DENTAL CHEMISTRY ANALOGY

INTRODUCTION

Description

To investigate the effects of fluoride treatment on teeth, students design a procedure using sodium fluoride and marble chips or eggshells.

Goals for This Experiment

The goals for this experiment are to have students:

1. design a simple experiment in response to the question posed by the scenario,
2. realize that results often cannot be predicted and modifications to the experiment may have to be made to answer the question posed,
3. understand the elements present in a well-designed experiment, and
4. practice the skills of handling a sample and measuring masses on a balance.

Recommended Placement in the Curriculum

The Dental Chemistry Analogy lab is most valuable if implemented after the completion of several other labs. Students will have had a chance to become familiar with an "experiment," how to use balances, etc. For most students, this will be the first time they have designed their own experiment. Students need to have some experience using balances, making observations, and forming conclusions.

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PRE-LAB ASSIGNMENT

In the experiment you are asked to design a simple experiment to illustrate (if possible) the protective effect the fluoride ion has against acid degradation of eggshells or marble chips.

This pre-lab assignment requires you to prepare, in advance of lab, a detailed experimental procedure you expect to follow. Be sure to describe, in detail, the steps you will follow as well as

- the identity of the material,
- the number of pieces,
- the times for soaking, and
- the concentration of solutions.

YOU MUST TURN THIS PROPOSAL IN TO YOUR INSTRUCTOR AT THE BEGINNING OF THE LABORATORY PERIOD TO GAIN PERMISSION TO WORK IN THE LABORATORY. Please feel free to talk about your plan with your instructor before class meets.

PLANS FOR YOUR DENTAL CHEMISTRY INVESTIGATION

GROUP MEMBERS:

I. Write a statement of the purpose of your particular investigation.

II.

A. Identify the following:

1. the variable whose values you will manipulate

2. the units in which the variable values will be expressed

3. probable sample sizes you expect to try

B. Identify the following:

1. the responding variable whose values you will measure

2. the units in which the variable values will be expressed

C. Identify the other variables of your procedure whose values you must keep constant.

III. List the expected steps of your investigative procedure.

YOU MUST TURN IN THIS PROCEDURE REVIEW AND PLAN OF ACTION TO YOUR INSTRUCTOR AT THE BEGINNING OF THE LABORATORY PERIOD TO GAIN PERMISSION TO WORK IN THE LABORATORY. Feel free to talk with your instructor before class meets about your plan.

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SCENARIO

In this laboratory investigation, pretend you are an educational specialist for a science museum that has agreed to produce a special exhibit for Dental Health Month. During a brainstorming session, a collaborator recalls hearing of an experiment in which an eggshell was treated with "fluoride" on one side and then exposed to "acid" for the purpose of demonstrating the advantages to dental health of fluoride treatments, fluoride-containing toothpastes, and the addition of fluoride to municipal water supplies. Someone else suggests that marble chips might be sturdier and more easily obtained in quantity. A lively discussion follows. Obviously teeth, eggshells, and marble chips are not identical materials. The following questions arise:

- What are teeth, eggshells, and marble chips made of?
- How are these materials similar and/or how are these materials different?
- Can eggshells and/or marble chips be an adequate substitute in a model study for this museum exhibit?

BACKGROUND

Tooth enamel material is a complex calcium phosphate mineral that is mostly hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$, with other elements in small amounts (3% total). In the presence of fluoride ions, some of the hydroxy groups (OH groups) in the outer enamel are replaced with fluoride ions making fluorapatite, $Ca_{10}(PO_4)_6F_2$. This process is called ion exchange and is shown by the following equation:

$$Ca_{10}(PO_4)_6(OH)_2 + 2\ F^- (aq) \rightarrow Ca_{10}(PO_4)_6F_2 + 2\ OH^- (aq)$$

Fluorapatite is harder and more resistant to corrosion by acids than hydroxyapatite. Fluoride ions also suppress bacterial acid production.

The precise effect of sodium fluoride solution on eggshells or marbles chips isn't known. One possibility is that ion exchange occurs at the surface of the shells or chips in a way analogous to the ion exchange process that occurs with tooth enamel. Eggshells and marble chips are predominantly calcium carbonate, $CaCO_3$. Thus, if ion exchange did occur, calcium fluoride would be expected to form on the surface of the shell or chip. A second possibility is that the sodium fluoride that is added simply sticks to the tooth's surface.

