### Course Information

- **Department/Program:** Electrical and Computer Engineering
- **Course Prefix/Number:** ECE 725
- **Previous Prefix/Number:** N/A
- **Date of Last Action:**
- **Course Title:** Quantum Engineering
- **Abbreviated Title:** QUANTUM ENGRG
- **Scheduling:**
  - Fall
  - Spring
  - Summer
  - Every Year
  - Alt. Year Odd
  - Alt. Year Even
  - Other
- **Credit Hours:** 3
- **Offered by Distance Education Only:**
- **Contact Hours:**
  - Lecture/Recitation 3
  - Seminar
  - Laboratory
  - Problem
  - Studio
  - Independent Study/Research
  - Internship/Practicum/Field Work
- **Grading:** ABCDF, S/U
- **Instructor (Name/Rank):** Gerald J. Iafrate, Professor
- **Graduate Faculty Status:**
  - Associate
  - Full
- **Anticipated Enrollment:**
  - Per semester 20
  - Max. per Section 30
  - Multiple sections Yes
  - No
- **Prerequisite(s):** ECE 730, and PY 401 or equivalent
- **Corequisite(s):**
- **Pre/Corequisite for:**
- **Restrictive Statement:**
- **Curricula/Minors:**
  - Required
  - Qualified Elective
- **Proposed Effective Date:** 01/01/05
- **Approved Effective Date:**

### Catalog Description

Development of advanced engineering concepts at the quantum level relevant to nanoscience, nanoelectronics, and quantum photonics. Topics include tunneling phenomena, specifics of time dependent and time independent perturbation methodology for addressing applications under consideration, including the WKB approach, and an introduction to second quantization for engineers. Applications include, but not limited to, tunneling in a two-level system, molecular rotation through excitation, field emission, van der Waal interactions, optical absorption in quantum wells, and electron transport through model molecules.

### Recommended By

- **Department Head/Director of Graduate Programs**
- **Chair, College Graduate Studies Committee**
- **College Dean(s)**

### Approved By

- **Dean of the Graduate School**
Justification: Nanoscience and engineering is emerging as a prominent technological area worldwide. In a recent National Research Council review of the US National Nanotechnology Initiative (NNI), “Small Wonders, Endless Frontiers”, nanotechnology was cited as a significant technology for the twenty-first century. In keeping with this emerging trend, the Department of Electrical and Computer Engineering educates students and executes research in the functional area of “Nanoelectronics and Photonics”. This course provides engineering students with complementary physical principles of quantum mechanics in context with illustrative applications related to nanoscience and engineering. It therefore provides the students with a solid foundation and a working technical knowledge of key fundamental physical principles for advanced degree work in nanotechnology and photonics.

Objectives: Upon successful completion of this course, students will:

1. be able to apply basic quantum mechanics principles in context with advanced nanoscience and engineering applications.

2. be able to treat the phenomena of quantum tunneling and its application to exactly solvable problems; develop and apply the WKB approximate method as a tool in non-analytically solvable tunneling problems.

3. be able to derive and apply Raleigh Schrodinger perturbation theory (RSPT); use examples of Stark effect in a quantum well and van der Waal interactions.

4. be able to derive and apply time dependent perturbation theory; apply examples of “golden rule” development for transition rates, optical absorption in nanosystems, transport through a model molecule.

5. be able to apply the concept of photons; derive the mathematical realization of photons in terms of harmonic oscillators and connect to the meaning and consequences of second quantization of the electromagnetic field.


Enrollment since first offering as ECE792F

<table>
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<tr>
<th>SEMESTER</th>
<th>YEAR</th>
<th>INSTRUCTOR</th>
<th>ENROLLMENT</th>
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</thead>
<tbody>
<tr>
<td>Spring</td>
<td>2002</td>
<td>G.J. Iafrate</td>
<td>5</td>
</tr>
<tr>
<td>Spring</td>
<td>2003</td>
<td>G.J. Iafrate</td>
<td>7</td>
</tr>
<tr>
<td>Spring</td>
<td>2004</td>
<td>G.J. Iafrate</td>
<td>15</td>
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**Resources:**  No new resources are required.

**Consultation with Physics:**

Dear Joel,

The physics department course and curriculum committee met with Professors Iafrate and Hauser along with physics quantum mechanics professors (present and past) to discuss the proposed Course Action Form (CAF) to create a Quantum Engineering class.

Overlap of course content and student marketplace issues were carefully discussed. While some concerns were raised by physics professors, the committee felt that the case for the creation of the course is sufficiently strong to support the CAF. Professor Iafrate agreed to some changes in the course description and in the course syllabus which placed the emphasis in a slightly different light that more clearly distinguishes it from physics courses.

With these changes in place, the physics department course and curriculum committee endorses the CAF to create Quantum Engineering.

