Last Name:_________________First Name___________________ID____________________
Discussion Section:_________Discussion TA Name:__________________________________

Instructions—
This is a closed book exam. You have two (2) hours to complete it.

I. Fill in ALL the information requested on the lines above and sign the Formula Sheet.

II. At the end of this exam, you must return this Exam Booklet complete with all pages, *including the formula sheet*, along with your answer sheet. Note that this is a different policy than the one applying to hour exams.

III. If you do not turn in a complete Exam Booklet, including the formula sheet, your Answer Sheet will not be graded and you will receive the grade AB (Absent) for this exam.
Kindly paper clip *the Answer Sheet to the Exam Booklet*

1. Use a #2 pencil. Do not use a mechanical pencil or pen. Darken each circle completely, but stay within the boundary. If you decide to change an answer, erase vigorously; the scanner sometimes registers incompletely erased marks as intended answers; this can adversely affect your grade. Light marks or marks extending outside the circle may be read improperly by the scanner. Be especially careful that your mark covers the **center** of its circle.
2. **This Exam Booklet is Version A**. Mark **A** in the TEST FORM box on your answer sheet. **DO THIS NOW!**
3. Print your **NETWORK ID** in the designated spaces at the *right* side of the answer sheet, starting in the left most column, then **mark the corresponding circle** below each character. If there is a letter "o" in your NetID, be sure to mark the "o" circle and not the circle for the digit zero. If and only if there is a hyphen "-" in your NetID, mark the hyphen circle at the bottom of the column. When you have finished marking the circles corresponding to your NetID, check particularly that you have not marked two circles in any one of the columns.
4. Print your **LAST NAME** and **FIRST INITIAL** on the answer sheet in the designated spaces, starting in the left most column, then mark the corresponding letter circles below.
5. Do not write in or mark the circles in any of the other boxes (STUDENT NUMBER, DATE, SECTION, SCORES, SPECIAL CODE).
6. Sign your name **(DO NOT PRINT)** on the STUDENT SIGNATURE line.
7. On the **SECTION** line, enter your **DISCUSSION SECTION**. You may omit filling in the SECTION box and COURSE and INSTRUCTOR lines.

CHECK NOW THAT YOU HAVE COMPLETED ALL OF THE ABOVE STEPS, YOUR GRADE DEPENDS ON IT!

Before starting work, check to make sure that your test booklet is complete. You should have **12 pages (33 problems)**, excluding the Formula Sheets at the end. Grading policy is explained on page 2.

Academic Integrity—*Giving assistance to or receiving assistance from another student or using unauthorized materials during a University Examination can be grounds for disciplinary action, up to and including expulsion.*

Exam Grading Policy—

The exam is worth a total of 162 points, composed of two types of questions.

MC5: *multiple-choice-five-answer questions, each worth 6 points.*
Partial credit will be granted as follows.

(a) If you mark only one answer and it is the correct answer,
you earn **6** points.
(b) If you mark *two* answers, one of which is the correct answer,
you earn **3** points.
(c) If you mark *three* answers, one of which is the correct answer,
you earn **2** points.
(d) If you mark no answers, or more than *three*, you earn **0** points.

MC3: *multiple-choice-three-answer questions, each worth 3 points.*
No partial credit.

(a) If you mark only one answer and it is the correct answer,
you earn **3** points.
(b) If you mark a wrong answer or no answers, you earn **0** points.

The next two problems refer to the situation below.

In the following two problems, it is assumed that an electron is confined in a two-dimensional square well potential of width L and with infinite potential walls. The energy of an electron in a two-dimensional infinite square well is: $E(n_x,n_y)=(\hbar^2\pi^2/2mL^2)\cdot(n_x^2+n_y^2)$, where $n_x=1,2,3,\ldots$ and $n_y=1,2,3,\ldots$

1. What is the relationship between the ground state energy of an electron confined in a three-dimensional square well potential (E_{3D}), and the ground state energy of an electron confined in a two-dimensional square well potential (E_{2D}). Assume that both wells have the same width L and that both have infinite potential walls.

a. $E_{3D} = E_{2D}$
b. $E_{3D} = 1.25\ E_{2D}$
c. $E_{3D} = 1.5\ E_{2D}$
d. $E_{3D} = 2\ E_{2D}$
e. $E_{3D} = 2.25\ E_{2D}$

2. For an electron in a two-dimensional infinite square well potential, how does the degeneracy of the electron's *third* energy level, D_3, compare to the degeneracy of its *second* energy level, D_2?

a. $D_3<D_2$
b. $D_3=D_2$
c. $D_3>D_2$

3. The energies of the bound states of an electron in the attractive Coulomb potential (i.e., the hydrogen atom potential) ________.

a. are always positive.
b. can be positive or negative.
c. are always negative.

