AP Physics C: Mechanics and Electricity and Magnetism
Course Organization

Singapore American School
2019-2020

Section 1: Course Organization

The theoretical foundation for this course is the *Modeling Theory of Cognition*, which posits that humans construct mental (conceptual) models to make sense of the world. These conceptual models are constructed of systems, structures, and representations, which allow us to understand and connect information, processes, and skills. To help students develop a coherent system of conceptual models in physics, this course uses a guided-inquiry learning cycle—known as the modeling cycle—that has students do the following: 1) Perform a laboratory activity to develop a relationship between two variables, creating an initial conceptual model for a topic; 2) Discuss and practice parts of the conceptual model, developing an understanding of the conceptual model; and 3) Apply the model through more laboratory activities or projects. By the end of each modeling cycle, students have developed a coherent conceptual model for a topic; the conceptual model contains multiple representations, limits of the model, and applications of the model.

(See Sections 5 and 6 for a full list of conceptual models. See Section 7 for a conceptual model organizer.)

Although the goal is to perform a full modeling cycle for each topic, every course has constraints. For this course, the constraint is time; students have an 80-minute class on an alternating-day schedule, giving a mean of 200 minutes per week. This lower amount of time has forced difficult choices about parts of the modeling cycle, so sections of the course have different foci on parts of the modeling cycle. For the Algebra-Based Electricity and Magnetism section, the focus is on the first and second parts of the modeling cycle—students will develop relationships between variables and create complete conceptual models through discussion and practice. For the Calculus-Based Mechanics section, the focus is on the second and third parts of the modeling cycle—students will create complete conceptual models through discussion and practice and apply the models through laboratory activities. For the Calculus-Based Electricity and Magnetism section, the focus returns to parts one and two of the modeling cycle. If your course has more time available, consider adding the missing parts of the models to each section.

Although this course has a lower amount of time, students entering this course are well-prepared. All students have completed at least one previous physics course, with a high percentage coming from an AT Computational Physics course. Students must also have a co-requisite of any calculus course, though most students have completed at least one calculus course. Students at the Singapore American School are highly motivated, working diligently to perform well in their courses.

Because students have completed a physics course—with an emphasis on Mechanics—this course integrates Electricity and Magnetism with Mechanics. Thanks to the idea from Greg Jacobs, this course begins with Algebra-Based Electricity and Magnetism, moves to Calculus-Based Mechanics, then returns to Calculus-Based Electricity and Magnetism. This sequence allows students to experience new material at the beginning of the course and creates space for the calculus teachers to progress through their storyline. In addition, students are less familiar with topics in Electricity and Magnetism; working through the topics twice in a single year helps deepen their understanding of the conceptual models.

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Adapted from AMTA Modeling Instruction and College Board resources.

The assessment system in this course is a Standards-Based Grading approach, so students will receive a semester grade from a combination of standards. Section 3 lists the topics with the percentage, learning objectives from the 2019 Course and Exam Description books, and class during which each assessment will occur. Each topic is assessed at least twice, so students will have multiple opportunities to provide evidence of their learning.

General Timeline

Classes	**Content**	**Topics**
1 – 26	Algebra-Based Electricity and Magnetism	- Electric Field - Electric Force - Electric Potential and Electric Potential Energy - Capacitance - Resistance - Circuits – Resistor-Only - Magnetic Field - Magnetic Force
27 – 53	Calculus-Based Mechanics	- Linear and Angular Kinematics - Linear and Angular Momentum - Force and Torque - Energy, Work, and Power - Oscillations and Gravitation
54 – 68	Calculus-Based Electricity and Magnetism	- Circuits – RC, RL, and RLC - Electric Potential - Electric Flux and Gauss' Law - Magnetic Flux and Ampère's Law - Faraday's and Lenz's Laws - Maxwell's Equations

69 – 71	Review and AP Exam	- Review of Mechanics and Electricity and Magnetism
		- AP Exams on Monday, 4 May
		  - Mechanics: 12:00 pm
		  - Electricity and Magnetism: 2 pm

72 – 78	Project	- Topic in Mechanics or Electricity and Magnetism

Table of Contents:

Section 2: Schedule

- Students are in each class for 80 minutes on an alternating-day schedule.
- ***Task*** Types and *Science Practices*
  - **Activity**: Laboratory work, either hands-on or computer-based
    - *Discovery*: These activities have students collect data, graph, and perform analysis to determine a relationship between two variables. *Science Practices*: 2.A, 2.B, 2.C, 2.D, 2.E, 2.F, 3.A, 3.B, 3.C, 3.D, 4.A, 4.B, 4.C, 4.D, 4.E.
    - *Verification*: These activities have students verify a previously-studied relationship between two variables. *Science Practices*: 2.A, 2.B, 2.C, 2.D, 2.E, 2.F, 3.A, 3.B, 3.C, 3.D, 4.A, 4.B, 4.C, 4.D, 4.E.
    - *Claim-Evidence-Reasoning (CER)*: These activities have students make a claim about situation, gather evidence about the claim, and provide reasoning about the veracity of the claim. *Science Practices*: 3.A, 3.B, 3.C, 3.D, 4.A, 4.B, 4.C, 4.D, 4.E, 7.A, 7.B, 7.C, 7.D, 7.E, 7.F.
  - **Discussion**: Lecture and question session on a topic.
  - **Practice**: Conceptual problems: TIPERs, card sorts, and other methods; Mathematics-based problems—paper- or computer-based sources (WebAssign or AP Classroom). *Science Practices*: 1.D, 3.C, 3.D, 4.D, 5.D, 5.E, 6.A, 6.B, 6.C, 6.D.
  - **Model**: Development of a conceptual model for a topic. *Science Practices*: 1.A, 1.B, 1.C, 1.E, 3.C, 3.D, 4.A, 4.B, 4.E, 5.A.
  - **Assessment**: A written or computer-based (AP Classroom) check for understanding through conceptual questions and mathematics-based problems. *Science Practices*: 1.D, 3.C, 3.D, 4.D, 5.D, 5.E, 6.A, 6.B, 6.C, 6.D.
  - **Review**: Discussion and practice for a set of topics. *Science Practices*: 1.D, 3.C, 3.D, 4.D, 5.D, 5.E, 6.A, 6.B, 6.C, 6.D.
- ***Model*** is the conceptual models for a topic—see the next section of this document for the models in Electricity and Magnetism and Mechanics.
- ***Learning Objectives*** are from the 2019 Course and Exam Description for Mechanics and Electricity and Magnetism. Each *Learning Objective* is listed for an activity, discussion, or model.
- ***Science Practices*** are from the 2019 Course and Exam Description for Mechanics and Electricity and Magnetism. See above for groupings of *Science Practices* for each *Task*.

