Thinking Big and Small: An Approach to Engineering Physics as a Major

Dr. Scott Kirkpatrick, Rose-Hulman Institute of Technology

Scott Kirkpatrick is an Assistant Professor of Physics and Optical Engineering at Rose-Hulman Institute of Technology. He teaches physics, semiconductor processes, and micro electrical and mechanical systems (MEMS). His research interests include heat engines, magnetron sputtering, and nanomaterial self-assembly. His masters thesis work at the University of Nebraska Lincoln focused on reactive sputtering process control. His doctoral dissertation at the University of Nebraska Lincoln investigated High Power Impulse Magnetron Sputtering.

Dr. Richard W. Liptak, Rose-Hulman Institute of Technology

Richard W. Liptak received his B.S. in Engineering Physics from John Carroll University in 2004. After graduation he joined the group of Prof. Steve Campbell and Prof. Uwe Kortshagen where he focused his work on the development of novel gas phase surface passivation techniques to synthesize air-stable full-visible spectrum emitting SiNCs. While at Minnesota he was awarded a NSF IGERT Fellowship. He received his M.S. (2006) and PhD (2009) in Electrical Engineering from the University of Minnesota. Following graduation he spent a year as a postdoctoral research associate working for Prof. Mark Rodwell in the UCSB Molecular-Beam Epitaxy Lab where he focused his research on investigating the ALD process on III-V semiconductors and the epitaxial growth of ohmic contacts on III-V materials. He returned to the University of Minnesota in 2010 as a research scientist investigating techniques to tailor the surface chemistry of SiNCs for use in light emitting diodes and solar cell applications. More recent work has focused on the growth and integration of CIGS and CIAGS homojunction and heterojunction solar cells. In the fall of 2013, he joined the Department of Physics and Optical Engineering at the Rose-Hulman Institute of Technology as an Assistant Professor. Current research efforts are focused on the development of plastic electronics, atomic layer deposition and supercapacitors.

Dr. Renat Letfullin, Rose-Hulman Institute of Technology

Renat R. Letfullin is associate professor of physics and optical engineering department at the Rose-Hulman Institute of Technology. He has made outstanding contributions to the fields of wave and quantum optics, lasers, aerosol physics, nanoscience including nanooptics and nanobiotechnology. He is an outstanding theoretician and experimentalist in the fields of optics and kinetics of chemical pulsed lasers, and during the past decade has branched out into biophotonics and nanomedicine. He has discovered new phenomena and scientific effects in these fields, where examples include: effect of diffractive multifocal focusing of plane and spherical waves, effect of giant laser energy gain, the autowave of a new type – self-supporting photon-branched chain reaction, and effect of focusing of de Broglie matter-waves. He has carried out an extensive array of studies in aerosol optical physics, including laser heating and evaporation of aerosol particles and optical properties of nanoparticles. He has developed and designed new self-contained laser systems with multimega joule output energy per pulse, optical reactor for efficient laser processing of dispersed materials, phase technique for optical diagnostics of small particles, and new diffractive atom lens. His latest achievements are in the field of nanophotonics and nanomedicine, including discoveries of a plasmon explosion of nanoparticles, new dynamics modes in selective phototherapies, RF and X-ray optics of nanoparticles.

A well-respected international researcher, Letfullin has authored 150 articles and conference proceedings, including 12 book chapters in 10 different books. His work has garnered many grants and awards including 4 patents in laser technology and optical engineering. He has led the development of several new research laboratories for research on biophotonics and nanomedicine, created innovative teaching tools including online video courses and webinars, and supervised numerous masters and doctoral students.

For his achievements in optics, photonics, laser physics, nanophotonics, biophotonics, and nanomedicine Dr. Letfullin has been elected to the Fellow of SPIE and a Senior member of SPIE. He is also a member of the Optical Society of America and American Society for Engineering Education.
Thinking big and small: An approach to engineering physics as a major

An engineering physics curriculum focusing on micro and nanotechnology has been developed which still allows students to apply themselves over a broad range of science and engineering disciplines. The core components of this curriculum are seven courses in micro and nanotechnology; a breadth of introductory mechanical, optical and electrical engineering courses; advanced physics courses; and a capstone design sequence. The courses in micro and nanotechnology include sequences in, nanotechnology, semiconductors and MEMS. Two courses in nanotechnology highlight scaling laws, self-assembly, and traditional physics concepts at the nanoscale including heat, optics, fluids, Electronics, mechanics, and biology. Two courses in MEMS develop concepts in design, fabrication, and operation of electrical, and mechanical devices at the micro scale. The topic of semiconductors is covered in a sequence of three courses starting with semiconductor materials, developing into semiconductor devices and finishing with fabrication and integration. Students gain additional training in practical areas of mechanical, electrical and optical engineering including statics, AC and DC circuits, and photonics, opening the students to upper level courses in these disciplines. The capstone sequence begins with a 10 week junior design course where a series of small design projects tests their ability to solve problems in a variety of disciplines. Following the junior design course, the students have a 20 week senior design sequence where they design, build and deliver a prototype for an external client. Aside from these core components the students gain additional breadth through courses in math, chemistry, and computer science. This curriculum was designed to include room for a technical area of focus outside of the engineering physics curriculum through a set of engineering electives, requiring an additional sequence of engineering courses finishing with a junior or senior level course.
Introduction

