DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS
AP PHYSICS

CHAPTER 5, CIRCULAR MOTION; GRAVITATION

LESSON 5-6, NEWTON'S LAW OF UNIVERSAL GRAVITATION
LESSON 5-7, GRAVITY NEAR THE EARTH'S SURFACE; GEOPHYSICAL APPLICATIONS

Big Idea(s):

- Objects and systems have properties such as mass and charge. Systems may have internal structure.
- Fields existing in space can be used to explain interactions.
- The interactions of an object with other objects can be described by forces.
- Interactions between systems can result in changes in those systems.

Enduring Understanding(s):

- 1.A: The internal structure of a system determines many properties of the system.
- 1.C: Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
- 2.A: A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena.

Enduring Understanding(s):

- 2.B: A gravitational field is caused by an object with mass.
- 3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.
- 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using .

Enduring Understanding(s):

- 3.C: At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.
- 4.A: The acceleration of the center of mass of a system is related to the net force exerted on the system, where .

Essential Knowledge(s):

- 1.A.1: A system is an object or a collection of objects. Objects are treated as having no internal structure.
  - A collection of particles in which internal interactions change little or not at all, or in which changes in these interactions are irrelevant to the question addressed, can be treated as an object.
- 1.C.1: Inertial mass is the property of an object or a system that determines how its motion changes when it interacts with other objects or systems.

Essential Knowledge(s):

- 2.A.1: A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector.
  - Vector fields are represented by field vectors indicating direction and magnitude.
  - When more than one source object with mass or electric charge is present, the field value can be determined by vector addition.
  - Conversely, a known vector field can be used to make inferences about the number, relative size, and location of sources.

Essential Knowledge(s):

- 2.A.2: A scalar field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a scalar. In Physics 2, this should include electric potential.
  - Scalar fields are represented by field values.
  - When more than one source object with mass or charge is present, the scalar field value can be determined by scalar addition.
  - Conversely, a known scalar field can be used to make inferences about the number, relative size, and location of sources.

Essential Knowledge(s):

- 2.B.1: A gravitational field at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field.
  - On the Earth, this gravitational force is called weight.
  - The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force.
  - If the gravitational force is the only force exerted on the object, the observed free-fall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in newtons/kilogram) at that location.

Essential Knowledge(s):

- 2.B.2: The gravitational field caused by a spherically symmetric object with mass is radial and, outside the object, varies as the inverse square of the radial distance from the center of that object.
  - The gravitational field caused by a spherically symmetric object is a vector whose magnitude outside the object is equal to .
  - Only spherically symmetric objects will be considered as sources of the gravitational field.

Essential Knowledge(s):

- 3.A.1: An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.
  - Displacement, velocity, and acceleration are all vector quantities.
  - Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values.
  - A choice of reference frame determines the direction and the magnitude of each of these quantities.

Essential Knowledge(s):

- 3.A.2: Forces are described by vectors.
  - Forces are detected by their influence on the motion of an object.
  - Forces have magnitude and direction.
- 3.A.3: A force exerted on an object is always due to the interaction of that object with another object.
  - The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object by other objects.

Essential Knowledge(s):

- 3.B.1: If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.

Essential Knowledge(s):

- 3.B.2: Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.
  - An object can be drawn as if it was extracted from its environment and the interactions with the environment identified.
  - A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force.
  - A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free-body diagram to the algebraic representation.

Essential Knowledge(s):

- 3.C.1: Gravitational force describes the interaction of one object that has mass with another object that has mass.
  - The gravitational force is always attractive.
  - The magnitude of force between two spherically symmetric objects of mass m_1 and m_2 is , where r is the center-to-center distance between the objects.
  - In a narrow range of heights above the Earth's surface, the local gravitational field, g, is approximately constant.

Essential Knowledge(s):

- 4.A.1: The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass.

Essential Knowledge(s):

- 4.A.2: The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time.
  - The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system.
  - Force and acceleration are both vectors, with acceleration in the same direction as the net force.

Learning Objective(s):

- (1.C.1.1): The student is able to design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration.
- (2.B.1.1): The student is able to apply to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems.
- (2.B.2.1): The student is able to apply to calculate the gravitational field due to an object with mass M, where the field is a vector directed toward the center of the object of mass M.

Learning Objective(s):

- (2.B.2.2): The student is able to approximate a numerical value of the gravitational field (g) near the surface of an object from its radius and mass relative to those of the Earth or other reference objects.
- (3.A.1.1): The student is able to express the motion of an object using narrative, mathematical, and graphical representations.
- (3.A.1.2): The student is able to design an experimental investigation of the motion of an object.

