Food Science –

Chemical Reactions:

Laboratory for Secondary Level Students

Student Manual

WS2

WOMEN SUPPORTING
WOMEN IN THE SCIENCES

Meet a Scientist

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About me:

I graduated with distinction in my PhD in Materials Science and Engineering. I am currently a researcher of materials science and technology, and my ultimate career dream is to work in a professorial position.

When I was young ...

I was raised by a single mother after the death of my dad when I was only five years old. My family was extremely poor, and I went to school with bare feet, no school uniform, and a single meal a day. What helped me succeed is the discipline I had and following the advice I received from my mother, relatives, teachers, and sponsors.

My advice for students interested in science:

Make sure that you have a vision of who you want to become, be disciplined, use your time wisely, respect your teachers, read more science books, share your findings, and find a mentor to guide you. For me, the most important element was to have faith in God that I could do anything through him who strengthens me.

Mission Statement

This laboratory will teach chemical reactions to a target audience of middle and high school/secondary-aged students (ages ~12-18) through experiments related to food ripening and spoilage.

Contents

1. Introduction to WS2 Laboratories

1.1. Information about WS2

Women Supporting Women in the Sciences (WS2), an international organization unifying and supporting graduate and professional-level women and allies in science, technology, engineering, and mathematics (STEM), was awarded an American Physical Society (APS) Innovation Fund in 2020 to form international teams to design and distribute low-cost physics and materials science lab kits to 5000 primary and secondary school students, predominantly in eastern Africa. The lab kits are intended to utilize local resources and include topics that are especially relevant to young girls in order to spur their interest in STEM subjects. The international teams, which designed the content found in these laboratory manuals, worked with WS2 Partners in eastern Africa in order to successfully deliver and teach the science lab kits to their local communities through 2022. WS2 gratefully acknowledges the hard work of the teams in the creation of this lab kit content. For more information about WS2, please visit our website at ws2global.org.

WS2 is sponsored by the APS Innovation Fund, Northwestern University Materials Research Science and Engineering Center, and Northwestern University Multicultural Student Affairs. WS2 Partners receiving lab kits are representatives from Makerere University (Uganda), Masinde Muliro University of Science and Technology (Kenya), Mbeya University of Science and Technology (Tanzania), Mkwawa University College of Education (Tanzania), Nelson Mandela African Institution for Science and Technology (Tanzania), University of Dar es Salaam (Tanzania), University of Dodoma (Tanzania), and University of Rwanda (Rwanda). The APS, Materials World Modules, SciBridge, and Projekt Inspire have provided valuable input on WS2 lab kit design. WS2 especially thanks WS2 Partner representatives (John Bakayana, Pendo Bigambo, Daudi Mazengo, Lawrence Robert Msalilwa, Celine Omondi, Marcellin Rutegwa), Tom Coon and students of Haile-Manas Academy (Debre Birhan, Ethiopia), and Carla Johnston and students of Frank Bergman Elementary School (Manhattan, KS, USA) for piloting the lab kits with small focus groups in late 2021. WS2 also tremendously thanks the virtual lab kit design team that created the content for this lab manual.

1.2. Key Vocabulary

- <u>Chemical reaction:</u> a change when the final components are chemically distinct from the starting components; clues that a chemical reaction has taken place include the release of light or heat, a color change, gas production, an odor, a sound, or the formation of solids
- <u>Reactants:</u> the starting components of a chemical reaction
- <u>Products:</u> the final components of a chemical reaction
- <u>Conservation of mass:</u> the principle that during chemical reactions no mass is created or destroyed
- <u>Oxidation:</u> The process by which matter reacts with oxygen
- <u>Acid:</u> A type of chemical that produces hydrogen ions (H^+) when dissolved in water and has a value below seven on the pH scale
- <u>Base:</u> A type of chemical that produces hydroxide ions (OH^-) when dissolved in water and has a value above seven on the pH scale

1.3. Key Questions

- What are different chemical reactions that food can undergo?
- What are clues that a chemical reaction has taken place?
- How does fruit ripen?

1.4. Purpose

In this lab, students will learn about several chemical reactions that are responsible for food ripening and spoilage including spoiling by acids, ripening by ethylene gas, and oxidation. They will also learn about factors that can enhance these chemical reactions, including heat, light, and environment.

