The following questions are designed to give you some practice with concepts mostly covered <u>since the midterm</u> (you should look at old practice midterms for sample problems covering the earlier course material!). Some are specifically designed to be difficult in order to make sure you can go beyond simple "plug and chug" problems. These problems will be gone over during the final exam review session.

1. An electron has a wavefunction $\Psi(r,\theta,\phi) = Ce^{-r/a}$.
This electron is in what orbital angular momentum state?

a. s
b. p
c. d

2. An electron in a hydrogen atom is in a p state. Which of the following statements is true?

a. The electron has a total angular momentum of $\hbar$.
b. The electron has an energy of -13.6 eV.
c. The probability to find the electron within 0.1 nm of the origin changes in time.
d. The electron's wavefunction has at least one node (i.e., at least one place in space where it goes to zero).
e. The electron has a z-component of angular momentum equal to sqrt(2)* $\hbar$.

3. Now we prepare the electron in superposition of the 2s and 2p (m = 0) states:
$\Psi(r,\theta,\phi, t = 0) = [\Psi_{2,0,0}(r,\theta,\phi) + \Psi_{2,1,0}(r,\theta,\phi)]/\sqrt{2}$.
Which of the following statements is true?

a. The electron will always be equally likely to be found above the x-y plane (z >0) and below the x-y plane (z < 0).
b. The electron probability distribution will change as a function of time.
c. Measuring the energy will yield a definite result.

4. An electron in an infinite square well of width L = 1 nm has the wavefunction:

$$\psi(x) \propto \sqrt{\frac{2}{L}}\left[\sin(\frac{3\pi x}{L}) + \sin(\frac{5\pi x}{L}) - 2\sin(\frac{\pi x}{L})\right].$$

What is/are the possible result/results for a measurement of the electron's energy?

a. 0.376 eV
b. 2.51 eV
c. 0.376 eV, 3.39 eV, or 9.41 eV
d. 11.3 eV
e. 12.1 eV

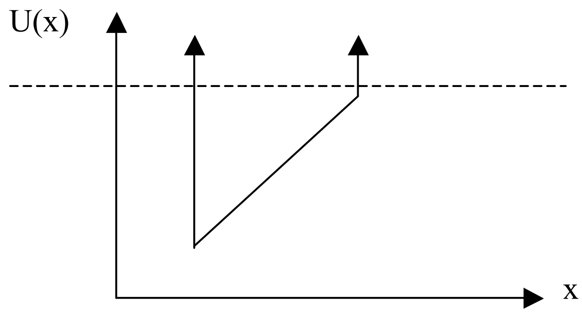
5. What is the probability of measuring the electron in the previous problem to have an energy of 0.376 eV?

a. 4
b. 0.67
c. -0.67
d. 0.5
e. 0

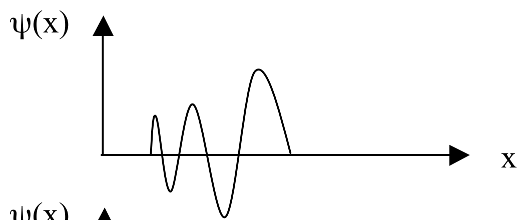
6. If indeed we measure the electron to have energy 0.376 eV, and then we shine on light of wavelength 824.5 nm, what will happen?

a. The electron will be excited to a state with energy 1.75 eV.
b. The electron will be excited to the state with energy 1.504 eV.
c. The electron will not be excited.

7. A particle is trapped in the potential well shown below. Which of the wavefunctions most closely describes the particle?



a.



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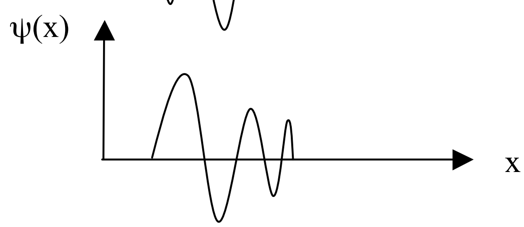
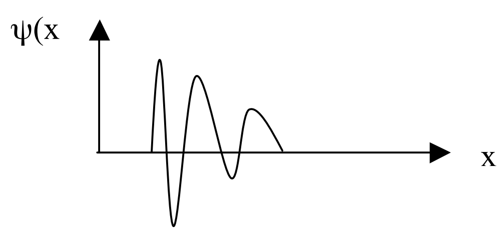
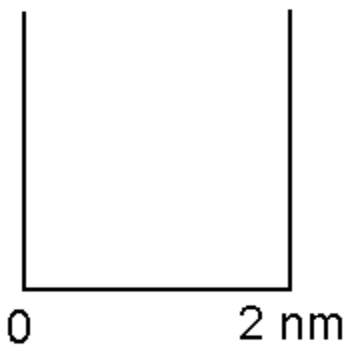


c.