Class	Task	Model	Learning Objectives	Science Practices
1	- Introductions and Speed Meeting - Electricity and Magnetism Pre-Assessment: EMCA			
2	- Electricity and Magnetism Pre-Assessment: BEMA - Discussion: Charge; Electric fields - Activity (Discovery): Determine the electric field created by various charge distributions. [Use *Charges and Fields* from PhET.] - Practice: Electric fields	Electric Field and Force	FIE-1.B FIE-1.C FIE-1.D FIE-1.E	Activity: Discovery Practice

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Class	Task	Model	Learning Objectives	Science Practices

3	- Activities (Discovery):
	  - Determine the relationship between charge and electric force. [Use *Forces and Electric Charge II* from Pivot Interactives.]
	  - Determine the relationship between distance and electric force. [Use *Coulomb's Law Observational Experiment* from Pivot Interactives.]
	- Discussion: Electric force; Relationship between electric force and field
	- Practice: Electric force; Electric field
		Electric Field and Force	ACT-1.A
			ACT-1.B
			ACT-1.C
			ACT-1.D
			
			FIE-1.A
			FIE-1.F
			FIE-1.G
				Activity: Discovery
				
				Practice

4	- Model: Electric field and force - Activity (Discovery): Determine the relationship between distance and electric potential. [Use *Charges and Fields* from PhET.] - Discussion: Electric potential	Electric Field and Force Electric Potential and Electric Potential Energy	CNV-1.A	Model Activity: Discovery
5	- Assessment: Electric field and force - Discussion: Electric potential and electric potential energy - Practice: Electric potential and electric potential energy	Electric Field and Force Electric Potential and Electric Potential Energy	CNV-1.B CNV-1.C CNV-1.D CNV-1.E CNV-1.F	Assessment Practice
6	- Model: Electric potential and electric potential energy - Discussion: Relationships between electric field, electric force, electric potential, and electric potential energy; Conductors - Practice: Electric potential and electric potential energy	Electric Field and Force Electric Potential and Electric Potential Energy	ACT-2.A ACT-2.B ACT-2.C ACT-2.D ACT-2.E ACT-3.A ACT-3.B	Model Practice
7	- Assessment: Electric potential and electric potential energy - Activity (Discovery): Determine the electric field and electric potential in a parallel-plate capacitor. [Use *E-Field* from Pivot Interactives.]	Electric Potential and Electric Potential Energy Capacitance	CNV-4.A	Assessment Activity: Discovery

Class	Task	Model	Learning Objectives	Science Practices
8	- Discussion: Capacitance - Activity (CER): Define and analyze a claim related to the impact of a dielectric on the capacitance of a parallel-plate capacitor. [Use *Capacitor Lab* from PhET.] - Discussion: Dielectrics - Practice: Capacitance and dielectrics	Capacitance	CNV-4.B CNV-4.C CNV-4.F CNV-4.G CNV-4.H CNV-4.I FIE-2.A FIE-2.B FIE-2.C FIE-2.D	Activity: CER Practice
9	- Discussion: Combining capacitors - Practice: Combining capacitors - Model: Capacitance	Capacitance	CNV-7.A	Practice Model
10	- Practice: Capacitance - Assessment: Capacitance	Capacitance		Practice Assessment
11	- Practice: Electric field and force, electric potential and electric potential energy, and capacitance	Electric Field and Force Electric Potential and Electric Potential Energy Capacitance		Practice
12	- Assessment: Electric field and force, electric potential and electric potential energy, and capacitance	Electric Field and Force Electric Potential and Electric Potential Energy Capacitance		Assessment
13	- Activity (Discovery): Make a bulb light with one wire, one battery, and one bulb. - Discussion: Resistor-only circuits - Activity (Discovery): Determine the relationship between electric potential and current.	Resistance Circuits	FIE-3.A FIE-3.B	Activity: Discovery

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Class	Task	Model	Learning Objectives	Science Practices
14	- Discussion: Resistor-only circuits and resistance - Activity/Practice (Verification): Calculate and verify electric potential, current, and resistance of resistor-only circuits. [Use *Circuit Construction Kit* from PhET.]	Resistance Circuits	FIE-3.C FIE-3.D FIE-3.E FIE-3.F CNV-5.A CNV-5.B CNV-6.A CNV-6.B CNV-6.C CNV-6.D CNV-6.E	Activity: Verification Practice
15	- Activity (CER): Determine the optimum load resistance to generate maximum power from photovoltaic cells. [Use *Optimizing Power Generation from Photovoltaic Cells* from Pivot Interactives.]	Circuits		Activity: CER
16	- Model: Resistor-only circuits and resistance - Activity/Practice (Verification): Calculate and verify electric potential, current, and resistance of resistor-only circuits. [Use *Circuit Construction Kit* from PhET.]	Resistance Circuits	CNV-6.F CNV-6.G	Model Activity: Verification
17	- Practice: Resistor-only circuits and resistance - Assessment: Resistor-only circuits and resistance	Resistance Circuits		Practice Assessment
18	- Activity (Discovery): Determine the magnetic field generated by a current-carrying wire. - Discussion: Magnetic field	Magnetic Field	FIE-5.A FIE-5.B	Activity: Discovery
19	- Practice: Magnetic field - Activity (Discovery): Determine properties that increase or decrease the strength of the magnetic field in a solenoid.	Magnetic Field		Practice Activity: Discovery
20	- Model: Magnetic field - Activity (Discovery): Determine force on a current-carrying wire.	Magnetic Field Magnetic Force	FIE-4.A	Model Activity: Discovery

Nathan Belcher, Ed.D. (contactnathanbelcher@gmail.com) – v1 – August 2019

Class	Task	Model	Learning Objectives	Science Practices
21	- Discussion: Magnetic force - Practice: Magnetic force	Magnetic Force	FIE-4.B FIE-4.C FIE-5.C CHG-1.A CHG-1.B CHG-1.C CHG-1.D CHG-1.E	Practice
22	- Model: Magnetic force - Activity (Verification): Research and report on an application of magnetic field and force.	Magnetic Force		Model Activity: Verification
23	- Practice: Magnetic field and force - Assessment: Magnetic field and force	Magnetic Field Magnetic Force		Practice Assessment
24	- Review: Algebra-based electricity and magnetism	All in E/M		Review
25	- Assessment: Algebra-based electricity and magnetism	All in E/M		Assessment
26	- Mechanics Pre-Assessment: FCI - Activity (Verification): Create a method for landing a marble in a moving buggy. - Discussion: Linear kinematics and projectile motion - Practice: Linear kinematics and projectile motion	Constant Linear Velocity Uniform Linear Acceleration 2-D Motion	CHA-1.A CHA-1.B CHA-1.C CHA-2.A CHA-2.B CHA-2.C CHA-2.D	Activity: Verification Practice
27	- Mechanics Pre-Assessment: MBT - Activity (Discovery): Using a flying pig, determine the relationship between angle and time. - Discussion: Angular kinematics - Practice: Angular kinematics	Constant Angular Velocity Uniform Angular Acceleration	INT-2.A CHA-4.A CHA-4.B	Activity: Discovery Practice

Nathan Belcher, Ed.D. (contactnathanbelcher@gmail.com) – v1 – August 2019

Class	Task	Model	Learning Objectives	Science Practices
28	- Model: Linear and angular kinematics - Practice: Linear and angular kinematics - Assessment: Linear and angular kinematics	Constant Linear Velocity Uniform Linear Acceleration 2-D Motion Constant Angular Velocity Uniform Angular Acceleration		Model Practice Assessment
29	- Activity (Verification): For two types of collisions, determine if linear momentum is conserved. - Discussion: Linear momentum - Practice: Linear momentum - Model: Linear momentum	Linear Momentum	INT-5.A INT-5.C CON-4.A CON-4.B CON-4.C CON-4.E CON-4.F	Activity: Verification Practice Model
30	- Activity (Discovery): Determine the balance point for various configurations of mass. - Discussion: Center of mass, moment of inertia, and angular momentum - Practice: Center of mass, moment of inertia, and angular momentum	Angular Momentum	CHA-3.A CHA-3.B CHA-3.C CON-4.D CON-5.A CON-5.B INT-6.C INT-6.D INT-6.E	Activity: Discovery Practice
31	- Activity (Verification): During a collision, determine if angular momentum is conserved. - Practice: Angular momentum	Angular Momentum	CON-5.C CON-5.D	Activity: Verification Practice
32	- Model: Angular Momentum - Assessment: Linear and angular momentum	Linear Momentum Angular Momentum		Model Assessment