At Rose-Hulman Institute of Technology we have an ABET accredited engineering physics program. Our department of Physics and Optical Engineering offers three degrees, Optical Engineering, Physics and Engineering Physics. The program requires courses to be taken in several departments including mechanical engineering and electrical engineering. The topics our students are educated in range from semiconductor manufacturing to thermodynamics.

Our goal with this program was to generate engineers capable of understanding and applying modern physics to solve problems. It is our expectation that students graduating with this degree will be able to contribute to any company, being able to breakdown and solve complex problems at the boundaries between classic engineering disciplines.

The major components covered within this degree are covered in the following subtopics. In order to see the opportunities that develop between classic disciplines such as electrical and mechanical engineering, our students need enough breadth over these categories to speak to different types of engineers as well as recognize problems that arise from classic engineering disciplines crossing over. We provide the breadth by requiring courses in electrical engineering, mechanical engineering, optical engineering, and physics.

We provide depth for our engineering physics majors by focusing on micro and nanotechnology and fabrication. Our students take two courses in nanotechnology, five courses in semiconductors and microfabrication with hands-on lab experiences.

Finally we combine this with a three course capstone design sequence beginning in their junior year, and ending in their senior year culminating in a prototype for an industrial client.

Modern Physics

Courses Offered: PH255, PH401, EP280 & EP380

We introduce students to modern physics starting in physics III with the concept of relativity. As sophomores the students take modern physics (PH255) while also taking introduction to nanotechnology. These courses complement each other as modern physics provides the theory that is applied in the nanotechnology course, such as tunneling. The following quarter, students take a second nanotechnology course (EP380). This second nanotechnology course builds upon the modern physics they already have to include investigating quantization, and the application of the Schrödinger’s equation to observe probabilities, and determine Eigen frequencies for various nanoparticles with modeling software.
Figure 1 shows a student's model of an electron's orbital around hydrogen developed in FEM software COMSOL.

Finally, our students take a quantum physics class PH401. This provides our students with a stronger understanding of quantum mechanics, a key component for micro and nanotechnologies.

Software and Modelling


We foresee that our students need to be able to perform some amount of programming in order to have a positive contribution to society in the future. We require our engineering students to take an introductory course in programming, and follow this up with writing their own code during the junior design course, as shown in FIG 2.
Our students are also introduced to modern engineering tools such as modeling by utilizing a finite element software package COMSOL, starting as freshman, and continuing to use this modeling software each year. As freshman our students use COMSOL to model simple heat flow behavior and compare this to what would be expected from basic formulas. As sophomores, the student use COMSOL to model electrons surrounding a hydrogen atom. In Their junior year, the student model heat flow within a heat sink, and make design decisions.
utilizing their observations. As seniors the students apply electrical, thermal and mechanical behaviors to create a model of MEMS devices such heat actuators.

**Mechanics and Thermodynamics**


We expect our students to have a good understanding of mechanics, stress, and strain and thermodynamics. Our students take three courses within the mechanical engineering department. This allows the students to take additional upper level courses within mechanical engineering if they find this to be an area of interest for themselves. We also apply basic mechanics in several courses within their curriculum within the PHOE department. Within EP 380 the students calculate and model AFM tips as cantilever beams, and observe the different possible frequencies. The students then experimentally observer the frequencies of oscillation utilizing a tapping mode AFM tip.

The students also receive an education in thermodynamics and fluid flow, these relationships are initially started in PH235 (Many Particle) and examined more in depth in PH327 (Thermodynamics). Finally as shown in figure 3 the students develop are expected to apply this knowledge during their junior design sequence.

