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Sean Connor
Director of Student Affairs
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Saylor Academy awards
Dan Rinniceanu

this certificate of achievement for
PHYS101: Introduction to Mechanics

15 august 2018

Issue Date



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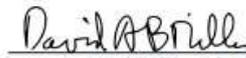
Certificate ID

Dan Rimniceanu

has successfully completed a free online offering of

Quantum Mechanics for Scientists and Engineers

with **Distinction**.



David Miller, Ph.D.
W.M. Keck Foundation Professor of Electrical Engineering
Professor, by courtesy, of Applied Physics
Stanford University

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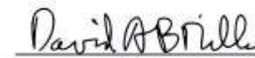
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Dan Rimniceanu

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Quantum Mechanics for Scientists and Engineers 2

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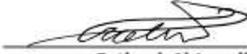
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Dan Rimniceanu

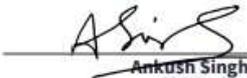
has successfully completed a free online offering of

Reservoir Geomechanics

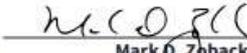
and has demonstrated understanding of practical issues in energy production combining knowledge of the stresses in the Earth with the principles of rock mechanics, structural geology, petroleum engineering, and earthquake seismology.



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Dan Rimniceanu

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Introduction to Haptics



Allison Okamura, Ph.D.
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PHYS101: Introduction to Mechanics

In general, the goal of physics is to develop descriptions of the natural world that correspond closely to actual observations. Given this definition, the story behind everything in the universe, from rocks falling to stars shining, is one of physics. In principle, the events of the natural world represent no more than the interactions of the elementary particles that the material universe is made of. In practice, however, it turns out to be more complicated than that.

As the system under study becomes more and more complex, it becomes less and less clear how the basic laws of physics account for the observations. Other branches of science, such as chemistry or biology, are needed. In principle, biology is based on the laws of chemistry, and chemistry is based on the laws of physics, but our ability to understand something as complex as life in terms of the laws of physics is well beyond our present knowledge. Physics is, however, the first rung on the ladder of our understanding of the physical universe.

In this course, we will study physics from the ground up, learning the basic principles of physical laws, their application to the behavior of objects, and the use of the scientific method in driving advances in this knowledge. This first of two courses (the subsequent course is Introduction to Electromagnetism) will cover the area of physics known as classical mechanics. Classical mechanics is the study of motion based on the physics of Galileo Galilei and Isaac Newton. While mathematics is the language of physics, you will only need to be familiar with high school level algebra, geometry, and trigonometry. The small amount of additional math and calculus that we need will be developed during the course.

Unit 1: Introduction to Physics

Our first step in this course is to gain a basic understanding of the language and analytical techniques that are specific to physics. This unit will include a brief outline of physics and the scientific method, measurement units and scientific notation, and the concepts of significant figures, order-of-magnitude estimates, and scaling.

Completing this unit should take you approximately 6 hours.

- Upon successful completion of this unit, you will be able to:
 - explain the difference between a theory and a law;
 - perform unit conversions using both metric and traditional U.S. units;
 - write numbers expressed in decimals as scientific notation and write numbers expressed in scientific notations as decimals; and
 - solve problems with the values of the most common metric prefixes.

• 1.1: Physical Quantities and Units

- [OpenStax College: "College Physics"URL](#)

Read the Preface and sections 1.1 and 1.2 of "Chapter 1: Introduction: The Nature of Science and Physics".

- [1.1 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Subunit 1.1 NotesURL](#)

This notes page includes some high-level takeaways and equations covered in this subunit. Feel free to add to this document; we deliberately left it in DOC format to encourage you to add to and expand it. Consider sharing your notes with your classmates on our [discussion forum](#) for this course.

- **1.2: Accuracy, Precision, and Significant Figures**

- [OpenStax College: "College Physics"URL](#)

Read sections 1.3 and 1.4 of "Chapter 1: Introduction: The Nature of Science and Physics".

- [1.2 Practice ProblemsQuiz](#)

Try solving these practice problems.

- [Texas A&M University: "Math Skills Review, Significant Figures"URL](#)

After reading the *College Physics* material, please click on the link above, and review these rules on significant digits.

Unit 2: Motion in a Straight Line

Our formal study of physics begins with kinematics, which is defined as the study of motion without considering its causes. The word "kinematics" comes from a Greek term meaning "motion." In this unit, we will study motion without worrying about what forces cause or change it. Such considerations come in later units. In this unit, we will examine the simplest type of motion - namely, motion along a straight line, or one-dimensional motion.

Completing this unit should take you approximately 13 hours.

- Upon successful completion of this unit, you will be able to:
 - compare and contrast distance and displacement;
 - define and distinguish between vector and scalar physical quantities;
 - explain the relationship between instantaneous and average values for physical quantities;
 - compare and contrast speed and velocity;

- solve one-dimensional kinematics problems;
- describe the effects of gravity on an object in motion;
- calculate the position and velocity of an object in free fall; and
- draw and interpret graphs for displacement and velocity as functions of time, and determine velocity and acceleration from them.

- **2.1: Vectors, Scalars, and Coordinate Systems**

- [Khan Academy: "One-Dimensional Motion: Displacement, Velocity, and Time"Page](#)
-

Please click on the link above and watch this lecture series, pausing to take notes, before moving on to the reading below.

- [OpenStax College: "College Physics"URL](#)
-

Read sections 2.1 and 2.2 of "Chapter 2: Kinematics". Look over the corresponding conceptual questions in each section to test your understanding.

- [2.1 Practice ProblemsQuiz](#)
-

Try solving these practice problems.

- **2.2: Velocity, Speed, and Acceleration**

- [Khan Academy: "One-Dimensional Motion: Acceleration"Page](#)
-

Please click on the link above and watch this lecture series, pausing to take notes, before moving on to the reading below.

- [OpenStax College: "College Physics"URL](#)
-

Read sections 2.3 and 2.4 of "Chapter 2: Kinematics". Look over the conceptual questions in each section to test your understanding.

- [2.2 Practice ProblemsQuiz](#)
-

Try solving these practice problems.

- **2.3: Motion with Constant Acceleration**

- [OpenStax College: "College Physics"URL](#)
-

Read sections 2.5 and 2.6 of "Chapter 2: Kinematics". Look over the conceptual questions in each section to test your understanding.

- [2.3 Practice ProblemsQuiz](#)
-

Try solving these practice problems.

• 2.4: Falling Objects

- [Khan Academy: "One-Dimensional Motion: Kinematic Formulas and Projectile Motion"Page](#)

Please click on the link above and watch this lecture series, pausing to take notes, before moving on to the reading below.

- [OpenStax College: "College Physics"URL](#)

Read section 2.7 of "Chapter 2: Kinematics". Look over the conceptual questions at the end of the section to test your understanding.

- [2.4 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's Calculus-Based Physics: "1st Semester SAC Physics Problems"URL](#)

Work on solving problems 1, 2, and 3 from 106A and 3 from 107. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

• 2.5: Graphical Analysis

- [OpenStax College: "College Physics"URL](#)

Read section 2.8 of "Chapter 2: Kinematics". Look over the conceptual questions in the section to test your understanding.

- [2.5 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's Calculus-Based Physics: "1st Semester SAC Physics Problems"URL](#)

Work on solving problems 1, 2, and 3 from SAC108. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

Unit 3: Kinematics in Two Dimensions

Most motions in nature follow curved paths rather than straight lines. Motion along a curved path on a flat surface or a plane is two-dimensional and thus described by two-dimensional kinematics. Two-dimensional kinematics is a simple extension of the one-dimensional kinematics covered in the previous unit. This simple extension will allow us to apply physics to many more situations, and it will also yield unexpected insights about nature.

Completing this unit should take you approximately 16 hours.

- Upon successful completion of this unit, the student will be able to:
 - add and subtract vectors;
 - determine the components of a vector given its magnitude and direction, and determine the magnitude and direction of a vector given its components; and
 - separately analyze the horizontal and vertical motions in projectile problems.

• 3.1: Kinematics in Two Dimensions

- [OpenStax College: "College Physics"URL](#)

Read section 3.1 of "Chapter 3: Two-Dimensional Kinematics".

• 3.2: Vector Addition and Subtraction

-  [Massachusetts Institute of Technology: "Review of Vectors"URL](#)

Read this material carefully before viewing the Khan Academy lecture sequence below.

- [Khan Academy: "Two-Dimensional Motion: Two-Dimensional Projectile Motion"Page](#)

Watch this lecture series, pausing to take notes, before moving on to the reading below. Don't worry if it seems intimidating. We will review the dot and cross products at a more appropriate level later when they are needed for this course.

• 3.3: Constant Acceleration Motion

- [OpenStax College: "College Physics"URL](#)

Read sections 3.2 and 3.3 of "Chapter 3: Two-Dimensional Kinematics". Look over the conceptual questions at the end of each section to test your understanding.

- [3.3 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's Calculus-Based Physics: "1st Semester SAC Physics Problems"URL](#)

Work on solving problems 1, 2, and 3 from SAC106 and problems 1 through 4 from SAC109A. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

• 3.4: Projectile Motion

- [OpenStax College: "College Physics"URL](#)

Read sections 3.4 and 3.5 of "Chapter 3: Two-Dimensional Kinematics". Look over the conceptual questions in each section to test your understanding.

○ [3.4 Practice Problems Quiz](#)

Try solving these practice problems.

○  [Jeffery W. Schnick's Calculus-Based Physics: "1st Semester SAC Physics Problems" URL](#)

Work on solving problems 1, 2, 3, and 4 from SAC10. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

Unit 4: Dynamics

The study of motion is kinematics, which describes the way objects move, their velocity, and their acceleration. Dynamics consider the forces that affect the motion of moving objects. Newton's laws of motion are the foundation of dynamics. These laws provide examples of the breadth and simplicity of principles under which nature functions. They are also universal laws in that they apply to similar situations on Earth as well as in space.

Completing this unit should take you approximately 26 hours.

- Upon successful completion of this unit, the student will be able to:
 - compare and contrast mass and inertia;
 - determine the net force on an object;
 - draw and interpret free-body diagrams representing the forces on an object;
 - identify the correct use of normal and tension forces in terms of Newton's third law of motion;
 - use Newton's second law of motion to analyze dynamic problems;
 - give examples of the effects of friction on the motion of an object;
 - state Hooke's law;
 - solve problems involving springs; and
 - identify the fundamental physical properties of a simple pendulum, and describe the relationships among them.

• 4.1: Newton's First and Second Laws of Motion

○ [Khan Academy: "Newton's Laws of Motion" Page](#)

Please click on the link above and watch this lecture series, pausing to take notes, before moving on to the reading below.

○ [OpenStax College: "College Physics" URL](#)

Read sections 4.1, 4.2, and 4.3 of "Chapter 4: Dynamics: Force and Newton's Laws of Motion". Look over the conceptual questions in each section to test your understanding.

- [4.1 Practice Problems Quiz](#)

Try solving these practice problems.

- **4.2: Newton's Third Law of Motion and Normal and Tension Forces**

- [Khan Academy: "Normal Force and Contact Force" Page](#)

Watch this lecture series, pausing to take notes, before moving on to the reading below.

