the vertical axis yields information on

    A. microstrain

    B. crystallite size

    C. instrumental broadening

    D. lattice parameter

11. (1 point) In space group Pm$\bar{3}$m (primitive cubic), which reflection is systematically absent?

    A. (100)

    B. (110)

    C. (111)

    D. none

12. (1 point) Which of the following plane families has the highest multiplicity in a cubic lattice?

    A. {100}

    B. {110}

    C. {111}

    D. {210}

13. (1 point) At fixed θ, heavier elements scatter X-rays more strongly because their atomic scattering factor f
    A. drops off faster with angle
    B. has a larger magnitude
    C. is constant
    D. is purely imaginary

14. (1 point) Hydrogen has a negative coherent neutron scattering length, which causes
    A. constructive interference
    B. destructive interference
    C. no contrast
    D. resonance scattering

15. (1 point) The "phase problem" in crystallography refers to the inability to measure directly the
    A. structure-factor amplitudes
    B. structure-factor phases
    C. unit-cell dimensions
    D. Bragg angles

16. (1 point) A key advantage of powder diffraction over single-crystal methods is that
    A. it requires no single crystal
    B. it gives directional intensities
    C. it solves phases directly
    D. it has no peak overlap

17. (1 point) A typical Frenkel defect in AgCl involves:
    A. Cl vacancy + Cl interstitial
    B. Ag vacancy + Ag interstitial
    C. Cl vacancy + Ag interstitial
    D. Ag vacancy + Cl interstitial

18. (1 point) In an ideal Schottky defect in NaCl, the ratio of vacancies is:
    A. 1 Na^+ : 1 Cl^-
    B. 2 Na^+ : 1 Cl^-
    C. 1 Na^+ : 2 Cl^-
    D. 2 Na^+ : 2 Cl^-

19. (1 point) Metal nanoparticles exhibit unique properties primarily due to their:
    A. High melting point
    B. Large surface-to-volume ratio
    C. High density
    D. Bulk crystalline structure

20. (1 point) Gold nanoparticles display different colors depending on their size due to:
    A. Bragg diffraction
    B. Surface plasmon resonance

C. Interband transitions
D. Quantum tunneling

21. (1 point) Which of the following is a common example of a metal oxide nanomaterial?
A. Silver (Ag)
B. Copper (Cu)
C. Titanium dioxide (TiO_2)
D. Graphene

22. (1 point) ZnO nanorods are primarily used for:
A. Heat insulation
B. UV detection and photocatalysis
C. Electrical wiring
D. Lubrication

23. (1 point) Ceramic nanomaterials typically exhibit:
A. High electrical conductivity
B. Low melting point
C. High hardness and thermal stability
D. Ductility

24. (1 point) A quantum dot is an example of a:
A. Zero-dimensional nanomaterial
B. One-dimensional nanomaterial
C. Two-dimensional nanomaterial
D. Three-dimensional nanomaterial

25. (1 point) Nanotubes belong to which dimensional classification?
A. Zero-dimensional
B. One-dimensional
C. Two-dimensional
D. Three-dimensional

26. (1 point) Graphene is considered a:
A. Zero-dimensional nanomaterial
B. One-dimensional nanomaterial
C. Two-dimensional nanomaterial
D. Three-dimensional nanomaterial

27. (1 point) Nanocomposites with nanoparticles dispersed in a matrix are examples of:
A. 0D materials
B. 1D materials
C. 2D materials
D. 3D materials

28. (1 point) Carbon nanotubes are widely used in composites because of their:

A. Low melting point
B. High tensile strength and electrical conductivity
C. Magnetic properties
D. Transparency

29. (1 point) Fullerenes (C_{60}) are best described as:
A. Zero-dimensional carbon nanomaterials
B. One-dimensional carbon nanomaterials
C. Two-dimensional carbon nanomaterials
D. Three-dimensional carbon nanomaterials

30. (1 point) The sol-gel process is a:
A. Bottom-up synthesis method
B. Top-down synthesis method
C. Mechanical process
D. Thermal decomposition process

31. (1 point) Ball milling is an example of:
A. Bottom-up synthesis
B. Top-down synthesis
C. Electrochemical deposition
D. Atomic layer deposition