Carbonates, either as solids or in solution, undergo the following characteristic decomposition reaction in the presence of an acid:

$$CO_3^{2-}{}_{(aq)} + 2H^+{}_{(aq)} \rightarrow [H_2CO_{3\,(aq)}] \rightarrow CO_{2\,(g)} + H_2O_{(l)}$$

YOUR TASK

The question is... Can you find a simple experiment using eggshells or marble chips, sodium fluoride solutions, and acetic acid solutions that clearly demonstrates by analogy the protective effect of fluoride ions in dental rinses, toothpastes and drinking water?

To find an answer, you should... design and carry out an experiment that clearly illustrates or clearly does not illustrate how fluoride ion treatment can protect eggshells or marble chips from reacting with dilute acid. (The idea here is to come up with a simple experiment that the public will understand and that mimics dental applications.)

A suggested general procedure... Treat eggshells or marble chips, rinse well with distilled water, dry, and weigh them. Expose the shells or chips to dilute acetic acid, rinse again, dry, and weigh for comparison. Acetic acid is recommended for two reasons: 1) it eliminates any chance of hydrofluoric acid, a very toxic chemical, being formed as a by-product of the reaction; and 2) acetic acid is chemically similar to the acid formed naturally in the mouth (as a result of bacterial action) that causes tooth decay.

MATERIALS AVAILABLE TO YOU

- Solutions:
  1.0 M sodium fluoride solution (1.0 M NaF)
  0.5 M sodium fluoride solution (0.5 M NaF)
  0.25 M sodium fluoride solution (0.25 M NaF)
  1.0 M acetic acid solution (1.0 M CH_3COOH)
  Upon request, other solutions may be available.

- Eggshells and marble chips will also be available.

- A limited number of real teeth (cleaned and appropriately sterilized) may be available. If you wish to include one or more in your investigation, consult your instructor.

Points you should consider during the process of experimental design...

- Sodium fluoride is not very soluble in water. Additionally, the toxicity of sodium fluoride solutions increases as the solution concentration increases. Hence, the most concentrated solution of sodium fluoride is 1.0 M. (More dilute solutions may be used.)

- Preweighed eggshells or marble chips that have been soaked overnight are available for your design. A group may use no more than two of these samples.

- Eggshells and marble chips come in various sizes with different surface areas. If the protective effect occurs on the surface of the shells or chips, the surface area of the sample may be more important than the sample mass, even though the mass is more easily measured. Consider how the sample size might be adjusted to consider this surface effect.

- Experience has demonstrated that consistent data can be obtained by drying the eggshells and marble chips with a paper towel prior to weighing.

CAUTION: Solutions containing fluoride ions are toxic. Do not place your fingers in the sodium fluoride solution or into acidified solutions of treated shells or chips. Use tweezers, forceps, and glass rods for handling these materials until the pieces are well rinsed with water.

Care of the balances: Be sure that you take care NOT to place soaking wet items directly on the balance pans. If you plan to weigh samples, first blot them dry with a paper towel, then use a pre-weighed (or tared) weighing dish on the balance. Be sure to clean the balance after every use.

Time will be at a premium, it is important that you work effectively and efficiently. One laboratory period will be allowed for this investigation.

REPORTING YOUR EXPERIMENT

⇒ Write a report to the Science Museum Committee with your answer to the questions described in the scenario. This report should include the following:

- an opinion of whether or not your experiment successfully accomplished the task assigned;
- a description of your experimental procedure, with enough detail so that a reader could repeat your experiment, using only your written description;
- your opinion as to how the limitations of time, equipment, or flaws in your experimental design affected the results and applicability of your experiment;
- the recommendation you would make as to the feasibility of including your experiment, or some modification of it, in a hands-on activity for the public on the role of chemistry in promoting dental health; and
- suggestions for further experiments, especially those suggested by your results, that would be useful or necessary to address the original task given you.

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INSTRUCTOR NOTES

Time Required

The pre-lab assignment should take students between 30–60 minutes. The laboratory experiment should take 2–3 hours. If students complete their experiment in a shorter amount of time, check to see if they have repeated the experiment at least once. If they have not, ask them how they know their results from one trial are accurate and require them to repeat their procedure.

