Model Geysers - **By Brian Davis, brdavis@iusb.edu 20 Sep 2013.**

Background

I became interested in this one winter afternoon when my 8-year-old daughter, Ellie, out of the blue announced that her science fair project would be to build a working geyser (we had visited Yellowstone National Park a couple of years earlier, which was where she got the itch). Unsure at first if it was even possible, I looked around and found that there were a whole lot of "Science Fair geysers"… most of which were not proper "thermal" geysers at all, but just liquid driven by cold-gas expansion (like the "Diet Coke & Mentos" phenomenon). Some deeper searching on-line turned up two important resources. The first was Gregory L. Jones website, which includes nice plans for a working science-fair geyser: Building a Science Fair Geyser (http://www.wyojones.com/science_fair_projects_and_geyser.htm)

He presents two models, one based on laboratory glassware (including a long glass Pyrex tube – not easy to come by), and a second one based on "hardware store" material (a metal can for the chamber, a copper tube for the conduit), as well as important safety information (remember, you are dealing with boiling water and steam, as well as Bunsen burners, electrical hotplates, and erupting water – Use Caution!). A second more detailed approach for a college-level geyser model was an article by Samo Lasic & Gorazd Planinsic published in the European Journal of Physics in 2006: Geyser model with real-time data collection (http://www.fmf.uni-lj.si/~planinsic/articles/LasicArticle.PDF)

This second article described a simple instrumented model, with two thermocouples and a pressure sensor to record information about the geyser as it erupted concurrently with a video of the chamber. This had a lot of interesting information on the eruption of the model geyser, and with the very gracious support of the chemistry department at IUSB, I was able to reproduce their model and enjoyed watching the eruptions through the pretty glass tubing, but given the amount of glass I wasn't really comfortable with this for a science fair project. So with the proof of concept demonstrated, I looked at ways to make a more accessible (and somewhat safer) model. The result was useful for an 8-year-old to play around with, and flexible enough for her father to end up complicating the system beyond reason.

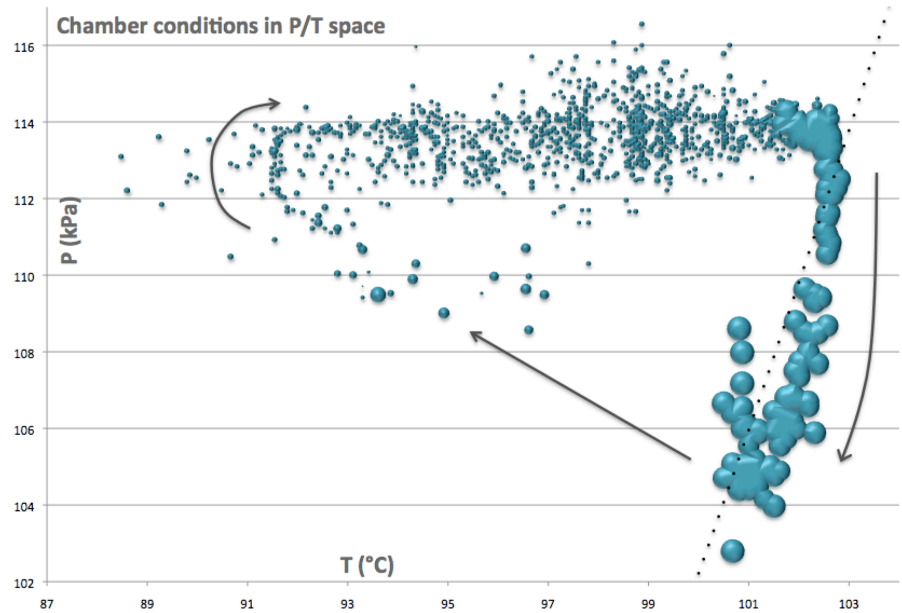
Another very important resource on this journey has been the men and women of GOSA (Geyser Observation and Study Association) and others on the Geyser mailing list. Their observations have been instrumental in both guiding and inspiring geyser research, including this author. In particular, Paul Strasser, Jeff Cross, and Carlton Cross have contributed practical hands-on experience with model geysers (including ones much bigger than I ever considered!), and T. Scott Bryan's wonderful book "The Geysers of Yellowstone" has provided much food for thought on the huge variations in geyser behavior. If you want to understand geysers, these are the folks to talk to.