- [OpenStax College: "College Physics" URL](#)

Read sections 4.4 and 4.5 of "Chapter 4: Dynamics: Force and Newton's Laws of Motion". Look over the conceptual questions in each section to test your understanding.

- [Saint Anselm College: Jeffery W. Schnick's "Free-Body Diagrams Practice Problems" Quiz](#)

Try these practice problems, and be sure to make a serious attempt before viewing the answers.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems" URL](#)

Work on solving problems 1 through 4 from SAC112, problems 1 through 4 from SAC112A, and problems 1 through 3 from SAC113. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

- **4.3: Applications of Newton's Laws of Motion**

- [Khan Academy: "Balanced and Unbalanced Forces" and "Slow Sock on Lubricon IV" Page](#)

Watch this lecture series, pausing to take notes, before moving on to the reading below.

- [OpenStax College: "College Physics" URL](#)

Read sections 4.6 and 4.7 of "Chapter 4: Dynamics: Force and Newton's Laws of Motion". Look over the conceptual questions in each section to test your understanding.

- [4.3 Practice Problems Quiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)

Work on solving problems 1 through 10 from SAC114. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

• 4.4: Friction

- [Khan Academy: "Inclined Planes and Friction"Page](#)

Watch this lecture series, pausing to take notes, before moving on to the reading below.

- [OpenStax College: "College Physics"URL](#)

Read section 5.1 of "Chapter 5: Further Applications of Newton's Laws: Friction, Drag, and Elasticity". Look over the conceptual questions in each section to test your understanding.

- [4.4 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)

Work on solving problem 3 from SAC102. The [solution](#) is available, but make a serious attempt to solve the problem before looking at the solution.

• 4.5: Springs

- [Khan Academy: "Tension"Page](#)

Watch this lecture series, pausing to take notes, before moving on to the reading below.

- [OpenStax College: "College Physics"URL](#)

Read section 16.1 on Hooke's Law and motion and energy associated with a spring. Look over the conceptual questions in the section to test your understanding.

- [4.5 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)

Work on solving problems 1 and 2 from SAC102 and 1, 2, and 3 from SAC109. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

- **4.6: The Simple Pendulum**

- [OpenStax College: "College Physics"URL](#)

Read section 16.4 on the simple pendulum. Look over the conceptual questions in the section to test your understanding.

- [4.6 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)

Work on solving problems 1 through 4 from SAC127. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

Unit 5: Circular Motion and Gravity

In this unit, we will study the simplest form of curved motion: uniform circular motion, or motion in a circular path at constant speed. In some ways, this unit is a continuation of the previous unit on dynamics, but we will introduce new concepts such as angular velocity and acceleration, centripetal force, and the force of gravity.

Completing this unit should take you approximately 15 hours.

- Upon successful completion of this unit, the student will be able to:
 - compare and contrast the physical properties associated with linear motion and rotational motion;
 - explain why an object moving at a constant speed in a circle is accelerating;
 - apply Newton's law of gravity;
 - solve problems involving planets and satellites; and
 - explain what it means when an astronaut in earth orbit is described as being "weightless".

- **5.1: Angular Velocity and Acceleration**

- [Khan Academy: "Harmonic Motion"Page](#)

Watch this lecture series, pausing to take notes, before moving on to the reading below.

- [OpenStax College: "College Physics"URL](#)
-

Read sections 6.1 and 6.2 of "Chapter 6: Uniform Circular Motion and Gravitation".
Look over the conceptual questions in each section to test your understanding.

- [5.1 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)

Work on solving problems 1 through 6 in SAC116 and 1 through 6 in SAC117.
The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

- **5.2: Centripetal Force**

- [Khan Academy: "Centripetal Acceleration"Page](#)

Watch this lecture series, pausing to take notes, before moving on to the reading below.

- [OpenStax College: "College Physics"URL](#)

Read sections 6.3 and 6.4 of "Chapter 6: Uniform Circular Motion and Gravitation".
Look over the conceptual questions in each section to test your understanding.

- [5.2 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)

Work on solving problems 1, 2, and 3 from SAC119. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

- **5.3: Newton's Law of Gravity**

- [Khan Academy: "Newton's Law of Gravitation"Page](#)

Watch this lecture series, pausing to take notes, before moving on to the reading below.

- [OpenStax College: "College Physics"URL](#)

Read sections 6.5 and 6.6 of "Chapter 6: Uniform Circular Motion and Gravitation".
Look over the conceptual questions in each section to test your understanding.

- [5.3 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)
-

Work on solving problems 1 through 4 from SAC115. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

Unit 6: Work and Energy

Energy is the capacity of a physical system to perform work. It plays an essential role both in everyday events and in scientific phenomena. You can probably name many forms of energy from that provided by our foods to the energy we use to run our cars to the sunlight that warms us on the beach. Not only does energy have many interesting forms, but it is involved in almost all phenomena and is one of the most important concepts of physics.

Energy can change forms, but it cannot appear from nothing or disappear without a trace. Thus, energy is one of a handful of physical quantities that we say is conserved.

Completing this unit should take you approximately 14 hours.

- Upon successful completion of this unit, the student will be able to:
 - calculate the work done on an object by a force;
 - use the relationship between work done and the change in kinetic energy to make calculations;
 - state the work-energy theorem;
 - describe the concept of potential energy and how it relates to work;
 - compare and contrast conservative and non-conservative forces;
 - solve dynamics problems using conservation of energy; and
 - illustrate what is meant by power.

• 6.1: Work and Kinetic Energy

- [Khan Academy: "Work and Kinetic Energy"Page](#)
-

Watch this lecture series, pausing to take notes, before moving on to the reading below.

- [OpenStax College: "College Physics"URL](#)
-

Read sections 7.1 and 7.2 of "Chapter 7: Work, Energy, and Energy Resources".

- [6.1 Practice ProblemsQuiz](#)
-

Try solving these practice problems.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)
-

Work on solving problems 1, 2, and 3 from SAC122. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

- **6.2: Conservative Forces and Potential Energy**

- [OpenStax College: "College Physics"URL](#)

Read sections 7.3 and 7.4 of "Chapter 7: Work, Energy, and Energy Resources". Look over the conceptual questions in each section to test your understanding.

- [6.2 Practice ProblemsQuiz](#)

Try solving these practice problems.

- **6.3: Conservation of Energy**

- [OpenStax College: "College Physics"URL](#)

Read sections 7.5 and 7.6 of "Chapter 7: Work, Energy, and Energy Resources". Look over the conceptual questions in each section to test your understanding.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)

Work on solving problems 4, 5, and 6 from SAC102. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

- **6.4: Power**

- [OpenStax College: "College Physics"URL](#)

Read sections 7.7, 7.8, and 7.9 of "Chapter 7: Work, Energy, and Energy Resources". Look over the conceptual questions in each section to test your understanding.

- [6.4 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)

Work on solving problems 1 through 4 from SAC124. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

Unit 7: Momentum and Collisions

We use the term momentum in various ways in everyday language. We speak of sports teams gaining and maintaining the momentum to win. Generally, momentum implies a tendency to continue on course - to move in the same direction - and is associated with mass and velocity. Momentum has its most important application in analyzing collision

problems, and, like energy, is important because it is conserved. Only a few physical quantities are conserved in nature, and studying them yields fundamental insight into how nature works, as we shall see in our study of momentum.

Completing this unit should take you approximately 12 hours.

- Upon successful completion of this unit, the student will be able to:
 - define linear momentum;
 - use Newton's 2nd law in terms of momentum;
 - describe the relationship between impulse and momentum;
 - define elastic, inelastic, and totally inelastic collisions;
 - use conservation of momentum to solve collision problems; and
 - demonstrate the physics behind rocket propulsion.

7.1: Momentum and Impulse

- [OpenStax College: "College Physics"URL](#)

Read sections 8.1, and 8.2 of "Chapter 8: Linear Momentum and Collisions". Look over the conceptual questions in each section to test your understanding.

- [7.1 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)

Work on solving problems 1 through 4 from SAC125. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

7.2: Conservation of Momentum in Collisions

- [Khan Academy: "Momentum"Page](#)

Watch this lecture series, pausing to take notes, before moving on to the reading below.

- [OpenStax College: "College Physics"URL](#)

Read sections 8.3, 8.4, and 8.5 of "Chapter 8: Linear Momentum and Collisions". Look over the conceptual questions in each section to test your understanding.

- [7.2 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)
-

Work on solving problems 1 through 5 from SAC104. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

- **7.3: Collisions in Two Dimensions**

- [OpenStax College: "College Physics"URL](#)

Read sections 8.6, and 8.7 of "Chapter 8: Linear Momentum and Collisions". Look over the conceptual questions in each section to test your understanding.

- [7.3 Practice ProblemsQuiz](#)

Try solving these practice problems.

Unit 8: Statics and Torque

What might desks, bridges, buildings, trees, and mountains have in common - at least in the eyes of a physicist? The answer is that they are ordinarily motionless relative to the Earth. Thus, their acceleration in the Earth frame of reference is zero. Newton's second law states that net $F = ma$, so the net external force is zero on all stationary objects and for all objects moving at constant velocity. There are forces acting, but they are balanced. That is, the forces are in equilibrium.

Completing this unit should take you approximately 8 hours.

- Upon successful completion of this unit, the student will be able to:
 - define the conditions necessary for a rigid body to be in equilibrium;
 - define torque remembering that it is a vector physical quantity; and
 - solve statics problems.

- **8.1: Conditions for Equilibrium**

- [OpenStax College: "College Physics"URL](#)

Read sections 9.1, 9.2, and 9.3 of "Chapter 9: Statics and Torque". Look over the conceptual questions in each section to test your understanding.

- [8.1 Practice ProblemsQuiz](#)

Try solving these practice problems.

- [Khan Academy: "Cross Product and Torque"Page](#)

This video discusses torque as a cross product of the lever arm and the force vector and illustrates how the direction of the torque is related to the directions of the lever arm and the force.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)

Work on solving problems 1 and 2 from SAC118. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

- **8.2: Applications of Statics**

- [OpenStax College: "College Physics"URL](#)
-

Read section 9.4 of "Chapter 9: Statics and Torque". Look over the conceptual questions in the section to test your understanding.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)
-

Work on solving problems 1 through 5 from SAC121. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

- **8.3: Simple Machines**

- [OpenStax College: "College Physics"URL](#)
-

Read sections 9.5 and 9.6 of "Chapter 9: Statics and Torque". Look over the conceptual questions in each section to test your understanding.

- [8.3 Practice ProblemsQuiz](#)
-

Try solving these practice problems.

Unit 9: Angular Momentum

Why do tornadoes spin so rapidly? The answer is that the air masses that produce tornadoes are themselves rotating, and when the radii of the air masses decrease, their rate of rotation increases. An ice skater increases her spin in an exactly analogous way. The skater starts her rotation with outstretched limbs and increases her spin by pulling them in toward her body. The same physics describes the spin of a skater and the wrenching force of a tornado. Clearly, force, energy, and power are associated with rotational motion. These and other aspects of rotational motion are covered in this unit. We will see that all important aspects of rotational motion either have already been defined for linear motion or have exact analogs in linear motion.

Completing this unit should take you approximately 16 hours.

