The Physics of Explosive Eruptions

Objectives

1. To investigate and experiment with the controls on explosive volcanism including ballistics velocity, column height, vesicularity, and tephra distribution and their relationship to column height.
2. To work with equations governing some of those concepts, using data collected from the experimental part of the lab.
3. To either entice and hopefully not deter prospective students and their parents from coming to Colgate during April Visit Days.

You will be using liquid nitrogen and containing it in plastic bottles, which are then immersed under water in a trash can. The liquid nitrogen will expand then burst the bottles, sending water into the air. This simulates the process behind an eruption column (i.e., a gas-driven eruption). You should assume the water plays the role of the volcano itself (the rock), the expanding nitrogen is the gas in the magma, and the water column is equivalent to the eruptive plume.

Stuff to Bring to Lab:

1. Rain gear and/or clothes that can get wet and muddy if you don’t like getting wet and muddy.
2. Covered shoes (everyone please remind Schlitsky (Schlitzer’s new name) and Erma (that is not a typo, Emma likes to be called Erma, just ask her) to do this especially).
3. Warm clothes if it’s cold out.
4. Calculators.
5. Tables prepared in advance for each experiment, for easier recording of data. You can bring your field books from the field trip if you have them because they can handle being written on if wet, and they will get wet.
7. Someone in each group should bring a digital camera.

I. Trash Can Experiments to Design

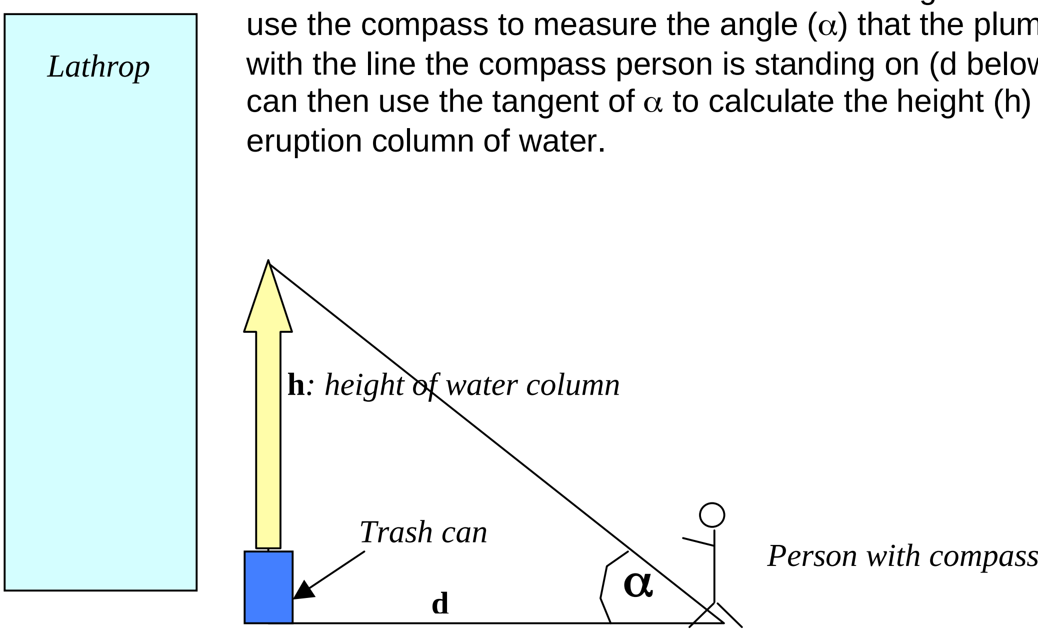
a) **Test run.** Before you do any formal experiments, you have to do one test "eruption" with either the TA or me watching, so that we can check for proper procedures. This will include a dry run (without liquid nitrogen), then a real one.

b) **Simple eruption column**. The goal is to measure the height of the eruption column and to perfect that method for your subsequent experiments. You will also use these data in some calculations (below).

i) Use about 50 mL of liquid nitrogen, which is <1/4 of an individually sized soda bottle. This can be approximate, but estimate the volume you used and record it. If you use a lot more or less, then record it for adjusting your calculations later.

ii) Use an individually-sized soda bottle for this experiment.

iii) To measure height, you need to get a Silva compass from me or someone in your group. Someone who knows how to use it should be stationed some measured distance (use the tape measure) from the trash can, along with some observers. If you don't know how to use it, talk to one of us. During the eruption, have the person standing on the line watch the plume carefully and note where it reached relative to the building behind it. Then use the compass to measure the angle (α) that the plume made with the line the compass person is standing on (d below). You can then use the tangent of α to calculate the height (h) of the eruption column of water.