![Infrared Image of a Heat Sink](image)

*Figure 3 Shows an infrared image of a heat sink developed by students in their junior design course.*
Electronics


We expect any EP student graduating from RHIT to possess a solid background in electronics. Their training in the subject begins in our introductory Physics courses (PH112 & PH113) where they are first exposed to concepts in electricity and magnetism such as electric fields and potentials, electric current and resistance, DC circuits, capacitance, sources of magnetic fields, Faraday's law and inductance. This basic skill set is further developed in their sophomore year when the students take ECE203 and ECE204, two 10-week courses focusing on topics in DC and AC circuits. These classes further develop the students’ circuit design and analysis skills, and incorporate hands-on laboratories which allow the students to construct, test and troubleshoot several different types of circuits, while allowing them to gain invaluable experience with test equipment such as voltmeters, ammeters, power meters, oscilloscopes and function generators. During their junior year, the students are exposed to four courses in this thrust area. PH316 and PH317 are advanced classes in electricity and magnetism while PH405 and EP406 discuss fundamentals in semiconductor materials and devices. Both PH405 and EP406 have a lab component in which the students once again receive hands-on training. In PH405, students investigate the structure of several semiconductors via an XRD and SEM, perform bandgap, 4-pt probe, Hall effect measurements and study the generation and recombination of charge carriers in semiconductor materials. During the final lab in the course they investigate the behavior of a simple diode (p-n junction). This is carried over into the EP406 lab where the students spend the first three weeks of the quarter fabricating their own silicon diode. Following fabrication, they test their device using the methods that they learned in PH405 and compare their results to the commercially available diode. The final six weeks of lab has the students investigating several different semiconductor devices such as the silicon npn BJT and n-channel MOSFET, PIN diodes and basic digital logic circuits. The students training in electronics will conclude with EP407 which is currently being designed. This course will force the students to utilize the knowledge gained in previous electronics and fabrication courses to design, build and characterize advanced semiconductor devices such as CMOS transistors and logic circuits such as NOR or NAND gates, simple adders and an ALU.
The students' ability to understand and work with electronic devices is further tested in EP415, our junior design class. In this course, the students are challenged to construct an electronic circuit which meets a specific set of requirements. The design is completely up to the students, as shown in Figure 5. Using provided parts, the students must deliver a working prototype to pass the project.
Optics


EP students graduating from RHIT are also expected to be proficient in the field of optics. Training in optics begins in the third quarter of their freshman year in introductory Physics. In the PH113 course, the students are introduced to basic concepts in the field of optics such as: basics of electromagnetic waves, reflection and polarization, diffraction, and simple geometric and physical optics principles. Following this course, the students have the option of taking two advanced sophomore level optics courses which cover more advanced topics in physical or geometric optics. EP students are required to take OE295 and optical engineering course which focuses on photonic devices and systems. This course encompasses a variety of topics which include an introduction to optical radiation, radiometry and photometry. Additional material in the course cover concepts such as Blackbody radiation, thermal sources and optoelectronics (devices and detectors). Both PH113 and OE295 are lab courses which provide the students hands-on experience in physical optics, photonics and optoelectronics. These courses coupled with their lab experience prepare the EP students for EP415 where they are required to complete a lens design project during the last three weeks of the class (Figures 6 and 7). Similar to the electronics project described above, the students are given a set of requirements and they are instructed to design a system which will meet those requirements. During this three week project, the students develop a Gantt chart to plan out their work, go through a engineering design review (at the mid-point in their project) and give a final presentation and demonstration of their product.
Figure 6 shows an image the students created allowing them to see the "A" grade image.

Figure 7. A lens system capable of reading a line of text from 10 and 20 feet away from the target. This design was developed during EP415 by EP students.

The students are also introduced to the role optics plays in the semiconductor fabrication process in EP410 and EP411. Photolithography equipment such as projection and contact aligners and steppers are discussed in detail. The students are exposed to the concepts of a photomask – what it is and how you fabricate it and why you use it in the fabrication process. Figures of merit such as numerical aperture, minimum feature size and resolution are discussed as well. Advanced concepts are introduced in EP411.

Design


The EP students are exposed to the concept of design throughout their career at RHIT. This begins during their freshman year when they take an introductory design course (either EM103 or ECE160). The introductory design course introduces the engineering design process to the students. The students are introduced to several design concepts including: problem definition, analysis techniques, examining alternate solutions, identifying specifications for a final solution, and are instructed on proper techniques for giving oral and written reports. What is unique about this course is that it stresses the importance of teamwork through group design efforts. Following the freshman design sequence, the students receive several more design projects throughout their career at RHIT. This begins in EP411 when they are tasked to design a MEMS device in which they must develop a process flow, fabricate in the cleanroom and successfully test in order to receive a satisfactory grade in the course. EP407 includes design projects in which students must design (via simulations, process flow) fabricate and test complicated semiconductor structures such as logic gates and CMOS devices. Their design experience at RHIT culminates with EP415-417, the EP senior design sequence. In EP415, the students are introduced to the design process and work on four miniature design projects throughout the 10 week quarter to help them prepare for the capstone project. Each miniature project is unique.
The mechanical projects tests and refines the students’ CAD skills. The thermal/heat sink projects, forces the students to create accurate simulation models which they can use to machine a heat sink which meets specifications when operating in conductive or convective mode. The electrical project tests the students’ ability to construct multiple circuit modules and combine them together to make a functional circuit which completes a task. Finally, the optical and software project challenges the students to build a lens system to image text at certain distances while also demonstrating (via code) the resolution and MTF of their design. The optical/software project includes a mid-project technical design review and final presentation. Both activities are intended to prepare the students for their twenty week capstone project. The EP design sequence culminates with a capstone project in which students work with an industrial client on a design project. During the twenty-week experience, the students work closely with the client to develop specifications for the project, construct a project plan and budget and hold weekly group meetings to help their client informed of their progress. The students are subjected to two mid-term design reviews, give a final presentation (both oral and poster) to the class and their client on their work and submit a final report which documents all work completed during the twenty week experience.

