Thermodynamics
The Heat Plume of a Fire

Lesson 2

Based on the US Forest Service's

"FireWorks Northern Rocky Mountains & Northern Cascades Curriculum"

Smith, Jane Kapler; Abrahamson, Ilana; Berkowitz, Caitlyn; and McMurray, Nancy. 2018. FireWorks curriculum featuring ponderosa, lodgepole, and whitebark pine forests. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer).

FIRE LESSON: Single matches and stove lighters are used in this activity to model physical phenomena that students will investigate. Exercise caution when conducting this activity. This activity should only be conducted in an appropriate laboratory setting under instructor supervision. A safety checklist and a safety quiz are included in this activity's slideshow. Students should successfully complete the safety quiz before conducting this activity.

Lesson Overview In this lesson, students learn about the three mechanisms that transfer heat energy away from a fire. These concepts are explored with two similar experiments that require students to determine the size and shape of heat plumes associated with lit matches. Since this may be the first opportunity many students have to investigate fire, safety procedures are also covered.

Lesson Goal Provide an opportunity to gain confidence in safely conducting experiments with

Subject Areas: Science, Mathematics, Writing, Speaking and Listening, Health and Safety

Duration: 50-60 minutes (One class period)

Group Size: Groups of 2-4

Setting: Classroom for introduction; laboratory for activity

Vocabulary: Thermodynamics, Conduction, Convection, Radiation, Plume

fire. Increase understanding of the factors that contribute to heat dispersal from a fire.

Objectives

- ➔ Students can list and describe the three ways by which heat energy may be transferred from a burning object.
- ➔ Students can draw a heat plume from a burning match and can explain why the heat plume has that shape.
- ➔ Students can list some of the safe practices for conducting laboratory experiments that include fire.

Academic Standards

Table 1: Next Generation Science Standards - High School - Disciplinary Core Ideas

HS-PS3 Energy	PS3.A, PS3.B, PS3.D
HS-LS1 From Molecules to Organisms: Structures and Processes	LS1.C
HSLS2 Ecosystems: Interactions, Energy, and Dynamics	LS2.B

Table 2: Next Generation Science Standards - High School - Performance Expectations

HS-PS3 Energy	HS-PS3-4

Teacher Background The focus of this activity is **thermodynamics -** the flow, movement, or transformation of energy. The movement of heat energy released from an **exothermic** reaction, such as combustion, occurs by three transfer mechanisms: 1) **convection**; 2) **radiation**; and 3) **conduction**. When an object burns, most of the heat energy disperses upward because of the buoyant nature of hot gases in a "cooler" air column. This upward movement of hot gas is due to convection and is the underlying cause of a **heat plume**'s shape. If wind is present at the site of a fire, the heat plume will also have a sideways component that results in a diagonal shape. As a result of radiation and conduction, a smaller portion of a fire's heat will move in directions other than upward and will move between objects depending upon the situation.

In this activity, students first develop a diagram that depicts the shape of the heat plume from a match. Students will also be introduced to factors that influence fire behavior such as fuel availability and topography.

Table 3: Key Terms

Heat Plume	Upward-moving hot gases that transfer energy from a fire by convection.
Conduction	Heat is transferred through direct contact between atoms or molecules within solid objects. In fire, conduction enables heat to move from an object's outside to its inside and from one solid object to another one that is touching it.
Convection	Heat is transferred by hot gases as they expand into the cooler gases surrounding them. Since Earth's atmosphere becomes "thinner" (less dense) as you go up in altitude, "up" has less resistance to the expanding gases than "sideways" or "down." Thus hot air generally rises.
Exothermic	Type of chemical reaction that releases heat energy.
Radiation	Heat is transferred through space from the object where it is generated to the first atom or molecule that intercepts it. For example, heat from the sun travels through almost 100 million miles of space before it is intercepted by the leaves of plants, (where photosynthesis occurs) or our skin (where sunburn occurs). Radiation from a fire can heat fuels before ignition.
Thermodynamics	The field of physical science dealing with the movement or flow of heat energy and its relationship with other forms of energy and work.

Materials and Preparation Determine the location where this activity will be conducted. Understand that this demonstration can produce flames that are 10-20 centimeters long. Can this activity be done safely in the area you have chosen? Another important consideration is the presence of smoke detectors. It may be necessary to contact school staff that can address any concerns related to smoke detectors/fire alarms. If there are safety issues, a different location

will be needed such as a chemistry laboratory with appropriate ventilation or a welding shop. It will be very difficult to perform this activity outside since even the slightest wind will blow out a single match and will dramatically influence the behavior of a heat plume.

A download of a graph sheet for plotting results to "map" a heat plume is available in **Table 4** (below). Laminating this "plume-mapping" graph will allow it to be reused.

Table 4: "The Heat Plume of a Fire" Resources

"The Heat Plume of a Fire" Resources
Heat Plume Graph Paper (USFS FireWorks)

Since this is the first activity with fire, it would be best to discuss safe laboratory procedures the day before the activity is scheduled. This will give students an opportunity to be appropriately dressed. The "FireWorks Safety" poster is a great source of basic fire safety information. The poster is included as a slide in this lesson's slideshow presentation. If you are unable to produce a poster-sized version, be sure to project the "poster" and go over each point. The poster is included on the student worksheet.

