PHYS 3313 – Section 001
Lecture #21

Wednesday, Apr. 9, 2014
Dr. Jaehoon Yu

- Simple Harmonic Oscillator
- Barriers and Tunneling
- Alpha Particle Decay
- Use of Schrodinger Equation on Hydrogen Atom
- Solutions for Schrodinger Equation for Hydrogen Atom

Announcements

- Research paper deadline is Monday, Apr. 28
- Research presentation deadline is Sunday, Apr. 27
- Homework #5
  - CH6 end of chapter problems: 34, 39, 46, 62 and 65
  - Due Wednesday, Apr. 16
- Reading assignments
  - CH7.6 and the entire CH8
- Bring out homework #4 at the end of class
- Quiz results
  - Class average: 27.7/50
    - Equivalent to 55.4/100
    - Previous quizzes: 30.2/100 and 53.4/100
  - Top score: 50/50
- Colloquium today, Dr. Hadavand of UTA

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Two Years after the Discovery: New Information about the Higgs and Beyond

Dr. Haleh Hadavand

The University of Texas at Arlington
The Physics Department

4:00 pm Wednesday April 9, 2014 room 101 Science Hall

Abstract:

Since the discovery of the Higgs like particle discovered at the LHC on July 4, 2012, the ATLAS experiment has analyzed about 2.4 times more data. We can now measure the spin and mass of this particle to a greater level of accuracy. We also have more accurate information about the branching fraction to the various final states. We find that although this particle is consistent with a Standard Model Higgs, many Beyond Standard Model scenarios are still viable. One of these models is Supersymmetry which postulates 5 Higgs Bosons. I will show results of searches for one of these particles, the Charged Higgs Boson, and show other evidence which points to the viability of these Models. I will also go over the new Higgs results since the discovery.

Refreshments will be served at 3:30p.m in the Physics Lounge

Reminder: Special project #5

- Show that the Schrodinger equation becomes Newton's second law in the classical limit. (15 points)
- Deadline Monday, Apr. 21, 2014
- You MUST have your own answers!

Reminder: Research Project Report

1. Must contain the following at the minimum
   - Original theory or Original observation
   - Experimental proofs or Theoretical prediction + subsequent experimental proofs
   - Importance and the impact of the theory/experiment
   - Conclusions
2. Each member of the group writes a 10 (max) page report, including figures
   - 10% of the total grade
   - Can share the theme and facts but you must write your own!
   - Text of the report must be your original!
   - ***Due Mon., Apr. 28, 2014***

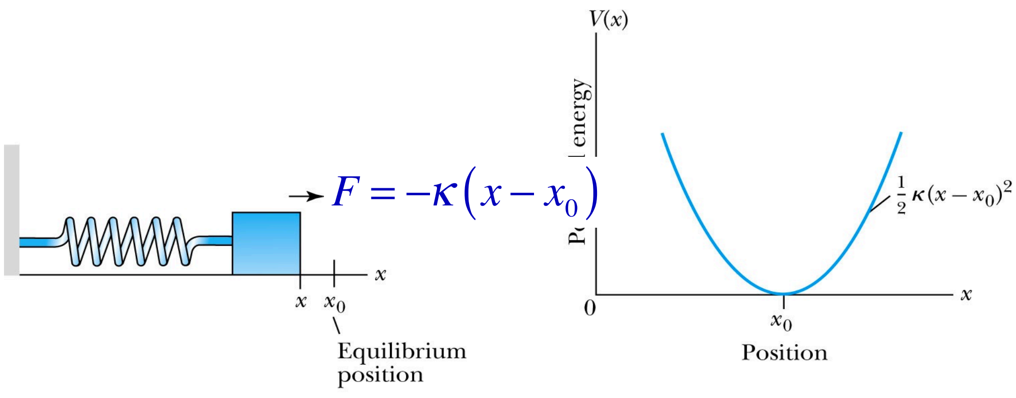
Group Number	Reseasrch Group Members	Research Topic # & Title	Presentation Date and Order
1	J. Paul Carpenter, Erwin Christopher, Matthew Gartman, Hope Montgomery	7. Rutherford Scattering	4/30 - 2
2	Tyler Anway, Jay Lundy, Salvador Rendon, Dustin Wilbers	3. The Photo-Electric Effect	4/28 - 3
3	Alejandro Arroyo, John Crouch, Ryan Jones, Michael Porter	2. Michelson-Morley Experiment	4/30 - 4
4	Christopher Dunn, Josh Kaker, Garrett Leavitt, Giang Tran	4. The property of molecules - the Brownian Motion	4/28 - 2
5	Cole Boutwell, Oscar Rodriguez, Kevin Strehl, Hector Zapata	1. Black-body Radiation	4/28 - 4
6	Soha Aslam, Arthur D'Auteuil, Alberto Garcia, Andrew Mcginnis, Jose Montelongo	8. Super-Conductivity	4/28 - 1
7	Jesus Alcala, Derric Edwards, Ronald Musser, Cody Tipton	5. Compton Effect	4/30 - 1
8	Austin Mcdonald, Robert Moore, Panpiroon Punnakanta, Dalton Sussumes, Troy Piqq	6. Discovery of Electron	4/30 - 3