Sincerely,

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Michael Paesler
Professor and Director of Graduate Programs
Physics Department
North Carolina State University
Raleigh, NC 27695-8202
USA
Course Description: Quantum Engineering investigates advanced engineering concepts relevant to nanoscience, nanoelectronics, and quantum-level photonics based on the principles of quantum mechanics. Basic principles of quantum mechanics that are reviewed include: tunneling phenomena; time dependent and time independent perturbation theory, the WKB approach, and an introduction to second quantization. Applications include, but are not limited to, tunneling in a simple two-level system, molecular-rotation through excitation, field emission, van der Waal interactions, optical absorption, and electron transport through molecules.

Instructor: Dr. Gerald J. Iafrate, Professor – Room 334C EGRC Building, Centennial Campus, 513-2310.

Office Hours: T, H 2:30p.m. – 3:30p.m., EGRC 334C, or by appointment.


Prerequisites: This course utilizes advanced concepts from differential equations, vector calculus, and basic modern physics. Course prerequisites: ECE 730 and PY 401 or equivalent.

Course Outline (Chronological):

<table>
<thead>
<tr>
<th>Lectures</th>
<th>Topics</th>
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<tbody>
<tr>
<td>5</td>
<td>Review of Schrodinger equation and its interpretation</td>
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<td>Quantum mechanics, language, principles</td>
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<td></td>
<td>Wave function dynamics, time evolution</td>
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<td>Development in terms of stationary states</td>
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<td>Two level system: application to vertical (inelastic) and horizontal (elastic, tunneling) transitions</td>
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<td>6</td>
<td>Tunneling phenomena</td>
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<td>Exact analysis; piecewise constant potential barrier</td>
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<td>Tunneling through a barrier in an infinite box; connection with two level system</td>
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<td>Approximate approach – WKB tunneling formula</td>
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<td>WKB; Wilson – Sommerfield quantization rule for confined states</td>
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<td></td>
<td>Applications: field emission from solid surfaces and tips; energy adjustments from alteration of quantum confinement boundaries</td>
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<td>5</td>
<td>Time independent stimulation of nanosystems</td>
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<td>Stationary perturbation theory (RSPT)</td>
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<td>Stark effect; particle in a quantum well</td>
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<td>van der Waal interactions</td>
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<td>6</td>
<td>Time dependent stimulation of nanosystems - transitions</td>
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<td>Time dependent perturbation theory</td>
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<td>Transition rates – Fermi Golden Rule</td>
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<td>Tunneling through Bardeen transfer Hamiltonian method; metal-insulator-metal tunneling</td>
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<td>Optical absorption in semiconductors; extension to quantum wells</td>
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</table>
Course Outline (cont’d)

Molecular rotation through excitation
Transport through model molecules; quantum capacitance and coulomb blockade

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Introduction to second quantization
Description of electromagnetic field in terms of harmonic oscillators; passage to quantum fields
The interaction of light with matter; spontaneous emission, induced emission
Spintronics

GRADING POLICY:

• There will be 2 semester exams and 1 final exam, equally weighted at 30% each
• Homework is 10% of the grade. It will be assigned every week, it is primarily for recitation for working knowledge and will be based on participation, timeliness and completeness.

• Homework will be assigned, collected, and reviewed for approach on a regular basis, and should be handed in at the beginning of the period it is due. Required homework will be assigned every week, 10% of the grade, primarily for recitation for working knowledge and will be based on participation, timeliness and completeness. Late homework (whole homework sets only) will be accepted up to the last day of class to insure that the student has been allowed to satisfy the requirements for homework assignments. If you anticipate not being present on the day homework is due, please make arrangements to hand it in early. You may work in groups on the required homework – in fact, you are encouraged to. You must turn in individual solutions, however. Homework input is required and will be recorded; solutions are discussed by instructor together with students in recitation sessions. Homework participation is expected since this is where a major part of learning is done.

MAKE-UP POLICY:
If serious reasons prevent a student from taking an exam on the scheduled date the opportunity to make-up will be offered according to the official academic policies (http://www.ncsu.edu/provost/academic_policies/grading/reg.htm).

• Dropping Deadline: The last day to drop this course or change to audit status is Friday, March 18, 2005.

• Auditing: Students officially auditing this course will be required to participate in the homework problems and other out of class assignments should they arise. Auditors must turn in individual assignments. Auditors will not be required to take the semester tests or the final.

Students with disabilities
Reasonable accommodations will be made for students with verifiable disabilities. In order to take advantage of available accommodations, students must register with Disability Services for Students at 1900 Student Health Center, Campus Box 7509, 515-7653. http://www.ncsu.edu/provost/offices/affirm_action/dss/. For more information on NC State’s policy on working with students with disabilities, please see http://www.ncsu.edu/provost/hat/current/appendix/appen_k.html.

Academic integrity
All the provisions of the code of academic integrity apply to this course. See the university statement on academic integrity: http://www.ncsu.edu/provost/academic_policies/integrity/reg.htm. See also the student code of conduct: http://www.fis.ncsu.edu/ncsulegal/41.03-codeof.htm. In addition, it is my understanding and expectation that your signature on any test or assignment means that you neither gave nor received unauthorized aid.