- Upon successful completion of this unit, the student will be able to:
 - solve kinematics problems involving rotational motion;
 - solve dynamics problems involving rotational motion;
 - define rotational inertia;
 - compare and contrast the dynamics of linear and rotational motion;
 - apply energy concepts to rotational motion; and
 - give several everyday examples of conservation of angular momentum.

- **9.1: Kinematics of Rotational Motion**

- [Khan Academy: "Center of Mass"Page](#)

Watch this lecture, pausing to take notes, before moving on to the reading below.

- [OpenStax College: "College Physics"URL](#)

Read sections 10.1 and 10.2 of "Chapter 10: Rotational Motion and Angular Momentum". Look over the conceptual questions in each section to test your understanding.

- [9.1 Practice ProblemsQuiz](#)

Try solving these practice problems.

- [James H. Dann and James J. Dann's "People's Physics Book, Chapter 9: Rotational Motion"URL](#)

Scroll down the page to "Ch 9: Rotational Motion," and select the link to open the PDF document. Read the entirety of Chapter 9. From pages 9-4 to 9-10, solve problems 1-4, 10-13, 16, and 21.

- **9.2: Dynamics of Rotational Motion**

- [OpenStax College: "College Physics"URL](#)

Read sections 10.3 and 10.4 of "Chapter 10: Rotational Motion and Angular Momentum". Look over the conceptual questions in each section to test your understanding.

- [9.2 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)

Work on solving problems 3 from SAC103 and 1, 2, and 3 from SAC123. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.

- **9.3: Conservation of Angular Momentum**

- [OpenStax College: "College Physics"URL](#)

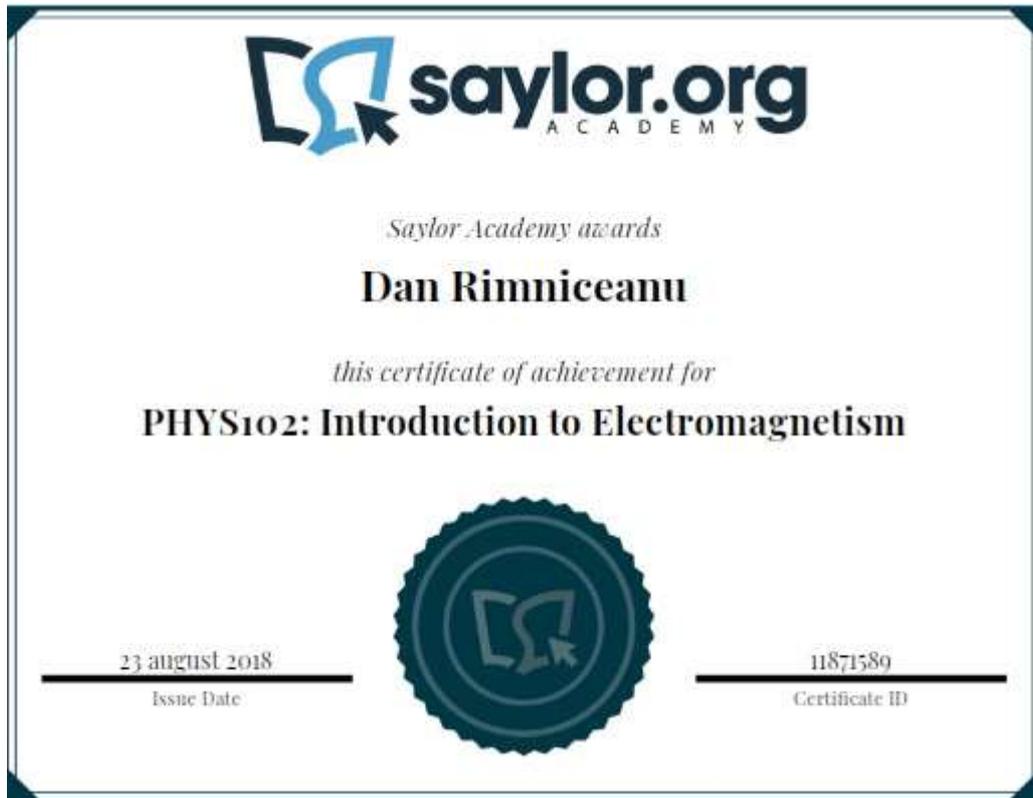
Read section 10.5 of "Chapter 10: Rotational Motion and Angular Momentum". Look over the conceptual questions in the section to test your understanding.

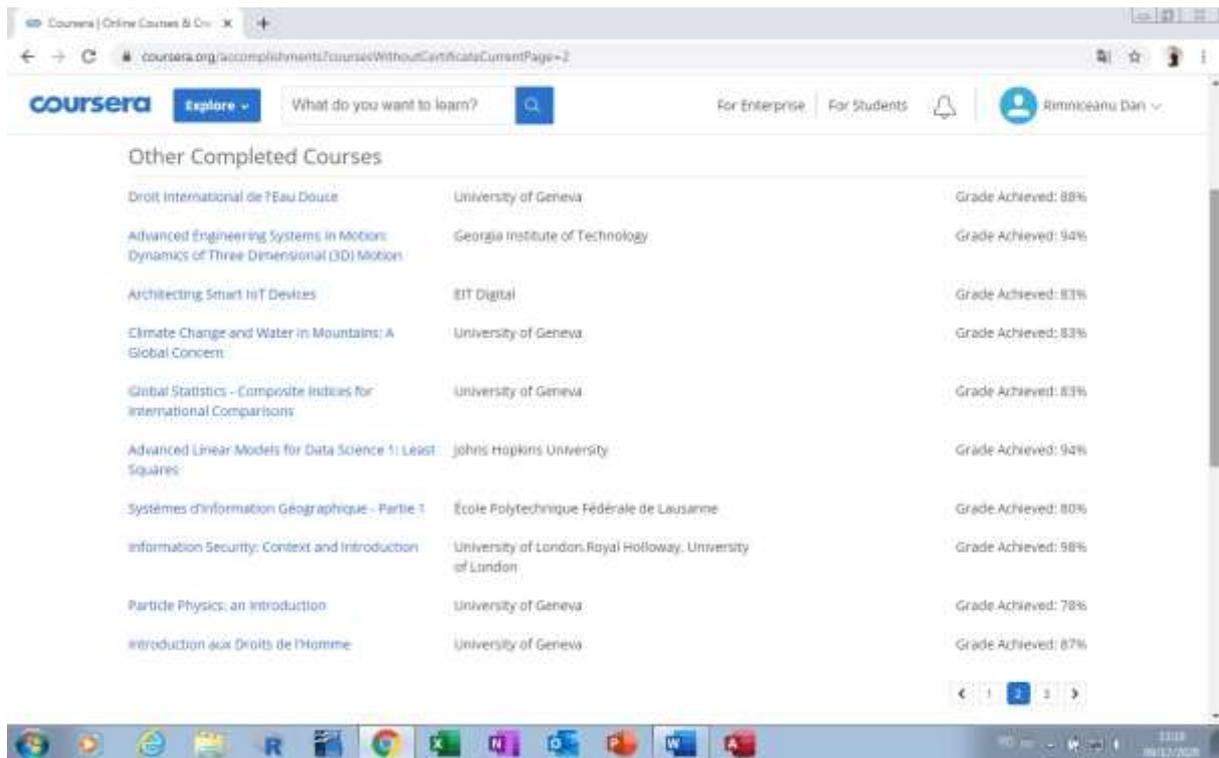
- [9.3 Practice ProblemsQuiz](#)

Try solving these practice problems.

-  [Jeffery W. Schnick's "Calculus-Based Physics: 1st Semester SAC Physics Problems"URL](#)

Work on solving problems 1 through 4 from SAC105. The [solutions](#) are available, but make a serious attempt to solve the problems before looking at the solutions.





The physics of the universe appears to be dominated by the effects of four fundamental forces: gravity, electromagnetism, weak nuclear forces, and strong nuclear forces. These forces control how matter, energy, space, and time interact to produce our physical world. All other forces, such as the force you exert in standing up, are ultimately derived from these fundamental forces.

We have direct daily experience with two of these forces: gravity and electromagnetism. Consider, for example, the everyday sight of a person sitting on a chair. The force holding the person on the chair is gravitational, and that gravitational force balances with material forces that "push up" to keep the individual in place. These forces are the direct result of electromagnetic forces on the nanoscale. On a larger stage, gravity holds the celestial bodies in their orbits, while we see the universe by the electromagnetic radiation (light, for example) with which it is filled. The electromagnetic force also makes possible the advanced technology that forms much of the basis for our civilization. Televisions, computers, smartphones, microwave ovens, and even the humble light bulb are made possible by control of electromagnetism. The average physics major will spend more time understanding and applying the concept of electromagnetic force than he or she will spend studying any other type of force.

The classical (non-quantum) theory of electromagnetism was first published by James Clerk Maxwell in his 1873 textbook *A Treatise on Electricity and Magnetism*. A host of scientists during the nineteenth century carried out the work that ultimately led to Maxwell's electromagnetism equations, which is still considered one of the triumphs of classical physics. Maxwell's description of electromagnetism, which demonstrates that electricity and magnetism are different aspects of a unified electromagnetic field, holds

true today. In fact, Maxwell's equations are consistent with relativity, which was not theorized until 30 years after Maxwell completed his equations.

In this course, we will first learn about waves and oscillations in extended objects using the classical mechanics that we learned about in [PHYS101](#). We will also establish the sources and laws that govern static electricity and magnetism. A brief look at electrical measurements and circuits will help us understand how electromagnetic effects are observed, measured, and applied. We will then see how Maxwell's equations unify electric and magnetic effects and how the solutions to Maxwell's equations describe electromagnetic radiation, which will serve as the basis for understanding all electromagnetic radiation, from very low frequency, long-wavelength radio waves to the most powerful astrophysical gamma rays. We will briefly study optics, using practical models largely consistent with the predictions of Maxwell's equations but that are easier to use. Finally, this course provides a brief overview of Einstein's theory of special relativity. We will assume that you have a basic knowledge of calculus.

This course will require you to complete a number of problems. Unlike mechanics, most of the phenomena encountered in the field of electromagnetism are not found in everyday experience – at least, not in a form that makes the actual nature of the phenomena clear. As a result, learning electromagnetism involves developing intuition about a rather unintuitive area of physics. In the end, developing physical intuition is less about getting the right answer than it is about getting a wrong answer and then understanding why it is wrong. In an ideal situation, this course would require you to work out problems concerning the phenomena and observe various important phenomena in the laboratory. However, because this is an online course, we do not have the luxury of lab sessions. We have included a number of interactive demonstrations to compensate for this. When you approach a problem, try to work out the size of those quantities that clarify the basic nature of the question proposed. Thinking of these numbers as data from an ideal laboratory will help you develop a sense of how electromagnetism works – a sense that most people do not get from the mathematical description of the physics.

Optional Review: Topics in Vector Calculus

This unit is a review of the mathematical background necessary to solve many problems in the study of electromagnetism. You may wish to refer to it as necessary as you work through the rest of the course.

If you already feel comfortable with these topics, you may skip this unit. This unit is **not** required to complete this course.