Learning Objective(s):

- (3.A.1.3): The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis using narrative, mathematical, and graphical representations.
- (3.A.2.1): The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation.
- (3.A.3.1): The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces.

Learning Objective(s):

- (3.A.3.3): The student is able to describe a force as an interaction between two objects and identify both objects for any force.
- (3.A.3.4): The student is able to make claims about the force on an object due to the presence of other objects with the same property: mass, electric charge.
- (3.B.1.1): The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations with acceleration in one dimension.

Learning Objective(s):

- (3.B.1.3): The student is able to reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object.
- (3.B.2.1): The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively.
- (3.B.2.1): The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively.

Learning Objective(s):

- (3.C.1.1): The student is able to use Newton's law of gravitation to calculate the gravitational force the two objects exert on each other and use that force in contexts other than orbital motion.
- (3.C.1.2): The student is able to use Newton's law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving orbital motion (for circular orbital motion only in Physics 1).
- (4.A.1.1): The student is able to use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively.

Learning Objective(s):

- (4.A.2.1): The student is able to make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time.
- (4.A.2.2): The student is able to evaluate using given data whether all the forces on a system or whether all the parts of a system have been identified.
- (4.A.2.3): The student is able to create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system.

Introductory Video: Force of Gravity

Reading Activity Answers

- Hyperlink to Reading Activity Answers

Newton's Law of Universal Gravitation

- Newton observed:
  - The force of gravity is inversely proportional to the square of the distance between two bodies
  - The force is directly proportional to the masses of the two bodies
  - There exists a constant of proportionality, called the Gravitational Constant, between the force of gravity and the masses and distance between two bodies

Newton's Law of Universal Gravitation

- Newton was never able to measure the gravitational constant
- The constant was not accurately measured until over 100 years after Newton proposed it

$$G = 6.67 x 10^{-11} \frac{Nm^2}{kg^2}$$

Newton’s Law of Universal Gravitation

- *Every particle in the universe attracts every other particle with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between them. This force acts along the line joining the two particles.*

$$F = G\frac{m_1 m_2}{r^2}$$

Newton's Law of Universal Gravitation

- For bodies that are relatively close together, ***r*** refers to the distance between the two bodies' centers of mass
  - e.g., a satellite orbiting the earth
  - This means that *r* is equal to the radius of the earth plus the height above the earth's surface

$$r = r_{earth} + h$$

Newton's Law of Universal Gravitation

- For two bodies whose distance between them is very large with respect to their radii, these bodies can be considered as point masses

$$r_{earth} = 6.38x10^3 km$$

$$r_{sun} = 6.96x10^5 km$$

$$d_{earth-sun} = 1.50x10^8 km$$

What is ‘g’?

- What is the acceleration due to gravity (g) 1000km above the surface of the earth?

$$F = mg = G\frac{mM_e}{r^2}$$

$$g = G\frac{M_e}{r^2}$$

What is ‘g’?

- What is the acceleration due to gravity (g) 1000km above the surface of the earth?

$$g = G\frac{M_e}{r^2}$$

$$G = 6.67x10^{-11}\,N \cdot m^2 / kg^2$$

$$m_e = 5.98x10^{24}\,kg$$

$$r = r_{earth} + h$$

$$r = 6{,}380km + 1000km$$

$$r = 7.38x10^{6}\,METERS!$$

What is ‘g’?

- What is the acceleration due to gravity (g) 1000km above the surface of the earth?

$$g = G\frac{M_e}{r^2}$$

$$G = 6.67x10^{-11}\ N \cdot m^2 / kg^2$$

$$m_e = 5.98x10^{24}\ kg$$

$$r = 7.38x10^{6}\ m$$

$$g = \left(6.67x10^{-11}\right)\frac{\left(5.98x10^{24}\right)}{\left(7.38x10^{6}\right)^2}$$

$$g = 7.32\ m/s^2$$

What is 'g'?

