The Candidacy Examination may be taken after earning 18 credits beyond the baccalaureate degree and must be taken prior to the end of the second semester in residence after 24 credits beyond the baccalaureate degree have been earned. Students entering with a master’s degree must therefore take the Candidacy Examination prior to the end of second semester in residence, not counting the summer session. The student must be registered with either full-time or part-time degree status for the semester in which the Candidacy Examination is taken.

This examination is offered twice a year, during October/November and March/April. The examination consists of two parts, a Written Component and a Research Component, both of which are administered by an Examination Board comprising three tenure-track/tenured ESM faculty members or full-time full professors in the ESM Department. There are five Boards, one for the Fundamentals Exam and one for each Concentration/Specialty Exam (see below), that are appointed at the beginning of each academic year.

Part I: Written Component

The Written Component of the Candidacy Exam consists of two written examinations: a Fundamentals Exam in Applied Mathematics, and a Concentration/Specialty Exam. All students have to take the Fundamentals Exam and then each student must choose, in consultation with his/her research advisor, to be examined on one of the Concentration areas. There is a Board for each Concentration Exam that creates the exam and then examines the student on the Research Component (see Part II below). The Fundamentals Exam is also created by its own Board. In the following sections, the structure and content covered by all exams are outlined.

To guide students in preparation, a detailed list of courses and texts indicative of the scope and level of questions on all exams is made public by each Board in meetings at the beginning of every semester. Graduate students are strongly advised to attend these meetings.
Fundamentals Exam in Applied Mathematics (3 hours)

The purpose of this exam is to establish that students in all concentration areas have the basic competency in, and capacity to do, mathematics required for further graduate study in the Engineering Sciences.

The exam emphasizes the following topics: multivariable calculus, elementary properties of series, Taylor and Fourier series; complex analysis, functions of a complex variable; vector spaces, vector algebra, and linear algebra; elementary ordinary differential equations; elementary partial differential equations and boundary value problems; and elementary numerical methods. These topics will be presented at the introductory graduate level. Note, however, that the Fundamentals Exam material is expected to represent the more fundamental aspects of the material taught in those courses. Additional, more advanced treatments of these and other topics are included in the Concentration Exams, as the different Boards deem necessary.

The Concentration/Specialty Exam (3 hours)

Students must choose to be examined in one of the following four areas. A representative list of topics is included below with each category.

In general, questions on the Concentration Exams are at the level of upper-level undergraduate and beginning graduate courses, though at the beginning of every academic year each Board will provide a detailed list of topics and texts indicating the expected level prior to each exam.

The broad coverage of each Concentration Exam is intended to provide an evaluation of the fundamental knowledge required for advanced study in the student’s chosen field of Engineering Science. However, exams may be structured to give students some choice in the questions that must be adequately answered in order to pass, based on the emphasis of a specific number of subspecialties within each concentration area. The minimum passing requirements will be clearly spelled out by each Examination Board at the beginning of each semester.

Mechanics. This exam may include material from the following subject areas: advanced mechanics of materials; elementary continuum mechanics and elasticity; advanced dynamics, linear vibrations, and wave propagation; and applied mathematics (this includes: partial and ordinary differential equations, linear algebra, complex variables, numerical methods, calculus of variations, and advanced calculus).

Materials. The exam assesses the student’s general knowledge of metallic, semiconductor, ceramic, and polymer materials, and their properties in relation to engineering device applications. The focus is on concepts gleaned and retained from undergraduate courses in chemistry, physics, materials, mechanics and devices. Questions may be qualitative as well as quantitative, and deal with behavior of materials; their growth, characterization and processing; response to load and/or environment; and
synthesis into useful structures. Basic expertise in quantitative analysis and design of engineering devices is also evaluated.

**Electromagnetism.** The exam assesses the student’s general knowledge in the following areas: electrostatics; time-varying electromagnetic fields and Maxwell’s equations; plane-wave propagation in different linear materials and across boundaries; electric circuits and elementary circuit analysis; wave-particle duality of electromagnetic radiation and interaction with matter, photons; blackbody radiation, Compton and photoelectric effects; absorption, skin depth and plasma frequencies in metals, polarization of dielectrics; complex conductivity; magnetization and magnetic domains; masers and lasers; geometrical and physical optics.

