Advanced Physics with Calculus Syllabus

Unit I: Kinematics (6 days)

This unit is designed to provide experiences for students that will help them review fundamental concepts of kinematics from first-year physics and simultaneously begin to develop some of the calculus tools that will be needed in this course. The usual daily routine (not to be rigidly adhered to) is assign one worksheet and one problem each day for homework. The papers are collected the next day, shuffled randomly, and redistributed to be corrected in class by students. Solutions are presented on the blackboard, with as much input as possible from students. (Sometimes a student who has not completed his or her assignment may be sent to the blackboard.) Point values are decided by the teacher. Students score and sign the papers, and return them to the teacher, who records the scores and returns them. On some occasions only part of a worksheet is graded and the rest is completed at the blackboard with as much input as possible from the students.

K-1 River Race
K-2 Review of Kinematics
K-3 Superball Game (experiment)
K-4 Simple Trajectories
K-5 Motion Along a Curved Path
K-6 A New Way to Look At Circular Motion
Kinematics Review Sheet

Unit II: Mathematics (29 to 33 days)

While it is advisable for students to study calculus concurrently with A.P. physics, there are certain calculus tools that are too important to wait for. In this unit students discover differentiation and integration of polynomials trig functions, and exponential functions in ways that are different enough from the standard methods so that the material will be complementary to (rather than a duplication of) the work that they do in their calculus course. Because it is important for students to develop these tools as they are needed, the material in this unit is distributed through the entire first semester.

M-1 The Law of Cosines and the Pythagoras Theorem
M-2 Differentiating Polynomials
M-3 The Derivative of a Product
M-4 The Bird and the Trains
M-5 Polynomial Approximations
M-6 Finding the Area of a Sphere without Calculus
M-7 Simple Integration
M-8 The Volume of a Pyramid or Cone without Calculus

M-9 Finding the Volume of a Sphere without Calculus
M-10 Integration for Beginners
M-11 Summary of Discoveries about Integration
M-12 Definite and Indefinite Integration
M-13 Sines and Cosines
M-14 More About Sines and Cosines
M-15 The Area and Volume of a Sphere (calculus version)
M-16 Introducing Exponential Functions
M-17 Discovering the Numerical Value of "e"
M-18 More About Exponential Functions
M-19 The Chain Rule
M-20 Separation of Variables
M-21 Integrating the Function $y = x^{-1}$
M-22 Summary of Integration and Differentiation
M-23 Integrating $\sin^3 x$ by "Substitution"
M-24 Introducing Vector Products
M-25 Second-Order Differential Equations
M-26 The Gremlin Theory of Averaging
M-27 Integrating $(A^2 - x^2)^{-1/2}$ (optional)
M-28 More Polynomial Approximations (optional)
M-29 Interpreting Imaginary Exponents (optional)
M-30 Exponential Solutions to Second-Order Differential Equations (optional)
M-31 More Examples of Integration by Substitution
M-32 Golden Trumpet & Dark Night Sky
M-33 Unit Vectors

Unit III: Dynamics (9 days)

This unit provides students with experiences that help them review what they learned in Physics I about the causes of motion. At the same time students continue to discover useful aspects of calculus. Some overlap between the more advanced topics in this unit and the introductory parts of the next one is beneficial.

D-1 The Atwood Machine
D-2 Bungee Jumping
D-3 Bungee Contest (experiment)
D-4 Molasses Problem (computer version)
D-5 The Capstan (experiment)
D-6 Capstan Theory
D-7 Colliding Steel Balls
D-8 The Conveyor Belt Problem and Other Amusements
D-9 Two Questions about Planet X

Unit IV: Equilibrium (7 days)

Students investigate rotational equilibrium, discover ways to locate an object's center of mass, and develop integration skills by practicing on useful problems. Some overlap between this unit and the adjacent ones is beneficial. The timing of lab exercises can be adjusted to fit lab schedule. Problems from old A.P. examinations make excellent homework assignments. Students must learn to write out solutions clearly enough so that any classmate can understand their reasoning when papers have been exchanged.

