What makes the colors in candle flames?

Color is one of the most striking characteristics of everyday life, in large part because the human eye is such a wonderful instrument for perceiving colors. Recent articles in this "Light Touch" column have discussed how white light is actually made up of the full rainbow of colors, and how the colors of light sources can tell us about those sources. So, what does color tell us about flames? For example, candle flames have been around all of us throughout our lives, and we take them for granted as romantic, if not terribly bright, sources of light. But how do candles produce light? And what do the colors of the light they produce tell us?

Candles actually produce light in two very different ways. Most of the light from a candle comes from glowing soot particles, which are made up mainly of carbon, much like tiny pieces of charcoal. Soot particles are formed in the bottom of the flame as wax evaporating from the wick starts to burn. At first, they grow as they move upward in the flame ("hot air rises"), and are heated by the flame until they become "yellow-hot," the color given off by almost anything that is heated up to the temperature typical of many flames, namely about 2000 K ("K" stands for "degrees Kelvin;" 2000 K = 2273 C = 4123 F). Then they burn up higher in the flame and disappear.

We think of soot as being dirty, messy, and environmentally bad, but within a flame it is actually very beneficial and doesn't cause any harm as long as it burns up before it leaves the flame. Without glowing soot particles to give off light, flames produce very little light at all, even though they still produce a lot of heat. A good example of this is the flame produced by a gas stove; it certainly gets hot, but even Abraham Lincoln wouldn't have used it to read by. (In case you are wondering about camping lanterns, they produce light by using a flame to heat what is called a "mantle" until it is glowing almost white-hot, so the flame is not directly producing the light.)

The other way that candles produce light is really more interesting (at least to optical scientists), even though it produces only a small fraction of the light given off by the flame. This "other way" is responsible for the bluish light emitted from the base of candle flames (and many other types of flames as well). This light tells us something about the chemical reactions going on in the flame. To really understand a flame, we need to know all about these chemical reactions. Each reaction is fairly simple, but literally hundreds of reactions are going on at once; complex computer programs are often needed to keep track of them all.

One of the interesting things about many of these reactions is that they produce molecules with a special kind of "internal energy," energy that is present in a form different from the "thermal energy" we generally associate with heat. This particular form of internal energy can be given off as bursts of light, and the color of the light is determined by the molecule that produces the burst.

To put this a different way, if we look closely at the color of this "other type" of light coming from a flame, we can use it to learn something about the molecules that are in the flame. This topic is called Flame Emission Spectroscopy, and there are entire books written on the subject. The bluish light you see at the base of the candle flame comes mainly from three molecules that are produced in the flame: CH, C_2, and CO_2. The last of these three is the one that we hear about all the time, namely carbon dioxide. It is a "stable" molecule, meaning basically that it stays around for a long time. The other two react very quickly with other molecules, so they don't last very long, and we rarely (if ever) hear anything about them. But the fact that they are responsible for so much light coming from flames tells us that they have a lot to do with flame chemistry; CH in particular turns out to be very important in flames.

Many of the other atoms and molecules in flames also produce light, but we can't see it with our eyes. However, we can easily make other colors by adding other things to the flame. The easiest example to try yourself is to sprinkle some table salt into a flame; the burst of yellow that you see is from sodium in the salt (chemically, salt is called "sodium chloride"). Other chemicals (usually metals) produce other colors. Logs treated with special chemicals burn with very colorful flames. A more impressive example is the bright colorful light from fireworks, which is produced by chemical additives.

So the next time you see a candle burning, look more closely at the flame. It's not as simple as you probably thought it was, and like many other things around us, we can learn a great deal from its colors.

JOHN E.M. GOLDSMITH is a Senior Member of the Technical Staff at the Combustion Research Facility, Sandia National Laboratories, Livermore, Calif.