And to begin sounding like a broken OSHA recording - please be careful, and do this under adult supervision!

These models work with glass, boiling water, and electricity, so while they look like fun toys, take the safety seriously!

The Theory

The *basic* idea of a thermal geyser is fairly simple. A tall tube (or conduit) is filled with water and heated at the bottom. The temperature increases until the water at the bottom is hotter than 100° C, but doesn't boil due to the increased pressure due to the water above it. The temperature continues to rise throughout the column until at some depth the water starts to boil. If this is sufficient to push some of the water out of the conduit, the pressure will be reduced, and water that was previously prevented from boiling starts boiling under the reduced pressure. This drives out still more water, reducing the pressure still further, and leading to run-away boiling and ejecting most of the water in the conduit. For those of you who understand the basics of a P-T diagram, here's the [best example I've found on the web](http://www.swisseduc.ch/stromboli/perm/yellowstone/modelgeyser-en.html) (http://www.swisseduc.ch/stromboli/perm/yellowstone/modelgeyser-en.html) so far... and not being satisfied with that, I generated my own from data I collected. The size of the "bubbles" represents how much boiling is going on, and the little dotted line is approximately the vapor pressure curve: the geyser heats at constant pressure (moves right across the top), then boils and ejects water, driving down the pressure and the temperature (big "bubbles" tracking downward, before filling rapidly with cooled water (moving rapidly up and left to restart the process). Note that in practice, there's a lot more going on in a geyser: boiling can occur at different depths, conditions in the conduit during eruption are a two-phase mixture of water and steam that in places approaches the speed of sound, and the conduit geometry (as well as the heat source(s) and water supply) is anything but simple.



The Model

A basic model of a geyser needs three things: water, heat, and a vertical channel (or conduit) to erupt through. Since I wanted this to be easily reproducible, avoiding hard-to-find materials was a priority. I decided to retain a glass flask for the chamber on the bottom (primarily so I could see what was happening there), but I needed to find something else in place of the long, breakable, hard-to-get Pyrex tube (I also wanted to avoid copper tubing, as ultimately I wanted something bigger and cheaper). I ended up using CPVC pipe (*not PVC* – CPVC is slightly yellowish, and rated for "hot and cold water". PVC will warp and bend pretty rapidly at 100° C... again, trust me on this, I've learned the hard way). The CPVC is not rated for boiling water but since the model isn't under high pressure, it seems to do the trick just fine (after many hours above 100° C, the pipes are just slightly sagging under load). Better yet, it can be found in hardware stores everywhere, comes in a variety of sizes, and has lots of different fittings for variety. To make changing things in the system easy, I used repair compression fittings: short pieces of pipe with threaded compression fittings and rubber sleeves at both ends, used for joining two pieces of pipe temporarily. Any heat source would work fairly well; I used a $20 single-burner "hot plate" I picked up a Target. To catch the water at the top, I used a small "disposable" plastic bowl with a hole drilled in the bottom (note: most real geyers do not "recycle" their water this way, but instead fill with cooler water from the surrounding water table. For a simple model, self-recharge is a little easier).

Parts List:

• 6' of CPVC pipe (½")
• 2 "repair" compression fittings (½"; these are the "bulky" sections of pipe in the first picture, and have hand-tightened fittings at both ends to join pipes)
• 500 ml Pyrex flask*
• #8 rubber stopper (fits tightly in flask; ask at a large hardware store, and if you already have your flask bring it with you to test fit)
• 2 or more ¾" flat metal washers (these need to just fit over the threads on the male CPVC connector)
• ½" nut or lock-ring (needs to screw onto male CPVC connector threads; the type used for electrical conduit seem to work, and if you're lucky you can get some thin washers here that will function as well)
• Electrical hotplate or similar heat source
• 2 or more ½" rubber washers (or similar, see below)
• male ½" CPVC connector
• small plastic bowl (15-20 cm wide, 10 cm deep, with a flat middle bottom)
• CPVC primer and cement**

Tools:

• saw (handsaw with box form to allow straight cuts is handy)
• drill with 5/8" & 7/8" wood bit***
• clamp of some type and scrap plywood (to hold rubber stopper during drilling)

*various sizes would work (I've used from 125 ml up to 1000 ml). A cheaper substitute is difficult to come by. Other people have told me a canning or mason jar will shatter under the sudden shocks and temperature changes, so is NOT recommended. A metal container might also work, with either a properly-sized rubber stopper or using screw-on CPVC fittings through a hole drilled in the lid similar to how the CPVC is attached to the catchbasin. I've NOT tested any of these alternatives however. *Proceed at your own risk*!