Research Presentations

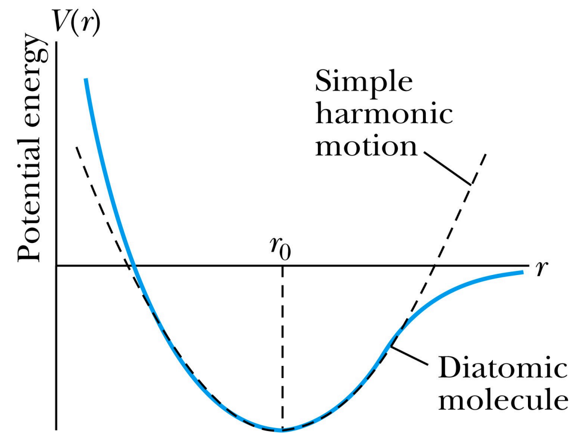
- Each of the 10 research groups makes a 10min presentation
  - 8min presentation + 2min Q&A
  - All presentations must be in power point
  - I must receive all final presentation files by 8pm, Sunday, Apr. 27
    - No changes are allowed afterward
  - The representative of the group makes the presentation followed by all group members' participation in the Q&A session
- Date and time:
  - In class Monday, Apr. 28 or in class Wednesday, Apr. 30
- Important metrics
  - Contents of the presentation: 60%
    - Inclusion of all important points as mentioned in the report
    - The quality of the research and making the right points
  - Quality of the presentation itself: 15%
  - Presentation manner: 10%
  - Q&A handling: 10%
  - Staying in the allotted presentation time: 5%
  - Judging participation and sincerity: 5%

The Simple Harmonic Oscillator

- Simple harmonic oscillators describe many physical situations: springs, diatomic molecules and atomic lattices.



(a) (b)



- Consider the Taylor expansion of a potential function:

$$V(x) = V_0 + V_1(x - x_0) + \frac{1}{2}V_2(x - x_0)^2 + \cdots$$

The minimum potential at $x=x_0$, so $dV/dx=0$ and $V_1=0$; and the zero potential $V_0=0$, we have