- **Vector Algebra**

-  [Michael Corral's Vector Calculus: "Chapter 1: Vectors in Euclidean Space" File](#)

Read the first four sections of "Chapter 1: Vectors in Euclidian Space" on pages 1 through 30. Work through examples in the text and try the odd-numbered exercises after each section. You can find the answers on page 189.

- **Multivariable Calculus**

- **Double and Triple Integrals in Cartesian Coordinates**

- [Khan Academy: "Double Integrals"Page](#)

Watch this lecture series. Double integrals are typically used to calculate volumes.

-  [Michael Corral's "Vector Calculus, Chapter 3: Multiple Integrals"File](#)

Read the first two sections of "Chapter 3: Multiple Integrals" on pages 101 through 109. Then, work through examples in the text and try the odd-numbered exercises 1-13 at the end of section 3.1 on page 104 and odd-numbered exercises 1-11 at the end of section 3.2 on page 109. You can find the answers on page 191.

- [Khan Academy: "Triple Integrals"Page](#)

Watch these videos, which demonstrate how triple integrals could be used to calculate mass and find the center of mass of three-dimensional objects.

-  [Michael Corral's "Vector Calculus, Chapter 3: Multiple Integrals"File](#)

Read "Section 3.3: Triple Integrals" on pages 110 through 112. Work through examples in the text and try the odd-numbered exercises 1-9 at the end of the section on page 112. You can find the answers on page 191.

- **Integrals in Curvilinear Coordinates**

-  [Michael Corral's "Vector Calculus, Chapter 1: Vectors in Euclidean Space"File](#)

Read "Section 1.7: Curvilinear Coordinates" on pages 47 through 50. Work through examples in the text and try the odd-numbered exercises 1-9 on page 50. You can find the answers on page 189. Some integrals are much easier to take when they are expressed in terms of coordinates that are not Cartesian – cylindrical or spherical. This reading explains how to convert curvilinear coordinates to Cartesian and vice versa.

- [James Sousa's "Triple Integrals Using Cylindrical Coordinates" and "Triple Integral and Volume Using Cylindrical Coordinates"Page](#)

Watch these two videos on using triple integrals in cylindrical coordinate systems.

-  [Michael Corral's "Vector Calculus, Chapter 3: Multiple Integrals"File](#)

Read pages 121 through 123 of "Section 3.5: Change of Variables". Work through examples in the text and try the exercises 1 and 3 at the end of this section. The answers are on page 191.

- **Line and Surface Integrals**

- [Khan Academy: "Line Integrals and Vector Fields" and "Using a Line Integral to Find the Work Done by a Vector Field Example"Page](#)

Watch these videos, which introduce line integrals. Line integrals are needed to calculate the physical quantities of work and circulation.

-  [Michael Corral's "Vector Calculus, Chapter 4: Line and Surface Integrals" File](#)
Read "Section 4.1: Line Integrals" on pages 135 through 142. Work through examples in the text and try the odd-numbered exercises 1-13 at the end of the section on page 142. The answers are on page 191.
- [Khan Academy: "Parameterizing a Surface" Page](#)
Watch this lecture series, which introduces and gives examples of surface integrals.
- [Khan Academy: "Surface Integrals" Page](#)
Watch this lecture series, which covers surface integrals in detail.
- [Khan Academy: "Flux in 3D and Constructing Unit Normal Vectors to Surface" Page](#)
Watch this lecture series. The flux of a field, electric or magnetic, is used to determine how strong the field is. The Gauss Law and Faraday Law of electromagnetism both involve the flux of electric and magnetic field, respectively.
-  [Michael Corral's "Vector Calculus, Chapter 4: Line and Surface Integrals" File](#)
Read "Section 4.4: Surface Integrals and Divergence Theorem" on pages 156 through 164. Work through examples in the text and try the odd-numbered exercises 1-9 at the end of the section. The answers are on the page 191.

- **Differential Equations**

- [Khan Academy: "Intro to Differential Equations" Page](#)
Watch this lecture series, which introduces differential equations.
- [Khan Academy: "Separable Differential Equations" Page](#)
Watch this lecture series, which introduces separable differential equations.
-  [Clinton Community College: Elizabeth Wood's "Supplemental Notes for Calculus II: First Order Differential Equations" File](#)
Work through the six examples on the page. Be sure to solve them on your own before looking at the solutions.

Unit 1: Mechanical Vibrations and Waves in Extended Objects

In PHYS101, we learned how to describe the motion of particle-like masses using classical mechanics. We will start PHYS102 by examining how objects of size – length, width,

depth – behave. We will focus on vibrating systems and the propagation of mechanical waves through media; think of ripples traveling outward from a stone dropped into water. This course will also lay the basic foundation for the development of a classical theory of mechanics for extended solids.

Completing this unit should take you approximately 7 hours.

- Upon successful completion of this unit, you will be able to:
 - describe the properties of simple harmonic motion and provide examples;
 - define the following terms related to wave motion: frequency, wavelength, diffraction, and interference;
 - state Hooke's Law; and
 - solve problems using simple harmonic motion.

• **1.1: Periodic Motion and Simple Harmonic Oscillators**

- [Khan Academy: "Springs and Hooke's Law" and "Harmonic Motion"Page](#)

Please watch both these videos, pausing to take notes, before moving on to the reading below.

- [Wolfram Demonstrations Project: "A Non-Harmonic Oscillator"URL](#)

To use this demonstration, you must download and install the [Mathematica Viewer](#) from the Wolfram Demonstrations Project. This demonstration illustrates a very simple example of a non-harmonic oscillator - a helium balloon on a string. There are two sources of non-linearity. First, as the balloon rises, it lifts more string. Therefore, the mass of the oscillator is a function of the position of the oscillating mass, which leads to nonlinear behavior. In addition, a damping term has been included which mimics the effect of air resistance. Adjust the various control parameters to gain a feel for which parameters have a larger effect of the motion of the oscillator. Check out the special cases suggested in "Details" section of the demonstration: motion in the absence of damping (set the damping constant to 0), motion of the balloon when the string has no mass – then, the force of gravity no longer increases as the balloon goes up, and the motion when mass of the string is large and the damping constant is large – what happens to the balloon eventually in this case?

- [University of Texas: Professor Richard Fitzpatrick's "Classical Mechanics: Oscillatory Motion"URL](#)

Please read this chapter after viewing the lecture above. There are 6 worked examples in the chapter. Try each of these problems before looking at the solutions. Make sure you understand not only the solutions but also how to approach solving the problem so that you can obtain the solution yourself. You will be responsible for being able to solve problems of this type on the final exam.

- [Wolfram Demonstrations Project: "Simple Harmonic Motion of a Spring"URL](#)

To use this demonstration, you must download and install the [Mathematica Viewer](#) from the Wolfram Demonstrations Project. The demonstration illustrates the motion of a mass on a spring. When the mass is pulled down, the spring exerts a restoring force described by Hooke's Law that pulls the mass upwards. The result is that the mass travels up and down in simple harmonic motion, where the displacement of the mass is described by a sinusoidal curve. Think of this demonstration as an experiment to verify (or not) the effect of Hooke's Law on the period of oscillation. Use [this worksheet](#) as your guide in working with this demonstration.

- **1.2: Vibrations**

-  [Fullerton College: Benjamin Crowell's "Light and Matter, Chapter 17: Vibrations"URL](#)

Please download this entire book. This is a very large file, but we will be using this text throughout most of the course. This version also contains the solutions to the Self-Check questions. Read sections 1 and 2 of "Chapter 17: Vibrations" on pages 445-441.

- **1.3: Wave Motion**

- [Khan Academy: "Introduction to Waves"Page](#)

Please watch this lecture series, pausing to take notes, before moving on to the reading below.

-  [Fullerton College: Benjamin Crowell's "Light and Matter, Chapter 19: Free Waves"URL](#)

Please read the three sections of "Chapter 19: Free Waves" on pages 481-499. Answer the Self-Check questions in the text. You can find the answers on page 553. Think about the Discussion Questions on pages located throughout the chapter, and work out problems ##1 -3 and #4 on pages 507 – 508. You can check some of the answers [here](#).

- [Wolfram Demonstrations Project: "Superposition of Waves"URL](#)

To use this demonstration, you must download and install the [Mathematica Viewer](#) from the Wolfram Demonstrations Project. This demonstration illustrates the superposition of two waves traveling in opposite directions. First, try setting the frequencies of the two waves to be equal. Notice that as the time passes, the superposition of two waves goes from "double" the wave (the wave with the same frequency and twice the amplitude), when the waves are in same phase, to "no wave" (the waves cancel each other out completely), when they are in the opposite phase. Then, explore what happens when the frequencies of the waves

are close to each other, but a little bit different. How does the superimposed wave look like? This effect is easier to see when the frequencies are large. Try clicking on the "plus" icon in the top right corner of the demonstration, and selecting "autorun." Notice that the superimposed wave contains an oscillation within an oscillation, one with the sum, and another one with the difference of the original frequencies.

- [Wolfram Demonstrations Project: "Waves on a String with a Mass in the Middle"URL](#)
-

To use this demonstration, you must download and install the [Mathematica Viewer](#) from the Wolfram Demonstrations Project. Waves are partially reflected by local changes in the medium through which they propagate. This is illustrated here by the introduction of a point mass on a vibrating string. The transmitted wave becomes smaller in amplitude as the mass becomes larger. Why? Is there a phase shift associated with reflection/transmission? Why?

Unit 2: Electrostatics

We are now beginning our study of electricity and magnetism. We will discover that electricity and magnetism are two different aspects of the same phenomenon, which is usually referred to as electromagnetism. Our starting place will be electrostatics or, more simply, the rules governing the behavior of static charges. The first experiments on electrical phenomena were carried out by our friend from PHYS101, Thales of Miletus. He observed that one could generate a static charge on amber by rubbing it with wool.

Completing this unit should take you approximately 20 hours.

- Upon successful completion of this unit, you will be able to:
 - state Coulomb's law and identify the units of the physical quantities contained in the law;
 - solve problems involving electric forces, electric fields, and electric potentials;
 - explain Gauss' law in words;
 - compare and contrast the electric potential and the electric field;
 - solve problems using Gauss' Law;
 - solve problems involving the motion of charged particles in an electric field;
 - define capacitance and describe the factors that determine capacitance;
 - describe the effect of a dielectric material in a capacitor; and
 - define electric potential energy and describe how capacitors can be used to store energy.

• 2.1: Introduction to Electricity

- [Khan Academy: "Charge and Electric Force \(Coulomb's Law\)"Page](#)
-

Please watch this lecture series, pausing to take notes, before moving on to the reading below.

-  [Fullerton College: Benjamin Crowell's "Light and Matter, Chapter 21: Electricity and Circuits"URL](#)
-

Please read the sections one and two of "Chapter 21: Electricity and Circuits" on pages 561-565. Complete the Self Checks throughout the chapter (answers on page 1010). Think about the Discussion Questions and Examples, and work out problems ##1 – 9 on pages 601-602. You can check some of the answers [here](#).