Figure 8: 3D-printed siege weapons designed by EP students in EP415. Several different designs are present (catapult and ballista). The students were required to design a device which launched a marble 15 feet. The students could only use materials which were provided in the class: rubber bands, screws, dowel rod, weights and cloth. They also were limited to only 8 hours of 3D print time.
Humanities

Required Courses: RH131, RH330, SV150 or SV152

When our EP students graduate from RHIT, we want them to be well-rounded. To help accomplish this, the students are required to take 9 courses in the humanities. Three courses are required: Rhetoric and Composition (RH131), Technical Communications (RH330) and Introduction to Micro or Macro Economics (SV150 or SV152). The six other courses need to be taken in a specific focus area. Of the six courses the students need to take to satisfy their humanity requirements, two courses must focus on global studies (GS), two courses must emphasize society and values (SV) and two courses must concentrate on ideas and arts (IA). The last course the students take in the humanities at RHIT can be designated either a IA, SV or GS and is typically in an area of interest for the student. For example, if the student was minoring in economics, several of his or her humanities courses would be focused in this area.

Nanotechnology


Our students become introduced to the nanoscale as freshman. We introduce the students to analysis equipment such as scanning electron microscopes, atomic force microscopes, as well as microfabrication techniques by creating a PN junction solar cell. The students are then introduced to scaling laws and applied basic modern physics in their introduction to nanoengineering course, as well as hands-on labs creating nanoscale components as shown in Figure 8. The nanoengineering, entrepreneurship and ethics course then requires the students to apply these concepts as the students develop models and create their own process flows and generate their own models regarding nanoscale devices. Throughout this course sequence, basic physics is applied and taught to the student in terms of the micro and nanoscale, including optics, mechanics, electronics, fluids and biology.
MEMS and sensing


During their time at RHIT, the EP students take two courses in MEMS and one course in sensing. During EP410, the introductory MEMS course, the students are introduced to several topics in microfabrication such as properties of silicon wafers, wafer-level processes, vacuum systems, thermal oxidation, thin-film deposition via physical vapor deposition (thermal evaporator, electron-beam evaporation and sputtering), dry and wet etching processes, fundamentals of photolithography, surface and bulk micromachining techniques, and process integration. The last three weeks of the course focus on MEMS applications. The fundamentals behind the fabrication and operation of thermal heat actuators, capacitive accelerometers, DLP, bio-sensors, and pressure sensors are discussed in detail. During this course the students have a hands-on laboratory in which they fabricate and test a thermal heat actuator. What is unique about this course is that it is cross-listed over several departments which gives students in mechanical, electrical, chemical and bio-medical engineering the opportunity to take this course and receive hands-on training in microfabrication.
Figure 10. A thermal heat actuator fabricated by EP students in the EP410 lab.

The EP students receive further training in microfabrication and MEMS when they enroll in the EP411 course. This course builds on their microfabrication knowledge by introducing advanced concepts such as chemical vapor deposition (CVD), atomic layer deposition, doping processes (ion implantation and diffusion), molecular beam epitaxy, chemical mechanical polishing and rapid thermal processing. Interconnect and packaging concepts are also discussed. The course concludes with three weeks on advanced MEMS devices such as piezoresistive and piezoelectric actuators, microfluidics and metamaterials. This course also includes COMSOL modeling project and a review of systems engineering principles. This course includes a lab component in which the students work on a team of 3 to 4 students to fabricate a MEMS device. They are required to develop a process flow, design masks, fabricate and test their device by the end of the quarter. Their progress is assessed via a mid-project design review and a final demo and presentation.
The EP students also take a course in sensing at RHIT. This course covers the fundamentals of sensing and sensing systems including: sensor characteristics and signal conditioning, microcontrollers and review of common circuits utilized in sensing systems. This is followed by a discussion of a subset of sensors (displacement, thermal, radiation, humidity, pressure & flow, force & touch and chemical). Specifically, the course covers the fundamentals, fabrication and applications of several sensing technologies. There is also a laboratory component of this course where the students receive hands-on training with several of these sensing technologies.