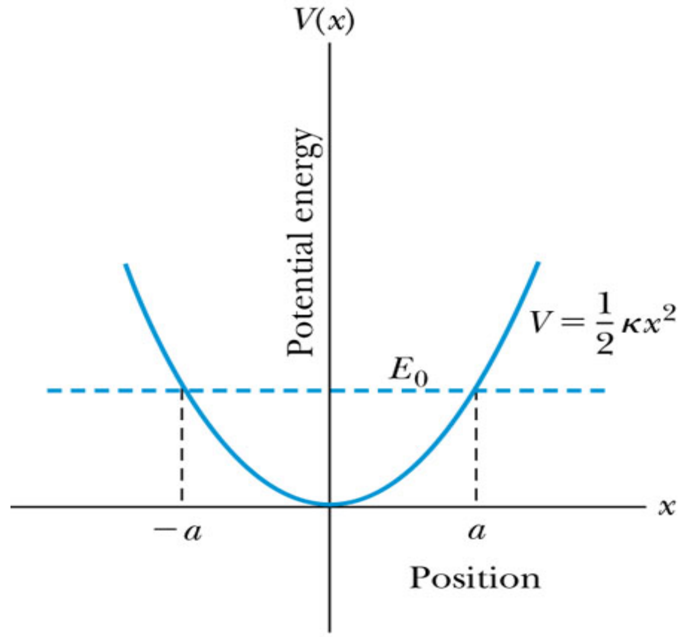
$$V(x) = \frac{1}{2}V_2(x - x_0)^2$$

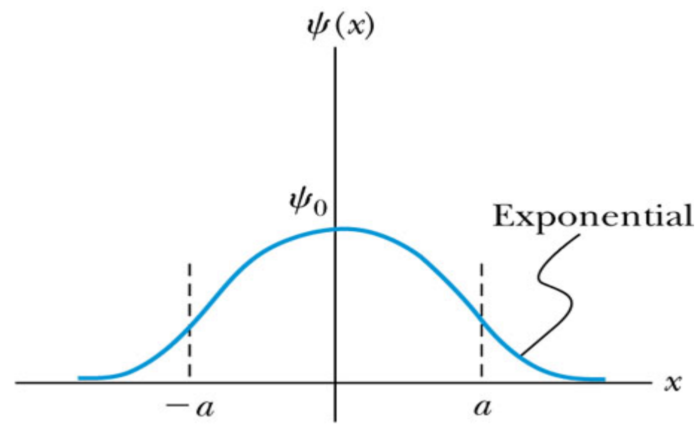
Substituting this into the wave equation:

$$\frac{d^2\psi}{dx^2} = -\frac{2m}{\hbar^2}\left(E - \frac{\kappa x^2}{2}\right)\psi = \left(-\frac{2m}{\hbar^2}E + \frac{m\kappa x^2}{\hbar^2}\right)\psi$$

Let $\alpha^2 = \frac{m\kappa}{\hbar^2}$ and $\beta = \frac{2mE}{\hbar^2}$ which yields $\frac{d^2\psi}{dx^2} = \left(\alpha^2 x^2 - \beta\right)\psi$.

