PHYS 3313 – Section 001
Lecture #16

Wednesday, Nov. 6, 2013
Dr. Jaehoon Yu

- Barriers and Tunneling
- Alpha Particle Decay
- Use of Schrodinger Equation on Hydrogen Atom
- Solutions for Schrodinger Equation for Hydrogen Atom
- Quantum Numbers

Announcements

- Research paper template is posted onto the research link
  - Deadline for research paper submission is Monday, Dec. 2!!
- Colloquium today
  - 4pm Wednesday, Nov. 6, SH101, Dr. David Nygren of Lorentz Berkeley National Laboratory, Triple extra credit
- Bring homework #5 after the class

Physics Department
The University of Texas at Arlington

SPECIAL COLLOQUIUM

National Academy of Sciences Member

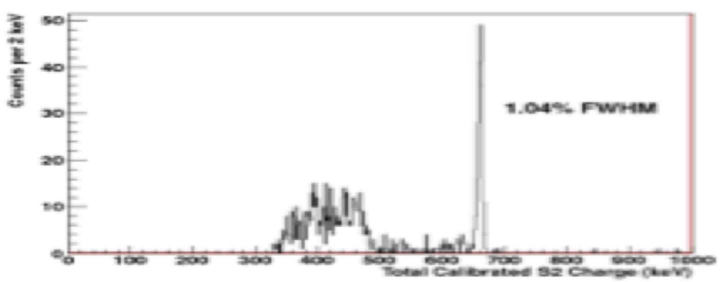
Dr. David Nygren

Physics Division, Lawrence Berkeley National Laboratory

4:00 pm Wednesday, November 6, 2013, Room 101 SH

Abstract:

The first detection of single ionizing events occurred more than 100 years ago when Ernest Rutherford and Hans Geiger succeeded in recording individual alpha-particles from radon decay using a gas-filled detector and an electrometer. Remarkably diverse and useful innovations followed, and continue to emerge even today. Thus, gas-filled detectors are the exemplary evolutionary survivors in nuclear and particle physics experimental technique. Although this ample record has many interesting chapters, I will focus on my favorite topics within this humble corner of the quest to understand our universe. The evolution of these devices is interesting not only for their substantial contributions to scientific progress, but also for what was, surprisingly, overlooked as technology evolved.



Energy spectrum measured for ^{137}Cs γ-rays (662 keV) with a high-pressure xenon gas TPC, relevant to the search for neutrino-less double-beta decay in ^{136}Xe. This appears to be the best energy resolution ever obtained in a xenon-based detector. This result also implies several important benefits for a direct detection WIMP search – including the possibility of directional sensitivity to the expected "WIMP wind" in a massive detector.

A special reception 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. (15 points)
- Deadline Monday, Nov. 11, 2013
- You MUST have your own answers!