**Student plan of study**

Our student plan of study includes room for some technical and non technical electives, as shown in Figure 12, including an elective early in their course load in the sophomore year, allowing students to explore areas of interest for a particular student without penalizing them by requiring an additional year to graduate.
Conclusion

We have created a Engineering physics program which provides a fundamental background in physics and microtechnology while allowing the students to focus on their own area of interest and including the breadth for them to explore different foci. The allows our graduates to become ideal candidates for a wide variety of graduate school opportunities as well as excellent candidates for industrial positions.
Appendix A

Program Educational Objectives statements for Engineering Physics:

- Our graduates will be in a career path and within it, be promoted; or be in pursuit of an advanced degree
- Our graduates will contribute to the society locally, nationally or globally
- Our graduates will collaborate within their organization; be active in research and development, in a relevant area of science and technology.
- Our graduates will continue to develop professionally.

EP Student Learning Outcomes

1. An ability to use the principles of science and mathematics to identify, formulate and solve engineering problems.
   a. Demonstrate competency in applying knowledge of mathematics (such as multivariable calculus, differential equations, linear algebra, complex variables, and probability and statistics), physics and chemistry
   b. Demonstrate competency in applying theoretical and experimental knowledge in physics, optics, solid state, and semiconductor devices for modeling, analysis and design of devices and systems.
   c. Demonstrate an awareness of multiple possible solutions.
   d. Use correct data, tools and adequate assumptions to solve problems.

2. An ability to apply both analysis and synthesis in the engineering design process, resulting in designs that meet constraints and specifications. Constraints and specifications include societal, economic, environmental, and other factors as appropriate to the design.
   a. Research and gather information.
   b. Elicit customer needs and define realistic constraints.
   c. Identify viable alternatives in design and make an informed selection.
   d. Incorporate economic, societal and environmental analysis and analyze their constraints in design.

3. An ability to develop and conduct appropriate experimentation and testing procedures, and to analyze and draw conclusions from data.
   a. Apply safe laboratory practices.
   b. Develop, plan, and conduct an experiment to meet a specified request for a customer.
   c. Use modeling as a method to rapidly experiment with a design’s characteristics and develop trends.
   d. Use appropriate statistical and analytical procedures to estimate uncertainties and interpret results.
   e. Be able to recognize the necessity to use graphical and numerical analysis.
   f. Draw conclusions from the data.
4. **An ability to communicate effectively with a range of audiences through various media.**
   a. Identify the technical knowledge and information needs of the audience.
   b. Provide technical content that is factually correct, supported with evidence, explained with sufficient detail, and properly documented utilizing various media.)

5. **An ability to demonstrate ethical principles in an engineering context.**
   a. Demonstrate knowledge of the Code of Ethics for Engineers.
   b. Evaluate the ethical dimensions of professional practice.

6. **An ability to establish goals, plan tasks, meet deadlines, manage risk and uncertainty, and function effectively on teams.**
   a. Share responsibilities and team duties by taking on different roles when applicable.
   b. Set milestones for the project.
   c. Discern feasible solutions.
   d. Identify risks.
   e. Develop a strategy for action.
   f. Meet objectives on schedule.
   g. Document work.
   h. Build consensus.

   a. Apply knowledge gained by reading technical journals to generate their own ideas.
   b. Take knowledge gained from technical journals and put the information into practice.
   c. Be active in their profession, by being active in a professional society, presenting at technical conferences, participating in summer internships or research opportunities.
   d. Able to relate current events to their profession.
Appendix B

Current RHIT Course Descriptions

COURSES LISTED IN PHYSICS

PH 111 Physics I 3.5R-1.5L-4C F,W Coreq: MA 111
Kinematics, Newton's laws of motion, gravitation, Coulomb's law, Lorentz force law, strong and weak nuclear forces, conservation of energy and momentum, relevant laboratory experiments.

PH 112 Physics II 3.5R-1.5L-4C W,S Prereq: PH 111 and MA 111; Co: MA 112
Torque and angular momentum, oscillations, one-dimensional waves, electric fields and potentials, electric current and resistance, DC circuits, capacitance, relevant laboratory experiments.

PH 113 Physics III 3.5R-1.5L-4C S,F Prereq: PH 112 and MA 112; Coreq: MA 113
Sources of magnetic fields, Faraday's law, inductance electromagnetic waves, reflection and polarization, geometric and physical optics, introduction to relativity, relevant laboratory experiments.

PH 235 Many-Particle Physics 3.5R-1.5L-4C F Prereq: PH 111 or Coreq: EM 202; and Coreq: MA 112
Dynamics of rigid body, harmonic motion; mechanics of fluids; heat, kinetic theory, thermodynamics. Alternate week laboratories.