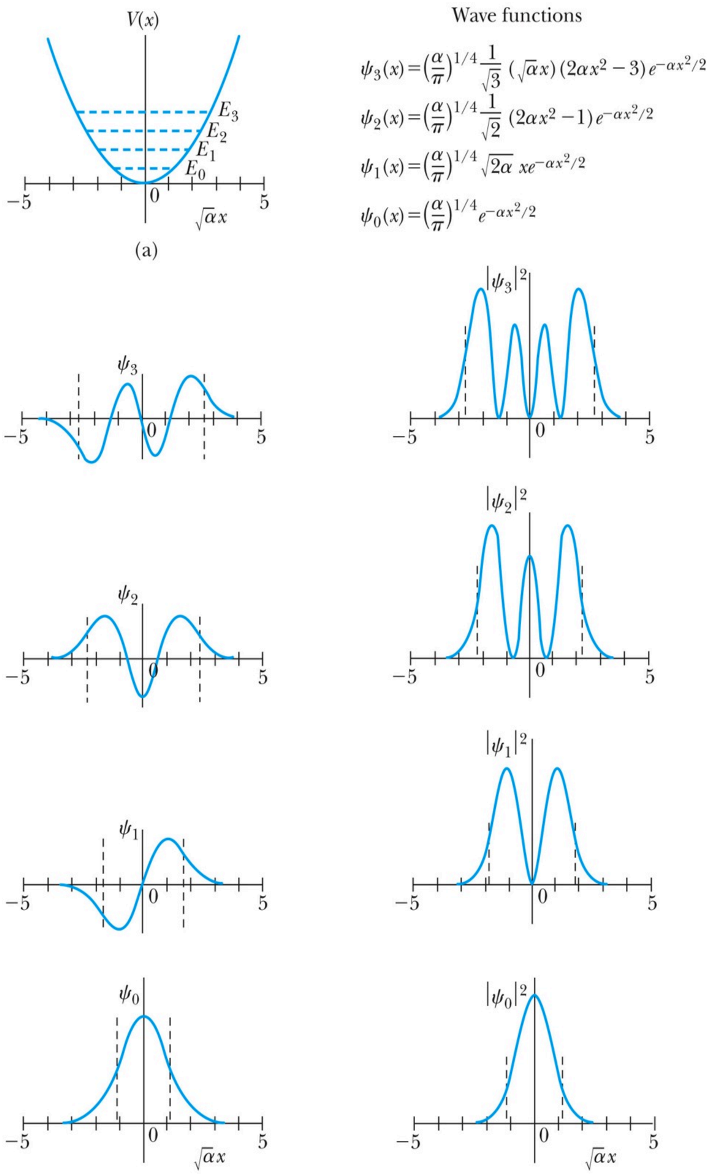
Parabolic Potential Well

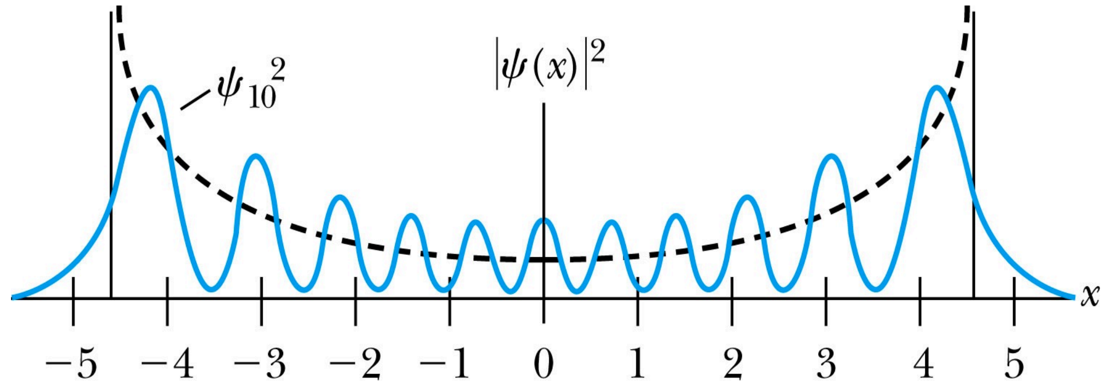




- If the lowest energy level is zero, this violates the uncertainty principle.
- The wave function solutions are $\psi_n = H_n(x)e^{-\alpha x^2/2}$ where $H_n(x)$ are Hermite polynomial function of order *n*.
- In contrast to the particle in a box, where the oscillatory wave function is a sinusoidal curve, in this case the oscillatory behavior is due to the polynomial, which dominates at small *x*. The exponential tail is provided by the Gaussian function, which dominates at large *x*.

Analysis of the Parabolic Potential Well





- The energy levels are given by

$$E_n = \left(n + \frac{1}{2}\right)\hbar\sqrt{\kappa/m} = \left(n + \frac{1}{2}\right)\hbar\omega$$

- The zero point energy is called the Heisenberg limit:

$$E_0 = \frac{1}{2}\hbar\omega$$

- Classically, the probability of finding the mass is greatest at the ends of motion's range and smallest at the center (that is, proportional to the amount of time the mass spends at each position).
- Contrary to the classical one, the largest probability for this lowest energy state is for the particle to be at the center.

