INTERNATIONAL
TENNIS HALL OF FAME

The Physics of Tennis

Lesson 2: Gravity and the motion of the ball in the game of tennis

Unit Overview: This unit activity provides an excellent opportunity for teachers to introduce the concept of the acceleration of freely falling objects (neglecting air resistance) produced by the force of gravity. It also reinforces overall a systems approach as identified and required in the new Next Generation Science Standards (NGSS). Middle and high school level students in this unit investigation will learn that there are a lot of physics principles and mathematics involved when you try to analyze and understand the game of tennis. Whether you simply hold a tennis ball as you get ready to serve it, or are analyzing the motion of all of the game's components when the game is being played, this complex interactive game can be *modeled.*[1] That is done by asking the right *investigable*[2] questions and calling upon simple principles of Newton's Laws of motion and energy relationships. This unit will support implementation of the ***Next Generation Science Standards*** and add classroom instructional value to a visit to the International Tennis Hall of Fame.

Objectives:

Students will be able to-

- Understand the role of the unbalanced force of gravity during the game that produces acceleration.
- Understand the role of inertia when a ball is in flight based on Newton's First Law.
- Calculate the weight of a tennis ball at the high school level (the gravitational force.)
- Identify boundaries of the system.
- Identify the types of energy used in this system. (restricted to potential & kinetic energy)
- Understand the introduction of inputs and outputs.

Lesson Time Required: 1 class period

Next Generation Science/Common Core Standards:

- NGSS MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

- N G S S HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Possible Sources:

- video of a serving motion
- *Beginning Tennis* by Julie Jensen

Materials Needed:

- tennis ball
- paper
- Styrofoam cups
- water
- plastic bins or basins
- drop cloths

Vocabulary:

- Gravity- or gravitation, is a natural phenomenon by which all things with mass are brought toward one another, including planets, stars and galaxies
- Inertia- a property of matter by which it continues in its existing state of rest or uniform motion in a straight line, unless that state is changed by an external force.

Lesson & Activity

The force of gravity is what allows the game of tennis to be played. Without gravity, the ball wouldn't come down and bounce in the court after it was hit. A tennis ball is constantly undergoing acceleration because it is acted on by the force of gravity. The force of gravity always is acting downward on the ball, and is perpendicular to the court surface. An equation for the magnitude of the force of gravity on the ball it is given by the equation:
$F_g=mg$ where F_g is the weight of the object; m is the mass in kg of the object; and g is the acceleration due to gravity. On the earth the average value is 9.8 m/s^2, but it does enough in different locations to affect the motion of the ball.
When a ball is served there are several options, but it can be modeled as a simple motion of the ball and racquet, especially in the most common flat serve. The ball is thrown straight up and then allowed to fall under the influence of gravity. The player then times his swing to hit the ball, slightly downward to add speed but the best pros try to keep the serve to a horizontal contact, so the ball essentially moves straight ahead at the time of impact and then on a parabolic path like any projectile. A lot of

physics texts always seem to include discussions of rifle shots or cannons, but this is a great sample for students, that have more appeal. That parabolic motion can be thought of in two dimensions; horizontal motion and vertical motion.
First, the students should investigate acceleration with normal lab experiments at both the middle school and high school level. They can do this by rolling tennis balls down an incline, for example.

Focus Question: How does the force of gravity affect the ball during the game of tennis?

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1. Describe how the force of gravity and other forces act on a ball during a tennis game. Include:
   - When the ball is in the player's hand.
   - When the ball is thrown upward as it moves.
   - When the ball starts to come down.
   - When the ball is hit by a racquet.
   - When the ball leaves the racquet after being hit forward.

Focus question: Do all objects fall at the same rate?

1. Explain Galileo to the students.
2. Utilize a volunteer student. First, ask students to make a prediction: which would fall faster, a tennis ball or a piece of paper?
3. Drop the ball and flat paper, not at the same time. Then ask them to predict what would happen if you dropped both at the same time from the same height. Ask them to justify their prediction. Most students would rush to the prediction that the paper will fall slower because it is lighter than the ball.
4. Drop the ball and the paper, crumpled up into a tight ball, at the same time to have them see that they fall at about the same rate. Ask them: is the paper lighter than it was before because it is merely crumpled up into a ball shape? Have them generate a claim based on the evidence they have observed.
5. Next, we want to have students collect more evidence to support the claim that all objects, including the tennis ball, will fall at the same rate, neglecting air resistance.
    a. Each group will need a Styrofoam cup, water, and a plastic bin/basin.
    b. Students should punch a small hole through the side of the cup near the bottom
    c. Students should place their thumb over the hole and fill the cup with water up to the line near the top rim of the cup
    d. Ask the students what will happen to the water inside the cup if they remove their thumb from the hole. Have them write down their predictions.

e. The students will then remove their thumbs from the hole and allow a small amount of water to stream from the hole, falling into the empty bin/basin. Let them observe how the water comes out of the cup (a parabolic path). Teachers can then introduce the parabola if necessary.
f. Quickly students should replace their thumb on the hole and refill the cup.
g. Ask students what would happen if they were to release the cup, will the water flow from the hole during the fall?
h. Have a student in each group stand on a chair and release the cup so that it is released from a greater height.
i. Students observe that the water does not leak out as it falls due to gravity as the cup and contents are falling at the same rate.

6. What did they observe in this experiment?