- What is the acceleration due to gravity (g) ***at*** the surface of the earth?

$$g = G\frac{M_e}{r^2}$$

$$G = 6.67x10^{-11}\, N \cdot m^2/kg^2$$

$$m_e = 5.98x10^{24}\, kg$$

$$r_e = 6.38x10^{6}\, m$$

$$g = \left(6.67x10^{-11}\right)\frac{\left(5.98x10^{24}\right)}{\left(6.38x10^{6}\right)^2}$$

$$g = 9.80\, m/s^2$$

Gravity Near the Earth's Surface; Geophysical Applications

- Gravity is not the same all over the world:
- ***How come?***

Gravity Near the Earth's Surface; Geophysical Applications

- Gravity is not the same all over the world:
  - Earth is not a perfect sphere
  - Earth's terrain is not uniform
  - Earth's mass is not distributed precisely uniformly
  - Earth's rotation has an effect on g
  - Varies locally due to the presence of composition irregularities and rocks of different densities

Gravity Near the Earth's Surface; Geophysical Applications

- Precise measurements at a given location needed for sensitive experiments
- Slight reductions in the value of g have often led to discoveries of oil

Sample Homework Problems

- #28

$$F = G\frac{m_s m_e}{r^2}$$

$$G = 6.67x10^{-11}\, N \cdot m^2 / kg^2$$

$$m_s = 1350kg$$

$$m_e = 5.98x10^{24}\, kg$$

$$r = r_{earth} + h = 6{,}400km + 12800km$$

$$r = 1.92x10^7\, METERS!$$

Sample Homework Problems

- #28

$$F = G\frac{m_s m_e}{r^2}$$

$$F = \left(6.67x10^{-11}\right)\frac{(1350)\left(5.98x10^{24}\right)}{\left(1.92x10^{7}\right)^2}$$

$$F = 1461$$

- ***What are the units?***

Sample Homework Problems

- #28

$$F = G\frac{m_s m_e}{r^2}$$

$$G = 6.67x10^{-11}\ N \cdot m^2 / kg^2$$

$$m_s = 1350kg$$

$$m_e = 5.98x10^{24}kg$$

$$r = 1.92x10^{7}\ METERS!$$

- ***Newtons!***

Sample Homework Problems

- #40

$$\Sigma F = F_J + F_S - F_v$$

$$F = G\frac{mm_e}{r^2}$$

$$G = 6.67x10^{-11}\ N \cdot m^2 / kg^2$$

$$m_e = 5.98x10^{24} kg$$

$$r = d_s - 1.5x10^{11}$$

$$F_J = G\frac{(318m_e)m_e}{\left[(7.78 - 1.5)x10^{11}\right]^2}$$

$$F_J = 1.98x10^{18} N$$

Sample Homework Problems

- #40

$$\Sigma F = F_J + F_S - F_v$$

$$F = G\frac{mm_e}{r^2}$$

$$G = 6.67x10^{-11}\, N \cdot m^2 / kg^2$$

$$m_e = 5.98x10^{24}\, kg$$

$$r = d_s - 1.5x10^{11}$$

$$F_S = G\frac{(95.1m_e)m_e}{\left[(14.3 - 1.5)x10^{11}\right]^2}$$

$$F_S = 1.38x10^{17}\, N$$

Sample Homework Problems

- #40

$$\Sigma F = F_J + F_S - F_v$$

$$F = G\frac{mm_e}{r^2}$$

$$G = 6.67x10^{-11}\ N\cdot m^2/kg^2$$

$$m_e = 5.98x10^{24}kg$$

$$r = d_s - 1.5x10^{11}$$

$$F_V = G\frac{(0.815m_e)m_e}{[(1.08-1.5)x10^{11}]^2}$$

$$F_V = 1.10x10^{18}N$$

Sample Homework Problems

- #40

$$F = G\frac{m_s m_e}{r^2}$$

$$G = 6.67x10^{-11}\ N \cdot m^2 / kg^2$$

$$m_e = 5.98x10^{24}\,kg$$

$$m_s = 1.99x10^{30}\,kg$$

$$r = 1.5x10^{11}$$

$$F_{Sun} = G\frac{m_s m_e}{\left[(1.5)x10^{11}\right]^2}$$

$$F_{Sun} = 3.53x10^{22}\,N$$

Sample Homework Problems

- #40

About
3 hundred-
thousandths

$$\Sigma F = F_J + F_S - F_v$$

$$\Sigma F = 1.98x10^{18} + 1.38x10^{17} - 1.10x10^{18}$$

$$\Sigma F = 1.02x10^{18}$$

$$F_{Sun} = 3.53x10^{22}$$

$$\frac{F_{planets}}{F_{Sun}} = \frac{1.02x10^{18}}{3.53x10^{22}} = 2.89x10^{-5}$$

Enduring Understanding(s):

- 1.A: The internal structure of a system determines many properties of the system.
- 1.C: Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
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QUESTIONS?

Homework:

#28-41