-  [Fullerton College: Benjamin Crowell's "Light and Matter, Chapter 26: The Atom and \$E=mc^2\$ "URL](#)
-

Please read the first three sections of "Chapter 26: The Atom and $E=mc^2$ " on pages 731-742. Answer the Self-Check questions in the text (answers on page 1011). Think carefully about the Millikan's Fraud discussion, which illuminates the basis of science and how it is eventually self-correcting. Think about the Discussion Questions and Examples, and work out some the problems #2 and #4 on the page 787. You can check your answer to the problem #4 [here](#).

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Electricity"URL](#)
-

Read this chapter. There are 3 worked examples in the chapter. Try each of these problems before looking at the solutions. Make sure you understand not only the solutions but also how to approach solving the problem so that you can obtain the solution yourself. You will be responsible for being able to solve problems of this type on the final exam.

- [Wolfram Demonstrations Project: "Repulsion of Charged Objects"URL](#)
-

This demonstration illustrates the relationship between the charge on the two balls and the separation between them, Use [this worksheet](#) to work out this relationship by considering the balance of the forces acting on the charged balls.

- [Wolfram Demonstrations Project: "Van de Graaff Generator"URL](#)
-

This demonstration illustrates how a Van de Graaff generator generates static charges and collects the charges on a metal sphere. The voltage on the sphere is proportional to the amount of charge collected. Though it appears that the collected charge on the sphere would increase indefinitely, in reality, paths for loss of the collected charge exist and typically limit the static voltage on the sphere to a fraction of a megavolt, although Van de Graaff generators specialized for use in nuclear accelerators can generate 10 megavolts or more.

- **2.2: Electric Field and Gauss' Law**

-  [Fullerton College: Benjamin Crowell's "Light and Matter, Chapter 22: The Nonmechanical Universe"URL](#)

Please read the sections one, two and three of "Chapter 22: The Nonmechanical Universe" carefully (PDF pages 618-630). Answer the Self-Check questions in the text (answers on page 1010). Think about the Discussion Questions and Examples, and work out the problems ##1 – 7 and #10 on pages 644-645. You can check some of your answers [here](#).

- [Khan Academy: "Electric Field"Page](#)

Please watch all three videos in this lecture series, pausing to take notes, before moving on to the reading below.

- [Yale University: Ramamurti Shankar's "PHYS201: Gauss' Law and Applications to Conductors and Insulators"URL](#)

Watch this lecture, pausing to take notes, before moving on to the reading below. Please test your understanding of the lecture by attempting the ten problems in [this problem set](#). Solutions may be found [here](#).

-  [Fullerton College: Benjamin Crowell's "Light and Matter, Chapter 22: The Nonmechanical Universe"URL](#)

Please read sections seven and eight of "Chapter 22: The Nonmechanical Universe" on pages 638-641. Answer the Self-Check questions in the text (answers on page 1010). Think about the Discussion Questions and Examples

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Gauss' Law"URL](#)

Please read this chapter after viewing the lectures above. Try the worked example 4.1 before looking at the solutions. Make sure you understand not only the solutions but how to approach solving the problem so that you can obtain the solution yourself. You will be responsible for being able to solve problems of this type on the final exam.

- [Wolfram Demonstrations Project: "Motion of a Charge in an Electric Field"URL](#)

This demonstration illustrates the effect that a uniform electric field has on the motion of an electric charge. Why do the charges follow a parabolic path? Think of an analogy that describes the effects of gravity on a projectile.

- **2.3: Electric Potential and Electric Potential Energy**

- [Khan Academy: "Electric Potential Energy, Electric Potential and Voltage"Page](#)

Please watch this lecture, pausing to take notes, before moving on to the reading below.

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Electric Potential"URL](#)
-

Please click on the link above, and read this chapter after viewing the lectures above. Try all four worked examples before looking at the solutions. Make sure you understand not only the solutions but also how to approach solving the problem so that you can obtain the solution yourself. You will be responsible for being able to solve problems of this type on the final exam.

- [Wolfram Demonstrations Project: "Electric Dipole Potential"URL](#)
-

This demonstration illustrates what you would find in a lab experiment where two electrically charged bodies are placed on a table, and you measure the electric potential (roughly speaking, the voltage relative to a reference point) as a function of position on the table. The electric potential is displayed as a series of equipotential curves, or curves along which the electric potential is constant. Vary the position and strength of the charges, and then view the results with both the 3D and the contour plot. Turn on the field direction, and notice that the electric field is everywhere perpendicular to the equipotential curves. This is because the electric field is proportional to the gradient of the electric potential.

- [Wolfram Demonstrations Project: "Lines of Force for Two Point Charges"URL](#)
-

This demonstration is an extension of the previous demonstration on Electric Dipole Potential. Shown here again is an electrostatic dipole where the strengths of the electric charges can be varied. The graph shows the lines of electric field. The lines of electric field are everywhere perpendicular to the equipotential curves. Note that this does not mean that the MAGNITUDE of the electric field is constant along an electric field line; it only means that the magnitude of the electric field points along that line. Vary the positions and magnitude of the two charges to gain some feel for how the electric field behaves. The calculations required by the demonstration are complex, so wait between changes for the graph to once again become smooth.

- **2.4: Capacitors and Capacitance – Storage of Electric Energy**

- [Khan Academy: "Circuits with Capacitors"Page](#)
-

Please watch this lecture series, pausing to take notes, before moving on to the reading below.

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Capacitance"URL](#)
-

Please read this chapter. There are 4 worked examples in the chapter. Try each of these problems before looking at the solutions. Make sure you understand not only the solutions but how to approach solving the problems so that you can obtain the solutions yourself. You will be responsible for being able to solve problems of this type on the final exam.

o [Wolfram Demonstrations Project: "Parallel-Plate Capacitors"URL](#)

This demonstration can be treated as a combination laboratory project and homework problem. The capacitance of a parallel plate capacitor depends on the area and separation of the plates and the dielectric constant of the material between them. In this demonstration, you will control the geometry and materials of the capacitor, and you will measure the charge resident on the capacitor as a function of applied voltage. First, keep the voltage fixed, and set the values for the area of the plates, plate separation, and the dielectric constant. Calculate the capacitance using the formula given in the demonstration or the reading resources, and confirm that you get the same result as the program (pay attention to the units of all physical quantities!) Then, use the values of the voltage and the capacitance to calculate the charge on the capacitor. Again, confirm that your result is the same as that in the demonstration.

o [Wolfram Demonstrations Project: "Partially Filled Capacitors"URL](#)

This demonstration, again, can be used as an interactive homework problem. A partially-filled capacitor can be viewed as a pair of capacitors, one filled and the other unfilled. (Note that this is only true for geometries where the dielectric interface is approximately on an equipotential surface, as nothing then changes when the extra pair of metal plates is inserted. This same technique could be used on a partially-filled cylindrical or spherical capacitor, for example, provided the dielectric surface was cylindrical or spherical, respectively.) Use the formula for the capacitance in terms of the area of the plates, distance between the plates, and the dielectric constant to write down the capacitance of the "filled" and "empty" capacitors. Notice that the distance between the plates of each capacitor depends on the percentage k of the dielectric material, as shown in the demonstration. Then, use the formula for the equivalent capacitance of the two capacitors connected in series to derive the result in the "Details" section of the demonstration. The values of A and d is fixed and given in the "Details" section of the demonstration. You can select a value of k and a dielectric material (you will have to look up the value of the dielectric constant), and calculate the capacitance of the partially filled capacitor. Again, confirm that your result agrees with the demonstration.

o [Wolfram Demonstrations Project: "Electric Field Energy in Capacitors"URL](#)

This demonstration provides examples for both capacitors and inductors, but for now, work only with the capacitors. Treat this demonstration as a laboratory

experiment in which you measure the capacitance of various geometries and use theory to confirm that the capacitances are correct. Then, determine the electromagnetic field energy driven by applied voltage from the demonstration. First, calculate the charge on the capacitor's plates, and resultant electric field between the plates. Use the formulas given in the description in the demonstration, or the readings above, and confirm your result. Then, calculate the electric energy stored in the capacitor, and the electric energy density. Again, confirm your result.

Unit 3: Electronic Circuit Theory

Although the study of electric and magnetic fields is interesting in and of itself, it may not seem directly useful in the real world. However, the interplay between these phenomena is responsible for much of the technology you see in your everyday life. For example, all electronics apply various features of electromagnetism, so that computers, HDTV, iMacs and iPads, smartphones, motors, fans, lights, and so on are applied electromagnetic devices. In this unit, we will take a quick look at the foundations of electronics, while at the same time adding to our understanding of electromagnetism.

Completing this unit should take you approximately 8 hours.

- Upon successful completion of this unit, you will be able to:
 - state Ohm's law in words;
 - apply Ohm's law to simple circuits;
 - calculate effective resistance of a network of resistors;
 - determine the resistance of a cylindrical wire;
 - compare and contrast voltage and current;
 - use the junction and loop rules to analyze basic circuits;
 - explain how a battery works; and
 - calculate the power in a DC circuit.

• 3.1: Electric Current, Voltage and Resistance

- [Khan Academy: "Introduction to Circuits and Ohm's Law", "Resistors in Series", and "Resistors in Parallel"Page](#)

Please watch these three lectures, pausing to take notes, before moving on to the reading below.

-  [Fullerton College: Benjamin Crowell's "Light and Matter, Chapter 21: Electricity and Circuits"URL](#)

Please read the sections three through eight of "Chapter 21: Electricity and Circuits" carefully (PDF pages 566-608). Complete the Self Checks throughout the chapter (answers on page 981). Think about the Discussion Questions and Examples, and work out the problems ##10 – 12, ##16 – 17, and ##24 – 38. You can check some of the answers [here](#).

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Electric Current"URL](#)

Please read these sections: "Electric Circuits," "Ohm's Law," "Resistance and Resistivity," "EMF and Internal Resistance," and "Resistors in Series and in Parallel." Try worked Examples 7.1 and 7.2 before looking at the solution. Make sure you understand not only the solutions but how to approach solving the problems so that you can obtain the solutions yourself. You will be responsible for being able to solve problems of this type on the Final Exam.

- [Wolfram Demonstrations Project: "Resistors in Series"URL](#)

Treat this demonstration as a laboratory experiment. Measure voltage, resistance, and current levels for a variety of conditions, and use Ohm's Law to explain the results. Think how the equivalent resistance of the circuit is compared to that of individual resistors' (less or greater?) and how this affects the resultant current.

- [Wolfram Demonstrations Project: "Resistors in Parallel"URL](#)

Treat this demonstration as a laboratory experiment. Measure voltage, resistance, and current levels for a variety of conditions, and use Ohm's Law to explain the results. Think how the equivalent resistance of the circuit is compared to that of individual resistors' (less or greater?) and how this affects the resultant current. Which connection – series or parallel – should be used to produce maximum possible current?

- **3.2: Electric Circuits**

- [Khan Academy: "Analyzing a More Complex Resistor Circuit", "Resistivity and Conductivity", and "Ammeter and Voltmeter"Page](#)

Please watch these lectures, pausing to take notes, before moving on to the reading below.

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Electric Current"URL](#)

Please read these sections: "Kirchhoff's Rules," "Capacitors in DC Circuits," "Energy in DC Circuits," and "Power and Internal Resistance." Try worked examples 7.3 and 7.4 before looking at the solution. Make sure you understand not only the solutions but also how to approach solving the problems so that you can obtain the solutions yourself. You will be responsible for being able to solve problems of this type on the Final Exam.

