Physics 160
Principles of Modern Physics
(Spring 2008)
Midterm Examination #2

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Name: Honor Code:

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## I. Multiple Choice (20 points)

Circle all that apply. In some cases there may be multiple correct answers.

1. (2 pts.) Compared to the energy levels for a particle in an infinite square well, the energy levels for the bound states of a particle in a *finite* square well are …
   (a) lower.
   (b) higher.
   (c) exactly the same.
   (d) answer depends on the depth of the well.

2. (2 pts.) If the total angular momentum of an atomic state is $j$=3/2, into how many Zeeman levels will it be split by application of a magnetic field?
   (a) one
   (b) two
   (c) three
   (d) four
   (e) five
   (f) six

3. (2 pts.) Electrons are …
   (a) fermions with spin 0.
   (b) fermions with spin ½.
   (c) fermions with spin 3/2.
   (d) bosons with spin 0.
   (e) bosons with spin ½.
   (f) cute little fellers.

4. (2 pts.) How many neutrons are there in the nucleus of $^{57}Fe$?
   (a) 0
   (b) 26
   (c) 31
   (d) 57

5. (2 pts.) A radioactive sample has an initial activity of 1 mCi and a half-life of 7 days. What is the activity three weeks later?

(a) 1 mCi
(b) 0.5 mCi
(c) 0.333 mCi
(c) 0.25 mCi
(d) 0.125 mCi
(e) 0.1 mCi

6. (2 pts.) The binding energy per nucleon is greatest for which of the following nuclei?

(a) $^{1}$H
(b) $^{4}$He
(c) $^{56}$Fe
(d) $^{238}$U

7. (2 pts.) In the Stern-Gerlach experiment, a beam of atoms was deflected by …

(a) a uniform gravitational field
(b) a non-uniform gravitational field
(c) a uniform electric field
(d) a non-uniform electric field
(e) a uniform magnetic field
(f) a non-uniform magnetic field

8. (2 pts.) The coupling of the spin and orbital angular momentum of the electron leads to splitting of energy levels (or lifting of the degeneracy). This effect is known as…

(a) fine-structure slitting.
(b) hyper-fine structure splitting.
(c) super-duper-awesomely-fine structure splitting.
(d) the Zeeman effect.
(e) the Compton effect

9. (2 pts.) The nuclei of all atoms have about the same …

(a) radius
(b) volume
(c) mass
(d) density
(e) charge

10. (2 pts.) Compared to the magnetic dipole moment of the electron, the magnetic dipole moment of the proton is

(a) about 1000 times smaller
(b) about 100 times smaller
(d) about the same
(e) about 10 times larger
(f) about 100 times larger
(g) about 1000 times larger

# I. Short Answer Section (40 points)

11. (8 points) What is the ground state electron configuration for each of the following elements?
(a) Lithium