Class	Task	Model	Learning Objectives	Science Practices
33	- Discussion: Balanced and unbalanced force - Practice: Balanced and unbalanced force	Balanced Force Unbalanced Force	INT-1.A INT-1.B INT-1.C INT-1.D INT-1.E INT-1.F INT-1.G INT-3.A INT-3.B INT-5.B INT-5.D INT-5.E	Practice
34	- Activity (Verification): Using a flying pig, determine the angle the string makes with the ceiling by two different methods; goal is less than 2% difference. - Discussion: Centripetal force - Practice: Centripetal force	Unbalanced Force	INT-2.A INT-2.B INT-2.C INT-2.D INT-2.E	Activity: Verification Practice
35	- Practice: Balanced and unbalanced force	Balanced Force Unbalanced Force	INT-1.H INT-1.I INT-1.J	Practice
36	- Practice: Balanced and unbalanced force - Assessment: Balanced and unbalanced force	Balanced Force Unbalanced Force		Practice Assessment
37	- Review: Calculus-based mechanics in the first semester	All in Mechanics		Review
38	- Assessment: Calculus-based mechanics in the first semester	All in Mechanics		Assessment
39	- Review: Semester exam	All in semester		Review
	- Semester Exam	All in semester		Assessment

Nathan Belcher, Ed.D. (contactnathanbelcher@gmail.com) – v1 – August 2019

Class	Task	Model	Learning Objectives	Science Practices
40	- Activity (Discovery): Determine the relationship between torque and moment of inertia. - Discussion: Balanced and unbalanced torque - Practice: Balanced and unbalanced torque	Balanced Torque Unbalanced Torque	INT-6.A INT-6.B INT-7.A INT-7.B INT-7.C	Activity: Discovery Practice
41	- Model: Balanced and unbalanced torque - Practice: Balanced and unbalanced torque	Balanced Torque Unbalanced Torque		Model Practice
42	- Practice: Balanced and unbalanced torque - Assessment: Balanced and unbalanced torque	Balanced Torque Unbalanced Torque		Practice Assessment
43	- Activity (Verification): Determine the maximum height of an object rolling up an incline. - Discussion: Energy - Practice: Energy	Energy, Work, Power	CON-1.D CON-1.E CON-2.A CON-2.C INT-7.E	Activity: Verification Practice
44	- Model: Energy, work, and power - Discussion: Energy, work, and power - Practice: Energy, work, and power	Energy, Work, Power	CON-1.A CON-1.B CON-1.C CON-1.F CON-2.B CON-2.D CON-3.A CON-4.B INT-4.A INT-4.B INT-4.C INT-7.D	Model Practice
45	- Practice: Energy, work, and power	Energy, Work, Power		Practice
46	- Assessment: Energy, work, and power	Energy, Work, Power		Assessment

Nathan Belcher, Ed.D. (contactnathanbelcher@gmail.com) – v1 – August 2019

Class	Task	Model	Learning Objectives	Science Practices
47	- Activity (Discovery): Determine the factors that influence the period of a pendulum.	Oscillations	INT-8.K	Activity: Discovery
48	- Activity (Discovery): Determine the factors that influence the period of a mass hanging by a spring. - Discussion: Oscillations - Practice: Oscillations	Oscillations	INT-8.A INT-8.B INT-8.C INT-8.D INT-8.E INT-8.F INT-8.G INT-8.H INT-8.I INT-8.J INT-8.K	Activity: Discovery Practice
49	- Model: Oscillations - Discussion: Gravitation - Practice: Gravitation	Oscillations Gravitation	FLD-1.A FLD-1.B FLD-1.C CON-6.A CON-6.B CON-6.C CON-6.D CON-6.E CON-6.F CON-6.G CON-6.H CON-6.I	Model Practice
50	- Activity (Verification): Given constraints, calculate and verify the intersection point of a pendulum and block on a buggy. - Practice: Oscillations and gravitation	Oscillations Gravitation		Activity: Verification Practice
51	- Practice: Oscillations and gravitation - Assessment: Oscillations and gravitation	Oscillations Gravitation		Practice Assessment
52	- Review: Calculus-based mechanics in the second semester	All in Mechanics		Review
53	- Assessment: Calculus-based mechanics in the second semester	All in Mechanics		Assessment

Class	Task	Model	Learning Objectives	Science Practices
54	- Activity (Discovery): Determine the time constant for combinations of resistors and capacitors. - Discussion: RC circuits - Practice: RC circuits	Circuits	CNV-7.B CNV-7.C CNV-7.D CNV-7.F CNV-7.G	Activity: Discovery Practice
55	- Discussion: RL circuits and RLC circuits - Practice: RL circuits and RLC circuits - Discussion: Electric flux	Circuits Electromagnetism	CNV-2.A CNV-10.A CNV-10.B CNV-10.C CNV-10.D CNV-10.E	Practice
56	- Discussion: Gauss' Law - Practice: Gauss' Law	Electromagnetism	CNV-2.B CNV-2.C CNV-2.D CNV-2.E CNV-2.F CNV-4.E	Practice
57	- Discussion: Electric potential; Fields and potentials of charge distributions - Practice: Electric potential; Fields and potentials of charge distributions	Electromagnetism	CNV-1.G CNV-3.A CNV-3.B CNV-3.C	Practice
58	- Practice: Circuits, Gauss' Law and electric potential - Assessment: Circuits, Gauss' Law and electric potential	Circuits Electromagnetism		Practice Assessment
59	- Activity (Discovery): Determine the magnetic flux density inside a levitated disk magnet. [Use *Magnet Accelerated by Electric Current* from Pivot Interactives.]	Magnetic Force		Activity: Discovery
60	- Discussion: Magnetic flux and Ampère's Law - Practice: Magnetic flux and Ampère's Law	Electromagnetism	CNV-8.A CNV-8.B CNV-8.C CNV-8.D CNV-8.E CNV-9.A	Practice

Class	Task	Model	Learning Objectives	Science Practices
61	- Activity (Discovery): Determine the magnetic field in a gap using a coil moving through the gap. [Use *Electromagnetic Induction* from Pivot Interactives.] - Discussion: Faraday's and Lenz's Laws - Practice: Faraday's and Lenz's Laws	Electromagnetism	FIE-6.A	Activity: Discovery Practice
62	- Discussion: Faraday's and Lenz's Laws - Practice: Faraday's and Lenz's Laws	Electromagnetism	ACT-4.A ACT-4.B	Practice
63	- Activity (CER): Develop and analyze a claim related to magnets falling through a solenoid.	Electromagnetism		Activity: CER
64	- Practice: Faraday's and Lenz's Laws - Discussion: Maxwell's equations	Electromagnetism	FIE-7.A	Practice
65	- Practice: Ampère's, Faraday's, and Lenz's Laws - Assessment: Ampère's, Faraday's, and Lenz's Laws	Electromagnetism		Practice Assessment
66	- Review: Calculus-based electricity and magnetism	All in E/M		Review
67	- Review: Calculus-based electricity and magnetism	All in E/M		Review
68	- Assessment: Calculus-based electricity and magnetism	All in E/M		Assessment
69	- Review: AP Exams	All		Review
70	- Review: AP Exams	All		Review
71	- AP Exams: Mechanics and Electricity and Magnetism	All	All	
72	- Project on a topic in Mechanics or Electricity and Magnetism			
73	- Mechanics Post-Assessments: FCI and MBT - Project on a topic in Mechanics or Electricity and Magnetism			