8. What state is this particle in (where n = 1 is the ground state)?

a. n = 2
b. n = 3
c. n = 4
d. n = 5
e. n = 6



9. An electron is in the 3rd excited state of a 2-nm wide infinite square well. What is the probability of measuring the electron to be between x = 0.23 nm and x = 0.27 nm?

a. 0.04
b. 0.10
c. 0.16
d. 0.32
e. 0.64

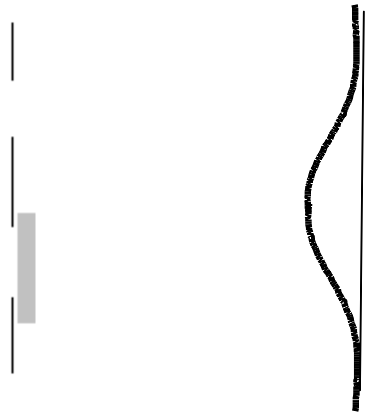
10. An electron with total energy E approaches a barrier of height U_0 and width L. Assuming $E<U_0$, which one of the following changes will **increase** the probability for the electron to appear on the other side of the barrier?

a. increase L
b. increase E
c. increase U_0

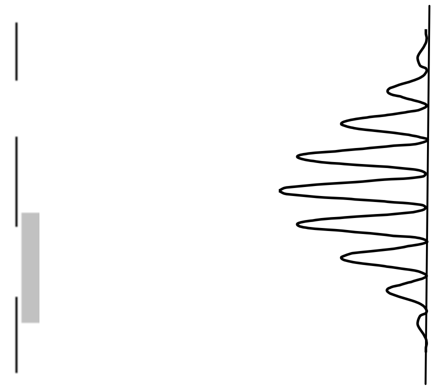
11. Which of the following normalized wave functions for the infinite square well has the shortest period of oscillation in time?

a. $(\sin(\pi x/L) + \sin(2\pi x/L))/\mathrm{sqrt}(L)$
b. $(\sin(2\pi x/L) + \sin(3\pi x/L))/\mathrm{sqrt}(L)$
c. $(\sin(\pi x/L) + \sin(3\pi x/L))/\mathrm{sqrt}(L)$

12. Which of the following probability distributions will you observe from a beam of electrons passing through a double slit with one slit covered? (Assume that the detection screen is far away from the slits, i.e, the diagrams are not drawn to scale)?



a.



b.

13. Now both slits are unblocked. However, we modify the experiment in the following way: We prepare the electrons incident on the slits so that they all have their spins "pointing up", i.e., so that $m_s = +1/2$. We install a tiny radio-coil near the top slit (this is only a thought experiment!), so that the spin of any electron that passes through the top slit is flipped (without affecting the spin of electron passing through the bottom slit). Now which pattern do we see?

a.
b.

14. What frequency of electromagnetic radiation will flip a "spin up" electron to a "spin down" electron in a magnetic field of 2.0 T?

a. $2.4*10^9$ Hz
b. $4.1*10^9$ Hz
c. $5.6*10^{10}$ Hz
d. $7.1*10^{11}$ Hz
e. $8.8*10^{12}$ Hz

15. A photon has energy 3 eV. What is its momentum?

a. 0
b. $1.6*10^{-27}$ kg m/s
c. $9.4*10^{-34}$ kg m/s

16. A laser with wavelength 300 nm illuminates a metal in a photoelectric effect experiment. It takes a stopping potential of 2 Volts to halt the ejected electrons. What is the work function of the metal?

a. 1.0 eV
b. 2.1 eV
c. 3.2 eV

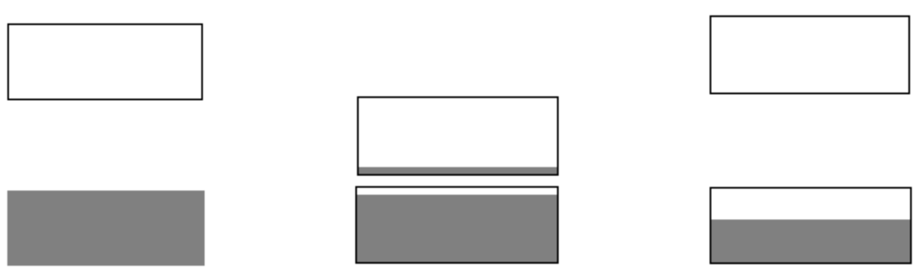
17. An electron is confined to a rectangular region in space with sides $L_x = 2$ nm, $L_y = 3$ nm, $L_z = 2$ nm. What is the energy of the ground state?