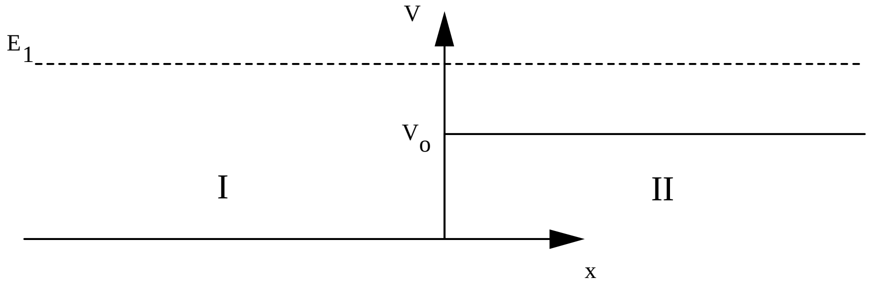
(b) Argon

(c) Potassium

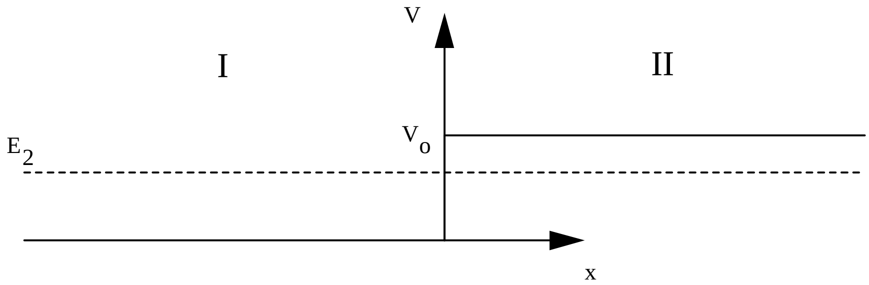
(d) Scandium

12. (8 pts.) Consider a particle in an infinite square well with dimensions $L_1$ (in the x-direction) and $L_2$ (in the y-direction). Make a contour plot sketch of the probability distribution if the particle is in the state with $n_1$=3, $n_2$=1. Under what conditions will this state be *degenerate* with another state? What are the quantum numbers for that state?

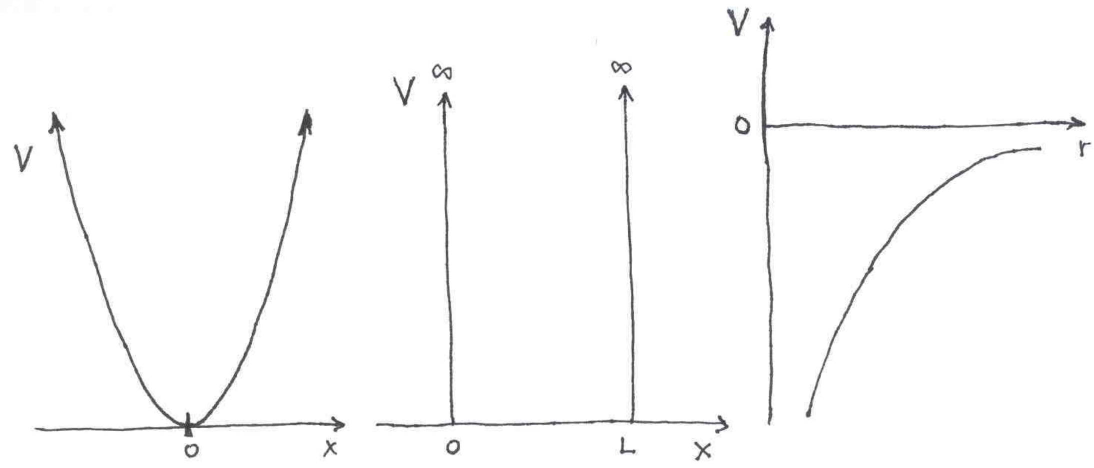
13. (8 pts.) A beam of monoenergetic particles is incident on the potential step shown below. If the beam has energy $E_1$, sketch the wavefunction in both region I and region II. Comment on whether particles are transmitted or reflected off the step.




14. (8 pts.) If the beam has energy $E_2$, sketch the wavefunction in both region I and region II. Comment on whether the particles are transmitted of reflected off the step.



15. (8 points) Three potential energy functions are shown below. Provide a name for each function and qualitatively indicate the first 4 energy levels, paying attention to the spacing between levels.



# II. Exercises (40 points)

16. (20 pts.) Particle in an Infinite Square Well

(a) The general solution to the time-independent Schrodinger Equation for a particle in a one-dimensional infinite square well is on your equation sheet. Find it and write it here.

(b) Show that the solution given in part (a) does indeed satisfy the time-independent Schrodinger Equation as long as the total energy takes on one of the allowed values.

(c) Sketch the wavefunction *and* the probability density for the second excited state (the $n$=3) state.

(d) If the particle is an electron and the box has width $L$ = 0.10 nm, what is the wavelength of the photon given off when the electron makes a transition from the $n$=3 state to the ground state?