2. Background on Main Topics

2.1. Chemical Reaction

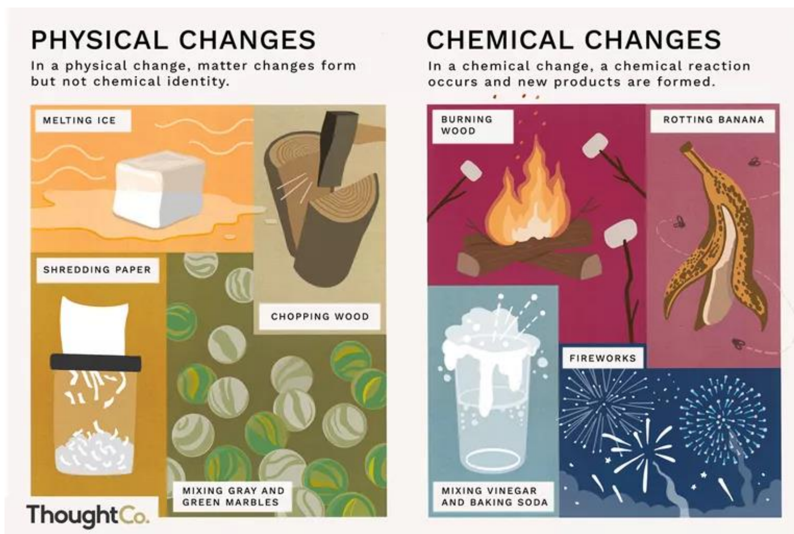

Figure 1. Examples of physical changes on left – melting ice, chopping wood, shredding paper, mixing marbles – and chemical changes on right – burning wood, rotting banana, mixing vinegar and baking soda, fireworks. Source: ThoughtCo.

Physical and chemical changes are readily noted in the preparation, storage, and consumption of food. Recall that physical changes occur when matter changes form, but not chemical identity. Cutting produce (here, produce means many types of farm-produced crops like fruits and vegetables), crumbling a piece of paper, or dissolving sugar in water are examples of physical changes. Chemical identity does not change; therefore, physical change is usually reversible (can return to its original form). For example, dissolved sugar in water can be reversed by evaporating the water from the solution. Once the water evaporates, sugar crystals will be left behind. Examples of physical changes are shown in Figure 1 (left).

A chemical change occurs when chemical reactions form new products with new chemical identities. Baking a cake, leaves changing color on trees, and food digesting in your stomach are examples of chemical changes (others shown in Figure 1 (right)). Chemical reactions have two components: the matter that is present at the start of the reaction, known as the reactants, and the matter that is present at the end of the reaction, known as the products. There may be clues that a chemical reaction has taken place, such as the release of light or heat, a color change, gas production, an odor, a sound, or the formation of solids. Since chemical reactions make new products, they are usually irreversible. Irreversible means the change cannot be undone. For example, when you burn wood, you cannot really turn the heat and gases back into a log very easily.

It is important to know that, during chemical reactions, no matter is created or destroyed in the formation of the products. This is known as conservation of mass. Consider the burning wood example: the wood (reactant) in the presence of oxygen in air (reactant) is consumed by fire, and the products are ash and gasses like water vapor and carbon dioxide. If we were to carefully measure the masses of the reactants and products, they would be equal because of the conversation of mass principle.

"red apple core" by roger.karlsson is licensed under CC BY 2.0

"red apple core two days" by roger.karlsson is licensed under CC BY 2.0

"Red apple core nine days" by roger.karlsson is licensed under CC BY 2.0

Figure 2. Example of a chemical change as an apple core sits out over several days. Notice how the core browns over time.
Source: Roger Karlsson