Group Size

Each student should work individually. Students can collaborate to investigate different effects (i.e., one student can investigate the effects of exposure time and another can investigate the effects of concentration), but each student should perform his or her own experiment.

Materials Needed

per class (20 students):

- 1.5 L of 1.0 M NaF: Weigh 63.0 g of sodium fluoride and bring to volume with distilled water.
- 1.5 L of 0.5 M NaF: Weigh 31.5 g of sodium fluoride and bring to volume with distilled water.
- 1.5 L of 0.25 M NaF: Weigh 15.8 g of sodium fluoride and bring to volume with distilled water.
- 2 L of 1.0 M acetic acid: Add 115 mL of concentrated acetic acid to 1500 mL of distilled water. Bring up to volume with distilled water.
- weighing dishes (or some type of container to weigh samples on the balance)
- wash bottles
- labels

per student:

- 10–20 g of marble chips
- ~8 medicine cups or other small containers (to soak chips in)

  OR
- 8 eggshell halves
- 8 150-mL or larger beakers or containers (large enough to completely soak eggshells)

Notes

✔ If eggshell halves are used, the amount of NaF solutions needed will be larger since it takes a much larger amount of solution to completely cover a large piece of eggshell (100–150 mL of solution for an eggshell compared to 20–30 mL for marble chips). You could however, use smaller pieces to cut down on the amount of NaF needed. You may want to ask students to let you know ahead of time if they want to use the eggshells. Because this would be expensive for all the students to use, you may wish to allow only 1–3 students per class to use them, or you can decide not to use the eggshells at all.

- ✔ You may wish to include a small number of real teeth for students to investigate. A dentist may be able to provide these. The teeth should be cleaned and appropriately sterilized.
- ✔ Since NaF etches glass when in contact with it over a period of time, store all NaF solutions in plastic bottles. Students can still soak their chips/eggshells in a glass container since the soaking time is relatively short. Chips soaked overnight should be soaked in a plastic container.

Safety, Disposal, and Special Handling

The fluoride ion is toxic, and chronic exposure of more than about 8 parts per million can be dangerous, with bone crumbling resulting. It is also a strong skin irritant. Students should handle the sodium fluoride solutions with care. Forceps and glass rods should be used to handle the eggshells and marble chips during treatment and until they are well rinsed. Students should not put their fingers into sodium fluoride solutions. Students should also not place their fingers in acidified solutions of treated shells or chips due to aqueous fluoride solutions.

Review the Material Safety Data Sheet (MSDS) of any chemical used in the experiment for information regarding safety and handling. Dispose of waste according to your local ordinances.

Pre-Lab Assignment (Optional)

The pages of the experiment, the "Plans for Your Dental Chemistry Investigation," and the "Pre-Lab Assignment," should be handed out the week before the experiment is performed. At this time, discuss the ideas of experimental design such as the following:

- sample size
- identifying the dependent (what is measured; in this experiment it is the gain or loss of mass) and independent variables (the treatment; in this experiment it is the exposure of the calcium carbonate to fluoride ions)
- a control (a standard of comparison; in this case, the control would be a sample of marble chips that are soaked in distilled water. The sodium fluoride is the treatment and is dissolved in distilled water. The control would include every substance *except* the treatment; in this case, distilled water.)
- repeating the measurements to help ensure validity

We opted to have the pre-lab assignment due at the beginning of the class period when we conducted this lab. Without it, the students were not allowed to do the experiment. We wanted them to think about their experimental design before the beginning of lab instead of writing the plan at the start of lab and then beginning the lab investigation late.

Points to Cover in Pre-Lab

Because this investigation contains a fair amount of chemistry and elements of experimental design which will be new to students in the first semester of General Chemistry, it is strongly recommended that you introduce and discuss some of the basic concepts and elements of good experimental design during the pre-lab if it was not discussed the week prior to this experiment. Experience has shown that students at this point in their careers need a fair amount of guidance in such inquiry lessons both in the pre-lab and during the laboratory itself.

