

**EDUCATOR**

# **INVESTIGATION 2: HEAT TRANSFER & IGNITION**

**CASE STUDY OF SCIENCE AND ENGINEERING**

SCIENTISTS ASK WHY. ENGINEERS ASK HOW.



**AGE GROUP**  
Middle School



**CATEGORY**  
Fire Forensics



**COMPLETION TIME**  
2 - 4 Class Periods

Enduring understanding: To investigate a fire, we must understand ignition and combustion principles. To solve a case, we must understand how to build a claim supported by evidence and reason.

## INVESTIGATION 2: HEAT TRANSFER & IGNITION.

*Note: Involves open flame and burning of small amounts of material in controlled lab setting.*

### **FIRE INVESTIGATORS MUST UNDERSTAND:**

- how fires start
- how fires spread
- how different amounts and shapes of materials burn differently

When we know how heat is transferred, we can better understand a fire scene. Knowing the ignition of different materials helps fire investigators understand and read a burn scene.

### **Exploration: This investigation is divided into two parts**

- A. How do fires spread?
- B. How do fires start?

### **The TESTABLE questions guiding our investigation are:**

- A) How does heat transfer between materials?
- B) Does shape and size effect ignition (catching fire) and combustion (burning)?  
Does the material effect ignition (catching fire) and combustion (burning)?

### **Essential knowledge and skills**

We will look for students to understand:

- The transfer of energy can be tracked as energy flows through a designed or natural system. (MS- PS3-3)
- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment. (MS-PS3)
- When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object (MS-PS3-2).

We will look for students to be able to:

- Construct, use, and present oral and written arguments supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon. (MS-PS3-5)

### **ASSESSMENT: This understanding looks like**

- Students can make a claim supported by evidence collected through visual observations and supported by reasoning based on understandings of heat transfer, surface to mass ratio, and ignition properties of different materials.

- Students can apply knowledge/elaborate on reasons that it is important for fire fighters and investigators to understand heat transfer, surface to mass ratio, and ignition properties of different materials.

## SUMMARY OF LAB

A) Students make observations about how thermal energy is transferred and how transferred heat starts fires.

B) Students compare the surface to mass ratio of a block of wood and a toothpick, then compare how easily they ignite. Students then make observations about how different materials ignite and burn.

Please take all precautions for safety as recommended for middle school lab classrooms. If you do not have the proper equipment or ventilation for fire testing, please use the video as it demonstrates the concepts and allows for students to make predictions and see results.

## EXPLORING THE ISSUE

### Background information

#### HEAT TRANSFER

Solids and liquids do not burn. Gases burn. Solids and liquids are broken down into simpler molecular compounds (a chemical change) by the effects of heat. These gases are the products of decomposition and that is what burns in a fire.

In a candle, how do we go from solid wax to gaseous fuel? The wax isn't burning until we add heat from the lighter or match, and then the heat is consistently applied by the burning wick. The solid wax is fuel, but does not burn until heat is applied.

Many things are fuel and can burn – things around us every day like clothes, hair, carpeting, furniture, etc. If heat comes into contact at a fast-enough rate, solids can turn to gaseous fuel through pyrolysis.

**Pyrolysis. A process in which material is decomposed or broken down, into simpler molecular compounds by the effects of heat alone; pyrolysis often proceeds combustion." [Pyrolysis. Product of decomposition through heat; a product of a chemical change caused by heating; (National Fire Protection Association)**

Knowing that when heat is applied, solids and liquids can turn to gaseous fuels, we need to know how heat is transferred. There are three main methods of heat transfer: 1) conduction, 2) convection, and 3) radiation.

- Conduction. The transfer of heat within a solid or between two solids.
- Convection. Heat transferred due to gasses – either hot gases interacting with each other or a hot gas hitting a cold surface and transferring heat to that surface.
- Radiation. Heat transferred by light energy.