4. A material which has only filled energy bands at zero temperature is <u>always</u> a metal.

a. True
b. False
c. Information provided is insufficient to decide.

5. A hydrogen atom undergoes a transition from an excited state n=8 to a state with n=7. What is the wavelength of the emitted photon?

a. 190 μm
b. 19 μm
c. 1.9 μm
d. 0.19 μm
e. 1.9×10^{-9} μm

6. Which of the following (n, l, m_l, m_s) combinations is impossible for an electron in a hydrogen atom?

a. (3, 2, -1, ½)
b. (6, 2, 2, ½)
c. (8, 6, -6, -½)
d. (3, 2, 0, -½)
e. (3, 3, -1, -½)

7. Suppose a hydrogen atom is prepared in the (n, l, m_l) = (3,2,0) state. The radial wave function for this state is $R_{32} = N\,(r/a_0)^2\, e^{-r/3a_0}$, where N is the normalization constant. At what <u>radius</u>, r_{max}, is the electron most likely to be found?

a. $r_{max} = 0.5\, a_0$
b. $r_{max} = a_0$
c. $r_{max} = 1.51 a_0$
d. $r_{max} = 4.13 a_0$
e. $r_{max} = 9 a_0$

8. Which of the following electron configurations violates the Pauli Exclusion Principle?

a. $1s^2\ 2p^5\ 3d^1\ 5f^{10}$
b. $1s^1\ 2p^6\ 3d^3\ 5f^{14}$
c. $1s^2\ 2p^1\ 3d^{10}\ 5f^8$
d. $1s^1\ 2p^1\ 3d^{11}\ 5f^{12}$
e. $1s^2\ 2p^3\ 3d^{10}\ 5f^8$

The next two problems pertain to the following situation.

An electron sits in the second energy level in an infinite 1-D potential well.

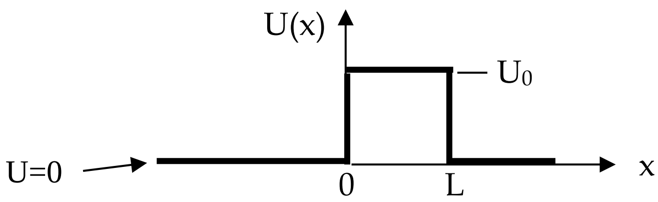
9. If the energy of the electron in this state is E_2=24 eV, what is the width L of the well?

a. L = 0.11 nm
b. L = 0.25 nm
c. L = 1.5 nm
d. L = 4.3 nm
e. L = 13 nm

10. If the electron makes a transition from this second energy level (E_2) to the ground state energy (E_1) of this infinite 1-D potential well, a photon of what wavelength λ will be emitted?

a. λ = 3.2 nm
b. λ = 18 nm
c. λ = 69 nm
d. λ = 142 nm
e. λ = 326 nm

The next three problems pertain to the following situation and figure.



An electron with an energy E=7 eV and traveling in the +x direction approaches a potential barrier of height U_0=9 eV and width L=0.3 nm

11. What is the wavelength λ of the electron in the region x < 0?

a. λ = 0.11 nm
b. λ = 0.46 nm
c. λ = 5.9 nm
d. λ = 63 nm
e. λ = 177 nm

12. What is the transmission probability T, i.e. the probability that the electron will penetrate through the barrier?

a. T = 0%
b. T = 0.34%
c. T = 1.3%
d. T = 7.9%
e. T = 24%

13. A muon is a particle with the same charge as the electron, but with a larger mass (m_{muon}=207$m_{electron}$). If a muon instead of an electron approaches the same barrier under the same conditions, which of the following is true?

a. The muon is more likely to penetrate the barrier than the electron
b. The muon is less likely to penetrate the barrier than the electron
c. The muon and the electron are equally likely to penetrate the barrier

The next two problems pertain to the following situation.

The wavefunction of a particle in a 1-D infinite square well potential of width L is given at t=0 by,

$$\psi(x,t=0) = A\{\sin(\pi x/L) + \sin(3\pi x/L) + \sin(5\pi x/L)\},$$

where A is a constant.

