

Homework #1

due Wednesday, October 15, 2025

1. (5 pts) Consider a quantum dot, whose shape can be approximated by a flat circular disk of radius R . The dot is parallel to an infinite metal plane, at a distance L from the plane. Assuming that we know from electrostatics that if $R \ll L$ the capacitance of the dot is $C = 8 \epsilon_0 \epsilon R$, estimate the radius of the dot that would enable observations of single electron effects at room temperature. Take ϵ to be the dielectric constant of silicon. How would your answer change if we wanted to make these observations at liquid Helium temperatures?
2. (5 pts) InP has a bandgap of 1.35 eV at room temperature. At 775 nm, the absorption coefficient is $3.5 \times 10^6 \text{ m}^{-1}$. Estimate the transmission through a $1 \mu\text{m}$ InP sample at 620 nm. Assume that the sample is made with anti-reflection coated surfaces.
3. (5 pts) Consider a 2.5 nm $\text{Zn}_{0.8}\text{Cd}_{0.2}\text{Se}/\text{ZnSe}$ quantum well which can be approximated by a box with infinite walls. The unit cell size of the crystal is 0.28 nm, and the electron and hole effective masses of $\text{Zn}_{0.8}\text{Cd}_{0.2}\text{Se}$ are $0.14 m_0$ and $0.5 m_0$, respectively. The bandgap is 2.55 eV.
 - (a) Find the lowest energies for the electron and hole. What is the expected energy of PL emission?
 - (b) If d varies by $\pm 5\%$, how much shift in the PL emission do you expect?
4. (5 pts) A $\text{Ga}_{0.47}\text{In}_{0.53}\text{As}$ quantum well laser is designed to emit at $1.55 \mu\text{m}$ at room temperature. Estimate the width of the quantum wells within the device. The bandgap is 0.75 eV and the effective masses of electrons and heavy holes are $0.041 m_0$ and $0.47 m_0$, respectively.
5. (10 pts) Work through the PRL 1980 paper by von Klitzing et al. Show that the results in Fig.1 are consistent with equation (4).
6. (15 pts) Work through the PRL 1988 paper by van Wees et al. Show how equation (2) transforms into equation (4). Discuss classical limit of equation (4) and what we would observe experimentally in the same experiments the authors performed, but in the classical limit.
7. Reading assignment: PRL **54**, 2696 (1985) (Aharonov – Bohm effect) and PRL **67**, 1626 (1991) (Coulomb blockade in quantum dots).

Additional reading regarding physics of low-dimensional semiconductors:

- 1) J. H. Davies, "The physics of low-dimensional semiconductors" (Cambridge Univ. Press, Cambridge, 1998)
- 2) D. K. Ferry, S. M. Goodnick, and J. Bird, "Transport in nanostructures" (Cambridge Univ. Press, Cambridge, 2009)
- 3) Ch. Hamaguchi, "Basic semiconductor physics" (Springer, Berlin, 2001)
- 4) M. Jaros, "Physics and applications of semiconductor microstructures" (Clarendon Press, Oxford, 1989)
- 5) M. J. Kelly, "Low-dimensional semiconductors" (Clarendon Press, Oxford, 1995)
- 6) Y. Murayama, "Mesoscopic systems" (Wiley-VCH, Weinheim, 2001)
- 7) W. Schafer and M. Wegener, "Semiconductor optics and transport phenomena" (Springer, Berlin, 2002)
- 8) C. Weisbuch and B. Vinter, "Quantum semiconductor structures" (Academic Press, Boston, 1991)