PH 255 Foundations of Modern Physics 3.5R-1.5L-4C W Prereq: PH 113 and Coreq: MA 211
Wave-particle nature of matter and radiation, Bohr model, Schrodinger equation, quantum description of the hydrogen atom, atomic and molecular spectra, and introduction to statistical physics.

PH 292 Physical Optics 3.5R-1.5L-4C F Prereq: PH 113
The wave equation; electromagnetic waves; phase and group velocities; complex refractive index; dispersion, interference; interferometers and applications, optical interferometry; coherence; polarized light; Jones vectors/matrices; production of polarized light; birefringence, Fraunhofer diffraction; diffraction gratings.

PH 316 Electric and Magnetic Fields 4R-0L-4C F Prereq: PH 113, MA211, and MA 212
Maxwell's equations in integral and point form, vector calculus; electric field and potential, electric fields in matter, boundary conditions; the magnetic field.

PH 317 Electromagnetism 4R-0L-4C W Prereq: PH 316
Further methods in electrostatics, Poisson's equation; magnetostatics, the vector potential; electromagnetic induction; magnetic properties of matter; further applications of Maxwell's equations, properties of electromagnetic radiation.
PH 327 Thermodynamics and Statistical Mechanics  4R-0L-4C  S  Prereq: PH 235 or consent of instructor

PH 401 Introduction to Quantum Mechanics  4R-0L-4C  W  Prereq: PH 255, or PH 113 and PH 265
Review of wave-particle experiments, atomic model, Bohr theory, deBroglie's hypothesis. Uncertainty principle, Schroedinger equation, quantum mechanical operators and stationary states, quantization and role of angular momentum.

PH 405 Semiconductor Materials and Applications  3R-3L-4C  F  Prereq: PH 113 or PH 255 or PH 265
Material structure electronic levels and energy bands; semiconductor doping; optical and electronic material characteristics; p-n junction and diode characteristics; bipolar junction transistor; basics of device fabrication. Laboratories on X-ray and Scanning Electron Microscope investigations, device characteristics and a three-week design project on production and testing of thin films. Cross-listed with PH 505.

COURSES LISTED IN OPTICAL ENGINEERING

OE 280 Geometrical Optics  3.5R-1.5L-4C  W  Prereq: PH 113  (Optional for EP Students)
First-order optics including graphical ray tracing, Gaussian methods, y-nu ray tracing, cardinal points, apertures, stops, pupils, vignetting, and obscuration. Optical invariant, dispersion, chromatic aberrations, glass selection, exact ray tracing, third-order monochromatic aberrations, introduction to computer-aided design and analysis. Relevant laboratory experiments.

OE 295 Photonic Devices and Systems  3.5R-1.5L-4C  S  Prereq: PH 113 and MA 211
Optical radiation, radiometry, and photometry. Blackbody radiation and thermal sources. Introduction to optoelectronic devices. Light emitting diodes and other optical sources. Optical detectors (thermal, photoemissive, and semiconductor detectors). Sources/effects of noise and SNR. Flux transfer in optical systems. Relevant laboratory experiments.

COURSES LISTED IN ENGINEERING PHYSICS

EP 280 Introduction to Nano-engineering  3.5R-1.5L-4C  W
Scaling laws in small systems; electronics and photonics devices and systems, basics of quantum and statistical mechanics, nanomaterials and fabrication: examples of zero, one, two, and three dimensional nanostructures, carbon nanotubes, Nanoelectronics: basics of solid state physics; electron energy band, semiconductors, tunneling and quantum structures, molecular electronics, Nanophotonics in metals and semiconductors, surface plasmon resonance and applications, photonic bandgap crystals.
EP 380 Nanotechnology, Entrepreneurship and Ethics  3.5R-1.5L-4C  S

EP 406 Semiconductor Devices and Fabrication  3R-3L-4C  W Prereq: PH405 or ECE250
Metal-semiconductor interfaces; photoresist and photolithography; thin film deposition; design and fabrication of semiconductor diodes; characterization of process diodes and transistors; MOSFETS; optoelectronic devices and lasers. Laboratory is a design project, the production and characterization of a diode and bipolar transistor. The project is a team exercise. Cross-listed with EP 506.

EP 407 Semiconductor Fabrication & Characterization  2R-6L-4C  F Prereq: PH405 or JR/SR standing & consent of instructor
Fabrication and characterization of micro/nanoelectronic devices; Semiconductor devices; Oxidation, ion implantation, etching, deposition, lithography, and back-end processing; Process integration of various technologies, including CMOS, double poly bipolar junction transistor, and GaAs MESFET. Process and device simulators illustrate concepts introduced in class. Modern tools/techniques for both bulk- and thin-film characterization; Laboratory is an integral component of this class. Students work in teams to fabricate a multi-junction semiconductor device, using various techniques which include photolithography, diffusion, oxidation, and etching. In-process measurement results are compared with final electrical test results. Circuits are used to carry out performance evaluation.

