Michael Faraday's The Chemical History of a Candle

with Guides to Lectures, Teaching Guides & Student Activities

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ESSENTIAL BACKGROUND

HOW A CANDLE WORKS

To deeply appreciate Faraday's astonishing linking of the flicker of a candle flame to how a gasp of air enables life, a reader needs to have a clear idea of the chemistry of a burning candle. For the reader eager to tackle the lectures, we outline below, in a single paragraph, the basics of a candle's operation. A study of the more detailed events happening when a candle burns will enhance a reader's understanding of the lectures and so we've expanded on the "quick overview" with a section entitled "A detailed look at a candle."

Quick overview

When a candle is first lit the flame consumes the wick until it reaches a point just above the wax. This heat from the flame melts the wax by radiation through the air and by conduction through the wick. Only the tip of the wick burns. This liquefied wax climbs the wick to the flame by capillary action, where the molten wax is vaporized. Next, the flame burns that vapor with oxygen supplied by the surrounding air. This reaction releases gases—mainly gaseous carbon dioxide and water vapor—and heat. The heat released melts more wax, which, again, crawls up the wick and so sustains the candle's flame. A candle, then, simultaneously carries out two actions: its flame burns vaporized wax and it delivers wax to that flame to sustain it.

A detailed look at a candle

While the quick overview above highlights the important actions occurring in a candle, it is in the details that we see the complex chemical and physical process that occur. We detail below the chemical composition of the wax, the function of the wick, the chemical and physical processes in the flame, and the nature of the emissions from a candle.

Wax

Candle wax is the fuel burned by a candle. The wax is a mixture of long-chain hydrocarbons with the formula C_nH_{2n+2}. Typically the composition of the various hydrocarbons averages to $C_{25}H_{52}$. Solid candle wax will not burn, nor will molten wax: only vaporous wax burns.

The wick

The wick has two functions. First, the wick conducts heat from the flame to the solid wax. This heat melts the wax. Second, the wick transports the molten wax to the flame: the liquefied wax crawls up the wick via capillary action. The liquid rises almost to the top of the wick, where it is engulfed by flame and vaporized. Only the tip of the wick glows and it turns black as it burns. Note that the flame consumes the wick at the same rate as the solid wax of the candle is depleted.

The flame

The flame burns the vaporized wax with oxygen supplied by the surrounding air. (See figure on page 10). This reaction releases gases—mainly gaseous carbon dioxide and water vapor—and heat. The carbon dioxide is formed from carbon in the candle wax and oxygen in the air, and the water forms from hydrogen in the wax and oxygen in the air.

The flame has three regions where different chemical and physical phenomena occur. Combustion, the chemical reaction that produces carbon dioxide and water, occurs in the blue outer edge of the flame. Here the vaporized wax burns completely—*complete* means converting all the carbon in the wax to carbon dioxide rather than carbon monoxide. This region, which is the hottest part of the flame, is not uniform: the blue is concentrated at the base of the flame, and decreases toward the top of the flame, where it is only a thin layer at the flame's edge.

Combustion also occurs in the grayish-yellow section of the flame that surrounds the tip of the wick. Here the flame vaporizes the molten wax. The liquefied wax cools the flame and so this is the section of the flame with the lowest temperature. The wax here undergoes *incomplete* combustion. Incomplete combustion happens when there is not enough oxygen to combine with carbon: air, which supplies the oxygen, cannot travel easily into the flame. Because the combustion is incomplete some of the carbon from the wax remains in the flame. This darkens the flame creating the grayish cast near the wick.

