PHYS 3313 – Section 001
Lecture #14

Wednesday, Oct. 30, 2013

Dr. Jaehoon Yu

- Infinite Square Well Potential
- Finite Potential Well
- Penetration Depth
- Degeneracy
- Simple Harmonic Oscillator

Announcements

- Homework #5
  - CH6 end of chapter problems: 3, 5, 11, 14, 22, and 26
  - Due on Wednesday, Nov. 6 in class
- Quiz #3
  - At the beginning of the class Wed., Nov. 6
  - Covers CH5.6 to what we cover Monday, Nov. 4
  - Prepare your own formula sheet
- Research paper template is posted onto the research link
  - Deadline for research paper submission is Monday, Nov. 25!!
- Colloquium today
  - 4pm today, SH101, Dr. O. Auciello, UTD
- Colloquium coming week
  - 4pm Monday, Nov. 4, SH101, Dr. Yujie Ding of Lehigh Univ.: Double extra credit
  - 4pm Wednesday, Nov. 6, SH101, Dr. David Nygren of Lorentz Berkeley National Laboratory, Triple extra credit

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Science and Technology of Multifunctional Oxide and Ultrananocrystalline Diamond (UNCD) Films and Applications to a New Generation of Multifunctional Devices/Systems

Dr. Orlando Auciello

The University of Texas at Dallas
Department of Materials Science and Engineering
Department of Bioengineering

4:00 pm Wednesday October 30, 2013 room 101 SH

Abstract:

New paradigms in the research and development of novel multifunctional oxide and nanocarbon thin films are providing the bases for new physics, new materials science and chemistry, and their impact in a new generation of multifunctional devices for micro/nano-electronics and biomedical devices and biosystems. This talk will focus on discussing the science, technology, and engineering of multifunctional oxide and nanocarbon thin films and app:lications to a new generation of multifunctional micro and nanodevices and systems, as described below:

1. **Science and technology of complex oxide thin films and application to key technologies:** Novel TiO_2/Al_2O_3 superlattices, exhibiting giant dielectric constant (up to k=1000), low leakage current (10^{-7}-10^{-9} A/cm^2) and low losses (≤ tang d=0.04), based on new physics underlined by the Maxwell-Wagner relaxation mechanism, which enables a new generation of microchip embedded capacitors for microchips implantable in the human body, the next generation of gates for nanoscale CMOS devices, and super-capacitors for energy storage systems;
2. **Science and technology of novel ultrananocrystalline diamond (UNCD) films and integration for fabrication of a new generation of industrial components and multifunctional and biomedical devices:** UNCD films developed and patented at by Prof. Auciello when working at Argonne National Laboratory (1996-2012) are synthesized by a novel microwave plasma chemical vapor deposition technique using an Ar-rich/CH_4 chemistry that produces films with 2-5 nm grains, thus the name UNCD to distinguish them from nanocrystalline diamond films with 30-100 nm grains. The UNCD films exhibit a unique combination of outstanding mechanical, trtibological, electrical, thermal, and biological properties, which already resulted in industrial components and devices currently commercialized by Advanced Diamond Technologies (a company co-founded by O. Auciello and J.A. Carlisle and spun-off from ANL in 2003). Devices and systems reviewed include: a) UNCD-coated mechanical pump seals for the petrochemical, pharmaceutical and car industries (**shipping to market**); b) UNCD-coated bearings for mixers for the pharmaceutical industry (**shipping to Merck-Millipore market**); c) new UNCD electrodes for water purification, which outperform all other electrodes in the market today (**shipping to market**); d) UNCD-AFM tips for science and nanofabrication (**shipping to market**); e) RF-MEMS switches monolithically integrated with CMOS driving devices for next generation of radars and mobile communication devices; f) UNCD-based MEMS biosensors and energy harvesting devices g) NEMS switch-based logic; h) bioinert UNCD coating for encapsulation of a microchip implantable in the retina to restore sight to people blinded by retina photoreceptors degeneration (**31 blind people received microchip implants in 5 countries and are reading letters and recognizing objects and walking through doors without aid**); i) UNCD bioinert coating for heart valves; j) UNCD coating for devices to drain eye liquid for treatment of glaucoma; k) UNCD coating for magnets located outside the eye to produce magnetic fields to attract superparamagnetic nanoparticles injected in the eye to reattach detached retina; l) UNCD coating for stents; m) UNCD coating for artificial joints (hips and knees); n) UNCD surface used as a unique platform for growing stem cells and induce differentiation into various cells of the human body.