**Bionanotechnology.** The exam is concerned with the fundamental physics of nanostructures at the physical/life science interface. The student should understand the fundamental laws of molecular materials, apply the principles of thermodynamics and statistical mechanics to bio and nano materials, be aware of the imaging and spectroscopic methods that are commonly used in bionanotechnology and explain the fundamentals of device applications. The scope of this exam is currently evolving, but is announced in detail every year by the Examination Board administering it.

**Part II: Research Component**

The second part of the Candidacy Exam consists of a research proposal and an oral presentation on an “Emerging Technology.” Topics are solicited from the ESM faculty, and are intended to be examples of new or anticipated interdisciplinary areas of research that extend beyond the borders of any one field of study. Students can also write a proposal on a topic of their own choosing with prior approval of their advisor and the Examination Board.

A research proposal should be a short paper about 5 pages in length. A certain degree of specificity is expected. The research proposal should summarize the main research questions in the chosen emerging technology area and discuss how the student might tackle the questions. The student is expected to come at the proposal from the point of view of their own disciplinary concentration, and should discuss how the ideas and methodologies of their concentration impacts, and contributes to the development of, the emerging technology area. The student is also asked to discuss the limitations of their own discipline in addressing the needs of the emerging field, and discuss possible interfacing with other disciplines actively pursued in the ESM Department.

The research proposal paper is intended to be an assessment of the student’s creativity as well as their communication via written English. This document must be given to the Board no more than 2 weeks after the completion of Part I of the exam.

The oral presentation and examination are scheduled within one week of handing in the proposal. The student is expected to give a short (about 15 minute)
presentation on their chosen emerging technology area, and then is examined on their proposal as well as on Part I (Written Component) of the Candidacy Exam, as deemed necessary and appropriate by the Examination Board. The oral presentation and examination do not generally exceed 90 minutes in duration, and can be much shorter.

The student’s research advisor is invited to join the Examination Board as a non-voting member. If the advisor is already a member of the Examination Board, he/she is not permitted to vote, but another ESM graduate faculty member is asked to temporarily act as a voting member.

Finally, it is also intended that this portion of the exam, involving a conceptual exercise on an emerging field, will promote synthesis and cross-disciplinarity within the ESM Department across the different specialties, and encourage within graduate students a unified view of all of the Engineering Sciences.

**Other Administrative Details**

During the second week of every semester, each Examination Board conducts an open meeting to advise doctoral students on the scope of the Candidacy Examination for its concentration/specialty and to answer questions on the nature of the forthcoming examination. Every student is strongly encouraged to speak to the Board of his/her chosen area, in preparation for the examination.

The Board evaluates student performance on each portion of the Candidacy Exam, and makes recommendation to pass or fail to the entire ESM Graduate Faculty, which makes the final decisions. The Board may also recommend, and the faculty require, that a student take certain additional courses, regardless of the outcome of the exam, which may include remedial education to improve English competency.

A student who does not pass the Candidacy Examination on the first attempt may be permitted by the ESM Graduate Faculty to retake the examination, in its entirety and without a change of track, the next time it is offered. Failing twice will result in the student being asked to graduate with a master’s degree (if all requirements for that degree are met by the student) rather than the doctoral degree.

Within six weeks after passing the Candidacy Examination, the student is required to set up the Doctoral Committee.
Exam Topics

The purpose of this exam is to establish that students in all concentration areas have the basic competency in, and capacity to do, mathematics required for further graduate study in the Engineering Sciences.

The exam emphasizes the following topics:

- multivariable calculus
- elementary properties of series, Taylor and Fourier series
- functions of a complex variable
- vector spaces, vector algebra, and linear algebra
- elementary ordinary differential equations
- elementary partial differential equations and boundary value problems
- elementary numerical methods

These topics will be presented at the introductory graduate level not exceeding that taught in EMch 524A and B. Note, however, that the Fundamentals Exam material will emphasize the more elementary aspects of the material taught in upper-level undergraduate courses typical for engineering students.

Additional, more advanced treatments of these and other topics are included in the Concentration Exams, as the different Boards deem necessary.