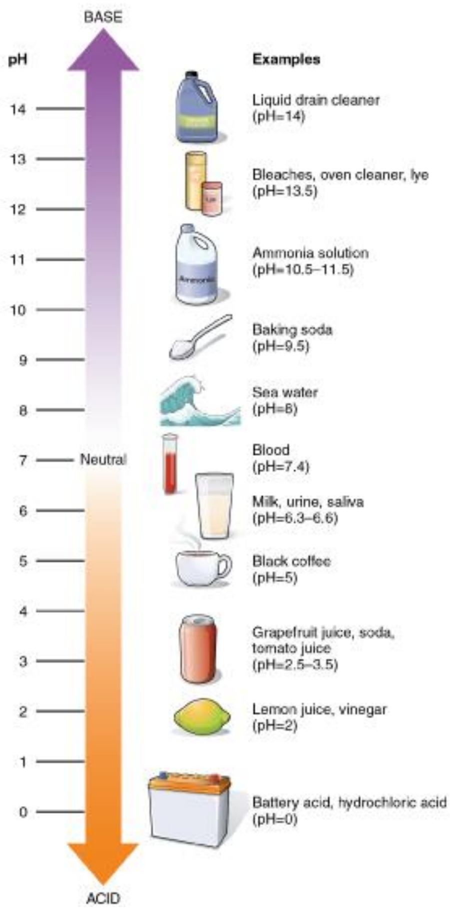

Figure 3. The pH scale with examples of common items that are basic (pH >7), neutral (pH = 7) and acidic (pH < 7).
Source: OpenStax College | commons.wikimedia.org

Chemical reactions are especially critical in the ripening and spoiling of food. For example, when the flesh of the apple turns brown after a bite is taken, it undergoes a chemical reaction called oxidation, which occurs when oxygen reacts with enzymes in the flesh of the apple and results in the browning of the apple over time (see Figure 2). Another example of oxidation is rusting, which occurs when iron changes to iron oxide when exposed to water and oxygen. If an apple is oxidized long enough that the apple browns significantly, the apple is likely spoiled. Spoiled food can look, feel, taste, and smell unpleasant and can also make you sick if you eat it.

Milk spoiling is another example of a chemical reaction. Fresh milk is a mixture of fat and proteins distributed evenly and suspended in a water-based solution. There are also bacteria present in milk that over time (or in the presence of heat) produce enough acid that cause the solid components, like the proteins, to separate from the liquid components. An acid is a type of chemical that produces hydrogen ions (H^+) when dissolved in water and has a value smaller than seven on the pH scale. An acid can be involved in a chemical reaction, like in the case of spoiling milk or when added to a base. A base is a type of chemical that produces hydroxide ions (OH^-) when dissolved in water and has a value higher than seven on the pH scale. Examples of common acids, bases, and neutral items are shown on the pH scale in Figure 3. In the case of milk, once spoiled, the solids left over are known as curds and the liquid is known as whey as seen in Figure 4. Once milk has spoiled, or curdled, the process cannot be undone, and the milk will taste sour. This sour taste is notable with respect to acids. Interestingly, cheese is made by deliberately curdling milk, but in other cases, curdled milk may be unsafe to drink, depending on how long it has been spoiled.

Chemical reactions that ripen and spoil food, possibly making it unsuitable for consumption, are impacted by various factors such as light, oxygen, heat, humidity, temperature, bacteria, and fungi. Food may be more likely to spoil when exposed to one or more of these factors over time.

Figure 4. Curdled milk with solid components (curds) and liquid components (whey). Source: Unknown author, CC BY-NC-ND.

2.2. Supplies List

- Bananas (alternatives: apples, plantains)
- Lemons (alternatives: limes, grapefruits) and oranges
- Milk
- Vinegar (alternatives: lemon, lime, or grapefruit juice)
- Baking soda
- Water
- Balloon
- Small clear cups (glass or plastic)
- Cotton fabric pieces (large enough to cover the opening of the small clear cups)
- Rubber bands (alternative: string)
- Plastic bags
- Empty clear bottle (glass or plastic)
- Pen/pencils

- Marker
- Knife for cutting produce (optional)

2.3. Safety Information

Before the students begin the laboratory, please take into consideration the following safety concerns:

- Demonstrate to the students how to safely hold a knife and cut produce to avoid injuries. You may also pre-cut the produce to avoid any safety concerns.
- Lemon and vinegar are acidic and may sting open cuts and wounds as well if they get into students' eyes.
- While tasting food is part of the food preparation process, please do not taste the food in this lab because the spoiled food may cause the taster to get sick.
- Modern balloons and rubber bands may contain latex. If there are students with latex allergies, they should avoid these supplies. Latex-free substitutes like plastic wrap for balloons and string for rubber bands may be used.