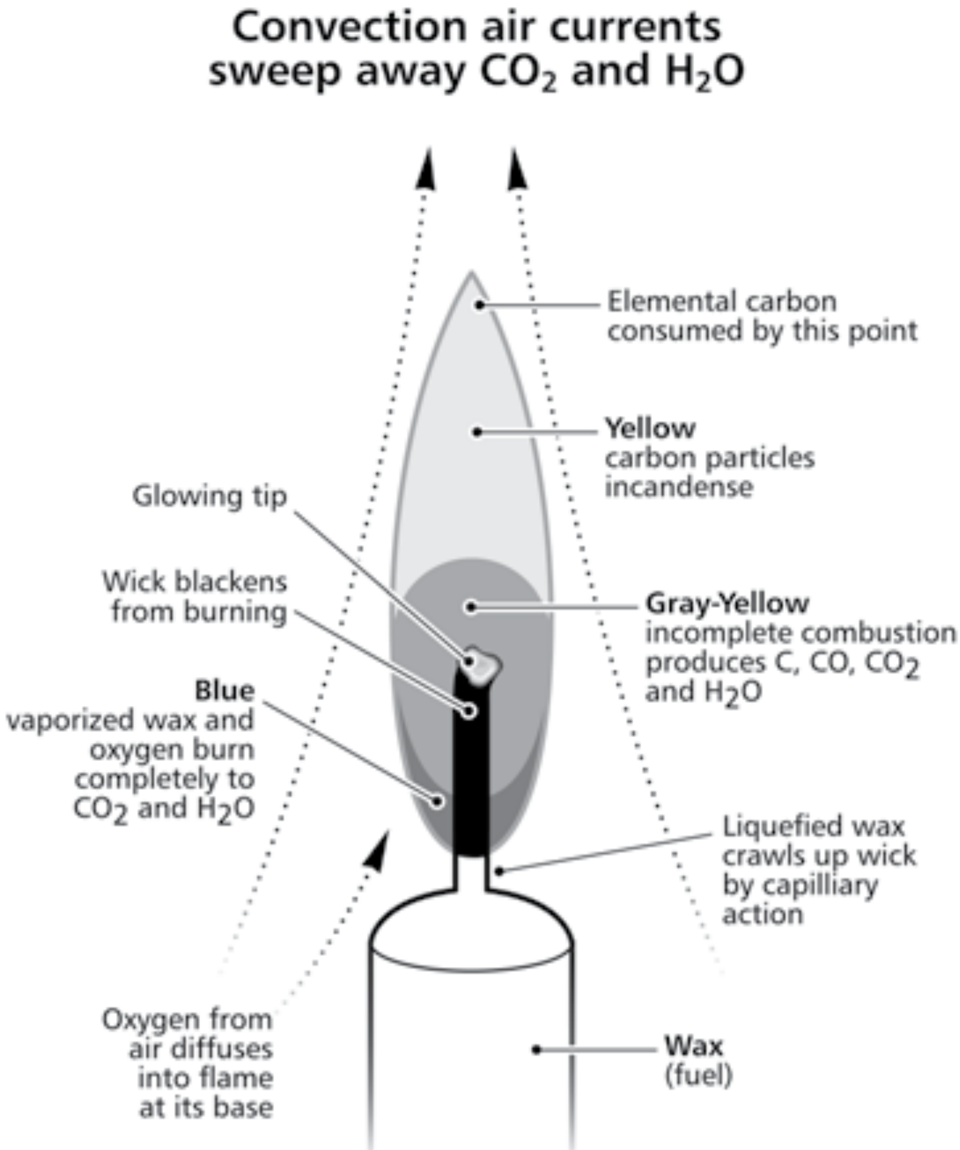
These heated, solid carbon particles, glow. As they rise in the flame they create a bright yellow region. This brightest part of the flame has a temperature between that of the hot blue region and the cooler grayish-yellow region. The glowing of the carbon particles is called *incandescence.* This phenomena occurs whenever a solid is heated enough to emit light. This incandescence is a physical change, unlike combustion in other parts of the flame, which is a chemical change.

The chemical and physical changes in the flame create its distinctive shape. The flame's heat expands the surrounding air. This less dense air draws up cooler air from below the candle. These convection currents create the teardrop shape of a flame. They also sweep away the carbon dioxide and water formed. The importance of these convection currents to the candle's operation is dramatically illustrated when a candle burns in zero gravity or in a vacuum chamber.

In these environments the convection currents no longer occur and so the flame becomes spherical. The oxygen spends more time in the flame and so the combustion is more complete, i.e., more carbon is turned to carbon dioxide and fewer carbon particles exist in the flame. Because there are fewer carbon particles the flame's interior is blue. The flame burns out because, without convection currents, carbon dioxide remains in the flame and smothers it.

Emissions from the candle

A properly burning candle emits little smoke. Any smoke that arises comes from incomplete combustion in the flame: tiny particles of unburned carbon mixed with gaseous products. This smoke will "soot" a piece of metal or glass placed in the smoke well above the flame. The amount of this black smoke, then, depends on the ratio of incomplete to complete combustion. A breeze, for example, can increase the amount of incomplete combustion and cause a candle to emit black smoke. In contrast, the smoke is white and heavy when the flame is extinguished. This white smoke is vaporized wax that has formed into droplets of molten wax. If ignited with a match this stream of wax can relight the wick as demonstrated in Faraday's first lecture.



As Faraday notes in his first lecture "there is not *a law under which any part of the universe is governed which does not come into play, and is touched upon in the chemistry of a candle." Heat from the flame melts the wax by radiation and conduction, capillary action draws the wax up the wick, molten wax is vaporized, chemical reactions produce the flame, heated solid carbon particles glow, and convection currents sweep away the products of combustion. The balanced chemical equation for the complete combustion of a candle is represented by:*

$$C_{25}H_{52}(s) + 38O_2(g) \rightarrow 25CO_2(g) + 26H_2O(g)$$