a. 0.094 eV
b. 0.19 eV
c. 0.23 eV

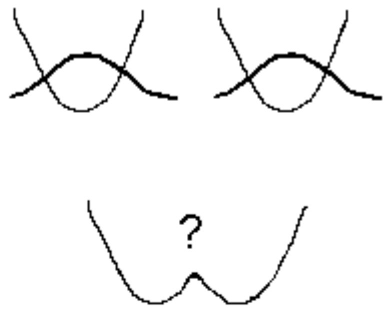
18. What is the degeneracy of the 1st excited state for the electron in the previous problem (neglecting the effect of spin)?

a. 1
b. 2
c. 3

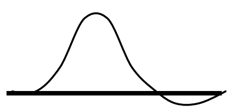
19. Which of the following energy band pictures corresponds to a conductor?

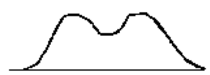


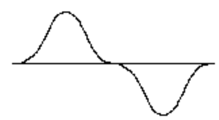
a. b. c.



20. Two harmonic oscillators in their ground states are brought near each other. Which of the following pictures shows the correct 1st excited state for the combined system?







a. b. c.

21. Assume there is one electron from each harmonic oscillator (and neglect electrostatic interactions between the electrons). If the "molecule" is in its lowest energy state, one of the electrons is in state (b.) above. Which of the above pictures is appropriate for the wave function of the second electron?

a.
b.
c.

22. A beam of electrons is sent toward a potential barrier (height = 2 eV) with velocity 6×10^5 m/s. If 97.5% of the incident beam is <u>reflected</u>, what is the width of the barrier?

a. 0.01 nm
b. 0.05 nm
c. 0.1 nm
d. 0.5 nm
e. 1 nm

23. A hydrogen atom in its ground state traveling in the +x-direction is passed along the through a Stern-Gerlach apparatus, producing a set of peaks. The uppermost peak only is then passed through *another* Stern-Gerlach apparatus (with the same magnetic field gradient dB/dz as the first). How many peaks are observed in the output of the second Stern-Gerlach apparatus?

a. 0
b. 1
c. 2
d. 3
e. 4

24. If instead we were to rotate the second Stern-Gerlach apparatus by 90°, so that the gradient was dB/dy instead, now how many peaks would be observed?

a. 0
b. 1
c. 2
d. 3
e. 4

25. What are the quantum numbers n and l of the outermost electron of a Br atom? Br has 35 electrons.

a. n=3, l=0
b. n=3, l=1
c. n=4, l=0
d. n=4, l=1
e. n=4, l=2

26. If the outermost electron is now excited (e.g., by a collision) to the n = 5, l = 1 state, to which final state(s) could the electron fall back down by emitting a photon? (Hint: What is the angular momentum of the photon?)

a. n=4, l=3
b. n=4, l=2
c. n=5, l=0
d. n=4, l=1
e. n=3, l=2

A calcium ion (charge |e|, mass = 6.65×10^{-26} kg) is trapped in an electromagnetic potential that approximates a **harmonic oscillator**. The frequency associated with the oscillation of the ion in the trap is 100 kHz.

27. If one wanted to excite the ion from the ground state of the trap *directly* to the *second excited state*, one might shine on radio waves with frequency:

a. 100 kHz
b. 200 kHz
c. 800 kHz

28. At time t = 0, the ion is prepared into an equal superposition of the ground state and the *second* excited state, $\psi = \frac{1}{\sqrt{2}}(\psi_0 + \psi_2)$. Which of the following describes the likely location of the ion:

a. The ion is more likely to be found in the left-hand side of the trap.
b. The ion is more likely to be found in the right-hand side of the trap.
c. The ion is equally likely to be found in either half of the trap.

29. We now let the system evolve in time. Which of the following best describes the future behavior of the ion:

a. The ion will "slosh" back and forth from the left-hand side of the well to the right-hand side.
b. The ion will "slosh" back and forth from being mostly located near the center of the well to being mostly located away from the center (i.e., nearer the "edges" of the well).
c. The probability density of the ion will not change over time.

30. Consider the following curve of resistance versus temperature.

What kind of material is this?

a. insulator
b. semiconductor
c. metal