Exam 1

Physics 140, 9:45-11:20 Thursday October 4 2018

You may use a 3"x5" card of notes, both sides, and a calculator. NO PHONES.

Do simple integrals. Leave complex ones unevaluated.

You're expected to do integrals like $\int cz^n dz$, $\int ce^{kx} dx$, $\int c \ln(ky) dy$, $\int \frac{1}{(a+r)} dr$, $\int c \cos(k\theta) d\theta$, or $\int c \sin(k\phi) d\phi$.

Don't do the integration on anything more complex. Instead, move all constants out of the integral, reasonably simplify all terms, specify limits, and clearly write the integral.

Possibly useful expressions, constants

k

e

me

mn

Periodic table

Present *clear* and *complete* answers.

Unjustified answers will earn no points. Any person who has taken this class should be able to understand what you did just by reading your solution. A diagram and a few words usually help. Start calculations with definitions (*e.g.* $\vec{v} \equiv \frac{d\vec{r}}{dt}$), facts (*e.g.* Newton's laws), or commonly used equations (*e.g.* constant acceleration equations).

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1. What is condensed matter physics? Provide a 1-5 sentence answer that any undergraduate science major would understand. Use your own words.

2. (a) What does the Bohr model (or an extended Bohr model) predict for ionization energies?

   (b) Are these consistent with experimental measurements? If they aren't consistent, *how* are they inconsistent? For example, too low, negative instead of positive, increasing, ...

3. (a) Write the ground state electron configuration of a given element.

   (b) What is *screening*, and how does it affect ionization energies? Provide a 1-5 sentence answer. Include at least one relevant diagram, equation, or numerical value to support your explanation. A specific example is always welcome.

   (c) By looking at the periodic table, identify which elements have the same number of electrons in their valence shell.

4. Why do atoms form a crystal?

   In particular, in an ionic material like NaCl, what leads to the attraction between Na and Cl?

   Briefly describe an energy calculation that shows that a NaCl crystal has a lower energy than unbound Na and Cl atoms.

5. Sketch a representative graph of the interatomic potential, $U(r)$. Identify the following on the plot

   (a) the equilibrium separation
   (b) region(s) that show the presence of a repulsive force
   (c) region(s) where the two atoms are *bound*
   (d) region(s) where the atoms are *free* or unbound.

6. Identify fcc, bcc, and simple cubic structures.

   Calculate the filling fraction for each.

7. Given a periodic structure, identify

   (a) a set of lattice vectors to define a unit cell
   (b) the unit cell
   (c) the basis of atoms for your choice of lattice vectors
   (d) whether your unit cell is primitive, non-primitive or is the conventional unit cell.

   Alternatively, construct (sketch!) the periodic structure from a set of lattice vectors and a basis.

8. (a) How is x-ray diffraction used to determine the lattice structure, particularly spacing?

   (b) From a graph of intensity versus angle, calculate the lattice spacing.

   (c) For a given lattice spacing, what kinds of wavelengths are useful?

9. (a) What is electron diffraction or neutron diffraction and how is it used to determine lattice structure, particularly spacing?

   (b) Determine the energy required to create a beam of electrons (or neutrons) with a specific deBroglie wavelength. Or the other way around.

10. Carry out calculations involving

    (a) Young's modulus, stress and strain
    (b) the modulus of rigidity, shear stress and shear angle
    (c) the bulk modulus, pressure and volume change
    (d) Poisson's ratio, strain parallel to the stress and perpendicular to the stress

11. (a) How can elastic deformation of a crystal be described microscopically?

    (b) Why can we expect Hooke's law to hold for a small strain?

    (c) Carry out a calculation to support your answer. (A Taylor series expansion is expected here.)

12. How do the stress-strain curves look for typical ductile and typical brittle materials? Identify the yield stress, yield strain, and Young's modulus in the curves.

13. The atoms in a lattice vibrate even at absolute zero. Explain why. Include a calculation in your explanation.

14. Model atoms in a crystal as a set of *independent* harmonic oscillators.

    Outline the calculation that leads to the result that the atoms oscillate at $\omega = \sqrt{\frac{\gamma}{m}}$. Start with Newton's second law and a proposed function for $x(t)$.

15. Model a crystal as a 1D chain of atoms.

    Outline the calculation that leads to the dispersion relation, $\omega(k)$. Start with Newton's second law and a proposed function for $u_n(x,t)$.

16. Consider a given dispersion relation $\omega(k)$.

    (a) At what frequencies will the atoms oscillate?
    (b) What value of k corresponds to the long wavelength limit?
    (c) Calculate the group velocity at certain limits (long wavelength and $k = \pi/a$)

17. In some crystal structures, the dispersion relation is said to have two branches. Why are the branches called the *acoustic* branch the *optical* branch?