32. (1 point) Chemical vapor deposition (CVD) is commonly used to synthesize:
A. Metal nanospheres
B. Graphene and carbon nanotubes
C. Ceramic nanofibers
D. Nanofluids

33. (1 point) Molecular beam epitaxy is typically employed in the growth of:
A. Polymer films
B. Metal foils
C. Semiconductor nanostructures
D. Oxide ceramics

34. (1 point) Lithography used in nanofabrication is a:
A. Top-down approach
B. Bottom-up approach
C. Chemical etching process
D. Self-assembly process

35. (1 point) In a nanofluid, nanoparticles are typically dispersed in:
A. Air
B. Solid matrix
C. Liquid medium
D. Vacuum

36. (1 point) The main purpose of adding nanoparticles to a fluid is to:
    A. Decrease viscosity
    B. Enhance thermal conductivity
    C. Reduce density
    D. Increase boiling point

37. (1 point) Which of the following methods involves etching away bulk material to create nanostructures?
    A. Chemical etching
    B. Sol-gel
    C. Self-assembly
    D. Molecular beam epitaxy

38. (1 point) The term "quantum confinement" is most relevant to which type of nanomaterial?
    A. Semiconductor nanomaterials
    B. Ceramic nanomaterials
    C. Metal nanomaterials
    D. Carbon-based nanomaterials

39. (1 point) Which property of metal nanoparticles is most affected by particle size?
    A. Density
    B. Optical absorption
    C. Hardness
    D. Thermal expansion

40. (1 point) Self-assembly is an example of:
    A. Physical vapor deposition
    B. Bottom-up synthesis technique
    C. Top-down fabrication
    D. Mechanical alloying

41. (1 point) TiO_2 nanoparticles are often used in sunscreens because they:
    A. Reflect infrared radiation
    B. Scatter and absorb UV radiation
    C. Act as lubricants
    D. Improve conductivity

42. (1 point) The enhanced catalytic activity of metal-oxide nanoparticles arises mainly from:
    A. Crystal defects
    B. High surface area and reactive sites
    C. Bulk conductivity
    D. High density

43. (1 point) Which of the following is NOT a bottom-up nanofabrication technique?
    A. Sol-gel
    B. Self-assembly
    C. Chemical vapor deposition

D. Mechanical milling

44. (1 point) The melting point of nanoparticles generally:
    A. Increases with decreasing size
    B. Decreases with decreasing size
    C. Remains constant
    D. Depends only on composition

45. (1 point) The high aspect ratio of nanowires makes them useful in:
    A. Catalysis
    B. Nanoscale electronics and sensors
    C. Thermal insulation
    D. Magnetic shielding

46. (1 point) Which synthesis method is most suitable for producing highly crystalline semiconductor nanowires?
    A. Ball milling
    B. Sol-gel
    C. Chemical vapor deposition
    D. Chemical etching

47. (1 point) In top-down nanofabrication, the main challenge is:
    A. Achieving precise atomic control
    B. Forming self-assembled structures
    C. Maintaining structural integrity at small scales
    D. Chemical contamination

48. (1 point) Scattering of light by nanoparticles is stronger when:
    A. Particle size is much smaller than the wavelength
    B. Particle size is comparable to the wavelength
    C. Particle size is much larger than the wavelength
    D. The particles are transparent

49. (1 point) The phenomenon where light changes direction when passing from one medium to another is called:
    A. Reflection
    B. Refraction
    C. Absorption
    D. Transmission

50. (1 point) The transmission of light through a nanomaterial decreases if:
    A. Scattering is low
    B. Absorption is low
    C. Absorption or scattering is high
    D. The refractive index is small

51. (1 point) Luminescence refers to:

A. Absorption of light
B. Reflection of light
C. Emission of light from a material after excitation
D. Scattering of light

52. (1 point) Fluorescence differs from phosphorescence mainly because fluorescence:
    A. Occurs almost immediately after excitation
    B. Continues long after excitation stops
    C. Requires heat to emit light
    D. Involves only nonradiative transitions

53. (1 point) When the size of a semiconductor nanoparticle decreases, its absorption edge:
    A. Shifts to longer wavelengths (red shift)
    B. Shifts to shorter wavelengths (blue shift)
    C. Remains unchanged
    D. Disappears completely

2 Free-Response Questions

54. (4 points) A solid aluminum, circular shaft has length 0.35 m and diameter 6 mm. How much does one end rotate relative to the other if a torque about the shaft axis of 10 N·m is applied? The elastic modulus of aluminum is 70×10^9 N/m^2.

