The shadow of the flame and other hands-on experiments on the candle, inspired by Faraday and Leonardo

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The simple experiments I'm going to do are inspired by Faraday and described in his book «A Chemical History of a Candle» of about 150 years ago.

I have found out that Faraday is known as a great scientist. But he was a great science showman, too. That's why I would like to present him, here, in this unknown role.

I like to begin my talk repeating Faraday's own words regarding a candle: **There is not a law under which any part of this universe is governed which does not come into play and is touched upon in these phenomena. There is no better, there is no more open door by which you can enter into the study of natural philosophy than by considering the physical phenomena of a candle**.

Here, I intend to follow his conceptual scheme and demonstrate that he was right.

The candle I have in my hands is a paraffin candle – more precisely a candle made in part of paraffin and in part of stearin. In other terms, the candle I have in my hands is similar to the one Faraday used in 1860, in fact the stearin was found in 1811 and the paraffin in 1830. People begun to mix the two materials, starting from 1854.

As you can observe, a candle is a very different thing from a lamp. With a lamp you take a little oil, fill your vessel, put in a little cotton prepared by artificial means, and then light the top of the wick. With the candle, you have here a solid substance with no vessel to contain it; and how is it that this solid substance can get up to the place where the flame is? How is it that this solid gets there, it not being a fluid?

You can see that a beautiful cup is formed. As the air comes to the candle, it moves upward by the force of the current which the heat of the candle produces, and so it cools all the sides of the wax to keep the edge much cooler than the part within; the part within melts by the flame that runs down the wick as far as it can go before it is extinguished, but the part on the outside does not melt.
The flame is fenced off from the fluid below, and does not encroach on the cup at the sides.

I cannot imagine a more beautiful example than the condition of adjustment under which a candle makes one part – the flame - subserve to the other – the cup - to the very end of its action. It is a chemical-physical machine! It is an interactive example in nature!

But how does the flame get hold of the fuel? There is a beautiful point about that: the capillary attraction.

I have here a substance which is rather porous, a paper tissue.
And I will pour it into a glass of water, at the bottom.
I have coloured the water, so you may see the action better.
You can observe that it rises and gradually creeps up the paper tissue higher and higher; and goes to the top.

When you wash your hands, you take a towel to wipe off the water; and it is by that kind of wetting, or that kind of attraction that the wick is made wet with the wax. In like manner, the particles of melted wax go up the cotton and get to the top.
Other particles then follow by their mutual attraction for each other, and as they reach the flame they are gradually burned. On purpose, the wick is braided to favour this attractive process.

Now, let's consider the shape or form of the flame.
We want to know how the matter of the candle finally comes at the top of the wick.
The flame you are seeing is a bright oblong, brighter at the top than towards the bottom, with the wick in the middle.
And, beside the wick, certain darker parts towards the bottom, where the ignition is not so perfect as in the part above.

Moreover, there is a faint blue part, that you can see better if you put the wick at the level of your eyes.

If you observe this flame without any other optical tool - you cannot understand how it works and you cannot see that there is a quantity of matter rising about it.

But you may see it! You may see this by putting the candle in the sun, as Faraday did.

Unfortunately, here, in this room, we have not the sun. Therefore instead of the sunlight, I will put the candle in the light of this overhead projector and we will see the image on this screen.

This way, you can see that the flame has a shadow. Into this shadow you can distinguish that there are parts which are surrounding the flame: a current formed, which draws the flame out. This surrounding atmosphere is very essential to the flame, and is always present with it.

It is surprising to note that a thing that produces shadows of other objects can be made to throw its own shadow on a screen. You can actually see streaming round the flame something which is not part of the flame, but is ascending and drawing the flame upward. What you are seeing surrounding the shadow is a current of hot air and in other words, you are observing the physical process of convection.
This way, Faraday suggested a sort of microscope of the flame!

Now, note on the screen that there is a dark part; it is, in reality, the shadow of the brightest part of the flame.

Let's discover why it is going on. First, we can see directly that an ascending current supplies the flame with air. And is this current which cools the sides of the cup of melted fuel!

For me, it has been a surprise to learn that the dark shadow of the bright flame was noted by Leonardo about three centuries before Faraday! And that Faraday was not aware of that. Let's make a quick comparison between Fadaray's and Leonardo's descriptions.

Please note on the left the scheme of Faraday. It puts in evidence the upward current around the flame and the dark core of the flame, like we have just seen. Leonardo interprets the same fact showing the currents passing on the edges of the cylinder and mixing hot air with cold air on the top of the flame. Please note the curling drawings on the edges of the flame, just on the sides where the flame is blue owing to the oxygen flux. Leonardo's interpretation is quite correct but it is, nevertheless, an Aristotelian one: the hot smoke is lighter than the air!

In order to explain the correspondence of the dark part of the shadow with the brightest part of the flame, please note before that the flame is hollow.
To do this, I suggest to use this metallic wire netting or a little fork.
This way you can open the flame as a banana. The metallic wire netting swallows the heat of the flame and blocks the combustion.
There are two types of smoke, black and white *smoke*, which emerge from the flame: with a rapid change, moving the hand.

The black smoke is made of soot and it is the cause of the dark shadow of the flame. The glowing particles of soot produce most of the candle's light.
The white smoke - instead - is made of the wax vapour!
And the smells are very different. Please smell: the black smoke has the smell of the smoke of an old car and the white one has the characteristic smell of a church.
Soot is visible when the combustion is incomplete: it is made of the molecules of the wax which have been broken but not still ignited. When the combustion is going to be complete, the soot disappears.

You can take soot from a candle with a "caress". The temperature of the candle is not very high. You can do the same action with the trick of the cork and you can paint "soot moustaches" on the face of a friend.
Is there, among you, anyone who likes to be masked with this soot? Please came to my place.

In the yellow tip of the flame, soot burns to produce carbon dioxide, water and bright yellow light.
At the end of his book, Faraday concludes his demonstration, stressing the analogy between the respiration of human beings and the candle combustion: both produce carbon dioxide and water vapour.
But I would like to conclude this talk with Faraday's own words, with which he attempts to present a more deep analogy: that between every man and a candle:
You may…be fit to compare to a candle; … you may, like it, shine as lights to those about you.