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Class	Task	Model	Learning Objectives	Science Practices
74	- Electricity and Magnetism Post-Assessments: BEMA and EMCA - Project on a topic in Mechanics or Electricity and Magnetism			
75	- Project on a topic in Mechanics or Electricity and Magnetism			
76	- Project on a topic in Mechanics or Electricity and Magnetism			
77	- Project on a topic in Mechanics or Electricity and Magnetism			
78	- Project on a topic in Mechanics or Electricity and Magnetism			

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Section 3: Scoring System

Semester 1					
Topic	**Semester Grade (%)**	**Learning Objectives**	**Assessment – Class Number**		
			1st	**2nd**	**3rd**
Electric Field and Force	12	FIE-1.B, FIE-1.C, FIE-1.D, FIE-1.E, ACT-1.A, ACT-1.B, ACT-1.C, ACT-1.D, FIE-1.A, FIE-1.F, FIE-1.G	5	12	Exam
Electric Potential and Electric Potential Energy	12	CNV-1.A, CNV-1.B, CNV-1.C, CNV-1.D, CNV-1.E, CNV-1.F, ACT-2.A, ACT-2.B, ACT-2.C, ACT-2.D, ACT-2.E, ACT-3.A, ACT-3.B	7	12	Exam
Capacitance	8	CNV-4.A, CNV-4.B, CNV-4.C, CNV-4.F, CNV-4.G, CNV-4.H, CNV-4.I, FIE-2.A, FIE-2.B, FIE-2.C, FIE-2.D, CNV-7.A	10	12	Exam
Circuits and Resistance	12	FIE-3.A, FIE-3.B, FIE-3.C, FIE-3.D, FIE-3.E, FIE-3.F, CNV-5.A, CNV-5.B, CNV-6.A, CNV-6.B, CNV-6.C, CNV-6.D, CNV-6.E, CNV-6.F, CNV-6.G	17	25	Exam
Magnetic Field and Force	12	FIE-5.A, FIE-5.B, FIE-4.A, FIE-4.B, FIE-4.C, FIE-5.C, CHG-1.A, CHG-1.B, CHG-1.C, CHG-1.D, CHG-1.E	23	25	Exam
Linear and Angular Kinematics	10	CHA-1.A, CHA-1.B, CHA-1.C, CHA-2.A, CHA-2.B, CHA-2.C, CHA-2.D, INT-2.A, CHA-4.A, CHA-4.B	28	38	Exam
Linear and Angular Momentum	12	INT-5.A, INT-5.C, CON-4.A, CON-4.B, CON-4.C, CON-4.E, CON-4.F, CHA-3.A, CHA-3.B, CHA-3.C, CON-4.D, CON-5.A, CON-5.B, INT-6.C, INT-6.D, INT-6.E, CON-5.C, CON-5.D	32	38	Exam

Forces	12	INT-1.A, INT-1.B, INT-1.C, INT-1.D, INT-1.E, INT-1.F, INT-1.G, INT-3.A, INT-3.B, INT-5.B, INT-5.D, INT-5.E, INT-2.A, INT-2.B, INT-2.C, INT-2.D, INT-2.E, INT-1.H, INT-1.I, INT-1.J	36	38	Exam
Laboratory Skills	10		20	29	34

Semester 2					
Topic	**Semester Grade (%)**	**Learning Objectives**	**Assessment – Class Number**		
			1st	**2nd**	**3rd**
Torque	10	INT-6.A, INT-6.B, INT-7.A, INT-7.B, INT-7.C	42	53	
Energy, Work, Power	20	CON-1.D, CON-1.E, CON-2.A, CON-2.C, INT-7.E, CON-1.A, CON-1.B, CON-1.C, CON-1.F, CON-2.B, CON-2.D, CON-3.A, CON-4.B, INT-4.A, INT-4.B, INT-4.C, INT-7.D	46	53	
Oscillations and Gravitation	10	INT-8.K, INT-8.A, INT-8.B, INT-8.C, INT-8.D, INT-8.E, INT-8.F, INT-8.G, INT-8.H, INT-8.I, INT-8.J, INT-8.K, FLD-1.A, FLD-1.B, FLD-1.C, CON-6.A, CON-6.B, CON-6.C, CON-6.D, CON-6.E, CON-6.F, CON-6.G, CON-6.H, CON-6.I	51	53	
Circuits	10	CNV-7.B, CNV-7.C, CNV-7.D, CNV-7.F, CNV-7.G, CNV-10.A, CNV-10.B, CNV-10.C, CNV-10.D, CNV-10.E	58	66	
Electrostatics	15	CNV-2.A, CNV-2.B, CNV-2.C, CNV-2.D, CNV-2.E, CNV-2.F, CNV-4.E, CNV-1.G, CNV-3.A, CNV-3.B, CNV-3.C	58	66	
Electromagnetism	15	CNV-8.A, CNV-8.B, CNV-8.C, CNV-8.D, CNV-8.E, CNV-9.A, FIE-6.A, ACT-4.A, ACT-4.B, FIE-7.A	64	66	
Laboratory Skills	10		43	50	63
Project	10		78		

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Section 4: Comparison of Models with Book Chapters and AP Problems

Books

- "HRW" is *Fundamentals of Physics* (8th Edition) by Halliday, Resnick, and Walker
- "OpenStax (Vol. 1)" is *University Physics, Volume 1* by OpenStax
- "OpenStax (Vol. 2)" is *University Physics, Volume 2* by OpenStax

AP Problems are released FRQs from the College Board. Although problems have parts from different models, the listed problem is the model with the most parts in the problem.

- Mechanics
- Electricity and Magnetism

Models	Book Chapters	AP Problems
Electric Field and Force Electric Potential and Electric Potential Energy	HRW - Ch. 21: 21.1 – 21.6 - Ch. 22: 22.1 – 22.8 - Ch. 24: 24.1 – 24.7, 24.8, 24.9, 24.10 OpenStax (Vol. 2) - Ch. 5: 5.1 – 5.6 - Ch. 7: 7.1 – 7.6	- 2010: 1 - 2016: 1
Circuits Capacitance Resistance	HRW - Ch. 25: 25.1 – 25.7 - Ch. 26: 26.1 – 26.7 - Ch. 27: 27.1 – 27.9 OpenStax (Vol. 2) - Ch. 8: 8.1 – 8.5 - Ch. 9: 9.1 – 9.5 - Ch. 10: 10.1 – 10.6 - Ch. 14: 14.4	- 2007: 1 - 2008: 2 - 2009: 2 - 2010: 2 - 2011: 2 - 2012: 2 - 2013: 2 - 2014: 1 - 2015: 2 - 2016: 2 - 2017: 2 - 2018: 2 - 2019 (1): 2 - 2019 (2): 1
Magnetic Field Magnetic Force	HRW - Ch. 28: 28.1 – 28.9 - Ch. 29: 29.1 – 29.3 OpenStax (Vol. 2) - Ch. 11: 11.1 – 11.7 - Ch. 12: 12.1 – 12.4	- 2007: 3 - 2008: 3 - 2019 (2): 3