*This draft: September 25, 2006; Contact: J.P. Cusumano: 5-3179, jpc3@psu.edu
Exam Format

There are 14 problems on the exam, each valued at 10 points. Grading for the exam is out of 100 points, and thus you must answer at least 10 of the 14 for full credit. It is recommended, however, that students attempt all of the problems since partial credit is given.

Answers to the problems should be succinct, but students must include all reasoning needed for the solution, including any necessary drawings or discussion. If you feel short on time, it is advisable to set up problems and come back to complete them as time permits.

The exam is closed book, however you may use one two-sided note sheet that you have prepared in advance. Calculators are permitted, but probably not needed.

Study References

Some texts suitable for studying the above topics are:


ESM Candidacy Specialty Exam in Mechanics: Goals and Scope

Prepared by the ESM Mechanics Faculty

January 15, 2007

Goals

Mechanics is the original engineering science and continues to be critical to the advancement of technology in the 21st century. Mechanics plays a central role in mechanical, aerospace, civil, materials, and industrial engineering, with profound implications in such emerging fields as nanotechnology, bioengineering, and structural health monitoring.

The Ph.D. Candidacy Specialty Exam in Mechanics tests fundamental knowledge of mechanics and applied mathematics. These areas are essential for further study of mechanics and are necessary to achieve a level of expertise expected of a doctoral student. This fundamental knowledge is generally acquired through a course of study that includes upper-level undergraduate and beginning graduate courses in mechanics and mathematics. It is the goal of this exam to ensure that the student has the ability to successfully complete Ph.D.-level course requirements in mechanics and applied mathematics.

Scope

The Mechanics Specialty Exam will be 3 hours in duration and will assess the student in two subject areas: solids and motion. Applied mathematics content will appear as a part of almost all of the questions in both solids and motion exams.

Solids (1.5 hrs)

The solids exam will contain six questions, two from each of the following three subjects: advanced strength of materials, continuum mechanics, and elasticity. To pass, the student must adequately answer any three questions from the six provided.

Motion (1.5 hrs)

The motion exam will contain six questions, two from each of the following three subjects: advanced dynamics, linear vibrations, and elastic wave propagation. To pass, the student must adequately answer any three questions from the six provided.
Applied Mathematics

While you are examined on applied mathematics during the Fundamentals Exam, it is such an important part of mechanics that you will also be tested on it as a natural part of the mechanics problems. With this in mind, you should be familiar with the following six subject areas in applied mathematics: (i) numerical analysis, (ii) variational calculus, (iii) partial differential equations, (iv) ordinary differential equations, (v) linear algebra, and (vi) complex variables.

Additional Information

To aid with your preparation for the exam, a list of books that cover the above-listed material will be provided each year by the Examination Board for the Mechanics Specialty Exam.

You are allowed five 8.5 \times 11 inch equation sheets for the two exams (total, not for each). You may write on both sides of each page. Note that all of your equation sheets must be turned in with your exam.

Please address any questions that you may have to the Examination Board.

A Note on the Research Component of the Exam

In addition to the information on the candidacy exam provided in the Engineering Science and Mechanics Graduate Programs Guide,* the mechanics faculty require that all topics for research proposals must involve at least one discipline outside of the field of the student’s dissertation. For example, as a mechanics student, you could include in your proposed project, interactions with researchers from biology, medicine, or materials. A positive evaluation of the proposal by the committee will rest, in part, on the degree to which you successfully imagine an interdisciplinary research program. As the Graduate Programs Guide states, you may come up with your own topic (to be approved by the Examination Committee in Mechanics) or you may choose a topic from the list provided by the Committee.

*Available at http://www.esm.psu.edu/students/graduate/
This document should serve as a guide for studying for the Specialty Exam in Mechanics. Within each subject area or component (e.g., Advanced Strength of Materials), we list those topics you should know in order to be prepared for that component. In addition, we list suggested books that contain that material (other books may, of course, be used). For each book, suggested chapters are given in square brackets after the bibliography information for that book.