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

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Dr. Yujie J. Ding

Department of Electrical and Computer Engineering
Lehigh University

Candidate for Faculty Position:
The Richard N. Claytor Distinguished Professorship in Optics

Monday November 4, 2013 at 4:00 pm in Room 101 SH

Parametric Generation of Terahertz Waves: from Saturation of Conversion Efficiency to Compact and Portable Sources for Variety of Applications

Abstract:

We have achieved the record-high photon conversion efficiency of 40% based on the parametric generation of high-power, tunable and monochromatic terahertz (THz) waves. Meanwhile, we have made a great progress on designing, assembling, and testing of dual-frequency solid-state lasers. Using these lasers, we have implemented portable and compact THz sources. We have significantly scaled up output powers through solid-state laser engineering. By replacing an active Q-switch with a passive Q-switch, we have investigated the parametric generation of the THz waves. We have explored intracavity generation of THz waves by using a nonlinear composite as an output coupler of an infrared laser. These novel configurations allow us to substantially reduce the dimension of the THz source and to realize a monolithic THz source. We have generated multiple THz frequencies and achieved interference effects using multiple infrared frequencies from solid-state lasers and dual signals and dual idlers from coupled optical parametric oscillators. We have investigated enhancements of THz output powers by exploiting polariton resonances, surface-emitting geometry, and extremely large internal electric fields in nitride heterostructures and nanostructures. Besides THz sources, photonics and applications, we have achieved single-photon detection at the communication wavelengths, reached the level well above the threshold for laser cooling based on anti-Stokes photoluminescence, restored distorted images based on phase conjugation, implemented coupled optical parametric oscillators which exhibit significantly reduced phase noises and have rich applications from quantum communications to biological imaging, and investigated novel nanostructures and nanodevices.

Refreshments will be served at 3:30p.m in the PhysicS lounge room 108SH

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!

Properties of Valid Wave Functions

Boundary conditions

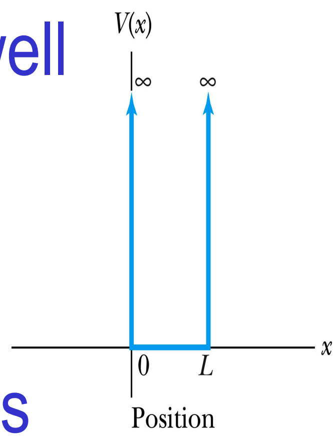
1) To avoid infinite probabilities, the wave function must be finite everywhere.
2) To avoid multiple values of the probability, the wave function must be single valued.
3) For finite potentials, the wave function and its derivative must be continuous. This is required because the second-order derivative term in the wave equation must be single valued. (There are exceptions to this rule when *V* is infinite.)
4) In order to normalize the wave functions, they must approach zero as *x* approaches infinity.

Solutions that do not satisfy these properties do not generally correspond to physically realizable circumstances.

Infinite Square-Well Potential

- The simplest such system is that of a particle trapped in a box with infinitely hard walls that the particle cannot penetrate. This potential is called an infinite square well and is given by

$$V(x) = \begin{cases} \infty & x \le 0, x \ge L \\ 0 & 0 < x < L \end{cases}$$



- The wave function must be zero where the potential is infinite.
- Where the potential is zero inside the box, the time independent Schrödinger wave equation $-\frac{\hbar^2}{2m}\frac{d^2\psi(x)}{dx^2} + V(x)\psi(x) = E\psi(x)$ becomes $\frac{d^2\psi}{dx^2} = -\frac{2mE}{\hbar^2}\psi = -k^2\psi$ where $k = \sqrt{2mE/\hbar^2}$.
- The general solution is $\psi(x) = A\sin kx + B\cos kx$.