(In case your trigonometry is rusty, tangent of an angle = opposite over adjacent = h/d).

Now you will be working with individual parameters that control the eruption. Your goal is to produce a data table and a graph for each experiment, along with a summary of your results in a paragraph. You may have to make approximations for some of your measurements, but do your best and explain your assumptions for each experiment. **For every eruption, record the column height, amount of liquid nitrogen used (approximately), depth of water in the can, and type of bottle used, along with any other relevant details or parameters you vary.**

b) DO TWO OF THE FOLLOWING TYPES OF EXPERIMENTS:
NOTE: This means planning these AHEAD of time.

1. Design a series of experiments to test the control of gas pressure on column height. Record your results quantitatively in an organized, labeled table. **You should do at least 3 experiments in this category to collect data.** It will be difficult to measure all parameters, in which case just do the best you can or use qualitative descriptors of things like gas pressure.

The question you are trying to answer is: how does the gas pressure (i.e., that builds up depending on the strength of the bottle) control the height of the column? This experiment is like varying the intensity of the eruption. The logistical problem here is that you can't measure gas pressure under these conditions. You can vary the amount of liquid nitrogen in your bottle (but that doesn't really control gas pressure) and (more appropriately) the strength of the bottle with the same amount of liquid nitrogen in it each time. Soda bottles are designed to withstand greater pressures than water bottles are, so pressure will be higher in them than in water bottles.

2. Design a series of experiments to test the effects of overlying rock pressure on column height. In this case, depth of water is equivalent to the overlying rock burden. **You should do at least 3 experiments in this category to collect data.**

3. Design a series of experiments to test parameters related to tephra distribution. Be sure that you pick up ALL TEPHRA right after you've recorded the results so that other people can use it. This also requires multiple experiments.

i. **How does column height/intensity of the eruption affect tephra distribution**? Consider distance, pattern of distribution, etc. Try making an isopach map (contours of equal tephra thickness) to illustrate your results. Tape measures are available.

ii. **Or how is distribution of tephra of different densities affected by the intensity of the eruption**? Again, consider distances and distribution patterns. Try to make an isopleth map (contours of equal clast sizes or densities) to illustrate your results.

c) **Base Surge** This is just an analog experiment, not one you have to graph or anything. This doesn't have to be quantitative, but try to capture it on film if you can. Try to reproduce a base surge (we talked about this in class awhile back, look it up if it's not familiar). It's the result of a collapsing eruption column. What were the essential conditions you had to achieve to reproduce a base surge, if you did? Why did you not succeed, if you didn't?

II. Experimental Procedure

IMPORTANT TO READ VERY VERY CAREFULLY

BEFORE YOU DO ANYTHING ELSE:

a) **Make sure everyone has safety glasses ON.**
b) **Establish a system to warn EVERYONE in your group when an eruption is about to take place.**
c) **Assign 1 person the task of watching the perimeter for innocent bystanders, but the others in the group must be aware of them as well. If this person calls out that someone is in the way, you must abort the experiment *immediately*. NEVER begin pouring liquid nitrogen UNTIL everyone in your group (including the perimeter watchers) have called it CLEAR.**
d) **Just to re-iterate…NEVER begin pouring liquid nitrogen until all members of your group are present, accounted for, have determined that the area is free of clueless individuals, AND have acknowledged that they are paying attention. Everyone has to be focused on the experiment.**
e) **Do a dry run of the entire process before handling any liquid nitrogen. You'll have to show one of us a dry run before we'll let you have it, so rehearse it and then get checked out with us. Read the instructions below and practice it twice, including clearing the area, then come get one of us and we'll issue liquid nitrogen once we've seen your lean, mean, explosives team's system.**
f) **Consider selecting an official note taker to keep track of your results, but rotate through the various jobs.**

INSTRUCTIONS FOR A GENERIC TRASH CAN EXPLOSION:

1) Contact with liquid nitrogen can be extremely dangerous and damaging. Its low temperature (< -200°C) will give you major burns should it contact your skin and can do permanent damage to your eyes (hence the safety glasses). Sealing liquid nitrogen in closed containers only makes this more dangerous, because of the potential for explosion. You must always act very *very* quickly and efficiently to get the sealed container underwater as fast as possible; no explosions are allowed above water, they are too dangerous because of plastic shrapnel and potential ear drum damage. Always wear gloves and safety glasses if you are anywhere in potential contact with liquid nitrogen; glasses only if you are on the perimeter. Consider yourselves informed.