Models	Book Chapters	AP Problems
Electromagnetism	HRW - Ch. 23: 23.1 – 23.8 - Ch. 29: 29.4, 29.5 - Ch. 30: 30.1 – 30.10 - Ch. 32: 32.1 – 32.5 OpenStax (Vol. 2) - Ch. 6: 6.1 – 6.4 - Ch. 12: 12.5 – 12.6 - Ch. 13: 13.1 – 13.7 - Ch. 14: 14.1 – 14.3 - Ch. 16: 16.1	- 2007: 2 - 2008: 1 - 2009: 1, 3 - 2010: 3 - 2011: 1, 3 - 2012: 1, 3 - 2013: 1, 3 - 2014: 2, 3 - 2015: 1, 3 - 2016: 3 - 2017: 1, 3 - 2018: 1, 3 - 2019 (1): 1, 3 - 2019 (2): 2
Constant Linear Velocity Constant Angular Velocity Uniform Linear Acceleration Uniform Angular Acceleration 2-D Motion	HRW - Ch. 1: 1.1 – 1.7 - Ch. 2: 2.1 – 2.9 - Ch. 4: 4.1 – 4.9 - Ch. 10: 10.1 – 10.5 OpenStax (Vol. 1) - Ch. 1: 1.1 – 1.7 - Ch. 3: 3.1 – 3.6 - Ch. 4: 4.1 – 4.5 - Ch. 10: 10.1 – 10.3	- 2007: 1 - 2013: 1 - 2015: 1 - 2018: 1
Linear Momentum Angular Momentum	HRW - Ch. 3: 3.1 – 3.8 - Ch. 9: 9.1, 9.2, 9.4, 9.7, 9.9, 9.10, 9.11 - Ch. 10: 10.7 - Ch. 11: 11.7, 11.9 – 11.11 OpenStax (Vol. 1) - Ch. 2: 2.1 – 2.4 - Ch. 9: 9.1, 9.3 – 9.6 - Ch. 10: 10.5 - Ch. 11: 11.2, 11.3 (no torque or energy)	- 2014: 3 - 2016: 3 - 2018: 2 - 2019 (1): 2

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Models	Book Chapters	AP Problems
Balanced Force Unbalanced Force	HRW - Ch. 5: 5.1 – 5.9 - Ch. 6: 6.1 – 6.5 - Ch. 9: 9.3, 9.5, 9.6, 9.12 - Ch. 10: 10.8, 10.9 - Ch. 11: 11.1, 11.2, 11.4-11.6, 11.8 - Ch 12: 12.1 – 12.6 OpenStax (Vol. 1) - Ch. 5: 5.1 – 5.7 - Ch. 6: 6.1 – 6.4 - Ch. 9: 9.2, 9.7 - Ch. 10: 10.6, 10.7 - Ch. 11: 11.1 - Ch. 12: 12.1, 12.2	- 2007: 1 - 2008: 1 - 2009: 3 - 2010: 1, 3 - 2011: 1, 2 - 2012: 3 - 2013: 2 - 2016: 1 - 2017: 1 - 2018: 3 - 2019 (1): 1 - 2019 (2): 1
Balanced Torque Unbalanced Torque	HRW - Ch. 10: 10.8, 10.9 - Ch. 11: 11.6, 11.8 OpenStax (Vol. 1) - Ch. 10: 10.6, 10.7 - Ch. 11: 11.1 - Ch. 12: 12.1, 12.2	- 2008: 2 - 2013: 3
Energy Work Power	HRW - Ch. 7: 7.1 – 7.9 - Ch. 8: 8.1 – 8.8 - Ch. 9: 9.8 - Ch. 10: 10.6, 10.10 - Ch. 11: 11.3 OpenStax (Vol. 1) - Ch. 7: 7.1 – 7.4 - Ch. 8: 8.1 – 8.5 - Ch. 10: 10.4, 10.8	- 2007: 3 - 2008: 3 - 2009: 1 - 2010: 2 - 2012: 2 - 2013: 3 - 2014: 1, 2 - 2015: 3 - 2017: 2, 3 - 2018: 2 - 2019 (1): 3 - 2019 (2): 2, 3
Oscillations Gravitation	HRW - Ch. 13: 13.1 – 13.8 - Ch. 15: 15.1 – 15.7 OpenStax (Vol. 1) - Ch. 13: 13.1 – 13.5 - Ch. 15: 15.1 – 15.4	- 2007: 2 - 2008: 3 - 2009: 2 - 2011: 3 - 2012: 1 - 2015: 2

Section 5: Models for Electricity and Magnetism

(I have listed at most two applications; however, models have many more than two applications.)

1. **Model for Electric Field and Force**
   a. Written Statements – Explanations and Predictions
      i. All matter is composed of charged particles, with varying charge mobility in different materials.
      ii. Like charges repel but opposite charges attract.
      iii. Neutral matter may be polarized, creating a localized electric field.
      iv. Electric force is dependent on charges and distance.
      v. The electric field vector points in the same direction as the electric force vector.
      vi. The permittivity of free space (ε_0) is included as a constant in the electric force and electric field equations.
      vii. This model is for stationary charges.
   b. Equations
      i. $\left|\vec{F}_e\right| = \frac{1}{4\pi\epsilon_0}\left|\frac{q_1 q_2}{r^2}\right|$
      ii. $\vec{E} = \frac{\vec{F}_e}{q}$
      iii. $\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q_1}{|\vec{r}|^2}\hat{r}$
   c. Graphs
      i. Electric field versus charge
      ii. Electric field versus distance
   d. Diagrams
      i. Free-body diagram
      ii. Force diagram
      iii. System interaction diagram
      iv. Electric field diagram
   e. Applications
      i. Spark plug
      ii. Taser
   f. Limits
      i. Moving charges

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2. **Model for Electric Potential and Electric Potential Energy**
   a. Written Statements – Explanations and Predictions
      i. Electric potential is a property of location, not a material.
      ii. Motion parallel to electric field lines does not have a change in energy; motion non-parallel to electric field lines does have a change in energy.
      iii. Electric potential energy is difficult to measure, so instead we typically measure electric potential.
   b. Equations
      i. $E_x = -\frac{dV}{dx}$
      ii. $\Delta V = -\int \vec{E} \cdot d\vec{r}$
      iii. $V = \frac{1}{4\pi\varepsilon_0} \sum_i \frac{q_i}{r_i}$
      iv. $U_E = qV = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r}$
   c. Graphs
      i. Electric field versus position
      ii. Electric potential versus charge
      iii. Electric potential versus distance
   d. Diagrams
      i. Equipotentials for point charges
      ii. Equipotentials for continuous charge distributions
   e. Applications
      i. Circuits
   f. Limits
      i. Moving charges