## CONDUCTION

Conduction is the transfer of heat within a solid or between two solids. A small, hardened drop of wax on a 6" (15.2cm) length of copper wire and wooden popsicle stick demonstrates conduction. When the copper wire is put in the candle flame, the wax on the other end of the copper wire melts. The heat from the flame is conducted through the wire to melt the wax. Metals are very conductive – they transfer energy or heat. Copper wiring is used in our homes to efficiently transfer energy throughout our home.

The wax on the wood stick, however, does not melt while the wood stick will most likely catch fire (be sure to put the stick into the pan of water). Heat is not conducted through wood; wood is an insulator, which is the opposite of conductor. A good insulator is air; wood is made of cellulose and air is trapped within. In a campfire or fire place, the popping and cracking sounds are the moisture and air bubbles expanding.

A fire investigator needs to understand what conducts heat and what does not to determine if there was a *competent energy source*, meaning enough energy to the source to turn solids to a gaseous fuel that will burn. If the material in the room does not conduct energy, it may not be a competent ignition source.

## CONVECTION

Convection is heat transferred due to gasses – either hot gases interacting with each other or a hot gas hitting a cold surface and transferring heat to that surface.

Holding an index card 1-2" (2.5 – 5cm) over the candle flame will turn the paper black (char) and may ignite. While holding a fresh index card 1-2" (2.5 – 5cm) to the side of the candle flame, there are no observable changes to the card. The temperature is higher above the flame than next to it. The thermal plume of the candle is convective heat transfer.

In a structure fire, the thermal plume deposits soot and chars the surface of the wall, which creates a pattern that fire investigators look for when trying to identify the location where the fire started.

Convection is how most heat energy is transferred in a house or building fire. The hot air rises and spreads out, and this rising hot air draws cooler air into the base. In a house fire, the temperature near the floor is cooler than above. This rising heated air makes the ceiling and walls hotter; when heat is applied at a fast-enough pace, the surfaces will pyrolyze. If all gases in the room ignite at the same time, it is a phenomenon called flashover.

## RADIATION

The index card to the side of the candle flame demonstrates radiative heat. If you place your hand to the side of the candle, it is warm while putting your hand over the candle it is hot (be careful!). Radiation is heat transferred by light energy. On a sunny day, sun on skin is sun transferring heat to you via thermal radiation. That's why sunscreen or staying out of the sun avoids burning the skin.

Convection compared to radiation heat transferred is demonstrated by roasting a marshmallow over a fire. Holding the marshmallow to the side will slowly roast the marshmallow (radiation) while holding it directly above the flames ignites the marshmallow (convection).

## **IGNITION**

When heat is transferred to materials, they will ignite and burn differently – most of these differences are observable before any measurements are taken. The same material (same chemistry) will ignite in different

ways depending on the surface area and amount of the material, or the surface to mass ratio. Different materials, like organic (naturally occurring) and synthetic (man-made) ignite and burn in different ways. It is important for fire fighters and investigators to know the characteristics of how common materials burn so they can predict the behavior of the fire as it burns and can read a fire scene once the fire is extinguished.

## **SURFACE TO MASS RATIO**

To demonstrate the principle of surface to mass ratio, open flame is applied to different shapes and masses of wood – the same chemistry with different geometry. A 2x4” (5x10cm) block of wood will most likely char and smoke, but not ignite while a popsicle stick/wood stick will ignite quickly and burn. The sawdust in the metal pan ignites, but doesn’t burn well.

The 2x4” (5x10cm) block of wood has a lower surface area and higher density, while the sawdust has a higher surface area and lower density. Surface to mass ratio is the amount of energy it takes to ignite a material – higher density materials take more energy to ignite, but burn longer (more fuel), while lower density materials are easily ignited but do not burn well.

## **INORGANIC VS. ORGANIC VS. SYNTHETIC**

Things in our homes and schools and offices are generally made of three different categories of materials. Inorganic materials occur naturally but are abiotic, or non-living. Inorganic materials are things like rocks, brick, concrete, and ceramic. Organic materials occur naturally, like wood, wool, and cotton. Synthetic materials do not occur in nature and are man-made, or synthesized by humans. Two of the categories of materials ignite and burn differently, and leave behind different evidence to read from.

