Clocks in Rocks: Visualizing Diffusion With Gelatin Exercise Instructions

This document is intended to be only instructions to conduct the gelatin diffusion exercise. For more information on the equations of diffusion and the applications to volcanology, visit this website https://www.rldegraffenried.com/gelatin-diffusion.html.

Preparing the experiments

The experiments take approximately 1.5-2 hours to set up, though the majority of that time is devoted to allowing the clear gelatin to chill and solidify. This time period could be shorter or longer depending on the number of experiments to prepare, and this estimate is for 4-6 experiments with a maximum of 4 different colors.

Materials:

- Gelatin powder (gelatin or agar agar)
- Food coloring
- Containers for experiments (see Fig. 1 – 3-4 cm diameter, 20 cm tall)
- Equipment for boiling water and stirring
- Additional containers for mixing colored gelatin
- Ruler
- Camera

1. **Prepare the clear gelatin (Fig. 1).** Prepare enough mixture at this stage so that each container you are using is half-filled, so the total amounts of water and powder needed will vary for each experiment set. For gelatin, we recommend mixing the gelatin powder and water in a 5% mixture, and for agar agar, a 10% mixture.
    a. Start boiling half of the water and start mixing the gelatin powder into the other half of the water at room temperature.
    b. Once the water has started gently boiling, add in the gelatin-water mixture that has been pre-mixed at room temperature.
    c. Vigorously stir the hot mixture while it is gently boiling until the liquid is completely clear.
    d. A few mL of bleach can be added to prevent bubbles and mold from forming in the gelatin.
    e. Once the mixture is ready, pour it into the experiment containers until they are half-way full.

Fig. 1. Example of a container filled with clear gelatin after Step 1e. This example shows the level of clarity needed to see diffusion readily. Even clearer gelatin just makes measurements easier.

2. **Chill the clear gelatin.** Before proceeding, the clear gelatin needs to be as solidified as possible, which is achieved fastest with a refrigerator, though it can be just left out at room temperature. With a fridge, we have left experiments to chill for 45 minutes to 1 hour.
3. **Prepare the colored gelatin (Fig. 2).**
    a. Follow steps 1a-1d to make the gelatin solution – **stop before 1e**.
    b. Transfer the mixture to a different container (or containers if using multiple colors) and add food coloring in the desired concentration.
    c. Mix thoroughly so that the color is homogeneous.
    d. Cool the colored gelatin solution to avoid dissolution of the clear gelatin. Be careful not to let it cool too much, though, or gelatin will not pour smoothly because the viscosity increases quickly as it cools. The solution is cool enough to pour when the

mixture leaves a film of a millimeter or so on the container for a second or two while swirling the liquid around, that is the optimum time to pour the colored gelatin solution on top of the clear gelatin.

e. Once the colored gelatin is poured on top of the clear gelatin, make sure to immediately mark the interface with a thin-tipped marker and capture a photo (if interested in using photo data).

Fig. 2. An example of an experiment with the colored gelatin poured in. Note that some of the gelatin has stuck to the walls in this case because the colored gelatin was close to being too cool to pour smoothly.

Measurement types

As we have envisioned the experiment, there are two possible measurements, though other ideas are possible and we encourage everyone to adapt this exercise to what best suits their students. First, the length of the diffusion front advancement can be measured relative to the interface using a ruler or something similar (Fig. 3). Second, photos can be taken and used for extracting color intensity profiles to approximate changes in concentration of food coloring. Measurements should be done at different intervals, with longer time periods in between measurements as total experiment duration increases. For the first couple of measurements, diffusion is rapid enough that there is measurable difference every 1.5-2 hours, but after that, several hours to a day may be needed.

Extracting color profiles and converting the values

Color intensity has to be extracted from the photos to be used for modeling. We recommend using NIH ImageJ as it is free. However, the raw color intensity values are unintuitive for diffusion – the clear gelatin will have high color values and the colored gelatin will have low color values. If using just the raw values, it gives an erroneous view of the either uphill diffusion or the lack of color is diffusing. These values can be modified to fix the unintuitive scaling and relate the values to concentration of food coloring. To relate high color value to high concentration, just invert the scale by subtracting the raw values from 255 (the max color intensity value in RGB color space). To relate color value to concentration of food coloring, the maximum and minimum intensity values (after being corrected for the color scale) can be set to represent maximum and minimum concentration values and then a linear interpolation can be used to assign concentration values to all the other values in between.

Potential experiment modifications

We have a few suggested variables that can be changed to examine factors that influence diffusivity:

- Temperature – experiments can be left in different places (e.g., fridge, slightly warm drying oven) to examine how diffusivity changes
- Food coloring concentration – changing food coloring concentration by a factor of 10 changes diffusivity
- Color of food coloring – different food coloring colors have different diffusivities

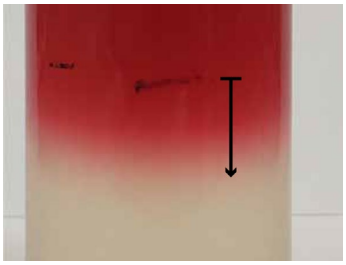

Fig. 3. Arrow denotes the measurement of the length to the diffusion front advancement.