- [Wolfram Demonstrations Project: "Effective Resistance"URL](#)
-

Treat this demonstration as a laboratory project in which you calculate the resistance expected for a given network before "measuring" the actual resistance using the demonstration. Use [this worksheet](#) as a guide to derive the general formula for the equivalent resistance of the given network.

o [Wolfram Demonstrations Project: "Galvanometer as a DC Multimeter"URL](#)

This demonstration illustrates how a current indicating meter (the galvanometer) can be used in simple circuits to measure voltage, current, or resistance over a wide range of values. Despite the text appended to the demonstration, there is no way to vary the circuit elements of the multimeter, and we are not supplied with the actual values used in the demonstration. However, the three selectable modes of operation all make simple application of Ohm's Law, so see if you can understand the operation of the multimeter based on Ohm's Law and the indicated circuits.

Unit 4: Magnetism

Earlier, we studied electric charges, potentials, and fields. We will now take a look at an important effect of moving charges: magnetism. Thales of Miletus set the stage for the scientific exploration of magnetism back in Ancient Greek times, when magnetism could only be observed via the behavior of natural magnets, called lodestones. Hans Christian Oersted first noted the relationship between moving electric charges and magnetism much later, when he accidentally discovered that an electric current could deflect a nearby compass needle in 1820. Forty-five years after Oersted made this observation, James Clerk Maxwell united electrical and magnetic phenomena into four reasonably simple equations known since as Maxwell's Equations.

Completing this unit should take you approximately 7 hours.

- Upon successful completion of this unit, you will be able to:
 - describe the magnetic field associated with a moving charge, a magnetic dipole, a long, straight current-carrying wire, a wire loop, and a solenoid;
 - find the force exerted by a magnetic field on a moving charged particle;
 - explain the fundamental difference between a magnetic and a non-magnetic material;
 - state Ampere's law;
 - solve problems involving the motion of a charged particle in a magnetic field; and
 - solve problems using Ampere's law.

4.1: Magnetic Field

o [OpenStax College: "College Physics"URL](#)

Read sections 22.1, 22.2, and 22.3. Think about the corresponding conceptual questions on the to assess your understanding of the sections.

- [Wolfram Demonstrations Project: "Observing Magnetic Fields with Iron Filings"URL](#)

This demonstration is designed to remind you of one of the most common elementary school demonstrations of magnetism, where fine iron filings decorate the lines of magnetic force, showing, as in the demonstration, the dipole-like magnetic field of a permanent magnet. If we place a ferromagnetic material, such as iron, in a magnetic field, it will induce a magnetic field in the iron that opposes the external field. As usual, one of Nature's rules is to arrange matters so that the total energy of the system is as small as possible. In this case, inducing an opposing field in the iron reduces the total magnetic energy. Because iron filings tend to be long and skinny, the induced field turns them into tiny bar magnets, with north and south poles aligned such that the north pole of the iron filing points along the local direction of the magnetic field and orients away from the north pole of the external magnet. Accordingly, when you place a few hundred iron filings on a surface over a magnet, you are able to visualize the magnetic lines of force.

- **4.2: Magnetic Force on Moving Electric Charges**

- [Khan Academy: "Magnets and Magnetic Force"Page](#)

Please watch this lecture series, pausing to take notes, before moving on to the reading below. Notice that since the force on a charge in a magnetic field is related to the cross-product of the charge's velocity and the field vector, two of the lectures are devoted to the review of the definition and calculation of the cross-product of two vectors.

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Magnetism"URL](#)

Please click on the link above, select the links to the following subsections, and read these webpages in their entirety: "The Lorentz Force," "Charged Particle in a Magnetic Field," and "The Hall Effect." In addition, select the links for Examples 8.1 and 8.2, and work through these examples before looking at the solutions in the text. Make sure you understand not only the solutions but also how to approach solving the problem so that you can obtain the solution yourself. You will be responsible for being able to solve problems of this type on the final exam.

- [Wolfram Demonstrations Project: "Motion of a Charge in a Magnetic Field"URL](#)

This is an idealized version of a classic laboratory experiment carried out with a cathode-ray tube. In this demonstration, you can see the entire path of the moving charge, rather than just its position at a screen (as you would with a cathode-ray tube). The initial velocity and magnetic field vectors are indicated, allowing you to determine the direction and strength of the Lorentz force on the

moving charge. This demonstration does not provide any measurements of the trajectory of the charge, but you can observe how it changes qualitatively with the change of the parameters. As usual, change each parameter in turn while keeping the others constant, in order to make conclusions. What affects the radius of the spiral path? Compare your observation with the theoretical results in the reading resources. How does the angle between the magnetic field vector and initial velocity affect the shape of the spiral? What happens if their direction is the same, and how can this be explain using the Lorenz's force formula?

- [Wolfram Demonstrations Project: "Motion of a Charge in Electric and Magnetic Fields"URL](#)

This demonstration shows the motion of an electric charge in uniform electric and magnetic fields. The charge, E field, and B field magnitudes are all controllable, as are the field orientations and the initial velocity vector of the charge. Note that for nearly all combinations of parameters, the result is that the charge spirals toward a position, comes to a stop save for circular motion, and then reflects back in roughly the original direction. Why?

- **4.3: Magnetic Field of a Current-Carrying Wire**

- [Khan Academy: "Magnetic Field Created by a Current"Page](#)

Please watch this lecture series, pausing to take notes, before moving on to the reading below.

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Magnetism"URL](#)

Read these sections: "Ampere Experiments", "Ampere's Law", "Ampère's Circuital Law," "Magnetic Field of a Solenoid," and "Gauss' Law for Magnetic Fields." In addition, click on the link to Example 8.3, and work through this example before looking at the solution. Make sure you understand not only the solution but also how to approach solving the problem so that you can obtain the solution yourself. You will be responsible for being able to solve problems of this type on the final exam.

- [Wolfram Demonstrations Project: "Magnetic Field of an Electric Current"URL](#)

This is a simulation of another classic classroom demonstration, in which you trace out the magnetic lines of force surrounding a current-carrying wire. The lines of magnetic force are circles surrounding the wire, and the direction of the magnetic field reverses when the current reverses. Practice using the right-hand rule to determine the direction of the magnetic field, and make sure you get the same result as in the demonstration.

- [Wolfram Demonstrations Project: "Magnetic Field of a Current Loop"URL](#)
-

This demonstration illustrates the magnetic field surrounding a current loop. The magnetic field has a cylindrical axis of symmetry on the axis of the current loop.

- **4.4: Magnetic Materials**

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Magnetism"URL](#)

Please read this section: "Origin of Permanent Magnetism."

- [Wolfram Demonstrations Project: "Magnetization"URL](#)

This demonstration illustrates the process of magnetization of a magnetic material in an external field. As the magnetic domains (small bar magnets) become more highly aligned, the magnetic field produced by the material increases. Note that when all (or most) domains are aligned, the material cannot become more highly magnetized. This is the phenomenon of magnetic saturation.

Unit 5: Electromagnetic Induction

You learned that stationary electric charges produce electric field, and moving electric charges (that is, electric current) produce magnetic field. In this unit, you will find out that the reverse is also true: changing magnetic flux produces electric field, or induces electric current. This is the phenomenon of the electromagnetic induction, which is a basic principles in such devices as generators of electric power, electric motors, and transformers.

Completing this unit should take you approximately 13 hours.

- Upon successful completion of this unit, you will be able to:
 - state Faraday's and Lenz's laws;
 - solve problems using Faraday's law;
 - define inductance and explain how it affects the change of current in a circuit;
 - analyze RC, RL, and RCL circuits; and
 - compare and contrast electromagnetic generators and motors.

- **5.1: Faraday's Law**

- [Yale University: Ramamurti Shankar's "PHYS201: Lenz's and Faraday's Laws"URL](#)

Watch this lecture, pausing to take notes, before moving on to the reading below. Please test your understanding of this lecture by attempting the problems #3, #11 and #12 from this [problem set](#). Check your solutions [here](#).

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Magnetic Induction"URL](#)

Read the following sections: "Faraday's Law," "Lenz's Law," "Magnetic Induction," "Motional EMF," and "Eddy Currents." Also, work through Examples 9.1-9.3 before looking at the solutions. Make sure you understand not only the solutions but also how to approach solving the problems so that you can obtain the solutions yourself. You will be responsible for being able to solve problems of this type on the final exam.

o [Wolfram Demonstrations Project: "Magnetic Flux through a Wire Loop"URL](#)

This demonstration illustrates the relationship between magnetic flux and size and orientation of the surface through which the magnetic field is passing. Note that the relationship is particularly easy to observe when constant magnetic fields parallel to the field lines can be seen. Here, a constant flux is simply a constant number of field lines penetrating the wire loop. Although the relationship is more difficult to observe when variable magnetic fields are used in the demonstration, the relationship is still the same: magnetic flux is the number of field lines penetrating the wire loop. Pick a value for the radius of the loop and calculate the magnetic flux through the loop in the two cases when the field is uniform: (0,0, 1) and (1, 1, 1), Do your results agree with the demonstration?

o [Wolfram Demonstrations Project: "Magnetic Braking via Eddy Currents"URL](#)

Many machines use magnetic brakes from the small to the gigantic. The analysis of the effect is simple in some ways and quite tricky in others. There are two ways of looking at magnetic braking, both of which are mentioned in the demonstration write-up. The basic idea is that when a conductor moves through a magnetic field, currents are induced that resist the motion. These are called Eddy currents, and the reduction in the kinetic energy of the conductor is equal to the resistive heating caused in the conductor by the induced Eddy currents. Another approach to explaining magnetic braking is that the Lorentz force acting on the electrons in the moving conductor acts to move the electrons outward, and the Lorentz force associated with that outward motion in the applied magnetic field serves to slow down the moving conductor. These two ways of thinking about magnetic braking are equivalent; that is, they make the same predictions. A couple of questions for reflection: If the conductor is a perfect conductor (no resistance, but not a superconductor), is there any braking effect? Also, can a magnetic brake by itself bring a moving conductor to a complete stop? Why, or why not?

o [Wolfram Demonstrations Project: "EMF Induced in a Wire Loop"URL](#)

Use [this worksheet](#) as a guide to explore the demonstration.

o [Wolfram Demonstrations Project: "Electromagnetic Ring Toss"URL](#)

This demonstration is modeled after a classic classroom demonstration. A conducting ring is placed atop an electromagnet, and a large pulse of current passes through the electromagnet. As seen in the lectures, readings, and

demonstrations above, a current is induced in the conducting ring in a direction that opposes the formation of the magnetic field. As usual, this is to minimize the total energy of the system. The result is that the current in the ring generates a magnetic field with the opposite sign as that of the electromagnet. Opposed magnetic fields repel, so the ring launches into the air. Why does nothing happen when we use the split ring?

- **5.2: Inductance**

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Inductance"URL](#)

Read these sections: "Mutual Inductance," "Self-Inductance," and "Energy Stored in an Inductor." Work through the Examples 10.1 and 10.2 before looking at the solutions. Make sure you understand not only the solutions but also how to approach solving the problems so that you can obtain the solutions yourself. You will be responsible for being able to solve problems of this type on the final exam.