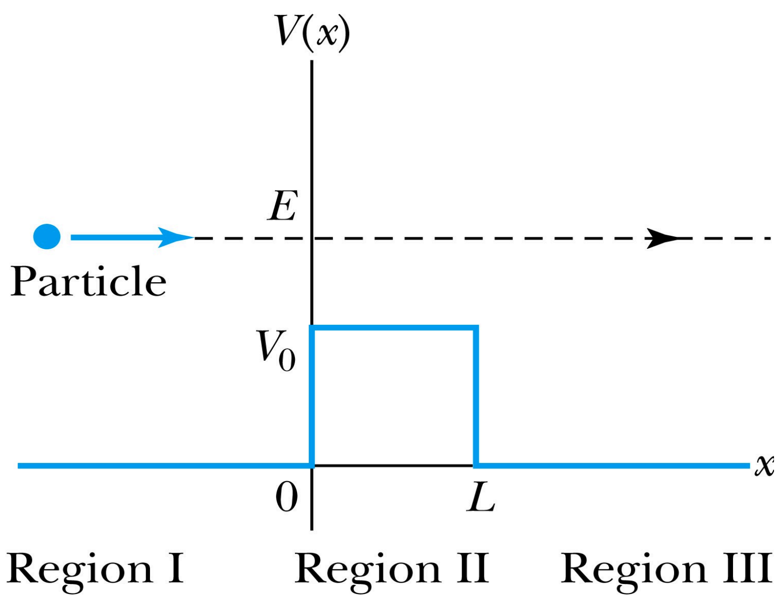
Research Presentations

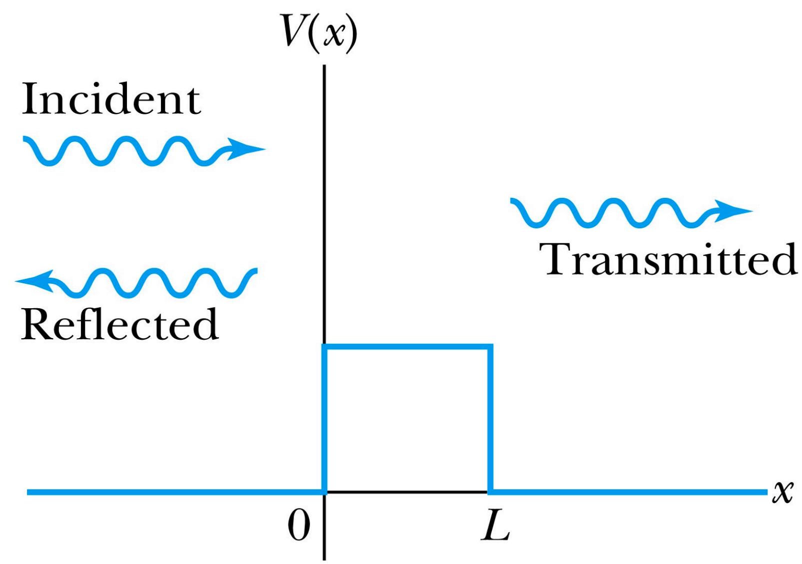
- Each of the 12 research groups makes a 10min presentation
  - 8min presentation + 2min Q&A
  - All presentations must be in power point
  - I must receive all final presentation files by 8pm, Sunday, Dec. 1
    - No changes are allowed afterward
  - The representative of the group makes the presentation with all group members participate in the Q&A session
- Date and time: Determined by drawing
  - In class Monday, Dec. 2 or in class Wednesday, Dec. 4
- 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%

Group Number	Reseasrch Group Members	Research Topic	Presentation Date and Order
1	Z.Citty, S. Lagerson, K. McElvain, J. Vellarreal	Michelson-Morley Experiment	
2	W. Brown, C. Hair, R. Reyes, H. Zapata	The Photo-Electric Effect	
3	R. Clark, M. Kruse, C. Nguyen, B. Watson	The Unification of Electromagnetic and Weak Forces	
4	J. Bolton, J. Day, B. Nuar,	Discovery of Electron	
5	J. Bowerman, C. McNutt, M. Obiang, E. Perez	The property of molecules - the Brownian Motions	
6	N. Boseman, V. Hopkins, S. Moorman, S. Moriaty	Black-body Radiation	
7	E. Bainglass, J. Chavez, K. Izuagbe,	Rutherford Scattering	
8	E. Blomberg, E. Duran, J. Grandinatti, R. Loew	The Discovery of Radioactivity	
9	P. Conlin, J. Guevara, F. Islam, A. Nelson	Special Relativity	
10	G. Brown, G. Collier, B. Ferguson, R. Subramaniam	Compton Effect	
11	K. Brackney, C. Dunn, S. Schroeder, S. Sheladia	Super-Conductivity	
12	A. Farrar, C. Jay, C. Smith, J. Umphress	The discovery of the Higgs particle	

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 $k_{II} = \frac{\sqrt{2m(E - V_0)}}{\hbar}$ 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:

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

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

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

- The corresponding solutions are:

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

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

Region III $(x>L)$ $\quad \psi_{III}=Fe^{ik_{III}x}+Ge^{-ik_{III}x}$

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

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

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

Transmitted wave $\quad \psi_{III}(\text{transmitted})=Fe^{ik_{III}x}$

Probability of Reflection and Transmission

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

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

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

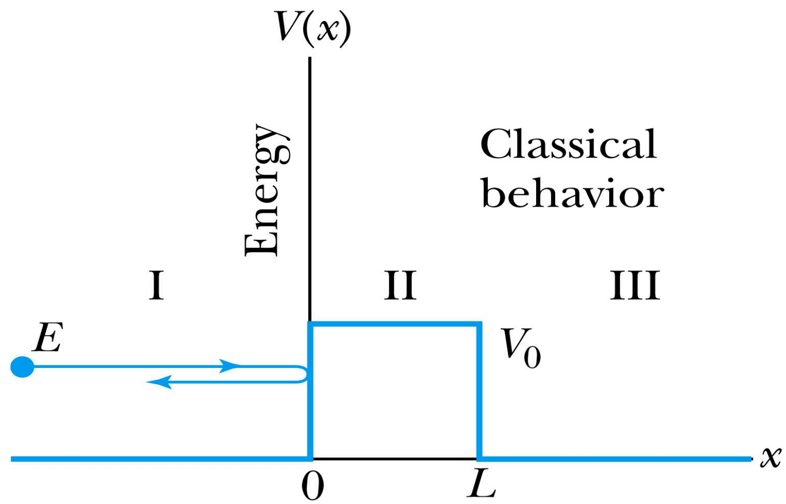
- The maximum kinetic energy of the photoelectrons depends on the value of the light frequency *f* and not on the intensity.
- Because the particles must be either reflected or transmitted we have: $R + T = 1$
- By applying the boundary conditions $x \to \pm\infty$, $x = 0$, and $x = L$, we arrive at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

Tunneling

- Now we consider the situation where classically the particle does not have enough energy to surmount the potential barrier, ***$E < V_0$***.