Quantization

- Since the wave function must be continuous, the boundary conditions of the potential dictate that the wave function must be zero at $x = 0$ and $x = L$. These yield valid solutions for B=0, and for **integer values** of n such that $kL = n\pi$ ➔ $k = n\pi/L$
- The wave function is now

$$\psi_n(x) = A\sin\left(\frac{n\pi x}{L}\right)$$

- We normalize the wave function

$$\int_{-\infty}^{+\infty}\psi_n^*(x)\psi_n(x)dx = 1 \qquad A^2\int_0^L \sin^2\left(\frac{n\pi x}{L}\right)dx = 1$$

- The normalized wave function becomes

$$\psi_n(x) = \sqrt{\frac{2}{L}}\sin\left(\frac{n\pi x}{L}\right)$$

- These functions are identical to those obtained for a vibrating string with fixed ends.

Quantized Energy

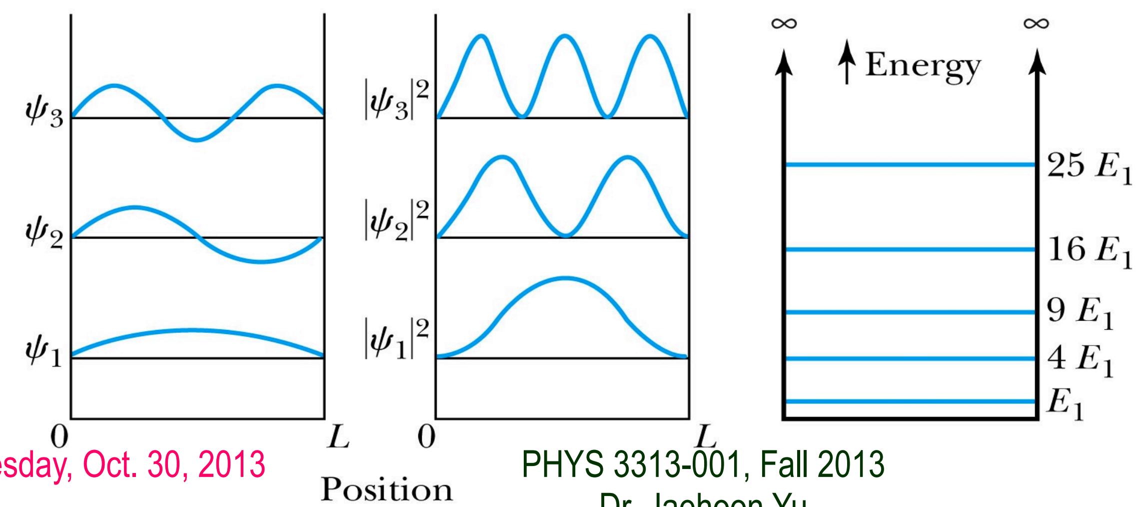
- The quantized wave number now becomes $k_n(x) = \frac{n\pi}{L} = \sqrt{\frac{2mE_n}{\hbar^2}}$
- Solving for the energy yields

$$E_n = n^2 \frac{\pi^2\hbar^2}{2mL^2} \quad (n = 1,2,3,\cdots)$$

- Note that the energy depends on the integer values of *n*. Hence the energy is quantized and nonzero.
- The special case of $n = 1$ is called the **ground state energy**.

$\psi_n(x) = \sqrt{\frac{2}{L}}\sin\left(\frac{n\pi x}{L}\right)$

$\psi_n^*\psi_n = |\psi_n|^2 = \frac{2}{L}\sin^2\left(\frac{n\pi x}{L}\right)$



$$E_3 = \frac{9\pi^2\hbar^2}{2mL^2} = 9E_1$$

$$E_2 = \frac{2\pi^2\hbar^2}{mL^2} = 4E_1$$

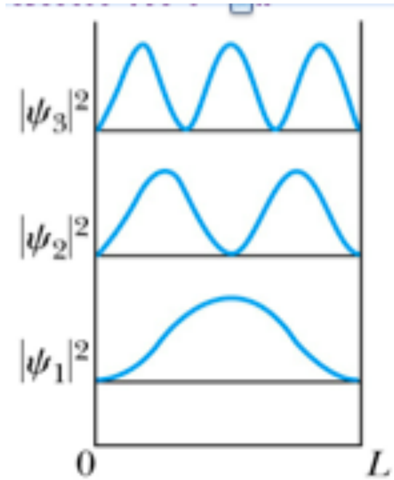
$$E_1 = \frac{\pi^2\hbar^2}{2mL^2}$$

How does this correspond to Classical Mech.?