3. Experiments

3.1. Part I. Capturing Reaction Products

3.1.1. Pre-Experiment Questions

1. In your life, how can you tell that a chemical reaction has occurred?

2. What are some examples of chemical reactions while preparing a meal?

3. What are acids and bases?

4. Though you may not have a way to measure pH of materials, if you were told that vinegar is an acid (pH<7) and baking soda is a base (pH>7), what do you predict will happen if the two are mixed?

    a. <u>Extension question:</u> Based on what acids and bases produce when dissolved in water, can you predict what is one product that would form from a reaction?

    b. <u>Extension question:</u> Based on your answer above, try writing out these reactants and products as a chemical reaction (______ + ______ → ______). Note these are generalized for acid and base reactions; actual acid and base reactions will be more complicated.

3.1.2. Materials

- Vinegar
- Baking soda
- Clear bottle (glass or plastic)
- Balloon

3.1.3. Procedure (work in groups of 2-4)

1. Gently pour 60 mL (~4 Tablespoons) of vinegar into the clear bottle. You can use a large spoon (filled 4 times) if you do not have another way to measure the vinegar.
2. Gently pour 1 Tablespoon (one large spoonful) of baking soda into the balloon. You may need to work together as a group to hold open the mouth/neck of the balloon as one student pours in the baking soda.
3. Without tipping the balloon upside down and pouring the baking soda out, stretch the mouth of the balloon over the mouth of the bottle.
4. Now, tip up the balloon to allow the baking soda to fall into the vinegar and watch what happens.

3.1.4. Post-Experiment Questions

1. What did you observe once you tipped the baking soda into the vinegar?

2. What was the chemical reaction you observed? Answer using the words "reactant", "product", "acid", and "base".

3. What do you know about the mass of the reactants compared to the mass of the products?

4. If you could repeat this experiment, what could you do to make the balloon inflate more? Less?

3.2. Part II. Curdling Milk

3.2.1. Pre-Experiment Questions

1. How do you store milk after it is opened? How can you tell when it is spoiled?

2. What happens when milk is spoiled? Answer using the word “acid”.

3. Instead of waiting for bacteria in the milk to produce acid, let's consider adding acid ourselves. Which liquid will cause milk to curdle the most, lemon juice (pH ~ 2), orange juice (pH ~ 4) or water (pH ~ 7)?

3.2.2. Materials

- Milk (should not be too cold)
- Slice of lemon
- Slice of orange
- Water
- 4 small clear cups
- Cotton fabric piece
- Rubber band

3.2.3. Procedure (work in groups of 2-4)

1. Pour 15 mL (~1 Tablespoon or one large spoonful) of milk each into three of your small cups. Label these cups "1", "2", and "3". Swirl the milk in these cups and make observations about the milk before adding any other liquids.
2. Place the cotton fabric piece over the top of the fourth cup and secure it into place with the rubber band. Label this cup "4".
3. Add 5 mL (~1 teaspoon or one small spoonful) of water to cup "1". Gently rotate the cup to allow the water to mix with the milk. Swirl the cup several times. Record your observations immediately after adding the liquid.
4. Wait 5 minutes and again record your observations. Look especially close for any solids that are stuck on the walls of the cup after swirling.
5. Pour the liquid from cup "1" over the cotton fabric on cup "4". Record your observations of any solids left behind, and then remove any solids from the cotton and discard them.
6. Repeat steps 3, 4, & 5 with cup "2" and orange juice instead of water. To get orange juice, squeeze the slice of orange over cup "2".

7. Repeat steps 3, 4, & 5 with cup "3" and lemon juice instead of water. To get lemon juice, squeeze the slice of lemon over cup "3".

3.2.4. Results

Cup #	Added liquid	pH of added liquid	Observations immediately after adding liquid	Observations 5 minutes after adding liquid	Amount of solids (curds) collected – rank 1, 2, 3 (1 is the most curds, 3 is the least)
1	Water	7			
2	Orange juice	4			
3	Lemon juice	2			
Milk before adding any other liquid (do not fill out sections with the X)	X	X		X	X

3.2.5. *Post-Experiment Questions*

1. Which added liquid curdled the milk the most? How do you know?

    a. Extension question: Why do you think this liquid curdled the milk the most?