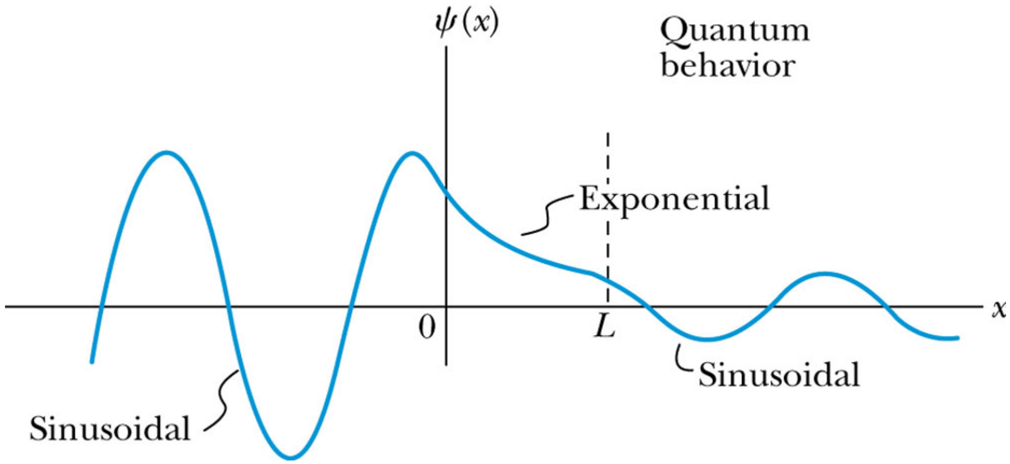


- The quantum mechanical result, however, is one of the most remarkable features of modern physics, and there is ample experimental proof of its existence. There is a small, but finite, probability that the particle can penetrate the barrier and even emerge on the other side.
- The wave function in region II becomes $\psi_{II} = Ce^{\kappa x} + De^{-\kappa x}$ where $\kappa = \frac{\sqrt{2m(V_0 - E)}}{\hbar}$
- The transmission probability that describes the phenomenon of **tunneling** is $T = \left[1 + \frac{V_0^2 \sinh^2(\kappa L)}{4E(E - V_0)}\right]^{-1}$

Uncertainty Explanation

- Consider when *κL* >> 1 then the transmission probability becomes:

$$T = 16\frac{E}{V_0}\left(1-\frac{E}{V_0}\right)e^{-2\kappa L}$$

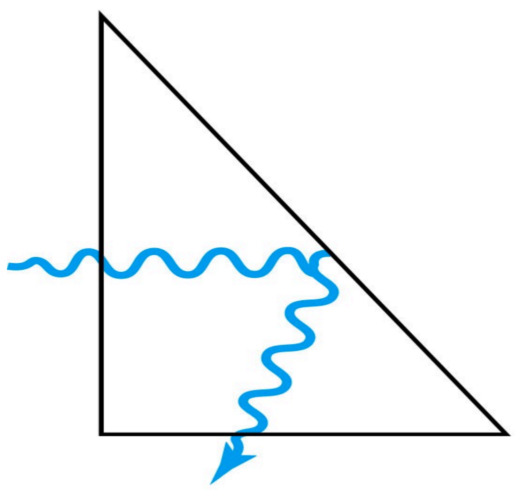


- This violation allowed by the uncertainty principle is equal to the negative kinetic energy required! The particle is allowed by quantum mechanics and the uncertainty principle to penetrate into a classically forbidden region. The minimum such kinetic energy is:

$$K_{\min} = \frac{(\Delta p)^2}{2m} = \frac{\pi^2\kappa^2}{2m} = V_0 - E$$

Analogy with Wave Optics

- If light passing through a glass prism reflects from an internal surface with an angle greater than the critical angle, total internal reflection occurs. The electromagnetic field, however, is not exactly zero just outside the prism. Thus, if we bring another prism very close to the first one, experiments show that the electromagnetic wave (light) appears in the second prism.
- The situation is analogous to the tunneling described here. This effect was observed by Newton and can be demonstrated with two prisms and a laser. The intensity of the second light beam decreases exponentially as the distance between the two prisms increases.



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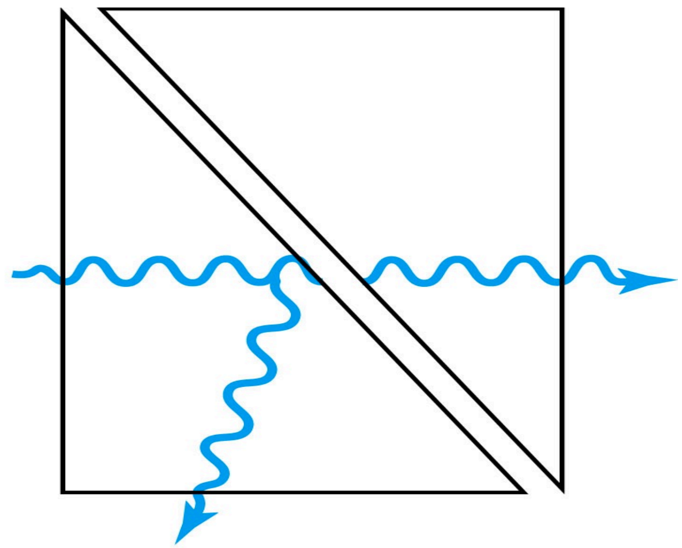

(b)