

# Superheated Steam

## Temperature and Heat

### Introduction

Why is steam a greater skin-burning threat than boiling water? How much energy is contained in steam? This demonstration will dramatically show the energy content of superheated steam.

### Concepts

- Heat energy
- Steam
- Condensation

### Materials

Water, 150 mL	Meker burner
Beaker, any size	Rubber stopper with hole, #6
Boiling chips, 2 or 3	Sheets of paper, 2" × 2", 2
Crucible tongs	Support stand and clamp
Copper coil tubing	Support ring or adjustable burner support block
Erlenmeyer flask, 250-mL	Thermometer (optional)
Hot plate	Towel
Match stick	

### Safety Precautions

*Superheated steam is very hot. Be sure students are not close to the demonstration apparatus and especially not in the "line of fire" of the jet stream. Hot water and steam will spurt out the open end of the copper tubing during the demonstration. Do not point the exhaust end of the copper coil tubing at anybody. Perform this demonstration on a table that is free of any items that should not get wet. Care should be taken when handling the Meker burner while heating the copper coil. Allow the copper tubing to cool completely before touching or disassembling the apparatus. Wear chemical splash goggles, heat-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.*

### Preparation (refer to Figure 1)

1. Carefully insert the bent end of the copper tubing into the hole of the #6 rubber stopper so that the end of the tubing is flush with the bottom of the stopper.
2. Fill a 250-mL Erlenmeyer flask with approximately 150 mL of tap water. Add 2 or 3 boiling chips.
3. Place the Erlenmeyer flask on a hot plate.
4. Obtain a support stand and clamp. Insert the rubber stopper (with inserted copper tubing) into the mouth of the Erlenmeyer flask so that it fits snugly. Secure the copper coil tubing to the tabletop (do not use plastic-coated clamps). *Make sure that the open end of the copper tubing is not pointing at anyone.*
5. Place a Meker burner beneath the copper coil on a support ring or adjustable support block so that the Meker burner flame will effectively heat the copper coil.
6. Place a few towels (paper or cloth) on the tabletop a foot or two in front of and beneath the exhaust end of the copper tubing to collect any water that will spurt out the end as the water and steam are heated. (Some of the steam condenses in the tubing and forms liquid water that is eventually pushed out by the flowing steam.)

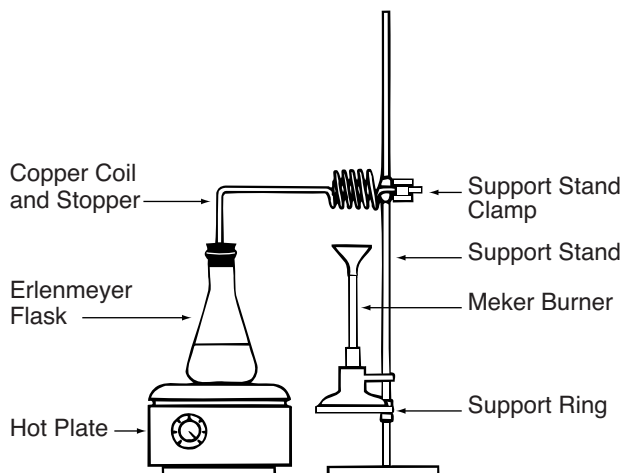


Figure 1.

7. Turn on the hot plate. Adjust the temperature control to the highest setting.
8. Once the water is boiling steadily and visible exhaust steam is seen flowing out of the copper tubing, follow the procedure below. If necessary, adjust the temperature control on the hot plate to maintain a rapid boil.