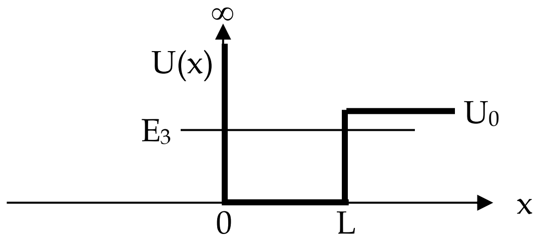
14. Which of the following statements best describes the time-dependence of this particle's probability density, $\psi^*(x,t) \bullet \psi(x,t) = |\psi(x,t)|^2$, for t>0?

a. The probability density is independent of time, because $\psi(x,t=0)$ IS an eigenstate.
b. The probability density is independent of time, because $\psi(x,t=0)$ IS NOT an eigenstate.
c. The probability density changes with time, because $\psi(x,t=0)$ IS an eigenstate.
d. The probability density changes with time, because $\psi(x,t=0)$ IS NOT an eigenstate.
e. There is not enough information given to tell whether or not the particle's probability density changes with time.

15. If E_1 is the lowest possible energy of the particle in this potential, what are the possible results of a measurement of this particle's energy E when it is described by the above wavefunction?

a. $E=(E_1+4E_1+9E_1)/3$
b. $E=(E_1+9E_1+25E_1)/3$
c. $E=E_1$, $4E_1$, OR $9E_1$
d. $E=E_1$, $9E_1$, OR $25E_1$
e. $E=E_1$, $3E_1$, OR $5E_1$

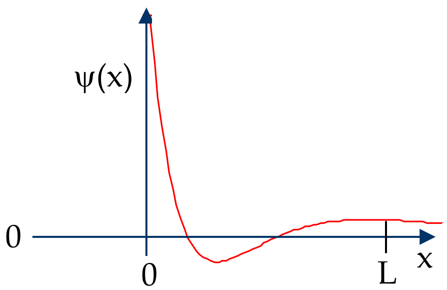
The next two problems pertain to the following situation and figure.



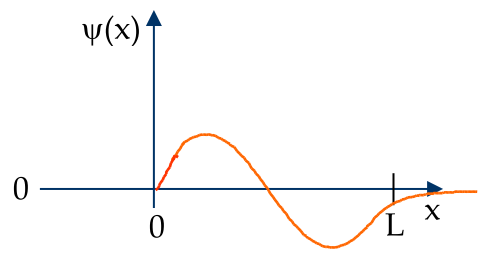
A particle is confined in the potential well of width L shown above, and is in its third allowed energy level, i.e., has an energy E_3.

16. Which of the following wavefunctions best describes the particle in the third energy level of the potential above?

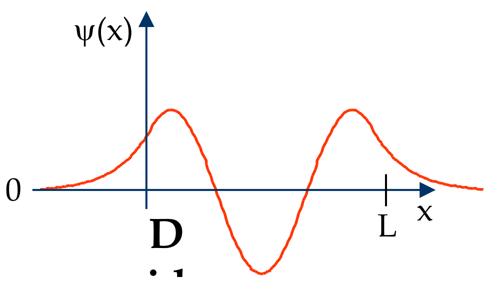
a.



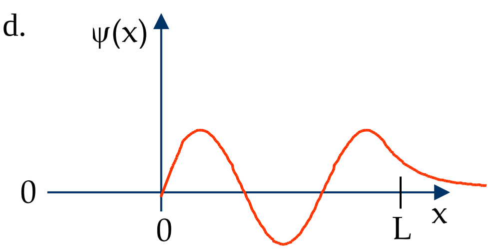
b.



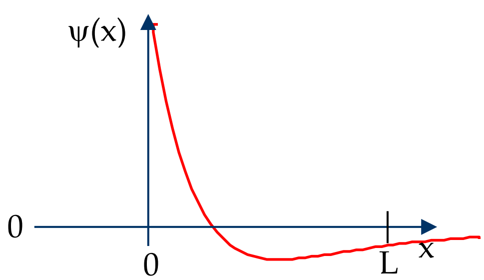
c.



d.



e.