**if you think just pressing the CPVC connections together really firmly will make them water-tight, you're correct. Right up to the point where they are put under even moderate pressure, thermally & mechanically cycled by the eruptions, causing them to expand and contract until they loosen, and fail. I found this out the hard way, so you don't have to.

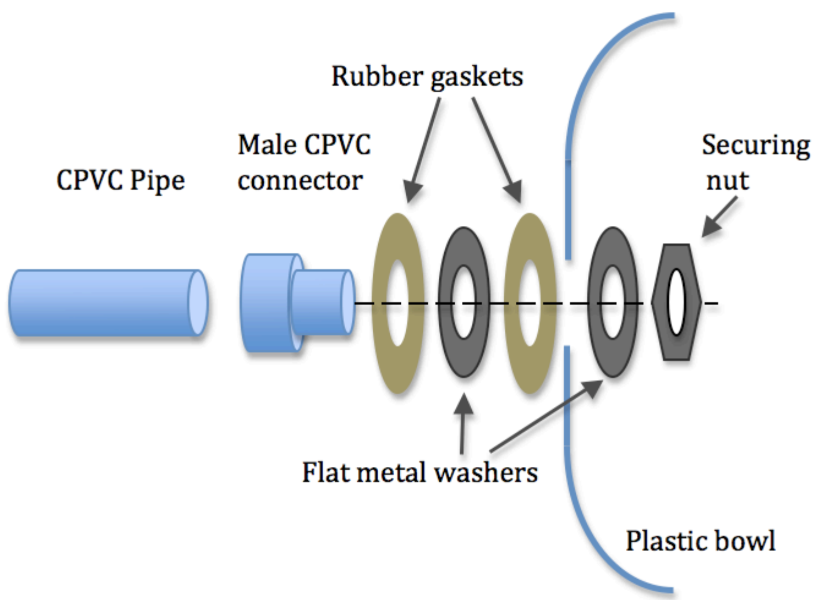
***I think these are the sizes you need, but measure and test before assuming!

Instructions:

1. Cut at least three lengths of CPVC tube: two 10 cm long, and one around 30 cm long (this middle one can be

varied as you experiment).

2. Hold #8 rubber stopper in a clamp (*not by hand*!) flat on a piece of scrap wood, and drill a 5/8" hole straight through the center; the hole should be just slightly smaller than the ½" CPVC pipe, so it's a tight fit. If using a clamp don't clamp the rubber stopper too hard or the drill will have problems (just tight enough to keep it from spinning). Be careful when doing this – it's very easy for the drillbit to bind up in the soft rubber, or slip. Another easier way I've found to do this is to skip the clamp and press down on the stopper using a thin piece of scrap plywood with a 5/8" hole already drilled in it as a guide, centered over the stopper. By pushing firmly down on the plywood, the rubber stopper is usually held fairly well between the two pieces of wood and doesn't rotate.
3. Push one 10 cm tube segment completely through the stopper. Stopper should still fit securely into flask (if it doesn't, pull the 10 cm tube slightly out, so that the bottom of the 5/8" hole can compress to allow the rubber stopper to slide in further).
4. Cement the other 10 cm segment securely into the CPVC male connector (the male connectors generally have a slight lip that will help support the metal washer and the bowl above it).
5. Drill (gently) another 7/8" hole in the center of the bottom of the bowl (as before, check the size of the hole; you want one just big enough for the threaded part of the male CPVC connector to fit, but not bigger).



6. Put a flat metal washer on the male CPVC connector threading, with a rubber washer on both sides of the metal washer. Note if you can't find proper rubber gaskets, you can fashion some from the soft non-slip material used to line kitchen drawers (the solid style), perhaps a piece of balloon rubber, or probably even small rubber bands. In fact, I'd suggest the custom-made one.
7. Push the male connector through the bottom of the bowl with the washer supporting the bowl bottom. Inside the bowl, place a second metal washer, and secure the entire assembly by tightening the ½" nut or lock-washer behind it. This will form a waterproof seal that also supports the bowl.
8. Use the two compression fittings to assemble the 10 cm standpipes on the flask and bowl onto the longer 30 cm pipe between them. Find some way to stabilize the model on top of the hotplate (this is going to depend on what you have and where you do this; I had the hotplate and flask on the floor, and a clamp to hold the pipe to the edge of the kitchen counter).