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3. **Model for Capacitance**
   a. Written Statements – Explanations and Predictions
      i. Creating an uneven distribution of charge produces an electric field and electric potential difference between two locations.
      ii. Capacitors store energy as an electric field.
      iii. Capacitance adds when capacitors are connected in parallel; capacitance reduces when capacitors are connected in series.
      iv. Capacitance is directly proportional to the dielectric constant and surface area; capacitance is inversely proportional to plate separation distance.
   b. Equations
      i. $C = \frac{\kappa\varepsilon_{0A}}{d}$
      ii. $\Delta V = \frac{Q}{C}$
      iii. $C_p = \sum_i C_i$
      iv. $\frac{1}{C_s} = \sum_i \frac{1}{C_i}$
      v. $U_C = \frac{1}{2} Q\Delta V = \frac{1}{2} C(\Delta V)^2$
   c. Graphs
      i. Capacitance versus plate area
      ii. Capacitance versus plate separation distance
   d. Diagrams
      i. Surface charge on a capacitor
      ii. Electric schematic
   e. Applications
      i. Capacitors
   f. Limits
      i. Irregularly-shaped capacitors

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4. **Model for Resistance**
   a. Written Statements – Explanations and Predictions
      i. Resistance is the net effect of atomic level 'obstacles' interfering with the motion of charge carriers.
      ii. Resistance is directly proportional to resistivity of the material and length, and inversely proportional to cross-sectional area.
      iii. Resistance adds when resistors are connected in series; resistance reduces when resistors are connected in parallel.
   b. Equations
      i. $R = \frac{\rho l}{A}$
      ii. $\vec{E} = \rho \vec{J}$
      iii. $I = Nev_d A$
      iv. $R_s = \sum_i R_i$
      v. $\frac{1}{R_p} = \sum_i \frac{1}{R_i}$
   c. Graphs
      i. Resistance versus length
      ii. Resistance versus cross-sectional area
   d. Diagrams
      i. Surface charge on a wire
      ii. Electric schematic
   e. Applications
      i. Underwater transmission cables
      ii. Resistors
   f. Limits
      i. Insulators
      ii. Semiconductors

5. **Model for Circuits**
   a. Written Statements – Explanations and Predictions
      i. A conducting path allows constrained charge motion between the points as an uneven charge distribution is maintained.
      ii. When there is more than one pathway for current to travel, the total current into the junction is equal to the total current leaving the junction.
      iii. The voltage gains and drops around a closed loop of a circuit is equal to zero.
      iv. The rate at which charge accumulates on a capacitor or current flows in a RC circuit depends on the resistance and capacitance.
      v. After a capacitor has been fully charged, current stops for that branch.
      vi. An uncharged capacitor initially acts as a short circuit.
      vii. The equation relating current, voltage, and resistance is only valid for ohmic materials.
      viii. An RC circuit is one containing one resistor and one capacitor.
   b. Equations
      i. $I = \frac{dQ}{dt}$
      ii. $I = \frac{\Delta V}{R}$
      iii. $P = I\Delta V$
      iv. $I = I_0 e^{-t/RC}$
      v. $Q = CV\left(1 - e^{-t/RC}\right)$
      vi. $Q = Q_0 e^{-t/RC}$
   c. Graphs
      i. Voltage versus current
      ii. Current versus time
      iii. Charge versus time
   d. Diagram
      i. Electric schematic
   e. Applications
      i. Power grids
      ii. Analog electronics
   f. Limits
      i. Non-ohmic materials
      ii. Digital electronics

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6. **Model for Magnetic Field**
    a. Written Statements – Explanations and Predictions
        i. Magnetic fields originate two locations: Permanent magnets and moving charges.
        ii. Field strength diminishes with distance from moving charge and increases with increasing charge motion.
        iii. Fields are loops and can be described with the right-hand rule.
        iv. Energy can be stored as a magnetic field in a solenoid.
        v. Inductance is a property of solenoids related to the geometry of the solenoid.
    b. Equations
        i. $\vec{B} = \frac{\mu_0}{4\pi}\frac{q\vec{v}\times\hat{r}}{r^2}$
        ii. $d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{l}\times\hat{r}}{r^2}$
        iii. $B_S = \mu_0 nI$
        iv. $U_L = \frac{1}{2}LI^2$
    c. Graph
        i. Magnetic field versus distance
    d. Diagrams
        i. Magnetic fields of permanent magnets
        ii. Magnetic fields of a short piece of current-carrying wire
        iii. Magnetic fields of continuous current distributions
    e. Applications
        i. Magnetic trapping
        ii. Solenoids
    f. Limits
        i. Non-classical particles

7. **Model for Magnetic Force**
   a. Written Statements – Explanations and Predictions
      i. Force is exerted on a charge moving in a magnetic field.
      ii. Directions of force, charge/current, and magnetic field can be found with the right-hand rule.
      iii. A current-carrying coil or magnetic dipole experiences torque in a magnetic field and twists to align with the applied magnetic field.
      iv. The total force on a moving charged particle is the sum of the electric force and magnetic force.
   b. Equations
      i. $\vec{F}_M = q\vec{v} \times \vec{B} = q|\vec{v}||\vec{B}|\sin\theta$
      ii. $\vec{F}_M = \int I\, d\vec{l} \times \vec{B} = I|\vec{L}||\vec{B}|\sin\theta$
      iii. $\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$
      iv. $\vec{\tau} = \vec{\mu} \times \vec{B}$
      v. $|\vec{\mu}| = nIA$
   c. Graphs
      i. Magnetic force versus velocity
      ii. Magnetic force versus magnetic field
      iii. Magnetic force versus angle
   d. Diagrams
      i. Free-body diagram
      ii. Force diagram
      iii. System interaction diagram
   e. Applications
      i. Cyclotron
      ii. Mass spectrometer
   f. Limits
      i. Non-classical particles

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8. **Model for Electromagnetism**
   a. Written Statements – Explanations and Predictions
      i. Electric flux is the quantitative measure of the amount and direction of electric field over an entire surface.
      ii. Gaussian surfaces can be used to determine values associated with electric fields and charge distributions.
      iii. Magnetic flux is the quantitative measure of the amount and direction of magnetic field over an entire surface.
      iv. Amperian loops can be used to determine values associated with magnetic fields and current distributions.
      v. The closed-loop integral of the dot product between magnetic field and the area vector is equal to zero; this implies that a magnetic monopole cannot exist.
      vi. Induced emf is related to the inductance and change in current or the change in magnetic flux.
   b. Equation
      i. $\Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{Q}{\varepsilon_0}$
      ii. $\varepsilon = \oint \vec{E} \cdot d\vec{l}$
      iii. $\Phi_B = \int \vec{B} \cdot d\vec{A}$
      iv. $\varepsilon = \oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$
      v. $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$
      vi. $\oint \vec{B} \cdot d\vec{A} = 0$
      vii. $\varepsilon = -L\frac{dI}{dt}$
   c. Graphs
      i. Emf versus time
   d. Diagrams
      i. Electric flux diagram, with Gaussian surface
      ii. Magnetic flux diagram, with Amperian loop
   e. Applications
      i. Electromagnetic waves (light!)
      ii. Electric motor
      iii. Electric generator
   f. Limits
      i. Non-classical particles

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Section 6: Models for Mechanics

(I have listed at most two applications; however, models have many more than two applications.)