17. Now, assume that this same particle is placed in a 1-D infinite square well potential having the same width, L, as the potential shown above. Which statement correctly describes the relationship between the energy of the particle in the third allowed energy level of the 1-D infinite square well potential, E_3', and the third allowed energy for the potential shown above (E_3)?

a. $E_3' < E_3$
b. $E_3' > E_3$
c. $E_3' = E_3$

18. A particle with a mass of 10^{-25} kg has a spread of velocities $\Delta v \sim 10$ m/s. Roughly, what is the uncertainty in the particle's position, Δx?

a. 0
b. 10^{-10} m
c. 10^{-3} m
d. 10^{3} m
e. 10^{10} m

19. If three identical finite square potential wells are moved closer together, the ground state energy of a particle confined in the wells will __________.

a. decrease
b. not change
c. increase

20. An electron is placed in a 5 T magnetic field. What frequency photon is emitted when the electron switches from its high energy spin state to its low energy spin state?

a. $f = 1.4\text{x}10^{1}$ Hz
b. $f = 1.4\text{x}10^{4}$ Hz
c. $f = 1.4\text{x}10^{11}$ Hz
d. $f = 1.4\text{x}10^{47}$ Hz
e. $f = 1.4\text{x}10^{64}$ Hz

21. The forbidden regions of electron energy in a solid are due to

a. the interference of electron waves scattered from the periodic atomic lattice.
b. the vanishing of the electron wavefunctions at the edges of the solid.
c. the presence of regions where the electron total energy is less than its potential energy

22. When light of wavelength $\lambda = 450$ nm shines on a certain metal, the maximum energy of the emitted electrons is 1.50 eV. How big is this metal's work function Φ?

a. Φ=0.17 eV
b. Φ=1.26 eV
c. Φ=1.89 eV
d. Φ=12.12 eV
e. Φ=20.11 eV

23. An electron and a neutron have the same kinetic energy. Which particle has the longer wavelength?

a. The electron
b. The neutron
c. They are the same

The next two questions refer to the following situation

A resultant wave with an amplitude A and a phase angle φ is the result of the superposition of three waves, as given below:

$E = A\sin(\omega t+\varphi) = 2\sin\omega t + 2\sin(\omega t + 30^\circ) + 2\sin(\omega t + 60^\circ)$

24. What is the amplitude A of the resultant wave?

a. A=1.0
b. A=2.1
c. A=3.2
d. A=4.0
e. A=5.5

25. What is the phase angle φ of the resultant wave?

a. $\varphi= 90^\circ$
b. $\varphi=60^\circ$
c. $\varphi=30^\circ$

26. A photograph is taken of an object which is placed 6m in front of the camera If the camera lens has a diameter of 2.0 cm, what is the minimum separation, Δx, of two points on the object that can be resolved by the camera lens? Assume that the wavelength of the light used is 550 nm.

a. Δx = 0.13 nm
b. Δx = 0.1 mm
c. Δx = 0.2 mm
d. Δx = 0.4 mm
e. Δx = 1 mm

27. Consider a 3 cm wide diffraction grating with 2,500 lines. For the first-order spectrum ($m = 1$), what is the separation, Δy, of light from red ($l = 650$ nm) and green ($l = 550$ nm) lasers on a screen 2 m from the diffraction grating (you may use the small angle approximation)?

a. $\Delta y = 0.016$ cm
b. $\Delta y = 0$ m
c. $\Delta y = 0.016$ nm
d. $\Delta y = 0.016$ mm
e. $\Delta y = 0.017$ m

28. Consider a five slit interference pattern. What angle φ (in radians) between adjacent phasors corresponds to the first zero in the intensity pattern.

a. $\varphi = 0$
b. $\varphi = \pi/5$
c. $\varphi = \pi/2$
d. $\varphi = 2\pi/5$
e. $\varphi = \pi$

29. Two 450 Hz sound waves with intensities of 0.5 and 0.3 W/m^2 arrive at your ear from different sources. The maximum intensity that will result is

a. 10.12 W/m^2
b. 4.32 W/m^2
c. 1.57 W/m^2
d. 0.51 W/m^2
e. 0.11 W/m^2

30. A slit of width, a, is illuminated with light of λ = 620 nm. The distance between the slit and the screen is L=2.5 m, and the distance on the screen between the maximum in the diffraction intensity and the first diffraction minimum on either side of the central maximum is y = 20 cm. What is the slit width, a? (You may use the small angle approximation).

a. 7.75 μm
b. 3.45 μm
c. 0.44 μm
d. 1.45 nm
e. 0.11 nm

31. It is possible to place up to six electrons in the ground state of a three-dimensional infinite square well.

a. True
b. False
c. True, if the square well is large enough

32. The larger the energy gap between the valence band and the conduction band of a semiconductor, the higher the frequency of the photon needed to excite an electron across the gap.

a. True
b. False
c. Depends on the temperature