LINKÖPINGS UNIVERSITET

Department of Science and Technology
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Exam for TNE041, **Modern Physics**, 26 August 2023, 8.00 – 12.00.

Allowed examination material: Physics handbook (Studentlitteratur)
calculator (with no wifi)
additional formulae (attached)
one hand-written sheet (A4, not copied, with notes on one side)

Define all quantities you use and give a clear answer, including unit if a numerical value is given. No points are given if only the answer is submitted, with the exception of true/false questions. The maximum score is 24 points (6x4). The limits for different grades given below is with bonus included. The solutions may be given in English or in Swedish.

The following limits for grades apply:

Grade 3	≥ 10 points
Grade 4	≥ 15 points
Grade 5	≥ 19 points

Questions are answered by Michael Hörnquist who is available on phone during the whole exam. Answers and short solutions will be available at Studieinfo at 4 pm at the latest. Results will be reported not later than 15 working days after the exam.

Good luck!

1. (a) Are the following statements true or false?
   i. The photoelectric effect shows that light is a wave phenomenom.
   ii. The function $\Psi(x,t) = A\sin(kx - \omega t)$ is a solution to the time-dependent Schrödinger equation for a free particle.
   iii. The reflection coefficient R for a free electron with energy 10 eV incident on a potential barrier of height 15 eV and width 2 nm is $R = 1$.
   iv. The Pauli principle applies to both electrons and protons, but not to neutrons.

   Only the answers (true/false) are required. (2p)

   (b) Determine the speed of a proton accelerated from rest by a potential of 1 GV. (2p)

2. An electron moving to the left with speed $0,8c$ collides with an incoming photon moving to the right. After the collision the electron is moving to the right with speed $0,6c$ and an outgoing photon moves to the left.

   (a) Determine the wavelength of the incoming electron. (1p)

   (b) Determine the wavelength of the incoming photon. (3p)

3. Consider a QM-particle described by the wave function ψ given as

$$\psi(x) = \begin{cases} 0 & \text{if } x < 0 \\ 2a^{3/2}xe^{-ax} & \text{if } x \geq 0 \end{cases}$$

   with $a = 1,0\ (\text{nm})^{-1}$.

   (a) Determine the probability to detect the particle in the interval $0 < x < a^{-1}$. (2p)

   (b) Calculate the uncertainty in the particle's position, i.e., determine Δx. (2p)

4. An electron is in the $n = 3$ state of a hydrogen atom.

   (a) What is its energy? (1p)

   (b) What two other properties besides energy are quantized as a consequence of the Schrödinger equation? (1p)

   (c) What are the possible values one might obtain if the properties in (b) are measured? Answers are supposed to be expressed in $\hbar$. (2p)

5. Consider copper (native) at room temperature (20^oC).

   (a) Calculate the Fermi energy within the free electron model, using only the free electron concentration as specific value for copper (PH T8.1). (2p)

   (b) Estimate how far a conduction electron would travel before colliding, using the resistivity value from PH T2.1 and the result and concentration value from (a). (2p)

6. (a) Write the electronic configurations for phosphorus ($Z = 15$). (2p)

   (b) Diamond (carbon) has a band gap of approximately 5 eV, silicon har one of 1 eV. Despite they have the same covalent crystal structure, diamond is transparent to visible light while silicon is opaque. Explain how this can be, based on the difference in band gaps. (2p)