2)	For safety reasons, it is essential to do a practice run of this entire procedure prior to pouring liquid nitrogen into the soda bottle, in which all participants rehearse their roles several times, basically a "dry" run.

3)	Fill the trashcan about 3/4 full of water (or however full you need for your experiment, but it *must* cover the explosive charge completely every time). It works best if you put the trash can on cement or a paved surface, not grass, and never on a cart (these will be damaged by the downward force of the blast). **Because of the design of trash cans these days, you need to make sure your can is sitting in a pile of sand (contained in a garbage bag) so that the indentation on the bottom of the can is entirely filled by sand from underneath.**

4)	Take a soda bottle and duct tape it to a cinder block (we're not using bricks this year), very thoroughly (i.e., not just one swipe of the tape). You should try to jam the bottle into the cinder block's hole and tape from there.

5)	Set the bottle upright on the ground with the funnel in it.

6)	Keep the funnel far enough out of the opening so that there is an air outlet for the bottle, otherwise you get bubbling liquid nitrogen splattering all over, and the bottle doesn't get filled fast enough. The person doing this should be wearing gloves and safety glasses.

7)	The second person (also in gloves and safety glasses) pours about 50 mL of liquid nitrogen into the bottle through the funnel (this is not a precise measurement; it's basically about an inch of liquid nitrogen into the bottom of the bottle; do not fill up the bottle or the demo will be a bust, you need room for the gas to expand).

8)	The person holding the funnel then tosses it aside quickly (time is of the essence at this point) and tightly caps the bottle.

9)	You then have about 10 seconds to get the block/bottle apparatus submerged in the garbage can. Place it gently in the can so that you don't tip it over sideways. Try to get it in the center of the can and not against a side, where it is more likely to blow out the plastic.

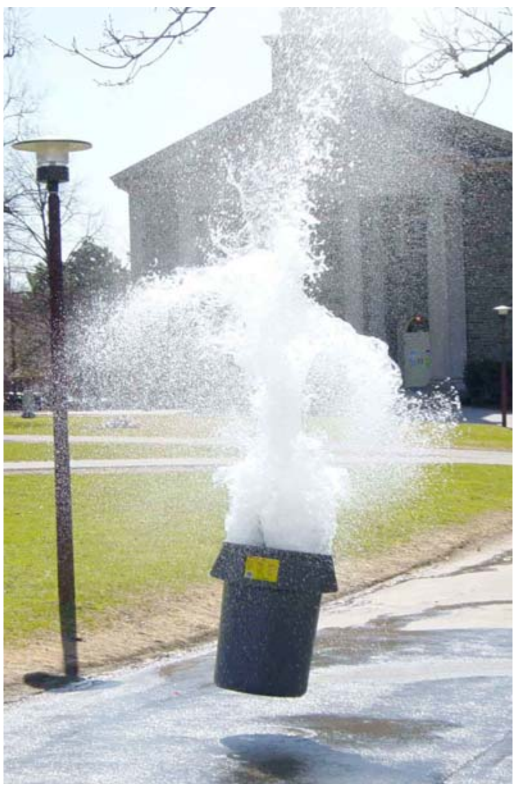
10) Back away quickly but calmly.

11) Then wait. The liquid nitrogen, at an unstable cold temperature, tries to equilibrate with its surrounding temperature by undergoing a phase change into a gas. This small amount of liquid expands (at standard temp and pressure) to well over 20 L, a volume considerably greater than the volume of the soda bottle. Because they are built to sustain overpressures from carbonated drinks, the bottle can resist the expansion while pressure builds substantially. Eventually the bottle fails, and the pressure wave due to the expansion passes into the water, resulting in a pressure-driven eruption column of water. The garbage can takes an impressive jump occasionally as well (jumps higher on concrete than on grass of course).

12) Keep everyone at least 10 feet away from the trashcan. If it doesn't explode immediately, do NOT approach it to check to see what's going on. It can take as long as 30 seconds depending on outside temperature and other factors. If you see "steam" bubbling out of the can (that's just escaping liquid nitrogen), then you may have a leak in the cap or bottle, and it may or may not explode. Again, wait several minutes before going near it. If after several minutes nothing happens, first call one of us over, then go and investigate, but carefully and with glasses on.