- ➔ Display the FireWorks Safety poster so it is visible in the area where the activity will be conducted.
- ➔ Make sufficient copies of the student worksheet for this activity (1 per student).
- ➔ Get a box of wooden kitchen matches and one stove lighter for each station.
- ➔ Be sure that the activity area has a fire extinguisher that is fully charged.
- ➔ Set up laboratory bench or other area to be used for demonstration with the following equipment:
  - ◆ Laminated graph sheet
  - ◆ Dry erase marker
  - ◆ Spray bottle, filled with water
  - ◆ Box of matches
  - ◆ Stove lighter
  - ◆ Ruler

- Metal tray
- Safety goggles/glasses for each student
- Leather gloves or oven mitt
- Tree model stand (or ring stand with clamp holder)
- Cross-piece with alligator clip
- Rubber band (to "stabilize" cross-piece)

➔ Set up the tree model stand and cross piece as shown above.

➔ To set the system up for the first trial, clip a match to one end with the ignitable tip pointing down as shown above.

Procedure Since this is the first activity in the "Fire in the Ozark Highlands" curriculum, it might be a good idea to cover the first few slides in the slideshow the day before students do the lesson. This will introduce students to the "FireWorks Safety" poster and ensure familiarity with safety considerations by having students take a quiz. This will also allow students to be appropriately dressed for the activity. On the day of the activity, begin with the slide about "How Is Heat Energy Transferred?"

➔ Hand out the student worksheets

➔ Present the "Heat Plume of a Fire" slideshow

➔ As groups work on the activity, be sure that students are displaying appropriate behavior and procedures. Since this is the first activity with a fire/flame, it is extremely important that students conduct themselves appropriately.

➔ When asked to check fire plume diagrams, ask students to:

- Describe the heat plume
- Describe where the three heat transfer mechanisms are at work
  - Convection appears to be the primary mechanism of heat transfer. The hot gases given off by combustion move upward in the cooler air surrounding the match.
  - Radiation allows heat to be detected to the sides and downward.
  - The reason gloves were worn was because conduction transfers heat energy through the metal alligator clip, cross-piece, and stand.

- ➔ As groups finish the activity, be sure that each station has been cleaned and organized appropriately. The stations should either be ready for the next class/group or "broken down" per teacher instructions.
- ➔ Once again, be sure all matches are out before they are disposed of; there is no smoke and no heat being released. Use the metal bucket in the activity area for match disposal. If in doubt, use the station's spray bottle to wet the matches before putting them in the metal bucket.
- ➔ Time permitting, it might be a good idea to quickly go over the three questions the worksheet ends with using the "FS / Module 1 / Lesson 1 - Heat Plume - Key for Student Worksheet" as a guide.

Assessment

Student Worksheet

Laminated Graph Sheet

Sample quiz/review questions for the "FireWorks Safety" poster

1) What material should clothing be made of when conducting an activity with a flame/fire?

a) Polyester
b) Cotton
c) Gore-tex
d) Nylon

Answer: b

2) What type of footwear must be worn when conducting experiments with fire?

a) Closed-toe shoes
b) Sandals
c) None / Going barefoot is best

Answer: a

3) What should be done with loose sleeves and/or loose hair before beginning an activity with flame/fire?

a) Should be tied back

b) Should be cut off

c) Should be moistened with water

d) Nothing

Answer: a

4) If a charged fire extinguisher is available in the classroom, does each lab station need to have a spray bottle filled with water?

YES

NO

Answer: YES

5) If a student already wears glasses, does she/he need to wear safety glasses/goggles?

YES

NO

Answer: YES

6) Fire is not out if there is any smoke or heat coming from the fuels.

TRUE

FALSE

Answer: TRUE

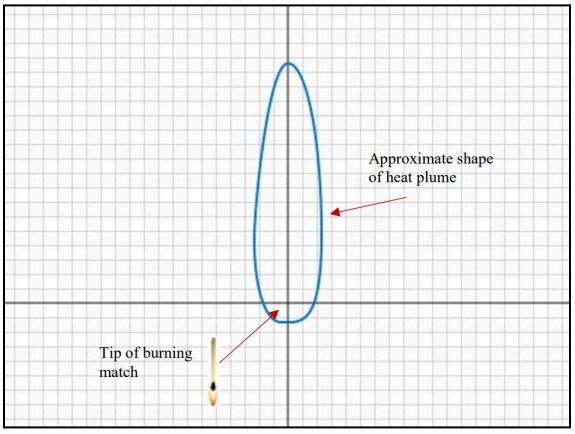
Evaluation

Student Worksheet

A key for the student worksheet can be found as a separate document entitled "Key for Student Worksheet."

Laminated Graph Sheet

When each group has transferred their heat detection measurements onto the laminated graph sheet, the diagram produced should be similar to the one below:



The overall shape of the heat plume is important not the distances since each student will have different "heat perception." To receive the instructor's initials on the worksheet and to continue in the activity, the heat plume must resemble the one above.

Sample quiz/review questions for the "FireWorks Safety" poster

Answers provided with the questions in the **Assessment** section.

Extensions None for this activity. "The Fire Triangle (Part 1) - Heat and Fuel" will provide students further opportunities to investigate heat transfer.

References/Resources None for this activity.