**Solids Component**

**Advanced Strength of Materials**

*Topics:*

- Castigliano’s theorems and Rayleigh-Ritz method applied to bars, trusses, beams, and frames
- unsymmetric bending and shear center of beams
- equation development and boundary conditions for plate bending equations in Cartesian and Polar coordinates; solutions to some simple problems
- column buckling
- stress-based criteria to predict yielding in ductile materials, slip in granular materials, and failure of brittle materials
- stress intensity factor approach to predict brittle fracture
- S-N curves, the Goodman correlation, and the Palmgren-Minor rule to predict fatigue life with a stress-based approach
- Paris law prediction of fatigue crack growth
- steady state creep behavior and predict time to rupture
Suggested Books and Chapters:


Continuum Mechanics

Topics:

- basic concepts of linear algebra
- notion of derivative as a linear operator
- divergence theorem
- Eulerian and Lagrangian descriptions of motion
- relationship between strain and motion
- Eulerian and Lagrangian characterizations of rigid body motion
- balance laws
- Cauchy theorem and stress
- work-energy theorem, principle of virtual work
- What are constitutive equations? What is the basic difference between constitutive equations for solids and constitutive equations for fluids?
- Concept of material symmetry. Concept of isotropy.

Suggested Books and Chapters:

- Ray M. Bowen (1989) *Introduction to Continuum Mechanics for Engineers*, Plenum Publishing. [Appendix A (no proofs); Chapter 2; Chapter 3 (without jump conditions); Chapter 4 (no proofs concerning material frame indifference and symmetry properties)].

- Morton E. Gurtin (1981) *An Introduction to Continuum Mechanics*, Academic Press. [Chapters 1 & 2 (without proofs); Chapter 3 (the only proofs required concern the characterization of homogeneous deformations and the Reynolds Transport theorem); Chapter 4 & 5; Chapter 6 (no proofs); Chapter 9 (skip the part concerning material frame indifference); Chapter 10 (up to the formulation of the governing equations for the linear elastic BVP)].
• Lawrence E. Malvern (1969) *Introduction to the Mechanics of a Continuous Medium*, Prentice Hall. [Chapter 2 (no proofs); Chapter 3.1–3.3; Chapter 4; Chapter 5.1–5.6; Chapter 6.1–6.3 (reading); Chapter 7.1–7.3].


**Elasticity**

*Topics:*

• Cartesian tensors

• integral theorems

• strain-displacement relations in a regime of small deformation, infinitesimal rotation tensor, hydrostatic and deviatoric components of stress and strain, principal strains, thermal strains

• strain compatibility equations

• equations of equilibrium

• elastic moduli, constitutive equations of an isotropic linear elastic material, constitutive equations of an isotropic linear thermo-elastic material

• the linear elastic boundary value problem, superposition, existence and uniqueness of solutions

• strain energy, principle of virtual work

• two-dimensional elasticity in Cartesian coordinates, plane strain, plane stress, generalized plane stress, anti-plane strain.

• basic understanding of the assumptions and solution behavior of the following problems:

  – two-dimensional problems of elasticity in cylindrical coordinates
  – torsion of prismatic cylinders, membrane analogy
  – stress analysis of rotating discs
  – stress analysis of thick-walled cylinders
  – bending of flat plates
  – stress analysis of axisymmetric shells
Suggested Books and Chapters:


- Pei Chi Chou and Nicholas J. Pagano (1967) Elasticity: Tensor, Dyadic, and Engineering Approaches, Dover Publications. [all Chapters]

Motion Component

Advanced Dynamics

Topics:

- time derivative of a vector
- kinematics in Cartesian, path, cylindrical, and spherical coordinates
- angular velocity and angular acceleration
- velocity and acceleration in a moving reference frame
- particle kinetics, including energy and momentum principles
- rigid body kinematics, including finite rotations (e.g., Euler angles)
- rigid body kinetics, including moments of inertia, and the translational and rotational equations of motion
- analytical mechanics, including generalized coordinates, virtual work, Hamilton’s principle, and Lagrange’s equations

Suggested Books and Chapters:


Linear Vibrations

Topics:

- What are “linear” vibrations? Why is this a useful and important concept? How do linear vibrations arise in physical problems?

- Harmonic oscillator: natural frequency; frequency response, impulse response, and their relationship; general forced response.
- Finite DOF systems: general form of such systems; natural frequencies and normal modes; force response; decomposition using normal modes (i.e., modal analysis).