13) Normally you will get a water column explosion within 10-20 seconds of the submersion of the apparatus.

III. What to hand in for lab:



1. You should produce a single-page summary of each set of experiments (word processed, single-spaced, 12 point font), including experimental procedure, variables you investigated, a data table of measurements (with units), a graph of your relevant results, and a paragraph interpreting your results and comparing them to actual volcanic processes. You should also compare your results to real eruption data from some appropriate source (cite it properly). If you include photos, those will not count toward the write-up page limit, so you can go over with those. Graphs don't count toward the total either. One set of reports per group is fine, provided everyone was equally involved in producing them. Don't divide and conquer here, it yields disjointed, poorly organized documents and most people end up clueless and in trouble on exams later because they didn't think through the concepts completely. So that means TWO experimental reports plus a

description of the base surge (which can be short). In each case, you should be comparing your results with what happens at real volcanoes, so use the textbook and other resources to back up your conclusions. Cite your sources. You should use at least one proper source per experiment (it can be the textbook). **Make sure all group members' names are included in the file.**

2. Also hand in results of the calculation questions below. Unlike the experiments, you need to hand in one copy of these *per person.* You can write these out by hand or do them in a Word document. You can work together on this, just acknowledge whoever worked with you.

IV. Analysis and Calculations Section

SHOW YOUR WORK or else I can't figure out what you did and give partial credit where appropriate. Throughout this section it is imperative that you use units to make sure your calculations are working properly. ALWAYS include ALL units in every part of every calculation. Not doing so will result in me taking points off your final score, even if your answers are right. I'm not doing this to be mean, but to make sure you learn how to use units to help you do calculations properly. If this is a foreign concept to you, be sure to talk to me or one of the TAs about how to do this. It's a hugely useful skill that you should've learned in high school (but if you didn't, see us).

Do all of these calculations with data from your first experiment, in which you measured the height of a water column.

a) Approximately 0.05 L of liquid nitrogen whose density is 0.81 g/mL was in the bottle. Let's say that the water in the garbage can was precisely measured as 120 L. What was the average vesicularity of the water immediately prior to the explosion? How does your vesicularity result compare to that estimated for magma at real eruptions? This might take some digging to locate, but cite your sources when you do find it. Rely on legitimate scientific sources, not Wikipedia or any other non-reviewed source (preferably either a real scientific paper or a USGS website). Some helpful information for you:

i) Vesicularity is calculated as follows (it's in %):

$$\text{Vesicularity} = [\text{volume of gas}/\text{volume of liquid}] \times 100$$

ii) Nitrogen is N_2 and has a molecular weight of 28 g/mole.

iii) Each mole of gas (at standard temperature and pressure conditions, which we will assume here) takes up 22.4 liters.

b) Using the standard projectile equation that ignores drag force (below), calculate the muzzle (or ejection) velocity of the water propelled from the garbage can in your first experiment. How does the muzzle velocity for our liquid nitrogen “volcano” compare to the velocities observed at actual volcanic eruptions? Be sure to cite your source. Class notes don’t count as a formal source (however accurate they might be…).

As you know from class, this is the standard projectile equation:

$$Height = U^2 / (2g)$$

where:

Height = height the water was propelled (in meters)
U = muzzle/ejection velocity of the projectile (water here, in meters/sec)
g = acceleration due to gravity (10 meters/sec^2)

c) Now that you know the ejection velocity, you can calculate the pressure (P_i) it took to propel the water using the modified Bernoulli equation:

$$\frac{1}{2} U^2 = (P_i - P_s) / S$$

where:

U is the muzzle/ejection velocity (in meters/second)
P_i is the reservoir pressure (in Pascals; a Pascal is a kg/meter second^2)
P_s is the atmospheric pressure (in Pascals, 101.3 kPa)
S is the density of the clast (in kg/m^3) (in this case, the clast is water, 1000 kg/m^3)

Again, try to find data from a real eruption for comparison and be sure to cite the source. Real scientific journals and legitimate scientific websites are the way to go here, as always.

d) Calculate the magnitude of one of your eruptions. Remember,

Magnitude = log (erupted mass, kg) –7.

Compare this to data from real eruptions.