Synthetic materials like, polystyrene (Styrofoam), which is made of synthesized oil by-products, ignites very rapidly when heat is applied. As it burns, it drips hot liquid and gives off a heavy black smoke with a rapid flame spread rate (i.e., how quickly the flame spreads on the material). Similar observations are made of synthetic carpet, furniture upholstery, clothing, etc.

Organic materials, however, ignite less quickly, burn slower, have a slower flame spread rate, and the smoke is considered “cleaner.”

Inorganic materials do not ignite or burn. They do not contain carbon. But, when heated, the gases from the inorganic materials will burn – gases from heated surfaces will ignite through the process of pyrolysis.

How materials burn will also provide information on how much potential energy is stored in them in the form of sugars, oils, fats. A marshmallow ignites rapidly and chars as it burns, while a cheese curl also ignites rapidly and but burns slowly and at a higher temperature. In this investigation, it is helpful to do visual observations of how these foods burn and compare them to household materials. In Investigation 3: Heat Release Rate, a quantitative measure of this difference will be taken and analyzed.

**SAFETY NOTE:** When observing these materials burn, it is important to have good ventilation in the classroom and a pan of water to extinguish the burning materials. It is also important to do this over a fire-retardant surface, like a lab table or concrete.

To conduct investigations in the classroom:

## **MATERIALS**

(one set per group of students or one set for teacher's demonstration)

- Pillar or small candle in center of metal/non-flammable pie pan or tray (not! plastic, paper, or wax coated material)
- Beaker of ice water
- 2 6" (15cm) lengths of copper wire
- A block of lumber/wood cut in 2x4" (5x10cm) (commonly used in construction, readily available at hardware store)
- 2 oz. (28g) of sawdust (handful) (also available at hardware store by asking lumber department for sample) – place in center of metal/non-flammable pie pan or tray (not! plastic, paper, or wax coated material)
- 5 popsicle sticks/also known as craft sticks (non-coated, not colored)
- Strip of carpet (small samples free at carpet stores)
- Polystyrene piece (small) (Styrofoam)
- Brick or ceramic tile
- Tongs to handle materials that are hot or briefly flaming
- Long reach lighter
- Metal/non-flammable pie pan or tray (not! plastic, paper, or wax coated material) with 1-2" (2.5 – 5cm) water
- Xplorlabs video: Investigation 2

## **PREPARATION**

Dip a toothpick into hot wax and place a small drop of wax on one end of one piece of copper wire. Do the same with a popsicle/craft stick.

## SAFETY CONSIDERATIONS

- Hair pulled back and sleeves rolled up
- Safety glasses on
- Fire retardant surfaces – table tops or go outside in schoolyard on open concrete or asphalt avoiding vegetation and structures overhead

## ROLES



### THE STUFF SUPERVISOR

Gathers and cleans up materials



### THE EXPERIMENT EXEC

Runs the experiment



### THE DIRECTOR OF DOCUMENTS

Reads the procedure to the group and helps the group members with data collection



### THE PRINCIPAL PRESENTER

Shares the group's work with the rest of the class

## PROCEDURE - EDUCATOR

### EVALUATE

#### WHAT EDUCATOR DOES

Using the C/E/R rubric, assess quality and accuracy of responses and provide feedback to students.

#### WHAT STUDENTS DO

Choose one question to answer:

What is the impact of the surface to mass ratio to ignition and burning? Based on our observations in this investigation, what can we claim about the impact of surface to mass on ignition and combustion?

How do different types of materials ignite and burn?

Based on our observations, what can we claim about how different materials ignite and burn?

What is our evidence for these claims?

Why is this important for fire investigators to understand?

*\*If time, students use the C/E/R rubric to do self-assessment or peer assessment and provide feedback to one another*

### EXTEND

#### XTENSION

Using the procedure for inorganic/synthetic/organic, look at the differences in how different types of food products burn based on oil/fat and sugar content – marshmallow, cheese curl, bologna.

Investigation 3 will explore the heat release rate of these food products using a calorimeter.