Eq-1 Inventing Torque
Eq-2 Center Of Mass
Eq-3 More About Center of Mass (experiment)
Eq-4 The Roberval Balance (experiment)
Eq-5 The Center Of Mass of a Wire Arc (experiment)
Eq-6 Wire Arc Pendulum Project (experiment)

Unit V: Rotational Motion (12 days)

In this unit students investigate rotational kinematics and dynamics, applying the basic calculus tools that have already been developed and discovering new ones along the way. Some of the material is best introduced while finishing previous units. The timing of lab exercises can be adjusted to fit lab schedule.

R-1 Rotational Motion
R-2 The Kinetic Energy of a Spinning Disk
R-3 More About Rotational Kinetic Energy
R-4 The Kinetic Energy of a Thrown Stick
R-5 The Kinetic Energy of a Rolling Object
R-6 Discovering the Parallel-**Ax**is Theorem
R-7 Rolling Race (experiment)
R-8 The Rotational Inertia of a Wire Arc
R-9 Inventing Angular Momentum
R-10 Another Example of a Cross-Product
R-11 Precession Experiment
R-12 Angular Momentum of a Satellite
Rotational Motion Review Sheet

Unit VI: Simple Harmonic Motion (4 to 7 days)

While investigating simple harmonic motion students discover and develop several more useful calculus tools. Some aspects of error analysis and statistical treatment of experimental data are found to be useful here. The timing of lab exercises can be adjusted to fit lab schedule.

SHM-1 Mass Bobbing on a Spring (experiment)
SHM-2 Torsion Pendulum Experiment

SHM-3 SHM Problems
SHM-4 Exponential Description of SHM (optional)
SHM-5 Damped Simple Harmonic Motion (optional)
SHM-6 Period and Amplitude
Simple Harmonic Motion Review Sheet

Unit VII: Gravitation (5 days)

Students investigate the universal law of gravitation, discovering some calculus curiosities along the way. This unit completes the preparation for the "Mechanics" section of the advanced placement exam.

G-1 Gravitation
G-2 Gravitational Fields the Easy Way
G-3 Constructing a Sun
G-4 Gravity Down in a Well
G-5 Elliptical Orbits

Unit VIII: Electric Fields (16 days)

Starting with Coulomb's law from physics I, students practice using the calculus tools already developed to investigate the wonders of electrostatics, including dipole fields, capacitance, electrostatic energy and the quantized energy levels of the Bohr atomic model.

EL-1 The Electric Field Produced by a Line of Charge
EL-2 The Electric Field Produced by a Uniform Charged Plane
EL-3 The Electric Field of a Dipole
EL-4 Dipole Experiment
EL-5 Complete Dipole Field Formulas
EL-6 The Electric Field on the Axis of a Charged Hoop
EL-7 Electric Field of a Uniformly Charged Plane, Method II
EL-8 Capacitance
EL-9 The Parallel-Plate Capacitor
EL-10 The Electric Field of a Uniformly Charged Sphere
EL-11 Discovering a Formula for Capacitance
EL-12 Energy Stored in an Electric Field
EL-13 The Complete Energy Density Formula
EL-14 Another Way to Get a Uniform E Field
EL-15 Graph-Sketching Exercises
EL-16 Bohr Atom
Electric Field Review

Unit IX: Gauss's Law (5 days)

Students discover Gauss's law and find that it makes certain problems in electrostatics much easier to solve. Gauss's law is always prominently featured on the A.P. examination.

GL-1 Particles Confined in a Sphere
GL-2 Gauss's Law
GL-3 Gauss's Law, continued
GL-4 More Uses For Gauss's Law
GL-5 Parallel Plates Again
Gauss Law Review Sheet

Unit X: Electrical Resistance (6 days)

Starting with Ohm's equation from first-year physics, students figure out the meaning of "resistivity" and develop systematic methods for solving circuit problems involving resistors and capacitors. Students gain experience in setting up and solving simultaneous equations, and linear first-order differential equations. The timing of lab exercises can be adjusted to fit lab schedule.

