



DNAZone Classroom Kit

Kit title	Vortex Rings
Appropriate grade level	Grades 9-12
Abstract	<p>This experiment seeks to sharpen students' ability to observe, document and draw conclusions from a complex and visually appealing phenomenon. The elements of setting up controls in an experiment are emphasized. The intent is to shape the student's ability to design an experiment and to study and understand chosen aspects of a real-world phenomenon. The basic procedure involves dropping dye into water, which in many instances results in the formation of a vortex ring. Instability in the ring builds and the ring breaks into smaller drops which form a new set of rings. This process may repeat itself several times to create a cascade of rings. Vortex motion is widespread in the air and water that surround us, and this experiment makes it visible.</p>
Time	120-minute lab period
PA Department of Education standards met with this kit	<p>Pennsylvania Common Core Standards for Reading & Writing in Science and Technical Subjects cc.3.5.9-12.D cc.3.5.6.9-12.A-F, I</p> <p>Pennsylvania Academic Standards for Science & Technology Inquiry & Design 3.2.10-12.B-D</p>
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Objectives:

- Students will use scientific inquiry to pose questions and arrive at answers while observing a simple natural phenomenon.
- Students may be able to analyze observations in mathematical or graphical form.
- Students will use deductive and inductive reasoning in analyzing patterns and relationships of observed phenomena.
- Students will design a lab procedure that can enable them to study an aspect of the observed phenomenon.

Class Time: two 45-minute periods, minimum

Teacher Preparation Time: 30 minutes

Material Needed:

- tall clear containers (preferably square)
- hot/cold water
- thermometer
- food dye
- ruler
- eye dropper
- stopwatch
- video camera and TV (optional)

Background Information for Students:

Students need little background information for the lab. For an advanced approach, the teacher may introduce notations of density, viscosity, surface tension, miscibility, diffusion and convection prior to the experiment.

Background Information for Teacher:

This exercise has proven to be very engaging to anyone who tries it. It can be as simple or as complex as the teacher desires. This lab is designed to teach students the steps of the scientific inquiry process. It can also be modified and used to teach students the concepts of displacement and velocity.

Students observe vortex rings that occur when a drop of dye is released into a liquid. Initially, a single vortex ring forms; after traveling downward a certain distance, instabilities cause the primary ring to break into a "cascade" of smaller rings. The individual smaller rings then travel until they too become unstable and break into individual mini cascades. The cascade process can happen up to four times. Based on their observations of the vortex rings, students design and carry out an experiment to determine the effect of changing one variable on some chosen aspect of the phenomena observed.



Advanced investigations that take into consideration introductory concepts of fluid mechanics can also be done. In general, diffusion, convection, density, viscosity, and interfacial tension all play a role in vortex ring formation, motion and stability. A more advanced discussion may include concepts of cascades, stability of rings and the role of vortex motion in fluid mixing. See reference for more information.

Tips for the Teacher:

- The biggest limiting factor for the teacher is that the water has to be completely still before the lab is performed. The teacher must put the water in the container at least an hour before the lab.
- The lab may be introduced several different ways:
 - The teacher may start with a demonstration of the apparatus and then let students make observations at a lab station.
 - The teacher may present the apparatus and then let the students make observations.
 - The teacher may set up several different lab stations and guide the students to make observations at each.
- Measurable variables include but are not limited to the following:
 - release height of drop above water
 - number of cascades formed
 - vertical position of vortex ring
 - distance before ring breaks into a cascade of smaller rings
 - horizontal position of vortex ring
 - ring diameter
 - release distance from container wall
 - velocity of vortex ring (measure position as function of time)
 - temperature of the dye or water
 - size of the drop
 - dye color and mixing of different colors
 - different concentrations of solutes in the water
 - density of dye
- The number of containers of water per lab group should equal the number of variations being measured in order to have the water fully “settled.” Students can do 3 – 5 trials per container by moving the location of the syringe.
- The plate with a hole for the syringe is both for bracing the syringe and for placing the dye drop at various locations in the container. If rested on a ring clamp attached to a ring stand, the height of the plate can be varied.
- Generally, the best rings formed by having the dye drops just touch the water surface. If the drop is released too high (>8 cm or so), there is significant dispersion and a slower moving primary ring.