### EVALUATION OF OUTCOMES:

#### Next Generation Science Standards

The transfer of energy can be tracked as energy flows through a designed or natural system. (MS- PS3-3)

#### Disciplinary Core Idea:

#### PS3.B Conservation of Energy and Energy Transfer

- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment. (MS-PS3)
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones. (MS-PS3-3)]



## PROCEDURE - EDUCATOR

### ENGAGE

#### WHAT EDUCATOR DOES

Light the candle and ask students:

- How the candle was lit/ignited?
- How the candle continues to burn?

*Give explanation of candle explaining pyrolysis - solids and liquids broken down into simpler molecular compounds (a chemical change) by the effects of heat. These gases that are the products of this decomposition from the liquids or solids are what burns in a fire.*

#### WHAT STUDENTS DO

Students share thinking in partners, small groups, or whole class.

### EXPLORE

#### WHAT EDUCATOR DOES

For pyrolysis to occur, heat must be applied to a material. How is that heat transferred?

Three methods – conduction, convection, radiation.

*Give small groups of students procedures and materials for each test or do with the whole class as a demonstration.*

##### A. Conduction

- Place a popsicle/wood stick and a copper wire piece (both without the wax bead) in the beaker of ice water.
- Ask students to feel the temperature of each sample and share what they feel.
- Why is one cold to the touch and the other not?
- Light the candle in the center of a metal pan or on fire-retardant surface.
- Using the popsicle/wood stick and a copper wire with the dried wax bead, one at a time place the opposite end of the bead in the open flame of the candle.
- Students to observe what happens to the dried bead of wax.

#### WHAT STUDENTS DO

Observe relative temperature of wood and copper in ice water.

Observe and record what happens to the wax bead on the copper wire and popsicle/wood stick.

## PROCEDURE - EDUCATOR

### EXPLAIN

#### WHAT EDUCATOR DOES

Define conduction – *the transfer of heat within a solid or between two solids.*

Ask students how this definition explains what they observed.

#### WHAT STUDENTS DO

Write or discuss how conduction applies to what was observed.

### EXPLORE

#### WHAT EDUCATOR DOES

*Give small groups of students procedures and materials for each test or do with the whole class as a demonstration.*

##### **B. Convection/Radiation**

1. Light the candle in the center of a metal pan or on fire-retardant surface.
2. Hold an index card 1-2" (2.5 – 5cm) directly over the flame.
3. Students observe the effects of the flame on the card (if card ignites, place in pan of water).
4. Hold new index card 1-2 inches (2.5 – 5cm) to the side of the flame.
5. Students observe the effects of the flame on the card.

#### WHAT STUDENTS DO

Observe and record index card over the flame (convection).

Observe and record index card next to the flame (radiation).

## PROCEDURE - EDUCATOR

### EXPLAIN

#### WHAT EDUCATOR DOES

Define convection – *heat transferred due to gasses – either hot gases interacting with each other or a hot gas hitting a cold surface and transferring heat to that surface.*

Define radiation – *heat transferred by light energy.*

Ask students how these definitions explain what they observed.

#### WHAT STUDENTS DO

Write or discuss which is a demonstration of convection and of radiation based on what was observed.

### ELABORATE

#### WHAT EDUCATOR DOES

How does knowing this help fire fighters?  
How does knowing this help fire investigators?

#### WHAT STUDENTS DO

Think – Pair – Share ideas on how this applies to fire fighting and fire investigation.

### EVALUATE

#### WHAT EDUCATOR DOES

Using the C/E/R rubric, assess quality and accuracy of responses and provide feedback to students.

#### WHAT STUDENTS DO

Question: How does heat transfer between materials?  
Based on our observations in this investigation, what can we claim about:

How heat transfers between materials?

What is our evidence for these claims?

Why is this important for fire investigators to understand?

*\*If time, students use the C/E/R rubric to do self-assessment or peer assessment and provide feedback to one another*

### EVALUATE

#### WHAT EDUCATOR DOES

Why do some things ignite faster than others?

#### WHAT STUDENTS DO

Students share thinking in partners, small groups, or whole class.