17. (20 pts.) Hydrogen atom

**Table 7-2** Radial functions for hydrogen

| | | |
|---|---|---|
| $n = 1$ | $\ell = 0$ | $R_{10} = \dfrac{2}{\sqrt{a_0^3}} e^{-r/a_0}$ |
| $n = 2$ | $\ell = 0$ | $R_{20} = \dfrac{1}{\sqrt{2a_0^3}}\left(1 - \dfrac{r}{2a_0}\right) e^{-r/2a_0}$ |
| | $\ell = 1$ | $R_{21} = \dfrac{1}{2\sqrt{6a_0^3}} \dfrac{r}{a_0} e^{-r/2a_0}$ |
| $n = 3$ | $\ell = 0$ | $R_{30} = \dfrac{2}{3\sqrt{3a_0^3}}\left(1 - \dfrac{2r}{3a_0} + \dfrac{2r^2}{27a_0^2}\right) e^{-r/3a_0}$ |
| | $\ell = 1$ | $R_{31} = \dfrac{8}{27\sqrt{6a_0^3}} \dfrac{r}{a_0}\left(1 - \dfrac{r}{6a_0}\right) e^{-r/3a_0}$ |
| | $\ell = 2$ | $R_{32} = \dfrac{4}{81\sqrt{30a_0^3}} \dfrac{r^2}{a_0^2} e^{-r/3a_0}$ |

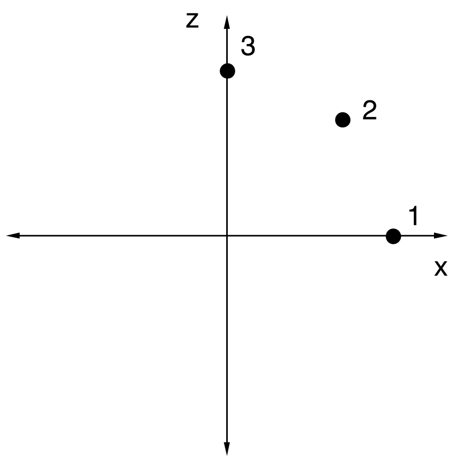
**Table 7-1** Spherical harmonics

| | | |
|---|---|---|
| $\ell = 0$ | $m = 0$ | $Y_{00} = \sqrt{\dfrac{1}{4\pi}}$ |
| $\ell = 1$ | $m = 1$ | $Y_{11} = -\sqrt{\dfrac{3}{8\pi}} \sin\theta\, e^{i\phi}$ |
| | $m = 0$ | $Y_{10} = \sqrt{\dfrac{3}{4\pi}} \cos\theta$ |
| | $m = -1$ | $Y_{1-1} = \sqrt{\dfrac{3}{8\pi}} \sin\theta\, e^{-i\phi}$ |
| $\ell = 2$ | $m = 2$ | $Y_{22} = \sqrt{\dfrac{15}{32\pi}} \sin^2\theta\, e^{2i\phi}$ |
| | $m = 1$ | $Y_{21} = -\sqrt{\dfrac{15}{8\pi}} \sin\theta\cos\theta\, e^{i\phi}$ |
| | $m = 0$ | $Y_{20} = \sqrt{\dfrac{5}{16\pi}}(3\cos^2\theta - 1)$ |
| | $m = -1$ | $Y_{2-1} = \sqrt{\dfrac{15}{8\pi}} \sin\theta\cos\theta\, e^{-i\phi}$ |
| | $m = -2$ | $Y_{2-2} = \sqrt{\dfrac{15}{32\pi}} \sin^2\theta\, e^{-2i\phi}$ |

(a) Using the tables from your textbook (reproduced above), write down the solution to the time-independent Schrodinger Equation for the electron wavefunction in the hydrogen atom when $n$=2, $l$=1, $m$=0.

(b) Write down the probability distribution for the wavefunction in part (a).

(c) At which of the three locations shown in the diagram are you most likely to find the electron when it is in the state described by the solution in part (a)? Explain why.




(d) If the electron makes a transition from the state in part (a) to the ground state, what is the wavelength of the emitted photon? Neglect the effects of electron spin here.

(e) Is the transition in part (d) allowed? Explain.

(f) If the energy width ($\Delta E$) for the excited state in the previous parts of this problem is $2 \times 10^{-7}$ eV, what is the lifetime of the excited state?