2007
Winning Lesson Plan
from Aurora, Colorado

Modeling the Drag Force of Spherical Balls in Glycerin
and
Indoor Sky Diving Lab

by
Carolyn Denise Evans Crapo
Grandview High School

Subject: AP Physics C
Grade Level: 12
Duration: Three 90-Minute Class Periods

Overview and Purpose

The purpose of this unit is for students to learn about what drag force is, the factors that affect it, and how it relates to terminal velocity. They also will learn how to solve problems using drag force equations. The unit lasts for three 90-minute class periods. The first period is spent on lecture and class discussion regarding drag forces. The second is spent doing a lab in the classroom called Modeling the Drag Force of Spherical Balls in Glycerin. During the third class period, the students go on a field trip to SkyVenture Colorado, an indoor sky diving facility. There, they perform a lab to find their drag coefficient.

Colorado State Science Standards Addressed:

Standard 1: *Students understand the processes of scientific investigation and design, conduct, communicate about, and evaluate such investigations.*

This standard is addressed through the two laboratory assignments in this unit. During these labs, students conduct investigations, communicate their results and evaluate the data they measured.

Standard 2.3: *Students understand that interactions can produce changes in a system, although the total quantities of matter and energy remain unchanged…What they should know and are able to do includes describing and predicting physical interactions of matter (for example velocity, force, work and power).*

This standard is addressed through the content studied. Students learn how drag forces change physical interactions and learn how to predict those changes.

Standard 6: *Students understand that science involves a particular way of knowing and understand common connections among scientific disciplines…What they know and are able to do includes using graphs, equations or other modes to analyze systems involving change and constancy,…[and] identifying and testing a model to analyze systems involving change and constancy.*

This standard is addressed through students graphing the data taken in the Glycerin Lab, and then through the students using the graphs to decide on an appropriate general model for the drag force of spherical balls in glycerin.

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Objectives

By the end of the unit, the students will be able to:

- State the factors that affect drag force of an object in various situations.
- Understand the two most common models for drag forces, and use laboratory data to decide which model best fits a given situation.
- Find the terminal velocity of an object moving vertically through a fluid that exerts a drag force proportional to velocity.
- Use the drag force models to solve problems with regard to predicting the velocity, drag force, surface area, etc. about a given object.

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Modeling the Drag Force of Spherical Balls in Glycerin

Introduction:

Because air resistance is difficult to measure, we will instead be finding the drag force on ball bearings dropped in glycerin. Experiments show that sometimes drag force is proportional to velocity and sometimes to the square of velocity. For spheres, “b” is typically proportional to radius and “c” is typically proportional to area. In all cases, the direction of the drag force is opposite to the direction of motion. The objective for this lab is to determine which model best fits ball bearings in glycerin and to find the constant “b” or “c.”

Materials:

- Large Glass Graduated Cylinder
- 5 spherical balls of varying mass and size
- Digital Video Camera with fire-wire cable
- Macintosh computer with IMovie installed
- Balance
- Meter stick
- Calipers
- Glycerin

Preliminary Questions:

- When the ball reaches terminal velocity, draw a force diagram for it. Using the fact that Fd = bv or Fd = cv2, write a sum or the forces equation and solve for terminal velocity (vt) and vt2 respectively.
- How will these relationships help you figure out which model best describes the drag force on the ball bearings? What could you graph to figure this out?

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Procedure:

1. Fill the graduated cylinder with glycerin to about 10 cm from the top.
2. Find the mass and radius of each ball and record in your data table.
3. Set the camera to record and videotape each ball being dropped into the glycerin.
4. Rewind the camera, connect the camera to the computer and import the videos.
5. Put an overhead transparency on the screen and choose a time interval from 0.01 to 0.10s, and mark where the bearing is after each interval you chose. Record the time interval you picked in your data table.
6. When the ball reaches terminal velocity, the spacing should become constant. Record several displacements during this terminal velocity section.
7. Repeat for each ball.

Analysis:

1. Find the average displacement for each ball. Use this to find average terminal velocity.
2. Graph vt vs. mass. On a separate graph plot vt2 vs. mass.
3. To see if the constants b and c are proportional to r and area respectively, plot "radius*vt " vs. mass and "cross sectional area*vt2 " vs. mass.
4. You can use your graphs to determine which model best fits the data. Fit a straight line to each graph. The best model will be the one in which the best-fit line closely resembles the data and goes through the origin (0,0).
5. Find a regression line for whichever graph appears to be a better fit for the data. Using the slope of your regression line find the constant "b" or "c" from the drag force equations. Then write the drag force equation you discovered from this lab. Note: If your best graph was either the rv or Av2 one, the constant will be a function of r or A.

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Indoor Sky Diving Lab

Objective:

This activity is to experience drag forces, to measure your drag force, and to find the drag coefficient for a person skydiving.

Background Information:

The drag force on an object always opposes motion and is always dependent on the velocity with respect to the medium through which the object is moving. The two most common models are that $F_d = bv$ or $F_d = cv^2$, where v is the velocity of the object and b and c are constants. The appropriate model is found by experiment. The model that most closely matches skydiving is $F_d = cv^2$. Specifically the constant c depends on the density of the medium (ρ), the cross-sectional area of the object (A) and a drag coefficient (D). This makes the equation for drag force, $F_d = \frac{1}{2} D\rho Av^2$. An object will keep falling until it reaches terminal velocity. At this speed, the force of gravity balances the drag force and the object stops accelerating. The wind tunnel simulates this terminal velocity because the sum of the forces when an object moves at constant velocity and when an object is at rest are both zero.

Materials:

Bathroom scale, meter stick

Procedure:

- Measure your mass in kilograms.
- We will approximate your cross sectional area as two rectangles, one for your body and one for your head. Find this approximate cross sectional area by doing the following:
  - Measure your height from the floor to the top of your shoulders.
  - With the help of your lab partner, measure the width of your back right under your armpits. Make sure to not wrap around, simply find the distance across the back.
  - Measure the height of your neck and head, beginning at your shoulders and measuring to the top of your head.
  - Measure the width of your head, measuring about at nose level.
- When in the wind tunnel, have a partner record the speed of the air necessary to keep you at rest in the tunnel. The speed is on the screen in front of the controller's booth.

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Indoor Sky Diving Lab (Cont'd)

Data and Preliminary Calculations:

Mass	kg
Height of Body	m
Width of Back	m
Area of Body rectangle	m^2
Height of Head	m
Width of Head	m
Area of Head rectangle	m^2
Velocity of Air	mi/h
Velocity in	m/s
1609 m=1mile)	m/s

Sky Diving Analysis:

- When the person is at rest, what is the acceleration of the person at that time? Therefore, what is the sum of the forces on the person?
- At that time, draw a force diagram of the person.
- Using the diagram and your mass, find the magnitude of the drag force.
- When you are at rest in the tunnel, what does the velocity of the air represent in terms of a normal sky diving situation?
- In sky diving, you never actually stop, why can we simulate the condition above while at rest? (Think about the sum of the forces in both situations).
- Using the drag force found, the air's velocity, your area, and the density of air (which is 1.21 kg/m^3), find the drag coefficient (D) for a skydiver in the tunnel.
- In the tunnel, if you want to move up, how do you do that? Why does this work? What would happen if you did this in actual freefall? Would you still move up? Explain.
- In the tunnel, how do you spin in a circle? Why do you think this makes you spin?