Short Answers (3 points each):

1. Explain why conduction electrons don’t contribute to the specific heat of a metal.

2. Calculate the energy required to ionize a Helium atom from He\(^+\) to He\(^{++}\).

3. Explain why light with wavelength of 600 nm incident on potassium (with work function 2.24 eV) is unable to produce the photoelectric effect.

4. Rank the following in terms of increasing de Broglie wavelength at room temperature: electrons, neutrons, Nitrogen atoms.

5. Explain the short-range nature of the strong nuclear force in terms of virtual mesons, as opposed to photons which have no mass.

6. Sketch the wave function and probability distribution for the \(n = 2\) state of an electron in a one-dimensional finite square well potential.

7. What is the electron orbital angular momentum of a potassium atom in the ground state? \((Z = 19)\)

8. Why can't a photon decay to an electron and positron in free space?
Quantitative Questions (16 points each):

9. A runner carries a pole 10m long towards the open front door of a small barn 5m long. A farmer stands near the barn at equal distance from the front and back door.
   The runner is moving at a speed of \( v = 0.866c \).
   a. What is the length of the barn as seen by the runner?
   b. What is the length of the pole as seen by the farmer?
   c. The farmer sees the pole reach the front door of the barn at \( t = 0 \) on his clock. At what time does he see the pole reach the back door?
   d. The farmer observes that when the pole reaches the back door both doors simultaneously close. At what times to the doors close in the runners frame of reference?
   e. Draw a space-time diagram from the farmer’s frame of reference. Include the coordinate axes of the runner (the moving frame), the world lines of the front and back of the pole, and the events corresponding to the closing of the front (\( F \)) and back (\( B \)) doors.

10. Consider the decay \( \psi \rightarrow \mu^+ + \mu^- \) of a \( \psi \) meson to a muon and an anti-muon. The rest mass of the \( \psi \) particle is \( m_\psi = 3100 \text{ MeV/c}^2 \), and the rest mass of each muon is \( m_\mu = 105.7 \text{ MeV/c}^2 \).
   a. What is the energy and momentum of the outgoing muon in the rest frame of the original \( \psi \) particle? What is the magnitude of the muon velocity?
   b. Now consider a frame in which the muon is at rest. What is the energy of the anti-muon?
   c. For each of the following decays, state whether it is an allowed interaction or state the conservation law that forbids the interaction.
      i. \( \psi \rightarrow \mu^+ + \mu^- \)
      ii. \( \psi \rightarrow p + e^- + \nu_e \)
      iii. \( \psi \rightarrow e^- + \nu_e \)
      iv. \( \psi \rightarrow \bar{\mu}^+ + e^- \)

11. Consider a proton moving in a one-dimensional potential well with \( V(x)=0 \) for \( x \) between 0 and \( L \) and \( V(x)=\infty \) elsewhere. The mass of a proton is \( m_p = 935 \text{ MeV/c}^2 \) and \( L = 2.5 \text{ fm} \).
   a. Write down the ground state wave function.
   b. Compute the ground state energy in MeV.
   c. What is the wavelength of a photon emitted in a transition from the first excited state to the ground state energy?
   d. What is the ground state energy of seven protons in this potential well?
Multiple Choice (3 points each):

12. If a charged pion that decays in $10^{-8}$ second in its own rest frame is to travel 30 meters in the laboratory before decaying, its speed must be most nearly
   a. $0.43 \times 10^8$ m/s
   b. $2.84 \times 10^8$ m/s
   c. $2.90 \times 10^8$ m/s
   d. $2.98 \times 10^8$ m/s
   e. $3.00 \times 10^8$ m/s

13. If the absolute temperature of a blackbody is increased by a factor of 3, the energy radiated per second per unit area does which of the following?
   a. Decreases by a factor of 81
   b. Decreases by a factor of 9
   c. Increases by a factor of 9
   d. Increases by a factor of 27
   e. Increases by a factor of 81

14. If the total energy of a particle of mass $m$ is equal to three times its rest energy, then the magnitude of the particle’s relativistic momentum is
   a. $mc / 3$
   b. $mc / 2$
   c. $2mc$
   d. $\sqrt{8mc}$
   e. $3mc$

15. A free particle with initial kinetic energy $E$ and de Broglie wavelength $\lambda$ enters a region in which it has potential energy $V$. What is the particle’s new de Broglie wavelength?
   a. $\lambda (1 + E/V)$
   b. $\lambda (1 - V/E)$
   c. $\lambda (1 - E/V)^{1/2}$
   d. $\lambda (1 + V/E)^{1/2}$
   e. $\lambda (1 - V/E)^{1/2}$

16. $^7$Be transforms into $^7$Li by
   a. emitting an alpha particle only
   b. emitting an electron only
   c. emitting a proton only
   d. emitting a neutron only
   e. electron capture by the nucleus with emission of a neutrino

17. The mean kinetic energy of the conduction electrons in metals is ordinarily much higher than $kT$ because
   a. electrons have more degrees of freedom than atoms
   b. the electrons and the lattice are not in thermal equilibrium
   c. the electrons form a degenerate Fermi gas
   d. electrons in metals are highly relativistic
   e. electrons interact via phonons
18. The muon decays with a characteristic lifetime of about $10^{-6}$ second into an electron, a muon neutrino, and an electron antineutrino. The muon is forbidden from decaying into an electron and just a single neutrino by the law of conservation of
   a. charge
   b. mass
   c. energy and momentum
   d. baryon number
   e. lepton number

19. The solution to the Schrödinger equation for the ground state of hydrogen is
   \[ \psi_0 = \frac{1}{\sqrt{\pi a_0}} e^{-r/a_0} \]

   In spherical symmetry the probability distribution is given by $4\pi r^2 \psi^* \psi$. What is the most probable value for $r$?
   a. 0
   b. $a_0/2$
   c. $a_0$
   d. $2a_0$
   e. $\infty$

20. A beam of electrons is accelerated through a potential difference of 25 kilovolts in an x-ray tube. The continuous x-ray spectrum will have a short wavelength limit of most nearly
   a. 0.1 Å
   b. 0.5 Å
   c. 2 Å
   d. 10 Å
   e. 50 Å