- One method of measuring the velocity of a vortex ring is to mark the location of the vortex ring at regular time intervals. Student A is assigned the task of dropping the dye into the water. Student B uses a stopwatch to count off regular time intervals. Student C watches the path of the vortex ring and marks the plexiglass with a dry erase marker at the level of the ring when each time interval is called. When a ring cascades into a set of smaller rings, the student randomly picks one of them to follow.
- Measuring the average velocity of each cascade is possible with four students working as a team. Student A is assigned the task of dropping the dye into the water. Student B times the event with a stopwatch, starting at the moment the drop hits the water. When the first cascade occurs, student C marks the level of one (randomly picked) cascade and student B hits the lap time button on the stopwatch. Student D records the time. At each succeeding cascade, student B hits the lap time button twice so that the student D can record each time of a cascade. This method needs teamwork! Each group should practice dropping dye several times before actually taking measurements.
- Successful experiments have been done measuring velocity as a function of dye color, drop height and water temperature.
- Larger drops usually produce four cascades. Smaller drops only produce two or three. Using scissors, drop size may be changed by cutting the nozzle of the syringe. Make sure the edge of the nozzle made by the cut is even.
- The longest-lived primary ring is seen at 40-50 C. At higher water temperatures, natural convection in the container distorts the ring cascade. At lower temperatures, primary ring travels a shorter distance before splitting, so more cascade steps may be seen. Subrings tend to rotate around the primary ring in warm water.
- The range for changing dye density is very small as it will start to dissipate when diluted even a small amount. It is difficult to manipulate the density of the water by additions of a salt solute because the higher density salt water settles to the bottom of the container over time. The density of the dye may vary with color.
- With cooking oil as ambient fluid, dye is heavier than cooking oil and sinks as spheres to the bottom (no rings). This is a consequence of the immiscibility of the dye and the oil. Some degree of miscibility is required for the rings to form.
- To change surface tension, try mixing soap with the water or placing a thin layer of oil on top of the water before putting the dye in it.
- It is known that better rings form if the dye is more viscous. To date, an attempt has not been made to change the viscosity of the dye.
- Use of a video camera and TV to playback frames allows a more quantitative study of shape changes and primary ring speed (from the image of the cm scale next to the container). A video camera also aids students in actually seeing the vortex rings and their motions.



Answers to Questions:

Annotated Reference:

N. Baumall, D.D. Joseph, P. Mohr, and U. Renardy, "Vortex Rings of One Fluid in Another in Free Fall", *Physics of Fluids A* v4(3), p567, Mar 1992.



VORTEX RINGS

Name: _____

Partners: _____

Introduction: What do you expect will happen when you let a drop of food coloring fall into a container of still water? Will it spread throughout the water? Will it drop to the bottom of the container as a bead? Will it do something else? Today you will have a chance to try this and observe what happens.

Procedure:

1. Fill a syringe with dye (food coloring).
2. Carefully put the syringe in the hole of the square plate.
3. Place the plate on top of the container of water.
4. Slowly push on the syringe so that a drop begins to form. The drop will release just as it touches the water.
5. In the space provided, write anything you observe that happens to the drop of dye.
6. Repeat steps 4 and 5 several times by moving the plate so that the hole for the syringe is over a different location in the water.
7. What happened when you dropped the dye into the water? Give a complete description (written or labeled diagram) for as many observations as you can make.

Observations of dye in water:



Experimental Design

1. List at least six items that you can measure when you drop the dye in the water.

2. What one item are you going to vary in this experiment? This is known as the "independent variable."

3. What one item are you going to measure in this lab? This is known as the "dependent variable."

4. List the remaining items from question 1 that do not include the independent or dependent variable. These items must not be varied and are called the "constants" or "controls." (If they do change, it is very difficult to determine the effect of the independent variable on the dependent variable.)

5. Write a statement that describes what you think will happen to your dependent variable when you change your independent variable. This is known as the hypothesis.

6. Write an experimental procedure based on your hypothesis. Be sure to include controls, the independent and dependent variables along with safety concerns.



Data:



6. Write an experimental procedure based on your answer to number 5.

7. a. Where do you see vortex motion in the real world?

b. How are they like the vortex rings seen?

c. How are they different from the rings seen?