2. Which added liquid curdled the milk the least? Why do you think this was?

3. What are ways to make the milk curdle faster?

a. Extension question: There is an enzyme called bromelain found in fresh pineapple juice that causes milk to curdle, but the enzyme is deactivated when it is heated. This enzyme also takes some time to activate upon being added to a mixture. What steps would you take to use bromelain to curdle milk effectively?

4. What are other liquids that you think could make milk curdle?

3.3. Part III. Bananas Ripening Bananas

3.3.1. Additional Background Information

When fruit ripens, the starch in the fleshy part of the fruit is broken down into sugar. This process sweetens the fruit and makes it more edible. For example, green bananas do not taste sweet and the riper they become, the sweeter they taste! One of the chemicals that starts this reaction is ethylene gas. Fruit ripening is a chemical reaction during which starch is converted to sugar.

Ethylene is produced and released by fast growing plant tissues, such as tips of fruits, flowers, damaged tissues, and reopening fruit. Some fruits such as bananas, tomatoes, apples, avocados, and mangos produce lots of ethylene. While ethylene gas can ripen fruit, it can also spoil food. You may have heard the saying, “One bad apple spoils the whole bushel.” This is because the bruised, damaged, or overripe fruit gives off ethylene that makes the other fruit ripen faster.

This experiment examines how the number of bananas affects the process of banana ripening and spoiling. Here, we are assuming that an increase in the number of bananas in a bag means an increase in ethylene gas production.

3.3.2. Materials

- 2 plastic bags
- 4 bananas (preferably from the same 'bunch' in order to have the same starting conditions for the 4 bananas)

3.3.3. Pre-Experiment Questions

1. What are some foods you do not store next to one another? Why not?

2. One of the reasons why you may not store many bananas next to each other is because it affects the ripening/spoiling process. Which banana in a bag do you think will ripen first: the one by itself, the one in a bag, or the one with another banana in the bag? Or will they all ripen the same amount? Why did you make this prediction?

3.3.4. Procedure (work in groups of 2-4)

1. Label the bags #1 and #2 with a marker.
2. Take 1 banana from the bunch. Make observations about the banana and set this banana aside.

3. Take 1 banana from the bunch. Make observations about the banana and place this banana in bag #1. Seal the bag.
4. Make observations about the final 2 bananas and place both bananas in bag #2. Seal the bag.
5. Store the bags in similar locations. Check on the bags once a day for 5 days and observe any changes with the bananas.
6. Record all observations in the table below.

Below is a picture of the general set-up.

3.3.5. Results

	Day 1 Date ____ Time ____	**Day 2** Date ____ Time ____	**Day 3** Date ____ Time ____	**Day 4** Date ____ Time ____	**Day 5** Date ____ Time ____
No Bag Banana	**Drawing:** **Observations:**	**Drawing:** **Observations:**	**Drawing:** **Observations:**	**Drawing:** **Observations:**	**Drawing:** **Observations:**
Bag #1 **Banana**	**Drawing:** **Observations:**	**Drawing:** **Observations:**	**Drawing:** **Observations:**	**Drawing:** **Observations:**	**Drawing:** **Observations:**
Bag #2 **2 Bananas Separated**	**Drawing:** **Observations:**	**Drawing:** **Observations:**	**Drawing:** **Observations:**	**Drawing:** **Observations:**	**Drawing:** **Observations:**

3.3.6. *Post-Experiment Questions*

1. Is fruit ripening a physical change or a chemical change? How do you know?

2. Why did we keep one banana out of the bag and left to sit in the air?

3. Which environment made the banana(s) ripen/spoil first? Explain your answer with your observations and results.

    a. Extension Question: Why did this happen?

4. Which banana ripened/spoiled last? Explain your answer with your observations and results.

    a. Extension Question: Why did this happen?

5. Did the sealed plastic bag make a difference in the speed of ripening? Why or why not?

4. Design Challenge

The Challenge: You have been tasked with making a complicated dish that involves ricotta cheese (basically the curds from milk) and fresh, ripened pears. The problem is that you only have the following supplies: milk, vinegar, under-ripe pears, lemons, oranges, paper bags, and plastic bags. You also have access to a stove top for heating ingredients and other kitchen supplies. What is your strategy using the supplies you have to make the dish in the least amount of time possible?

4.1. Pre-Design Questions

1. What results will you use from the experiments to design your solution to making the ricotta cheese and ripening the pears quickly?