Ex. 6.12: Harmonic Oscillator stuff

- Normalize the ground state wave function ψ_0 for the simple harmonic oscillator and find the expectation values <x> and <x^2>.

$$\psi_n(x) = H_n(x)e^{-\alpha x^2/2} \Rightarrow \psi_0(x) = H_0(x)e^{-\alpha x^2/2} = Ae^{-\alpha x^2/2}$$

$$\int_{-\infty}^{+\infty} \psi_0^* \psi_0 \, dx = \int_{-\infty}^{+\infty} A^2 e^{-\alpha x^2} \, dx = 2A^2 \int_0^{+\infty} e^{-\alpha x^2} \, dx = 2A^2 \left(\frac{1}{2}\sqrt{\frac{\pi}{\alpha}} \right) = 1$$

$$A^2 = \sqrt{\frac{\alpha}{\pi}} \Rightarrow A = \left(\frac{\alpha}{\pi}\right)^{1/4} \Rightarrow H_0(x) = \left(\frac{\alpha}{\pi}\right)^{1/4} \Rightarrow \psi_0(x) = \left(\frac{\alpha}{\pi}\right)^{1/4} e^{-\alpha x^2/2}$$

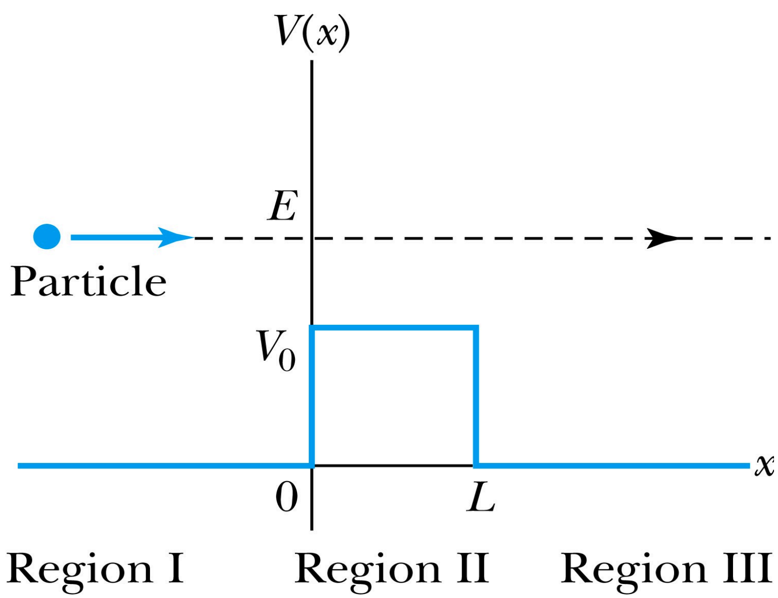
$$\langle x \rangle = \int_{-\infty}^{+\infty} \psi_0^* x \psi_0 \, dx = \sqrt{\frac{\alpha}{\pi}} \int_{-\infty}^{+\infty} x e^{-\alpha x^2} \, dx = 0$$

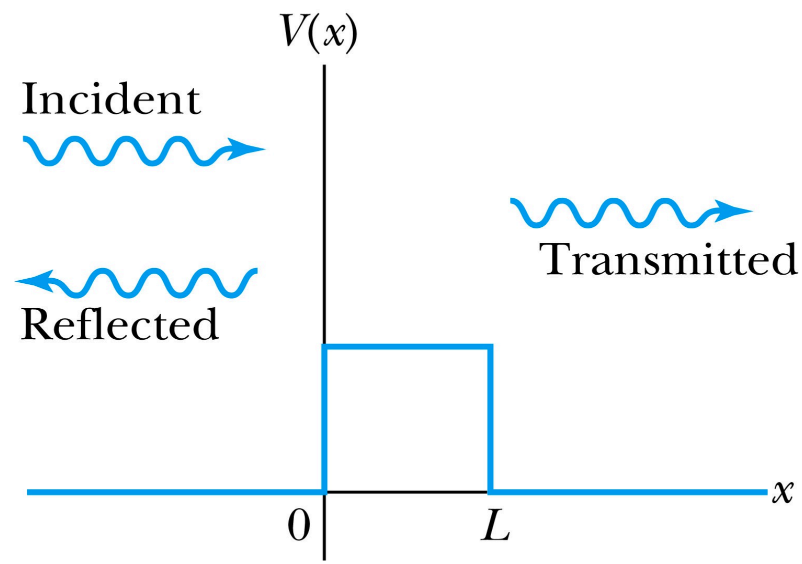
$$\langle x^2 \rangle = \int_{-\infty}^{+\infty} \psi_0^* x^2 \psi_0 \, dx = \sqrt{\frac{\alpha}{\pi}} \int_{-\infty}^{+\infty} x^2 e^{-\alpha x^2} \, dx = 2\sqrt{\frac{\alpha}{\pi}} \int_0^{+\infty} x^2 e^{-\alpha x^2} \, dx = 2\sqrt{\frac{\alpha}{\pi}} \left(\frac{\sqrt{\pi}}{4\alpha^{3/2}} \right) = \frac{1}{2\alpha}$$