- Vibrations of simple continuous systems: equations and simple boundary conditions for strings, membranes, rods, and beams.

- Natural frequencies and normal modes for simple continuous systems.

Suggested Books and Chapters:


Elastic Wave Propagation

Topics:

- dispersion principles
- unbounded isotropic and anisotropic media
- reflection and refraction, oblique incidence, wave scattering
- surface and subsurface waves, waves in plates, interface waves, layer on a half space, waves in rods, waves in hollow cylinders
- guided waves in multiple layers, and horizontal shear waves, respectively

Suggested Books and Chapters:


Relevant Mathematics Topics

Numerical Analysis

Topics:

- round-off errors, computer arithmetic, convergence, and Taylor series
- solutions to nonlinear algebraic equations in one variable
• interpolation and polynomial approximation
• numerical differentiation and integration and concepts of quadrature
• fundamental ideas for initial value problems for ODEs
• fundamental ideas for solution of linear algebraic systems of equations
• fundamental ideas in approximation theory
• fundamental ideas for boundary value problems for ODEs

Suggested Books and Chapters:

Variational Calculus

Topics:
• generalized coordinates
• first variation and generalized forces
• extremum problems
• stationary values of integrals and the Euler-Lagrange equations
• second variation

Suggested Books and Chapters:
• Charles Fox (1987) *An Introduction to the Calculus of Variations*, Dover Publications. [Chapters 1–4]

Ordinary Differential Equations

Topics:
• classification of ODEs
• techniques for first-order equations
• techniques for higher order linear ODEs
• power series solutions to ODEs
Suggested Books and Chapters:


Partial Differential Equations

Topics:

- Fourier series, Fourier integrals, and Fourier transforms
- classification of PDEs
- diffusion, wave, and Laplace equations: separation of variables solutions

Suggested Books and Chapters:


Linear Algebra

Topics:

- ideas and concepts behind the solution of systems of linear algebraic equations
- vector spaces, linear dependence, bases
- the eigenvalue problem

Suggested Books and Chapters:


Complex Variables

Topics:

- functions of a complex variable, analyticity
- complex integration, Cauchy’s theorem, the residue theorem
- Taylor series, Laurent series
Suggested Books and Chapters:

ESM Candidacy Exam – Fall 2006

Materials Section

Goal:

Evaluation of students’ fundamental understanding of the nature of materials, their synthesis, properties, modification under processing, and integration into engineering applications. The basic concepts include atomic bonding, structure, thermodynamics, kinetics and molecular architecture. The properties of engineering interest are mechanical, electrical, optical, optoelectronic and magnetic, as well as as phenomena such as Hall effect, photoelectron emission, ferroelectricity, photoelasticity and superconductivity. The students should also be familiar with the basic links between macroscopic and microscopic properties.

Scope:

The exam will assess the student’s general knowledge of metals, semiconductors, dielectrics and magnetic materials, and their properties in relation to engineering device applications. The focus will be on concepts gleaned and retained from undergraduate courses in chemistry, physics, materials, and devices. Questions will deal with general behavior of materials; their growth, characterization and processing; response to load and/or environment; and synthesis into useful structures. Basic expertise in quantitative analysis and design of engineering devices will also be evaluated.

Format:

The questions will consist of two parts:

1. Elementary properties and applications of materials. Any student taking the Materials Section of the Candidacy will be expected to tackle these questions covering basic material properties. The material will include the broad range of topics covered in the following Engineering Science undergraduate courses: ESc 314, ESc 414. There will be no choice, and ALL the questions must be answered.

2. Specialty topics involving electronic materials, solid state devices and thin films. Here students will be given a choice, and they can choose questions based on their specialized background and academic interests. Engineering Science courses of relevance for this part include the following: ESc445, ESc501, ESc577.

The exams will be closed book, and needed formulas and constants will be given with the exam. Students will NOT be allowed to bring their on formula sheets.