- What is the probability of finding a particle in a box of length L? $\frac{1}{L}$
- Bohr's **correspondence principle** says that QM and CM must correspond to each other! When?
  - When n becomes large, the QM approaches to CM
- So when n→∞, the probability of finding a particle in a box of length L is

$$P(x) = \psi_n^*(x)\psi_n(x) = |\psi_n(x)| = \frac{2}{L}\lim_{n\to\infty}\sin^2\left(\frac{n\pi x}{L}\right) \approx \frac{2}{L}\left\langle \sin^2\left(\frac{n\pi x}{L}\right)\right\rangle = \frac{2}{L}\cdot\frac{1}{2} = \frac{1}{L}$$

- Which is identical to the CM probability!!
- One can also see this from the plot of P!



Ex 6.8: Expectation values inside a box

Determine the expectation values for x, x^2, p and p^2 of a particle in an infinite square well for the first excited state.

What is the wave function of the first excited state? n=? 2

$$\psi_{n=2}(x)=\sqrt{\frac{2}{L}}\sin\left(\frac{2\pi x}{L}\right)$$

$$\langle x\rangle_{n=2}=\int_{-\infty}^{+\infty}\psi^*_{n=2}(x)x\psi_{n=2}(x)=\frac{2}{L}\int_0^L x\sin^2\left(\frac{2\pi x}{L}\right)dx=\frac{L}{2}$$

$$\langle x^2\rangle_{n=2}=\frac{2}{L}\int_0^L x^2\sin^2\left(\frac{2\pi x}{L}\right)dx=0.32L^2$$

$$\langle p\rangle_{n=2}=\frac{2}{L}\int_0^L \sin\left(\frac{2\pi x}{L}\right)(-i\hbar)\frac{\partial}{\partial x}\left[\sin\left(\frac{n\pi x}{L}\right)\right]dx=-i\hbar\frac{2}{L}\frac{2\pi}{L}\int_0^L \sin\left(\frac{2\pi x}{L}\right)\cos\left(\frac{2\pi x}{L}\right)dx=0$$

$$\langle p^2\rangle_{n=2}=\frac{2}{L}\int_0^L \sin\left(\frac{2\pi x}{L}\right)(-i\hbar)^2\frac{\partial^2}{\partial x^2}\left[\sin\left(\frac{2\pi x}{L}\right)\right]dx=\hbar^2\frac{2}{L}\left(\frac{2\pi}{L}\right)^2\int_0^L \sin^2\left(\frac{2\pi x}{L}\right)dx=\frac{4\pi^2\hbar^2}{L^2}$$

$$E_2=\frac{4\pi^2\hbar^2}{2mL^2}=\frac{\langle p^2\rangle_{n=2}}{2m}$$

Ex 6.9: Proton Transition Energy

A typical diameter of a nucleus is about 10^{-14}m. Use the infinite square-well potential to calculate the transition energy from the first excited state to the ground state for a proton confined to the nucleus.

The energy of the state n is $E_n = n^2 \frac{\pi^2\hbar^2}{2mL^2}$

What is n for the ground state? n=1

$$E_1 = \frac{\pi^2\hbar^2}{2mL^2} = \frac{\pi^2\hbar^2 c^2}{2mc^2 L^2} = \frac{1}{mc^2}\frac{\pi^2 \cdot (197.3eV \cdot nm)^2}{2 \cdot \left(10^5 nm\right)} = \frac{1.92 \times 10^{15} eV^2}{938.3 \times 10^6 eV} = 2.0MeV$$

What is n for the 1st excited state? n=2

$$E_2 = 2^2 \frac{\pi^2\hbar^2}{2mL^2} = 8.0MeV$$

So the proton transition energy is

$$\Delta E = E_2 - E_1 = 6.0MeV$$