1. **Model for Constant Linear Velocity**
    a. Written Statements – Explanations and Predictions
        i. Path length is defined as the total distance traveled along a path from starting position to ending position.
        ii. Displacement is defined as a change in the position state variable.
        iii. Speed is defined as path length per change in time.
        iv. Velocity is defined as a change in position per change in time.
        v. The slope of position versus time graph is velocity.
        vi. The area between function and time axis on velocity versus time graph is displacement.
    b. Equations
        i. $\Delta\vec{x} = x_f - x_i$
        ii. $\vec{v} = \frac{\Delta\vec{x}}{\Delta t}$
    c. Graphs
        i. Position versus time
        ii. Velocity versus time
    d. Diagram
        i. Motion map
    e. Applications
        i. Determining the "best" path when traveling
        ii. Calculating calories burned during a workout
        iii. Calculating the intersection point of two objects
    f. Limits
        i. Non-constant linear velocity
        ii. Changing the direction of the velocity

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2. **Model for Constant Angular Velocity**
   a. Written Statements – Explanations and Predictions
      i. Path length is defined as the total distance traveled along a path from starting position to ending position.
      ii. Angular displacement is defined as a change in the angle state variable.
      iii. Angular velocity is change in angle per change in time.
      iv. The slope of angle versus time graph is angular velocity.
      v. The area between function and time axis on angular velocity versus time graph is change in angular displacement.
      vi. The relationship between path length and angle is determined by the distance from the particle to the axis of rotation.
      vii. The relationship between tangential and angular velocities is determined by the distance from the particle to the axis of rotation.
   b. Equations
      i. $\Delta\vec{\theta} = \theta_f - \theta_i$
      ii. $s = r\theta$
      iii. $v = r\omega$
      iv. $\vec{\omega} = \frac{\Delta\vec{\theta}}{\Delta t}$
   c. Graph
      i. Angle versus time
      ii. Angular velocity versus time
   d. Diagram
      i. Motion map
   e. Applications
      i. Determining the "best" path around a curved surface
      ii. Determining the launch point of a projectile when swinging
      iii. Calculating the intersection point of two objects
   f. Limits
      i. Non-constant angular velocity

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3. **Model for Uniform Linear Acceleration**
   a. Written Statements – Explanations and Predictions
      i. Acceleration is defined as a change in velocity per change in time.
      ii. Slope of a velocity versus time graph is acceleration.
      iii. Area between function and time axis on acceleration versus time graph is change in velocity.
   b. Equations
      i. $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$
      ii. $v_x = v_{x0} + a_x t$
      iii. $x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$
      iv. $v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$
   c. Graphs
      i. Position versus time
      ii. Position versus $(\text{time})^2$
      iii. Velocity versus time
      iv. Acceleration versus time
   d. Diagram
      i. Motion map
   e. Applications
      i. Calculating the stopping displacement when driving a car
      ii. Determining the acceleration of a free-falling object
   f. Limits
      i. Non-uniform linear acceleration

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4. **Model for Uniform Rotational Acceleration**
   a. Written Statements – Explanations and Predictions
      i. Angular acceleration is defined as a change in angular velocity per change in time.
      ii. The slope of an angular velocity versus time graph is angular acceleration.
      iii. The area between function and time axis on angular acceleration versus time graph is change in angular velocity.
      iv. The relationship between tangential and angular accelerations is determined by the distance from the particle to the axis of rotation.
   b. Equations
      i. $a = r\alpha$
      ii. $\vec{\alpha} = \frac{\Delta\vec{\omega}}{\Delta t}$
      iii. $\omega = \omega_0 + \alpha t$
      iv. $\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$
      v. $\omega_x^2 = \omega_{x0}^2 + 2\alpha_x(\theta - \theta_0)$
   c. Graphs
      i. Angle versus time
      ii. Angle versus $(\text{time})^2$
      iii. Angular velocity versus time
   d. Diagrams
      i. Motion map
   e. Applications
      i. Calculating the angular acceleration of a vinyl record
      ii. Determining the angular acceleration of an object in a circle
   f. Limits
      i. Non-uniform angular acceleration

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5. **Model for 2-D Motion**
   a. Written Statements – Explanations and Predictions
      i. A projectile moves horizontally and vertically and traces a parabolic path in the absence of air resistance.
      ii. Horizontal and vertical motion of projectile are independent; time is the link between the two directions.
   b. Equations
      i. $x = x_0 + v_{x0}t + \frac{1}{2}a_x t^2$
      ii. $y = y_0 + v_{y0}t + \frac{1}{2}a_g t^2$
      iii. $v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$
      iv. $v_y^2 = v_{y0}^2 + 2a_g(y - y_0)$
   c. Graphs
      i. Position versus time
      ii. Linear acceleration versus time
   d. Diagrams
      i. Motion map
   e. Applications
      i. Launching and landing projectiles
      ii. Impact point of projectiles
   f. Limits
      i. Non-zero forces in the horizontal direction
      ii. More forces (besides F_g) in the vertical direction

6. **Model for Linear Momentum**
   a. Written Statements – Explanations and Predictions
      i. Linear momentum is defined as the mass multiplied by velocity.
      ii. The center of mass of an object is determined by amount and placement of mass.
      iii. Depending on the system, linear momentum can either be conserved or not conserved.
   b. Equations
      i. $\vec{p} = m\vec{v}$
      ii. $\vec{p}_{1i} + \vec{p}_{2i} + \cdots = \vec{p}_{1f} + \vec{p}_{2f} + \cdots$
      iii. $x_{CM} = \frac{\sum_i m_i x_i}{\sum_i m_i}$
   c. Graphs
      i. Linear velocity versus time
   d. Diagrams
      i. Motion map
      ii. $p_i - \Delta p - p_f$ chart
   e. Applications
      i. Determining the center of mass of non-standard objects
      ii. Calculating the initial or final velocity of an object for various cases
   f. Limits
      i. Non-constant velocity
      ii. Non-constant mass

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7. **Model for Angular Momentum**
   a. Written Statements – Explanations and Predictions
      i. Angular momentum of a particle is determined by the cross product of the distance from the rotation point and linear momentum.
      ii. Angular momentum of an object is determined by the moment of inertia of the object and its angular velocity.
      iii. The moment of inertia of an object is found by summing the combination of each small part of mass and distance from the rotation point.
      iv. The Parallel Axis Theorem provides a method for calculating the moment of inertia for an object with a rotation point other than the center of mass.
      v. Depending on the system, angular momentum can either be conserved or not conserved.
   b. Equations
      i. $\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$
      ii. $I = \int r^2 dm = \sum m\, r^2$
      iii. $I = I_{CM} + Md^2$
      iv. $\vec{L}_{1i} + \vec{L}_{2i} + \cdots = \vec{L}_{1f} + \vec{L}_{2f} + \cdots$
   c. Graphs
      i. Angular momentum and linear momentum
      ii. Angular momentum and angular velocity
   d. Diagrams
      i. Drawing of object
      ii. L_i — ΔL – L_f chart
   e. Applications
      i. Determine the angular momentum of a satellite in orbit
      ii. Determine if angular momentum is conserved or non-conserved for a given system
   f. Limits
      i. Non-constant linear momentum
      ii. Non-constant radius
      iii. Non-constant moment of inertia
      iv. Non-constant angular velocity