- [Wolfram Demonstrations Project: "Magnetic Field Energy in Inductors"URL](#)

This demonstration provides examples for both capacitors and inductors, but work only with the inductors for now. Treat this demonstration as a laboratory experiment in which you measure the inductance of various geometries and confirm from theory that the values are correct. Get the electromagnetic field energy generated by applied current from the demonstration, and confirm them by direct calculation based on the theoretical relations listed here and in the lectures and readings above. First, calculate the inductance of the coil, using the formula given in the description in the demonstration, or the readings above. Then, calculate current through the inductor using Ohm's Law, and magnetic field created by this current. Finally, calculate the magnetic energy stored in the inductor, and the magnetic energy density. Again, confirm your result.

You can also explore this demonstration conceptually, to get a feel for how the magnetic field inside the coil and magnetic energy density are affected by the geometry of the inductor, resistance, and applied voltage. Vary each of the parameters in turn and observe the changes in B and ρ . Why does not the magnetic field depend on the radius of the coil?

- **5.3: RC, RL and RCL Circuits**

-  [Fullerton College: Benjamin Crowell's "Light and Matter, Chapter 25: Capacitance and Inductance"URL](#)

Read this chapter carefully (on pages 713-727). Answer the Self-Check questions in the text (answers on page 1011). Think about the Discussion Questions and Examples, and work out problems #1-8 on the page 729.

- [Wolfram Demonstrations Project: "Series RLC circuits"URL](#)

This demonstration shows the graphs of the voltage and current in the circuit containing a resistor, and inductor, and a capacitor connected in series, driven by the alternating voltage. The frequency of the alternating voltage supplied by the battery will determine the phase shift φ between the voltage and the current. Pick the values of the parameters and calculate the phase shift using the formula in the demonstration. Then, try to vary the frequency until you make the phase shift 0 (this might be difficult to accomplish, but try to make it as small as you can), and confirm that this frequency is close to the resonant frequency of the circuit.

- **5.4: Electromagnetic Generators and Motors**

- [Khan Academy: "Electric Motors"Page](#)
-

Watch this lecture series, pausing to take notes, before moving on to the reading below.

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Magnetic Induction"URL](#)
-

Read the following sections: "The Alternating Current Generator," "The Direct Current Generator," "The Alternating Current Motor," and "The Direct Current Motor." Work through Examples 9.4 and 9.5 before looking at the solutions. Make sure you understand not only the solutions but also how to approach solving the problems so that you can obtain the solutions yourself. You will be responsible for being able to solve problems of this type on the final exam.

- [Wolfram Demonstrations Project: "Barlow's Wheel - A Primitive Electric Motor"URL](#)
-

This is a demonstration of one of the simplest electromagnetic motors ever invented. Before looking it up, figure out just how it works. (Hint: Lorentz force.)

- [Wolfram Demonstrations Project: "Faraday Disk Generator"URL](#)
-

The Faraday Disk is a simple electric generator. Before looking it up, figure out how it works.

Unit 6: Maxwell's Equations

At this point in the course, we have developed the mathematical structure for and a general understanding of all of Maxwell's Equations. Now we want to sit back and summarize our findings by identifying what they are, what they mean, and how we can use them.

There are four Maxwell equations that describe all classical electromagnetism. Maxwell's equations take on a particularly simple form when describing the behavior of electric and magnetic fields in regions devoid of matter; that is, in a vacuum. (Note that for most purposes, air is close enough to being a vacuum that the presence of an atmosphere can be ignored.) These are Maxwell's free space equations.

There are four Maxwell free space equations. These include the two flux equations - the electric and magnetic forms of Gauss' law. These state that the electric or magnetic flux through a closed surface is proportional to the electric or magnetic charge enclosed within that surface. Note that in the magnetic case, there are no magnetic charges (also called magnetic monopoles), so that the magnetic flux through and closed surface is zero.

The other two free space Maxwell's equations are Faraday's Law of Induction and a modified version of Ampere's Circuital Law. Once again, these electric and magnetic equations have similar formalisms, thereby emphasizing the close relationship of the electric and magnetic fields. Faraday's Law of Induction states that the induced EMF in any closed circuit is proportional to the time rate of change of the magnetic flux through the circuit, while Ampere's Law states that the integrated magnetic field around a closed curve is proportional to the currents passing through a surface bounded by the curve. Maxwell's main contribution (beyond realizing that these four equations provided a complete theory of electromagnetism) was the discovery and description of the displacement current, which is a source of the magnetic field associated with the rate of change of the electric displacement field in a region.

Inside materials, Maxwell's Equations are modified by the electric permittivity and magnetic permeability of the materials, but they remain the basis for the classical model of electromagnetism. In this unit, we will concentrate on Maxwell's Equations as a single theory that unites the half-century of previous work on electromagnetism.

Completing this unit should take you approximately 8 hours.

- Upon successful completion of this unit, you will be able to:
 - state Maxwell's equations and identify each mathematical operator and physical quantity in the equations;
 - state in words the information contained in each of Maxwell's equations;
 - describe how Maxwell's equations resulted in the prediction of electromagnetic waves and the realization that light was an electromagnetic wave;
 - list several examples of electromagnetic phenomena; and
 - solve problems involving properties of electromagnetic waves.

- **6.1: Maxwell's Equations**

-  [Dr. Glen Dash's "A Dash of Maxwell's, Chapter 1: Introduction"URL](#)

Most of this chapter reviews Maxwell's time-independent equations but often from a different viewpoint that acts synergistically with our previously covered material. Take particular note of the definition on page 7 of the electric flux density vector $\mathbf{D} = \epsilon \mathbf{E}$, where \mathbf{E} is the electric field vector and ϵ is the dielectric constant times the free space permittivity ϵ_0 . Similarly, on page 12 the magnetic flux density vector $\mathbf{B} = \mu \mathbf{H}$, where \mathbf{H} is the magnetic field vector and μ is the magnetic permeability, sometimes described as the relative permeability times the

permeability of free space. For this class, these equations that allow the use of Maxwell's Equations in a material are assumed to be scalar functions of position. The general case is that they are tensors, but the scalar approximation simplifies gaining an initial understanding of the behavior of electromagnetism systems. Work through the examples until you understand how to approach solving similar problems.

- [Wolfram Demonstrations Project: "Maxwell's Displacement Current"URL](#)
-

This is an illustrative explanation of displacement current, which is arguably the linchpin of Maxwell's full theory of electromagnetism, as well as the single most confusing concept in that theory.

There is no electric current between the plates of a capacitor. However, Ampere's Circuital Law tells us that the integral of the magnetic field B around a closed loop C is proportional to the flux of the current density through a surface S attached to the loop. This is independent of the shape of S . In the demonstration, consider a closed loop positioned around one of the wires carrying electric current into the charging capacitor. If S is chosen so that the wire penetrates the surface, the flux of the current density through S is simply the electric current.

Now draw another surface S' so that it passes between the capacitor plates, thereby making no contact with the current carrying wire. There is no electric current between the capacitor plates, so it would appear that the flux of the current density through S' is zero. However, Ampere's Circuital Law tells us that the magnetic field integral around loop C is still the same non-zero value. We appear to meet a contradiction.

What the apparent contradiction is actually telling us is that Ampere's Circuital Law is incomplete. The electric field between the plates of a charging capacitor changes with time, so it would appear that a time-varying electric field must generate a magnetic field which is consistent with the current charging the capacitor. The way Maxwell chose to think about this by identifying a fictitious current between the capacitor plates called the displacement current such that the total displacement current flux between the plates was equal to the current charging the capacitor. Although there is no actual electrical current between the plates, we still refer to the source of magnetic field associated with a changing electric field as the displacement current.

• 6.2: Electromagnetic Waves

- [Yale University: Ramamurti Shankar's "PHYS201: Maxwell Equations and Electromagnetic Waves I"URL](#)
-

Watch this lecture, pausing to take notes, before moving on to the reading below. Please test your understanding of this lecture by attempting the problem #6 from this [problem set](#). Check your solution [here](#).

-  [Dr. Glen Dash's "A Dash of Maxwell's, Chapter 2: Why Things Radiate"URL](#)

This chapter develops the time-varying version of Maxwell's Equations and uses them to examine not only the properties of EM radiation, but also why anything emits this radiation in the first place. Again, stick with the math until you can see the physics.

- [Wolfram Demonstrations Project: "Propagation of a Plane EM Wave"URL](#)

This demonstration schematically indicates the time-dependent electric and magnetic fields associated with an electromagnetic wave. Note that the electric and magnetic fields are mutually perpendicular to one another and to the path the wave follows.

As the electric field changes in time, a magnetic field is generated as described by Maxwell's generalization of Ampere's Circuital Law. As the magnetic field changes in time, an electric field is produced as described by Faraday's Law of Induction. Given this word picture, why are the electric field strength and the maximum magnetic field strength proportional at all times? Which direction does the wave velocity point, toward positive or negative x? (Hint: Look at Poynting's Theorem.)

- [Wolfram Demonstrations Project: "Measuring the Speed of Light with Marshmallows and a Microwave Oven"URL](#)

Try this experiment using your microwave oven. Why do the melted spots appear in a regular pattern?

- **6.3: Energy and Intensity of Electromagnetic Waves**

- [Yale University: Ramamurti Shankar's "PHYS201: Maxwell Equations and Electromagnetic Waves II"URL](#)

Watch this lecture, pausing to take notes, before moving on to the reading below. Please test your understanding of this lecture by attempting the five problems in this [problem set](#). Check your solutions [here](#).

- **6.4: Spectrum of Electromagnetic Radiation**

- [OpenStax College: "College Physics"URL](#)

Read chapter 24, "Electromagnetic Waves". Think about the accompanying conceptual questions to assess your understanding of the chapter.

Unit 7: Optics

An optical phenomenon involves the interaction between electromagnetic waves and matter. We will focus on visible, infrared, and ultraviolet light, but much of the study of optics will apply to some extent to radio waves and x-rays. The complete study of optics involves enormously complex mathematics, a thorough understanding of both classical and quantum optical effects, and a great deal of ingenuity for success.

For the purposes of this course, optics will be limited to the classical description of electromagnetism provided by Maxwell's equations: the full wave optics. Even this level of description is quite complicated for most optical phenomena, so we will apply simplified models to develop a basic understanding of how optics works. In geometric optics, we assume that all light travels in straight lines. In paraxial optics, we assume that all optical systems handle light rays near a symmetry axis of the optical system, which allows us to largely ignore aberration, a vast array of terribly complex optical effects.

Completing this unit should take you approximately 11 hours.

- Upon successful completion of this unit, you will be able to:
 - determine the size, location, and nature of images by using the mirror and lens equations;
 - solve problems using the law of refraction;
 - describe the interference pattern in a double-slit experiment and explain experiment's results; and
 - explain how rainbows are produced.

- **7.1: Geometric Optics**

-  [Fullerton College: Benjamin Crowell's "Light and Matter, Chapter 28: The Ray Model of Light"URL](#)

Read sections one through four of "Chapter 28: The Ray Model Of Light" (pages 814-826), which will serve as an introduction to the following the Khan Academy lecture series on the phenomena of reflection and refraction. Answer the Self-Check question in the text (answer on page 1012). Think about the Discussion Questions and Examples, and work out the six problems on the page 829-830.