Other points to cover in the pre-lab discussion:

- Review or introduce the correct use of a balance and the concept of "taring."
- Explain to the students that when studying cause and effect, only one variable can be changed at a time.
- Point out to the students that it may be difficult to observe a small change in mass. The students may want to use several marble chips for each sample. This way, the sample will have a reasonable mass and the gain or loss of mass will be large enough to observe.
- Discuss the variation in surface area and ask students what type of effect they think this could have on the experiment. (The larger the surface area, the more calcium carbonate surface there is to react with both the sodium fluoride and acetic acid.) Lead them to the conclusion that the ideal experimental samples would have the same or very similar surface areas.
- Some time should be spent making sure students are comfortable with what they plan to do. Ideally, students will have talked with you ahead of time. Realistically, very few will do this.

Some Specific Suggestions and Interesting Facts

- Besides basic chemistry and experimental design issues, student success in this laboratory depends on good weighing techniques. It is recommended that you pay particular attention to this and, if appropriate, reinforce appropriate use of balances and sample handling.

- Oral B Tooth and Gum Care contains 0.4% stannous fluoride. It is used in the Recommended Opening Demonstration. Many other pastes are preparations of 0.15% sodium fluoride (e.g., Crest) or sodium monofluorophosphate. *See demonstration for explanation of why higher concentrations of F^- are used in the lab.*

- The scenario used in this lab allows comparison of percent fluoride ion in stannous fluoride preparations versus the lower percent fluoride ion in sodium fluoride preparations. Comparison of the molar concentrations might also be introduced. The amount of fluoride added to water in fluoridation (about one part per million), may also come up.

- Experience indicates the shells and chips lose weight when exposed to the fluoride ion. This is what you would expect if ion exchange occurs on the shells or chips resulting in calcium fluoride on the surface and sodium carbonate in solution. However, students may not realize that if sodium fluoride is adsorbed onto the surface of the shell or chip, a gain in weight would result. You should be aware that both may actually be occurring. This possibility has not been rigorously researched. Therefore, the students will see a loss (possibly due to ion exchange), or even a small gain (possibly due to NaF adsorption or extra water weight if the sample is not completely dry) in the mass of their sample.

- Because the materials are inexpensive, unless you use eggshells, students can work alone and then compare their data with others. Alternatively, students could work in groups to design a study and assign different parts to different group members. (One person uses similarly sized chips weighing about 1 gram, while another uses randomly sized chips weighing about 1 gram; or one person varies the time that chips are exposed to one fluoride concentration, while another exposes chips to varying fluoride concentrations for a set time.) Even the length of time the treated chips are exposed to the dilute acetic acid can be varied. Student results **will** depend on the experimental design that they employ. One student's study may suggest that the analogy seems to apply, while another student's may be less definitive. Students whose experimental design is confusing will get confusing results. The challenge will be in helping them sharpen their design.

Recommended Opening Demonstration

In the pre-lab, you might demonstrate the procedure described in the scenario. First, brush one side of an egg with fluoride-containing toothpaste. (Oral B Tooth and Gum Care, which contains 0.4% stannous fluoride, works well.) After washing the toothpaste off, place the egg in vinegar in a transparent container and challenge the students to determine which side of the egg was treated with the fluoride toothpaste. Try placing the container on the overhead to see if that makes it more visible to the class. Alternatively, pass it around the room; for larger classes, this may require several eggs to be prepared.

When the demonstration was tested, the two sides of the egg were indistinguishable even after allowing the toothpaste to sit on the egg 15 to 20 minutes. This sets up the scenario and the need for additional or more precise experimentation to illustrate the protective effect of fluoride ion, if such an effect exists. The demonstration also illustrates the need for using higher fluoride ion concentrations in order to illustrate an effect in the short time available in the lab.

Likely Play-Out of Lab

Students will most likely decide to vary the concentration of sodium fluoride while holding the soaking time constant or varying the soaking time while holding the sodium fluoride concentration constant. Whatever they decide, (even if it is not this, as long as it is reasonable), they need to be given the time to decide whether their experiment is successful. Remind them that in most situations scientists don't know if an experiment will work. They simply do the experiment, decide if it is successful, and modify it if necessary. Students will need some encouragement to modify their experiment or repeat it if results are not what they expected.

REFERENCES

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