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8. **Model for Balanced Force**
   a. Written Statements – Explanations and Predictions
      i. Forces are interactions between two objects.
      ii. Forces can be classified as either contact or non-contact.
      iii. Objects acted upon by balanced forces will not accelerate; instead, they remain at rest or move with constant linear velocity.
      iv. Forces are symmetric interactions (exist in pairs); paired forces are equal in magnitude but opposite in direction.
   b. Equation
      i. $\sum \vec{F} = \vec{F}_{net} = 0$
   c. Diagrams
      i. Force diagram
      ii. Free-body diagram
      iii. Interaction diagram
   d. Applications
      i. Calculate the necessary force to keep an object in constant velocity
      ii. Determine the placement of an object to keep a structure standing
   e. Limits
      i. Unbalanced forces in any direction

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9. **Model for Unbalanced Force**
   a. Written Statements – Explanations and Predictions
      i. From changes in momentum, we infer forces.
      ii. From forces, we deduce changes in momentum.
      iii. Impulse is defined as the change in momentum or the integral of the force multiplied by time.
      iv. Acceleration is directly proportional to net force and inversely proportional to mass.
      v. The numerical value for coefficient of friction is determined by the surfaces.
      vi. Springs are an example of a restoring force; each spring has a spring constant.
      vii. The period of an object in circular motion is defined as the time needed to make one complete rotation.
      viii. As an object travels in a curved path, the direction of the velocity changes.
      ix. Acceleration (centripetal) from the velocity change in direction points toward the center of the circle.
      x. Force diagrams for an object undergoing circular motion show a net force directed toward the center of the circle.
   b. Equations
      i. $\vec{F} = \frac{d\vec{p}}{dt}$
      ii. $\vec{J} = \int \vec{F} dt = \Delta\vec{p}$
      iii. $\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$
      iv. $|\vec{F}_f| \leq \mu |\vec{F}_N|$
      v. $\vec{F}_S = -k\Delta\vec{x}$
      vi. $a_c = \frac{v^2}{r} = \omega^2 r$
      vii. $F_c = \frac{mv^2}{r}$
      viii. $T = \frac{2\pi}{\omega} = \frac{1}{f}$
   c. Graphs
      i. Impulse versus time
      ii. Force versus acceleration
      iii. Force of friction versus normal force
      iv. Spring force versus spring displacement
   d. Diagrams
      i. Force diagram
      ii. Free-body diagram
      iii. Motion map
      iv. Interaction diagram
   e. Applications
      i. Determine the forces experienced during a collision
      ii. Create a method for minimizing the forces experienced during a collision
   f. Limits
      i. Objects moving at speeds near the speed of light
      ii. Extremely small or large objects

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10. **Model for Balanced Torque**

a. Written Statements – Explanations and Predictions
    i. Torques is calculated by the cross product between the distance from a rotation point and the applied force.
    ii. When the net torque at a rotation point equals zero, the object will remain at rest or move with constant angular velocity.

b. Equations
    i. $\vec{\tau} = \vec{r} \times \vec{F}$
    ii. $\sum \vec{\tau} = \vec{\tau}_{net} = 0$

c. Graphs
    i. Torque versus force

d. Diagrams
    i. Force diagram

e. Applications
    i. Determine the amount of force it takes to rotate an object for different rotation points
    ii. Calculate the amount of torque needed to ensure the object does not rotate

f. Limits
    i. Non-zero net torque

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11. **Model for Unbalanced Torque**
   a. Written Statements – Explanations and Predictions
      i. When a non-zero net torque is exerted on a rotation point, the object will undergo an angular acceleration.
      ii. The net torque is equal to the product of the moment of inertia and angular acceleration.
   b. Equations
      i. $\vec{\alpha} = \frac{\Sigma\vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$
   c. Graphs
      i. Net torque versus angular acceleration
   d. Diagrams
      i. Force diagram
   e. Applications
      i. Determine the torque necessary to start or stop a spinning object
      ii. Calculate the torque needed to drive a screw into an object
   f. Limits
      i. Non-uniform angular acceleration

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12. **Model for Energy, Work, and Power**

a. Written Statements – Explanations and Predictions
   i. Energy is not disembodied; it is either stored in an object or by a field.
   ii. Kinetic energy—either translational, rotational, or both—is the energy stored by a moving object.
   iii. Elastic energy is stored in a deformable body.
   iv. The magnitude of potential energy depends on the strength of the field and arrangement of objects in the field.
   v. Thermal energy includes the kinetic energy associated with the random motion of particles and the potential energy associated with stretching, compressing, and bending the bonds among objects in a system.
   vi. Energy can be transferred between a system and the surroundings by working, heating, or radiating.
   vii. Power is the rate of energy transfer.
   viii. Working relates the net or individual force with the displacement through an integration of the path length.

b. Equations
   i. $K = \frac{1}{2}mv^2$
   ii. $\Delta U_g = mg\Delta h$
   iii. $U_S = \frac{1}{2}k(\Delta x)^2$
   iv. $K = \frac{1}{2}I\omega^2$
   v. $\Delta E = W = \int \vec{F} \cdot d\vec{r}$
   vi. $P = \frac{dE}{dt}$
   vii. $P = \vec{F} \cdot \vec{v}$

c. Graphs
   i. Velocity versus time
   ii. Energy versus position
   iii. Force versus position

d. Diagrams
   i. Force diagram
   ii. Free-body diagram
   iii. Energy bar chart (LOL diagram)

e. Applications
   i. Rube Goldberg machine
   ii. Motion of objects

f. Limits
   i. Energy of light

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13. **Model for Oscillations**

a. Written Statements – Explanations and Predictions

i. A plot of position versus time for ideal mass-spring or pendulum system follows repeating function (either sine or cosine).

ii. The period for a mass-spring system depends on mass and spring constant.

iii. The period for a pendulum depends on length and acceleration due to gravity.

b. Equations

i. $T = \frac{2\pi}{\omega} = \frac{1}{f}$

ii. $x = A\cos(\omega t + \varphi)$

iii. $v = -\omega A\sin(\omega t + \varphi)$

iv. $a = -\omega^2 A\cos(\omega t + \varphi)$

v. $T_S = 2\pi\sqrt{\frac{m}{k}}$

vi. $T_p = 2\pi\sqrt{\frac{l}{g}}$

c. Graphs

i. Position versus time

ii. Velocity versus time

iii. Acceleration versus time

d. Diagrams

i. Motion map

ii. Force diagram

iii. Free-body diagram

iv. Energy bar chart (LOL diagram)

e. Applications

i. Counter-balancing pendulum at the top of a skyscraper

ii. Windings in a clock

f. Limits

i. Pendula released from greater than approximately 10 degrees

ii. Friction of components

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14. **Model for Gravitation**
   a. Written Statements – Explanations and Predictions
      i. The motion of an object in orbit does not depend on the object's mass.
      ii. The relationship the cube of the radius and square of the period is true for circular and elliptical orbits.
   b. Equations
      i. $\left(\frac{4\pi^2}{GM}\right)r^3 = T^2$
      ii. $\left|\vec{F}_G\right| = \frac{Gm_1m_2}{r^2}$
      iii. $U_G = -\frac{Gm_1m_2}{r}$
   c. Graphs
      i. Period versus radius
      ii. Energy versus radius
   d. Diagrams
      i. Force diagram
      ii. Free-body diagram
      iii. Energy bar chart (LOL diagram)
   e. Applications
      i. Rocket launches
      ii. Satellite orbits
   f. Limits
      i. Systems where objects orbit each other

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Section 7: Model for a Concept in AP Physics C

Written Statements – Explanations and Predictions	Equations
Graphs	Diagrams
Applications	Limits

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Adapted from AMTA Modeling Instruction and College Board resources.