2. What other information do you need to know in order to design your solution?

3. Are there other variables you may want to test during the design process? Recall that a variable is something you change during the test.

    a. Extension question: What are the benefits and risks of testing variables during your design process?

4.2. The Design

Draw your design for ripening the pears and making the ricotta cheese in the box below.

4.3. Post-Design Questions

1. Explain your method to ripen the pears and make the ricotta cheese the fastest.

2. How do you feel about the results of your design process?

3. How would you change your method for next time after viewing yours and your classmates' results?

4. What was challenging about completing the design challenge? How did you work through those moments of confusion or frustration?

5. What did you enjoy most about completing this design challenge?

6. What advice would you give a group about completing this design challenge?

5. Extension Experiment: Compost vs Landfill

5.1. Background Information

One can recycle spoiled food and food scraps through composting. A compost is prepared by decomposing plant and food waste with recycled organic material. Some benefits of composting include fertilizing and enriching the soil, reducing the need for chemical fertilizers, encouraging the production of beneficial bacteria and fungi, and reducing food waste. Composting is an example of a chemical reaction because new matter is created as the organic material decomposes.

Besides composting, one might also throw food waste into the trash, which ends up in a landfill. A landfill is typically sealed off to prevent bad smells from leaking into surrounding communities and to keep hungry animals out. Since it is sealed off, a landfill does not have as much air compared to a compost pile.

This extension lesson will demonstrate the difference between throwing our food waste into a compost pile versus into a landfill. It also reinforces the concepts of chemical reactions in food contexts. The time frame of this extension activity is 8 weeks.

5.2. Materials

- 1 recycled glass jar without a lid
- 1 recycled glass jar WITH a lid
- Soil
- Bulking agents such as: Newspaper, wood shavings/chips, straw, dead leaves
- Food scraps and skins such: the food scraps above, banana peels, grass clippings, lettuce scraps, bread crusts, eggshells, *No dairy or meat*
- Water/Rain water

5.3. Pre-Experiment Questions

1. What can we do with all our spoiled food?

2. What is composting?

3. How is a compost pile different from a landfill?

4. What are the benefits of composting?

5. Predict how a compost jar will look different from a landfill jar after 8 weeks. Explain your reasoning for your predictions.

5.4. Procedure (work in groups of 2-4)

Student 1: One student will add a handful of soil into BOTH glass jars.

Student 2: Another student will add a handful of bulking agents into BOTH jars.

Student 3: The third student will add a handful of food scraps and skins into BOTH jars.

Students 2 and 3 repeat their steps until they run out of material or until BOTH jars are full to the top, whichever happens first.

Student 4: The last student will add a cup of water (or collect a cup of rainwater) and add to BOTH jars. One jar will not have a lid on - this is the compost jar. Student 4 will put the lid on the other glass jar and shake. The jar with the lid on is the landfill jar. Keep the lid on. Set the glass on the windowsill, exposing it to sunlight.

Make observations. Record your observations with the Compost vs. Landfill Observation Chart (see below, Results)

Shake the landfill jar and stir the compost jar once a week, for 8 weeks. Observe changes to both jars every week for 8 weeks and mark a line with a permanent marker to show where the 'new' top is.

<u>After answering the post-experiment questions, add the compost to your garden or farm.</u>

5.5. Results: Compost vs Landfill Observations

Week #	**Compost Jar (No Lid)** *What do you see? What do you notice? How does it smell? What do the food scraps look like? Draw what you see.*	**Landfill Jar (With Lid)** *What do you see? What do you notice? How does it smell? What do the food scraps look like? Draw what you see.*
Week #0 (Start) *Date* _____ *Time* _____		
Week #1 *Date* _____ *Time* _____		
Week #2 *Date* _____ *Time* _____		
Week #3 *Date* _____ *Time* _____		
Week #4 *Date* _____ *Time* _____		
Week #5 *Date* _____ *Time* _____		
Week #6 *Date* _____ *Time* _____		
Week #7 *Date* _____ *Time* _____		
Week #8 *Date* _____ *Time* _____		

5.6. Post-Experiment Questions

1. How is the compost jar different from the landfill jar?

2. Is the compost jar an example of a physical change or a chemical change? How do you know?

3. Is the landfill jar an example of a physical change or a chemical change? How do you know?

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