Res-1 Resistivity
Res-2 Resistivity, Current Density, and Power Density
Res-3 Some Circuit Problems
Res-4 Kirchoff Method
Res-5 The Simplest R-C Circuit
Res-6 More R-C Problems

Unit XI: Magnetic Fields (14 days)

Starting with experiments that may or may not have been performed in first-year physics, students investigate how magnetic fields are produced by electric currents. The timing of lab exercises can be adjusted to fit lab schedule.

Mag-1 Magnetic Fields
Mag-2 Tangent Galvanometer Experiment
Mag-3 Magnetic Field Mapping (experiment)
Mag-4 Magnetic Force on a Current-Carrying Wire (experiment)
Mag-5 A Standard Unit for Magnetic Field Strength
Mag-6 Magnetic Field Produced by Electric Current (experiment)
Mag-7 The Magnetic Field Produced by a Long, Straight Current (experiment)
Mag-8 The Magnetic Field Due to a Circular Current Loop
Mag-9 The Magnetic Field Inside a Solenoid
Mag-10 Helmholtz Coils
Mag-11 The Magnetic Field of a Moving Particle
Mag-12 Magnetic Force on a Charged Particle (experiment)
Mag-13 A New Way to Create an Electric Field

Mag-14 The Hall Effect
Magnetic Field Chapter Review

Unit XII: Ampere's Law (6 days)

Students discover a powerful technique for solving certain magnetic field problems which always appear on the A.P. exam.

A-1 Discovering Ampere's Law
A-2 The Magnetic Field of a Current Sheet
A-3 The Magnetic Field Inside a Solenoid
A-4 The Magnetic Field Inside a Wire
A-5 More About the Field in a Wire
A-6 Revising Ampere's Law
Ampere's Law Review Sheet

Unit XIII: Faraday's Law (15 to 16 days)

Students discover how a magnetic field that is changing or moving can induce an electromotive force. Students discover and investigate inductance and magnetic energy storage. Students discover that the fundamental laws of electricity and magnetism imply the existence of electromagnetic waves, and that such waves carry energy and momentum. Students also discover how the speed of such waves can be predicted.

F-1 Using Magnetic Force to Propel Electrons in a Wire
F-2 Induced Current and EMF
F-3 Generator-Capacitor Problem
F-4 Generating Magnetic EMF without Motion (experiment)
F-5 Faraday's Law
F-6 Predicting the EMF in a Rotating Loop
F-7 More About Magnetic EMF
F-8 Introducing Inductance
F-9 Demonstrating Inductance (experiment or lab demonstration)
F-10 The Inductor as an Energy Storage Device
F-11 Magnetic Energy Density
F-12 The Poynting Vector (optional)
F-13 Cyclotrons and Betatrons
F-14 A Moving Electric Field Creates a Magnetic Field
F-15 Self-Reproducing Fields
F-16 Electromagnetic Momentum
Faraday's Law Review Sheet

Unit XIV: Special Theory of Relativity (14 days, more or less)

Students discover that the speed of electromagnetic waves in a vacuum must be independent of the motion of the source or receiver. In working out the details and implications of this seemingly paradoxical behavior students discover time dilation, length contraction, the loss of simultaneity, the Lorentz-Einstein transformations and more. This material keeps things interesting for students after the A.P. exam. Instead of homework problems students can be assigned to write papers on certain aspects of relativity.

SR-1 Electromagnetic Waves
SR-2 The Train Paradox
SR-3 Richard Feynman's Famous Light-Clock
SR-4 Time Transformation
SR-5 Completing the Time Transformation
SR-6 Length of a Moving Object
SR-7 The Longitudinal Light-Clock
SR-8 Complete Lorentz Transformation
SR-9 Relativistic Mass and Momentum
SR-10 Relative Velocity and Acceleration
SR-11 Relativistic Kinetic Energy
SR-12 The Barn Paradox
SR-13 Two More Puzzles
Relativity Review Sheet