- [Khan Academy: "Reflection and Refraction"Page](#)

Watch this lecture series, pausing to take notes, before moving on to the reading below.

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Geometric Optics"URL](#)

Read these sections. Select the links for Examples 12.1 and 12.2, and work through these examples before looking at the solutions. Make sure you understand not only the solutions but how to approach solving the problems so that you can obtain the solutions yourself. Make sure you understand not only the solutions but how to approach solving the problems so that you can obtain the solutions yourself. You will be responsible for being able to solve problems of this type on the Final Exam.

- [Wolfram Demonstrations Project: "Specular and Diffuse Reflection"URL](#)
-

This demonstration illustrates the difference between specular reflection (like a mirror) and diffuse reflection (like a piece of paper). There is a continuum of behaviors between specular and diffuse reflection, and these are well-illustrated in this demonstration. Note that the key is not the amount of incident light reflected, but rather the extent to which information about the original direction of the light is lost in the reflection. The demonstration may run slowly on older computers.

- [Wolfram Demonstrations Project: "Snell's Law of Refraction"URL](#)
-

This demonstration illustrates the way in which light bends at an interface between the two media. Use [this worksheet](#) as a guide when exploring this demonstration.

- [Wolfram Demonstrations Project: "Total Internal Reflection"URL](#)
-

When a light ray is within a medium having a refractive index n_1 and is incident on an interface between that medium and a second medium having a smaller refractive index n_2 , Snell's Law tells you that the angle at which the light is refracted in the second medium is given by $\sin \theta_2 = (n_1/n_2) \sin \theta_1$.

What happens if $(n_1/n_2) \sin \theta_1$ is greater than 1? Because $\sin \theta_2$ cannot be greater than 1, the light ray cannot be refracted into the second medium. As a result, the ray is reflected from the interface. The reflection is total (neglecting possible processes of absorption which might occur right at the interface, such as in dye molecules or the like), because there is no mechanism whereby any of the light can penetrate into the second medium. (This is actually only the case for infinitely thick media, as light can penetrate a distance related to the skin depth. However, for most practical purposes the reflection is complete.)

Total internal reflection is unlike reflection from a metallized mirror, in which the metal absorbs some of the light incident on the surface. This difference explains why the reflecting face of a prism is usually left unmetallized whenever that is consistent with its optical function; more light passes through the optical system than does when a mirror is used.

- [Wolfram Demonstrations Project: "Rainbows"URL](#)
-

The color of a rainbow results from variable dispersion of different wavelengths of light, but this demonstration goes further in illustrating why the rainbow appears in a circular bow in the sky.

• 7.2: Paraxial Optics

- [Khan Academy: "Mirrors and Lenses"Page](#)
-

Watch this lecture series, pausing to take notes, before moving on to the reading below.

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Paraxial Optics"URL](#)

Read each section. Select the links for Examples 13.1 through 13.4, and work through examples before looking at the solutions. Make sure you understand not only the solutions but how to approach solving the problems so that you can obtain the solutions yourself. Make sure you understand not only the solutions but how to approach solving the problems so that you can obtain the solutions yourself. You will be responsible for being able to solve problems of this type on the Final Exam.

- [Wolfram Demonstrations Project: "Ray Diagrams for Lenses"URL](#)

This demonstration illustrates the dynamics between focal length, object distance, and real/virtual focal points of a simple lens. Explore this demonstration for both convergent and divergent lenses. Drag the object closer to the lens and observe how the magnification changes with distance. Pay attention to the path of the rays. Notice that for the convergent lens, at some point the image changes from real to virtual. How far is the object from the lens at this point? Change the height of the object and repeat the procedure. Does the same thing happen again?

- **7.3: Wave Optics**

- [University of Texas: Richard Fitzpatrick's "Electromagnetism and Optics: Wave Optics"URL](#)

Read the "Introduction," "Huygens' Principle," and "Young's Double-Split Experiment" sections. Select the links to Example 14.1 , and work through the example before looking at the solution. Make sure you understand not only the solution but how to approach solving the problem so that you can obtain the solution yourself. You will be responsible for being able to solve problems of this type on the final exam.

- [Khan Academy: "Interference of Light Waves"Page](#)

Watch this lecture series, pausing to take notes.

- [Wolfram Demonstrations Project: "Two-Slit Constructive and Destructive Interference"URL](#)

Interference is a nearly ubiquitous effect in wave optics. This demonstration illustrates how light waves interfere both constructively and destructively. The electric vector of the electromagnetic radiation is shown waves moving from the slits. When you examine the diffraction image, the points of constructive interference (where the two electric fields add) appear red, while the points of destructive interference (where the two electric fields cancel) appear white.

Unit 8: Special Relativity

The physical descriptions we have studied to this point were based on a notion of absolute space and time. A model for this point of view was that space is filled everywhere by a continuous medium called the ether. Light and other forms of electromagnetic radiation were waves in this ether, analogous to sound waves in air. All other phenomena were to be understood as various manifestations of Maxwell's electromagnetism, which was originally based on a mechanical model of ether. It seemed reasonable that the 19th Century 'theory of everything' could be tied down by measuring the 'elastic' properties of the ether.

Toward the end of the 1800s, however, this model became associated with more and more hastily patched cracks. The detailed history of the gradual realization that ether models were not quite right is complex and technical. However, there is one rather clear indication of trouble. In 1887, Albert Michelson and Edmund Morley of the Case Institute (now Case Western University) performed an experiment using an optical interferometer in which they compared the speed of light in two beams traveling at right angles to each other. If the speed of light relative to the ether was always the same, the measured speed of light would be larger or smaller depending on the direction the experiment was traveling through the ether. The motion of the Michelson-Morley experiment was provided by the rotation of the Earth on its axis and the orbital motion of the Earth around the Sun, as well as the absolute velocity (if any) of the Sun relative to the ether.

They expected to see both diurnal changes and yearly changes in the relative velocities of light in the two paths. True, the changes expected by classical ether theory were small (on the order of 0.01% of the velocity of light), but the Michelson-Morley interferometer was able to detect velocity changes about 6-7 times smaller. To the surprise of all, there were no changes whatever observed. This experiment was widely repeated, using constantly improving equipment - a new version of the experiment carried out in 2002 established that the velocity of light is constant to better than 1 part in 10¹⁵ - one of the most precise physical measurements ever accomplished.

The explanation of the Michelson-Morley null result was length contraction, as developed by Hendrik Lorentz and George Francis FitzGerald. Length contraction explained the Michelson-Morley result, the idea being that matter is held together by electromagnetic forces (true), and so the actual size of objects will change with motion through the ether (false). In the end, it was Albert Einstein's formulation of the theory of Special Relativity that gave us a consistent explanation of all such phenomena. His primary postulate was to accept that the speed of light and the laws of physics are constant in all reference frames – including reference frames that are in motion. Oddly, despite the fact that Einstein's theory completely explained the Michelson-Morley result, he took no motivation for his theory from that experiment.

Completing this unit should take you approximately 10 hours.

- Upon successful completion of this unit, you will be able to:
 - identify the postulates upon which the Special Theory of Relativity is based;

- solve problems involving time dilation and length contraction;
- explain the principle of equivalence as introduced in the General Theory of Relativity;
- compare and contrast the special and general theories of relativity;
- list the most significant consequences of Einstein's special and general theories of relativity; and
- explain the results of the Michelson-Morley experiment using the Special Theory of Relativity.

• 8.1: Introduction to Relativity

- [Yale University: Ramamurti Shankar's "PHYS 200: Introduction to Relativity"URL](#)

Watch this lecture, pausing to take notes, before moving on to the reading below. You will attempt to solve problems relating to this lecture after viewing another one of Professor Shankar's lectures in subunit 9.2.

-  [University of North Carolina at Charlotte: Mike Corwin's "Special Relativity"URL](#)

This reading provides an introduction to the material on special relativity that we will cover in this unit. Read the text carefully, but please do not think that you have to memorize every single fact. What you should strive for is to be sure that it makes sense to you as you are reading it and that when you are finished you can briefly summarize the main points of the reading. You should read this both as you start and after you have finished working your way through the unit.

- [Gal Barak's "Relativity in 5 Minutes"Page](#)

Watch this brief video for a concise review of the essential physics of relativity.

-  [Cabrillo College: David M. Harrison's "Two Swimmers"URL](#)

This applet demonstrates the expectation of Michelson and Morley that if the speed of light was constant through the ether (the speed of the swimmers is constant through the water) and the detection device is moving through the ether (the platform is moving through the water), then the travel time for the perpendicular light beams (the travel time for the two swimmers) would be different - common sense, right. Can you explain why the special theory addresses the fact that the travel times in the Michelson-Morley were actually the same?

- [WatchMojo: "Albert Einstein: His Life and Career"Page](#)

This video is a brief, but interesting, review of Einstein's life and career. The video also discusses some of his work and interests outside of physics.

- [EarBot: "Alfred Einstein and the Theory of Relativity"Page](#)

Watch this video, and make sure that you understand the logic of its two different conclusions.

- [Wolfram Demonstrations Project: "Russell's Thought Experiment"URL](#)

This demonstration illustrates what happens when you add a series of velocities that, in Newtonian mechanics, would reach speeds faster than the speed of light. The demonstration illustrates why relative speeds can add up to nearly the speed of light, but cannot exceed that speed.

- **8.2: Simultaneity, Time Dilation, and Length Contraction**

- [Yale University: Ramamurti Shankar's "PHYS 200: Lorenz Transformations"URL](#)

Watch this lecture, pausing to take notes, before moving on to the readings below. Please test your understanding if this lecture and Professor Shankar's lecture in subunit 8.1 by attempting the problems #1, 3, and 5-7 from this [problem set](#). Check your solutions [here](#).

- [University of Virginia: Michael Fowler's "Time Dilation: A Worked Example"URL](#)

This reading deals with synchronized clocks and shows how time dilation and length contraction can explain certain apparent paradoxes in relativity. Be sure that you understand the different logic used by Jack and by Jill to account for the observations.

- [University of Virginia: Michael Fowler's "More Relativity: The Train and the Twins"URL](#)

This reading shows two worked examples: one on a train moving through a tunnel and the other on the twin paradox. The last example uses the Doppler effect to show a clever way to explain the difference in ages.

-  [Cabrillo College: David M. Harrison's "Relativistic Length Contraction"URL](#)

Explore this applet, which illustrates the paradox, described in an earlier reading, of a muon originating in the upper atmosphere striking the surface of the earth.

- [Wolfram Demonstrations Project: "Spacetime Diagram"URL](#)

This demonstration illustrates how a set of events appears in two inertial frames moving with respect to one another.

- [The Nobel Prize: "Relativity"URL](#)

Read the introductory text on the webpage, select the links to "The Michelson-Morley Experiment" through "History of Special Relativity," and read all of these sections. This reading is a solid review of relativity.

- **8.3: The General Theory of Relativity**

- University of California, San Diego: Gene Smith's "General Relativity and Black Holes"[URL](#)
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Read this tutorial carefully.