Solution: +4pts if obtains 1.05 rad or 60 degrees
+2pts if incorrect final answer but used G=E/(2(1+v))
+1pt if obtains 0.39 rad (i.e. uses G=70GPa instead of converting from E)

55. (4 points) A steel wire with a radius of 0.0625 in and a yield strength of 120x10^3 psi is wound around a circular cylinder of radius 20 in for storage. Your boss, wanting to get a bonus from saving money on storage costs, suggests reducing the radius of the cylinder to 12 in. How do you respond?

Solution: From $\sigma_y = M_b y/I$ and $M_b = EI/\rho$ we get $\sigma_y = Ey/\rho$. Plugging radius 12inches in, $\sigma_y = 151 \times 10^3$ psi which is bigger than our yield strength. So if the radius of cylinder is reduced to 12 in, the stress in the steel wire will exceed the yield strength and thus make the steel wire fail (or undergone permanent plastic deformation). This is clearly not good and thus you should tell your boss about this and inform him that the minimum radius of the cylinder that can be used for this steel wire storage is 16 in. But for safety reason and if it is stored for a long time period, you might want to keep the stress in the steel wire well below the yield stress. In this case, the original 20 in radius is a good choice.

+2pts: Correctly identifies or uses the relationship between bending stress and radius of curvature
+1pt: Notes that bending stress exceeds yield strength with numerically correct reasoning (must state 150ksi>120ksi)
+1pt: States that reducing the radius to 12 in would cause yielding or permanent deformation, recommends keeping radius greater than or equal to 16-20inches. Must include qualitative justification (e.g. to avoid failure or plastic deformation)

56. (4 points) Sketch $(1\bar{2}2)$ and $[1\bar{2}2]$. Explain the difference between the two.

Solution:

+1pt: $(1\bar{2}2)$ is a crystallographic plane.

+1pt: $[1\bar{2}2]$ is a crystallographic direction.

+1pt: Draws plane correctly. (If you don't know what this looks like, I recommend checking out Cambridge's simulation at doitpoms.ac.uk)

+1pt: Draws direction correctly. Should be an arrow starting at (0,1,0) and ending at (1/2, 0, 1).

DO NOT AWARD POINTS for drawings if the axes are not labeled.

57. (2 points) A 1cm radius spherical soap bubble and a 2cm radius spherical soap bubble are connected by a very thin tube. The bubbles are made from the same solution with constant surface tension $\gamma = 30$ mN/m. Due to the pressure difference between the bubbles, air transfers from one bubble to the other until they are both the same size. Compute the change in surface free energy of the system between the initial and final states. *The air is ideal and the process is isothermal at room temperature. Neglect gravity, tube volume, and any evaporation.*

Solution: The Laplace pressure for a soap bubble is $\Delta p = 4\gamma/R$. For the common final radius R_F, we use the ideal gas law $PV = nRT$. The number of moles of gas is fixed because the system is closed by the bubble boundaries and the tube, the temperature is fixed because the process is isothermal, so PV is an invariant:

$$(p_0 + \frac{4\gamma}{R_1})V_1 + (p_0 + \frac{4\gamma}{R_2})V_2 = (p_0 + \frac{4\gamma}{R_f}) \cdot 2(\frac{4}{3}\pi R_f^3)$$

Using the given values and standard value for atmospheric pressure, $R_f \approx 1.651cm$. The initial area $A_i = 4\pi(R_1^2 + R_2^2) = 6.283 \times 10^{-3}m^2$, final area $A_f = 2 \cdot 4\pi R_f^2 = 6.850 \times 10^{-3}m^2$, so change $\Delta A = 5.672 \times 10^{-4}m^2$. The surface free energy is $G = 2\gamma A$ so the change is $\Delta G = 2\gamma\Delta A = 3.40 \times 10^{-5}J$.

+2pts: Correct numerical answer with reasoning shown.
+1pt: Incorrect numerical answer, but obtained correct radius.
+0.5pt: Incorrect numerical answer and incorrect radius, but used ideal gas law to conclude PV is invariant.
+0.5pt: Incorrect numerical answer, but used $\Delta G = 2\gamma\Delta A$.