Reference Books:

Any basic materials science text such as


Any undergraduate text on basic semiconductor materials and devices such as

ESM Department Candidacy Exam

Electromagnetism

Goals
This exam is to evaluate students’ fundamental understanding of electromagnetism. While students are expected to be familiar with the basic laws of static electric and magnetic fields, which may be “uncoupled” and viewed “independent” of one another, they must be familiar with the basic links of electric and magnetic fields and their unification into the more general framework of the Maxwell equations. In addition to electrostatics, magnetostatics, and electromagnetic wave propagation, a fundamental knowledge of electromagnetic wave interaction with matter is an important element for graduate students in the interdisciplinary ESM Department. Polarization and magnetization mechanisms contribute to the basic dielectric and magnetic. Students should have an appreciation that electromagnetic properties of matter are generally nonlinear and dependent on thermal and mechanical stresses. Coupled structural, electromagnetic, and thermal phenomena yield important material properties such as piezoelectricity and magnetostriction. Moreover, the wave-particle nature of electromagnetic radiation is important to its interaction with matter and students are, therefore, expected to understand this wave-particle duality. Also, students must be familiar with electric circuits and optics.

Scope
The exam will assess the student’s general knowledge in the following areas:

Electrostatics
- Coulomb’s law, E and D fields, Gauss’ law, electric potential, dipole, energy, density in an electric field, Gauss’ divergence theorem

Magnetism
- Biot-Savart law, Ampere’s law, Stoke’s theorem, B and H fields

Time-Varying Electromagnetic Fields and the Maxwell Equations
- Faraday’s law, Maxwell equations in differential and integral forms, plane wave propagation in different materials and scattering due to plane boundaries, gauges and gauge transformation, simple transmission lines and waveguides
The material is typically found in:

“Engineering electromagnetics” By Hayt and Buck, Pub. McGraw-Hill
or
“Classical Electrodynamics”, 3rd edition, (Chapters 1-9), By Jackson, Pub. Wiley

**Electric Circuits**

RLC circuit analysis, impedance and admittance, network theorems and analysis, power dissipation

The materials is typically found in:

“Engineering Circuit Analysis” By Hayt, Kemmerly. and Durbin

**Wave-Particle Duality of Electromagnetic Radiation and Interaction with Matter**

Photon, blackbody radiation, Compton and photoelectric effects, absorption, skin depth and plasma frequencies in metals, polarization of dielectrics, complex conductivity, magnetization and magnetic domains, masers and lasers

The material is typically found in:


**Optics**

*Geometrical optics*: rays, reflection, refraction, Snell’s laws, total internal reflection, lenses, prisms, optical fibers

*Physical optics*: Huygen’s principle and the wave nature of light, interference and interferometry, diffraction, dispersion, attenuation, microscopy

The material is typically found in:

Examining Board: Temporary Chair: A. Lakhtakia
Members: M.C. Demirel, J. Xu, T.J. Huang, B. Gluckman (Observer)

Description: The exam is concerned with the fundamental physics of nanostructures at the physical/life science interface. The student should understand the fundamental laws of molecular materials, apply the principles of thermodynamics and statistical mechanics to bio and nano materials, be aware of (be reasonably knowledgeable) on the imaging and spectroscopic methods that are commonly used in bionanotechnology and explain the fundamentals of device applications. The scope of this exam is currently evolving, but is announced in detail every year by the Examination Board administering it.

Syllabus: The scope of the examination covers material normally taught in the following 9 courses. The successful candidate would know the material covered in at least 3 of the courses very well. The examination will be divided into 3 parts, and questions from at least two of the three parts shall have to be satisfactorily answered.

Part 1.
E SC 314 Semiconductor Fundamentals

E SC 597B/497B Micro-Optoelectromechanical Systems and Nano-Optoelectronics

E SC 481/581 Elements of Microelectromechanical Systems Processing and Design

Part 2.
E SC 484 : Biologically Inspired Nanomaterials

ACS 402/502 - Fundamentals of Acoustics

E SC 400H Electromagnetics

Part 3.
E SC 597 Introduction to Biomolecular Materials

E SC 497B (now E SC 483) Simulation and Design of Nanostructures

PHYS 527: Computational Physics
An Introduction to Computer Simulation Methods (third edition) by Harvey Gould, Jan Tobochnik, and Wolfgang Christian Online book: http://sip.clarku.edu/3e/
Part 4. (not applicable to the candidacy exams of 2006-2007, but is being formulated for 2007-2008)

BIOE 512: Cell and Molecular Bioengineering