To make the model erupt, fill it with water (preferably hot) until the top of the conduit or standpipe is about 1 cm underwater in the bowl. Plug in the hotplate with a long extension cord to a distant outlet (this way, if the system leaks or floods the hotplate, you can unplug it without approaching the wet floor – safety first!). Now turn the hotplate on high, and wait. The first eruption may take a while if you filled the system with cold water, but soon the model will periodically erupt, with water rising out of the tube followed by steam and splashing, and then being sucked down again until the system heats up again. Unless you cover the bowl with a lid or something similar, some water will be lost during each eruption, so the model may need to be periodically "topped off" with extra water. The period between eruptions can depend on several things, including the length of the pipe which is easy to change with this model. Just swap out the middle length of pipe (between the two compression fittings) for a longer or shorter one, and restart the model. Watching the action in the "chamber" (flask) during an eruption is fascinating, with the boiling starting very slowly with collapsing steam bubbles and building to a crescendo as this hydrostatically pressurized water reaches its boiling point. The rising steam bubbles displace some water from the tube, lowering the hydrostatic pressure, and the water in the chamber begins to flash into steam and drive the eruption.

Tips and Cautions:

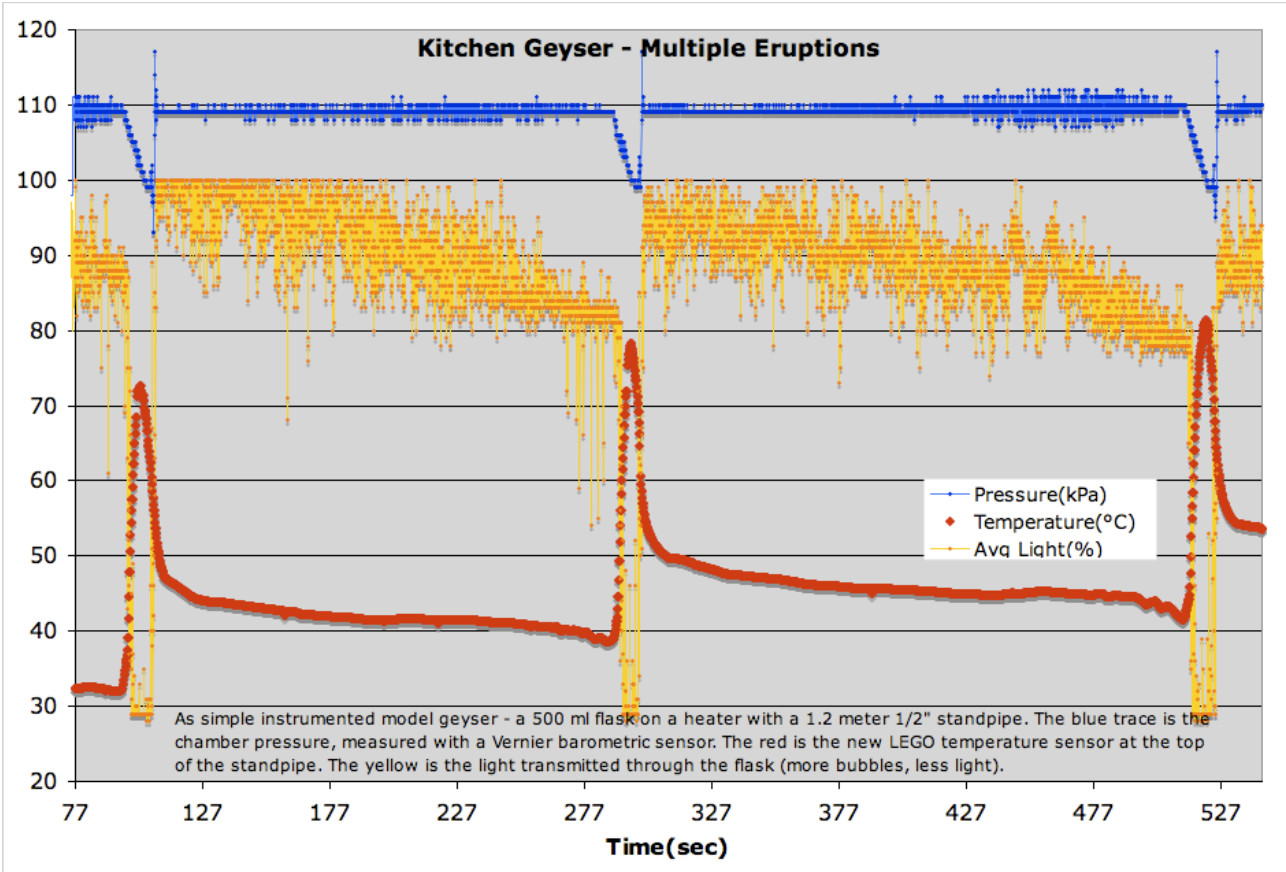
- You are working with BOILING WATER. Please be careful, and always consider safety first!
- Make sure the geyser is well-supported, and will not tip over or fall (especially during an eruption, which can shake it). "It balances" is NOT good enough (again, trust me on this, I know of what I speak). It really needs to be clamped to something near the top, by the basin.
- Be very careful with the heat source; if it is an open flame, make sure it doesn't get put out or risk starting a fire. If it's an electric heater of some sort, protect it from getting wet, and always have a way of unplugging it well away from any spilled water.
- Rubber stoppers have a tendency to work loose, squirting boiling water out under pressure. Make sure the stopper is very firmly pushed into the mouth of the flask (twisting helps), and even then stand back when the geyser is "hot". Note that a rubber stopper has the advantage of acting as an "overpressure relief" system here too (if the conduit were to become blocked, and the internal pressure in the chamber rises, the rubber stopper pops out before the chamber explodes - a very handy safety feature).
- A lid can be placed over the collection bowl to allow the geyser to recycle almost all the eruption water (some is still lost as steam).
- If you can locate a "filter flask" type flask, you can attach a tube to the side port and clamp it closed while the geyser is running. By opening the clamp, you can drain the geyser far easier than if you have to pick up and empty the entire thing (a major pain). Don't try to empty the system when it is hot! Let it cool in place for safety.