### Procedure

1. Have students observe the steam flowing from the end of the copper tubing. Ask students: What is the temperature of the steam? (It can be assumed to be approximately 100 °C or it can be measured by carefully placing the tip of a thermometer into the steam.) Is the steam a liquid or a gas? (Many will say it is a gas.) Why? (Actually, the “steam” they see is condensed particles of water—it is in liquid form.)
2. Grip the end of a small sheet of paper with crucible tongs and place the sheet into the exhaust steam at the end of the copper tubing. (Nothing happens, except the paper may become wet.) Remove the paper from the steam.
3. Ignite the Meker burner and adjust the flame so that it is effectively heating the copper coil. The steam will disappear within a few seconds as it turns into superheated steam. Ask students what state the water is in now? Why? Was the visible “steam” they observed earlier really a gas?
4. Carefully grasp a cool beaker with crucible tongs and place the side of the beaker in the superheated steam. The invisible gaseous water condenses on the beaker. (This shows that the water vapor is still there, but it is now in a true *gaseous* state. It condenses when it strikes a colder object—and it releases energy, see *Discussion*.)
5. Continue heating the copper coil with the Meker burner for a minute or two (until the coiled copper tubing gets red hot).
6. Grip the end of a small sheet of paper with the crucible tongs. Keep the paper clear of the Meker burner flame. Place the sheet of paper in the superheated steam exhaust about 1–2 cm from the end of the copper tubing. The paper will char and turn black!
7. Next, grip the base of a match stick with crucible tongs. Place the head of the match in the superheated steam exhaust about 1–2 cm from the end of the copper tubing. It will ignite! Water (superheated steam) can be used to light a match!

### Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The water may go down the drain. The boiling chips can go into the trash. The copper oxide formed on the outside of the copper tubing and the depleted copper tubing can be placed in the trash according to Flinn Suggested Disposal Method #26a.

- Slightly heating the copper coil in the beginning will help to evaporate any condensed water that may be trapped in the coils. This will help make a more visible “steam” cloud for procedure steps 1 and 2.
- When the copper coil is heated it turns black as copper oxide forms on the surface. This oxide will flake off as the copper coil cools. After the demonstration, turn off the Meker burner and move it to the side. Place a towel (cloth or paper) on the tabletop below the coil to collect the flaking copper oxide that falls from the coil. Once the coil has cooled to room temperature, the remaining copper oxide can be removed with a brush or towel. Please see the *Disposal* section for appropriate disposal procedures.
- If a Meker burner is not available, a Bunsen burner can also be used. The superheated steam may not reach as high a temperature so it may take longer for the superheated steam to char the paper. Also, the flame may not have a wide enough area to heat the entire coil like a Meker burner so it may be necessary to use a flame spreader or wing top. Another option is to hold the Bunsen burner at the base and slowly and continuously move the flame across the coil so that the entire coil heats evenly. *Please use extreme caution when handling an ignited Bunsen burner.*

- For a more dazzling display, flash paper can be used. It will ignite in the superheated steam! Flash paper can be found at many magic shops.
- After each demonstration, the thickness of the copper tubing will be slightly thinner due to the formation of copper oxide (on the outside and the inside of the copper tubing) that eventually flakes off. Therefore the life span of the copper coil is limited. It should last for 10–20 demonstrations.

## Discussion

An important concept of this activity is that, initially, the steam flowing from the copper tubing is not truly gaseous water. Gaseous water cannot be seen by the naked eye. Visible steam is actually composed of very tiny liquid water droplets that are suspended in the air. When water is heated to 100 °C (at sea level; slightly less for higher elevations), it begins to boil because there is sufficient energy to change the state of water from liquid to gas. The invisible gaseous water molecules break away from the surface of the water and rise. If there are enough water molecules leaving the surface at the same time, then there is a high tendency for them to collide with each other and interact to form tiny droplets of water as they rise above the surface. We associate these tiny visible water droplets that rise from a pot of boiling water or escape from a heated tea kettle as “steam.” The tiny water droplets do eventually break apart and form gaseous water molecules as the droplets flow to a less concentrated region and equilibrate with the surrounding air molecules. When the steam rises from the water and into the heated copper coil, the heating evaporates the tiny water droplets (again). The temperature of the gaseous water increases beyond 100 °C so the water molecules have too much kinetic energy to condense to the tiny droplets again. This is why the steam disappears when the copper coil is heated.

