Exam 2

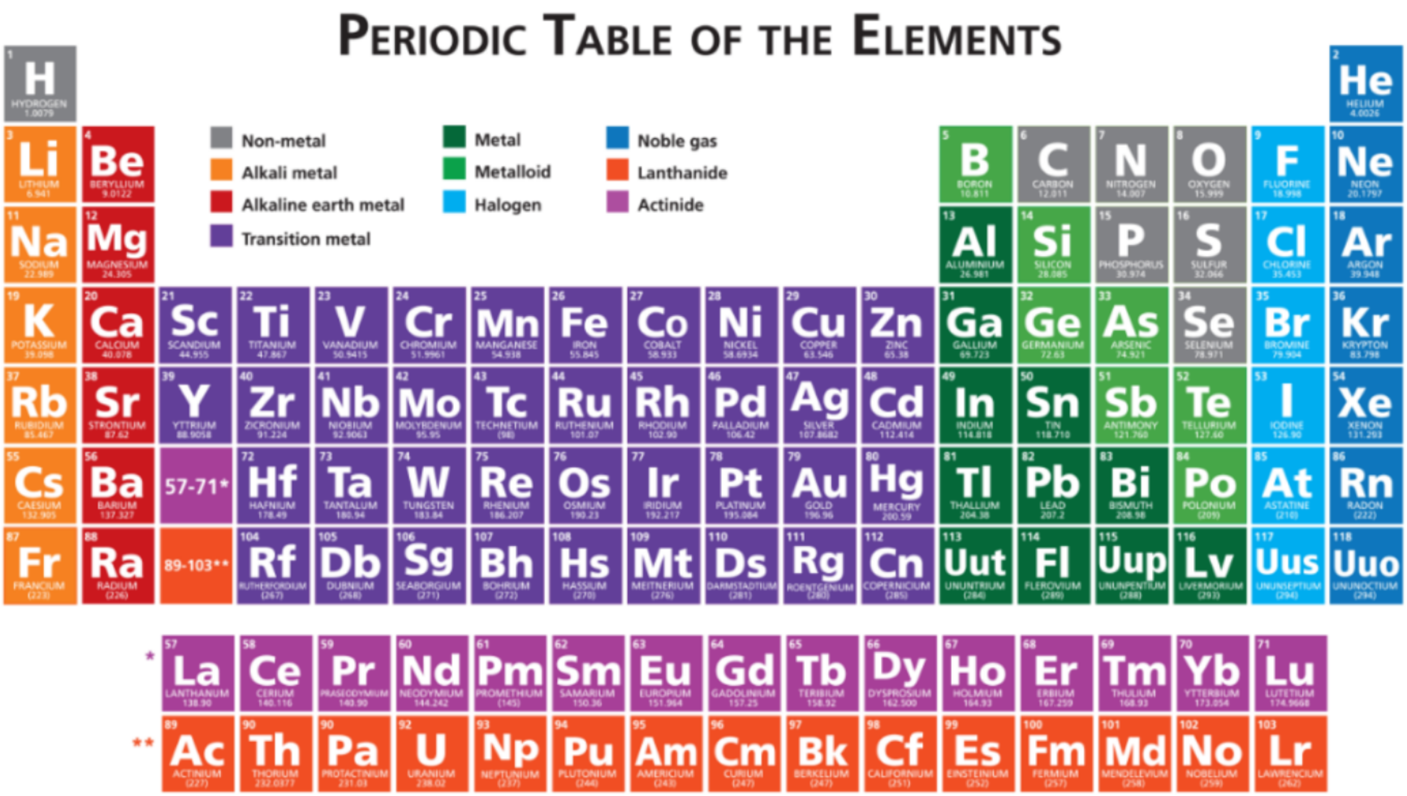
Physics 140, 9:45-11:20 Tuesday November 13 2018

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.



1. We consider lattice vibrations even at absolute zero. Why? Use the Heisenberg uncertainty principle and include a calculation to support your answer.

2. We often use the simple harmonic oscillator to model lattice vibrations. Why? Provide text, a diagram and one or two relevant equations.

   When is the harmonic approximation *not* valid?

3. What's the frequency of lattice vibrations? We addressed this with two models.

   (a) The first uses 3N independent oscillations. How do we determine ω?

   (b) The second uses an *infinite* chain of atoms. How do we determine ω?

   (c) Compare the two results for ω. How are they different?

   (d) We can usually modify the second to address a *finite* chain of identical atoms. Why do we do this? How does this change ω? Outline how this comes about.

4. What are *phonons*?

5. (a) What is heat capacity C?

   (b) What's typically experimentally observed for C at room temperature? As temperature decreases?

   (c) Calculate values C from macroscopic quantities (temperature and heat).

6. We considered three models for the heat capacity contribution from the lattice.

   (a) Why do we use lattice vibrations in explaining heat capacity?

   (b) Determine C from the energy of a system.

   (c) For the classical model: How energy is calculated? What's predicted for C and how does it match experimental observations?

   (d) Repeat (c) for the Einstein model

7. (a) What are the Debye model's assumptions? You can discuss this in terms of how its ideas are similar to or different from the Einstein model.

   (b) The Debye model uses the density of states $g(\omega)$. What does $g(\omega)$ describe? Where is it used in the Debye model?

8. (a) What's thermal conductivity κ?

   (b) Calculate values of κ from macroscopic quantities (temperature gradient and heat transfer).

   (c) What is the microscopic model for κ? Refer to mean free path, the speed of sound, and a diagram in your answer.

   (d) Why do we use lattice vibrations (phonons) in explaining κ?

9. Explain why a solid undergoes thermal expansion in a microscopic model.

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10. (a) Describe the basic assumptions of the Drude model for metals. Explain relaxation time and the mean free path in your answer.

    (b) What determines how fast electrons move in the Drude model?

    (c) Calculate thermal speed, relaxation time and mean free path.

11. (a) Where does electrical resistance come from in the Drude model?

    (b) When an electric field is applied, how does the electron drift speed compare with their thermal speed? Calculate drift speed.

    (c) What is the microscopic version of Ohm's law? Outline how to derive the microscopic version of Ohm's law with the Drude model.

    (d) Calculate values of conductivity of a metal based on the Drude model.

12. From an energy band schematic,

    (a) Determine if a material is a conductor, insulator or semiconductor.

    (b) Identify the conduction band and the valence band. Which electrons can participate in conduction?

    (c) Identify the Fermi level

13. Describe the basic assumptions of the free electron model.

14. The Fermi energy is given by $E_f = \frac{\hbar^2}{2m_e}(3\pi^2 n)^{2/3}$.

    (a) What does the Fermi energy describe? Do all electrons have an energy equal to E_f?

    (b) Outline how to arrive at this expression.

    (c) Calculate values of the Fermi energy and Fermi velocity.

15. (a) What does the Fermi-Dirac distribution describe?

    (b) Calculate the total number of electrons with energy $E \to (E+\Delta E)$ at some temperature T. This is an integral. Identify each of the terms. Leave it as an integral.

16. (a) What happens to the F-D distribution when temperature increases? What is the soft-zone and how is affected by T?

    (b) Only electrons in the soft-zone can participate in conduction. Calculate the density of these electrons. Leave your answer as an integral.

    (c) Typically, what percentage of the valence electrons can actually participate in conduction?