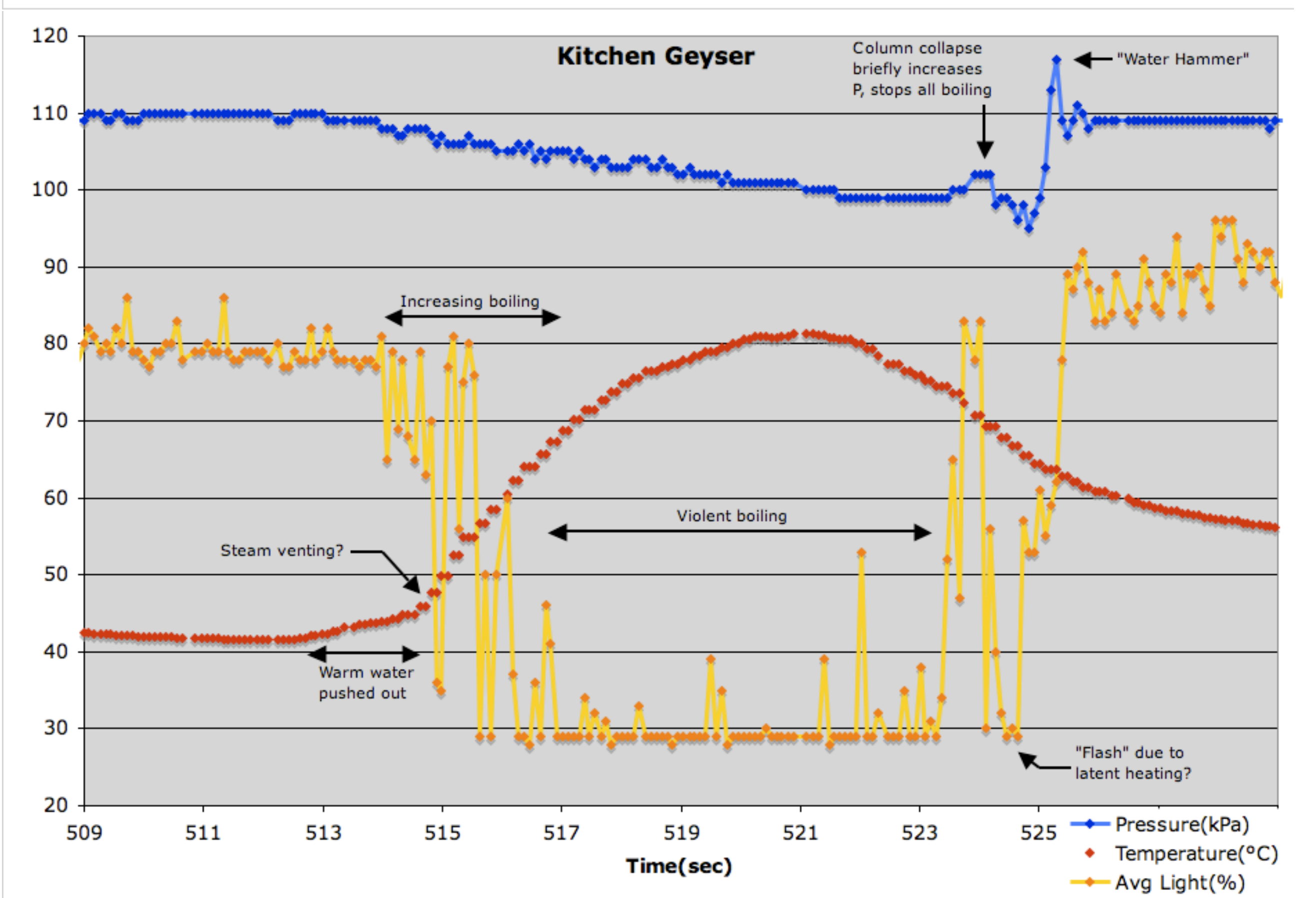
Instrumentation

This simple model is fun to build and watch all by itself, but there’s a lot more that can be done with it… if you can measure it. I “instrumented” the model with what I had handy, which turned out to be the NXT, a microcontroller “brick” sold by LEGO. While designed with simple robotics in mind, there are a large number of sensors that can be purchased from LEGO or other suppliers, and the ease of programming it makes it a natural starting point. I ended up using three sensors to gather very basic information about the model:

1. Barometric pressure sensor (from Vernier, order code BAR-BTA) attached to a port on the side of the flask to measure chamber pressure. Range limited to 81 to 106 kPa, but with 10 bit resolution it can measure the pressure changes associated with eruption.
2. LEGO NXT digital temperature sensor positioned in the mouth of the conduit. Reading -40 to 125 °C with a resolution of 0.0625° C, this can register when an eruption happens as the temperature shoots up.
3. LEGO light sensor. By shining a laser pointer through the flask and into the light sensor steam bubbles can be detected (more bubbles block more light)

With any one of these sensors the eruptions can be automatically detected, counted, and timed; the NXT is more than sufficient to do this. In addition, it can be programmed to log the sensor values, allowing the events during an eruption to be reconstructed with a time resolution of about 10 Hz.





Variations and Future Directions
A simple geyser model isn't too hard to put together, but by using CPVC pipe for the conduit (joined by compression fittings) it becomes very easy to make a wide variety of "plumbing" systems for the model. For instance…

- Vary the conduit length (simple science fair experiment; how does the eruption interval change with conduit length?)
- Use different diameter pipes (or even different diameters in different sections)
- Add a constriction anywhere in the conduit (or at the exit)… perhaps with an adjustable ball valve
- Put in bends or curves, or even an S-shaped section
- Add multiple parallel channels, dead-end side chambers, or mid-conduit chambers
- Make a branching conduit fed from two or more chambers

Your imagination is the limit here. However, two things to keep in mind with the above list are that connections should be cemented properly, and valves, if they are used at all, should be used *very cautiously*. Normally the model works at low pressure (just the hydrostatic pressure of the water column). But if a valve is closed, the pressure can build to dangerous levels without warning (remember, boiling is suppressed by high pressure – you won't see it coming), and the result is something rupturing or breaking and jetting high-pressure live steam. *Never run the geyser with the chamber "sealed off"*... in the real world, that's called a hydrothermal explosion. DANGER!