EP 408 Microsensors  3R-3L-4C  S Prereq: JR or SR standing, and consent of instructor

EP 410 Introduction to MEMS: Fabrication and Applications  3R-3L-4C  S Prereq: JR or SR standing

EP 411 Advanced topics in MEMS  3R-3L-4C  F Prereq: EP410 or equivalent course
Topics such as: Microlithography, design process, modeling; analytical and numerical. Use of software for layout design and device simulation. Characterization and reliability of MEMS devices. MEMS and microelectronic packaging. Introduction to microfluidic systems. Applications in engineering, biomedicine, and chemistry. Cross-listed with ECE 419, and CHE 419.
Principles of design. Codes of ethics appropriate to engineers. Case studies related to optical engineering and engineering physics professional practice, teamwork, contemporary issues, patents and intellectual property. Team-oriented design project work on selected topics in optical engineering and engineering physics. Introduction to product development practices, product research, planning and project management. Preliminary design of a product and product specifications. Deliver a design document specific to customer needs and constraints. Cross-listed with OE 415.

EP 416 Engineering Physics Design II  2R-6L-4C  F  Prereq: EP 415
Team-based capstone design project following structured design processes and utilizing knowledge gained from prior coursework. Project planning and budgeting, development of product/process specifications, application of engineering standards, system design and prototyping subject to multiple realistic constraints (cost, schedule, and performance). Formal midterm design review. Deliver initial statement of work and interim technical report. Laboratory activities supporting the formal design process. Cross-listed with OE 416.


COURSES LISTED IN CHEMISTRY

CHEM 111 General Chemistry I  3R-3L-3C  F,W,S  Prereq: None; Coreq: CHEM111L
Topics include stoichiometry, nomenclature, phases, and writing balanced chemical equations. Quantum theory is introduced in relation to chemical applications. Atomic structure is introduced. Bonding principles and molecular structure are discussed in terms of Lewis Dot Structures, Valence Bond Theory, VSEPR Theory, Hybridization, and Molecular Orbital Theory.

CHEM 111L General Chemistry I Laboratory  0R-3L-1C  F,W,S  Prereq: None; Coreq: CHEM 111
Fundamental chemistry laboratory skills are introduced along with data analysis in support of topics presented in CHEM111 recitation.

CHEM 112 Chemistry Honors  4R-3L-5C  F  Prereq: Advanced placement
An accelerated course covering topics in CHEM 111 and CHEM 113. Upon successful completion of this course, an additional 3 credits will be awarded. Enrollment is limited to those students who complete the Rose-Hulman online Chemistry Advanced Placement Examination given prior to the freshman orientation period.

CHEM 113 General Chemistry II  3R-3L-3C  W,S  Prereq: CHEM 111 and CHEM 111L;  Coreq: CHEM 113L
Topics in this course include the fundamentals of thermodynamics and kinetics. The
fundamentals of chemical equilibrium are introduced. Definitions of acid and bases are discussed utilizing the Bronsted-Lowry and Lewis models. Nuclear chemistry is also included.

CHEM 113L General Chemistry II Laboratory  0R-3L-1C  W,S  Prereq: CHEM 111 and CHEM 111L; Coreq: CHEM 113
Fundamental chemistry laboratory skills are introduced along with data analysis in support of topics presented in CHEM113 recitation.

COURSES LISTED IN ELECTRICAL ENGINEERING

ECE 203 DC Circuits  3R-3L-4C  S,F  Prereq: MA111 and PH112

ECE 204 AC Circuits  3R-3L-4C  F,W  Prereq: PH113 and either ECE203 with a grade of C or better or ES203 with a grade of C or better

COURSES LISTED IN ENGINEERING MECHANICS

EM 103 Introduction to Design  1R-3L-2C  S  Prereq: None
Introduces the engineering design process including problem definition, analysis, alternate solutions, specifications of final solution, and techniques of oral and written communications. Stresses the importance of teamwork through group design efforts.

EM 104 Graphical Communications  1R-2L-2C  F  Prereq: None
Introduces the basic techniques used in engineering and scientific communication. Topics will include sketching of pictorials, computer-aided drawing, orthographic drawings, auxiliary views, reading engineering drawings and using electronic forms of communication

EM 121 Statics and Mechanics of Materials I  4R-0L-4C  F,W,S  Prereq: MA 111
Covers two- and three-dimensional force systems, equilibrium, structures, distributed forces, and strength and elastic deflection of engineering materials due to loads applied axially. Emphasizes free-body diagrams.
COURSES LISTED IN HUMANITIES AND SOCIAL SCIENCES

RH 131 Rhetoric and Composition  4R-OL-4C
Emphasizes rhetorical analysis of texts and images, research methods, and the conventions of academic writing, including argumentation.