## PROCEDURE - EDUCATOR

### EXPLORE

#### WHAT EDUCATOR DOES

Give small groups of students procedures and materials for each test or do with the whole class as a demonstration.

##### Surface to mass ratio

1. Light the candle in the center of a metal pan or on fire-retardant surface.
2. Discuss differences/similarities between 2x4" (5x10cm) block of wood, popsicle/wood stick, and sawdust (all same material, but different sizes and shapes, densities and mass).
3. Hold 2x4" (5x10cm) over the candle's flame with the wood touching the flame.
4. Students observe the 2x4" (5x10cm). Identify charring (blackening of wood).
5. Hold popsicle/wood stick in the candle's flame.
6. Students observe the popsicle/wood stick (if ignites, place in pan of water).
7. Extinguish candle and replace candle with sawdust in center of metal pan.
8. Hold long reach lighter flame to the sawdust.
9. Students observe sawdust in presence of flame.

#### WHAT STUDENTS DO

Observe and record differences and similarities in the materials.

Observe and record how each material ignites and burns.

### EXPLAIN

#### WHAT EDUCATOR DOES

Ask students to report what they observed.  
Call attention to the materials that ignited quickly/slowly, burned quickly/slowly, thinking about mass and density.  
Based on their observations of the wood, ask students to define surface to mass ratio.

#### WHAT STUDENTS DO

Report what was observed – differences and similarities in how the wood products ignited and burned.

What role did mass and density play in how the material was ignited by the flame? What role did mass and density play in how the material burned?  
How would you define surface to mass ratio?

## PROCEDURE - EDUCATOR

### EXPLORE

#### WHAT EDUCATOR DOES

The size and shape of the material matters to ignition and combustion, does the type of material have an effect on ignition and combustion?

*Give small groups of students procedures and materials for each test or do with the whole class as a demonstration.*

#### Inorganic vs. organic vs. synthetic

##### A. Organic – wood

1. Light the candle in the center of a metal pan or on fire-retardant surface.
2. Define organic material.
3. Make predictions about how/if the material will ignite and burn with reasons for predictions (I think...because...)
4. Hold the popsicle/wood stick with tongs and lower the popsicle/wood stick into the candle's flame.
5. Students observe and record flame spread, smoke, burning.
6. Extinguish by placing the popsicle/wood stick into the pan of water.

##### B. Synthetic - polystyrene

1. Define synthetic material.
2. Make predictions about how/if the material will ignite and burn with reasons for predictions (I think...because...)
3. Hold the small piece of polystyrene with tongs and lower the polystyrene into the candle's flame.
4. Students observe and record flame spread, smoke, burning.
5. Extinguish by placing the polystyrene into the pan of water.

#### WHAT STUDENTS DO

Observe and record organic, synthetic, and inorganic ignition, flame spread, burning, smoke.

## PROCEDURE - EDUCATOR

### EXPLORE CONT.

#### WHAT EDUCATOR DOES CONT.

3. Hold the small piece of polystyrene with tongs and lower the polystyrene into the candle's flame.
4. Students observe and record flame spread, smoke, burning.
5. Extinguish by placing the polystyrene into the pan of water.

#### C. Inorganic – brick/ceramic tile

1. Define inorganic material.
2. Make predictions about how/if the material will ignite and burn with reasons for predictions (I think...because...)
3. Hold the piece of brick/ceramic tile and lower into the candle's flame.
4. Students observe and record flame spread, smoke, burning.
5. Extinguish by placing the brick/ceramic tile into the pan of water.

### EXPLAIN

#### WHAT EDUCATOR DOES

What were the differences in how the materials ignited and burned?  
What are possible explanations of those differences?

Support student thinking with explanations based on the properties of inorganic, synthetic, and organic materials.

#### WHAT STUDENTS DO

Write or discuss differences and offer possible explanations.

### ELABORATE

#### WHAT EDUCATOR DOES

How does knowing this help fire fighters?  
How does knowing this help fire investigators?

#### WHAT STUDENTS DO

Think – Pair – Share ideas on how this applies to fire fighting and fire investigation.