*Why does the paper char when held in the superheated steam?* As gaseous water (or any gas) condenses to form a liquid, the molecules are going from a higher energy state to a lower energy state. Therefore, energy (in the form of heat) must be released. The amount of heat energy released is associated with the specific heat of gaseous water (33.1 J/mol·°C at 1 atm), the heat of vaporization of water at 100-°C (40600 J/mol at 1 atm) and the specific heat of liquid water (75.3 J/mol·°C at 1 atm). Note that the heat of vaporization of water is much larger than the specific heat of water. This means that most of the released heat energy is associated with the condensation of water vapor. Much more heat is released during the condensation process at 100 °C than when water (liquid or vapor) cools even several hundred degrees! For example, when one mole of water vapor at 100 °C cools and condenses to liquid at 99 °C, 40675.3 J of heat is released. Compare this to one mole of boiling water at 100 °C that cools to 99 °C. Only 75.3 J of heat is released. Therefore, when water vapor strikes a colder object (such as skin) and condenses to the liquid state (at 100 °C) it releases a larger amount of heat energy compared to boiling water (also at 100 °C) that heats an object. This is why steam causes severe skin burns more rapidly than boiling water. This is dramatically shown when the paper chars in the superheated steam. The water vapor condenses onto the paper and releases a large amount of energy that raises the temperature of the paper above its kindling point, or the point at which the material begins to burn. The paper usually will not ignite because the fast-moving superheated steam flushes away the oxygen as well. However, the match will ignite because its chemical make-up contains a chemical supply of oxygen (an oxidizer) that will facilitate a flame.

## Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

***Unifying Concepts and Processes: Grades K–12***

Evidence, models, and explanation  
Constancy, change, and measurement

***Content Standards: Grades 5–8***

Content Standard B: Physical Science, properties and changes of properties in matter, transfer of energy

***Content Standards: Grades 9–12***

Content Standard B: Physical Science, structure and properties of matter, interactions of energy and matter

## Answers to Worksheet Questions

1. Note any observations you made regarding the following:

a. The initial appearance of the steam.

*The steam looked like a small, thin cloud coming out of the copper tubing.*

b. What happened when a piece of paper was held in that initial steam?

*The piece of paper became wet, but it did not appear to heat up at all.*

c. The appearance of the superheated steam.

*The superheated steam was not visible.*

d. What happened when a beaker was held in the superheated steam?

*Water vapor condensed on the side of the beaker, even though the steam could still not be seen.*

e. What happened when a piece of paper was held in the superheated steam?

*The piece of paper was charred and turned completely black where the steam touched it.*

f. What happened when a match was held in the superheated steam?

*The match ignited.*

2. What state was the initial steam in? What state was the superheated steam in? Explain how the difference occurred.

*The initial steam was actually in liquid form—it was composed of tiny water droplets. The droplets were formed due to the large number of water molecules that were leaving the liquid water in gaseous form at the same time. They interacted with one another and became liquid again.*

3. The specific heat of gaseous water at 100 °C is 33.1 J/mol·°C at 1 atm, the heat of vaporization of water at 100 °C is 40600 J/mol·°C, and the heat of liquid water at 100 °C is 75.3 J/mol·°C. What releases more heat—water condensating from 100 °C to 99 °C or boiling water cooling to 99 °C?

*The water undergoing condensation releases much more heat (40675.3 J) because the heat of vaporization of water is so much higher than the specific heat of liquid water at 100°.*

## References

Bilash, B. *A Demo A Day: A Year of Physical Science Demonstrations*; Flinn Scientific: Batavia, IL, 1997; p 27.

Shakhashiri, B. Z. *Chemical Demonstrations*, Vol. 2; University of Wisconsin: Madison, WI, 1985; pp 92–95.

## Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Superheated Steam* activity, presented by Peg Convery, is available in *Temperature and Heat*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

## Materials for *Superheated Steam* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Superheated Steam Demonstration* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP6158	Superheated Steam Demonstration
AP2306	Rubber Stoppers, Size 6, One-Hold, 1 lb

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

# Superheated Steam Worksheet

## Discussion Questions

- Note any observations you made regarding the following:
  - The initial appearance of the steam.
  - What happened when a piece of paper was held in that initial steam?
  - The appearance of the superheated steam.
  - What happened when a beaker was held in the superheated steam?
  - What happened when a piece of paper was held in the superheated steam?
  - What happened when a match was held in the superheated steam?
- What state was the initial steam in? What state was the superheated steam in? Explain how the difference occurred.
- The specific heat of gaseous water at 100 °C is 33.1 J/mol·°C at 1 atm, the heat of vaporization of water at 100 °C is 40600 J/mol·°C, and the heat of liquid water at 100 °C is 75.3 J/mol·°C. What releases more heat—water condensating from 100 °C to 99 °C or boiling water cooling to 99 °C?