RH 330 Technical and Professional Communication  4R-OL-4C Prereq: RH 131
Provides students with instruction and practice in analyzing contexts, audiences, and genres; crafting documents to meet the demands and constraints of professional situations; integrating all stages of the writing process; and collaborating effectively within and across teams.

SV 150 Introduction to Microeconomics 4R-0L-4C F,W,S
Analyzes the market behavior of buyers and sellers. Topics include demand and supply, costs, competition, oligopoly, monopoly, economic efficiency and resource allocation, the effects of government intervention, and international trade. A student cannot take both SV 150 and SV 151, Principles of Economics, for credit.

SV 152 Introduction to Macroeconomics 4R-0L-4C F,W,S
Analyzes the performance of the entire economy. Topics include demand and supply, GDP, unemployment and inflation, the impact of monetary and fiscal policy, business cycles, determinants of economic growth, and international finance. A student cannot take both SV 152 and SV 151, Principles of Economics, for credit.

Note: RHIT EP Students are required to take RH131, RH330, SV150 or SV152 and 6 additional HSS courses – where 2 classes must focus on society and values, 2 courses are focused in ideas and arts and two course must focus in global studies.

COURSES LISTED IN MATHEMATICS

MA 111 Calculus I  5R-0L-5C F,W
Calculus and analytic geometry in the plane. Algebraic and transcendental functions. Limits and continuity. Differentiation, geometric and physical interpretations of the derivative, Newton’s method. Introduction to integration and the Fundamental Theorem of Calculus.

MA 112 Calculus II  5R-0L-5C F,W,S Prereq: MA111

MA 113 Calculus III  5R-0L-5C F,W,S Prereq: MA112
Vectors and parametric equations in three dimensions. Functions of several variables, partial derivatives, maxima and minima of functions of several variables, multiple integrals, and other coordinate systems. Applications of partial derivatives and multiple integrals.
MA 211 Differential Equations  4R-0L-4C  F,W,S  Prereq: MA113
First order differential equations including basic solution techniques and numerical methods. Second order linear, constant coefficient differential equations, including both the homogeneous and non-homogeneous cases. Laplace transforms, Introduction to complex arithmetic, as needed. Applications to problems in science and engineering.

MA 212 Matrix Algebra and Systems of Differential Equations  4R-0L-4C  F,W,S  Prereq: MA113
Basic matrix algebra with emphasis on understanding systems of linear equations from algebraic and geometric viewpoints, and eigenvalues and eigenvectors. Solution of systems of first order linear differential equations by eigensystems and investigation of their solution structure determined by eigensystems. Phase portrait analysis and classification of the nature of the stability of critical points for linear and nonlinear systems. Fourier series. Introduction to complex arithmetic, as needed. Applications to problems in science and engineering.

MA 223 Engineering Statistics I  4R-0L-4C  F,W,S  Prereq: MA112
This is an introductory course in statistical data analysis. Topics covered include descriptive statistics, introduction to simple probability concepts, and random variables (including their linear combinations and expectations). The Central Limit Theorem will be presented. Hypothesis testing and confidence intervals for one mean, one proportion, and one standard deviation/variance will be covered as well as hypothesis testing and confidence intervals for the difference of two means. An introduction to one factor analysis of variance and simple linear regression will be presented. A computer package will be used for statistical analysis and simulation. Experimental data from a variety of fields of interest to the science and engineering majors enrolled will also be used to illustrate statistical concepts and facilitate the development of the student’s statistical thinking. A student cannot take both MA 223 and MA 382 for credit.

COURSES IN PROGRAMMING

ME 123 Computer Programming  4R-0L-4C  F,W,S  Prereq: ME/PHOE major or permission of instructor
Software tools and engineering processes for mechanical engineers. Topics may include: structured programming (Matlab), simulation of rigid body motion, presentation software, and spreadsheets. Introduction to teaming and creativity.

CSSE 120 Introduction to Software Development  3R-3L-4C  F,W,S
An introduction to procedural and object-oriented programming with an emphasis on problem solving. Problems may include visualizing scientific or commercial data, interfacing with external hardware such as robots, or solving numeric problems from a variety of engineering disciplines. Procedural programming concepts covered include data types, variables, control structures, arrays, and data I/O. Object-oriented programming concepts covered include object creation and use, object interaction, and the design of simple classes. Software engineering concepts covered include testing, incremental development, understanding requirements, and teamwork.

Note: RHIT EP students are required to take either ME123 or CSSE120.