$$\langle x^2 \rangle = \frac{\hbar}{2\sqrt{m\kappa}} \Rightarrow \omega = \sqrt{\kappa/m} \Rightarrow \langle x^2 \rangle = \frac{\hbar}{2m\omega}$$

Barriers and Tunneling

- Consider a particle of energy E approaching a potential barrier of height V_0 and the potential everywhere else is zero.
- We will first consider the case when the energy is greater than the potential barrier.
- In regions I and III the wave numbers are: $$k_I = k_{III} = \frac{\sqrt{2mE}}{\hbar}$$
- In the barrier region we have $$k_{II} = \frac{\sqrt{2m(E - V_0)}}{\hbar} \quad \text{where } V = V_0$$





Reflection and Transmission

- The wave function will consist of an incident wave, a reflected wave, and a transmitted wave.
- The potentials and the Schrödinger wave equation for the three regions are as follows:

$$\text{Region I } (x<0) \qquad V=0 \qquad \frac{d^2\psi_I}{dx^2}+\frac{2m}{\hbar^2}E\psi_I=0$$

$$\text{Region II } (0<x<L) \qquad V=V_0 \qquad \frac{d^2\psi_{II}}{dx^2}+\frac{2m}{\hbar^2}(E-V_0)\psi_{II}=0$$

$$\text{Region III } (x>L) \qquad V=0 \qquad \frac{d^2\psi_{III}}{dx^2}+\frac{2m}{\hbar^2}E\psi_{III}=0$$

- The corresponding solutions are:

$$\text{Region I } (x<0) \qquad \psi_I=Ae^{ik_Ix}+Be^{-ik_Ix}$$

$$\text{Region II } (0<x<L) \qquad \psi_{II}=Ce^{ik_{II}x}+De^{-ik_{II}x}$$

$$\text{Region III } (x>L) \qquad \psi_{III}=Fe^{ik_Ix}+Ge^{-ik_Ix}$$

- As the wave moves from left to right, we can simplify the wave functions to:

$$\text{Incident wave} \qquad \psi_I(\text{incident})=Ae^{ik_Ix}$$

$$\text{Reflected wave} \qquad \psi_I(\text{reflected})=Be^{-ik_Ix}$$

$$\text{Transmitted wave} \qquad \psi_{III}(\text{transmitted})=Fe^{ik_Ix}$$

Probability of Reflection and Transmission

- The probability of the particles being reflected *R* or transmitted *T* is:

$$\mathrm{R} = \frac{\left|\psi_I(\text{reflected})\right|^2}{\left|\psi_I(\text{incident})\right|^2} = \frac{B \cdot B}{A \cdot A}$$

$$T = \frac{\left|\psi_{III}(\text{transmitted})\right|^2}{\left|\psi_I(\text{incident})\right|^2} = \frac{F \cdot F}{A \cdot A}$$

- The maximum kinetic energy of the photoelectrons depends on the value of the light frequency *f* and not on the intensity.
- Because the particles must be either reflected or transmitted we have: $R + T = 1$
- By applying the boundary conditions $x \to \pm\infty$, $x = 0$, and $x = L$, we arrive at the transmission probability:

$$T = \left[1 + \frac{V_0^2 \sin^2\left(k_{II} L\right)}{4E\left(E - V_0\right)}\right]^{-1}$$

- When does the transmission probability become 1?